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АНОТАЦІЯ

Чжун Демінь. Бенчмаркінг формування циркулярних кластерів. – Кваліфікаційна наукова праця на правах рукопису.

Дисертація на здобуття ступеня доктора філософії за спеціальністю 292 «Міжнародні економічні відносини». – Західноукраїнський національний університет, Тернопіль, 2025.

У дисертації розроблено систему оцінки для вимірювання розвитку регіональної циркулярної економіки, зокрема, в місті Сіньюй, на основі розглянутих еталонних практик формування циркулярної економіки та циркулярних кластерів, з метою визначення ефективних стратегій і механізмів сприяння сталому використанню ресурсів і захисту навколишнього середовища.

Досліджено, що циркулярна економіка Китаю демонструє контрастну модель захисту навколишнього середовища відповідно до економічного розвитку та використання ресурсів: сильну на заході, слабку на сході та помірну в центральних регіонах. Зазначено, що є значні регіональні відмінності в охороні навколишнього середовища. На сході існує дворівнева диференціація: Пекін, Тяньцзінь, Шанхай і Фуцзянь працюють добре (перший і другий рівні), а Гуандун, Цзянсу, Шаньдун, Хебей і Ляонін — гірше (четвертий і п’ятий рівні). У центральному регіоні Аньхой, Шаньсі та Хенань – мають низький рівень захисту навколишнього середовища (четвертий та п’ятий рівні), тоді як Цзянсі, Хунань та Хубей мають помірний рівень (третій рівень). У західному регіоні Сіньцзян, Сичуань, Внутрішня Монголія та Шеньсі мають низькі рівні (четвертий і п’ятий рівні), тоді як Тибет, Цінхай, Нінся, Ганьсу, Чунцін, Юньнань, Гуйчжоу та Гуансі мають помірні або кращі рівні (рівень третій або вище).

У дисертації розроблено модель розвитку регіональної циркулярної економіки за трьома вимірами показників: економічні, ресурсні та екологічні показники. Вони коливаються від 0 до 1 після нормалізації. Початок (0,0,0) є теоретичним, тоді як (1,1,1) представляє ідеальний максимум. Модель утворила куб у першому квадранті, розділений на вісім октантів. Індекс розвитку регіональної циркулярної економіки представлено просторовою точкою в

моделі, що відображає її статус у певний час. Шлях еволюції циркулярної економіки передбачає перехід точок від першого до восьмого октанту з часом. Відповідно десять послідовних років шляху розвитку регіону представлено траєкторією з десяти пунктів. Доведено, що шлях розвитку зазвичай висхідний, але може змінюватися залежно від пріоритетів регіону. Різні регіони можуть йти різними шляхами для одного часового ряду. Аналіз цих шляхів спрямований на виявлення проблем, визначення найкращих практик і коригування майбутніх шляхів, інформуючи про прийняття рішень. Еволюція шляху розвитку регіональної циркулярної економіки відображено просторовою траєкторією від початку О біля 1-го квадранта до вершини А 8-го квадранта. Цей шлях фіксує розвиток, причому координати кожної точки представляють економічні, екологічні та соціальні показники життєздатності в певний час (X, Y, Z відповідно).

Доведено, що створення екологічного механізму оцінки є важливим заходом для досягнення трансформації високотехнологічної зони Сіньюй. Реалізація таких заходів, як чіткі цілі, встановлення індикаторів, створення механізмів, а також посилення державної підтримки, допоможе сприяти виходу високотехнологічної зони та великих підприємств на шлях швидкого розвитку зелених, низькотехнологічних зон, вуглецевої циркулярної економіки та досягнення скоординованого розвитку економіки та навколишнього середовища.

З точки зору управління бенчмаркінгом у дисертації проаналізовано світові стандарти циркулярної економіки, включаючи практику розвитку в таких країнах і регіонах, як Європейський Союз, Німеччина, Франція, Японія та США. Це дослідження в поєднанні з практикою циркулярної економіки Китаю проаналізувало поточну ситуацію та проблеми розвитку циркулярної економіки Китаю та відповідно висунуто пропозиції.

Проаналізовано, що бенчмаркінг розвитку циркулярної економіки в промислових кластерах включає контрольні показники на рівні підприємства, еко-промислового парку та соціальні критерії. Здійснено порівняльний аналіз бенчмаркінгу на рівні підприємства: 3M, DuPont і Xerox у США. Ці багатонаціональні лідери, використовуючи капітал, розвинену технологію та талант, передбачили обмеження ресурсів і навколишнього середовища, уможлививши ініціативи маломасштабної циркулярної економіки. Доведено, що завдяки реалізації проекту з виробництва електроенергії з утилізованого тепла компанія Xinyu Iron and Steel Company успішно реалізувала ефективне відновлення та утилізацію доменного газу, що не тільки зменшує викиди парникових газів, але й значно покращує ефективність використання енергії. Крім того, деякі підприємства в місті Сіньюй також зменшили споживання енергії та підвищили ефективність виробництва шляхом впровадження передових енергозберігаючих технологій та обладнання, таких як високоефективні двигуни та енергозберігаючі лампи. З точки зору підвищення ефективності використання ресурсів, наприклад, індустрія переробки відновлюваних ресурсів у місті Сінью реалізувала ефективну переробку та утилізацію відходів шляхом створення надійної системи переробки.

Проаналізовано, що індустріальні парки Китаю загалом мають нижчий ступінь промислової кореляції порівняно з іноземними. Екологічний промисловий парк Yueleang Bay у Китаї, подібний до Каренбурга в Данії, має нижчий ступінь (0,29 проти 0,36), Guangxi Guigang (0,21) також нижчий, ніж американський Choctaw Park (0,33), ступінь Національного демонстраційного парку Південно-Китайського моря (0,17) нижчий за японський парк Кокубо (0,26). Дослідження підтверджують, що західний індустріальний парк міста Цяньань має значні можливості для покращення промислової кореляції порівняно з іншими країнами. Разом ці зусилля сприяють створенню суспільної атмосфери, сприятливої для адаптації циркулярної економіки економіки, сприяння збереженню ресурсів, захисту навколишнього середовища та соціально-економічному розвитку. Розширена співпраця між державним і суспільним секторами вирішуватиме глобальні ресурсні та екологічні проблеми.

Проаналізовано, що перспективами розвитку циркулярних кластерів є: (1) технологічні інновації та обмін: завдяки розвитку економіки замкнутого циклу країни потребуватимуть технологічної співпраці, спільної розробки та застосування передових технологій; (2) державний діалог і координація: зміцнять діалог, формулюючи та впроваджуючи заходи, узгоджені з глобальними цілями сталого розвитку. Це зменшить торгівельні та інвестиційні бар'єри, сприяючи співробітництву та інвестиціям у сфері циркулярної економіки; (3) розбудова потенціалу та навчання: міжнародна співпраця посилить національний досвід через програми розвитку потенціалу. (4) демонстраційні проекти та платформи співпраці: репрезентативні проекти циркулярної економіки для обміну досвідом і результатами, сприяючи інноваціям у технологіях та управлінні; (5) міжнародні організації та багатосторонні механізми: ці суб'єкти зміцнюватимуть співпрацю в циркулярній економіці, встановлюючи міжнародні стандарти та норми. Вони допоможуть країнам вирішити глобальні ресурсні та екологічні проблеми, досягнувши цілей сталого розвитку.

Доведено, що в економіці з низьким рівнем викидів вуглецю місцеві органи влади повинні налагодити підтримку великих підприємств, окрім традиційних методів, таких як збільшення кредитів і податкові пільги. Екологічні податки в поєднанні з фіскальними субсидіями, податковими пільгами, зеленими кредитами та страхуванням, а також екологічними закупівлями можуть скерувати підприємства до низьковуглецевих технологій та циркулярного виробництва.

Обґрунтована необхідність впливу уряду на поведінку споживання енергії та сприяння довгостроковим низьковуглецевим механізмам, включаючи коригування промислової структури, заохочення передових технологій і моделей управління, підвищення енергоефективності та скорочення викидів вуглецю.

Доведена доцільність врахування принципів циркулярної економіки на мікро-, мезо- та макрорівнях при формуванні циркулярних кластерів. На мікрорівні підприємства можуть створювати системи мікроциркуляції, зокрема, покращувати процеси очищення на хімічних підприємствах для перетворення побічних продуктів назад у сировину. На мезорівні створювати індустріальні парки циркулярної економіки, щоб сприяти обігу матеріалів між підприємствами, що працюють на першому та нижчому рівнях. На макрорівні об'єднувати мікро- та мезо-зусилля, де кожен соціально-економічний учасник виконує певну роль у загальному макроекономічному циклі.

Обґрунтовано, що промисловим кластерам Китаю необхідно прийняти концепцію циркулярної економіки, досягаючи скорочення, повторного використання та переробки ресурсів для формування промислових екологічних ланцюгів. Доведено необхідність застосування бенчмаркінгу та розвитку зразкових провідних підприємств, що створюватимуть комунікаційні платформи та екоальянси. Створення та удосконалення довгострокових промислових кластерних механізмів із розумними стимулами та ефективним управлінням сприятиме гармонійному розвитку регіональної економіки на основі циркулярних промислових кластерів.

Ключові слова: циркулярна економіка, промисловий кластер, бенчмаркінг, система оцінювання, циркулярні кластери, сталий розвиток, регіональний розвиток, периферійні території, зелена інфраструктура, економічний розвиток, інновації, промислові екологічні ланцюги, низьковуглецева економіка.

ANNOTATION

Zhong Demin. Benchmarking the formation of circular clusters. – Qualification scientific work in the form of a manuscript.

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The dissertation develops an assessment system for measuring the development of a regional circular economy, in particular, in the city of Xinyu, based on the considered reference practices of the formation of a circular economy and circular clusters, in order to determine effective strategies and mechanisms for promoting sustainable resource use and environmental protection.

It is studied that China's circular economy demonstrates a contrasting model of environmental protection in accordance with economic development and resource use: strong in the west, weak in the east, and moderate in the central regions. It is noted that there are significant regional differences in environmental protection. In the east, there is a two-level differentiation: Beijing, Tianjin, Shanghai and Fujian perform well (levels one and two), while Guangdong, Jiangsu, Shandong, Hebei and Liaoning perform worse (levels four and five). In the central region, Anhui, Shanxi and Henan have low levels of environmental protection (levels four and five), while Jiangxi, Hunan and Hubei have moderate levels (level three). In the western region, Xinjiang, Sichuan, Inner Mongolia and Shaanxi have low levels (levels four and five), while Tibet, Qinghai, Ningxia, Gansu, Chongqing, Yunnan, Guizhou and Guangxi have moderate or better levels (level three or higher). The thesis develops a model for the development of a regional circular economy based on three dimensions of indicators: economic, resource and environmental indicators. They range from 0 to 1 after normalization. The origin (0,0,0) is theoretical, while (1,1,1) represents the ideal maximum. The model formed a cube in the first quadrant, divided into eight octants. The regional circular economy development index is represented by a spatial point in the model, reflecting its status at a certain time. The path of evolution of the circular economy involves the transition of points from the first to the eighth octant over time. Accordingly, ten consecutive years of the region’s development path are represented

by a trajectory of ten points. It is proven that the development path is usually upward, but can vary depending on the priorities of the region. Different regions can follow different paths for the same time series. The analysis of these paths aims to identify problems, identify best practices and adjust future paths, informing decision-making. The evolution of the regional circular economy development path is reflected by a spatial trajectory from the origin O near the 1st quadrant to the vertex A of the 8th quadrant. This path captures development, with the coordinates of each point representing economic, environmental, and social indicators of viability at a given time (X, Y, Z, respectively).

It is proved that the establishment of an environmental assessment mechanism is an important measure to achieve the transformation of Xinyu High-tech Zone. The implementation of measures such as clear goals, setting indicators, establishing mechanisms, and strengthening government support will help promote the high-tech zone and large enterprises to enter the path of rapid development of green, low-tech zones, carbon circular economy, and achieve coordinated development of economy and environment.

From the perspective of benchmarking management, the thesis analyzed the global standards of circular economy, including the development practices of countries and regions such as the European Union, Germany, France, Japan, and the United States. This study, combined with the practice of China's circular economy, analyzed the current situation and problems of China's circular economy development and put forward proposals accordingly.

It is analyzed that the benchmarking of circular economy development in industrial clusters includes enterprise-level benchmarks, eco-industrial park-level benchmarks, and social criteria. A comparative analysis of enterprise-level benchmarking is carried out: 3M, DuPont, and Xerox in the United States. These multinational leaders, using capital, advanced technology and talent, have anticipated the limitations of resources and the environment, enabling small-scale circular economy initiatives. It is proven that through the implementation of the waste heat power generation project, Xinyu Iron and Steel Company has successfully realized the efficient recovery and utilization of blast furnace gas, which not only reduces greenhouse gas emissions but also greatly improves energy efficiency. In addition, some enterprises in Xinyu City have also reduced energy consumption and improved production efficiency by introducing advanced energy-saving technologies and equipment, such as high-efficiency motors and energy-saving lamps. In terms of improving resource efficiency, for example, the renewable resource recycling industry in Xinyu City has realized the efficient recycling and utilization of waste by establishing a reliable recycling system.

It is analyzed that China's industrial parks generally have a lower degree of industrial correlation compared with foreign ones. The Yueleang Bay Ecological Industrial Park in China, similar to the Danish Karenburg, has a lower degree (0.29 vs. 0.36), Guangxi Guigang (0.21) is also lower than the American Choctaw Park (0.33), the degree of the South China Sea National Demonstration Park (0.17) is lower than Japan's Kokubo Park (0.26). Studies confirm that the Western Industrial Park of Qian'an City has significant potential to improve industrial correlation compared with other countries. Together, these efforts contribute to creating a social atmosphere conducive to the adaptation of the circular economy, promoting resource conservation, environmental protection and socio-economic development. Enhanced cooperation between the public and private sectors will solve global resource and environmental problems.

It is analyzed that the prospects for the development of circular clusters are: (1) technological innovation and exchange: due to the development of a closed-loop economy, countries will need technological cooperation, joint development and application of advanced technologies; (2) government dialogue and coordination: strengthen dialogue by formulating and implementing measures consistent with the global sustainable development goals. This will reduce trade and investment barriers, promoting cooperation and investment in the circular economy; (3) capacity building and learning: international cooperation will strengthen national expertise through capacity building programs. (4) demonstration projects and cooperation platforms: representative circular economy projects to share experiences and results, promoting innovation in technology and management; (5) international organizations and multilateral mechanisms: these entities will strengthen cooperation in the circular economy by setting international standards and norms. They will help countries solve global resource and environmental problems by achieving sustainable development goals.

It is proven that in a low-carbon economy, local governments should establish support for large enterprises, in addition to traditional methods such as increased loans and tax breaks. Environmental taxes, combined with fiscal subsidies, tax breaks, green credits and insurance, and green procurement, can guide enterprises towards low-carbon technologies and circular production.

The need for government to influence energy consumption behavior and promote long-term low-carbon mechanisms is justified, including adjusting the industrial structure, encouraging advanced technologies and management models, improving energy efficiency and reducing carbon emissions.

It is proven that it is appropriate to take into account the principles of the circular economy at the micro-, meso- and macro-levels when forming circular clusters. At the micro-level, enterprises can create micro-circulation systems, in particular, improving the purification processes in chemical plants to convert by-products back into raw materials. At the meso level, establish circular economy industrial parks to facilitate the circulation of materials between enterprises operating at the first and lower levels. At the macro level, integrate micro and meso efforts, where each socio-economic participant plays a certain role in the overall macroeconomic cycle.

It is argued that China's industrial clusters need to adopt the concept of circular economy, achieving resource reduction, reuse and recycling to form industrial ecological chains. It is proved that the need for benchmarking and the development of exemplary leading enterprises to create communication platforms and eco-alliances is needed. The establishment and improvement of long-term industrial cluster mechanisms with reasonable incentives and effective management will promote the harmonious development of the regional economy based on circular industrial clusters.

Keywords: circular economy, industrial cluster, benchmarking, evaluation system, circular clusters, sustainable development, regional development, peripheral areas, green infrastructure, economic development, innovation, industrial ecological chains, low-carbon economy.

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INTRODUCTION

Relevance of the topic. The balance between economic development and environmental protection is crucial today. Circular economy, emphasizing resource utilization and recycling, is pivotal for sustainable growth. Benchmarking, a management tool, supports circular economy formation. Discussing benchmarking in circular economy holds practical and theoretical significance.

Practically, circular economy and benchmarking address resource scarcity and pollution, issues exacerbated by population growth and traditional economic models. By reusing resources and reducing waste, circular economy fosters eco-economic harmony. Benchmarking helps enterprises discover industry best practices, enhancing resource efficiency and waste management, thereby promoting circular economy development.

Theoretically, benchmarking enriches circular economy theory. As a new growth model, circular economy's theoretical framework is evolving. Benchmarking's successful applications in various fields offer insights for circular economy research. Studying benchmarking in circular economy reveals its mechanisms and operational laws, aiding policy formulation.

Practically, benchmarking guides enterprises and governments in circular economy development. It helps enterprises improve resource utilization and waste disposal, enhancing competitiveness. Governments can reference benchmarking for policy-making, fostering industry-wide circular economy progress. Benchmarking also fosters inter-enterprise cooperation and healthy competition.

Globally, benchmarking research in circular economy addresses challenges like climate change. Circular economy, a global model, needs international promotion. Benchmarking provides a common platform for cross-country cooperation, sharing best practices to elevate circular economy development and contribute to global sustainability.

Large number of works by Ukrainian and foreign scientists explain the basic principles of circular economy and its use to develop circular economy, and foreign scientists such as Krysovatyy, A., Zvarych, I., & Zvarych, R. etc. [220], Orekhova, T., Zerbino Pierluigi[3], Zhu Dejie [5], Wu Jinsheng [6], Ning Wenping et al. [8], Marte Faber

[9],Mahdi Ghasemi et al. [10], Gao Shaokui et al. [11], JI Kunsheng [12], QI Jiancho [13],Ma, K.[14], Duan Ning [15], Feng Zhijun [16], Yu Donglin et al.[17],Lin et al.[18], Zhang, Etc. [19], kong jie, etc. [20], John et al. [21], Jan et al. [22], [23], such as zhang Lin et al. [24], wear, etc. [25], Lin et al. [26], [27], [28] Murugappan, Hing into [29], Jan, etc. [30], [31], such as wang xu, etc. [32], pei, etc. [33], Joe [34], such as Chen Yancun etc. [37], Chen Fangdeng [38], Cullen, j.m [41], Daly, H.E [44], [46], such as xiao-xia deng Duan Ning [47], von [49], Fu Lei [50], Gao Yongdeng [51], Gao Yongdeng [52], He Lei [55], Huang Xin [57], JiKunSheng [58], ai-jun jia [59], Jiang Guogang [60], such as Jiang Guoyong etc. [61], Jiang Liqiang etc. [62], [63], such as Jiang Xiaojun Kong jie Jiang Honghong [64], [67].

Large number of works by Ukrainian and foreign scientists explain the basic principles of Benchmark clusters industrial parks and their use, promoting the development of circular economy in industrial parks, and foreign scientists such as， Babkin etc. [35], [39], such as Chen lei Chu Shao Zhong etc. [40], Daddi etc. [42], Feng Yong [48], [56], such as Mark Cellickson, etc. [65], [66] such as Mr. Jiang, li, etc. [74], [89], such as mt. Mazzoni, F[92], Mendez Alva Francisco et al. [93], Mig [95], Su Ronghua [104]. Lishchynskyi, I., Borysiak, O., Zhyvko, M.

Large number of works by Ukrainian and foreign scientists explain the basic principles of ecology environmental problems resources and the comprehensive use of ecological environment, resources and environment factors to achieve circular economic development in society and economy. Foreign scientists such as Battisti Martina [2],Liu.Q [4], Baiyun Obo State Key Laboratory of Rare Earth Resources Research and Comprehensive Utilization [7], Cao Fengzhong et al. [36],Dai Li [43], Chala, V., Deng Rui et al. [45],Giama et al. [53], Gong Yuping [54], Liang Jie et al. [76], Liu Wei et al. [82] Renewable resources to alleviate natural resource shortage [86],Reznikova et al. [101], Shi Lei [103], Wang Yufeng et al. [117] have made useful contributions.

Connection of work with scientific programs, plans, topics.

The dissertation is part of a fundamental scientific research project on the topic "National Concept of Eco-Security of Society and Inclusion of the Circular Economy in Pandemic Conditions" (state registration number 0121U109485); fundamental scientific research project on the topic "Concept of Recovery and Green Reconstruction of Ukraine" (state registration number 0124U000003); implementation of an international project (Erasmus+ Jean Monnet Module) on the topic "European Inclusive Circular Economy: Post-War and Post-Pandemic Module for Ukraine" (registration number 101085640); Geoeconomic and Civilizational Challenges of the Development of the Global Economy (state registration number 0121U111077).

The purpose of the study is to deepen the theoretical concepts of circular cluster formation and develop practical recommendations for improving the level of development and quality of industrial clusters as a result of empirical research. Its objectives are:

- to clarify benchmarking's role in circular economy practice and offer insights for Xinyu's and broader regional sustainable development;
- to reveal how benchmarking promotes circular economy formation in Xinyu by analyzing its resource optimization and utilization efficiency strategies;
- to investigate Xinyu's innovative benchmarking models and practices in circular economy, summarizing successful experiences for other regions;
- to focus on benchmarking's impact on Xinyu's economic competitiveness, highlighting circular economy's role in balancing economic and environmental growth;
- to provide empirical evidence for government and departments to formulate precise circular economy policies, fostering healthy development;
- to form mechanism analysis of benchmarking in circular economy: In-depth analysis of specific mechanisms of benchmarking in promoting the practice of Xinyu circular economy, including information sharing, best practice dissemination, continuous improvement mechanism, etc;
- to develop resource recycling system construction and benchmarking effect: Based on Xinyu resource optimization and utilization efficiency strategy analysis, further explore the role of benchmarking management in the construction of urban resource recycling system;
- to analyze regional adaptability of innovation benchmarking models: Based on the investigation of innovation benchmarking models and practices of Xinyu circular economy, the adaptability of these models under different economic, social and environmental backgrounds is analyzed;
- to focus on strategies for improving economic competitiveness from the

perspective of circular economy: Focusing on the impact of benchmarked management on the competitiveness of Xinyu economy, in-depth analysis of how circular economy can achieve the dual goals of economic growth and environmental protection by improving resource utilization efficiency, promoting industrial transformation and upgrading, and enhancing innovation ability.

The object of the study is the benchmarking management of circular economy, especially the practice in Xinyu City, Jiangxi Province. As the target city of this study, Xinyu city's circular economy development status, benchmarking management implementation and effectiveness are the important contents of this study.

The subject of the study is the formation of circular clusters under benchmarking management, specifically focusing on the case of Xinyu City, Jiangxi Province.

Research methods. To achieve the specified goal, the dissertation used a set of theoretical, historical, empirical and other research methods. In particular, the dissertation used: the method of theoretical generalization - to substantiate the theoretical concepts of the circular economy and form the conceptual apparatus of the study; the method of qualitative and quantitative analysis to identify the essence of the problem through deductive reasoning; methods of analysis and synthesis - to identify systems for assessing the circular economy, which allows for accurate and objective reflection of the development of the region through calculations based on data; the monitoring method - to identify changes in cluster analysis; the SWOT analysis method - to identify the strengths and weaknesses of the implementation of the circular economy in the region; data processing methods, in particular: the method of statistical analysis, an assessment system with interdependent indicators that comprehensively reflects the assessment requirements in a hierarchical structure. Assessment of the development of the circular economy involves assessing the state of the region, determining the weight of indicators and comprehensive analysis. Scientific assessment is important for promoting development. Correlation and regression analysis methods – to identify dependencies between indicators, cluster analysis – the study uses principal component analysis and AHP to assess the level of development of the circular economy; tabular and graphical methods – to visualize data, main provisions and research results.

The dissertation is based on the use of a wide factual base and analytical materials of the United Nations, the World Bank, the World Trade Organization (WTO), the United Nations Conference on Trade and Development (UNCTAD).

The scientific novelty of the obtained results is the creation of an evaluation system to measure the development of the regional circular economy, development of new approaches to scientifically assess the progress in Xinyu High-tech Zone. The scientific essence could be concluded as follows:

First obtained:

- a methodological approach was developed, reflected through a system of indicators for assessing the development of the regional circular economy for its classification by characteristics in the provinces of China, on the basis of which the spatial distribution of the circular economy was carried out and regions were classified accordingly by the use of China's resources;
- a system of indices for assessing the regional development of circular economy clusters was proposed based on current legislation, regional experience and 35 indicators in three dimensions of "economy-resource-environment" (indices of economic production (C1), industrial structure (C2), resource consumption (C3), use (C4), waste disposal (C5) and pollution control (C6), as well as their development paths). On the basis of which, a model for the development of the regional circular economy was developed and an analysis of the evolution of the development path of circular economy clusters was carried out;

Improved:

- the conceptual justification and theoretical positioning of industrial clusters in the circular economy system in the projection of the world benchmarking of the formation of circular clusters;
- the system of interaction between enterprises, industrial parks and the government at the micro-level of regional circular economy development and the method of measuring the degree of development of industrial clusters;
- the system of evaluation of the circular economy of Xinyu High-tech Zone has been improved based on benchmarking and three-dimensional

characteristics of the circular economy and resource consumption indicators (B3) and (B4), on the basis of which a matrix of evaluation of resource use indicators;

Further developed

– the ecological evaluation mechanism of the transformation of Xinyu High-tech Zone towards the rapid development of green, low-tech zones, carbon circular economy, and the achievement of coordinated development of economy and environment;

– the proposal of circular economy development in Xinyu High-tech Zone for planning the industrial chain of the new steel industry of circular economy and the industrial chain scheme of the coal and chemical industry of circular economy based on the correlation index between Xinyu High-tech Industrial Park and domestic and foreign industrial parks;

– the conceptualization of key problems of the implementation and functioning of circular clusters, in particular in the Xinyu High-tech Zone, has been further developed, including the challenges faced by enterprises, parks and the government during the planning and development of the regional circular economy.

The practical value of the results. The practical significance of the results of the dissertation is the introduction a novel method for evaluating regional circular economy development, utilizing a primary index system to extract principal components and enhancing scientific feasibility through AHP evaluation. It comprehensively assesses economy, resources, efficiency, and various aspects of regional circular economy development using AHP hierarchical analysis; guidance for enhancing regional circular economy development by evaluating China's 31 provinces, municipalities, and autonomous regions. It provides insights into the current status of circular economy across provinces, aiding governments, enterprises, and the public in understanding regional circular economy development and offering references for improvement.

Applicant's personal contribution. The literature review reveals limited achievements on evaluating circular economy development across China's 31 provinces, focusing mainly on one or few provinces. While numerous circular economy evaluation methods and principal component analysis-based studies exist, holistic analysis dominates, lacking subsystem and module-level principal component analysis. Furthermore, China's circular economy evaluation index systems vary in focus, lacking completeness and authority for provincial evaluations.

This paper employs three evaluation methods to assess economy, resources, environment, and comprehensive performance in circular economy development across 31 provinces. These methods complement each other, overcoming the limitations of a single approach. Consequently, this study offers a more objective and comprehensive evaluation of China's regional circular economy.

Approbation of the results of the dissertation. The main results of the dissertation were published at 2 national and international scientific conferences: XXI International Scientific and Practical Conferences "Economic and social relations of Ukraine in the XXI Century: (Ternopil, May 13, 2022).; International Scientific and Practical Conference of Students of that Young Event "The International Economy in the Minds of the Clymatic changes: the Post of the Pandemic Transition". (Ternopil, April, 11, 2022;

Publication of obtained results. The main provisions of the dissertation are published in 7 scientific publications, including 4 articles in scientific professional publications of Ukraine, included in international scient metric databases, 1 article in a foreign publication indexed by the Scopus and Web of Science databases, the rest are conference proceedings.

Scope and structure of the dissertation. The dissertation consists of an introduction, three sections, conclusions, a list of references, and appendices. The total volume of work is 216 pages, in particular: 194 pages of the main text, 46 tables, 28 figures, a list of references that includes 220 items, 2 appendixes.

CHAPTER 1. THE THEORETICAL BASIS OF CIRCULAR ECONOMY

1.1. Overview of Circular Economy-Related Theories

Since the 1970s, industrial symbiosis theory has evolved, broadening in scope and deepening in content. Its horizontal expansion now encompasses regional and broader byproduct and waste exchange networks, while green supply chain theory has prompted vertical exploration. These developments form a comprehensive industrial symbiosis framework. Integrating this theory with Chinese practices has yielded a unique circular economy theory, rooted in the "Spaceship Earth" concept but distinctly Chinese in research on models, legislation, and assessment. Circular economy models represent a development of industrial symbiosis, merging the two theories. Widely researched and applied, circular economy concepts have been integrated into many Chinese economic organizations. However, their integration with industrial clusters, crucial for economic development due to their self-organization, structure, member composition, influence, and scalability, remains underappreciated. Combining circular economy theory with industrial cluster models and identifying successful practices holds significant practical importance.

This chapter explores research trajectories of industrial symbiosis, circular economy, and industrial cluster theories to develop an integrated circular economy model suited for regional sustainability. The next section presents a relevant literature review, maintaining consistency with terminology throughout the document.

The Circular Economy, introduced by British economists D. Pearce and R. Koch, focuses on resource reutilization for sustainable development. Germany and Japan began developing it in the mid-1990s. It aims to protect the environment and maintain ecological balance by adopting the "*3R*" principles: Reduce, Reuse, and Recycle. This transforms the traditional "resources-products-waste" cycle into a closed-loop system of "*resources-products-waste-renewable resources-remanufactured products*," addressing pollution, resource scarcity, and ecological degradation. Through collective efforts, it establishes a model of clean production, eco-industry, pollution control, and waste utilization, ensuring sustainable economic, social, and natural system development.

The theoretical foundation of Circular Economy stems from the law of conservation of energy, suggesting resources in economic production are conserved in total. Resources transform but do not disappear; post-production, some become products, others waste. Waste can be processed into valuable resources, reintroduced into production cycles, achieving recycling. Circular Economy emphasizes a closed-loop process: "*raw materials-products-waste-new raw materials-new products.*"

In China, Circular Economy was introduced by Liu Qingshan in 1994, emphasizing waste recycling for resource regeneration[4]. In 1998, Tongji University's Zhu Dajian published articles introducing Circular Economy[5]. Wu Jisong, Water Resources Director, defined it as an economic model enhancing resource utilization efficiency, shifting from linear to eco-resource cycling[6]. China's National Development and Reform Commission defines Circular Economy as efficient, cyclical resource use, adhering to "reduction, reuse, recycling," low consumption, low emissions, and high efficiency, aligning with sustainable development.

Translations may vary by context; maintaining consistency with document terminology is essential.

Currently, academic consensus on the Circular Economy concept is lacking. Based on literature review, the author defines it in the following representative ways:

From the perspective of comprehensive resource utilization, Circular Economy is an economic model focused on efficient use and recycling, guided by reduction, reuse, and resourceization principles. It features low consumption, low emissions, and high efficiency, aligning with sustainable development and transforming the traditional "*mass production, consumption, and disposal*" model(2024)[7].

At the 1992 Rio Summit, the UN defined sustainable development as meeting current needs without compromising future generations' [10]. The 2002 Johannesburg Summit clarified it as development balanced by economic growth, environmental protection, and social progress [11].

Circular economy alleviates resource shortage and pollution, promoting ecological sustainability by efficiently using resources, recycling, and disposing of waste. It fosters economic development by creating a "*resource-product-renewable resources*" loop, enhancing industrial structure, and developing service-oriented economy. It also promotes social progress by extending the industrial chain and increasing employment. Thus, circular economy embodies sustainable development's core idea but doesn't fully realize all its goals.

From an environmental perspective, Circular Economy is characterized by material, energy, and closed-loop circulation, aiming for minimal or zero pollutant emissions[11]. It integrates clean production, resource utilization, ecological design, and sustainable consumption, operating as an ecological economy guided by ecological principles.

Ecological economy aims to form a closed cycle like an ecosystem in production, use, and waste, aiming for zero resource input and waste discharge without altering nature(Wenping Ning & Songmao Wang.2024)[8]. However, human economic activities follow economic rather than ecological laws, often violating ecological principles for profit. Thus, ecological economy remains ideal in market economies. Circular economy, mimicking ecology, aims to unify economic and ecological laws, promoting sustainable development by ecologically orienting economic activities(Malte Faber,2024)[9].

Ecological economy serves as the theoretical foundation for circular economy, while circular economy is a concrete manifestation of ecological economy with more specific content, clearer means, and stronger operability.

From a technological perspective, Circular Economy is a paradigm shift promoting environmentally harmonious economic development, adhering to reduction, reuse, and recycling principles(Mahdi Ghasem et,2024)[10]. It establishes a closed-loop cycle of "*resources-products-renewable resources*," aiming for optimal production, consumption, and minimal waste.

In recent years, China has advocated a resource-saving and environment-friendly society, integral to the circular economy. A resource-saving society encourages the government, organizations, and individuals to enhance resource utilization efficiency, minimizing waste in production, construction, circulation, and consumption. This aims to maximize economic and social benefits with minimal resource and energy use, maintaining a balance between supply and demand. Given China's rapid economic growth and population increase, the establishment of such a society addresses the prominent contradiction of resource scarcity.

An environmentally friendly society prioritizes the natural ecology's carrying capacity in production, living, and consumption, preventing pollution and damage. China's pollution mainly stems from waste in production and life. To establish such a society, we must reduce resource consumption, reuse and recycle waste, and treat non-reusable waste environmentally. Resource-saving and environment-friendly societies appear distinct but are intertwined; saving and efficiently using resources aids environmental protection, while protecting the environment reduces waste and emissions, promoting a resource-saving society. Thus, these goals are identical.

Circular economy, resource-saving society, and environment-friendly society are interconnected yet distinct. Circular economy precedes the latter two concepts, serving as a key means to establish them. Both resource-saving and environment-friendly societies are vital for China's socialist harmonious society goal. Achieving this goal requires multiple approaches, with circular economy being a significant one. By maximizing resource use and minimizing waste, circular economy links closely with these "*two societies.*"

From a human-nature relationship perspective, Circular Economy integrates clean production and waste utilization, emphasizing ecological principles in economic activities. It reconstructs the economy based on natural ecosystems' material circulation and energy flow, seamlessly integrating it into natural processes, thereby creating a new economic model.

Circular economy innovates traditional economic models and reflects deeply on the human-nature relationship. It recognizes that economic development must respect nature's laws, integrating economic activities within the ecosystem. To achieve this, circular economy reconstructs the system based on natural material circulation and energy flow, minimizing resource consumption and waste generation. Waste is comprehensively utilized to transform into new resources, forming a closed cycle.

The circular economy integrates the economic system into natural material cycles, replacing the traditional model's linear relationship of resource consumption, pollution, and growth with a new model of circulation, harmony, and symbiosis. This model benefits environmental protection and fosters sustainable economic development, offering a fresh perspective on human-nature relations and economic direction.

Circular economy is crucial for ecological civilization and sustainability.

From an economic perspective, Circular Economy reconstructs the system based on natural ecosystems' material circulation and energy conversion, maximizing resource use and minimizing waste. It integrates the economy into natural material cycles, fostering coordinated development with the environment. Broadly, it encompasses resource-efficient, environmentally friendly social production, including conservation, utilization, recycling, and protection[15]. Narrowly, it focuses on reusing and recycling waste materials, akin to "*garbage*" or "*waste*" economies.

At the practical level, cleaner production (small cycle/enterprise-level circular economy) serves as the micro foundation for circular economy implementation. It's a new production mode that reduces resource consumption and waste generation by optimizing product design, production, service, resource utilization, and waste disposal. Unlike end-of-pipe pollution treatment, cleaner production signifies a significant shift in China's pollution control. The circular economy, a broader concept, encompasses not just product design and production process circularity, but also societal material circulation and reuse, surpassing clean production in scope.

Cleaner production aims to control and prevent pollution, objectively promoting resource conservation. Conversely, the circular economy focuses on saving and recycling resources, which also aids pollution control, especially solid waste prevention. Despite mutual promotion, their direct goals differ, making them irreplaceable. Thus, China's circular economy and cleaner production legal systems should coexist, each with its focus, complementing each other.

Eco-industrial parks, or enterprise-level circular economy, form the medium basis for circular economy implementation. Based on clean production, they facilitate upstream-downstream enterprise interactions to utilize secondary resources, reducing waste and emissions. Circular economy, encompassing material recycling and reuse during and after consumption, is broader and more integral than clean production and eco-industrial parks, serving as a key path to sustainable development.

Table 1.1

Aspects and Definitions of Circular Economy with Their Peculiarities

Definition	Define content	Peculiarity
1	**2**	**3**
Comprehensive utilization of resources	An economic growth model with efficient use and recycling of resources as the core and guided by the principles of reduction, reuse and resource utilization.	Low resource consumption, low emission and high efficiency.
Environmental protection	It integrates clean production, comprehensive utilization of resources, ecological design and sustainable consumption.	Material, energy, closed loop cycle.
Technological paradigm	Promote an economic development model that is compatible with the environment and follows the principles of reduction, reuse and recycling.	Optimal production, optimal consumption, minimum waste.
The relationship between man and nature	Integrate cleaner production and integrated waste use into the economy.	Apply ecological principles to guide human economic activities.
Economic perspective	The economic system is harmoniously integrated into the material circulation process of the natural ecosystem to form an economic model of coordinated development of economy and environment.	Maximize resource efficiency and minimize waste emissions.

Source: Made by the author

Circular Economy adheres to the 3R principles: Reduce, Reuse, and Recycle, applicable to production, distribution, and consumption, as outlined in China's Circular Economy Promotion Law.

The Reduction principle focuses on minimizing natural resource consumption, especially non-renewables, by controlling usage and enhancing efficiency. It aims to maximize output per resource unit. This involves prioritizing renewable resources, improving energy recycling, enhancing resource utilization, and transforming consumer patterns to green consumption, driving the use of energy-efficient products.

The Reuse principle aims to extend product and service durability by designing them for multiple uses. It opposes single-use disposable products, promoting designs that allow repeated utilization, repair, refurbishment, or remanufacturing. The goal is to maximize the product lifecycle and minimize premature waste.

The Recycling principle focuses on the output side, ensuring used products are recycled into resources. It aims to maximize waste-to-resource conversion, reducing emissions and conserving natural resources.

In Circular Economy, the three principles have a hierarchical importance. Its core goal is to minimize and prevent waste in economic processes. While recycling is valuable, it's just one aspect of reducing waste at the end of a product's lifecycle.

In Circular Economy, the 3R principles have different priorities. The primary goals are minimizing waste and reducing resource consumption. The application sequence is Reduction, Reuse, Recycle, as illustrated in Figure 1.1.

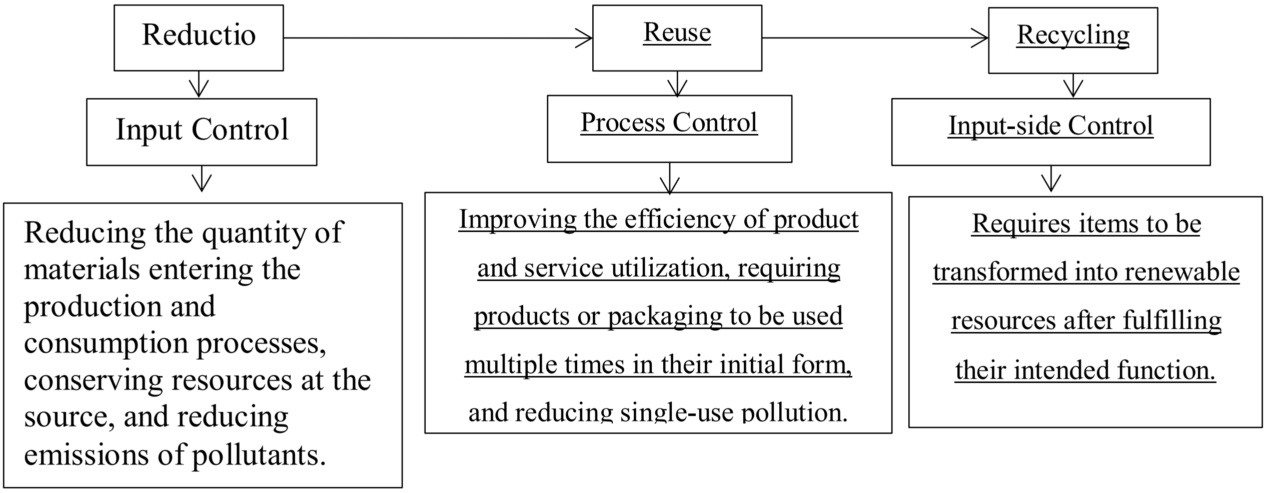

Fig. 1.1. The Fundamental Model of Circular Economy

Source: Made by the author

Implementing a circular economy requires technological advancement, integrated innovation, and alignment with the "3R" principles. Ethical norms, societal support, and legal frameworks are also essential for reducing environmental impact and promoting circular economy practices.

The circular economy is crucial for sustainable development, reflecting on traditional growth models. Its essence is harmonious development with nature and society, making it a natural choice for sustainability.

As the circular economy gains acceptance, its principles have expanded beyond the core "3R" to include "4R," "SR," and "8R." Chen Rui and Niu Wenyuan (2002) introduced the "4R" principle, encompassing reduction, reuse, no recycling, and reorganization.

Ji Kunsen (2004) proposed the "4R" principles of the circular economy: Reduction, Reuse, Recycling, and Rethinking. Rethinking emphasizes continuous reflection to minimize waste, maximize resource productivity, reduce pollution, and enhance waste recycling [12].

Yu Donglin & Chen Changyi. (2022) taked the circular economy industrial park of A city as the research basis, through empirical investigation and analysis, summarizing experience, it is found that in the process of promoting the construction of circular economy industrial park, there are still problems and shortcomings such as lack of industrial planning, lack of space expansion, incomplete supporting factors, and few high-end and sophisticated enterprises [17].

The circular economy operates at three levels: enterprise, industrial park, and societal. Enterprises advance the circular economy by reducing energy consumption, enhancing efficiency, managing waste, and recycling. They develop remanufacturing processes, recover old products, disassemble systematically, and reuse components. The internal cycles within a company, like DuPont's model, integrate the 3R principles, achieving circular use of raw materials and low emissions [18].

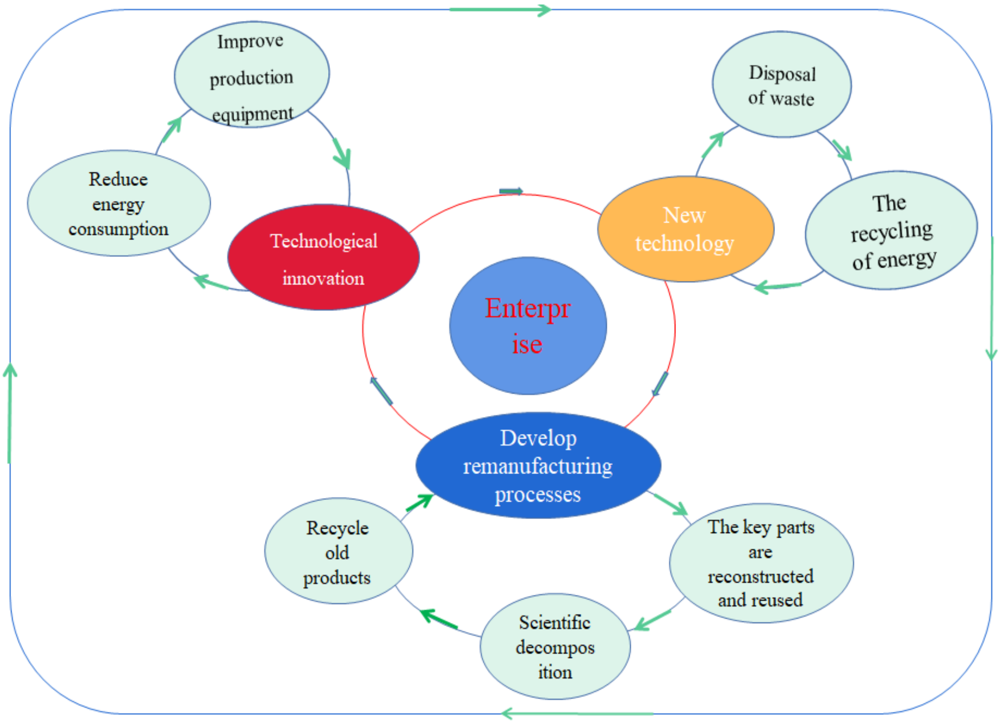

Fig. 1.2. Simulation of the hierarchical system structure at the enterprise level in a circular economy

Source: Made by the author

At the park level, eco-industrial parks model the circular economy by connecting one enterprise's output to another's input, forming an ecological industrial chain[14]. For instance, if Company A's waste can be processed by Company B, and B's waste by Company C, these enterprises can integrate, refining waste into raw materials and achieving circular economic development, minimizing emissions.

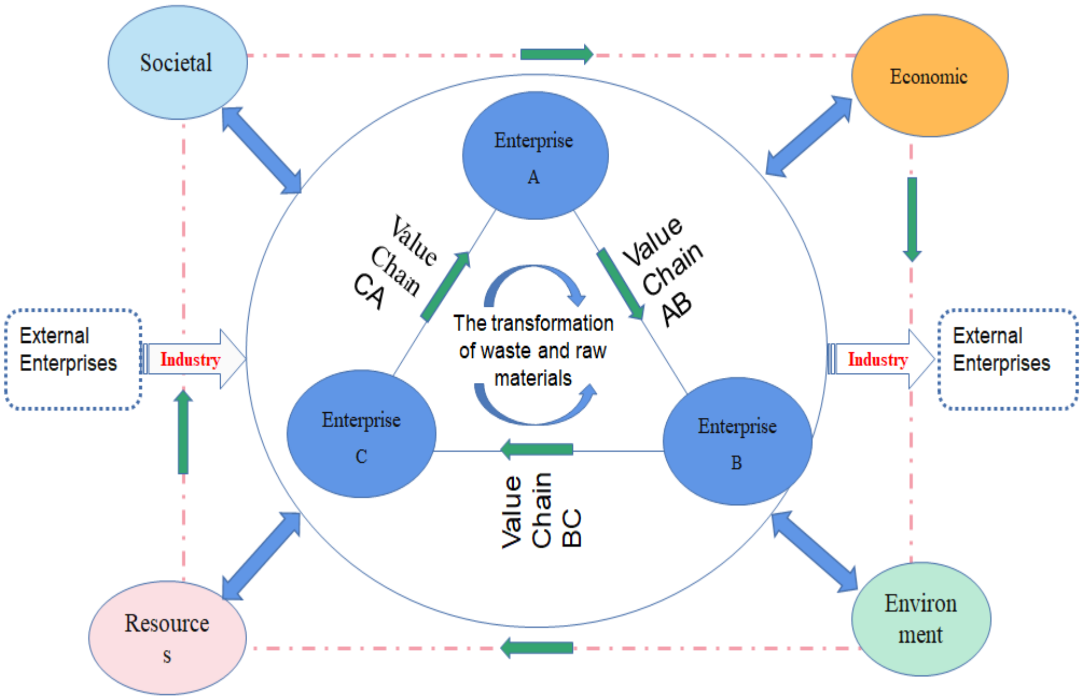

Fig. 1.3. Schematic Diagram of the Hierarchical System of Circular Economy at the Park Level

Source: Made by the author

At the societal level, circular economy development involves integrating social organizations to form a circular society. Governments can advocate, supervise, and use macroeconomic policies to guide enterprises and consumers toward circular production and consumption. This establishes a recycling system for energy and materials across enterprises, consumers, and service organizations. Germany and Japan have introduced concepts and legislation for a "circular society," aiming to efficiently utilize resources and minimize environmental pollution.

The traditional industrial economy views economic production as isolated, ignoring natural ecosystems and their limited capacity, solely focusing on maximizing economic benefits. This violates natural laws and, with increased productivity and economic scale, has led to resource depletion, environmental damage, and ecological degradation, threatening human survival and development. Hence, humanity must reconsider the role of natural ecosystems in societal and economic development.

As a supplement to the traditional economy, the circular economy introduces a feedback loop into the traditional "resource-product-waste" flow, forming a "resource-product-waste-renewable resources" cycle. This enhances resource utilization and reduces waste discharge.

The circular economy system in Figure 1.3 is a "nature-economy" compound system formed by coupling natural and economic subsystems. It maximizes resource utilization and minimizes pollution through material, information, energy, value, technology, and knowledge flows, enabling harmonious coexistence and sustainable development of economy and ecology, man and nature.

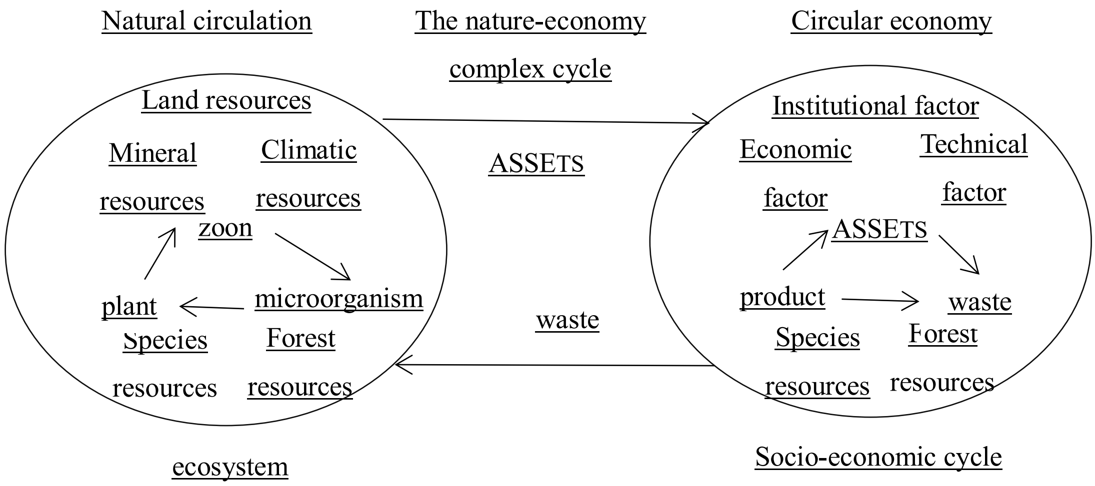

Fig. 1.4. Structure of circular economy system based on material flow

Source: Made by the author

The natural circulation subsystem, based on the ecosystem, supports the circular economy system. It forms a natural cycle through various elements within the system, providing resources for the socio-economic system. Sustainable utilization and maintenance of this cycle, without exceeding ecosystem thresholds, ensures the ecosystem's virtuous cycle and human access to Earth's ecological benefits.

The natural cycle subsystem comprises biological and abiotic environments, producers, consumers, and decomposers. It includes ten resource types like species, land, water, marine, mineral, energy, forest, grassland, climate, and tourism. The quantity, quality, and combination of these resources affect the subsystem's virtuous cycle.

When the natural ecosystem remains undisturbed, its self-organization maintains harmony and virtuous cycling. However, human activities like large-scale resource exploitation, extensive economic growth, and unreasonable consumption have disrupted this cycle, leading to issues like farmland loss, water scarcity, forest destruction, erosion, vegetation damage, and climate change.

The economic cycle subsystem is crucial for circular economy and human society's survival. It operates by inputting resources, discharging waste, and interacting with the natural system. Mimicking the natural ecosystem, it organizes production and consumption into a "resource-production-consumption-renewable resources" cycle to maximize resource and environmental efficiency. To reduce economic pressure on natural resources and interfere with the natural cycle, the subsystem must be planned and developed in an organized manner, fostering harmony between economy and nature.

Besides natural factors, the economic cycle subsystem is influenced by institutional, technical, economic, and social factors. Institutional factors involve government behavior and systems, often manifesting in macro-controls like administrative, legal, economic, and market mechanisms. Technical factors are crucial, as technological progress improves resource utilization, promotes substitution, alleviates resource shortages, treats environmental pollution, reduces waste discharge, and enhances recycling. Economic factors include labor productivity, national income, urbanization, and industrialization levels. A strong economy ensures technology and resource-environmental protection investments, advanced industrial structures, and resource sourcing from other regions, fostering low consumption, high output, and minimal pollution in developed areas. Conversely, less developed areas face capital, technology, and talent shortages, leading to increased resource input, neglected resource utilization and environmental governance, and vicious cycles of environmental degradation, investment environment worsening, productivity hits, poverty exacerbation, and more. Social factors concern population size and quality. Large populations strain resources and environments, causing ecosystem imbalances and economic vicious cycles. High-quality populations prioritize resource and environmental protection, promoting conservation and comprehensive utilization in production and consumption for economic virtuous cycles.

The "*nature-economy*" composite cycle system aims for an ideal circular economy where the ecosystem and social economy coexist. To achieve this, we must first ensure the dynamic balance of the ecosystem, providing renewable resources and a healthy environment for sustainable economic development. Secondly, economic input and output must stay within the ecosystem's carrying capacity, minimizing human impact and fostering harmony between the economy and nature. Lastly, by integrating social recycling in the economic subsystem with natural circulation in the ecosystem, achieving unity and coordination in material circulation throughout, we can ensure harmonious coexistence and sustainable development between humanity, the economy, and nature.

The circular economy system discussed here is a "*concept system*" capturing the essentials of various circular economy models across regions and industries. Viewing it as an abstraction from material "entity systems" aids in theoretically exploring its commonalities and developmental mechanisms.

Evolution of Circular Economy Theory. Origin: The circular economy theory originated in the 1960s. In 1966, American economist Balding introduced the concept of astronaut economics in 'Economics for an Upcoming Spaceship Earth,' emphasizing closed-loop resource flow within a fixed-resource economy, advocating minimal production capacity to prevent environmental degradation and resource depletion[19]. This sparked awareness of wasteful resource use in high-consumption, high-growth societies. Many scholars consider it a turning point for resource utilization and recycling in the mid-to-late 20th century. David Pearce and Tunay first used 'Circular Economy' in 'Natural Resources and Environmental Economics' (1993), exploring material cycles from a resource management perspective. Despite numerous publications on ecological economics and industrial ecology, circular economy-focused works were scarce until 2002, when Chinese scholars, under government advocacy, published extensively, marking the true inception of the Chinese circular economy concept[20].

Development of Circular Economy Theory. Currently, scholars have varying interpretations of the circular economy's essence, with significant differences among ecological economics, environmental economics, and economics. Below are perspectives from different scholars：Lin , Jian Danda (2019) defined the circle of circular economy as a closed-loop system framework centered on "natural resources", and its operating mechanism was a feedback loop of "resource-product-renewable resources", aiming to minimize environmental burden by optimizing resource allocation and energy use [18].Wu Shaozhong (2022) emphasized that circular economy aims to control the waste generated by human production activities and promote the integration of the production process with the circular mechanism of nature through the construction of a recycling system, so as to maintain the ecological balance [19].Wu Pingge (2020) proposed that circular economy is a comprehensive system of clean production and waste resource utilization. Guided by ecological principles, it simulates the material cycle and energy flow of the natural ecosystem to restructure economic activities, aiming to realize the deep integration of the economic system and the material cycle of the natural ecosystem, maximize the efficiency of resources and energy, and eliminate environmental pollution. Improve the quality and effectiveness of economic development [32].Chong Zifeng (2022) further explains that the core of circular economy is to build a closed-loop material flow and promote the transformation of economic activities to the feedback mode of "resource-product-renewable resources" and the paradigm of "low exploitation, high utilization and low emission", so as to integrate the economic system into the material cycle of the natural ecosystem and maximize the efficiency of resources and energy [21].Zhong Aimin (2018) pointed out that circular economy transforms the traditional linear economic growth model into an economic development model based on resource ecological cycle by improving the efficiency of resource utilization in human activities, and this transformation is realized in the complex system composed of human, natural resources and technology[27].

Xie Zhenhua (2004) views the circular economy as a closed-loop pattern of 'resource consumption - products - renewable resources,' contrasting with traditional open-loop 'resource consumption - products - waste emissions' [23]. Its technical characteristics include reduction, reuse, and regeneration, with a core goal of enhancing environmental resource utilization efficiency based on ecological economics.

Qi Jianguo (2004) views the circular economy as a technological paradigm revolution, representing China's emerging industrialization's highest form, establishing a new economic model through institutional innovation [13].

Zuo Tieyong (2004) notes that the circular economy, centered on efficient resource utilization and recycling, is a paradigm based on 'reduction, reuse, and recycling.' It features low consumption, low emissions, and high efficiency, aiming for maximum benefits with minimal resource and environmental costs. It emphasizes human-centeredness and is crucial for implementing the new scientific development concept, reflecting deep reflections on the human-nature relationship [25].

Ma Kai (2004) asserts that the circular economy, centered on efficient resource utilization and recycling, is a growth model based on 'reduction, reuse, and resource utilization.' It features low consumption, low emissions, and high efficiency, aligning with sustainable development. This represents a shift from the traditional 'mass production, consumption, and waste' model [14].

Duan Ning (2005) proposes that the circular economy pursues human sustainable development, using renewable resources and the environment as its basis. It meets human material needs and features efficient coordination among producers, consumers, and decomposers [15].

Feng Zhijun (2006) contends that the circular economy follows natural ecological material circulation patterns, adhering to ecological principles and rational resource use. It integrates the economic system into natural ecosystems, realizing ecological economic activities [28]. It advocates harmonious coexistence with the environment, following 'reduction, reuse, and resource utilization' principles, and employing a comprehensive process approach to reduce input quality and recycle products and waste. It forms a closed-loop 'resources - products - renewable resources' cycle, transitioning from waste elimination to purification and utilization, leading to optimal production, consumption, and minimal waste [29].

In summary, human behavior towards circular economy practice evolved over decades. In the 1970s, pollution treatment was a key concern. By the late 1980s, converting waste into reusable resources emerged as a research focus. However, the issue of waste disposal remained unresolved. In the late 1990s, sustainable development became prominent as major countries completed industrialization, revealing the drawbacks of traditional linear economic growth. This led to the search for a harmonious coexistence model between economic development and environmental protection. The sustainable development strategy gained global consensus, shifting from end management to source management and comprehensive production monitoring. In this process, minimizing resource waste and maximizing resource utilization emerged, promoting economic development while conserving resources and protecting the environment. Developed countries, led by Germany, adopted circular economy as a concrete path to sustainability. Germany's circular economy system features legislation, standardized waste management, operational standards, market mechanisms for waste reuse, logistics management, public awareness, supporting technology, and robust supervision. Recognized globally for its comprehensive legislation, Germany inspired major developed countries to adopt legal means for circular economy implementation. The EU, US, Japan, Australia, and Canada revised waste management regulations, aligning with closed-loop recycling and waste reduction, significantly contributing to circular economy development and promotion.

In summary, circular economy, a new trend vs. traditional economies, focuses on developing through waste recycling to minimize environmental harm from natural resource use and waste emissions in production and consumption. It achieves low-input, high-efficiency, and low-emission economic growth, akin to a "closed Materials Cycle economy" or ecological economics[30].

Indicator System for Circular Economy. GDP, introduced by Keynes, is widely used for development assessment but fails to account for resource and environmental valuation, hindering sustainable development reflection. Circular economy, distinct from traditional models, requires a unique set of indicators for evaluation.

Scholars globally have proposed indicators considering coordinated economic, social, and resource-environmental development in national accounting to address resource and environmental measurement.

Green GDP, an improved indicator, combines economic and environmental accounting into a new national system. It represents the total value of final products and services without reducing capital assets. Despite challenges, Green GDP has advanced in developed countries like Norway, which pioneered natural resource accounting in 1978 and laid the groundwork with its 1987 report. The UN Statistical Division's 1989 and 1993 frameworks facilitate green national, resource, and pollution accounting, adopted by developed (e.g., US, Japan) and developing (e.g., Mexico, Indonesia, Thailand) countries.

Nordhaus and Tobin introduced the Economic Welfare Measures (MEW) concept in 1972. It adjusts GDP by subtracting environmental pollution and urbanization-related losses, and adding values like household labor and leisure.

Herman Daly and John Cobb introduced the Index of Sustainable Economic Welfare (ISEW) in 1959, encompassing personal consumption, income distribution adjustments, household labor, volunteer work, and various services. It also deducts social, human, and natural costs[31] to estimate actual welfare levels.

In May 1990, the UNDP introduced the Human Development Index (HDI) in its "1990 Human Development Report," measuring longevity, knowledge, and living standards[32]. Calculated as a weighted average, HDI represents the average achievement in these three dimensions.

The Genuine Progress Indicator (GPI), proposed by Redefining Progress in 1995, is a sustainability economic welfare index[33]. It comprises economic, social, and environmental accounts with 31 contributing factors, akin to ISEW.

William Rees and Mathis Wackernagel introduced the Ecological Footprint concept in 1996 to assess humanity's living within ecological carrying capacity[34]. It measures resource consumption for human development, based on determining resources used and waste generated, which can be converted into biologically productive land area.

In 2004, the UK's New Economics Foundation introduced the Measure of Domestic Progress (MDP), reflecting social progress towards sustainability by combining economic progress, environmental costs, resource consumption, and social factors[35]. It was inspired by indicators like ISEW and GPI, with a focus on ISEW.

Other indices include Subjective Well-Being (SWB) by Wanner Wilson in 1960, Genuine Saving by the World Bank in 1995, and the SEEA by the UN Statistical Division[36]. These adopt a broader, multidimensional perspective to assess economic development.

In China, experts and scholars have extensively researched comprehensive economic development evaluation, yielding valuable insights.

In 2004, the Chinese Academy of Sciences' Sustainable Development Group introduced the *'Comprehensive Well-Off Society'* Indicator System, encompassing societal evolution's dynamics, quality, and equity. It includes three categories: development dynamics (e.g., industrialization, informatization, globalization), quality (e.g., economic quality, social operation), and equity (e.g., income, education). These categories comprise 40 basic indicators like GDP per capita and urban-rural income disparity[37].

Developing a circular economy fosters sustainable development by reducing resource consumption, resolving scarcity, creating growth, expanding employment, and benefiting economy, society, and ecology. It's crucial for achieving a comprehensive well-off society, linking the evaluation systems of both.

In 2004, Feng Zhijun proposed a comprehensive circular economy indicator system based on domestic and international research, encompassing social, economic, and ecological subsystems. Each is independently evaluated for circularity, forming a composite index [16].

Shang Hongyun and Zhou Shengjun proposed indicator systems for evaluating circular economy development across agriculture, services, enterprises, eco-industrial parks, and urban areas. Their system includes economic, environmental, and social functions, each with over ten indicators culminating in the Circular Economy Development Index (CEDI) [40].

Liu Linyan (2019) proposed a circular economy evaluation system under the guidance of The State Council, including four subsystems: economy (scale, structure, infrastructure), resources (conditions, conversion efficiency, recycling), environment (quality, cleaner production, protection), and society (development, technical education, and green management) [83].

Zhu Dongyuan (2017) proposed the framework of circular economy index system, which includes three main indicators: economic development (9 indicators, including per capita GDP and the proportion of green industries), green development (reduction, reuse and resource utilization, each with 10 detailed indicators) and social development (9 indicators, including the contribution rate of science and technology and unemployment rate) [42].

Yuan Jingyan (2022) proposed a four-tier system of circular economy evaluation system: Objectives (comprehensive evaluation), criteria (economic/social development, resource utilization, recycling, ecological quality), indicators (economic development, structure, efficiency, energy/material consumption, recycling, pollution emission, control, protection), and detailed sub-indicators are given [43].

Indicator Systems in Chinese Statistics: China's "Circular Economy Promotion Law" narrowly defines the circular economy as activities reducing, recycling, and utilizing resources in production, distribution, and consumption. The focus is on resources and the environment. While related evaluation and statistical systems are still being developed, the law mandates including resource output rate, waste reuse, and utilization rate in government circular economy plans.

To address China's circular economy needs, a 2003 National Science and Technology R&D Program project on circular economy theory and eco-industrial technology included a sub-project on indicators and planning guidelines. Based on this, in 2007, the National Development and Reform Commission, Ministry of Ecology and Environment, and National Bureau of Statistics jointly issued the "Circular Economy Indicator System," emphasizing resource utilization and environmental protection. It covers four main categories: resource output, consumption, comprehensive utilization, and waste emission, with two sets of specific indicators for macro-level and industrial parks.

Table 1.2

Macro Circular Economy Assessment Indicator System

Primary Indicators	**Secondary Indicators**
Resource Output Indicators	Primary Mineral Resource Output Rate
	Energy Output Rate
Resource Consumption Indicators	Unit energy consumption per GDP
	Unit energy consumption per industrial value added
	Comprehensive energy consumption per key industry's main products
	Water consumption per unit GDP
	Water consumption per unit industrial value added
	Water consumption per unit product for key industries
	Efficient utilization coefficient of agricultural irrigation water

Comprehensive Resource Utilization Indicators	Industrial solid waste comprehensive utilization rate
	Reuse rate of industrial water
	Urban wastewater recycling rate
	Harmless treatment rate of urban domestic garbage
	Recycling rate of scrap steel
	Recycling rate of non-ferrous metals
	Recycling rate of waste paper
	Recycling rate of waste plastics
	Recycling rate of waste rubber
Waste Emission Indicators	Disposal volume of industrial solid waste
	Industrial wastewater discharge volume
	Sulfur dioxide emissions
	COD (Chemical Oxygen Demand) emissions

Source: Made by the author

Table 1.3

Circular Economy Industrial Park Evaluation Indicator System

Primary Indicators	**Secondary Indicators**
1	**2**
Resource output indicators	Primary mineral resource output rate
	Energy output rate
	Land output rate
	Water resource output rate
Resource consumption indicators	Energy consumption per unit of GDP
	Water consumption per unit of GDP
	Energy consumption per unit of key products
	Water consumption per unit of key products
Comprehensive Resource Utilization Indicators	Industrial solid waste comprehensive utilization rate
	Industrial water reuse rate
Waste Emission Indicators	Industrial Solid Waste Disposal Amount
	Industrial Wastewater Discharge
	Sulfur Dioxide Emissions
	COD (Chemical Oxygen Demand) Emissions

Source: Made by the author

This evaluation indicator set lays the foundation for the national circular economy statistical system, enabling governments, industrial parks, and companies to formulate development plans and enhance management, crucial for circular economy development.

Clustered Circular Economy Development Model Analysis

Clustered Circular Economy Connotation: Industrial clusters, a prominent feature of industrialization, are a common economic geographical phenomenon globally. Various concepts such as industrial districts, agglomerations, complexes, and business clusters exist in economic literature, closely related and often logically connected(Xu Kangning, 2003).These concepts represent different research perspectives on industrial clusters.

The study of industrial clusters originated in the late 19th century with Alfred Marshall's theory of external economies. Michael Porter formally proposed the concept in "The Competitive Advantage of Nations," defining it as interconnected businesses and institutions in a specific area. Various scholars later offered supplementary views. Due to disciplinary differences, concepts and extensions vary. Rosenfeld (1997) viewed industrial clusters as dynamic, emphasizing industry interaction. Thus, the fundamental concept can be extended[45].

An industrial cluster is a geographically concentrated industry seeking performance advantages through agglomeration. It evolves through concentration, interaction, competition, and cooperation, ultimately driving development and growth. In this paper, the region formed is termed an industrial cluster area, akin to the "industrial cluster" in literature. It comprises interconnected businesses of various sizes and levels within a specific industry, agencies, and related actors through vertical and horizontal relationships[46]. This area is a stable, flexible spatial agglomeration entity, bridging pure markets and hierarchical structures.

The industrial cluster area refers to a geographical region, ranging in scope from an industrial park or city to a province, country, or multinational network.

Within the industrial cluster area, enterprises belong to specific industries but engage in division of labor and cooperation for efficiency. They extend vertically to sales channels and customers, and horizontally to auxiliary product manufacturers and related enterprises. This results in Porter's vertical and horizontal clusters: vertical clusters interconnected through buying and selling, and horizontal clusters sharing markets, technologies, skills, or resources. The area should also include institutions for training, education, research, and technical support.

Classification of Industrial Clusters. Academic research on industrial clusters presents diverse perspectives, leading to various classification methods based on existing literature and research.

Amin classifies industrial clusters into three types: traditional, high-tech, and large-enterprise-based. Traditional clusters focus on handicrafts, specialized production, and informal cooperation. High-tech clusters invest heavily in R&D and produce sophisticated, technology-intensive products. Large-enterprise-based clusters produce large-scale, high-value products and are controlled by core enterprises with collaborating suppliers. Information flow within these clusters is bidirectional[47].

Peter Knorriga and Jorg Meyer Stamer [48] classified industrial cluster areas in developing countries into three types based on Markusen (2016): Italian-style, satellite-style, and hub-and-spoke-style, as detailed in Table 1.4.

Table 1.4

Classification of Industrial Cluster Areas Based on Markusen

	Italian-Style Industrial Cluster Areas	**Satellite-Style Industrial Cluster Areas**	**Wheel-and-Spoke-Style Industrial Cluster Areas**
1	**2**	**3**	**4**
Characteristics	Mostly dominated by small and medium-sized enterprises; high specialization; intense local competition; built on trust relationships.	Mostly composed of small and medium-sized enterprises relying on external companies with low labor costs as the foundation	Clear hierarchical system with a significant presence of large local enterprises and small to medium-sized enterprises.
Advantages	Flexible specialization; high product quality; significant innovation potential.	Cost advantage in tacit knowledge and skills	Cost advantages; a significant role of flexible large enterprises.
Disadvantages	Path dependency faces challenges in adapting to economic and technological disruptions.	Reliance on limited involvement of external participants for sales and inputs affects competitive advantage	The entire cluster depends on the performance of a few large enterprises.
Development Path	Stagnation/decline; shifting internal labor division; outsourcing some activities to other regions; a wheel-and-spoke structure emerges.	Upgrading involves integrating forward and backward processes to provide customers with a complete set of products or services.	Stagnation and decline occur if large enterprises decline, stagnation, and internal division of labor change.
Policies	"Collective action" leads to regional advantages; integration of the public and private sectors.	Typical tools for upgrading in small and medium-sized enterprises include	The cooperation between large enterprise associations and support organizations for small and medium-sized

	Italian-Style Industrial Cluster Areas	Satellite-Style Industrial Cluster Areas	Wheel-and-Spoke-Style Industrial Cluster Areas
1	**2**	**3**	**4**
		training and technology diffusion.	enterprises increases the strength of small and medium-sized enterprises.

Source: Made by the author

Chen Jihai[49]classifies industrial clusters into three models based on the strength of market mechanisms and government roles: Planned, Government-Supported, and Market-Led Industrial Cluster Models.

The Planned Industrial Cluster Model, typical in planned economies like China's pre-reform era, rapidly allocates resources to support key industries. However, rigid planning, fragmented organization, and poor information flow often hinder economic goals, causing structural contradictions within cluster areas.

The Market-Led Industrial Cluster Model, prevalent in developed European and American economies, features advanced market mechanisms driving cluster growth and evolution. External policies are indirect and supportive, with government intervention focusing on regulating factors post-cluster emergence.

The Government-Supported Industrial Cluster Model is seen in developing economies like Japan, Taiwan, South Korea, and India. Unlike market economies in Europe and the US, these models have less mature markets and rely heavily on government support. Due to their industrial starting points and historical government intervention, a combination of government efforts and market mechanisms promotes cluster formation.

Zhang L.Y's classification [100]divides industrial cluster areas into three types based on generation mechanisms: Original, Embedded, and Derivative.

Original industrial cluster areas integrate local elements and cultural factors, naturally evolving to become highly resilient, exemplified by Wenzhou in Zhejiang Province, China.

Embedded cluster areas use policy and geographical advantages to attract FDI, swiftly setting up export-oriented manufacturing bases and evolving into large-scale clusters, like Shenzhen in Guangdong, China.

Derivative cluster areas become major high-tech hubs by tapping into market proximity and technological expertise, exemplified by Zhongguancun in Beijing, China.

Alex Hoen's classification[51]considers industrial clusters from two perspectives: scope and levels of analysis, and inter-entity relationships.

Based on industry levels, industrial clusters are categorized into micro-level (individual enterprises) and meso- to macro-level (clusters of various industries).

Secondly, industrial clusters can be further divided into six types based on intra-cluster entity relationships, as detailed in Table 1.5.

Table 1.5

Industrial Clusters Based on the Innovation Chain and Product Chain

Project	**Innovation Chain**	**Product Chain**
1	**2**	**3**
Micro-level	Companies and research institutions characterized by the diffusion of technology and knowledge.	Group of companies within the value chain of suppliers and buyers.
Meso-level	Industry clusters characterized by the diffusion of technology and knowledge	Industry cluster with forward and backward linkages.
Macro-level	Economic systems divided by the diffusion of technology and knowledge in industries.	Economic system categorized according to the formation of value chains and product chains.

Source: Made by the author

Many scholars have studied industry cluster types from various perspectives. The OECD's report categorizes them into: (1) national level, involving government-initiated institutional arrangements (e.g., high-tech parks); (2) sector/industry level, focusing on inter-industry and production chain links; and (3) enterprise level, centered on core companies with specialized suppliers. The latter two often form based on geography, culture, industry links, and market factors.

In 1988, UNCTAD categorized industry clusters into five types based on technological level, change extent, and collaboration: informal, organized, innovation, technology clusters, and incubators/export zones. Chen Jiagui et al. (2005) classified them into internal traditional, internal brand, and foreign-investment-based clusters.

Measuring Industry Cluster Intensity. Qualitative Methods for Assessing Industry Cluster Intensity

Industry clusters' cross-industry nature makes direct quantitative data acquisition challenging using standard methods. Thus, qualitative methods are crucial for studying influencing factors and assessing cluster intensity. Two primary qualitative methods exist for this purpose:

Porter's Diamond Model [51], introduced in "The Competitive Advantage of Nations," analyzes elements contributing to industry success. Porter emphasized that competitive advantage stems from vertically and horizontally linked industry clusters. The model identifies four factors determining clustering: factor conditions, demand, related and supporting industries' performance, and firm strategy, structure, and rivalry.

Factor conditions refer to a nation's production-related factors in a specific industry, including natural, capital, human, knowledge resources, and infrastructure. Demand conditions relate to domestic market demand for industry products/services, covering market nature, size, growth, and international demand potential[52]. The domestic market offers initial scale economies, enhancing efficiency, and domestic customer pressure directly influences product development.

Related industries' performance and capabilities influence innovation and internationalization in clusters. Competitive upstream industries enhance downstream responsiveness and efficiency, spurring new industries in technology, manufacturing, logistics, market development, and services. Firm strategy, structure, and rivalry depend on industry characteristics and national conditions, shaping domestic competitors' performance.

Qualitative Methods for Measuring Industry Cluster Intensity[53] include Harold Hotelling's Locational Model, which identifies two forces driving firm centralization until equilibrium: the centripetal demand effect clustering firms around the market center, and the centrifugal competitive effect spreading firms to the periphery. Firms' optimal location balances these effects. The model warns of limited clustering, with excessive concentration leading to dispersion. It analyzes factors affecting clusters and guides targeted measures to leverage centripetal forces, forming industry clusters.

Quantitative Methods for Measuring Industry Cluster Intensity

Industry Spatial Concentration[54], or market concentration, is a practical and widely used indicator measuring the degree of concentration within an industry, reflecting the share of the largest enterprises in the entire sector.

In industry analysis, the largest enterprises (typically top 4-8) are chosen arbitrarily to measure spatial concentration. For overall industrial clustering, the concentration of top 50, 100, 200, or 500 enterprises is calculated, using indicators like sales, value added, employees, or assets. This reflects market share and oligopoly, indicating geographical concentration but not inter-industry connections. However, it signals industrial concentration, aiding in cluster discovery and understanding the industry's general clustering situation, including enterprise size distribution within the cluster.

Location Quotient[55] measures the specialization level of a region by comparing its industrial structure to a higher-level region's average. It indicates the degree of industrial concentration and clustered scale advantage of a specific industry, serving as a meaningful indicator for regions to identify comparative advantages in industries.

The location quotient analysis assumes: (1) uniform labor productivity across regions, (2) no international trade, (3) no cross-regional trade of production capacity and labor, and (4) a unified consumption pattern.

The location quotient theory indicates cluster existence and reflects an industrial area's market influence, crucial for determining industry clusters. It accurately reflects spatial industry concentration, aiding in comparing longitudinal and horizontal concentration levels. However, it does not show the degree of intra-cluster connections.

Spatial Gini Coefficient[56] originates from income distribution analysis, with the Lorenz curve showing equality (overlap with absolute equality line) or inequality (overlap with absolute inequality line). Smaller Lorenz curve curvature indicates a smaller Gini coefficient and more equal distribution; larger curvature suggests greater inequality.

The spatial Gini coefficient measures industry concentration and regional distribution. Lorenz curves and Gini coefficients visually reflect industry clustering. Scholars like Krugman (1991), Liang Qi (2003), Wen Mei (2004), and Wang jie (2015) have used spatial Gini coefficients to assess manufacturing concentration and trends across regions.

The Herfindahl-Hirschman Index (H-index) sums market shares of firms in a specific industry. Unlike industry concentration, location quotient, and Gini coefficient, which focus on industry-level regional concentration, the H-index reflects distribution concentration within the industry using market share.

Beyond these methods, others measure industrial clustering, including geographic concentration index, analytic hierarchy process, and principal component analysis. Some reflect market concentration's influence on total production, illustrating clustering results and cluster relationships. Others gauge concentration based on criteria, offering reference value despite imprecise measures.

Theoretical analysis of circular economy's spatial organization and industrial clusters focuses on its regional development. Evaluating or exploring circular economy models necessitates discussing its spatial organization.

Circular economy relies on regional scale economy networks. Waste must reach a certain scale to be economically recyclable, based on large-scale production. If circular economy is confined to individual enterprises, it lacks economic feasibility. Expanding to multiple clustered enterprises addresses scale issues. Thus, we must discuss spatial organization of enterprises for circular economy implementation.

Enterprise clusters form due to external economy, specialized labor, transportation costs, and factor allocation. Traditional operation modes may be unsustainable due to resource and environmental constraints, necessitating a higher-level system view. Ecological organization of environment, technology, capital, information, talent, and systems ensures sustainable development, with circular economy as a fundamental approach. Industrial clusters and circular economy are endogenous to each other, requiring close spatial organization for material and energy exchanges at low transaction costs. This chapter establishes an endogenous analysis framework to explain this process.

Spatial organization of circular economy spans from individual enterprises to global scales, corresponding to enterprise, industrial, and social cycles. Effective circular economy implementation requires studying spatial organization and tailoring measures to each level. A four-fold spatial analysis views circular economy as developing within enterprises, industrial parks, regions, and interregions, progressing successively from smaller to larger scales, with each level building on the previous.

Literature typically categorizes the levels of circular economy into three: small (enterprise-level), medium (industrial-level), and large (social-level) cycles, though definitions vary. A common view is that the small cycle pertains to enterprises, the medium to industries, and the large to society.

The enterprise layer cycle, the first cycle, involves an enterprise's production process from raw material input, product manufacturing, waste discharge, to waste recycling. Cleaner production is the primary means of this cycle.

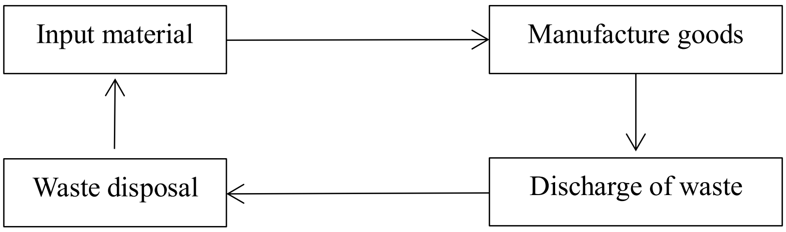

Fig. 1.5. Cycle at the enterprise layer

Source: Made by the author

The industrial cycle optimizes resource allocation within and across industries, extending the biological chain and forming ecological symbiosis. This often occurs in eco-industrial parks, a common circular economy approach. Unlike the traditional economy with only the 'arterial' industry, the circular economy introduces the 'venous' industry for waste disposal.

The social cycle aims for minimal natural resource use in production and encourages consumers to adjust their demands to what the natural ecosystem can sustain, fostering a beneficial cycle.

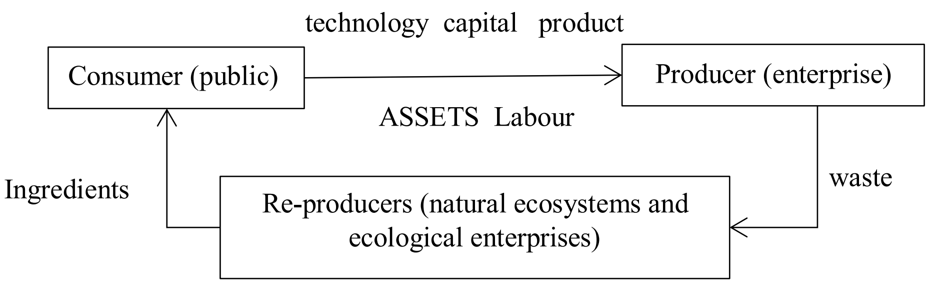

Fig. 1.6. Cycle at the socioeconomic level

Source: Made by the author

It encompasses material, energy, information, technology, capital, and talent flows within socio-economic, scientific-technological, and natural-ecological systems. This large cycle involves continuously enhancing natural resource utilization through technological progress, developing renewables, restoring degraded ecosystems, and meeting human needs, thereby achieving ecological balance and sustainable development.

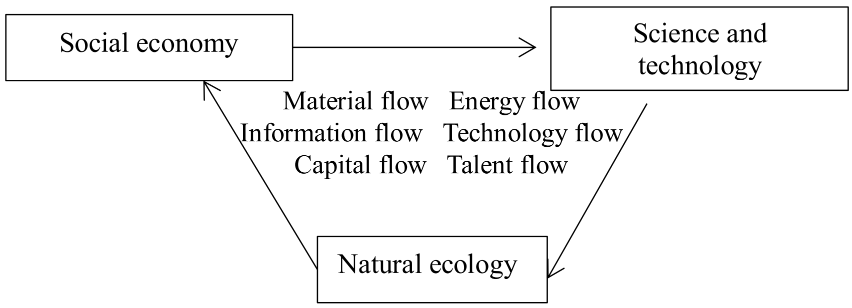

Fig. 1.7. Large cycles of the three systems

Source: Made by the author

Small-scale circular economy is the foundation for large-scale circular economy. Without implementation in basic units like enterprises and households, regional, national, or global circular economy is challenging. These units focus on front-end prevention, while larger scales emphasize end-of-event treatment.

Exploring the relationship between circular economy and industrial clusters through a simplified model.

Assuming enterprises A and B produce the same product and waste G, consider the following hypotheses:

First, under the current external constraints such as green barriers in resources and environment or products, both companies have to carry out circular economy.

Second, although there are a series of external constraints, enterprises still pursue profit maximization as the goal to carry out circular economy.

Third, the market structure is a perfect competition market, that is, the economic profit of both enterprises is 0.

Fourth, waste G is the only variety of the two enterprises, and its amount is proportional to the product output.

In a perfectly competitive market, enterprises aim for profit maximization by producing at the lowest long-term average cost (Q point), where marginal cost equals marginal benefit. Figure 1.8 illustrates this. Before circular economy, A and B firms' lowest long-term average cost point was Q0; below this, firms would exit the market.

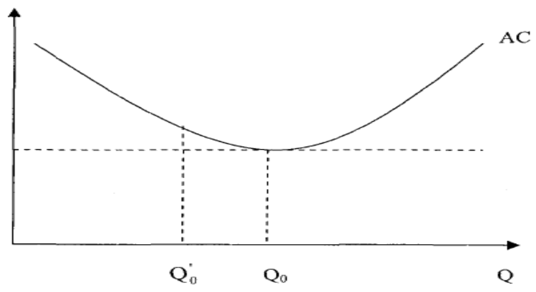

Fig. 1.8. Long-term production cost curve of an enterprise

Source: Made by the author

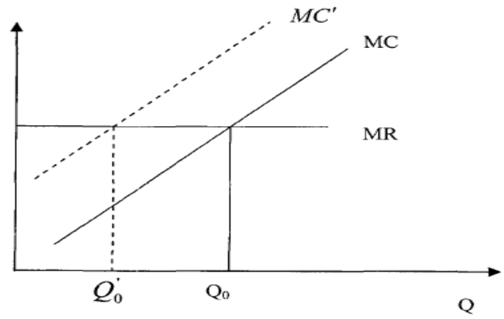

Fig. 1.9. Marginal cost and marginal revenue curve of enterprises

Source: Made by the author

Under external constraints, enterprises must adopt circular economy, extending their industrial chain and increasing marginal cost. To equate marginal cost with revenue, production must shift to Q0, not the pre-circular economy optimal Q0. This raises overall costs, deviations from lowest long-term average cost, negative economic profits, potentially leading to market exit.

If enterprises A and B form a circular community, sharing resources, cooperating technically, and recycling waste centrally, their production costs will approach the lowest point. With more companies joining, costs further decrease, leading to synergies, economies of scale, and a sustainable circular economy.

Industrial clusters offer scale and scope economies, reducing costs via positive externalities. Circular economy in these areas not only forms waste treatment scale economies but also leverages cluster benefits, offsetting potential side effects. Figure 1-9 shows that long-term average costs in clusters (AC') are lower than in non-clustered areas (AC), indicating scale economies and positive externalities.

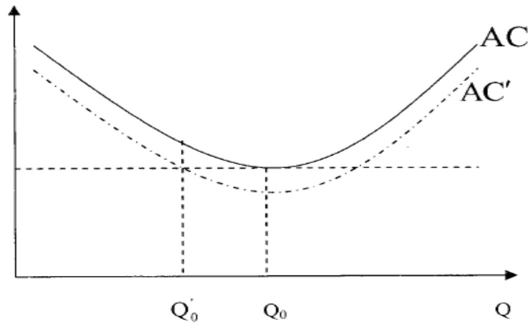

Fig. 1.10. Comparison of the long-term average cost curves of enterprises in and outside the cluster

Source: Made by the author

The analysis explores the dynamic mechanism of similar product/waste enterprises spontaneously clustering for circular economy. Synergies are pronounced across industrial chain levels or when one firm's waste is another's raw material (food chain clusters). Even unrelated firms, moderately concentrated, benefit from shared resources (info, facilities, capital, tech), facilitating circular economy implementation.

Based on the assumption of external constraints necessitating circular economy, the theoretical analysis shows industrial clustering as a prerequisite. Next, we analyze the necessity of circular economy within industrial clusters.

When single enterprises pursue circular economy, marginal costs rise. As enterprises cluster, waste scales attract recyclers, spontaneously promoting circular economy. However, clusters' scale economies and positive externalities also bring negative effects like resource scarcity and pollution, raising costs and reducing benefits, impacting sustainability. Developing circular economy in clusters mitigates these negatives, enhances economic benefits, creating a demonstration effect that draws outsiders, fostering a win-win 'circulation-economy' scenario.

Driven by enterprises' pursuit of circular economy and clusters' circular economy pull, agglomeration circular economy emerges. Existing cluster firms transform, turning the area into a circular economy hub. This endogenous, adaptable model thrives under circular economy constraints, fostering sustainable practices.

Based on the analysis, enterprise agglomeration leads to circular economy clusters, achieving circulation and economy. This market-driven, endogenous, stable circular economy results from clusters' and circular economy's combined strengths, manifested in four key ways:

First, circular economy and industrial clusters complement each other, mainly in efficiency and ultimate goals. This complementarity ensures more resource utilization and economic benefits, forming an effective combination.

Table 1.6

Comparison between circular economy and industrial cluster

Content	Circular economy	Industrial cluster
1	2	3
Starting point	It focuses on cooperation between enterprises on environment and resources	Focus on the economic cooperation between enterprises
Geographical position	Enterprises should be relatively concentrated	The geographical proximity of the business
Organizational structure	Enterprises rely on division of labor to form cooperative networks	Enterprises form a close competition and cooperation network
Organizational integrity	The industrial chain is closely integrated and has strong integrity	Strong integrity, with behavioral convergence
Efficiency basis	Ecological economy	External economy and scope economy
Ultimate goal	Harmony between economy and environment	The promotion and development of economic benefits

Source: Made by the author

Second, industrial clusters reduce circular economy costs and enhance benefits. Low economic benefit hampers circular economy. Small-to-medium enterprises face challenges in recycling due to limited resources and scale. Clustering brings together similar enterprises, scaling waste volumes, enabling shared recycling systems. This cuts recycling costs, lowers investment risks, and achieves economies of scale.

Third, industrial clusters boost circular economy operational efficiency by reducing transaction costs and enhancing resource use. This leads to lower transport and information costs, and shared facilities. While clusters' external economies benefit directly, circular economy's are socially focused but often neglected in economic evaluations. Combining them complements their external effects, enhancing circular economy efficiency.

Fourth, industrial clusters' information sharing fosters circular economy development. Unlike isolated enterprises, clusters ensure seamless information flow, providing timely and effective data for production. This aids firms in acquiring crucial circular economy insights and technologies, like waste utilization innovations. Furthermore, the organizational network within clusters facilitates efficient information exchange between upstream, downstream, and similar enterprises, enhancing circular economy progress and stable inter-firm cooperation, thereby promoting its effective development in the industrial cluster.

1.2. Circular Economy Benchmarking for Cluster Formation

The Essence of Benchmark Management. Benchmarking, also known as enterprise benchmark, competitive reference, etc., emphasizes its role as a management tool. Originally, "benchmark" was a craftsmen's or surveyors' reference point. It later evolved into a standard for measurement. Since Xerox Corporation advocated it in the late 1970s, "benchmark" has signified excellence.

Scholars globally have diverse definitions of benchmark management. R.C. Camp, its founder, defined it as a continuous process of comparing products, services, and practices with top competitors or industry authorities to drive optimization and achieve objectives[58]. This broad definition spans various levels and types, transcending national and industry boundaries. Simple and understandable, it encourages seeking best practices for exceptional performance, adopted by the International Benchmarking Network.

The APQC defines benchmark management as learning from external references through structured processes, emphasizing continuous comparison with best practices and encouraging interactivity and information sharing. However, it neglects internal comparisons and the method of seeking best practices. Despite this, over 100 large companies have adopted this definition.

Vaziri advocates for a simple, clear definition that guides users on actions and goal achievement. He defines benchmark management as continuously comparing a company's understanding of key customer needs with industry bests (direct competitors or acknowledged best practices)[59] to identify areas for improvement. This definition underscores its relevance to internal and external customer satisfaction.

Luo Liangqing and Liu Yishou define benchmark management as a systematic, process-oriented approach that establishes performance standards, identifies benchmark organizations excelling in specific areas, compares performance, and aims to narrow gaps through process analysis and transformation. The goal is to continuously seek optimal models and enhance operational performance effectively.

Kong Jie and Cheng Zhaihua (2004) define benchmark management as assessing and comparing an organization's products, services, and practices with leading organizations within the same industry or department, analyzing their superior competitiveness, and formulating improvement strategies. This links benchmark management to enterprise or country competitiveness, but lacks specific standards[20].

Tian Fang, considering the Chinese context, defines benchmark management as continuously discovering best practices from within or outside the organization and industry, comparing with competitors or leading enterprises, and using these as internal development goals with localization adjustments[60].

In summary, benchmark management is a practical, process-improvement approach focused on identifying and implementing best practices. It goes beyond mere comparison, encompassing activities and goals aimed at enhancing organizational performance through systematic optimization and continuous improvement.

The fundamental task in circular economy development is transitioning from a linear to a circular system. Given the circular economy's recent global emergence, there's no established system, and collected "best practices" may not represent the ultimate state. Moreover, their optimality is uncertain. Hence, setting the strategic benchmark as the ideal circular economy state fosters innovation.

The ideal circular economy involves green design, clean production, advanced green logistics, circular consumption, minimal waste, and maximal resource recovery. Entities at all levels exhibit strong resource and environmental awareness, robust environmental ethics, clear roles, and institutional frameworks encompassing environmental ethics, legal frameworks, and policies. Micro-level organizations should have well-developed management systems.

Determining strategic benchmarks for the circular economy involves recognizing the gap between current status and the ideal state, considering organizational goals, current situations, and constraints. Mid-term and short-term benchmarks are crucial, varying by country due to different factors but leading to the same goal. For China, specific factors such as economic goals, resource scarcity, and environmental challenges must be considered. Mid-term and short-term benchmarks should focus on energy conservation, waste reduction, emissions control, and building a basic circular economy system with institutional development.

In China, two main approaches to the circular economy exist: constructing circular industrial chains through eco-industrial parks and addressing resource bottlenecks. However, the first approach oversimplifies the circular economy by focusing solely on material recycling. The true essence of China's circular economy lies beyond mere circularity, emphasizing the "3R" principles—reduction first, reuse second, and recycling last. Recycling is only a choice when reduction and reuse are not feasible. An optimized circular economy, where minimal waste is left for recycling, represents an advanced form, recognizing that recycling itself consumes resources and has environmental impacts.

In China, the focus on industrial development leans more towards achieving "reduction" than "reuse" or "recycling," despite the importance of resource bottlenecks. China's resource and energy utilization is intensive and inefficient. Xu Kuangdi emphasized at the 2005 China Development High-Level Forum that optimizing industrial structure is key to conservation. Setting technical thresholds for environmental protection and resource consumption, halting the development of inefficient, highly-polluting industries, and promoting industrial upgrading are crucial means to address current resource and environmental challenges.

Despite industrial structure optimization and upgrading, resource and environmental issues may still persist, hindering the ideal circular economy. Even developed industrialized countries need to develop their circular economy. Beyond addressing current resource bottlenecks through energy conservation, waste reduction, and emissions control, it is crucial to focus on constructing a circular economy system with institutional development as its core for future development.

Limited (2018)research exists globally on combining the circular economy with the sustainable development of industrial clusters, often focusing solely on its relationship with regional economic development.

Zhu Aimin and others contend that the circular economy optimizes resource allocation in cluster enterprises, addresses pollution, and complements industrial cluster development.

Ci Fuyi (2016)believes cluster-based circular economy will be key to forming industrial clusters, emphasizing benefits in policy design. Wu Feimei suggests its development needs government, industry, and enterprise collaboration for swift and effective progress.

Lü Hui (2023)proposes integrating the circular economy into industrial cluster evolution as a strategic choice. Zheng Jianzhuang, in his book, presents core indicators and models for economic sustainability by combining circular economy and industrial ecology principles. He analyzes mechanisms to define resource conservation, utilization efficiency, and environmental pollution levels, applying these to research objects like industrial clusters.

In his book, Feng Wei (2017)combines industrial agglomeration with the circular economy, emphasizing regional and industrial perspectives. He proposes that the circular economy offers a new approach to regional economic development, suggesting industrial agglomeration based on it as a strategic policy.

Industrial ecology shows self-organizing ecological networks outperform human-planned parks. Industrial clusters, key to regional economic growth, offer competitive advantages and economies of scale, benefiting cluster enterprises and regional industrial activities and ecosystems, crucial for national sustainable development.

Regional industrial ecological development hinges on a self-organized model with clusters as its core. Identifying an effective regional industrial environmental management model is crucial in industrial ecology. This chapter integrates industrial symbiosis, circular economy, and cluster theories to propose an integrated circular economy model. After analyzing its characteristics and foundations, it focuses on model construction, offering case studies to guide future regional industrial ecological development.

World Benchmarks in Circular Economy.

Globally, major economies including the EU, US, Japan, Singapore, and China view circular economy development as crucial for economic growth and climate goals, enacting various regulations, directives, and action plans.

The European Union has long advocated for a "circular economy," contrasting it with traditional linear models. In the industrial era, the economy operated as a one-way "resource-product-waste" process, hence known as the linear economic model.

Early EU circular economy legislation focused on waste management, with the 1975 regulation on waste being the first. Directive 2008/98 requires Member States to prioritize waste prevention and reuse, recycling, or upgrading, and mandates waste prevention and management plans. Special regulations cover waste classification and activities related to radioactive, mining, packaging, electrical and electronic equipment, and automotive waste. Energy products are taxed based on Directive 2003/96, promoting biofuels and renewable fuels. The 2011 proposal amended energy tax rules. In 2003, the European Commission implemented the National Action Plan for sustainable public procurement, with Directives 2014/24 and 2014/25 expanding sustainable procurement procedures.

In 2010, amidst the economic crisis, the EU launched the "Europe 2020" strategy aiming to enhance competitiveness and employment. Recognizing "Resource Efficient Europe" as a driver for sustainable growth, the EU developed a resource efficiency roadmap to improve resource productivity and decouple growth from resource use, focusing on environmental impacts.

On December 2, 2015, the European Commission presented the Resource Efficient and Circular Economy Package based on the earlier roadmap. In July 2014, a preliminary proposal was adopted, but in February 2015, it was withdrawn to create a more ambitious draft. The 2014 proposal included measures to: (1) increase municipal waste recycling to 70% by 2030; (2) raise packaging waste recycling to 80% for materials like glass, paper, metal, and plastic by 2030; and (3) ban landfilling of recyclable and biodegradable waste by 2025.

The European Commission's 2015 circular economy package aims to transition the EU to a strong, sustainable circular economy. It includes: (1) an action plan with concrete measures for the entire cycle from production to secondary raw material markets; (2) legislative amendments, such as the Waste Framework, Landfilling, and Packaging and Packaging Waste Directives. However, NGOs criticize the modest recycling and landfill targets.

In 2015, the EU adopted the Circular Economy Action Plan, framed by the Europe 2020 Strategy to fight climate change and promote growth. In 2020, an updated plan became a key part of the European Green Deal, proposing sustainable product concepts in seven areas to reduce resource use and carbon emissions. The Sustainable Products Initiative, to be adopted by 2022, aims to leverage global circular economy opportunities and steer the EU towards sustainable, low-carbon development.

Germany, a highly industrialized country with limited natural resources, faces increasing energy and resource shortages due to industrialization. In response, Germany began exploring renewable resources, leading to the emergence of the circular economy.

Germany's circular economy focuses on "garbage economy," emphasizing waste treatment and reuse as its core.

In the late 20th century, Germany recognized that waste end treatment alone couldn't solve environmental issues and began exploring waste reduction and reuse. With recycling services widespread, over 1 million people in Germany are involved in environmental protection, including 240,000 in the circular economy, generating a total output value of over 50 billion euros and accounting for over 18% of international trade.

Germany has specific measures for treating various types of waste, including domestic, paper, glass, batteries, packaging, oil, vehicles, and construction waste. In 1993, Germany had over 50 waste-to-energy devices and 10 waste power plants with a 1,000 MW capacity, achieving a 17% average generation efficiency. Today, nearly all German waste incineration plants produce electricity, and in 1998, 50% of residential electricity came from waste incineration. By 2004, Germany's municipal solid waste incineration rate reached 25%.

Germany is a pioneer in circular economy legislation, with roots in the 1935 Nature Protection Act and significant post-WWII developments. The following table outlines Germany's circular economy legal and regulatory framework.

Table 1.7

Laws and regulations of circular economy in Germany

Year	Content
1	**2**
1972	《Waste Disposal Act》
1974	《Atmospheric emission Control Act》
1976	《Water Pollution Discharge Control Law》
1978	"*The Blue Angel* "Project
1983	《Combustion Pollution Control Act》
1984	《Waste Management Law》
1994	Enactment of 《Circular Economy and Waste Management Law》
1998	《Packaging Act》 《Biological Waste Ordinance》
2000	《Renewable Energy Promotion Law》
2004	《Renewable Energy Amendment Act》
2005.3.24	《Electronic and Electrical Appliances Law》
2005.5.28	Third Amendment to the 《Packaging Ordinance》
2005.7.12	《Fees Ordinance of the Electronic and Electrical Services Act》
2005.9.1	《Refuse disposal Assessment Ordinance》
2005.10.8	Second Amendment to the 《Annex to the Basel Agreement》
2006.1.7	Fourth Amendment to the 《Packaging Ordinance》
2006.2.9	First Amendment to the 《Scrap Car Ordinance》
2006.7.15	《Simplified Waste Monitoring Act》(Effective on February 1, 2007)

Source: Made by the author

Germany's comprehensive legal and policy system for circular economy ensures its development. With over 8,000 national and state environmental laws and 400 EU regulations, the German Circular Economy and Waste Management Law stands out as the guiding framework. It promotes a closed-loop resource system across all sectors, emphasizing producer responsibility for a product's lifecycle and prioritizing waste avoidance, recycling, and disposal.

Germany's efficient waste disposal is attributed to its comprehensive waste recycling organization management, particularly its binary recycling system.

Duales System Deutschland (DSD), a joint stock company founded in Cologne in 1990 by 95 businesses, now has 600 shareholders. It operates as a non-profit, funded by Green Dot royalties from licensing the trademark to enterprises, under the initiative of German industry federations.

DSD aims to recycle waste packaging in Germany, managing all packages with the "Green Dot" logo. Non-users must self-recycle, meet limits, and provide proof. Unauthorized use of the logo violates trademark law. Currently, 19,000 German firms use it, promoting packaging recycling with 210 sorting workshops handling 2.5 million tons annually. The "Green Dot" system has spread to 22 European countries.

Germany has advanced renewable resources and circular economy through legislation, policy, subsidies, tax incentives, and scale management, effectively protecting resources, climate, land, water, and public health.

France's approach to the "circular economy" faced setbacks and hesitation, ultimately introduced by the EU into French law post-2015 with limited national will. The law, while a tool, alone is insufficient; it must adapt to encourage the principle's implementation.

Decentralized legislation of "circular economy" in France.

France's measures include: (1) imposing energy taxes as per EU regulations (Customs Act, Art. 265); (2) implementing the EU Public Procurement Directive (Executive Order 2015/899); (3) developing an ecological tax system, which in 2012 accounted for 1.8% of GDP (EU avg.: 2.6%). The EC encouraged shifting the tax burden to consumption and the environment in 2013, but public acceptance is challenging. Tax reforms have been sensitive since 2013, with ecological tax reforms awaiting a 2016 fiscal law amendment. (4) The Waste Prevention and Management Decree was amended in 2015, revising services for local planning, ship recycling, and waste committees, and simplifying procedures. An administrative decree was issued in 2015 for industrial site rehabilitation.

France's Green Growth Energy Transition Act (Aug. 17, 2015) includes a special chapter on the circular economy, aiming to combat waste and promote circular practices. It sets targets like halving waste and achieving 60% recycling by 2025, improves product concepts, strengthens proximity in waste management, and expands incentives. A key highlight is introducing a new circular economy model and simplifying procedures. The circular economy aims to transcend linear models through rational consumption and resource use, emphasizing reuse, recovery, and secondary materials. It promotes industrial ecology, sustainable management of renewable resources, product lifecycle extension, waste prevention, and regional cooperation based on proximity. The goal is to decouple resource consumption from GDP growth, reducing environmental impact and enhancing well-being. The proximity principle encourages local waste disposal to avoid secondary pollution. The decree simplifies urban planning, building permits, and other procedures, allowing local governments to introduce ecological criteria for subsidies and support renewable energy.

In the legal framework:(1) The Environmental Code views the transition to a circular economy as a tool for achieving Sustainable Development Goals, with "sustainable public procurement" aligned with this transition.(2) The Energy Code stipulates that the circular economy should be a goal of energy policy.(3) The Consumer Code also addresses aspects related to the circular economy.

The characteristics of French "circular economy" legislation include:(1)focus on resource efficiency.(2)Fragmented policies targeting various industries, with specific institutions for product design aimed at achieving sustainable development goals.(3)Clear quantitative objectives set by legislation to serve this economic model.

Japan, an island nation rich in forest resources but poor in others, is a significant resource consumer. Hence, developing a circular economy to maximize resource utilization and improve the economic structure has become a pressing issue for Japan.

In the 1960s, Japan established a committee to address public hazards. By the 1970s, it focused on source pollution control. In the 1980s, Japan proposed a model for ecological and economic harmony. The 1990s saw the introduction of the "circular economy" concept, creating a "resource-product-renewable resources" feedback loop. Through government leadership, legal frameworks, and public participation, Japan formed a comprehensive circular economy strategy and became a global leader in energy solutions.

Japan boasts the most comprehensive circular economy legislation globally, structured into three levels: basic, comprehensive, and specific laws and regulations.

Japan's circular economy legal system is shown in the following table:

Table 1.8

Japanese circular economy legal system

Legal level	Legal name	Set time
1	**2**	**3**
Basic law	Environmental Basic Law	1993
	Basic Law on Establishing a Circular Society	2000
Comprehensive method	Waste Disposal Law	1970
	Law on the Promotion of Effective Use of Resources	1991

Special method	Law on the Collection and Recycling of Containers and Packages	1995
	Special Household Machinery Cycle Act	1998
	Building Materials Recycling Act	2000
	Recyclable Food Resources Recycling Act	2000
	Green Procurement Law	2000
	Special Measures Law on Proper Disposal of Polychlorinated Biphenyls Waste	2001
	Vehicle Regeneration Law	2002

Source: Made by the author

Japan's circular economy legislation features: strategic alignment with environmental and resource realities, aiming for sustainable development; shared responsibilities among state, local governments, enterprises, and the public; legally stipulated plans and timelines for establishing a circular society; prior environmental impact assessment; support for tech research, education, and circular economy knowledge dissemination; encouragement of civil society initiatives; and strengthened international cooperation.

Practice Mode in Japan's circulatory society balances material flow through a combination of '*arteries*' and '*veins*.' The '*vein industry*,' or resource recycling industry, transforms waste into reusable resources and products using advanced technology, ensuring environmental safety. It involves converting waste to renewable resources and processing these into products. The 'arterial industry' completes the '*resource-product-consumption*' transformation.

To develop the vein industry, Japan has established ecological industrial parks with a management mode of '*government-industry-academic integration,*' involving local and central governments, enterprises, research institutions, and administrative departments.

From 2003 to 2018, Japan issued the Basic Plan for Establishing a Sound Material Circular Society every five years, outlining actions and measures. Since 2008, Japan linked the circular economy with low-carbon development. In 2020, the 'Green Growth Strategy' aimed for carbon neutrality, with resource and carbon recycling industries as key supports.

The U.S. was inspired by economist Balding's 1969 'spaceship theory' for circular economy. It was an early pioneer, establishing 'Recycling Day' on November 15, 1997. Today, the circular economy is integral to the U.S. national economy.

Legislation in the US, a country with a robust legal system, recognizes its importance in guiding circular economy development. While lacking a national circular economy law, the US has the Resource Conservation and Recovery Act and Pollution Prevention Act. Additionally, both federal and state governments have implemented policies supporting circular economy growth.

The Solid Waste Treatment Act of 1965, amended several times until 1984, evolved into the Resource Conservation and Recovery Act. Since the mid-1980s, over half of U.S. states have passed laws promoting renewable resource use.

The U.S. government passed legislation to control pollution, including the 1990 Pollution Prevention Act emphasizing source reduction and the Clean Air Act banning chlorofluorocarbon refrigerant emissions, promoting recovery and recycling of harmful gases.

Eco-Industrial Parks (EIPs) were first proposed by Indigo Development Research Institute in 1992. Over 20 years later, the Presidential Council on Sustainable Development's Task Force has promoted their development. By the early 21st century, the US had about 20 EIPs, encompassing industries, agriculture, and residential systems. These parks can be broadly categorized into three types:

One type is virtual, exemplified by Brownsville Eco-Industrial Park. It doesn't require co-location, using modern IT to model material/energy relationships via computers and form industrial ecological chains. This saves land and infrastructure costs, avoids relocation, and offers flexibility in land-scarce, high-rent, well-connected areas. However, it incurs higher transportation costs.

The second type is retrofit, exemplified by Fairfield Eco-Industrial Park in Maryland. It's a petroleum and organic chemical hub using industrial ecology principles to transform existing companies and exchange waste/energy regionally. All enterprises adopt circular production for sustainable products. The bio-fuel power generation in the park fully supplies electricity, enabling enterprises to reduce fossil fuel dependence.

The third type is new, exemplified by Cape Charles Sustainable Technology Park in Virginia. It attracts enterprises with green manufacturing technology and builds infrastructure for waste exchange. This park requires significant investment and high member standards.

The US has implemented fiscal, tax, and energy policies to promote circular economy, leading globally. The 'Five Zero' strategy, including zero-carbon electricity, transportation, waste manufacturing, buildings, and vehicles, aligns with circular economy principles. Developing a circular economy has become a common choice for nations to foster growth and green transitions.

China's circular economy practice.

Post-1992 UN Conference on Environment and Development, China led the formulation of Agenda 21 - China's White Paper on Population, Environment, and Development for the 21st Century. To achieve the third national socio-economic goal, China issued the Program of Action for Sustainable Development in 2003, building on past achievements and addressing new sustainable development challenges.

Practice of China's circular economy development

China's circular economy originated in the Han and Tang Dynasties with simple models like 'mulberry fish ponds.' Early on, due to limited productivity and resources, people developed waste utilization habits, forming a basic circular economy focused on conservation. While classical circular economy was driven by low productivity and resource scarcity, modern circular economy is compelled by excessive resource consumption due to high productivity.

China's modern circular economy evolved through three stages: beginning, awakening and selection, and a new stage.

Initially, from 1990s to 2003, the field was in its nascent stage, introducing concepts and demonstrations. Prior to this, in the 1970s and 1980s, China emphasized waste utilization from industrial and mining enterprises, particularly end-of-pipe pollution control. Following the 1993 Shanghai Conference on Industrial Pollution Prevention, clean production pilots shifted focus from end-to-source and full production process pollution prevention.

In 1995, China passed the Solid Waste Law, encompassing much of circular economy principles. In 1996, Chizhou in Anhui became the first national ecological economy demonstration zone. By 1999, Hainan was approved as China's first ecological demonstration province, Suzhou New Tech Development Zone as the first

IS014000 national demo zone, and the Clean Production Promotion Law was drafted, marking China's circular economy initiation. By 2002, 314 ecological demonstration zones were under construction nationwide, including 40 cities, 264 counties, and 10 others, with Hainan, Jilin, Heilongjiang, and Fujian approved as pilot projects.

Secondly, the awakening and selection phase began around 2003, as governments, professionals, and scholars recognized that developing a circular economy was the necessary response to escalating environmental pollution and resource scarcity.

In March 2003, Premier Zhu Mingji first proposed supporting environmental protection industry and circular economy in the Government Work Report. This marked the term's debut in such a report. The 16th CPC Central Committee's Fourth Plenary Session decision highlighted "saving resources, protecting the environment, vigorously developing a circular economy, and building a conservation-oriented society" as key to adhering to the scientific outlook on development. In September 2004, the National Development and Reform Commission held the first circular economy work conference, outlining foreign circular economy developments, discussing China's necessity and urgency, and proposing policy measures.

Under the advocacy of the Central Committee and leaders at all levels, media, and scholars extensively discussed the importance of environment and resources, emphasizing that circular economy is the correct choice for sustainable development and implementing the scientific outlook.

Third, the new stage began in 2005. In January, major projects worth nearly 100 billion yuan, including the Three Gorges underground power station, were halted. From March to October, various meetings emphasized circular economy development. In November, the National Development and Reform Commission, with six other ministries, issued the Circular Economy Pilot Notice, covering 42 enterprises, four areas, 13 industrial parks, and 10 provinces/cities.

The Outline of the Eleventh Five-Year Plan, approved by the Tenth NPC in March 2006, dedicated a special chapter to outlining goals, tasks, and measures for circular economy development.

In August 2008, China implemented its first Circular Economy Promotion Law, marking a new stage of rapid and standardized development for circular economy.

China's circular economy practice at the four-fold spatial level

Since the 1990s, China has practiced circular economy, piloting it in 1999 at enterprise, regional, and societal levels. Based on studies of strategic frameworks, legislation, and indicator systems, the State Environmental Protection Administration drafted opinions to accelerate circular economy development and formulated technical guidelines for provinces, cities, and industrial parks.

In October 2005, the first batch of 42 pilot enterprises in seven key industries were announced. By December 2007, the second batch expanded to 42 enterprises across 11 industries, including iron and steel, nonferrous metals, coal, electricity, chemicals, building materials, paper, textile printing and dyeing, machinery, agricultural processing, and agriculture (forestry).

Among the pilot enterprises, Guangxi Guitang Group and Shandong Lubei Group are particularly notable.

Guigang City, southeast of Guangxi, is a major inland port city in South China with a tropical monsoon climate. Its favorable natural conditions make it a significant sugarcane production base in China.

Guizang Group, formerly Guangxi Guixian Sugar Factory, is a key "First Five-Year Plan" project. By forming an ecological industrial model centered on sugarcane, it has achieved notable economic and environmental benefits despite industry challenges. It has become China's largest sugar factory and was honored as a "national environmental protection advanced enterprise."

Your Sugar Group's framework comprises six systems: sugar, sugar field, paper, cogeneration, alcohol, and environmental treatment. Each system produces outputs and interconnects through intermediate and waste exchanges, forming a complete, closed ecological industrial network.

The sugar model features "complex symbiosis and waste recycling." Guitang Group arranges waste utilization among subsidiaries, forming stable symbiotic relationships. Two main ecological chains exist: "sugarcane-sugar-bagasse papermaking" and "sugarcane-sugar-molasses-alcohol-compost." Due to their coupling, waste is viewed as a resource, leading to full resource sharing, pollution benefit transformation, and industry structural pollution resolution.

Shandong Lubei Group, formerly Wuli Sulfuric Acid Plant, has assets of 5 billion yuan, 52 member enterprises, and 5,300 employees across 400 sq km. It operates in 10 industries, including chemicals, building materials, and light industry. As the world's largest phospho-sulfate cement co-producer and China's largest phospho-compound fertilizer base, it boasts the best economic benefits in the national fertilizer industry.

The ecological industry system in northern Shandong grew from scratch, expanding from simple phosphorus, sulfuric acid, and cement co-production to PSC, seawater, and salt-alkali electricity chains. Today, industrial chains have deepened and added value. As the ecosystem evolves, it minimizes waste, efficiently uses energy, and maximizes economic, environmental, and social benefits alongside economic development.

The Lubei model features "symbiotic disaster and industrial extension," characterized by complex symbiosis. Under the group's unified decision, enterprises connect through by-products, integrating resources. As a "family," sensitive issues like infrastructure investment, interest distribution, and business secrets are resolved through group coordination or administrative orders.

Many enterprises have joined cleaner production efforts. In 2006, China trained 2,643 cleaner production auditors in 46 courses, preparing technical talent for local audits. By 2006's end, 1,366 enterprises had China's environmental labeling certification, with 931 valid certificates covering over 21,000 product models. Annual output value of these products reached 100 billion yuan. Among developing nations, China is recognized for its top performance in cleaner production.

Eco-industrial parks, based on circular economy and industrial ecology principles, simulate natural ecosystems for logistics and energy flow. China has established 33 such parks, including 13 in the first batch and 20 in the second, encompassing both industrial and agricultural zones. Baotou's aluminum and Shihezi's demonstration parks exemplify how these parks operate in China.

Baotou National Ecological Industry (Aluminum) Demonstration Park, in Donghe District, Baotou City, spans 19.8 sq km. Guided by circular economy and ecological industry theories, it aims to build an aluminum-focused park centered on "aluminum-electricity joint operation," with electrolytic aluminum and deep processing as key areas. Highlighting high energy, technology, and low pollution, the park will optimize its structure, layout, and facilities over 8 years. It's divided into core, expansion, and radiation areas, focusing on aluminum, electric power, building materials, casting, and rare earth high-tech industries.

The park has established planning, management, and development organizations. The Construction Coordination and Administrative Service Office, staffed by Donghe District government personnel, exercises governmental functions and provides coordination services. Park enterprises meet entry criteria and benefit from national and regional preferential policies.

Shihezi, in Xinjiang Uygur Autonomous Region, is an economic, scientific, educational, and medical hub. The local reclamation area faces environmental degradation and weak resource conversion. Based on planting friendly grass, the Shihezi Ecological Industrial Park, supported by Tianhong Paper Group, integrates planting, papermaking, breeding, livestock processing, sewage treatment, and eco-tourism across three functional areas. Managed macro by the municipality and implemented by enterprises, the park benefits from national and local policies, promotes green investment, and enforces clean production and ISO14000 environmental management for incoming enterprises.

At the city and regional level, recycling cities are a relatively new concept globally, lacking a universal definition. In essence, a circular city emerges as circular enterprises and ecological industrial parks expand, transforming urban industrial structure, production, consumption, and management. This transformation integrates various industrial ecological chains across primary, secondary, and tertiary industries, organizing city production, consumption, waste treatment, and management into an ecological network system.

China's circular economy pilot program covers 27 provinces and cities, spanning two batches. The first batch includes Beijing, Liaoning, Shanghai, Jiangsu, Shandong, Chongqing (Three Gorges Reservoir Area), Ningbo, Tongling, Guiyang, and Hebi. The second batch comprises Tianjin, Shanxi, Zhejiang, Henan, Gansu, Qingdao, Shenzhen, Yigan, Fuxin, Baishan, Qitaihe, Huaibei, Pingxiang, Jingmen, Yulin, Shizuishan, and Shihezi. These provinces and cities encompass both resource-rich and resource-poor areas, eastern, central, and western regions, emerging economies, and traditional industrial bases in the northeast.

China's regional and interregional circular economy features three strategic models: spontaneous transformation in developed areas like southern Jiangsu and Shanghai; resource-based transformation in Northeast China and other old industrial bases such as Liaoning; and leapfrog transformation in pilot regions like Guiyang.

Suzhou High-tech Zone, founded in 1990, is located in the west of Suzhou and within the Yangtze River Delta's Taihu Lake plain, an economically developed area in China. Spanning 52 square kilometers, it's divided into three zones: a central business area, two tech industrial zones, and a central living area. Over 90% of its projects focus on emerging industries like electronic information, precision machinery, fine chemicals, new materials, and environmental protection, with electronic information contributing over 70% of the region's total industrial output value.

Suzhou High-tech Zone leverages location, industry, capital, and humanity to develop circular economy. Its plan aims to build an industrial system centered on high-tech, guided by circular economy principles and industrial ecology, tailored to the zone's characteristics. By optimizing functional layout and enhancing existing ecological chains, it seeks to maximize resource efficiency across enterprises, groups, and society, minimizing emissions. Development focuses on production (ecological industry), consumption (sustainable practices), and recycling (waste reduction, resource recovery industries), linking production and consumption. Infrastructure, policies, and safeguards will be strengthened to support ecological industry and circular economy development.

Suzhou High-tech Zone's circular economy development comprises two parts: the logistics system (production, consumption, and circulation) and the support system (social security and infrastructure). Figure 1.11 outlines the overall framework.

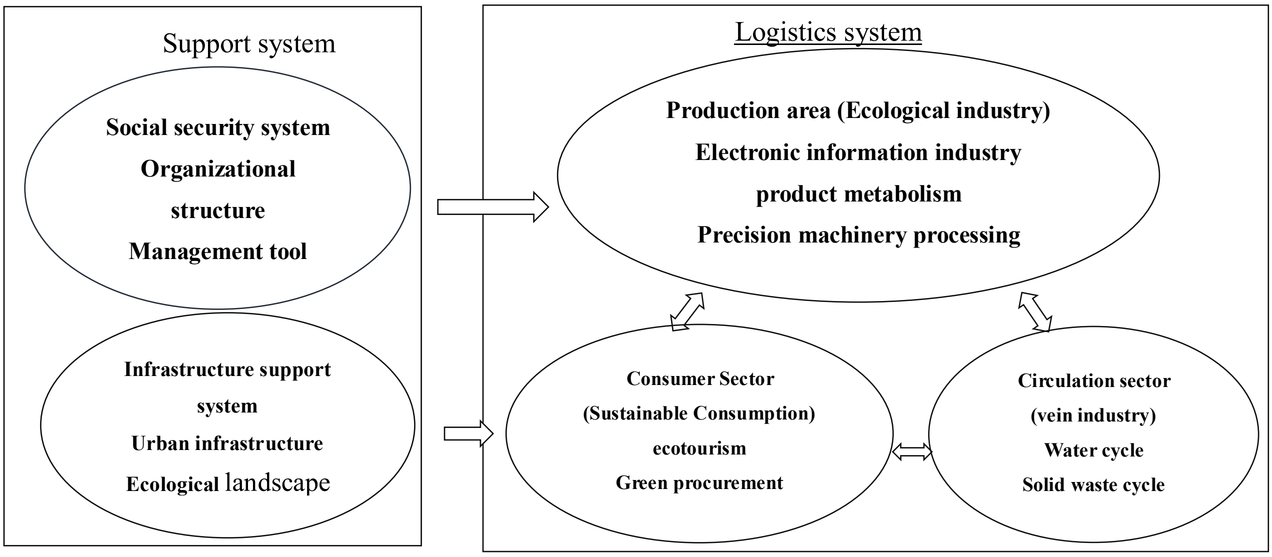

Fig. 1.11. Overall framework of circular economy development in Suzhou High-tech Zone, China

Source: Made by the author

Guiyang, the political, economic, and cultural hub of Guizhou Province, faces triple pressures: resource depletion, low recycling rates, and significant pollution. In May 2002, Guiyang became China's first circular economy pilot city, marking the western region's first attempt at strategic transformation through circular economy development.

Guiyang's circular economy city construction spans 8034 sq km, encompassing "one goal, two links, three core systems, and eight recycling systems." The goal is comprehensive prosperity with sustained economic growth, improved living standards, and ecological preservation. The two links focus on transforming production and consumption modes. The three core systems outline a circular economy industrial framework across three major industries. The eight recycling systems cover phosphorus, aluminum, herbal medicine, coal, eco-agriculture, construction, tourism, service industries, and circular consumption. Figure 1.12 illustrates the overall framework.

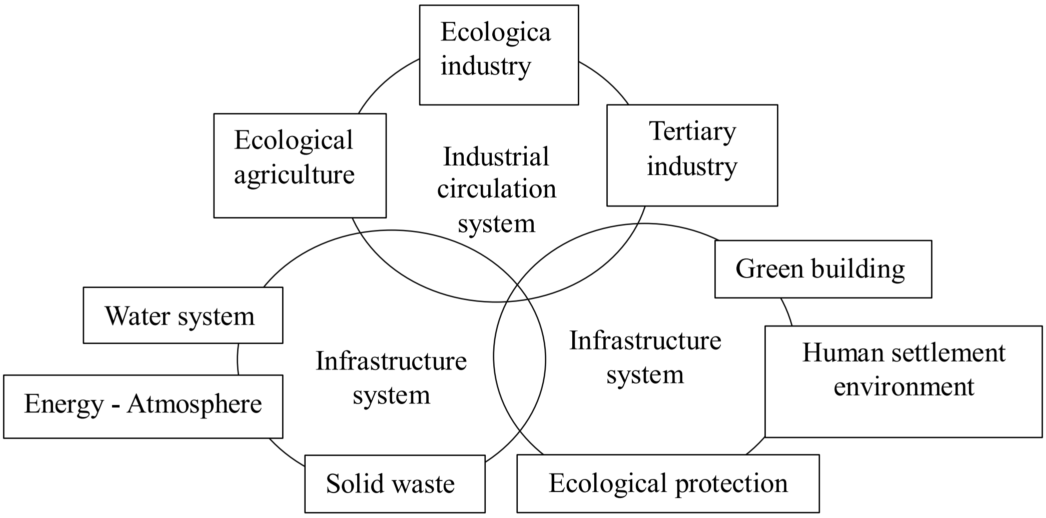

Fig. 1.12. Overall framework of circular economy eco-city construction

Source: Made by the author

Liaoning, a key manufacturing hub, has significantly contributed to China's modernization but faces environmental degradation from extensive resource use. In 2002, Liaoning became the first circular economy pilot province, exploring the "3+1" model. '3' represents large, medium, and small cycles, while '1' signifies an industry.

At the small cycle level, Liaoning promotes clean production in enterprises to reduce material and energy consumption, minimizing pollutants. It aims to combine technological transformation, enhance cleaner production in key polluters, and establish demonstration enterprises, achieving or nearing domestic advanced levels in energy, material, water consumption, and pollution-free discharge.

At the middle cycle level, Liaoning builds ecological industrial parks by: 1) transforming resource-exhausted cities like Fushun and Fuxin to develop alternative industries utilizing waste and associated minerals; 2) integrating and upgrading development zones, introducing key projects to form a symbiotic enterprise network; 3) transforming old industrial zones with scientific projects to achieve logistics, energy, technology, and infrastructure sharing, focusing on Shenyang Tiexi New Area.

At the great circulation level, Liaoning aims to construct a urban resource recycling society and regional resource recycling industry base. City-wise, based on "reduction, reuse, and resource utilization," systems for recycling urban solid waste, special waste, and water have been established to boost renewable resource utilization. Regionally, leveraging Northeast China's economic, technological, and regional advantages, Liaoning has established a hazardous waste disposal and waste resource recycling base. Eight cities, including Anshan, Benxi, Dalian, Fushun, Fuxin, Huludao, Panjin, and Shenyang, have been designated as recycling cities, each with tailored goals, recycling enterprises, ecological industrial parks, circular economy frameworks for ecological agriculture, and urban resource recycling societies.

China's circular economy legislation plays a crucial role in modern society. As the primary means of social adjustment, law ensures balanced social operation and development. Unified social norms and coordinated legal systems are essential for integrating resource conservation, environmental protection, economic development, and social progress, fostering a sustainable and virtuous economic-social cycle.

Since the founding of the People's Republic of China, China's circular economy legislation has evolved through three main stages:

The Plain Legislation stage (1983, Jianguo I) featured single laws and regulations by the State Council, covering specific aspects without comprehensive theoretical support for circular economy, despite some circular economy influences in the legislation's guiding ideology.

During the Environmental Protection Legislation stage (1983-1995), numerous laws and regulations were enacted, focusing on environmental protection. The 1989 Environmental Protection Law of China is a comprehensive basic law aimed at protecting the environment, preventing pollution, and promoting industrial development. Yet, the concept of developing a circular economy and society had not yet been established.

After 1995, the legislative focus shifted to harmonious circulation, involving various sectors. The Solid Waste Law marked this shift, and the 2008 Circular Economy Promotion Law aimed to enhance resource utilization, protect the environment, and achieve sustainable development. This comprehensive law clearly outlines circular economy concepts, assessments, incentives, and legal responsibilities.

The table below outlines key laws and regulations related to circular economy since China's founding.

The table above shows China's circular economy legislation has evolved from individual laws to comprehensive legislation by the National People's Congress. This shift underscores China's growing emphasis on circular economy laws, aligning with the principle of a legal economy. Law's role in modern society is increasingly crucial. Undoubtedly, circular economy legislation will boost its development, with the Circular Economy Promotion Law significantly contributing to China's goal of becoming a resource-saving, environment-friendly society and achieving comprehensive well-being.

1.3. Construction of Evaluation Indicator System for Clustered Circular Economy Development

A systematic review focusing on the integration of clusters and algorithms in benchmarking construction:In the field of data mining and machine learning, clustering is a basic and important research topic. Many applications need to obtain balanced clustering results, so it is particularly important to propose a balanced clustering model and optimize the algorithm. Weibo Lin[1] proposed a balanced clustering model, which controlled the balance degree of clustering results through uniform regularization function, and solved it by k-means method, which significantly improved the efficiency of the algorithm. Experimental results on several reference datasets show that the proposed model is superior to existing balanced clustering algorithms in terms of speed and quality of results.

In addition to the balanced clustering model, the review and classification of clustering algorithms are also important research directions. Absalom E. Ezugwu[2] provides a systematic and comprehensive review of traditional and recent clustering techniques, highlighting the important role of clustering in various disciplines and discussing applications in the fields of big data, artificial intelligence, and robotics. This review provides a reference for researchers and practitioners to design more efficient clustering algorithms.

The clustering integration method is an important extension of the classical clustering problem by integrating multiple weak clustering results to generate strong consensus results. The adaptive cluster integration method (SPCE) proposed by Peng Zhou[3] solves the problem that the existing methods do not fully consider the adverse effects of difficult instances by gradually incorporating easy to difficult instances into ensemble learning. Experimental results show that the proposed method performs better than traditional methods on multiple benchmark datasets.

Shenfei Pei[4] proposed k-sums clustering methods to demonstrate advantages in computation and memory overhead by directly minimizing distances between points in the same cluster. Experimental results on multiple datasets show that the performance of the proposed method is comparable to the latest clustering methods, but the time complexity is low. In addition, Jia Wo[5] evaluated three common clustering methods (hierarchical clustering, K-means, and expectation maximization), and the results showed that data transformation had a significant impact on clustering results and stability, and provided suggestions for related applications.

Oyewole Gbeminiyi John[21] reviewed the application and trend of data clustering, highlighted the application of clustering technology in key industries such as manufacturing, transportation, energy and healthcare, and pointed out that with the increase of data scale, the demand for new feature extraction methods, validation indicators and clustering technologies is increasing. The clustering class balance integration method proposed by Zohaib Jan[22] significantly improves the accuracy of classification and prediction by creating an appropriate number of strong data clusters and integrating them on the basic classifier based on the training of strongly balanced data clusters.

Tao Zhang[19] proposed a density center-based automatic clustering algorithm (DAC) for iot data analysis, which selects the appropriate density center through adaptive neighborhood and decision graph. Experimental results show that DAC outperforms six classical and newer algorithms in accuracy. Peng Zhou[9] proposed a cluster integration method based on structured hypergraph learning to improve the reliability of clustering tasks through dynamic learning of hypergraphs. Experimental results show that this method is superior to traditional hypergraph integration methods and the latest cluster integration methods.

The two-grain weighted integrated clustering model proposed by Li Xu[10] transforms the reliability assessment of clusters into the uncertainty measurement problem of rough sets, and designs a sample local similarity measurement method at a finer granularity level. Experimental results show that this method is insensitive to the size and diversity of base cluster members, and has good robustness and stability.

The balance and efficiency of clustering algorithms are important research topics in data mining and machine learning. The following is the discussion and solution of this problem in several literatures.

Weibo Lin et al. proposed a balanced clustering model, aiming to control the balance of clustering results by introducing a uniform regularization function, while minimizing the sum of square distances to the cluster center [24]. Using the idea of k-means method, they have significantly improved the solving efficiency of the model through a novel and simple acceleration technique. Experimental results show that the proposed algorithm is more than 100 times faster than the existing balanced clustering algorithm on most data sets, and the solution is better.

Xiangguang Dai et al. proposed a balanced clustering algorithm based on cooperative neural dynamic optimization [25]. They formulated the balanced clustering problem as a combinatorial optimization problem and reformulated it as the Ising model. By using particle swarm optimization rules to re-initialize locally converging Hopfield networks or Boltzmann machines, the algorithm inherits the almost certain convergence of cooperative neural dynamic optimization. Experimental results show that the proposed algorithm is superior to four existing balanced clustering algorithms in terms of quality.

Yuming Lin et al. proposed a constrained equilibrium clustering method called τ-equilibrium clustering to generate clusters with controllable equilibrium degree [26]. In the cluster allocation stage, the cluster size is constrained by the upper limit of cluster size and the maximum number of clusters. They also designed a parallel version of the method to improve execution efficiency. The experimental results show that the proposed method outperforms the current state-of-the-art methods on nine benchmark datasets.

Hu Ding et al. studied the balanced k-center, k-median and k-means clustering problems in high-dimensional data [27]. They developed a new method based on geometric space partitioning, which not only improves the approximation factor of the algorithm, but also significantly reduces the running time, especially when k is constant to achieve linear or near-linear running time.

Elango Murugappan et al. analyzed the balanced clustering method for task assignment of multiple robots [28]. They found that K-means clustering is most suitable for solving multi-robot task assignment problems with complex topologies, and has better scalability compared to Gaussian mixture model (GMM) and hierarchical clustering methods.

These studies show that by introducing regularization function, cooperative optimization and geometric space partitioning techniques, the efficiency of the algorithm can be significantly improved while the balance of clustering results can be improved. The experimental results of these methods in different application scenarios show their superiority.

Classification and application of clustering algorithms: Clustering algorithm is an important data analysis technique that extracts meaningful information by dividing samples into groups. According to different classification criteria, clustering algorithms can be divided into various types, and each type presents unique advantages and challenges in different application scenarios.

Classification of clustering algorithm: Hierarchical clustering algorithms: Hierarchical clustering algorithms organize data by creating hierarchical structures, which are mainly divided into two methods: bottom-up (condensation) and top-down (splitting). Cohesive hierarchical clustering starts with each data point and merges the most similar points until all points are in one cluster; Split-level clustering starts as a whole and continuously splits into smaller clusters. The advantage of hierarchical clustering algorithm is that it can provide multiple consistent partitioning of data at different levels, which is suitable for analyzing complex data structures [27].

Non-hierarchical clustering algorithms: Non-hierarchical clustering algorithms typically include partition-based methods such as K-means and density-based methods such as DBSCAN. K-means assigns data points to K clusters by iteratively optimizing the objective function; DBSCAN uses density connections to find clusters of arbitrary shapes. Non-hierarchical clustering algorithm has the advantage of high computational efficiency and is suitable for processing large-scale data(Xingcheng,2022).[29].

Deep map clustering: The deep map clustering method combines the advantages of deep learning and graph clustering, learns the low-dimensional representation of the data through the neural network, and then performs clustering. Such methods perform well in processing complex structured data (such as social networks, molecular structures, etc.) [22].

Multi-view clustering: Multi-view clustering algorithm uses data from different perspectives or modes to cluster. Common methods include generative and discriminative methods. Multi-view clustering can capture the features of data more comprehensively and improve the accuracy of clustering (.Jan, et al.2021)[30].

Hybrid clustering algorithm: Hybrid clustering algorithm combines the advantages of various clustering methods, and can handle classification and clustering problems at the same time. For example, a hybrid heuristic algorithm can process both labeled and unlabeled data in the same model, enabling dynamic class/cluster configuration [24].

The application of clustering algorithm: Software system modularization: Clustering algorithms are widely used in software system modularization to help understand and maintain large software systems by dividing programs into small but meaningful parts. For example, FCA algorithm overcomes time and space constraints by operating dependence matrix and is suitable for modularization of large-scale software systems [21].

Medical diagnosis: Clustering algorithms play an important role in disease and cancer diagnosis, improving the performance of classification models through feature selection and clustering. For example, dynamic feature selection and clustering methods combined with principal component analysis and genetic algorithm have significantly improved the accuracy of medical diagnosis models [28].

Iot data Analytics: With the popularity of the Internet of Things, the amount of data has exploded. Clustering algorithm plays a key role in iot data analysis, helping to determine the initial clustering center of data, and improving the clustering accuracy through improved clustering algorithm [30].

Natural disaster assessment: Clustering algorithms are also used in the assessment of natural disasters (such as flash floods) to improve the accuracy of comprehensive models through classification and clustering methods. For example, ISOMax algorithm has shown better fitting and prediction ability in flash flood susceptibility assessment [29].

Industrial applications: Clustering algorithms are widely used in key industries such as manufacturing, transportation, energy and healthcare to help achieve the Sustainable Development Goals. For example, clustering technology can be used in combination with other analytical techniques to process large-scale and diverse data more efficiently [26].

Challenges and future directions of clustering algorithm application: Clustering algorithms perform well in different application fields, but still face some challenges, such as processing large-scale data, determining the optimal number of clusters, and processing high-dimensional data. Future development directions include combining deep learning techniques, developing more effective feature extraction methods and validation indicators, and exploring new clustering algorithms to cope with complex data structures and diverse application scenarios [27].

Cluster integration method and its improvement: Clustering integration method is a method to obtain consensus results by integrating multiple basic clustering results, so as to improve the stability and robustness of a single clustering method. In this paper, several main clustering integration methods and their improvements are reviewed.

A clustering integration method based on structural hypergraph learning has been proposed [31]. The traditional hypergraph method obtains the final consensus result by dividing the predefined static hypergraph, but the predefined hypergraph may also be unreliable due to the unreliability of the basic clustering method. To solve this problem, Peng Zhou et al proposed a cluster integration method based on structural hypergraph learning, which dynamically learns hypergraphs from the underlying results and forces them to have a clear cluster structure, thus eliminating the need for any uncertain post-processing, such as hypergraph partitioning. The experimental results show that the proposed method is superior not only to the traditional hypergraph integration method, but also to the most advanced clustering integration method.

The method of optimizing the participation of multiple fusion functions in consensus creation extends the hierarchical clustering integration technique by introducing new evolutionary fusion functions [32]. This method generates multiple hierarchical clustering methods by bagging, and then uses genetic algorithm to search among different fusion functions to obtain consensus clustering. Experimental results show that the proposed method performs better than conventional clustering integration methods on multiple data sets.

Geometric consistency fuzzy clustering integration method improves the clustering performance by introducing geometric consistency constraints into image segmentation [33]. Pengfei Shi et al. proposed a geometrically consistent fuzzy clustering integration model, which includes constraints between the member relationship and its reconstruction on the spatial data, so that the member matrix is geometrically consistent with the original target image. Experimental results show that the proposed method is superior to several advanced methods in both synthetic and actual image segmentation.

The self-stepping clustering integration method reduces the negative impact of difficult instances on consensus results by gradually incorporating easy to difficult instances into ensemble learning [39]. The self-stepping cluster integration (SPCE) method proposed by Peng Zhou et al integrates instance difficulty assessment and ensemble learning into a unified framework, and proposes a joint learning algorithm to optimize the objective function. The experimental results show that the method is effective on the benchmark data set.

Hybrid ensemble learning methods solve specific problems by combining ensemble learning and intelligent optimization algorithms. Ning Wang et al.(2021)[31]. proposed a hybrid approach for identifying gang-related arson cases that includes a feature selection method based on recursive feature elimination (RFE), a data imbalance processing algorithm, an optimal combination of base classifiers, and a weighted integration strategy. Experimental results show that the method significantly outperforms other popular machine learning methods on the National Fire Incident Reporting System (NFIRS) database.

Centreless clustering method and its performance evaluation: Centreless clustering is a kind of clustering method that does not depend on the preset center point or centroid, and mainly determines the clustering relationship of data points through other strategies. The following is a review of several centreless clustering methods and their performance evaluation:

Fuzzy clustering method: Fuzzy clustering introduces fuzzy partitioning, which makes the clustering result more consistent with the structure of the real data set. Hong-Yu Wang et al. [41] reviewed fuzzy cluster validity evaluation methods, focusing on fuzzy cluster validity index (FCVI) and combined fuzzy cluster validity evaluation method (CFCVE). The accuracy and stability of various methods are analyzed through comparative experiments, the advantages and disadvantages of current research are pointed out, and the future research direction is prospected.

Clustering method based on extreme learning Machine: Shuliang Xu(2020)[32] et al proposed a fuzzy granular neighborhood limit clustering algorithm based on extreme learning machine. The algorithm uses fuzzy neighborhood rough set to select new features, eliminates redundant attributes, and introduces adaptive adjustment mechanism to solve parameter problems. The experimental results show that the proposed algorithm is superior to the comparison algorithm on most datasets, and can obtain the smallest intra-class distance and the largest inter-class distance.

k-sums method based on neighborhood graphs: Shenfei Pei[33] et al. proposed a clustering method called k-sums, which realizes clustering by minimizing the sum of distances between points in the same cluster. The calculation and memory overhead of this method are both O(nk), indicating that it can scale linearly to a large number of data points. Experiments show that the performance of k-sums is comparable to that of several advanced clustering methods at low time complexity.

Distributed clustering algorithm: Cheng Qiao et al. [34] proposed an asynchronous distributed clustering algorithm for data clustering in wireless sensor networks. The algorithm is not set.

Conclusion of Chapter 1

This chapter comprehensively analyzes circular economy theories, cluster circular economy development models, and global benchmarking of circular economy practices.

Guided by circular economy theories, this section elucidates the composition, function, and characteristics of cluster circular economy, and constructs its conceptual system model.

Circular economy involves reduction, reuse, and resource recovery in production, circulation, and consumption. It aims to transform unsustainable, resource-intensive models. In today's global economy, developing a resource-saving circular economy has become a key approach for governments to address the contradiction between economic growth and resource scarcity, ensuring sustainable development.

Third, the circular economy's three core principles—resource reduction, product reuse, and waste recycling—form its basic framework, leading to diverse interpretations. Despite this, all theoretical approaches share common factors determining a country's circular economy potential: objectives, institutional environment, legal aspects, pricing of primary products, and factors of production.

Fourth, circular economy practices span macro-level cooperative consumption, zero-waste societies, medium-sized industrial parks, and micro-level clean production, corresponding to provinces, cities, autonomous regions, parks, and enterprises. Enterprises, particularly in high-energy industries like chemicals and metallurgy, drive circular economy applications. These applications show economic value, aiming to maximize resource use and drive socio-economic progress. Countries strive for a scientific, rigorous circular economy evaluation system but face complexities and professional demands, leading to uneven development across countries, industries, parks, and enterprises.

Fifth, traditional industrial economies feature a linear flow of "resource-product-waste," relying heavily on resource exploitation, burdening the environment. In contrast, the circular economy model, "resource-product-renewable resource," efficiently uses closed-loop material flow. As society deepens its understanding of environmental protection and sustainable development, the circular economy gains increasing attention.

Analyze and understand circular economy principles at micro, meso, and macro levels. At the micro level, enterprises can build microcirculation systems, like enhancing purification processes in chemical enterprises to transform by-products back into raw materials. At the meso level, establish circular economy industrial parks to promote material circulation among upstream and downstream enterprises. At the macro level, integrate micro and meso efforts, where each socio-economic participant fulfills specific roles in the overall macroeconomic cycle.

This chapter extends and expands the previous theoretical review, offering conceptual and model frameworks to assess cluster circular economy development. [1] [2] [3] [4] [5] [6] [7]

CHAPTER 2. EVALUATION SYSTEM, EVOLUTION PATH AND EMPIRICAL ANALYSIS OF CIRCULAR ECONOMY DEVELOPMENT

2.1. Construction of the Evaluation Indicator System for Regional Circular Economy Development

Currently, circular economy evaluation indicator systems are either too broad, covering all social aspects, or too narrow, focusing solely on resources and the environment. This paper argues that the core of circular economy lies in the economic and ecological realms, advocating for indicators from these three perspectives: economy, resources, and environment. Through literature review, analysis of local planning documents, statistical data incorporation, and expert consultation, initial indicators were obtained (see Table 2.1):

Table 2.1

Preliminary Selection of Circular Economy Evaluation Indicators

Evaluation Level	Factor Level	Indicator Level	Unit	Indicator Type
1	2	3	4	5
Economic Indicators (B1)	Economic Output Indicators(C1)	GDP (D1)	Billion yuan	Positive
		Per Capita GDP(D2)	Yuan	Positive
		Per Capita Disposable Income of Urban Residents (D3)	Yuan	Positive
		Per Capita Net Income of Rural Residents (D4)	Yuan	Positive
		Consumer Spending Level(D5)	Yuan	Positive
	Industrial Structure Indicators (C2)	Value Added of the First Industry(D6)	Billion yuan	Positive
		Value Added of the Second Industry(D7)	Billion yuan	Positive
		Value Added of the Third Industr(D8)	Billion yuan	Positive
Resource Indicators (B2)	Resource Consumption Indicators(C3)	Energy Consumption per 10,000 Yuan of GDP (D9	Ton of Standard Coal/10,000 yuan	Inverse
		Energy Consumption per 10,000 Yuan of Industrial Added Value (D10)	Ton of Standard Coal/10,000 yuan	Inverse
		Water Consumption per 10,000 Yuan of GDP (D11)	10,000 cubic meters/billion yuan	Inverse
		Water Consumption per 10,000 Yuan of Industrial Added Value (D12)	10,000 cubic meters/billion yuan	Inverse
	Resource Utilization Indicators (C4)	Comprehensive Utilization Rate of Industrial Solid Waste (D13)	%	Positive
		Harmless Treatment Rate of Urban Domestic Waste (D14)	%	Positive

1	2	3	4	5
Resource Indicators (B2)	Resource Utilization Indicators (C4)	Reuse Rate of Urban Water (D15)	%	Positive
		Reuse Rate of Industrial Water (D16)	%	Positive
		Reuse Rate of Urban Wastewater (D17)	%	Positive
		Urban Wastewater Treatment Rate (D18)	%	Positive
		Ratio of Construction Land Use (D20)	%	Positive
Environmental Indicators (B3)	Waste Emission Indicators(C5)	General Industrial Solid Waste Generation (D21)	10,000 tons	Inverse
		Total Wastewater Discharge (D22)	10,000tons	Inverse
		Industrial Wastewater Discharge (D23)	10,000 tons	Inverse
		Industrial Air Emissions (D24)	10,000 cubic meters	Inverse
		Sulfur Dioxide Emissions (D25)	10,000 tons	Inverse
		Industrial Sulfur Dioxide Emissions (D26)	10,000 tons	Inverse
		Nitrogen Oxide Emissions (D27)	10,000 tons	Inverse
		Industrial Nitrogen Oxide Emissions (D28)	10,000 tons	Inverse
		Dust Emissions (D29)	10,000 tons	Inverse
		Industrial Dust Emissions (D30)	10,000 tons	Inverse
	Pollution Control Indicators (C6)	Proportion of Total Environmental Pollution Investment (D31)	%	Positive
		Proportion of Total Industrial Pollution Investment (D32)	%	Positive
		Green Coverage Rate of Built-up Areas (D33)	%	Positive
		Forest Coverage Rate (D34)	%	Positive
		Grassland Coverage Rate (D35)	%	Positive

Source: Made by the author

A system's hierarchy is crucial. The circular economy, as a complex system, comprises various functional sets with distinct roles and varying complexity[46]. Circular economy evaluation assesses a region's development quality, evaluating current status or ideal planning levels. By analyzing indicator values, it identifies strengths and weaknesses in implementation, aiding in gap identification and planning[47].

This study selects Economic, Resource, and Environmental criteria with six factor-level indicators: Economic Output, Industrial Structure, Resource Consumption, Resource Utilization, Waste Emission, and Pollution Control. Each factor comprises basic or composite indicators, crucial for system rationality.

To choose a suitable evaluation indicator system, understanding the circular economy's structure, functions, and characteristics, along with regional development goals, is essential. Determining evaluation indicators is based on the former, while selecting functional sets is based on the latter.

General Steps for Indicator Selection

Some initial indicators may be redundant or unrepresentative. To ensure a comprehensive and independent indicator system, further screening through principal component analysis is necessary. This step extracts principal components as evaluation indicators, reducing overlap and simplifying the system. The selection process is outlined in Figure 2.1.

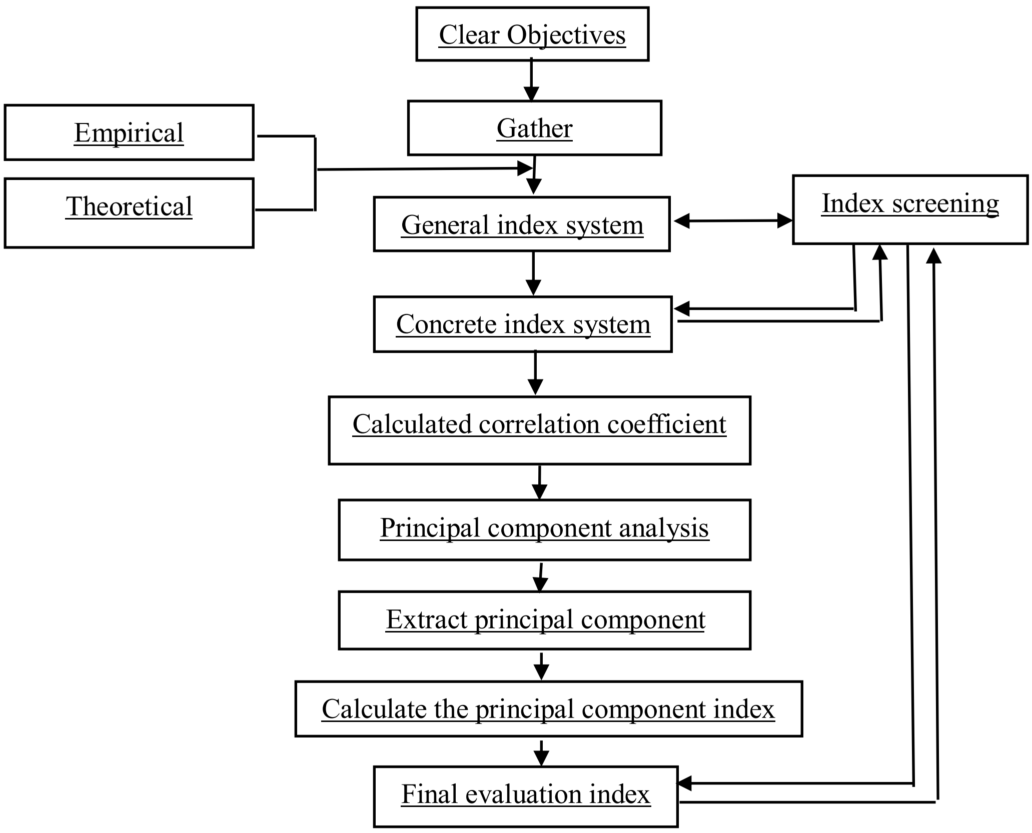

Fig. 2.1. Process of Circular Economy Indicator Selection

Source: Made by the author

(1) Normalization of Raw Data

The data for this study is derived from the "China Statistical Yearbook 2022" and the "China Environmental Statistics Yearbook 2022." Due to the diverse dimensions of the various indicators, it is necessary to normalize the data to achieve dimensionless expressions. Currently, there are several common methods for normalizing raw data：

$$x_i' = \frac{x_i - x_{min}}{x_{max} - x_{min}} \quad (2.1)$$

$$x_i' = \frac{x_{max} - x_i}{x_{max} - x_{min}} \quad (2.2)$$

In which， x_i represents the original data of the indicato； x_i' represents the normalized value of the original data x_i； $\bar{x}$ is the mean of x_i； σ is the standard deviation of x_i； x_{min} is the minimum value in the indicator corresponding to x_i； x_{max} s the maximum value in the indicator corresponding to x_i.

Existing studies have shown that this normalization method for the original data can significantly eliminate differences in dimensions and disparities in the magnitude of indicators. Moreover, this normalization transformation method (Equation 2.1) has a more pronounced effect. Therefore, we adopt the normalization transformation method to transform the original data in this study.

(2) KMO Test and Bartlett's Sphericity Test

Before conducting principal component analysis on the data, it is necessary to perform tests to determine whether it is appropriate for such an analysis. Common test methods include Bartlett's Sphericity Test and the KMO Test. For Bartlett's Sphericity Test, it is suitable for principal component analysis when the probability is less than 0.05. As for the KMO Test, a KMO value greater than 0.5 indicates suitability for principal component analysis.

(3) Principal Component Analysis of Indicators

In selecting indicators, to meet the completeness principle of the indicator system, many indicators are often chosen. However, for the sake of simplifying calculations during evaluation, there is a desire to use fewer indicators to comprehensively reflect the situation. Therefore, it is necessary to select indicators that have strong correlations with many other indicators as evaluation indicators, known as principal component indicators.

The following method can be employed to screen principal component indicators: After obtaining the data for specific indicators, calculate the correlation coefficients between indicators within each functional set to obtain a correlation coefficient matrix. The formula for calculating the correlation coefficient between each pair of indicators is as follows:

$$\gamma = \frac{\sum(x_i - \overline{\mathrm{x}})(y_i - \overline{\mathrm{y}})}{\sqrt{\sum(x_i - \overline{\mathrm{x}})^2 \sum(y_i - \overline{\mathrm{y}})^2}} \quad (2.3)$$

In this formula, γ represents the correlation coefficient, with values ranging between [-1,1], A higher absolute value indicates a stronger correlation；The variables x_i and y_i denote the normalized values of the respective indicators, while $\overline{\mathrm{x}}$ and $\overline{\mathrm{y}}$ represent the means of the indicators x_i、y_i.

(4) Indicator Principal Component Analysis

In the selection of indicators, to meet the principle of completeness of the indicator system, a considerable number of indicators are often chosen. However, during evaluation, for the purpose of simplifying calculations, there is a desire to comprehensively reflect the situation with fewer indicators. Therefore, it is necessary to select those indicators that have a strong correlation with many other indicators as evaluation indicators, namely principal component indicators.

The following method can be employed to screen principal component indicators: after obtaining the data for specific indicators, calculate the correlation coefficients between each indicator within each functional set, resulting in a correlation coefficient matrix. The formula for calculating the correlation coefficient between each pair of indicators is as follows:

$$\gamma = \frac{\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i}^{n}(x_{i=1} - \bar{x})^2}\sqrt{\sum_{i=1}^{n}(y_i - \bar{y})^2}} \quad (2.4)$$

Then, calculate the mean correlation coefficient (average absolute value) for these indicators and determine the overall average correlation coefficient. Finally, select the indicators whose absolute correlation coefficient is greater than this value as principal component indicators.

(5) Determining the Number of Principal Components

The number of principal components is generally determined based on eigenvalues or the contribution rate of variance. Indicators with eigenvalues greater than 1 or a cumulative contribution rate of variance exceeding 90% are chosen as principal components. Principal component indicators can reflect most of the information from the original variables.

(6) Determining the Weights of Each Principal Component

Before calculating the comprehensive score, determine the relative weights of each principal component. Use the contribution rate of variance for each principal component as its weight in calculating the comprehensive score.

(7) Comprehensive Evaluation

After determining the weights for each principal component, combine them with the respective scores of each principal component by weighted summation. Calculate the comprehensive scores for each sample, and based on these scores, conduct an overall ranking of the selected samples.。

Principal Component Analysis of Regional Circular Economy Development

Economic Indicators:Based on the initially designed economic indicators (as shown in Table 2.2), obtain the raw data for the relevant preliminary selected indicators of economic development for the 31 provinces, autonomous regions, and municipalities directly under the central government in China in 2021 from the 2022 China Statistical Yearbook.

Table 2.2

Preliminary Economic Indicators

Serial Number	Economic Indicators	Code Translation
1	**2**	**3**
1	GDP	e_1
2	Per Capita GDP	e_2
3	Per Capita Disposable Income of Urban Residents	e_3
4	Per Capita Net Income of Rural Residents	e_4
5	Resident Consumption Level	e_5
6	Value Added of the First Industry	e_6
7	Value Added of the Second Industry	e_7
8	Value Added of the Third Industry	e_8

Source: Made by the author

Before the screening, the data is standardized according to equation (2.1); then, KMO test and Bartlett's sphericity test are conducted, and the test results are shown in

Table 2.3. The KMO value is 0.648 (greater than 0.5), and the probability (P value) of Bartlett's sphericity test is 0 (less than 0.05). Based on the comprehensive analysis of these test results, it is considered feasible to conduct principal component analysis (see Table 2.3).

Table 2.3

KMO Test and Bartlett's Sphericity Test for Economic Indicators

Project	KMO and Bartlett's Test	Numeric
1	2	3
Kaiser-Meyer-Olkin Measure of Sampling Adequacy		0.648
Bartlett's Sphericity Test	Approximate Chi-Square	543.49
	df	28
	Sig	000

Source: Made by the author

After verifying that the processed data is suitable for principal component analysis, the eight selected economic indicators were subjected to principal component analysis using SPSS 27.0 software. The results are presented in Table 2.4 :

Table 2.4

Factor Variances of Economic Indicators

Code Translation	Initial	Extract
1	**2**	**3**
e_1	1.000	0.99
e_2	1.000	0.898
e_3	1.000	0.976
e_4	1.000	0.953
e_5	1.000	0.895
e_6	1.000	0.966
e_7	1.000	0.949
e_8	1.000	0.944
extraction method	Principal Component Analysis (PCA)	

Source: Made by the author

Table 2.5

Factor Loading Matrix of Economic Indicators

Variable	**Factor Matrix [a]**	
	Ingredients	
1	**2**	**3**
e_1	0.825	0.557
e_2	0.334	0.887
e_3	0.757	0.635
e_4	0.909	0.356
e_5	0.815	0.48
e_6	0.844	0.503
e_7	0.885	0.407
e_8	0.865	0.443
Extraction Method: Principal Component Analysis.		
a. 2 principal components have been extracted		

Source: Made by the author

The factor loading matrix of economic indicators (Table 2.5) shows that seven initial indicators have high loadings on the first principal component, reflecting GDP, income, consumption, and industry value-added. Per capita GDP mainly loads on the second principal component, which also captures some information from other income indicators.Thus, extracting two principal components to form two new variables replacing the original eight. The linear combinations of these new variables are derived from the initial factor loading matrix.

x_1=0.825e_1+0.0334e_2+0.757e_3+0.909e_4+0.815e_5+0.844e_6+0.8585e_7+0.865e_8(2.5)

x_2=0.557e_1+0.887e_2+0.635e_3+0.356e_4-0.48e_5-0.503e_6-0.407e_7-0.443e_8 （2.6）

Based on the proportion of variance explained by the extracted principal components, the original indicators can be replaced by the principal components. The formula for calculating the scores after replacement is as follows:

y_1=0.637x_1+0.309x_2 （2.7）

According to equations (2.5), (2.6), and (2.7), the scores of the extracted principal components of economic indicators and the corresponding comprehensive rankings can be calculated, as shown in Table 2.7.

Table 2.6

Scores and comprehensive rankings of principal components for economic indicators.

Region	x_1	x_2	y_1	Ranking
1	**2**	**3**	**4**	**5**
Beijing Municipality	3.77	1.13	2.05	6
Tianjin Municipality	2.95	0.094	1.59	9
Hebei Province	2.01	0.98	1.59	10
Shanxi Province	1.09	0.15	0.74	23
Inner Mongolia Autonomous Region	1.94	0.05	1.25	15
Liaoning Province	2.49	0.39	1.71	7
Jilin Province	1.4	0.143	0.93	18
Heilongjiang Province	1.33	0.41	0.97	17
Shanghai Municipality	4.23	1.24	2.31	5
Jiangsu Province	4.49	1.15	3.22	1
Zhejiang Province	3.9	0.07	2.51	4
Anhui Province	1.42	0.58	1.08	16
Fujian Province	2.37	0.11	1.55	11
Jiangxi Province	1.18	0.33	0.86	22
Shandong Province	3.71	1.55	2.84	3
Henan Province	2.06	1.25	1.7	8
Hubei Province	1.86	0.75	1.42	13
Hunan Province	1.79	0.82	1.39	14
Guangdong Province	4.43	1.21	3.2	2
Guangxi Zhuang Autonomous Region	1.14	0.5	0.88	20
Hainan Province	0.75	0.15	0.43	26
Chongqing Municipality	1.37	0.02	0.88	21
Sichuan Province	1.75	1	1.43	12
Guizhou Province	0.48	0.24	0.38	27
unnan Province	0.87	0.39	0.68	24
Tibet Autonomous Region	0.15	0.08	0.07	31
Shaanxi Province	1.28	0.32	0.92	19
Gansu Province	0.37	0.21	0.3	29
Qinghai Province	0.41	0.15	0.22	30
Ningxia Hui Autonomous Region	0.66	0.25	0.34	28
Xinjiang Uygur Autonomous Region	0.82	0.18	0.58	25

Source: Made by the author

Given that the two extracted principal components represent 95% of the information in all economic indicators, preliminary analysis of the economic development level in the circular economy can be conducted using the scores of the principal components. According to the calculation results in Table 2.6, the 31 provinces, autonomous regions, and municipalities directly under the central government can be classified into five regional categories (see Table 2.7).

Table 2.7

Classification of Economic Development in Regional Circular Economy in

China's Provinces

Levels	**Ranking**	**Regions**
1	**2**	**3**
Level 1 (High)	1-6	Jiangsu, Guangdong, Shandong, Zhejiang, Shanghai, Beijing
Level 2 (Relatively High)	7-12	Liaoning, Henan, Tianjin, Hebei, Fujian, Sichuan
Level 3 (Medium)	13-18	Hubei, Hunan, Inner Mongolia, Anhui, Heilongjiang, Jilin
Level 4 (Relatively Low)	19-24	Shaanxi, Guangxi, Chongqing, Jiangxi, Shanxi, Yunnan
Level 5 (Low)	25-31	Xinjiang, Hainan, Guizhou, Ningxia, Gansu, Qinghai, Tibet

Source: Made by the author

Figure 2.2 shows the spatial distribution of circular economy in China's provinces. From the perspective of spatial distribution of economic development of circular economy in China's provinces, the distribution of economic development level generally follows the conventional pattern of strong in eastern region, weak in western region and medium in central region. In addition to Sichuan in the west, Jiangxi in the central region has fallen to a lower level of development [48].

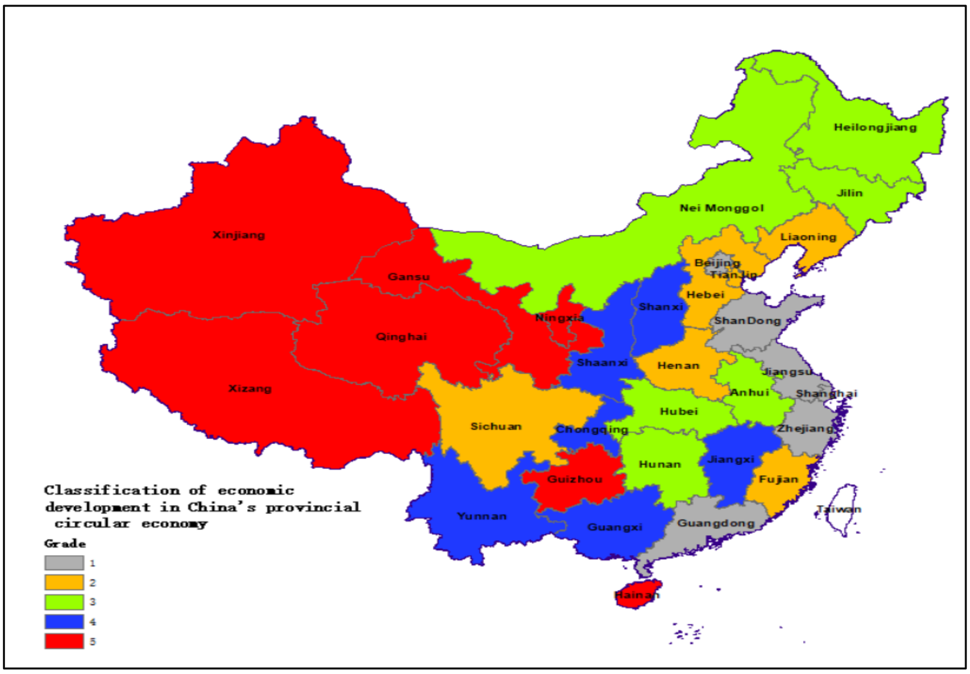

Fig. 2.2. Spatial distribution of circular economy in China's provinces

Source: Made by the author

At the highest (Level 1) and relatively high (Level 2) economic development levels, the eastern region dominates with 83% of the 12 regions, including Jiangsu, Guangdong, Shandong, Zhejiang, Shanghai, Beijing, Liaoning, Tianjin, Hebei, and Fujian. The central and western regions only have Henan and Sichuan. Among the 6 regions with moderate development (Level 3), Hubei, Hunan, and Anhui are central, Heilongjiang and Jilin are eastern, and Inner Mongolia is western. At lower (Level 4) and backward (Level 5) levels, the western region accounts for 77% of the 13 regions, including Shanxi, Guangxi, Chongqing, Yunnan, Xinjiang, Guizhou, Ningxia, Gansu, Qinghai, and Tibet. In the central region, Jiangxi and Shanxi rank relatively high, and Hainan is the only eastern region[49].

Resource Indicators:Guided by the preliminary economic indicators (Table 2.8), we sourced raw data for 2021 resource utilization in China's 31 provinces, autonomous regions, and municipalities from the 2022 China Statistical Yearbook. Key indicators included: industrial water consumption per unit of value-added, GDP water consumption, comprehensive utilization rate of industrial solid waste, urban sewage recycling rate, and proportions of agricultural and construction land to built-up areas, all derived through straightforward calculations.

Table 2.8

Primary resource indicators

Number.	Resource Indicators	Code
1	2	3
1	Energy Consumption per 10,000 yuan of Gross Domestic Product (GDP)	m_1
2	Energy Consumption per 10,000 yuan of Industrial Value Added	m_2
3	Water Consumption per 10,000 yuan of Gross Domestic Product (GDP)	m_3
4	Water Consumption per 10,000 yuan of Industrial Value Added	m_4
5	Comprehensive Utilization Rate of Solid Waste (per 10,000 yuan of Industrial Value Added)	m_5
6	Harmless Treatment Rate of Urban Household Garbage	m_6
7	Reuse Rate of Urban Water	m_7
8	Reuse Rate of Industrial Water	m_8
9	Recycling Rate of Urban Sewage	m_9
10	Disposal Rate of Urban Sewage	m_{10}
11	Proportion of Agricultural Land in Rural Areas	m_{11}
12	Proportion of Construction Land in Built-Up Areas"	m_{12}

Source: Made by the author

Before filtering, it is necessary to standardize the data. Positive indicators are processed according to equation (2.1), and reverse indicators are processed according to equation (2.2). Then, a Kaiser-Meyer-Olkin (KMO) test and Bartlett's Sphericity test are conducted, and the test results are shown in Table 2.9. The KMO value is 0.556 (greater than 0.5), and the probability (P) value of Bartlett's Sphericity test is 0 (less than 0.05). Considering these test results collectively, it is deemed suitable to proceed with principal component analysis.

Table 2.9

KMO Test and Bartlett's Sphericity Test for Resource Indicators

Kaiser-Meyer-Olkin (KMO) and Bartlett's Test		Numeric
Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy		0.556
Bartlett's Sphericity Test	Chi-square test	260.523
	df	66
	Sig.	0.000

Source: Made by the author

After verifying the processed data and confirming its suitability for principal component analysis, the analysis was conducted using SPSS 27.0 software on the 12 selected resource indicators. The results are as follows (see Table 2.10):

Table 2.10

Common Factor Variances of Resource Indicators

Common Factor Variances		
1	2	3
Code	Initial	Extraction
m_1	1.000	0.896
m_2	1.000	0.883
m_3	1.000	0.712
m_4	1.000	0.622
m_5	1.000	0.727
m_6	1.000	0.727
m_7	1.000	0.867
m_8	1.000	0.913
m_9	1.000	0.679
m_{10}	1.000	0.824
m_{11}	1.000	0.889
m_{12}	1.000	0.842
Extraction Method: Principal Component Analysis		

Source: Made by the author

Table 2.11

Factor Loading Matrix of Resource Indicators

Component Matrix[a]				
Variable	Component			
	1	2	3	4
m_1	0.156	0.853	0.362	0.111
m_2	0.187	0.888	0.236	0.05
m_3	0.67	0.34	0.274	0.271
m_4	0.717	0.112	0.262	0.163
m_5	0.671	0.473	0.171	0.155
m_6	0.751	0.138	0.28	0.256
m_7	0.67	0.327	0.444	0.338
m_8	0.713	0.313	0.525	0.179
m_9	0.095	0.18	0.465	0.649
m_{10}	0.848	0.095	0.279	0.135
m_{11}	0.251	0.161	0.68	0.581
m_{12}	0.438	0.717	0.3	0.215
Extraction Method: Principal Component Analysis				
a. Four components have been extracted				

Source: Made by the author

The principal component analysis of 12 selected resource indicators (Table 2.10) revealed four components with eigenvalues >1, contributing 79.8% cumulatively and identified as principal components. Table 2.11 shows: The first component correlates strongly (prob. >0.5) with seven indicators, including GDP and industrial value-added energy & water consumption, waste utilization, garbage treatment, and water reuse rates. The second component correlates with GDP and industrial value-added energy consumption, and construction land proportion. The third component correlates with industrial water reuse and agricultural land proportion. The fourth component correlates with urban sewage recycling and agricultural land proportion.

Therefore, considering the extraction of four principal components, four new variables can be constructed to replace the original 12 variables. The linear combinations of these four new variables can be obtained based on the initial factor loading matrix, and they are, respectively:

$$x_3 = -0.156m_1 - 0.187m_2 + 0.67m_3 + 0.717m_4 + 0.671m_5 + 0.751m_6 + 0.67m_7 + 0.713m_8 + 0.095m_9 + 0.848m_{10} + 0.251m_{11} + 0.438m_{12} \quad (2.8)$$

$$x_4 = 0.853m_1 + 0.888m_2 + 0.34m_3 - 0.112m_4 + 0.473m_5 + 0.138m_6 - 0.327m_7 - 0.313m_8 - 0.18m_9 - 0.098m_{10} - 0.161m_{11} + 0.717m_{12} \quad (2.9)$$

$$x_5 = 0.362m_1 + 0.236m_2 + 0.274m_3 - 0.262m_4 - 0.171m_5 - 0.28m_6 + 0.444m_7 + 0.525m_8 - 0.465m_9 - 0.279m_{10} + 0.68m_{11} - 0.3m_{12} \quad (2.10)$$

$$x_6 = 0.111m_1 + 0.05m_2 + 0.271m_3 - 0.163m_4 - 0.155m_5 + 0.256m_6 - 0.338m_7 - 0.179m_8 + 0.649m_9 + 0.135m_{10} + 0.581m_{11} - 0.215m_{12} \quad (2.11)$$

Based on the proportion of variance explained by the extracted principal components, the original indicators can be replaced by the principal components. The formula for calculating the scores after replacement is as follows:

$$y_2 = 0.3313x_3 + 0.2229x_4 + 0.1464x_5 + 0.0979x_6 \quad (2.12)$$

Using equations (2.8) to (2.12), the scores of the extracted principal components for resource indicators and the corresponding comprehensive rankings can be calculated, as shown in Table 2.12.

Table 2.12

Scores and Comprehensive Rankings of Principal Components for Resource Indicators

Region	x_3	x_4	x_5	x_6	y_2	Ranking
1	2	3	4	5	6	7
Beijing Municipality	4.12	2.08	0.09	1.15	1.93	10
Tianjin Municipality	5.25	2.10	0.66	0.02	2.30	1
Hebei Province	4.53	0.66	0.77	0.53	1.81	15
Shanxi Province	4.62	0.42	0.67	0.30	1.75	20
Inner Mongolia Autonomous Region	4.31	0.45	0.94	0.69	1.73	22
Liaoning Province	4.45	0.94	1.00	0.48	1.88	11
Jilin Province	3.85	1.17	1.21	0.47	1.76	19
Heilongjiang Province	3.24	1.21	1.04	0.49	1.54	26
Shanghai Municipality	3.41	2.80	0.33	0.32	1.74	21
Jiangsu Province	4.60	1.81	0.73	0.30	2.06	4
Zhejiang Province	4.57	1.65	0.98	0.57	2.08	3
Anhui Province	4.55	1.33	1.15	0.36	2.01	6
Fujian Province	4.22	1.56	1.11	0.66	1.97	9
Jiangxi Province	4.09	1.16	1.30	0.53	1.86	12
Shandong Province	5.03	1.52	0.78	0.45	2.16	2
Henan Province	4.66	1.22	0.97	0.31	1.99	8
Hubei Province	4.11	1.13	1.07	0.51	1.82	14
Hunan Province	3.44	1.56	0.67	0.82	1.66	23
Guangdong Province	4.41	1.64	1.15	0.47	2.04	5
Guangxi Zhuang Autonomous Region	4.23	1.06	1.10	0.39	1.83	13
Hainan Province	3.93	1.32	0.88	0.62	1.79	16
Chongqing Municipality	3.78	1.63	0.57	0.81	1.78	17
Sichuan Province	3.98	0.99	1.12	0.66	1.77	18
Guizhou Province	4.10	0.34	0.59	1.20	1.64	24
Yunnan Province	3.25	1.05	0.14	1.37	1.47	28
Tibet Autonomous Region	0.10	1.82	1.08	0.59	0.65	31
Shaanxi Province	4.50	1.10	1.27	0.64	1.99	7
Gansu Province	3.68	0.51	0.95	0.06	1.48	27
Qinghai Province	3.48	0.69	0.39	0.35	1.40	29
Ningxia Hui Autonomous Region	4.41	0.20	0.74	0.28	1.55	25
Xinjiang Uygur Autonomous Region	2.37	0.76	0.59	0.29	0.90	30

Source: Made by the author

Considering that the four extracted principal components represent 80% of the information in all resource indicators, the scores of the principal components can be used for preliminary analysis of the resource utilization level in the circular economy. Based on the calculation results in Table 2.12, the 31 provinces, autonomous regions, and municipalities directly under the central government can be classified into five regional categories (see Table 2.13).

Table 2.13

Classification of Resource Utilization in China's Provincial Circular Economy

Levels:	Ranking	Regions
1	2	3
Level 1 (High)	1-6	Tianjin, Shandong, Zhejiang, Jiangsu, Guangdong, Anhui
Level 2 (Relatively High)	7-12	Shaanxi, Henan, Fujian, Beijing, Liaoning, Jiangxi
Level 3 (Medium)	13-18	Guangxi, Hubei, Hebei, Hainan, Chongqing, Sichuan
Level 4 (Relatively Low)	19-24	Jilin, Shanxi, Shanghai, Inner Mongolia, Hunan, Guizhou
Level 5 (Low)	25-31	Ningxia, Heilongjiang, Gansu, Yunnan, Qinghai, Xinjiang, Tibet

Source: Made by the author

The spatial distribution of resource utilization in China's provincial circular economy generally follows an east-strong, west-weak, central-moderate pattern. Notably, Shaanxi in the west has achieved good resource utilization (Level 2), while Shanghai in the east has declined to Level 4. Of the 12 regions with high to relatively high resource utilization (Levels 1 & 2), 8 (67%) are in the east, including Tianjin, Shandong, Zhejiang, Jiangsu, Guangdong, Fujian, Beijing, and Liaoning. In the central region, only Anhui, Henan, and Jiangxi are included, and Shaanxi in the west. Among the 6 regions with medium resource utilization (Level 3), the west has Guangxi, Chongqing, and Sichuan; the east has Hebei and Hainan; and the central region has Hubei.

Among the 13 regions with lower to poorer resource utilization efficiency (Levels 4 & 5), 8 (62%) are in the western region, including Inner Mongolia, Guizhou, Ningxia, Gansu, Yunnan, Qinghai, Xinjiang, and Tibet. The central region includes Shanxi and Hunan, while the eastern region includes Jilin, Shanghai, and Heilongjiang. Shanghai's resource utilization is lowered due to missing data on water reuse and recycling rates. Overall, resource utilization in the central and western regions slightly exceeds their economic development level, with western regions decreasing from 10 to 8 in Levels

4 & 5, and half of central regions improving to Levels 1 & 2. Compared to economic development, eastern regions in Levels 1 & 2 decreased from 10 to 8, while western regions in Levels 4 & 5 decreased from 12 to 10 in terms of resource utilization.

Environmental Indicators:Drawing on the preliminary environmental indicators (Table 2.14), raw data for 2021 environmental protection levels across China's 31 provinces, autonomous regions, and municipalities were sourced from the 2022 China Statistical Yearbook. The data were standardized using equation (2.1), with grassland coverage calculated as total grassland area divided by built-up area.

Table 2.14

Preliminary Environmental Indicators

Number.	Environmental Indicators	Code
1	**2**	**3**
1	Total Industrial Solid Waste Generation	p_1
2	Total Wastewater Discharge	p_2
3	Industrial Wastewater Discharge	p_3
4	Industrial Air Emissions	p_4
5	Sulfur Dioxide Emissions	p_5
6	Industrial Sulfur Dioxide Emissions	p_6
7	Nitrogen Oxide Emissions	p_7
8	Industrial Nitrogen Oxide Emissions	p_8
9	Particulate Matter Emissions	p_9
10	Industrial Particulate Matter Emissions	p_{10}
11	Percentage of Total Environmental Pollution Investment	p_{11}
12	Percentage of Total Industrial Pollution Investment	p_{12}
13	Green Coverage Rate of Builtup Areas	p_{13}
14	Forest Coverage Rate	p_{14}
15	Grassland Coverage Rate"	p_{15}

Source: Made by the author

Before filtering, it is necessary to standardize the data, where positive indicators are processed according to Equation (2.1), and reverse indicators are processed according to Equation (2.2). Then, a Kaiser-Meyer-Olkin (KMO) test and Bartlett's sphericity test are conducted, and the results are shown in Table 2.15. The KMO value is 0.678 (greater than 0.5), and the probability (P-value) of Bartlett's sphericity test is 0 (less than 0.05). Considering the comprehensive analysis of these test results, it is deemed suitable to proceed with principal component analysis.

Table 2.15

KMO Test and Bartlett's Sphericity Test for Environmental Indicators

KMO and Bartlett's Test		
Kaiser-Meyer-Olkin Measure of Sampling Adequacy		0.678
Bartlett's Test of Sphericity	Approx. Chi-Square	726.096
	df	105.000
	Sig.	0.000

Source: Made by the author

After confirming the suitability for principal component analysis through testing the processed data, the principal component analysis for the above 15 environmental preliminary indicators was conducted using SPSS 27.0 software. The results are presented in Table 2.16：

Table 2.16

Common Factor Variances for Environmental Indicators

Common Factor Variance		
Indicator	**Initial**	**Extract**
1	2	3
p_1	1.000	0.815
p_2	1.000	0.902
p_3	1.000	0.896
p_4	1.000	0.89
p_5	1.000	0.867
p_6	1.000	0.892
p_7	1.000	0.961
p_8	1.000	0.941
p_9	1.000	0.925
p_{10}	1.000	0.937
p_{11}	1.000	0.677
p_{12}	1.000	0.302
p_{13}	1.000	0.502
p_{14}	1.000	0.881
p_{15}	1.000	0.751
Extraction Method: Principal Component Analysis		

Source: Made by the author

Table 2.17

Factor Loading Matrix for Environmental Indicators

Component Matrix			
Indicator	Indicator		
	1	2	3
p_1	0.818	0.292	0.248
p_2	0.57	0.678	0.343
p_3	0.655	0.607	0.315
p_4	0.936	0.053	0.101
p_5	0.925	0.105	0.002
p_6	0.941	0.078	0.004
p_7	0.969	0.044	0.142
p_8	0.96	0.003	0.137
p_9	0.884	0.313	0.213
p_{10}	0.886	0.322	0.223
p_{11}	0.251	0.648	0.441
p_{12}	0.256	0.459	0.164
p_{13}	0.271	0.519	0.399
p_{14}	0.083	0.712	0.606
p_{15}	0.086	0.652	0.564
Extraction Method: Principal Component Analysis			
a. 3 components have been extracted			

Source: Made by the author

The principal component analysis of 15 preliminary environmental indicators identified three components with eigenvalues >1, contributing cumulatively to 80.9% of the total. These three were extracted as principal components (Table 2.16). The first component mainly loads the first 10 indicators, including waste and emissions. The second component mainly loads four indicators, including wastewater discharge and environmental investment. The third component mainly loads forest coverage rate.

Therefore, considering the extraction of three principal components, three new variables are used to replace the original 15 initial variables. The linear combinations of these three new variables can be obtained based on the initial factor loading matrix, and they are:

$$x_7 = 0.818p_1 + 0.57p_2 + 0.655p_3 + 0.936p_4 + 0.925p_5 + 0.941p_6 + 0.969p_7 + 0.96p_8 + 0.884p_9 + 0.886p_{10} - 0.251p_{11} + 0.256p_{12} - 0.271p_{13} + 0.083p_{14} + 0.086p_{15} \quad (2.13)$$

$$x_8 = -0.292p_1 + 0.678p_2 + 0.607p_3 + 0.053p_4 - 0.105p_5 - 0.078p_6 + 0.044p_7 + 0.003p_8 - 0.313p_9 - 0.322p_{10} + 0.648p_{11} + 0.459p_{12} - 0.519p_{13} - 0.712p_{14} + 0.652p_{15} \quad (2.14)$$

$$x_9 = -0.248p_1 + 0.343p_2 + 0.315p_3 + 0.101p_4 + 0.002p_5 - 0.004p_6 + 0.142p_7 + 0.137p_8 - 0.213p_9 - 0.223p_{10} + 0.441p_{11} + 0.164p_{12} + 0.399p_{13} + 0.606p_{14} - 0.564p_{15} \quad (2.15)$$

Based on the proportion of eigenvalues extracted from the principal components, the original indicators are replaced by the principal components. The formula for calculating the scores after replacement is:

$$y_3 = 0.5123x_7 + 0.1979x_8 + 0.0992x_9 \quad (2.16)$$

According to equations (2.13)-(2.16), the scores and comprehensive rankings of the extracted principal components for environmental indicators can be calculated, as shown in Table 2.18:

Table 2.18

Principal Component Scores and Comprehensive Ranking for Environmental Indicators

Region	x_7	x_8	x_9	y_3	Ranking
1	2	3	4	5	6
Beijing	7.74	0.28	1.13	4.02	4
Tianjin	7.61	0.37	0.40	4.01	5.00
Hebei	1.41	1.05	0.60	0.99	31
Shanxi	2.82	1.59	0.94	1.85	27
Inner Mongolia Autonomous Region	3.10	1.37	0.78	1.94	26
Liaoning	3.70	0.99	0.68	2.16	24
Jilin	6.72	0.35	0.32	3.54	10
Heilongjiang	5.76	0.62	0.50	3.12	16
Shanghai	7.29	0.13	0.21	3.78	8
Jiangsu	3.15	0.28	0.18	1.54	29
Zhejiang	5.35	0.13	0.01	2.72	23
Anhui	5.26	0.57	0.42	2.85	22
Fujian	6.44	0.24	0.28	3.38	11
Jiangxi	5.93	0.67	0.56	3.22	14
Shandong	2.01	0.30	0.09	1.10	30
Henan	3.18	0.13	0.03	1.66	28
Hubei	5.83	0.28	0.28	3.07	18
Hunan	5.88	0.20	0.23	3.07	17
Guangdong	4.31	0.63	0.32	2.05	25
Guangxi Zhuang Autonomous Region	5.98	0.29	0.30	3.15	15

Region	x_7	x_8	x_9	y_3	Ranking
1	2	3	4	5	6
Hainan	8.48	0.90	0.63	4.58	1
Chongqing	6.84	0.51	0.45	3.65	9
Sichuan	5.55	0.25	0.24	2.92	21
Guizhou	6.05	0.78	0.48	3.30	13
Yunnan	6.05	0.82	0.57	3.32	12
Tibet Autonomous Region	8.60	0.42	0.41	4.53	2
Shaanxi	5.60	0.74	0.47	3.06	19
Gansu	6.89	1.19	0.73	3.83	7
Qinghai	7.71	0.67	0.58	4.14	3
Ningxia Hui Autonomous Region	7.07	1.12	0.72	3.92	6
Xinjiang Uygur Autonomous Region"	5.17	1.33	0.90	3.00	20

Source: Made by the author

Considering that the three principal components extracted represent 81% of the total information for all environmental indicators, a preliminary analysis of the environmental protection level in the circular economy can be conducted using the scores of the principal components. Based on the results from Table 2.18, the 31 provinces, autonomous regions, and municipalities can be classified into five categories (refer to Table 2.19).

Table 2.19

Classification of Environmental Protection in China's Regional Circular Economy

Level	Ranking	Regions
1	2	3
Level 1 (High)	1-6	Hainan, Tibet, Qinghai, Beijing, Tianjin, Ningxia
Level 2 (Moderately High)	7-12	Gansu, Shanghai, Chongqing, Jilin, Fujian, Yunnan
Level 3 (Medium)	13-18	Hunan, Hubei, Jiangxi, Guizhou, Guangxi, Heilongjiang
Level 4 (Moderately Low)	19-24	Xinjiang, Shaanxi, Sichuan, Anhui, Zhejiang, Liaoning
Level 5 (Low)	25-31	Guangdong, Inner Mongolia, Shanxi, Henan, Jiangsu, Shandong, Hebei

Source: Made by the author

Figure 2-3 shows the spatial distribution of circular economy environmental protection in China's provinces. It can be seen from the spatial distribution of circular economy environmental protection in China's provinces that the pattern of environmental protection in circular economy development is exactly the opposite of the spatial distribution pattern of economic development and resource utilization: the western region is strong, the eastern region is weak, and the central region is weak.

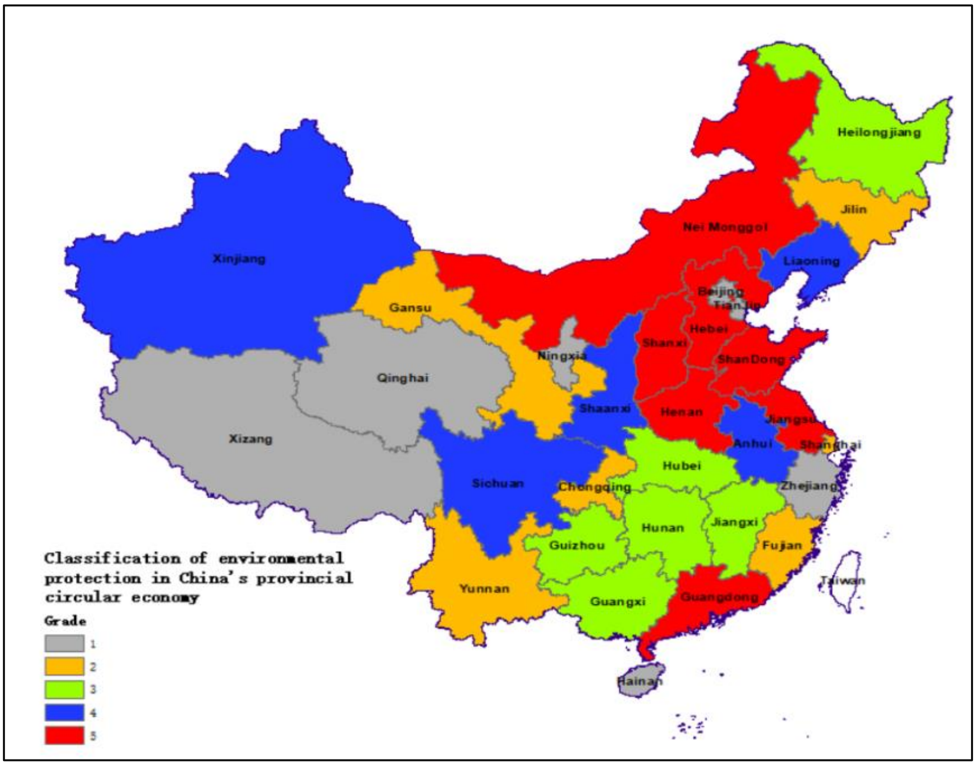

Fig. 2.3. Spatial distribution of circular economy environmental protection in China

Source: Made by the author

China's provincial circular economy shows a contrasting environmental protection pattern to economic development and resource utilization: strong in the west, weak in the east, and moderate in the central regions. Notably, regional variation in environmental protection is significant. In the east, a two-tier differentiation exists, with Beijing, Tianjin, Shanghai, and Fujian performing well (levels one and two), and Guangdong, Jiangsu, Shandong, Hebei, and Liaoning performing poorly (levels four and five).

In the central region, Anhui, Shanxi, and Henan have poor environmental protection (levels four and five), while Jiangxi, Hunan, and Hubei have moderate levels (level three). In the western region, Xinjiang, Sichuan, Inner Mongolia, and Shaanxi have low levels (levels four and five), while Tibet, Qinghai, Ningxia, Gansu, Chongqing, Yunnan, Guizhou, and Guangxi have moderate or better levels (level three or above).

Comprehensive Analysis:Based on principal component extraction for economic, resource, and environmental indicators, a preliminary evaluation and ranking of

China's provincial circular economy is conducted. Economic development and resource utilization follow an east-strong, west-weak, central-moderate pattern, while environmental protection is opposite. Some regions deviate from these patterns. To simplify, we temporarily exclude weighting factors due to controversy, summing principal component scores equally (assuming equal importance) to rank provincial circular economy development (see Table 2.20).

Table 2.20

Comprehensive Scores and Rankings of Circular Economy Principal Components in Provincial Regions of China

Region	y_1	y_2	y_3	**Sum**	**Ranking**
1	**2**	**3**	**4**	**5**	**6**
Beijing	2.05	1.93	4.02	8.00	1
Tianjin	1.59	2.30	4.01	7.90	2
Hebei	1.59	1.81	0.99	4.39	30
Shanxi	0.74	1.75	1.85	4.34	31
Inner Mongolia Autonomous Region	1.25	1.73	1.94	4.92	28
Liaoning	1.71	1.88	2.16	5.75	21
Jilin	0.93	1.76	3.54	6.23	11
Heilongjiang	0.97	1.54	3.12	5.63	22
Shanghai	2.31	1.74	3.78	7.83	3
Jiangsu	3.22	2.06	1.54	6.82	7
Zhejiang	2.51	2.08	2.72	7.31	4
Anhui	1.08	2.01	2.85	5.94	17
Fujian	1.55	1.97	3.38	6.90	6
Jiangxi	0.86	1.86	3.22	5.94	16
Shandong	2.84	2.16	1.10	6.10	14
Henan	1.70	1.99	1.66	5.35	25
Hubei	1.42	1.82	3.07	6.31	9
Hunan	1.39	1.66	3.07	6.12	13
Guangdong	3.20	2.04	2.05	7.29	5
Guangxi Zhuang Autonomous Region	0.88	1.83	3.15	5.86	18
Hainan	0.43	1.79	4.58	6.80	8
Chongqing	0.88	1.78	3.65	6.31	9
Sichuan	1.43	1.77	2.92	6.12	12
Guizhou	0.38	1.64	3.30	5.32	26
Yunnan	0.68	1.47	3.32	5.47	24
Tibet Autonomous Region	0.07	0.65	4.53	5.25	27
Shaanxi	0.92	1.99	3.06	5.97	15
Gansu	0.30	1.48	3.83	5.61	23
Qinghai	0.22	1.40	4.14	5.76	20

Region	y_1	y_2	y_3	Sum	Ranking
1	2	3	4	5	6
Ningxia Hui Autonomous Region	0.34	1.55	3.92	5.81	19
Xinjiang Uygur Autonomous Region	0.58	0.90	3.00	4.48	29

Source: Made by the author

According to the results in Table 2.20, the 31 provinces, autonomous regions, and municipalities directly under the central government can be classified into five categories, as shown in Table 2.21.

Table 2.21

Classification of Comprehensive Development of Regional Circular Economy in China

Level	Ranking	Regions
1	2	3
Level 1 (High)	1-6	Beijing, Tianjin, Shanghai, Zhejiang, Guangdong, Fujian
Level 2 (Relatively High)	7-13	Jiangsu, Hainan, Hubei, Chongqing, Jilin, Sichuan, Hunan
Level 3 (Medium)	14-19	Shandong, Shaanxi, Jiangxi, Anhui, Guangxi, Ningxia
Level 4 (Relatively Low)	20-25	Qinghai, Liaoning, Heilongjiang, Gansu, Yunnan, Henan
Level 5 (Low)	26-31	Guizhou, Tibet, Inner Mongolia, Xinjiang, Hebei, Shanxi

Source: Made by the author

China's circular economy generally follows an east-strong, west-weak pattern, but exceptions exist. Eastern coastal Liaoning and Hebei rank low (fourth and fifth levels), while central Hubei, Hunan, and western Chongqing, Sichuan rank high (second level). Among top performers (first and second levels), 9 are eastern (75%), including Beijing, Tianjin, Shanghai, etc. The western region has 3 medium-level (third level) regions, the central region has 2, and the eastern region has 1. Among lower performers (fourth and fifth levels), 8 are western (62%). In the east, Liaoning, Heilongjiang, and Hebei, and in the central region, Henan and Shanxi are included.

Analyzing rankings and indicators, western regions improved due to environmental protection. Chongqing and Sichuan rank high due to resource utilization and environmental protection, while Inner Mongolia is weak. In the central region, Henan ranks low due to weak environmental protection, and Shanxi ranks lowest due to overall weakness. Hubei and Hunan balance all aspects, ranking high (second level). In the east, economic development often exceeds resource utilization, with slightly lower environmental protection. However, Liaoning and Hebei fell due to poor environmental protection, indicating weaker comprehensive development.

2.2 Clustered Circular Economy Development Path Evolution Analysis

Dynamic Mechanism of the Evolution of Regional Circular Economy Development: The regional circular economy system encompasses economic, environmental, and resource subsystems, each with unique characteristics. The driving forces for its development are ecological support, economic development, and social stability. These forces interact, evolving with human and natural progress, and drive the long-term dynamic evolution of the entire regional circular economy.

Evolution of Ecological Support towards the "3R" Direction: Ecological support, crucial for human society's survival and development[51], has fueled human evolution and economic growth. It assesses regional resource and environmental capacities, including carrying and buffering capacities, but these are finite. Past rapid development strained these limits. The circular economy model aims to mitigate excessive consumption, repair, and sustain ecological support for humanity's ongoing benefit.

(1) Evolution of Resource Carrying Capacity

The acquisition of resources is fundamental to human activities[52]. Initially, humans viewed resources simply, unaware of their finitude. As productivity grew, regions' resources couldn't meet local needs, prompting recognition of resource value and some planning. The Industrial Revolution saw unprecedented productivity and large-scale resource exploitation, leading to a traditional linear economic growth pattern with low efficiency and near resource depletion. Recognizing Earth's resources' diversity and recovery, humans introduced the "3R" principle to save resource carrying capacity by reducing dependence, increasing utilization efficiency, and recycling waste. This formed a closed-loop flow, rejuvenating resource carrying capacity and marking the advanced circular economy stage. In summary, resource carrying capacity's evolution stems from humans' understanding and resource's changing role in their lives.

(2) Evolution of Environmental Buffering Capacity

The evolution of environmental buffering capacity aligns with resource carrying capacity. This capacity, rooted in self-renewal and self-purification, tolerates human interference like pollution and waste. For instance, seawater self-purifies impurities within limits[53]. However, extensive resource extraction disrupts environmental balance, undermining its self-repair. Human production processes generate pollution and energy consumption, further burdening the environment. Initially resilient, environmental buffering capacity now faces vulnerability, mirroring resource carrying capacity's evolution. As understanding deepens, measures align with the circular economy's "3R" principle, reducing pollution in production[54]. This repairs and protects environmental buffering capacity, guiding its evolution toward stability. In regional circular economy systems, respecting this capacity ensures sustained support for overall development.

Evolution of Economic Growth Force into Economic Development Force: The fundamental drive for an improved material life fuels human society's development. Economic activities are pivotal in satisfying this growing desire, fostering continuous progress and innovating productive forces and methods. Consequently, economic development serves as a sustained and impactful force for regional circular economy systems [55], complementing the foundational ecological support. Economic growth, the precursor to development, reflects quantitative strength and capacity changes in regional economies, attracting economist attention [56]. While growth emphasizes quantity, development signifies qualitative evolution in regional structures, particularly in industrial and spatial arrangements. Economic development force integrates resources, materials, energy, and information, akin to a chemical reaction where elements combine to create new substances and energy. It maximizes material needs satisfaction within system limits, contingent on sufficient resource and energy supplies. Thus, economic development force's action relies on a robust ecological support, necessitating a harmonious ecosystem approach. This involves aligning economic structures with ecosystem laws, leveraging regional traits, and implementing rational industrial layouts. By effectively combining resource allocation under macroeconomic and market functions, we can maximize economic development while preserving ecological foundations.

(3) Evolution of Social Stability Force

In the development of regional circular economy systems, social stability acts as a catalyst or stabilizer, akin to those in chemical reactions. It comprises fairness, social security, and moral constraints. Within ecological support limits, economic development aims to fulfill human material needs but may encounter destabilizing social factors. Without adequate social stability, the system risks overheating, akin to an uncontrolled chemical reaction. Thus, social stability is crucial for regulating the system's speed, intensity, and progress.

(4) Evolution of Social Equity Capability

If resources are humanity's common property, the benefits of a regional circular economy, supported ecologically, should reflect collective efforts. Fairness should guide resource acquisition, economic development, and profit distribution, benefiting all, not just a few. Large enterprises, while creating wealth, consume significant ecological resources[57]. If they dominate resource use, others suffer. Social equity aims to address this unfairness. Globalization intensifies resource competition, enabling non-local enterprises to access resources internationally. Future competition should focus on resource efficiency and fair market access, preventing monopolies. Equity capability ensures social constraints on such enterprises, emphasizing responsibility and enabling broader ecological benefit sharing.

(5) Evolution of Social Security Capability

Despite efforts toward resource distribution and fairness, resource scarcity ensures some will get less. To maintain system stability, social stability force provides security for those lacking ecological and economic support. Social security, through social contracts, economic distribution, and human rights protection, shares risks, transfers losses, and regulates conflicts, safeguarding basic rights and ensuring societal stability. Its evolution is gradual, influenced by economic development, industrial structure, and governance. As these normalize, the social security system improves, expanding protection with evolving social equity, fostering better regional development. Social security is a core action mode of social stability force, supporting system health and stability.

(6) Evolution of Moral Constraint Capability

If ecological and economic forces focus on hardware, social stability force emphasizes software, particularly moral constraint capability. External constraints like government policies and social systems are vital, but intrinsic moral capability is crucial for true stability. In regional circular economy systems, moral constraint mainly involves participants' ability to rectify harmful behaviors based on their moral values. For instance, businesses must consider social responsibility and rectify past rough management practices damaging ecological support. Similarly, the system's moral constraint force encourages green consumption and environmental awareness among the public, prompting active participation in circular economy construction.

The significance and purpose of constructing the evolution model of regional circular economy development path: The regional circular economy system is dynamic, constantly evolving due to various factors with unique characteristics. As people increasingly understand the laws governing this change, this paper aims to establish an evolution model for the regional circular economy path, building on the evaluation method introduced in Chapter Four[58]. This model aims to summarize and refine the laws of regional circular economy development. By clarifying these laws, it provides a theoretical foundation for practical advancements. The evolution concept encompasses the entire trajectory from initial design to harmonious human-nature development guided by sustainability. The proposed model records each stage's operational trajectory, visually elucidates it through quantitative analysis, and generalizes the laws of development, offering a theoretical basis for practical implementation. in summary, the significance of the model includes the following points:

(1) Clarifying and Visualizing Abstract Laws: Extracting and summarizing the developmental laws of the regional circular economy, a complex and multifaceted system, is challenging. Practical experience gradually reveals these laws, yet expressing them can be abstract. The Regional Circular Economy Development Path Evolution Model, using a three-dimensional space and quadrant division, intuitively classifies development stages[59]. Combined with qualitative analysis, spatial coordinates clearly reflect the development path. This visual model analyzes and summarizes laws, making abstract concepts clear and intuitive.

(2) Objective Data Collection and Analysis for Regional Circular Economy: The methods for collecting, processing, and calculating model data are objective and

scientific, accurately reflecting issues in regional circular economy development. Data stems from Chapter Four's evaluation, adhering to strict principles and using scientific weighting and calculation methods. By abandoning qualitative evaluation and relying solely on quantitative assessment, the objectivity and accuracy of the process are ensured. Rigorous data selection and processing methods guarantee the reliability of the results.

(3) The model's analytical approach and results offer significant guidance for policymakers in crafting circular economy strategies. Achieving sustainable human-nature harmony is the goal, with various paths to reach it. Given resource and environmental crises, summarizing past paths and transforming them based on circular economy principles is crucial. The Regional Circular Economy Development Path Evolution Model analyzes a region's path, identifies issues, and predicts future adjustments. It's vital for policy formulation, offering guidance to decision-makers, especially governments, in shaping circular economy policies and strategies.

(4) Reflecting General and Regional-Specific Laws: Regions pursuing circular economy development under overarching principles will share general circular economy traits. However, geographical, climatic, and resource differences will lead to unique paths[60]. The model captures both general and region-specific laws of circular economy evolution. For a given region, it analyzes the temporal evolution of its circular economy path, summarizing vertical development laws. Additionally, the model facilitates horizontal comparisons between regions, highlighting differences and similarities in their circular economy evolution paths over time.

Model Structure and Dimensions: The model for regional circular economic development's evolutionary path is built upon its evaluation. Its structure, dimensions, data sources, and methods are tied to the evaluation process. A system of evaluation indicators was previously established, with a hierarchical structure including economy, resources, and environment dimensions. These dimensions reflect the regional circular economic system's composition. To assess overall development, evaluating these three factors is necessary, leading to an overall development index. As the evolutionary path model is linked to the evaluation, it uses these three factors as its dimensions. The model structure is shown in Figure 2.4.

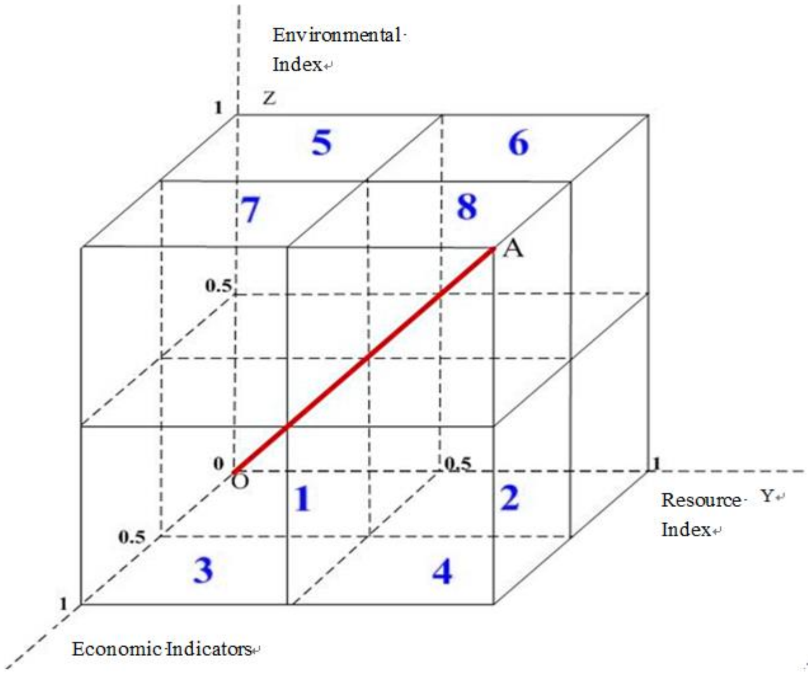

Fig. 2.4. Regional Circular Economy Development Path Evolution Model

Source: Made by the author

Figure 2.4 shows the Regional Circular Economy Development Path Evolution Model with three dimensions: Economic, Resource, and Environmental Indicators. These range from 0 to 1 after normalization. The origin (0,0,0) is theoretical, while (1,1,1) represents the ideal maximum. Point A signifies the optimal circular economy development. The model forms a cube in the first quadrant, divided into eight octants.

The Regional Circular Economy Development Index is represented by a spatial point in the model, reflecting its status at a given time. Points in the first octant have lower values, while those in the eighth octant have higher values for economic, resource, and environmental indicators. The evolution path involves points transitioning from the first to the eighth octant over time. For instance, ten consecutive years of a region's development path would be represented by a trajectory of ten points.

In Figure 2-1, the ray OA from the origin O (0,0,0) to point A (1,1,1) represents the optimal path of regional circular economy development, symbolizing the highest efficiency. The development path typically spirals upward but may vary due to region-specific priorities. Different regions may follow distinct paths for the same time series. Analyzing these paths aims to detect issues, identify best practices, and adjust future paths, informing decision-making.

The evolution of the regional circular economy development path, as depicted in

Figure 2-1, is a spatial trajectory from the origin O near the 1st quadrant to vertex A of the 8th quadrant. This path records development, with each point's coordinates representing the economic, ecological, and social livability indices at a given time (X, Y, Z respectively). The model can be expressed by a formula.

Objective Function：OPT=F（X，Y，Z）　（2-16）

Constraint Conditions：0≤X≤1

0≤Y≤1

0≤Z≤1

OPT: Regional Circular Economy System Development Status

X: Economic Indicators

Y: Resource Indicators

Z: Environmental Indicators

Formula 2-16 is a simplified representation of Figure 2-1, expressing that the development of regional circular economy at a specific time point is jointly determined by the values of economic, resource, and environmental indicators at that time point. In other words, the three coordinate values will determine a unique point in space, representing the development situation of the regional circular economy at that specific time point.

On the other hand, as shown in Table 2-1, in the regional circular economy development evaluation index system, Criterion Layer B consists of economic, resource, and environmental indicators. Layer B is further related to the final index layer D through the factor layer C. If we label the economic development index as B1, the ecological development index as B2, and the social livability index as B3, then crossing over the factor layer C allows for a clear visualization of the corresponding relationship between the components of Criterion Layer B, the indicators of Factor Layer D, and the coordinate axes of the model, as shown in Figure 2.5.

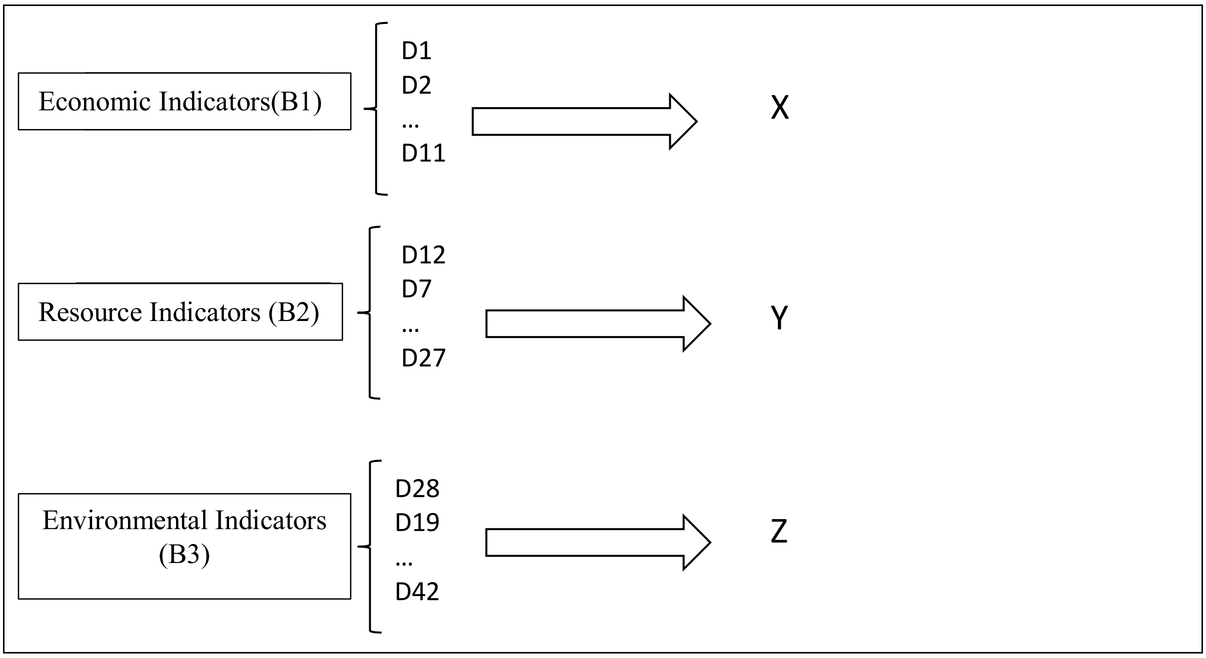

Fig. 2.5. Schematic Diagram of the Correspondence between the Criterion Layer, Indicator Layer, and Coordinate Axes

Source: Made by the author

As shown in Figure 2-5, the value of the economic index B1 is determined by the indicators D1-D5 in the indicator layer, corresponding to the values on the X-axis in the model. The value of the resource index B2 is determined by the indicators D6-D17 in the indicator layer, corresponding to the values on the Y-axis in the model. The value of the environmental index B3 is determined by the indicators D18-D23 in the indicator layer, corresponding to the values on the Z-axis in the model. This establishes the correspondence between the evaluation index system of regional circular economy development and the model of regional circular economy development path evolution. The data acquisition and processing of the latter will be closely connected with the former. In addition, in Equation 5-1, there are constraints on the values of X, Y, and Z. Since Figure 2-2 has established the correspondence between X, Y, Z and the evaluation index system, clarifying the sources of their respective data, in order to satisfy the constraints, it is necessary to normalize the raw data of all indicators so that each coordinate value satisfies the constraint of being between 0 and 1. The normalization method is as follows: assuming there are n evaluation indicators f, ($1 \leq j \leq n$), and the time series is measured in years, continuously examining the regional circular economic development over m years. Let the development situation in a certain year be denoted as a, ($1 \leq i \leq m$), and the matrix of n indicators for m years be denoted as

$X = (x_{ij})_{mxn,}$ which is called the decision matrix。

In the decision matrix $X =$ （x_{ij}）$_{mxn}$，

For positive indicators f_j， Take $x_j^* = \max_{1 \le i \le m} x_{ij} \neq 0$,

$s_{ij} = \frac{x_{ij}}{x_j^*}$， $(1 \le i \le m, 1 \le j \le n)$ (Formula5-2)

For reverse indicators f_j， 取$x_j^* = \min_{1 \le i \le m} x_{ij} \neq 0$,

$s_{ij} = \frac{x_j^*}{x_{ij}}$， $(1 \le i \le m，1 \le j \le n)$ (Formula 5-3)

$S = (S_{ij})_{m \times n}$， Thus, it is the normalized decision matrix.

Once the normalized decision matrix is categorized according to the correspondence shown in Figure 2-2, the data needed to calculate each coordinate value can be obtained. At this point, these data not only satisfy the correspondence with their respective coordinates but also fall within the constraint conditions, allowing for the next step of calculation.

Evaluation and Optimization of the Path Evolution of Regional Circular Economy Development，as well as determination of Dimensional Indicator Weights: After clarifying the significance of each dimension in the model, the source of data, and the normalization method, it is necessary to determine the weights of the data applied to each dimension in the model. Figure 2-2 shows the correspondence between the three axes of the model and the criterion layer and indicator layer in the evaluation index system. It also specifies that the data on each axis comes from the indicators corresponding to their respective layers. Therefore, the determination of weights for model dimensions is essentially the determination of the weights of each indicator in the evaluation index system for each axis.

It is worth noting that the correspondence shown in Figure 2-2 has already broken down the evaluation index system shown in Table 2-1. The premise of this breakdown is that the economic indicators, resource indicators, and environmental indicators represented by the X, Y, and Z axes in the model are independent of each other. In the model's processing, their correlation is ignored, and it is assumed that the coordinates of spatial points are precisely represented by the values located on the three axes. Each spatial point corresponds to a unique set of coordinates, which is a representation of the regional circular economic development situation on the model. In this way, when determining the weights of each indicator corresponding to each coordinate, it is equivalent to treating each coordinate as a target layer. The three coordinates constitute three independent target layers, each of which corresponds to its respective evaluation indicators. This correspondence is shown in Table 2-22:

Table 2-22

Relationship between Model Dimensions and Corresponding Indicators and Their Weights

Goal Level Indicator Level	X				Y				Z			
	Economic Indicators (B1)				Resource Indicators (B2)				Environmental Indicators (B3)			
Indicator Weight	D1	D2	……	D5	D6	D7	……	D17	D18	D19	……	D23
Sum of Indicator Weights	W_1	W_2	……	W_5	W_6	W_7	……	W_{17}	W_{18}	W_{19}	……	W_{23}
Goal Level	1				1				1			

Source: Made by the author

In the process of evaluating regional circular economy development, when the regional circular economy development index is taken as the target layer, whether the overall ranking weights determined by the AHP hierarchical analysis method or the weights determined by the entropy method are all for the target layer. The final weights determined sum to 1. In the model of the evolution of regional circular economy development paths, the difference lies in taking each dimension coordinate as the target layer. In this way, the sum of the weights of the indicators corresponding to each of the three dimensions is 1. At this point, the hierarchical structure of the dimension indicator weights is very clear. To ensure the accuracy of the calculation results, the AHP-entropy comprehensive weighting method is still used to calculate the weights of dimension indicators, ensuring the objectivity and scientific nature of the results. In contrast to calculating the weights of various indicators for the regional circular economy development index, there are three dimensions in the model, and accordingly, there are three target layers, so the weights of the indicators for each dimension need to be determined separately.

2.3. Empirical Study—A Case Study of the High-tech Zone in Xinyu City, Jiangxi Province

Determination of development benchmark of circular economy: The development of circular economy aims to transition from a linear to a circular system, optimizing resource use. Currently, circular economy practices are still emerging, with no complete system or definitive 'best practices.' As a new field, benchmarking existing practices may hinder innovation. The ideal circular economy involves green design, clean production, advanced green logistics, recycling consumption, minimal waste, and maximum resource recycling. All stakeholders—states, governments, enterprises, and the public—must possess strong resource and environmental awareness, environmental morality, clear roles, and fulfill environmental obligations.

Benchmark for economic development: The socio-economic system's circulation is crucial for circular economy and human society's survival. By mimicking natural ecosystems, it organizes production and consumption into a 'resource-production-consumption-renewable resources' cycle to maximize resource and environmental efficiency. Economic cycle subsystems must be planned to reduce pressure on natural resources and natural cycles, fostering harmony between economy and nature. Besides natural factors, institutional, technical, economic, and social factors also influence these subsystems. Institutional factors involve government behavior and systems, often implemented through administrative, legal, economic, and market mechanisms, such as administrative intervention, financial support, and property rights systems.

Technical factors significantly impact the economic virtuous circle, enhancing resource utilization efficiency, fostering resource substitution, and alleviating resource shortages. They also aid in pollution treatment, reducing waste emissions, improving recycling rates, and mitigating environmental pressure. Economic factors, including productivity, income, urbanization, and industrialization levels, underpin the virtuous cycle, with developed regions investing heavily in technology and environmental protection, leading to higher industrial structures and sustainable consumption patterns. In contrast, less developed areas face capital, technology, and talent shortages, leading to increased resource consumption and neglected environmental governance, perpetuating a vicious cycle. Population size and quality are crucial social factors; large populations strain resources and environments, potentially disrupting ecosystems and economies. Conversely, a high-quality population fosters resource conservation and comprehensive utilization, contributing to a virtuous economic cycle.

The theory of circular economy advocates the harmonious integration of the economic system into the material cycle of the natural ecosystem, which is a mode of economic development in harmony with the natural environment. Its ultimate goal is to build a circular economic form in harmony between man and nature, which is completely consistent with the scientific outlook on development, sustainable development and the goal of building a harmonious society.

The circular economy changes from the simple economy and management to the integration and optimization of the economy-society-nature complex ecosystem, aiming at the ultimate goal of building a harmonious society between man and nature, which embodies the fundamental requirement of people-oriented and sustainable development. To develop a circular economy, rationally arrange the scale, structure and layout of the economy according to the capacity (ecological threshold) and spatial distribution of the environment and resources, adjust and control the input of resources and the output of pollutants in the economic system, and minimize the demand for natural resources and the negative impact of economic activities on the ecological environment. It can reduce the pressure on resources and environment while increasing social output, so as to effectively alleviate the constraints of resources and environment, fundamentally solve the contradiction between economic development and resources and environment, and achieve the goal of harmony between man and nature.

The goal of circular economy system can be summarized as: to achieve the best use of resources in three dimensions: quantity, time and space.

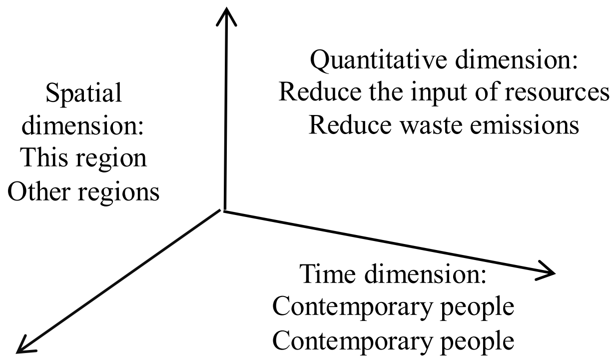

Fig. 2.6. Three-dimensional characteristics of circular economy system objectives

Source: Made by the author

(1) Quantitative dimension: it means to reduce the input of natural resources and reduce the amount of waste discharged into the environment, improve the efficiency of resource use, in order to achieve the best use of resources in quantity. (2) Spatial dimension: "Only misplaced resources, but no real waste." The spatial dimension of circular economy refers to the rational layout and planning adjustment of regional economic structure and industrial structure according to the spatial distribution of resources and environment and the status quo of social and economic development, so as to achieve the optimal allocation of resources at the spatial level and promote fairness and coordination among regions. (3) Time dimension: It refers to the realization of reasonable distribution and optimal utilization of resources within a certain time span, which not only meets the needs of the current generation, but also does not endanger the ability of future generations to meet their own needs. In other words, in the time dimension, it is necessary to reflect the sustainability of resource utilization and reflect intra-generational equity and intergenerational equity.

(2) Resource utilization benchmark: The research emphasizes that an ideal circular economy system is a natural-economic complex comprising the ecological and socio-economic systems. To ensure good circulation, we must first maintain the ecosystem's dynamic balance, providing renewable resources and a healthy environment for economic sustainability. Secondly, economic input and output must stay within the ecosystem's carrying capacity to minimize human impact and

harmonize the economy with nature. Lastly, achieving harmony between human-nature, economy-nature, and society-nature requires integrating material recycling in the economic subsystem with natural circulation in the ecosystem. This circular economy system is conceptual, summarizing commonalities across various systems. In reality, due to regional and industrial differences, their physical manifestations vary widely. Thus, viewing it as a conceptual system abstracted from physical entities aids in theoretically exploring circular economy commonalities and development mechanisms.

The direct purpose of developing a circular economy is to improve the efficiency of resource use, that is, to increase the amount of products (or output value and service) that can be produced per unit of natural resources. By means of reduction, resource utilization and reuse, circular economy develops the economy through the recycling of waste or waste materials to reduce the input of natural resources in the process of production and consumption and the discharge of waste to the environment, improve resource efficiency, and obtain more output and less pollution with less resources.

Environmental development benchmark: The natural cycle based on the ecosystem underpins the circular economy. It supplies material resources to the socio-economic system through an ecological chain formed by various elements. Sustainable utilization and maintenance of this cycle, without exceeding ecosystem thresholds, ensures its good circulation and sustainable ecological welfare. The natural cycle subsystem comprises biological and abiotic environments, producers, consumers, and decomposers, categorized into ten resource types. These resources' quantity, quality, and combination affect the subsystem's circulation. When undisturbed, the system's self-organization maintains harmony and virtuous cycling. However, human activities like large-scale resource exploitation, extensive growth, and unreasonable consumption have disrupted this mechanism, leading to ecological issues like farmland loss, water scarcity, forest destruction, erosion, vegetation damage, and climate change.

At present, the situation at home and abroad has undergone major changes, the international community has a more strict fixed on ecological environment protection, and the development of domestic industries has also undergone major changes, so there is a new demand for the development of circular economy and industrial clusters, so it is necessary to establish a new circular economy evaluation benchmark. Based on the above circular economy evaluation indicators, regional circular economy development path evolution model indicators, and national ecological industry demonstration park evaluation indicators in the "National ecological Industry Demonstration Park Standards", the cluster circular economy development evaluation system of this study is constructed, as shown in Table 2-23.

Table 2.23

Evaluation index system of cluster circular economy development

Paraclinic bed	Element level	Index level	Unit
1	**2**	**3**	**4**
Economic Indicators (A1)	1.Indicators of Economic output (B1)	GDP(D1)	Hundred million yuan
		GDP per capita (D2)	yuan
		Industrial value added per capita (D3)	yuan
		Proportion of added value of resource recycling Industry to added value of Industrial Park (D4)	yuan
		Household Consumption Level (D5)	yuan
	2.Industrial Structure Index (B2)	Value added of Primary Industry (D6)	Hundred million yuan
		Value added of Secondary Industry (D7)	Hundred million yuan
		Value-added of Tertiary Industry (D8)	Hundred million yuan
		Number of newly constructed eco-industrial chain projects after the implementation of the construction plan (D9)	a
		Comprehensive Utilization Rate of Industrial Solid Waste (D10)	%
		Recycling Rate of Renewable Resources (D11)	%
Resource Indicators (A2)	3.Resource Consumption Indicators (B3)	Energy consumption per 10,000 yuan of GDP (D12)	Tons of standard coal / 10,000 yuan
		Energy consumption per 10,000 yuan of industrial added value (D13)	Tons of standard coal / 10,001 yuan
		Water consumption per 10,000 yuan of GDP (D14)	Million cubic meters/billion yuan
		Water consumption per 10,000 yuan of industrial added value (D15)	Million cubic meters/billion yuan
	4.Resource Utilization Index (B4)	Industrial value added per unit of Industrial Land Area (D16)	100 million yuan per square kilometer
		Three-year Average Annual Growth Rate of Industrial Value Added per Unit of Industrial Land Area (D17)	%
		Comprehensive energy consumption elasticity coefficient (D18)	-

Paraclinic bed	Element level	Index level	Unit
1	2	3	4
		Energy consumption per unit of industrial added value (D19)	Tons of standard coal / 10,000 yuan
		Proportion of renewable energy use (D20)	%
		Elastic coefficient of fresh water consumption (D21)	-
		Fresh water consumption per unit of industrial added value (D22)	Cubic meter / 10,000 yuan
		Industrial water Reuse Rate (D23)	%
		Reclaimed water reuse rate (D24)	%
		Municipal Sewage disposal Rate (D25)	%
		Rural land use ratio (D26)	%
		Construction land ratio (D27)	%
Environmental Indicators (A3)	5.Waste Discharge Index (B5)	General Industrial Solid Waste generation (D28)	Ten thousand tons
		Total Wastewater discharge (D29)	Ten thousand tons
		Industrial Wastewater Discharge (D30)	Ten thousand tons
		Industrial Emissions (D31)	Million cubic meters
		Sulfur Dioxide Emissions (D32)	Ten thousand tons
		Industrial sulfur Dioxide Emissions (D33)	Ten thousand tons
		Nitrogen oxide emissions (D34)	Ten thousand tons
		Industrial nitrogen oxides Emissions (D35)	Ten thousand tons
		Dust Emission (D36)	Ten thousand tons
		Industrial Dust Emissions (D37)	Ten thousand tons
	6.Pollution Control Index (B6)	Proportion of total investment in environmental pollution (D38)	Ten thousand tons
		Proportion of total industrial pollution investment (D39)	%
		Green coverage rate of built-up area (D40)	%
		Forest cover (D41)	%
		Grassland coverage (D42)	%

Source: Made by the author

(3) Evaluation system index weight analysis

Thoughts and principles of AHP: Analytic Hierarchy Process (AHP) is an American operations research scientist and Professor T.L.Saaty of the University of Pittsburgh put forward in the early 1970s. AHP is a simple, flexible and practical multi-criteria decision-making method for quantitative analysis of qualitative problems. This decision-making method can easily and efficiently classify qualitative indicators quantitatively. The basic principle is to first analyze the nature and influencing factors of qualitative indicators, as well as the logical relationship between these indicators, and then integrate indicators according to the correlation among indicators, so as to establish a multi-level structural model. Then the quantitative information is calculated by mathematical means, and finally the relative weight value of the lowest index relative to the highest index is formed.

AHP method analyzes data sources: By summarizing the contents of the above indicators, a questionnaire survey table on the importance of each indicator is designed (see Appendix II). In order to determine the weight of the evaluation indicators, a total of 260 questionnaires were issued, and 245 valid questionnaires were recovered, including 167 from the Ecological Environment Bureau of Xinyu High-Tech Zone, 40 from the design and research Institute engaged in this aspect of design and research, and 38 from universities engaged in long-term research in this aspect of research.

AHP method determines the weight of evaluation indicators: In the comprehensive evaluation system, there are four criteria and 50 indicators, they are of different importance in the comprehensive evaluation, the status is important, should be given more important weight; On the contrary, a smaller weight should be given. The following uses analytic hierarchy process to determine the weight, and each evaluation finally obtains the weight vector of each evaluation index: First, establish and construct the judgment matrix. For the target layer, the relative importance of the elements in the comprehensive evaluation layer is compared in pairs, and the judgment matrix of pairwise comparison is obtained. Table 2.24 describes the meaning and description of the digital scale based on the 1-9 scale method:

Table 2.24

Importance comparison evaluation table

Aij	Definition	Aij	Definition
1	**2**	**3**	**4**
1	Ai and Aj are equally important	2	Somewhere between equal and slightly important

Aij	Definition	Aij	Definition
1	**2**	**3**	**4**
3	Ai is slightly more important than Aj.	4	Somewhere between slightly and obviously important
5	Ai is significantly more important than Aj	6	Somewhere between obvious and obviously important
7	Ai is obviously more important than Aj	8	Somewhere between the obvious and the absolutely important
9	Ai is absolutely more important than Aj	Count backwards	aij is the comparison result of the importance of index i and j，
			aij= 1/aji

Source: Made by the author

According to the comparison of the importance of each indicator, the judgment matrix of the criterion layer is obtained, as shown in Table2.25.

Table 2-25

Judgment matrix

Evaluation index	A2	A1	A3	Wi
1	2	3	4	5
A2	1	2	3	0.2987
A1	1/2	1	2	0.403
A3	1/3	1/2	1	0.2983

Source: Made by the author

As can be seen from Table 2-24, the maximum eigenvalue λmax of the judgment matrix is obtained as: 4.0458

Calculate the consistency index CI:

CI = (lambda Max - n)/(n - 1) = (4.0458 4)/(4-1) = 0.0153 (2.17)

The RI value is found according to the average random consistency index RI table:

When n=3, RI=0.75

Calculate the consistency ratio CR:

CR=CI/RI=0.0153/0.9=0.017<0.1, so the consistency of the judgment matrix is acceptable.

The detailed calculation process of the weight of the judgment matrix is as follows:

Calculate the product of each row of elements in the judgment matrix,

$$m_i = \prod_{j=1} a_{ij} = [1.70831.56671.16671.3] \qquad (2.18)$$

Then, calculate the NTH root of mi,

$$w_i^* = \sqrt[n]{m_i} = [1.04981.03290.97491.0274] \qquad (2.19)$$

Then the vector is normalized:

$$w_i = \frac{w_i^*}{\sum_{i=1}^{n} w_i^*} = [0.2917,0.225,0.2983,0.185] \qquad (2.20)$$

Among them, the maximum eigenvalue λmax is calculated as:

$$\lambda_{max} = \frac{1}{n}\sum_{i=1}^{n}\frac{(Aw)i}{W_i} = \frac{1}{4} \times 16.1832 = 4.04583 \qquad (2.21)$$

Where Awi=(λmax-n)/(n-1)*Wi

By substituting the values of λmax, n, and Wi into the formula, the Awi value is:

Awi=(4.0458-4)/(4-1)*[0.425,0.3917,0.2917,0.325]=[0.2364,0.2249,0.2028,0.2358]。

The consistency index CI is obtained as follows:

$$\mathrm{CI} = (\lambda\mathrm{max} - \mathrm{n})/(\mathrm{n} - 1) = (4.0458 - 4)/(4 - 1) = 0.0153 \qquad (2.22)$$

According to the RI table, when the judgment matrix is 4 orders, RI is 0.9.

The calculated average consistency is as follows: CR=CI/RI= 0.0153/0.9 = 0.017 <0.1 <0.1, passing the consistency test.

In addition, according to the comparison of the importance of each indicator, the judgment matrix of each sub-criterion layer in the indicator layer is obtained, taking A2 and A1 as examples, as shown in Table 2.26 and 2.27.

Table 2.26

Judgment matrix

Evaluation index	B1	B2	Wi
1	2	3	4
B1	1	1/2	0.5
B2	2	1	0.5

Source: Made by the author

As can be seen from Table 2-26, λmax=0.75, CI=-1.25, RI=0.58, CR=-2.1552, CR<0.1 have satisfactory consistency.

The detailed calculation process of the weight of the judgment matrix is as follows:

Calculate the product of each row of elements in the judgment matrix,

$$m_i = \prod_{j=1} a_{ij} = [2.0000，0.5000]。 \qquad (2.23)$$

Then, calculate the NTH root of mi,

$$w_i^* = \sqrt[n]{m_i} = [0.7071, 1.0000] 。 \qquad (2.24)$$

Then the vector is normalized:

$$w_i = w_i^* / \sum_{i=1}^{n} w_i^* = [0.6667, 0.3333] \qquad (2.25)$$

Among them, the maximum eigenvalue λmax is calculated as: $\lambda_{max} =$

$$\frac{1}{n}\sum_{i=1}^{n}\frac{(Aw)i}{W_i} = 1/2 \times 0.5 = 0.75: \qquad (2.26)$$

Awi=[0.7937,1.0000, 1.2599]。

The consistency index CI is obtained as follows:

$$\mathrm{CI} = \frac{\lambda_{max} - n}{n-1} = (0.75 - 2)/(2 - 1) = 0.6666 \qquad (2.27)$$

According to the RI table, when the judgment matrix is the 2nd order, RI is 0.58.

The calculated average consistency is: CR=CI/RI=-1.25/0.58=-2.1552<0.1, Passed the conformance test.

Table 2.27

Judgment matrix

Evaluation index	B3	B4	Wi
B3	1	2	0.5
B4	1/2	1	0.5

Source: Made by the author

As can be seen from Table 2-27, λmax=0.75, CI=-1.25, RI=0.58, CR=-2.1552, CR<0.1, with satisfactory consistency.

The detailed calculation process of the weight of the judgment matrix is as follows:

Calculate the product of each row of elements in the judgment matrix,

$$m_i = \prod_{j=1} a_{ij} = [2.0000，0.5000]。 \qquad (2.28)$$

Then, calculate the NTH root of mi,

$$w_i^* = \sqrt[n]{m_i} = [0.7071, 1.0000] 。 \qquad (2.29)$$

Then the vector is normalized:

$$w_i = w_i^* / \sum_{i=1}^{n} w_i^* = [0.6667, 0.3333] \qquad (2.30)$$

Among them, the maximum eigenvalue λmax is calculated as:

$$\lambda_{max} = \frac{1}{n}\sum_{i=1}^{n} \frac{(Aw)i}{W_i} = \frac{1}{2} \times 0.5 = 0.75: \qquad (2.31)$$

Awi=[0.7937,1.0000, 1.2599]。

The consistency index CI is obtained as follows:

$$\mathrm{CI} = \frac{\lambda_{max} - n}{n-1} = \frac{0.75-2}{2-1} = 0.6666 \qquad (2.32)$$

According to the RI table, when the judgment matrix is the 2nd order, RI is 0.58.

The calculated average consistency is:

CR=CI/RI=-1.25/0.58=-2.1552<0.1, (2.33)

Passed the conformance test.

Table 2.28

Judgment matrix

Evaluation index	B3	B4	Wi
B5	1	2	0.5
B6	1/2	1	0.5

Source: Made by the author

As can be seen from Table 2-28, λmax=0.75, CI=-1.25, RI=0.58, CR=-2.1552, CR<0.1 have satisfactory consistency.

Table 2.29

Judgment matrix

Evaluation index	B7	B8	B9	Wi
B7	1	2	1/2	0.33333
B8	1/2	1	2	0.33333
B9	2	1/2	1	0.33333

Source: Made by the author

As can be seen from Table 2.29, λmax=2, CI=-0.5, RI=0.58, CR= -0.86207, CR<0.1, with satisfactory consistency.

After the above steps are repeated to obtain the weiht of each sub-criterion layer, the analysis is carried out on the indicator layer. According to the comparison of the importance of each indicator, the respective judgment matrix is obtained, taking B1 and B2 as examples, as shown in Table 2-30, 2-31, 2-32, 2-33, 2-34, and 2-35.

Table 2.30

Judgment matrix

Evaluation index	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	D11	Wi
D1	1	2	2	1/2	2	2	2	2	1	2	2	0.1657
D2	1/2	1	1/2	1/5	1/2	1/2	2	1/2	1/2	1	1/2	0.0623
D3	1/2	2	1	1/3	1	1/2	1	1	1/2	2	1	0.0859
D4	2	5	3	1	4	5	3	4	2	2	2	0.1263
D5	1/2	2	1	1/4	1	2	1/2	1/2	1/3	1/2	1/2	0.0529
D6	1/2	2	2	1/5	1/2	1	2	1/2	1/2	1/2	1/2	0.0879
D7	1/2	1/2	1	1/3	2	1/2	1	1/2	1/2	1/2	1/2	0.0722
D8	1/2	2	1	1/4	2	2	2	1	2	2	2	0.1172
D9	1	2	2	1/2	3	2	2	1/2	1	2	1/2	0.1036
D10	1/2	1	1/2	1/2	2	2	2	1/2	2	1	2	0.0552
D11	1/2	2	1	1/2	2	2	2	1/2	1/2	1/2	1	0.0708

Source: Made by the author

As can be seen from Table 2-30, λmax= 2.0809, CI= 0.0909, RI=1.58, CR=0.0575, CR<0.1 have satisfactory consistency.

The detailed calculation process of the weight of the judgment matrix is as follows:

Calculate the product of each row of elements in the judgment matrix,

$m_i = \prod_{j=1} a_{ij} =$ [0.0078，5.00，3.00，8.6400，1.7361，3.200，3.2400，1.3107，0.3102，2.3045，1.5625] (2.34)

Then, calculate the NTH root of mi,

$$w_i^* = \sqrt[n]{m_i} = [0.2778, 1.6329, 1.4426, 2.1615, 1.3848, 1.8871, 1.8975, 1.17609, 0.6328, 1.5327, 1.3946] \quad (2.35)$$

Then the vector is normalized:

$$w_i = \frac{w_i^*}{\sum_{i=1}^{n} w_i^*} = [0.1657, 0.0623, 0.0859, 0.1263, 0.0529, 0.0879, 0.0722, 0.1172, 0.1036, 0.0552, 0.0708] \quad (2.36)$$

Among them, the maximum eigenvalue λmax is calculated as: $\lambda_{max} = \frac{1}{n}\sum_{i=1}^{n}\frac{(Aw)i}{W_i} = 1/11 \times 22.8899 = 2.0809$, (2.37)

Awi=[1.3451 ,0.5416,0.7179,2.6821 ,0.7279,0.7765,0.6490,0.9776] (2.38)

The consistency index CI is obtained as follows: $\mathrm{CI} = \frac{\lambda_{max}-n}{n-1} = \frac{10.1657-11}{11-1} = 0.0909$ (2.39)

According to the RI table, when the judgment matrix is 11th order, RI is 1.58.

The calculated average consistency is: CR=CI/RI=0.0909/1.58=0.0575 (2.40)

Table 2.31

Resource consumption indicators (B3) and (B4) Resource utilization indicators judgment matrix

Evaluation index	D12	D13	D14	D15	D16	D17	D18	D19	D20	D21	D22	D23	D24	D25	D26	D27	Wi
D12	1	2	2	1/2	3	2	2	1/2	2	1/2	2	2	1/2	1/2	1/2	1/2	0.1036
D13	1/2	1	1/2	1/2	2	2	2	1/2	1/2	1/2	1/2	1/2	1/2	1/2	1/2	1/2	0.0562
D14	1/2	2	1	1/2	2	2	2	1/2	1/2	1/2	1/2	2	2	1/2	2	1/2	0.0705
D15	2	2	2	1	3	3	3	2	2	2	2	2	1	1/2	2	1/2	0.0567
D16	1/3	1/2	1/2	1/3	1	1/2	1/2	1/3	1/2	1/3	1/3	1/2	2	1	2	2	0.0336
D17	1/2	1/2	1/2	1/3	2	1	1/2	1/2	1/2	1/3	1/2	1/2	1/2	1/2	1	1/2	0.0417
D18	1/2	1/2	1/2	1/3	2	2	1	1/2	1/2	1/3	1/2	1/2	2	1/2	2	1	0.0438
D19	2	2	2	1/2	3	2	2	1	2	1/2	2	2	1/2	1/2	1/2	1/2	0.1163
D20	1/2	2	2	1/2	2	2	2	1/2	1	1/2	1/2	2	1/2	1/2	2	1/2	0.0795
D21	2	2	2	1/2	3	3	3	2	2	1	2	2	1/2	1/2	1/2	1/2	0.0196
D22	1/2	2	2	1/2	3	2	2	1/2	2	1/2	1	2	1/2	1/2	1/2	1/2	0.0923
D23	1/2	2	1/2	1/2	2	2	2	1/2	1/2	1/2	1/2	1	1/2	1/2	1/2	1/2	0.0631
D24	2	2	1/2	1	1/2	2	1/2	2	2	2	2	2	1	1/2	1/5	1/2	0.0139
D25	2	2	2	2	1	2	2	2	2	2	2	2	1/2	1	1/4	1/2	0.0726

D26	2	2	1/2	1/2	1/2	1	1/2	2	1/2	2	2	2	5	4	1	2	0.0863
D27	2	2	2	2	1/2	2	1	2	2	2	2	2	1/2	1/2	1.2	1	0.0503

Source: Made by the author

Can be obtained from Table 2-31, max=0.0073，CI=0.0541，RI=0.58,CR=0.0352，CR<0.1，It has satisfactory consistency.

Calculate the product of each row of elements in the judgment matrix,

$m_i = \prod_{j=1} a_{ij} =$ [0.00390625, 000549747, 0.00054974, 0.07699305, 0.000486,0.03333,0.033333,0.066667,0.066667,0.0666667,0.06666667,0.06666,0.08,0.08,0.5,0.4] (2.41)

Then, calculate the NTH root of mi,

$$w_i^* = \sqrt[n]{m_i}$$

$$= [[0.2778, 1.6329, 0.999998, 1.4426, 4.18707, 3.35265, 2.1615, 4.77185, 1.14944, 1.3848, 4.59244, 1.88717, 2.019233, 1.89756, 0.625375]] \quad (2.43)$$

Then the vector is normalized:

[0.1036,0.0562,0.0705,0.0567,0.0336,0.0417,0.0438,0.1163,0.0795,0.0196, 0.0923,0.0631,0.0139,0.0726,0.0863 (2.44)

0.0503Among them, the maximum eigenvalue λmax is calculated as: $\lambda_{max} = \frac{1}{n}\sum_{i=1}^{n}\frac{(Aw)i}{W_i} = 1/16 \times 0.117033 = 0.0073$， (2.45)

Awi=[1.3111,0.7112,0.8974,1.9653,0.4154,0.5218,0.5869,1.4728,1.0079,1.7474,1.1671,0.7989, 2.7321, 1.3946,3.6325,5.88702] (2.46)

The consistency index CI is obtained as follows: $\mathrm{CI} = \frac{\lambda_{max} - n}{n-1} = 0.0541$ (2.47)

According to the RI table, when the judgment matrix is 18 orders, RI is 0.58.

The calculated average consistency is: CR=CI/RI=0.0541/0.58=0.0352 (2.48)

Table 2.32

Waste discharge index (B5) and pollution control index (B6) judgment matrix

Evaluation index	D28	D29	D30	D31	D32	D33	D34	D35	D36	D37	D38	D39	D40	D41	D42	Wi
D28	1	2	1/2	1/2	1/2	1/2	1/2	1/2	1/2	2	3	4	1/2	1/2	1/2	0.0654
D29	1/2	1	1/2	1/2	1/2	1/2	1/2	1/2	1/2	1/2	1/3	1	1/2	1/2	1/2	0.0476
D30	2	2	1	2	1/2	2	1/2	2	2	2	1/5	1/4	1/3	1/2	1/2	0.1308
D31	2	2	1/2	1	1/2	2	1/2	2	2	2	2	2	1/3	1	1/2	0.1139
D32	2	2	2	2	1	2	2	2	2	2	1/3	2	2	2	1/2	0.0326

D33	2	2	1/2	1/2	1/2	1	1/2	2	1/2	2	2	2	5	1/2	1/2	0.0863
D34	2	2	2	2	1/2	2	1	2	2	2	2	2	2	2	2	0.0503
D35	2	2	1/2	1/2	1/2	1/2	1/2	1	1/2	2	2	2	2	5	4	0.0751
D36	2	2	1/2	1/2	1/2	2	1/2	2	1	2	2	2	1/2	5	1/2	0.0991
D37	1/2	2	1/2	1/2	1/2	1/2	1/2	1/2	1/2	1	1/3	2	1/2	4	1/2	0.0569
D38	1	2	1/2	1/2	1/2	1/2	1/2	1/2	1/2	3	1	4	3	1/2	3	0.03126
D39	1/3	2	1/2	1/2	1/2	1/2	1/2	1/2	1/2	1/2	1/4	1	1/2	1/2	1/2	0.1033
D40	2	2	1	1/2	1/2	1/5	1/2	1/2	2	1/5	1/3	2	1	2	1/2	0.0426
D41	2	2	1/3	1/2	1/2	1/4	1/2	1/5	2	1/4	2	2	1/2	1	1/2	0.03271
D42	2	2	2	1/2	1	1/3	2	1/4	2	1/3	1/3	2	2	2	1	0.03213

Source: Made by the author

As shown in Table 2-32,λmax=10.5875，CI=0.0653，RI=1.49，CR=0.0438，CR<0.1，It has satisfactory consistency.

The detailed calculation process of the weight of the judgment matrix is as follows:

Calculate the product of each row of elements in the judgment matrix,

$m_i = \prod_{j=1} a_{ij} =$ [0.0312,0.0020,32.0000,8.0000,512.0000,0.5000,128.0000,0.1250,2.0000,0.0078, 0.0417, 1.3805,1.3218,1.26323,1.20457] (2.49)

Then, calculate the NTH root of mi,

$w_i^* = \sqrt[n]{m_i} = [0.17663, 0.04472, 5.65685, 2.82842, 22.627416, 0.7071, 11.313708, 0.35355, 1.4142135, 0.08831, 0.2042, 1.17494, 1.149695, 1.12393, 1.09752]$ (2.50)

Then the vector is normalized:

$$w_i = w_i^* / \sum_{i=1}^{n} w_i^* = [0.0654,0.0476,0.1308,0.1139,0.0326,0.0863,0.0503,0.0751,0.0991, 0.0569,0.03126,0.1033,0.0426,0.03271,0.03213] \quad (2.51)$$

Among them, the maximum eigenvalue λmax is calculated as: $\lambda_{max} = \frac{1}{n}\sum_{i=1}^{n} \frac{(Aw)i}{W_i} = 1/15 \times 105.8754 = 10.5875$， (2.52)

Awi=[0.6925,0.5248,1.3849,1.2056,1.8274,0.9137,1.5908,0.7954,1.0496,0.6028, 0.08948,1.3333,0.03191,1.2723,0.21062] (2.53)

The consistency index CI is obtained as follows: $\mathrm{CI} = \frac{\lambda_{max}-n}{n-1} = (10.5875 - 15)/(15 - 1) = 0.0653$ (2.54)

According to the RI table, when the judgment matrix is 15 orders, RI is 1.46.

The calculated average consistency is: CR=CI/RI=0.0438

The calculated average consistency is as follows: CR=CI/RI==0.0699

Repeat the above steps to obtain the weights of each indicator layer, and finally obtain the weight summary calculation result, as shown in Table 2-34:

Table 2.33

Cluster circular economy evaluation system index weight summary

Aligning layer	Factor layer (weight)	Index level	weight
1	2	3	4
Economic indicator （A1） （0.2917）	1.Indicators of economic output （B1）（0.5）	GDP(D1)	0.1657
		Per capita GDP (D2)	0.0623
		Industrial added value per capita (D3)	0.0859
		Proportion of added value of resource recycling industry to added value of industrial park (D4)	0.1263
		Residents' consumption level (D5)	0.0529
	2.industrial structure indicators (B2)（0.5）	Value added of the primary industry (D6)	0.0879
		Added value of the secondary industry (D7)	0.0722
		Value-added of Tertiary Industry (D8)	0.1172
		The number of newly constructed ecological industrial chain projects after the implementation of the construction plan (D9)	0.1036
		Comprehensive utilization rate of industrial solid waste (D10)	0.0552
		Recycling rate of renewable resources (D11)	0.0705
Resource index （A2） （0.225）	3.resource consumption indicators (B3) （0.5）	Energy consumption per 10,000 yuan of GDP (D12)	0.1036
		Energy consumption of 10,000 yuan industrial added value (D13)	0.0562
		Water consumption per 10,000 yuan of GDP (D14)	0.0705
		Water consumption of 10,000 yuan industrial added value (D15)	0.0567
	4. Resource utilization indicators (B4) （0.5）	Industrial added value per unit of industrial land area (D16)	0.0336
		Three-year average annual growth rate of industrial added value per unit of industrial land area (D17)	0.0417
		Comprehensive energy consumption elasticity coefficient (D18)	0.0438
		Comprehensive energy consumption per unit of industrial added value (D19)	0.1163
		Proportion of renewable energy use (D20)	0.0795
		Elastic coefficient of fresh water consumption (D21)	0.0196
		Fresh water consumption per unit of industrial added value (D22)	0.0923
		Reuse rate of industrial water (D23)	0.0631
		Reuse rate of reclaimed water (D24)	0.0139

Aligning layer	Factor layer (weight)	Index level	weight
1	2	3	4
		Urban sewage disposal rate (D25)	0.0726
		Rural land ratio (D26)	0.0863
		Construction land ratio (D27)	0.0503
Environmental index（A3）（0.2983）	5. Waste discharge indicators (B5)（0.5）	Amount of general industrial solid waste produced (D28)	0.0654
		Total wastewater discharge (D29)	0.0476
		Industrial wastewater dischargeD30)	0.1308
		Industrial waste gas emission (D31)	0.1139
		Sulfur dioxide emission (D32)	0.0326
		Industrial sulfur dioxide emissions (D33)	0.0863
		Nitrogen oxide emissions (D34)	0.0503
		Industrial nitrogen oxides emissions (D35)	0.0751
		Dust emission (D36)	0.0991
		Industrial dust emission (D37)	0.0569
	6. Pollution control indicators (B6)（0.5）	Proportion of total investment in environmental pollution (D38)	0.03126
		Proportion of total investment in industrial pollution (D39)	0.1033
		Green coverage rate of built-up area (D40)	0.0426
		Forest coverage rate (D41)	0.03271
		Grassland coverage (D42)	0.03213

Source: Made by the author

System evaluation model: After determining the content and weight of the evaluation system, the relevant evaluation models and standards are analyzed and expounded. The evaluators are a number of industry experts and related professional and technical personnel, and fully adopt the opinions of all personnel, negotiate with each other and determine the final score of each indicator. Specific as the following two methods:

First, the absolute weight is used to determine the evaluation results of the system. First of all, each index in the above system indicator layer must meet the qualification standard. Secondly, after the evaluation of an index is qualified, the evaluation result takes 0.6 times of its absolute weight as the score weight; A certain index is evaluated as good, and the score weight of the evaluation result is 0.8 times of its absolute weight. Evaluation of an indicator as excellent, evaluation results with its absolute weight of 1.0 times as the score weight. Finally, the full score of the system evaluation is 100 points, that is, 100 points is taken as the calculation base, multiplied with the score weights of indicators in the index layer, and cumulatively added to obtain the quality evaluation scores of individual projects. The calculation formula is as follows：

$$100 \times \sum_{i=1}^{n} A_i \, B_i \qquad (2.55)$$

A: Absolute weight of indicators at the system indicator layer

B: Actual score of the system indicator layer

Note: After obtaining the quality evaluation score of a single project, if you want to determine the completion effect and evaluation score of a criterion layer or sub-criterion layer, you can determine the specific completion situation according to the following formula

$$100 \times \frac{\sum_{i=1}^{n} C_i D_i}{\sum_{i=1}^{n} C_i} \qquad (2.56)$$

C: The absolute weight of indicators contained in a criterion layer or subcriterion layer.

D: The actual score of the indicators contained in a criterion layer or sub-criterion layer.

Second, the relative weight is used to determine the evaluation results of the system. First of all, each index in the above system indicator layer must meet the qualification standard. Secondly, after the evaluation of an index is qualified, the evaluation result takes 0.6 times of the relative weight of the index layer as the score weight; An index is evaluated as good, and the score weight of the evaluation result is 0.8 times of the relative weight of the index layer. To evaluate an index as excellent, the evaluation result takes 1.0 times of the relative weight of its index layer as the score weight. Finally, the full score of system evaluation is 100 points, that is, 100 points is taken as the calculation base, and the single project quality evaluation score is obtained through the following formula.

$$\left\{\sum_{k=1}^{n}\left[\sum_{j=1}^{n}\left(\sum_{i=1}^{n} B_i \, D_i\right) \times E_j\right] \times F_k\right\} \times 100 \qquad (2.57)$$

B: indicates the relative weight of the indicator layer

D: Actual score of the indicator layer

E: relative weight of the subcriterion layer

F: relative weight of criterion layer

Sources of evaluation data: When the cluster circular economy evaluation system is used to evaluate Xinyu High-tech Zone, the evaluation personnel can be the relevant management personnel inside the project participating units, the staff of the government supervision department with the relevant quality assessment responsibility outside the enterprise, and the professional and technical personnel of various industry associations or social organizations. The evaluation data results are determined by referring to the relevant national standards, local industry standards of Xinyu City, engineering design requirements, geological and hydrological environment, relevant construction technology and other documents, combined with the actual situation of the project. For some professional projects or key parts of quality control, multiple professionals can be hired to evaluate them respectively. Finally, the comprehensive evaluation value is taken as the evaluation data of each index. If there are large differences in the index evaluation data, the relevant personnel of the organizer shall organize an expert opinion meeting, reach a consensus through consultation and determine the evaluation results.

System evaluation criteria: Complete the evaluation of each index of the criterion layer and index layer, and delimit the final evaluation of a single project after determining the evaluation score of a single project (that is, the final score of the index of the target layer) through the above calculation method. A score between 60 and 70 is qualified, between 70 and 80 is good, and above 80 is excellent.

Evaluation process: According to the relevant standards, each index in the system is scored one by one, and the above calculation formula is used to calculate the evaluation score of Xinyu high-tech zone cluster circular economy. After summary, it is concluded that Xinyu High-tech zone cluster circular economy score weight is 0.783072, then the final evaluation score of Xinyu high-tech zone cluster circular economy development is 100×0.783072=78.3072 points, which meets the requirement that 70-80 points is good. Table 2-35 lists the actual score weights for each indicator. (Note: The data in the index layer column of the table is the actual score weight that determines the final evaluation score, which is obtained by multiplying the absolute weight of each evaluation index with the evaluation result. The data in the criterion layer and sub-criterion layer are further summarized by the score weight.)

Table 2.34

Actual score weights of each evaluation index of the project

Criterion layer	Relative weight	Subcriterion layer	Relative weight	Index level	Relative weight	Absolute weight	Evaluation result
1	2	3	4	5	6	7	8
A1(0.2191306)	0.299335	B1(0.0529626）	0.259921	D1（0.0103144）	0.165715	0.012893	0.8
				D2（0.0038672）	0.062134	0.004834	0.8
				D3（0.0040098）	0.085891	0.006683	0.6
				D4（0.0152244）	0.326126	0.025374	0.6
				D5（0.0038682）	0.082858	0.006447	0.6
		B2(0.0817158）	0.3274	D6（0.006837）	0.087871	0.006837	1
				D7（0.0033714）	0.072226	0.005619	0.6
				D8（0.0054702）	0.117178	0.009117	0.6
				D9（0.0081224）	0.10357	0.010153	0.8
				D10（0.003305）	0.056195	0.00559	0.6
				D11（0.004164）	0.07082	0.00694	0.6
A2(0.3540181)	0.376247	B3(0.0844516)	0.25481	D12（0.015362）	0.15671	0.015362	1
				D13（0.002632）	0.033559	0.00329	0.8
				D14（0.0024516）	0.041688	0.00486	0.6
		B4(0.0844516)	0.412599	D15（0.0036696）	0.046793	0.004587	0.8
				D16（0.011396）	0.116253	0.011396	1
				D17（0.00779）	0.079472	0.00779	1
				D18（0.013686）	0.139612	0.013686	1
				D19（0.005427）	0.09227	0.00945	0.6
				D20（0.0037098）	0.06377	0.006183	0.6
				D21（0.008078）	0.065403	0.008078	1
				D22（0.006122）	0.049566	0.006122	1
				D23（0.009693）	0.13086	0.016155	0.6
				D24（0.0112512）	0.113873	0.01464	0.8
				D25（0.0127902）	0.172599	0.021317	0.6
				D26（0.0063948）	0.0863	0.010658	0.6
				D27（0.0111342）	0.150256	0.018557	0.6
A3(0.146815）	0.342081	B5(0.08813）	0.432172	D28（0.0074232）	0.075128	0.009279	0.8
				D29（0.0073458）	0.09932	0.012243	0.6
				D30（0.0042192）	0.056937	0.00732	0.6
				D31（0.01928）	0.204962	0.01445	0.8
				D32（0.005923）	0.083981	0.005921	0.6

Criterion layer	Relative weight	Subcriterion layer	Relative weight	Index level	Relative weight	Absolute weight	Evaluation result
1	2	3	4	5	6	7	8
				D33（0.00921）	0.097966	0.00697	0.8
				D34（0.007898）	0.083981	0.005921	0.8
				D35（0.010663）	0.09075	0.006395	1
				D36（0.00995）	0.10581	0.007459	0.8
				D37（0.00806）	0.114281	0.00857	0.6
		B6(0.058685）	0.2133025	D38（0.010156）	0.143985	0.010151	0.6
				D39（0.00699）	0.074331	0.00524	0.8
				D40（0.01445）	0.246213	0.008679	0.8
				D41（0.00821）	0.139897	0.004931	0.6
				D42（0.0037）	0.0639	0.002224	0.8

Source: Made by the author

Xinyu City circular economy development experience, problems and suggestions

Fig. 2.7. Xinyu Industrial Park Topographic Map

Source: Made by the author

Beneficial experience: Since launching the circular economy pilot, Xinyu High-tech Zone has targeted three major enterprises: Xinsteel, new petrochemical, and Xinyu Thermal Power. Leveraging a solid industrial base and abundant solid waste resources, it addresses the district's challenges of traditional industries, heavy chemical enterprises, and environmental governance. Through urban, environmental, and high-tech parks, supported by ecological industrial, livable, and protection zones, the zone promotes circular economy key projects, extending steel, petrochemical, power, and environmental protection chains. A circular industrial system has emerged, facilitating shifts from traditional heavy industry to modern systems, from single heavy chemical industry to ecological and livable urban functions, and from linear to circular and sustainable development. This pilot explores a viable path for heavy chemical industry cluster parks' transformation through circular economy, creating a model relevant to traditional multi-industry cluster parks seeking similar transitions.

(1) Adhere to government leadership and strive to improve the mechanism for promoting work

Since the pilot, Xinyu High-tech Zone has given full play to the leading role of the government and the advantages of large enterprises in the area such as new steel and new petrochemical, and taken the development of circular economy as a major strategic measure to promote the transformation and upgrading of Xinyu High-tech Zone, and established a circular economy pilot coordination leading group with the participation of the district Party Committee, the main leaders of the district government, the leaders of large enterprises in the district and the heads of relevant departments. Established circular economy Office, large enterprises office and circular economy development center and other circular economy permanent work organizations; Highlighting the leading role of planning, China International Consulting Corporation, Xinyu University, Nanchang University, Jiangxi University of Science and Technology and other experts have been hired to prepare the circular economy Development Plan of Xinyu High-tech Zone, the Circular Economy Pilot Implementation Plan of Xinyu High-tech Zone, and the Industrial Development Plan of Circular Economy Industrial Park in High-tech Zone. To guide the comprehensive and orderly implementation of the pilot work on circular economy; In view of the complex nature and different sizes of enterprises in the zone, through the establishment of a circular economy coordination mechanism covering the whole region with multi-subject participation of government and enterprises and clear division of responsibilities, we strive to break through the traditional management system of segmentation, and constantly strengthen the links between the government and key enterprises, between the government and the park, between enterprises and the park, and between enterprises and enterprises. The whole region took joint actions around the development goal of circular economy, formed a joint work force, and gradually formed a working mechanism for government-enterprise coordination to promote the development of circular economy under the pattern of "small government and large enterprises".

(2) Adhere to the leading drive, and strive to build a circular industrial system

In recent years, Xinyu High-tech Zone based on the resources of high-tech zone, with new steel, new petrochemical and high-tech zone thermal power and other large enterprises as the main body, with project construction as the carrier, with industrial chain as the link, in iron and steel, petrochemical, electric power and other industrial fields to fully implement the circular production mode, initially formed a relatively complete three circular industrial system. First, the circular steel industry with New steel as the leader, the construction of gas and steam combined cycle power stations, dry and wet TRT, coke dry quenching, sintering flue gas desulfurization, sintering low-temperature waste heat power generation and water recycling and a large number of key energy conservation and emission reduction projects in the steel industry, gradually phasing out backward, high energy consumption equipment. Construction and formation of coking, smelting - by-product gas, waste heat and pressure - power generation, smelting - waste slag - new building materials, continuous casting, steel rolling iron oxide - steelmaking charge, magnetic materials, coking - coal tar, crude benzene - coking by-product deep processing, smelt-steel products - scrap steel - steelmaking, and other six iron and steel cycle industrial chain; Second, the recycling petrochemical industry takes the new petrochemical industry as the leader, speeds up the adjustment and upgrading of the industrial structure of enterprises, and builds a number of projects such as oil quality upgrading, sulfur recovery, catalytic CO incineration waste heat boiler technology transformation, low-temperature heat utilization of coking plants, and high-concentration sewage treatment stations to form refining - waste gas - sulfur - chemical products. 2 petrochemical cycle industrial chain, such as refining, gas and heating; Third, the recycling power industry is represented by the heat and power in the high-tech zone, and has implemented major projects such as the first phase of the 2×350MW cogeneration project, completed a number of energy saving and consumption reduction technology reforms such as the transformation of Unit 12 through the current, and constructed the formation of cogeneration - medium and low pressure steam - central heating, mobile heating, power generation - desulfurization gypsum - building materials and decorative materials. Power generation - fly ash - building materials (aerated concrete blocks, commercial concrete, etc.) three power cycle industry chain.

(3) Adhere to the main body of enterprises and strive to promote the horizontal coupling of industries

During the pilot period, Xinyu High-tech Zone, with the goal of improving the efficiency of resource and energy utilization and reducing waste discharge, actively promoted the cooperation between large enterprises in the region, and promoted the exchange and utilization of industrial waste and recycling combination. Xinyu High-tech Zone encourages cooperation among large enterprises such as new steel, new petrochemical and high-tech thermoelectric zones to promote the exchange and utilization of industrial waste. In recent years, the exchange and utilization of products and by-products between these large enterprises has been rapidly developed. During the pilot period, the secondary resources such as waste heat, pressure and gas generated by the three major enterprises of new steel, new petrochemical and high-tech zone met the production needs of enterprises themselves, and the exchange and utilization of secondary resources and energy among large enterprises also started rapidly. In order to realize the co-construction and sharing of regional resources and energy, New Steel and New petrochemical jointly invested 150 million yuan to build a medium pressure nitrogen pipeline, and provide 30 million standard cubic meters of surplus nitrogen prepared by New Steel Oxygen Company to new petrochemical every year. In addition, the high-tech zone thermal power and new petrochemical also jointly invested 78.14 million yuan, laying a total length of 7,620 meters of industrial central heating pipeline, the thermal power production of steam to the new petrochemical plant, to solve the new petrochemical oil quality upgrade after the production gas gap, to avoid the repeated construction of low energy efficiency self-use boiler investment. The implementation of these cooperation projects not only realizes the sharing and efficient use of resources and energy, but also reduces waste emissions and energy waste. These experiences can provide reference for other traditional multi-industry heavy chemical industrial parks and promote the development of their circular economy.

(4) Adhere to the integration of industry and city, and strive to build characteristic industrial parks

Since the pilot, Xinyu High-tech Zone has re-planned and adjusted the spatial layout of the city and the industrial agglomeration area in accordance with the requirements of the development of circular economy. In order to better promote the development of circular economy, the high-tech zone has integrated the industrial parks in the east to form a circular economy industrial park with a total area of 44.01 square kilometers, which is the largest industrial park in Xinyu City. In the past two years, Xinyu High-tech Zone has been guided by new industrialization, relying on the advantages of eastern industrial parks such as Workers' Village Urban Industrial Park, North Lake Industrial Park, Ship equipment Manufacturing Industrial Park and energy conservation and environmental protection Technology Industrial Park, and further improving the basic supporting facilities of North Lake Industrial Park. At the same time, in accordance with the goal of "building 10 square kilometers of industrial demonstration park", with the focus on energy conservation and environmental protection and the construction of Marine equipment manufacturing industrial park, the construction of roads and municipal infrastructure such as "four vertical and four horizontal, four villages, one station and one station" has been increased. These measures promoted the formation of the spatial development pattern of "two districts, three parks and seven clusters", and built the circular economy industrial park of "one district and four parks". This pattern aims to create a circular economy industrial park composed of multiple parks and clusters to promote the recycling of resources and sustainable development of the industry. Through these planning and construction, Xinyu High-tech Zone circular economy Industrial Park will become an intensive, efficient and sustainable industrial park, and make positive contributions to promoting the economic development and industrial upgrading of Xinyu City and its surrounding areas.

(5) Adhere to project support, and strive to consolidate the foundation of circular development

According to the requirements of the state to promote the pilot work of circular economy, Xinyu High-tech Zone vigorously promotes the construction of key projects of circular economy, and ensures that a number of key projects of circular economy are completed and put into operation on schedule. During the pilot period, Xinyu High-tech Zone established and updated 135 major district level circular economy project libraries with a total investment of 70.6 billion yuan in 8 categories, including comprehensive utilization of solid waste resources, energy conservation and emission reduction, sewage treatment, research and development and manufacturing of environmental protection equipment, remanufacturing, integration of public works, circular economy capacity building and ecological environment construction. On this basis, the high-tech zone has invested 19.91 billion yuan for the construction of 87 major circular economy projects and key projects. These projects include Xinsteel 360 square meters sintering machine flue gas desulfurization unit, gas steam cycle power station (CCPP), blast furnace gas residual pressure power generation (TRT), dry quenching coke, benzene hydrogenation, sulfur recovery, industrial port sewage treatment and reuse, 1.2 million tons of slag powder. These projects not only help reduce energy consumption and pollutant emissions, but also provide important support for the development of circular economy in Xinyu High-tech Zone. The completion and operation of these key projects not only help to improve the efficiency of resource utilization and reduce waste discharge, but also provide an important carrier and support for the development of circular economy in Xinyu High-tech Zone. These experiences can provide reference for other regions to develop circular economy.

(6) Adhere to the participation of all people and strive to create an overall atmosphere for circular development

Xinyu High-tech Zone in the circular economy pilot work, always adhere to the demonstration pilot as the leading, and constantly deepen the concept and practice of circular economy. Pilot work has been comprehensively carried out at the three levels of parks, enterprises and the whole society, forming a good atmosphere to jointly promote the development of circular economy. As a pioneer in Xinyu City, Xinyu High-tech Zone has conducted pilot exploration in many fields, such as "plastic limit", household waste classification and treatment, waste batteries and waste electrical appliances recycling, public bicycle rental, urban mineral resources trading and energy-saving lamp promotion. These pilot works not only help to promote the development of circular economy, but also provide beneficial reference for Xinyu to build a two-oriented society and beautiful Xinyu.

While promoting the pilot work of circular economy, Xinyu High-tech Zone also pays attention to ecological construction and environmental protection. In accordance with the development goal of building "new high-tech zones suitable for ecological work and living", the "three major transformations" of old cities, run-down areas and villages in cities have been accelerated. These renovation works have achieved remarkable results, providing a better living environment for residents of the high-tech zone. During the pilot period, Xinyu High-tech Zone also reformed the old industrial zone shantytowns. Up to now, the first phase of the shantytown renovation project of the High-tech zone has been basically completed, and two housing communities with a total area of 595,300 square meters, Linjiang Harbor and Qingyi Residence, have been built, and 7,865 sets of housing have been placed. A total of 11,142 shanty town residents scattered around large enterprises moved into new homes, accounting for 81.3% of the total number of shanty town residents resettled. This model provides useful experience and reference for the old industrial zone shantytown reconstruction. Through these efforts, Xinyu High-tech Zone has achieved remarkable results in the pilot work of circular economy, and has made positive contributions to promoting the sustainable development of the whole district and even the whole city.However, Although Xinyu High-tech Zone has achieved remarkable results in the development of circular economy, it still faces some difficulties and challenges：

(1) The problem of heavy industrial structure is still deep-rooted in some regions

Although heavy chemical industries such as steel and petrochemical have made great contributions to the country's development over the past decades, their high proportion has also brought many challenges. These heavy industries consume a great deal of energy, and the pressure on the environment is also considerable, resulting in the development of energy conservation and environmental protection industry is limited. At present, the scale of energy conservation and environmental protection industry is relatively small, and it has not yet become a pillar leading industry. What is more serious is that this kind of heavy industrial structure has led to a series of problems such as unreasonable allocation of resources, environmental pollution and ecological damage. A lot of resources are used for heavy chemical industry, and other environmental industries that need these resources are difficult to obtain adequate support. At the same time, emissions from the heavy chemical industry have also created a serious burden on the environment and are contrary to the country's sustainable development goals. Therefore, the problem of heavy industrial structure is not only a problem of economic structure, but also a major problem related to the future sustainable development of the country. We must attach great importance to gradually adjusting the industrial structure and promoting green economic development.

(2) Although some progress has been made in improving resource output, the overall performance of the region is still lagging behind the leading domestic level

This gap shows that there is much room for improvement in resource use and productivity. For steel enterprises such as New Steel, although the energy consumption of its steel products is at an advanced level in China, it is still slightly higher than the advanced level of foreign countries. This further highlights that enterprises still need to work hard in energy conservation and emission reduction to achieve energy consumption standards in line with international standards. This is not just a technical or equipment problem, but more of a systemic challenge. Enterprises need to carry out comprehensive optimization and improvement from the production process, technology research and development, management and other aspects. At the same time, the government and relevant departments also need to give more support and guidance to promote enterprises to accelerate technology upgrading and industrial transformation to achieve more efficient and environmentally friendly production methods.

Therefore, in the face of the gap between the resource output rate and the domestic leading level and the problem that the energy consumption of enterprises such as New steel is slightly higher than the advanced level of foreign countries, we need to face the challenge, actively seek solutions, and promote the whole region and enterprises to make greater progress in energy conservation and emission reduction.

(3) In terms of the utilization of industrial waste, most enterprises are still in the primary and low-end stage at present

This situation limits the effective use of resources and the overall development of the industry. In order to achieve more efficient resource recycling, it is necessary to break down the barriers between enterprises, industries and regions, and promote the circular flow of resources in a wider range.

The large-scale utilization of waste slag such as steel slag and sintering desulphurization slag is an important technical bottleneck. Although there are already some technical means for treating these wastes, the efficiency and effect of these technologies still cannot meet the needs of large-scale and cost-effective utilization. Therefore, the research and development of new technologies and methods to improve the utilization efficiency and effect of waste slag is the field that needs to be broken through. In addition, the degree of industrial correlation and recycling of the park also need to be improved. At present, the enterprises in the park have not formed a close industrial relationship, resulting in the recycling of resources limited. In order to improve the overall competitiveness of the park, it is necessary to strengthen the cooperation and exchanges between enterprises, promote the cooperation between the upstream and downstream industries, and form a complete industrial chain. At the same time, it is also necessary to improve the degree of recycling of the park, build a complete circular economy system, and realize the maximum utilization of resources.

(4) The slow gathering speed of related industries also restricts the formation of the overall competitive advantage of the industrial chain

In order to enhance the agglomeration effect of industry, it is necessary to strengthen policy guidance and market promotion, encourage enterprises to gather in specific regions and form industrial clusters. At the same time, it is also necessary to strengthen the integration and optimization of the industrial chain, enhance the overall competitive advantage, and promote the rapid development of the industry. In short, the problems in the utilization of industrial waste, the degree of recycling in the park, and industrial agglomeration require the joint efforts of the government, enterprises and all sectors of society to strengthen technological innovation, policy guidance, cooperation and exchange, and promote the sustainable development of the industry. Xinyu High-tech Zone is indeed facing some challenges and difficulties in the development of circular economy. Among them, the relatively weak statistical foundation is an obvious problem. Due to the lack of comprehensive and accurate data support, it is difficult to conduct in-depth analysis and evaluation of the operation status, development trend and problems of circular economy. This not only affects the scientific decision-making, but also restricts the further development of circular economy.

In addition, the system related to green assessment has not yet been fully established. Although there are some evaluation indexes and systems, there are still many problems in practice, such as ununified evaluation standards and unscientific evaluation methods. This leads to inaccurate and unreliable evaluation results, which in turn affects the promotion of green development. In terms of capacity building of circular economy, Xinyu High-tech Zone still has a long way to go. Enterprises' awareness and attention to circular economy need to be improved, and relevant technology research and development and application also need to be strengthened. Only through continuous technological innovation and industrial upgrading can the overall level of circular economy be improved. The service system and publicity and education also need to be strengthened. At present, the service system related to circular economy is not perfect enough, and enterprises lack effective guidance and support. At the same time, the public's knowledge and understanding of circular economy is relatively limited, which affects the promotion and application of circular economy to a certain extent.

To sum up, Xinyu High-tech Zone still needs to overcome difficulties and obstacles in the development of circular economy, such as weak statistical basic work, imperfect green assessment and evaluation system, insufficient circular economy capacity building, imperfect service system and inadequate publicity and education. Only by comprehensively strengthening the work in these aspects can we promote the sustainable development of circular economy and make greater contributions to the high-quality development of Xinyu City.To this end, after comprehensive research and analysis, this paper proposes the following countermeasures and suggestions：

(1) Support high-tech zones to seize policy opportunities for circular economy development.

In order to support Xinyu High-tech Zone to seize the policy opportunity of circular economy development, we should deeply understand and actively respond to the major measures of promoting circular economy in the country. The Circular Economy "Ten Hundred Thousand" Demonstration Initiative is a strategic plan aimed at accelerating the development of a circular economy, promoting the efficient use of resources and environmental protection. A series of incentive and support policies recently issued by the state have provided valuable opportunities for the development of Xinyu High-tech Zone. These policies aim to encourage and support regions and enterprises that meet the requirements of circular economy development to achieve coordinated development of economy and environment through technological innovation, industrial upgrading and mode transformation.

After Xinyu High-tech Zone successfully approved the national "Implementation Plan for Circular Transformation of the Park" in 2012, the district has obtained a certain basis and experience for circular economy development. On this basis, Xinyu High-tech Zone should continue to thoroughly implement national policies, strengthen communication and cooperation with the relevant departments of the state and provinces and cities, and actively strive for more policy support and resource tilt. In terms of resource utilization, Xinyu High-tech Zone should pay attention to improve the efficiency of resource utilization and promote the reduction, resource utilization and harmless treatment of waste. Through the introduction of advanced technology and equipment, optimize the production process and management mode, reduce energy consumption and material consumption, and maximize the utilization of resources. In terms of remanufacturing industry, Xinyu High-tech Zone should make full use of the existing industrial base and advantages to cultivate and develop the remanufacturing industry. Through strengthening cooperation and exchanges with domestic and foreign remanufacturing enterprises and research institutions, the introduction of advanced remanufacturing technology and concepts to promote the rapid development of the remanufacturing industry.

In summary, Xinyu High-tech Zone should firmly grasp the policy opportunity of promoting the development of circular economy, make full use of the guidance and support of national policies, strengthen its own capacity building, and promote economic transformation and upgrading. Only in this way can we achieve catch-up and inject new impetus into the high-quality development of Xinyu City.

(2) Accelerate the construction of "Xinyu City Mineral Resources" circular economy demonstration zone.

In order to accelerate the construction of "Xinyu City Mineral" circular economy demonstration zone, we need to take a series of measures to promote the rapid development of circular economy. After several years of construction, the construction of "Xinyu City Minerals" large circular economy demonstration zone has begun to take shape, which has laid a solid foundation for future development. At present, the member units in the demonstration zone have a high enthusiasm for the development of circular economy, which provides a strong driving force for promoting circular links and symbiotic disasters among industries. However, in order to achieve cross-enterprise, cross-industry, cross-industry and cross-administrative recycling of resources, it is necessary to further strengthen cooperation and coordination.

In order to accelerate the construction of the great circular economy demonstration zone, it is suggested to conduct in-depth research and formulate specific implementation opinions on the existing basis. This will help to clarify the future development direction and goals, while providing specific guidance and support for member units. In the process of implementation, the member units of the "Two places and three districts" are encouraged to actively break through development obstacles and strengthen cooperation and exchanges while promoting the development of local circular economy. By building a service platform to promote resource sharing and technological innovation, we can achieve a situation of "group development and multi-party win-win". This will help to enhance the competitiveness and influence of the entire demonstration area, and jointly build a big brand of Xinyu two-type social reform experiment.

To sum up, accelerating the construction of "Xinyu City Mineral" circular economy demonstration zone is an important measure to promote the sustainable economic and social development of Xinyu City. By strengthening policy support, technological innovation and cooperation and exchanges, it is believed that Xinyu can realize the rapid development of circular economy and make contributions to the sustainable development of the city and even the whole country.

(3) Support Xinyu High-tech Zone to accelerate the development of emerging industries such as energy conservation and environmental protection

Supporting the Xinyu High-tech Zone to accelerate the development of emerging industries such as energy conservation and environmental protection is of great significance for promoting regional economic transformation and upgrading and sustainable development. As a strategic emerging industry supported by the state, the energy conservation and environmental protection industry has huge market potential and development space. In order to support the Xinyu High-tech Zone to accelerate the development of emerging industries such as energy conservation and environmental protection, it is proposed to formulate a series of implementation opinions from the provincial and municipal levels to clarify the industrial development goals, key areas and policy measures. These implementation suggestions should include the following aspects:

Policy support：We will increase support for energy conservation and environmental protection industries through fiscal, taxation, financial and other policy means. Set up special funds to provide financial support to qualified enterprises and projects; We will implement preferential tax policies to reduce the tax burden on enterprises. We will guide financial institutions to increase credit for energy conservation and environmental protection industries.

Industrial planning：We will formulate plans for the development of energy conservation and environmental protection industries, and clarify the direction and key areas of industrial development. Guide enterprises to increase investment in technology research and development and product innovation, and enhance the core competitiveness of the industry. At the same time, strengthen exchanges and cooperation with advanced regions at home and abroad, introduce advanced technology and management experience, and promote industrial upgrading.

Platform construction：Support the construction of energy conservation and environmental protection industrial parks in Xinyu High-tech Zone and build an industrial agglomeration area. Through the construction of a public service platform, we provide enterprises with technology transfer and transformation, intellectual property protection, financing support and other services. We will strengthen cooperation with universities and research institutions and promote the integrated development of industry, education and research.

Marketing：Encourage enterprises to actively participate in energy conservation and environmental protection exhibitions, forums and other activities at home and abroad to expand brand influence. Support enterprises to carry out international cooperation, explore international markets, and enhance international competitiveness. At the same time, strengthen the mining of domestic market demand, improve the relevant standard system, and promote the wide application of energy-saving and environmental protection products.

Talent training：Strengthen the construction of talents in the field of energy conservation and environmental protection, and train a number of high-quality professionals. Universities and training institutions will be encouraged to offer relevant professional courses to improve the quality of personnel training. At the same time, through the introduction of overseas high-level talents and teams, to provide intellectual support for industrial development.

In summary, through provincial and municipal policy support, industrial planning, platform construction, market promotion and personnel training measures, Xinyu High-tech Zone is expected to speed up the development of emerging industries such as energy conservation and environmental protection, making these industries become pillar industries with obvious competitive advantages, and injecting new impetus into the sustainable development of regional economy.

(4) Support the establishment of green assessment and evaluation mechanism in high-tech zones

In order to support the establishment of green assessment and evaluation mechanism in Xinyu High-tech Zone and promote the transformation of the high-tech zone and large enterprises in the area, it is suggested to take measures in the following aspects: First, the objectives and principles of green assessment and evaluation should be clearly defined. Green assessment and evaluation should aim at promoting the sustainable development of high-tech zones and large enterprises in the area, follow the principles of science, objectivity and justice, and pay attention to the comprehensive evaluation of resource utilization, environmental protection and ecological restoration. Secondly, develop green assessment index system. According to the actual situation of the high-tech zone and the characteristics of large enterprises in the area, specific green assessment and evaluation indicators are formulated, such as resource consumption, pollutant emission, ecological restoration, etc. Through the establishment of a scientific and reasonable index system, enterprises are guided to improve environmental awareness, strengthen internal management, and achieve green development. Thirdly, establish the mechanism and process of green assessment and evaluation. Establish and improve the organizational structure and work flow of green assessment and evaluation, and clarify the division of responsibilities and evaluation procedures. At the same time, the dynamic monitoring and data acquisition system is established to ensure the accuracy and timeliness of data. In addition, the supervision and evaluation of green assessment should be strengthened. Establish an effective supervision mechanism to track and supervise the whole process of green assessment and evaluation. Regularly carry out evaluation work, dynamically adjust the green assessment evaluation indicators, and ensure the scientific and fair evaluation results. Finally, strengthen policy support and guidance. We will increase support for green development through fiscal, taxation, financial and other policy means. For enterprises or projects with outstanding performance in green assessment and evaluation, preferential policies and incentive measures will be given to encourage more enterprises to participate in green development.

To sum up, the establishment of green assessment and evaluation mechanism is an important measure for Xinyu High-tech Zone to achieve transformation. The implementation of measures such as clear objectives, setting indicators, establishing mechanisms, strengthening supervision and evaluation, and strengthening policy support will help promote the high-tech zone and large enterprises in the area to enter the track of rapid development of green, low-carbon circular economy, and achieve coordinated development of economy and environment.

Conclusion of Chapter 2

In this chapter, we have conducted a comprehensive analysis of the development of cluster circular economy, with a particular focus on the case of Xinyu High-tech Zone in Jiangxi Province. The study begins by constructing a robust evaluation index system for cluster circular economy development, which serves as the foundation for our subsequent analyses. This system is designed to capture the multifaceted nature of circular economy development, encompassing economic, resource, and environmental dimensions. By utilizing principal component analysis and other statistical methods, we ensure that the indicators are both comprehensive and non-redundant, providing a clear and accurate picture of the development status.

Our empirical research, grounded in benchmarking management, delves into the practices and outcomes of Xinyu High-tech Zone in pursuing circular economy development. This case study not only highlights the successful strategies employed by the zone, such as government leadership, industrial system building, and enterprise-centered industry coupling, but also identifies the challenges faced, including a heavy industrial structure and low-end industrial waste utilization. These insights offer valuable lessons for other regions seeking to adopt circular economy models.

Furthermore, we have conducted a thorough analysis of the development path evolution of cluster circular economy. This analysis reveals the internal laws and driving forces shaping the development trajectory, from ecological support towards the "3R" direction (Reduce, Reuse, Recycle) to the evolution of economic and social forces. By constructing a regional circular economy development path evolution model, we provide a tool for visualizing and understanding these complex processes. The model's significance lies in its ability to clarify abstract laws, facilitate objective data collection and analysis, and offer guidance for policymakers in crafting effective circular economy strategies.

Finally, we propose a system evaluation model and standard for assessing the actual effect and development level of cluster circular economy. This model integrates the evaluation index system, data sources, and evaluation criteria, ensuring a comprehensive and rigorous evaluation process. By applying this model to Xinyu

High-tech Zone, we identify both beneficial experiences and main problems, and offer countermeasures and suggestions for further improvement. Our findings suggest that breaking down barriers between enterprises, industries, and regions, and promoting the circular flow of resources on a wider scale, are crucial for achieving more efficient resource recycling and overall industry development.

In summary, this chapter contributes to the understanding of cluster circular economy development through a comprehensive evaluation system, empirical research, path evolution analysis, and system evaluation model. These studies not only provide theoretical support but also offer practical guidance for promoting the realization of circular economy in Xinyu High-tech Zone and beyond. As academic leaders in this field, we hope our work can inspire further research and practice in circular economy development, contributing to a more sustainable and resilient future.

CHAPTER 3. XINYU CITY CIRCULAR ECONOMY DEVELOPMENT PROBLEMS AND SUGGESTIONS

3.1. Analysis on the evolution of circular economy development path in Xinyu High-tech Zone

Using the analytic hierarchy process, this section briefly analyzes the circular economy in Xinyu High-Tech Zone. As a complex system, understanding its operation requires examining both the whole and individual subsystems. With evolving theory and practice, we summarize the general and specific laws governing its development. By establishing an evolution model, we aim to provide theoretical support and practical experience for circular economy development in Xinyu High-Tech Zone and beyond.

The evolutionary model of Xinyu High-Tech Zone's circular economy, guided by sustainable development, aims to record its development stages and clarify this path quantitatively. By combining comprehensive evaluation results, we accurately summarize its development law and predict future paths. Based on Chapter 5's discussion, Figure 2.1 presents the circular economy development path evolution model of Xinyu High-Tech Zone.

The evolution model of Xinyu High-Tech Zone's circular economy development path reflects the trajectory of spatial points over time, characterizing its evolution. Each point in the model represents a circular economy development index at a specific time, using three coordinates in a sub-quadrant. This study examines 2013-2022, with the ten-year path symbolized by the spatial trajectory of 10 points in the model.

Table 3.1 outlines the evaluation index system for regional circular economy development, including economic (B1), resource (B2), and environmental (B3) indices. Figure 2.2 illustrates how these indices correspond to model axes (X for B1, Y for B2, Z for B3). This establishes a link between the evaluation system and the development path evolution model. To calculate model coordinates, original data is standardized using the range transformation method.

Table 3.1

Indicators weights on the X, Y, and Z axes

Alignment layer	Exponential level	weight
1	2	3
X	Gross Domestic Product (D1)	0.1657
	Gross Domestic Product per capita (D2)	0.0623
	Industrial value added per capita (D3)	0.0859
	Proportion of added value of resource recycling industry to added value of industrial park (D4)	0.1263
	Household Consumption Level (D5)	0.0529
	Value added of Primary Industry (D6)	0.0879
	Value added of Secondary Industry (D7)	0.0722
	Value-added of Tertiary Industry (D8)	0.1172
	Number of new ecological industry chain projects after the implementation of the construction plan (D9)	0.1036
	Comprehensive Utilization Rate of Industrial Solid Waste (D10)	0.0552
	Renewable Resource Recovery Rate (D11)	0.0705
Y	Energy consumption per 10,000 yuan GDP (D12)	0.1036
	Energy consumption per 10,000 yuan of industrial added value (D13)	0.0562
	Water consumption per 10,000 yuan GDP (D14)	0.0705
	Water consumption per 10,000 yuan of industrial added value (D15)	0.0567
	Industrial value added per unit of Industrial Land Area (D16)	0.0336
	Three-year Average Annual Growth Rate of Industrial Value Added per Unit of Industrial Land Area (D17)	0.0417
	Comprehensive energy consumption elasticity coefficient (D18)	0.0438
	Energy consumption per unit of industrial added value (D19)	0.1163
	Proportion of renewable energy use (D20)	0.0795
	Fresh water consumption elasticity coefficient (D21)	0.0196
	Fresh water consumption per unit of industrial added value (D22)	0.0923
	Industrial Water Reuse Rate (D23)	0.0631
	Water reuse rate (D24)	0.0139
	Urban sewage treatment rate (D25)	0.0726
	Proportion of rural land (D26)	0.0863
	Proportion of construction land (D27)	0.0503
Z	General Industrial Solid Waste generation (D28)	0.0654
	Total Wastewater discharge (D29)	0.0476
	Industrial wastewater discharge D30)	0.1308
	Industrial Emissions (D31)	0.1139
	Sulfur Dioxide Emissions (D32)	0.0326
	Industrial sulfur Dioxide Emissions (D33)	0.0863
	Nitrogen oxide emissions (D34)	0.0503
	Industrial nitrogen oxide emissions (D35)	0.0751
	Dust Emission (D36)	0.0991

	Industrial Dust Emissions (D37)	0.0569
	Proportion of environmental pollution investment in total investment (D38)	0.03126
	Industrial pollution control investment as a proportion of total investment (D39)	0.1033
	Green coverage rate of built-up area (D40)	0.0426
	Forest cover (D41)	0.03271
	Grassland coverage (D42)	0.03213

Source: Made by the author

The study calculates data and index weights for each dimension of Xinyu High-Tech Zone's circular economy evolution model. Coordinates of space points for specific time points reflect the circular economy's status. From 2013 to 2022, annual X, Y, and Z axis indices were computed based on weight tables, as shown in Table 3.2.

Table 3.2

Data distribution of economic development (X-axis), resource development (Y-axis) and environmental development (Z-axis) of Xinyu High-Tech Zone from 2013 to 2022

exponent / Year	**Economic Development Index (X-axis)**	**Resource development Index (Y-axis)**	**Environmental Development Index (Z-axis)**
1	2	3	4
2013	0.47759	0.50425	0.53090
2014	0.55825	0.62362	0.68891
2015	0.62624	0.70267	0.77911
2016	0.70267	0.49348	0.28428
2017	0.77691	0.84569	0.91447
2018	0.85132	0.91790	0.98448
2019	0.92564	0.99011	0.75458
2020	0.86331	0.86233	0.86135
2021	0.94792	0.73454	0.52116
2022	0.83253	0.80675	0.78097

Source: Made by the author

From 2013 to 2022, the economic, resource, and environmental development indices of Xinyu High-Tech Zone were calculated, revealing changes in each area during this period.

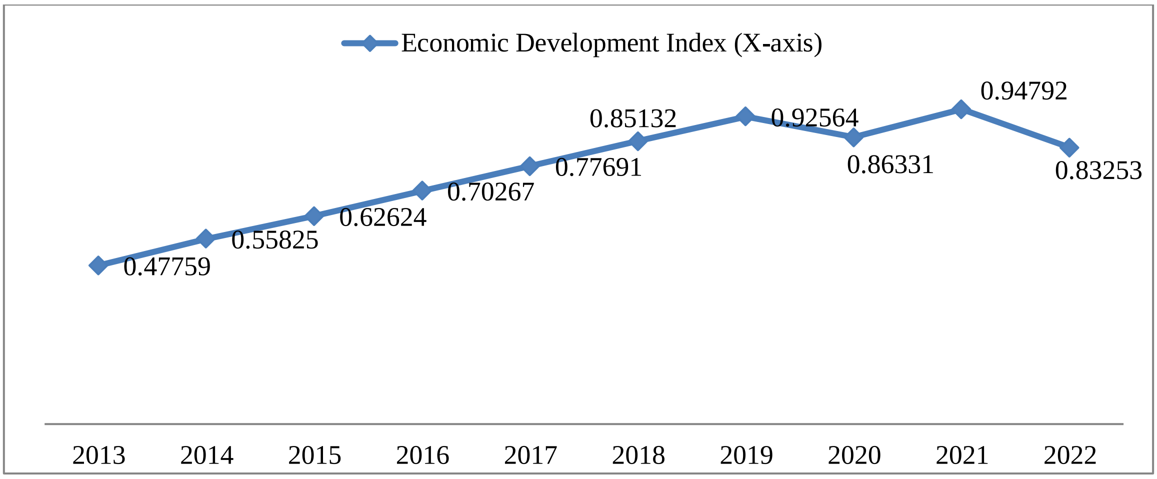

Fig. 3.1. Change of economic development index of Xinyu High-tech Zone

Source: Made by the author

Figure 3.1 shows that Xinyu High-tech Zone's economic development index rose overall from 2013 to 2022, with faster growth early on and slower recently. Between 2013-2014, it grew by 17%, and 2018-2019 saw an 8.7% increase. From 2017-2022, there were fluctuations, with peaks in 2019 (0.92564) and lows in 2013 (0.47759), indicating significant economic growth over the decade.

Based on recent data, Xinyu High-Tech Zone's economic development is expected to remain high but with slower growth. Vigilance is needed against potential economic fluctuations or challenges.

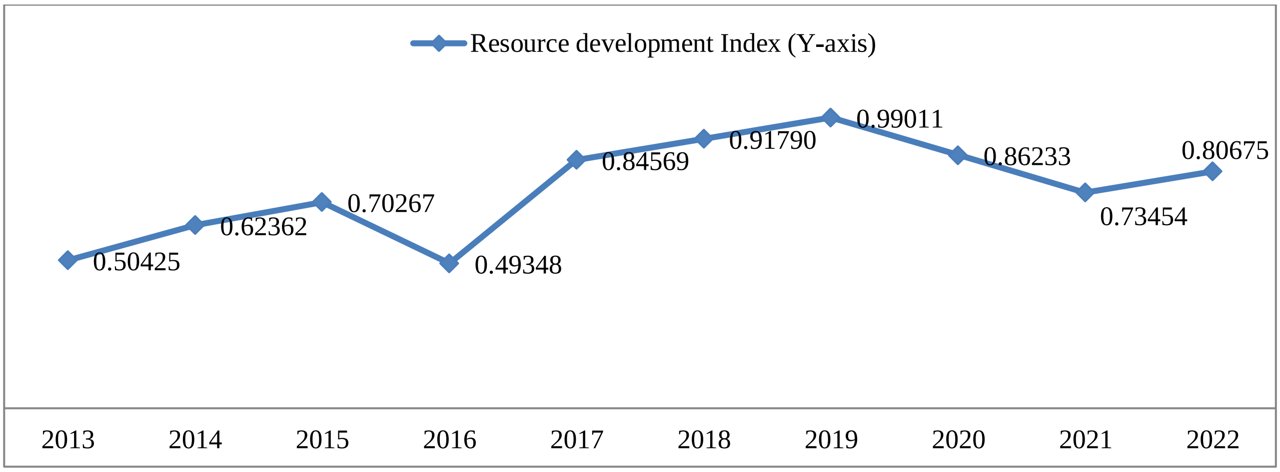

Fig. 3.2. Change of resource development index in Xinyu High-tech Zone

Source: Made by the author

Figure 3.2 shows the resource development index fluctuated from 2013 to 2022, overall trending upwards. It peaked at 0.99011 in 2019 and bottomed at 0.49348 in 2016. From 2013 to 2018, it rose, indicating strengthened activities. Since 2019, it declined but rebounded in 2020 and 2022, remaining below 2019's peak. This suggests challenges or policy adjustments. Fluctuations indicate impact from market demand, policy, and the natural environment. Thus, the industry must maintain a stable strategy to cope with external challenges.

Given recent data, resource development activities are expected to grow but may face challenges and uncertainties. Thus, close attention to market dynamics and policy changes is crucial for formulating reasonable strategies.

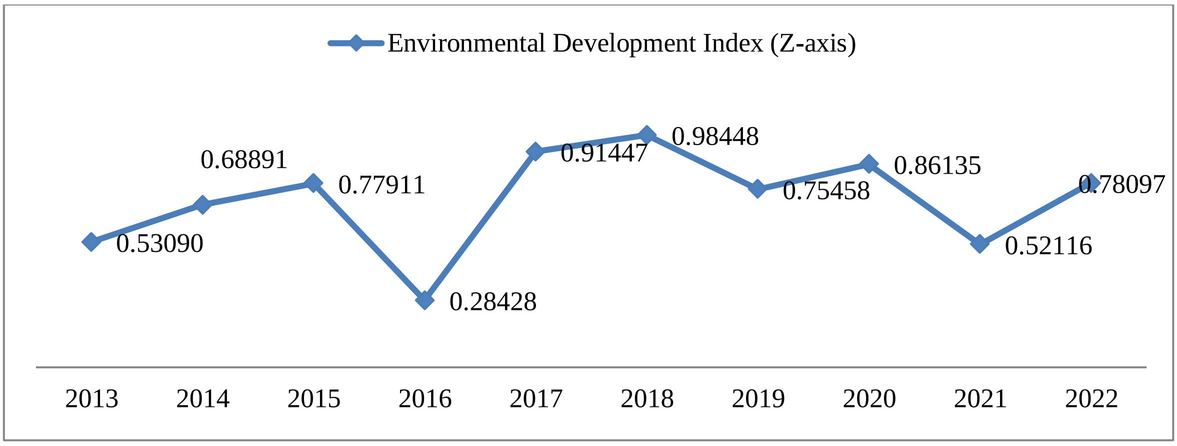

Fig. 3.3. Change of environmental development index of Xinyu High-tech Zone

Source: Made by the author

Figure 3.3 shows the environmental development index significantly rose from 2013 to 2018, peaking at 0.98448 in 2018, indicating strong efforts in environmental protection and sustainable development. The index dipped to 0.75458 in 2019 but recovered in 2020 and 2022, yet remains below 2018's peak. Fluctuations suggest ongoing challenges and uncertainties in environmental protection and sustainable development.

Based on this decade's data, the future environmental development index is likely to remain high but may face fluctuations and challenges. Thus, strengthening environmental protection and sustainable development efforts, while addressing external challenges, will be crucial for the environmental field.

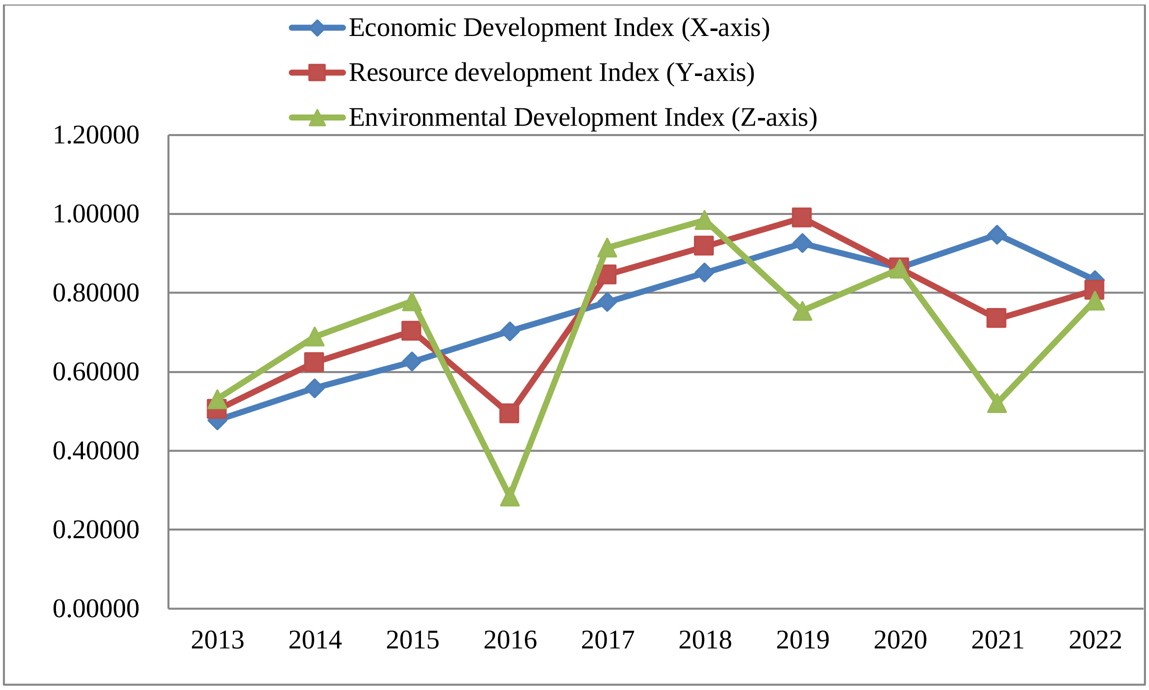

Fig. 3.4. Changes of economic, resource and environmental development index of Xinyu High-tech Zone

Source: Made by the author

As can be seen from Figure 3.4, from 2013 to 2022, the three major indexes experienced ups and downs, but on the whole showed a growth trend. This shows that in the past decade, the economy, resources and environment have all developed, but at different speeds and with different intensities.

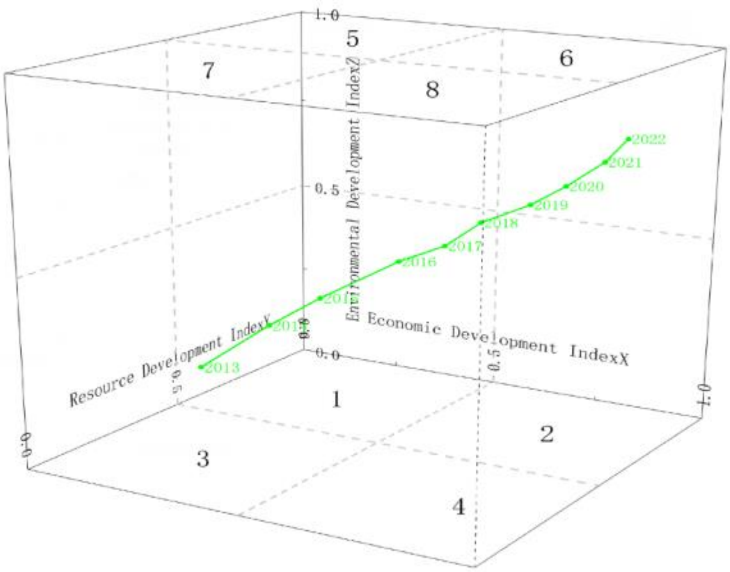

Figure 3.5. Development path and evolution path of circular economy in Xinyu High-tech Zone

Source: Made by the author

The economic development index significantly increased from 0.47759 in 2013 to 0.83253 in 2022, despite a slight decline in 2016. The resource development index peaked at 0.91790 in 2018 but fell later, recovering in 2021 before declining again in 2022. The environmental development index rose until 2017 but declined to a 10-year low of 0.52116 in 2021, recovering slightly in 2022. These fluctuations indicate impacts from economic growth and resource exploitation on environmental development.

Figure 3.4 shows the economic development index has significantly increased over the past decade, indicating strong growth. In contrast, the resource and environmental development indices peaked and declined, suggesting the need for balanced economic development with sustainable resource use and environmental protection.

The benchmarking of circular economy development in industrial clusters includes enterprise-level benchmarks, eco-industrial park-level benchmarks and social benchmarks. Its characteristics are as follows:

Benchmarking at enterprise level: In developed countries, circular economy practices primarily emerged spontaneously in enterprises like 3M, DuPont, and Xerox in the US. These multinational leaders, leveraging abundant capital, mature technology, and world-class talent, foresaw resource and environmental constraints, enabling small-scale circular economy initiatives. However, theoretical discussions were limited, mainly focusing on enterprise technology exploration.

In 1975, Joseph Lim of 3M's environmental division introduced the "Pollution Prevention Benefits" program, the first comprehensive company-wide approach to pollution elimination starting from production design. It encourages technicians to improve manufacturing to prevent hazardous waste and reduce costs, through product redesign, process changes, equipment replanning, and waste reuse/recycling.

In the late 1980s, DuPont, ranked 23rd among the world's largest companies, tested circular economy ideas in its factories. They adapted the 3R principle into a "3R manufacturing method" focusing on resource reduction, utilization cycles, and waste reuse/recycle for less or zero emissions. By eliminating harmful chemicals, reducing usage, and innovating recycling processes, they reduced plastic waste by 1994. Air emissions fell by 70%, resources were efficiently used, and they developed new products from recycled plastics like durable ethylene materials.

Xerox excels in product ecological management, covering environmental impact assessments across the product lifecycle, including manufacturing, product, and after-sales service. They maximize asset utilization through "Design for the Environment" principles and waste minimization programs.

Benchmarking of eco-industrial park level: Ecological industrial parks, based on circular economy and industrial ecology principles, are new industrial organizations that gather ecological industries. They adhere to the 3R principles of reduction, reuse, and recycling, aiming to minimize waste by using by-products from one factory as inputs for another. Through waste exchange, recycling, and clean production, factories achieve "zero emission" of pollutants within the park.

(1) Denmark's Kalenburg Industrial Symbiosis, the world's earliest ecological industrial park, formed in the 1970s. It consists of a power plant, oil refinery, pharmaceutical factory, and gypsum board plant. Waste or by-products from one enterprise are used as inputs for another, creating a network that reduces waste generation and treatment costs while enhancing product quality and economic benefits, fostering a virtuous cycle of economic development and environmental protection.

(2) The US is a pioneer in ecological industrial parks, with projects emerging since the 1970s supported by the EPA and PCSD. These projects focus on bioenergy, waste treatment, clean industry, and recycling. In 1994, four communities were designated as eco-industrial park demonstration sites. The US government established a special working group under PCSD to study the transition from theoretical models to practice. Today, nearly 60 eco-industrial parks exist in the US, including Chattanooga, Choctaw, and virtual Brownsville parks.

(3) Canada initiated a study on eco-industrial parks' ecological characteristics in 1992, launching the "Ecosystem and Industrial Parks" project in Bonside. Since 1995, Toronto's Portland Industrial Area has also embarked on an eco-industrial park project involving numerous manufacturing and service enterprises through waste and energy exchange. Currently, Canada has about 40 eco-industrial parks, nine of which exhibit strong eco-industrial traits and development potential.

(4) Japan initiated plans in 1997 to construct ecological industrial parks, aiming

to foster a resource-recycling society. These parks emphasize recycling while leveraging regional industrial strengths, nurturing environmental protection industries, introducing technology, and strictly managing waste discharge. Kitakyushu Ecological Industrial Park stands out by integrating "industrial revitalization" and "environmental protection," leveraging the city's industrial infrastructure, technologies, and resources. Government, research institutions, businesses, and citizens' networks have contributed significantly. Yamanashi and Fujisawa Ecological Industrial Parks are also notable. By October 2004, Japan had approved 23 such parks.

(5) Other countries have also made strides. Developed European nations like Austria, Sweden, Ireland, the Netherlands, France, Finland, the UK, and Italy have seen rapid advancements. Recognizing their industrial lag and pollution issues, developing countries have emulated these successes, planning and upgrading eco-industrial parks. India, Indonesia, Thailand, the Philippines, Malaysia, Namibia, and South Africa are among those initiating eco-industrial park projects.

(6) China's ecological industrial park development began late, in the late 1990s. It emerged as the third-generation industrial park after traditional and high-tech parks. In 1999, China piloted ecological industrial park demonstration zones, starting with Guiguang National Ecological Industry (Sugar Industry) Demonstration Park in Guangxi. Other provinces followed suit. In 2006, the State Environmental Protection Administration introduced three standards for ecological industrial parks. In 2007, a joint notice was issued to promote ecological transformation in national development zones. Today, large-scale parks like Guiguang, Nanhai in Guangdong, and Baotou Aluminum Factory in Inner Mongolia are well-established. In 2015, China's Ministry of Environmental Protection issued standards for national ecological industrial demonstration parks, detailing evaluation methods and indicators. By 2020, China had 104 state-level high-tech zones and 133 economic and technological development zones, with 71 planned national eco-industrial demonstration parks, of which 48 were approved.

Social benchmarks: The German Dual System Deutschland (DSD) is a prominent urban circular economy model. Germany's 1986 "Waste Management Law" established producer responsibility for the product lifecycle. This dual-track recycling system, managed by a specialized NGO, collects and processes waste packaging into recycled materials or new products for manufacturers. The DSD has greatly improved packaging waste recycling in Germany, with 210 workshops annually sorting 2.5 million tons of light packaging. Its "green mark" system is now adopted by 22 European countries.

Japan's model for establishing a circular society focuses on three aspects: industrializing environmental protection ("vein" industry), developing eco-friendly "artery" industry, and balancing material flow between them. The vein industry, key to Japan's circular society, involves waste recycling parks for packaging, household appliances, construction waste, food, automobiles, and related technology R&D. Japan faces challenges with discarded appliances, such as TVs, washing machines, air conditioners, and refrigerators, totaling 18 million units (600,000 tons) annually, including 100,000 tons of recyclable metal. To address this, Japan implemented the "Home Appliance Recycling Law" in 2001, assigning responsibilities to producers, sellers, and consumers for efficient resource use. Producers recycle used appliances, sellers collect and send them to manufacturers, and consumers bear recycling, transportation, and recycling costs (3,500-4,600 yen per appliance, plus transportation fees). The law mandates recycling rates for TVs, washing machines, air conditioners, and refrigerators.

Brief introduction of industrial clusters in Xinyu High-tech Zone: Xinyu High-tech Industrial Development Zone, adjacent to Xinyu City, was established in 2001 and covers 266 square kilometers, with a developable area of nearly 100 square kilometers and a population of 160,000. In 2009, it became the first provincial industrial park with deputy department-level status in Jiangxi Province and was upgraded to a state-level high-tech zone by The State Council in 2010. Following the principle of "open, strong industrial, and active business," it aims to build a multifunctional, ecological, and modern industrial new urban area. Since its inception, the zone has focused on cultivating high-tech industries and achieved remarkable growth. It has ranked among the top industrial parks in Jiangxi Province since 2005, serving as the city's and province's window to the world, a growth pole for economic development, a leader in technological innovation, a base for labor and employment, and a key model for accelerating open economy development in the province. It is one of the most developed, vibrant, and promising industrial parks in Jiangxi.

(1) Industrial environment

The district boasts nearly 700 industrial enterprises, led by five key industries: lithium, photovoltaic, electronic information, intelligent manufacturing, and food & medicine. These form four industrial parks, attracting leading enterprises like Ganfeng Lithium, Mullinsen, Voge Optoelectronics, and more. Specifically, there are 129 lithium new energy enterprises, 230 intelligent manufacturing enterprises, 271 photoelectric information & new materials enterprises, and over 70 food & pharmaceutical enterprises, including numerous designated-size and high-tech firms. Additionally, photoelectric, power storage & new energy equipment, and iron & steel deep processing industrial parks have been established. The park's distinctive industrial characteristics have shaped a "big three small" new energy industry pattern, centered on the photovoltaic industry with supplementary power & energy storage batteries, wind power generation, and energy-saving & emission-reduction equipment industries.

The Photoelectric Industrial Park, anchored by LDK, has attracted numerous upstream and downstream enterprises. Its main products—high-purity silicon, silicon wafers, solar cells, and modules—reach capacities of 10,000 tons, 3,000 MW, and 500 MW, respectively. This has formed a comprehensive industrial chain and cluster, spanning from silicon material to solar energy application products. The park has been approved by national ministries and commissions to establish various bases and centers, including for national silicon materials and industrial applications, screw expansion engine high-tech industrialization, new industrialization demonstrations, and photovoltaic basic materials and application products quality supervision and inspection.

The Power Energy Storage Industrial Park, spanning 25 square kilometers, embraces circular economy principles. As a key component of Xinyu High-tech Zone, it specializes in power energy storage technology's R&D, production, and application. The park hosts numerous leading enterprises and R&D institutions in battery manufacturing, energy storage system integration, and intelligent charging. Xinyu High-tech Zone's Power Energy Storage Industrial Park has achieved notable industrial scale, forming a comprehensive industrial chain and cluster. It also actively introduces advanced domestic and international energy storage technology and equipment to bolster the industry's competitiveness and influence.

The New Energy Equipment Industrial Park spans 19 square kilometers, focusing on equipment maintenance, manufacturing, heavy engineering machinery, and metallurgical machinery processing. Leveraging the fine steel industry's growth, the park has introduced Shougang Mining Company's heavy machinery project, pioneering national technology. Additionally, several equipment maintenance and manufacturing enterprises serving steel production and utilizing steel as raw material have surged, becoming a pivotal industry in the region.

The Steel and Iron Deep Processing Industrial Park, covering 25 square kilometers, brings together numerous steel material producers. It focuses on processing and manufacturing steel raw materials to supply high-quality steel to downstream enterprises. Many steel product processors utilize these materials for diverse deep processing operations, producing steel in various shapes and sizes for construction, machinery, automobiles, and other industries.

The photoelectric industry dominates the industrial park, but extended industries lag. The downstream chain and terminal product supplementary chain require strengthening to facilitate industrial transformation. Enhancing the circular economy concept, boosting industrial integration, tightening inter-industry links, and introducing eco-friendly, low-pollution enterprises are necessary.

(2) Infrastructure

Since its establishment, the park has focused on enhancing industrial carrying capacity. It has invested over 3 billion yuan in land consolidation, roads, water supply, drainage, power, greening, and other infrastructure. By 2023, it spent 1.6 billion yuan on relocating 8 villages, gaining 7,720 mu of land. Another 510 million yuan funded 60km of main roads, while 200 million yuan was used for water pipelines, new road greening, lighting, and a 35kv power project, including lines 322, 521, and modifications to a 10kv line.

Xinyu City boasts abundant water resources, averaging 264.15 million cubic meters annually. Park water consumption includes production water for steel and coking enterprises, and domestic water for residents. Most obtain water from selfprovided wells. Xinyu Iron and Steel Plant consumes the most, averaging 330,000 m^3 annually from 5 wells.

The park has multiple substations, including 220kv, 110kv, and 34kv models, with 3 220kv substations totaling 1.25 million kW in capacity. Table 3-3 outlines the park's power consumption.

Table 3.3

Forecast of electricity consumption in Xinyu High-tech Development Zone

Classification of electricity consumption	Land area km^2	The indicator kW/ha is used	The predicted electricity consumption is 10,000 kW
1	2	3	4
Residential land	1.16	200	2.32
Land for public facilities	0.99	800	7.92
First class industrial land	0.29	200	0.58
Second class industrial land	17.77	300	53.31
Third-class industrial land	20.22	500	101.1
Land for external transportation	0.59	2	0.01
Road square land	4.11	2	8
Land for municipal public facilities	0.8	10	0.08
greenbelt	8.25	1	0.08

Source: Made by the author

The park adheres to national environmental standards, controlling pollutants and strengthening discharge permit management. High-pollution, high-energy projects are prohibited. Wastewater and noise are treated, while solid waste is classified for recycling or harmless disposal. Plans include setting up garbage transfer stations and cleaning points every 3-4 square kilometers, leading to landfill for domestic waste. Qian'an City Zhicheng Lubricating Oil Co., Ltd. invested 22.37 million yuan to build Hebei's first industrial hazardous waste treatment project, capable of treating 27 types of waste from major steel mills among 49 specified, for a total of 7,920 tons annually.

Typical enterprise cases of circular economy development in Xinyu High-tech Zone:

(1) Xinyu Iron and Steel Co., LTD

Renamed after the integration of Hongdu Steel Plant and Wushishan Iron Mine by Xinyu Iron and Steel Co., Ltd., it offers over 800 varieties and 3,000 specifications of steel products, including medium and thick plates, hot/cold rolled sheets, wire, rebar, strips, metal/chemical products. Adhering to "high level, starting point, and standard," Xinyu Iron and Steel focuses on process simplification, modern equipment, high-end production, cleanliness, and digital management. Utilizing advanced technology and equipment, such as blast furnaces, converters, refining furnaces, casting machines, and mills, the company produces 7.8 million tons of iron, 8 million tons of steel, 4 million tons of hot-rolled strip, and 1.2 million tons of cold-rolled silicon steel, forming its own product system with electrical steel as a key product.

New Steel Company focuses on internal resource recycling and wastewater treatment. Wastewater from each process is mainly reused in partial circulation and cascade systems. The company has two primary sewage treatment stations (1# and 2#) and one depth treatment station. After preliminary treatment, wastewater is discharged into these systems, with some reused in the raw material yard, blast furnace, steel mill, and greening. Dehydrated water from depth treatment can be used by all company users. Future plans include deep desalination of concentrated brine from the plant's deep water treatment station and cold rolling line wastewater. Treated brine will be mixed with incoming water and supplied to New Steel and Qian'an Zhonghua Coal Chemical Co., Ltd. as new water. Deeply desalted brine will be reused in blast furnace slag flushing and braising furnaces.

Second, New Steel Company enhances solid waste utilization by implementing a comprehensive treatment and recycling system. This includes steel slag crushing, purification, slag tank partitioning, tail slag brick production, fine powder production from blast furnace slag, and dust sludge treatment, ensuring comprehensive resource utilization.

Utilization of steel slag in converters follows centralized treatment and graded utilization principles. A production line for crushing, purifying, partitioning, and tail slag brick making has been established, enabling comprehensive utilization. High-quality steel slag (block steel >85%, bean steel >90%) is recycled for steel and iron making. Caviar steel (>60%) serves as sintering auxiliary materials. Tailings are used for road paving or brick making.

Utilization of blast-furnace slag: The company invested in four micro-powder production lines (2.7 million tons/year) to dispose of slag internally and obtain cement raw materials. Dust and mud resource utilization: Following the principle of reuse, a treatment line transforms waste dust and mud into resources for mining company use.

Considering current steel market demands, ordinary steel prices are low due to the macroeconomic climate, while demand for high-strength threaded steel, galvanized sheet, bearing steel, gear steel, and silicon steel in the park is limited, with some products unavailable. This hinders park steel industry development. Guided by circular economy principles, Shougang New Steel aims to be a modern, advanced steel company with top-tier management and environment, aiming for national steel automation leadership and becoming China's top hot-rolled sheet producer. Figure 3-6 shows the new steel industry's circular economy industrial chain planning.

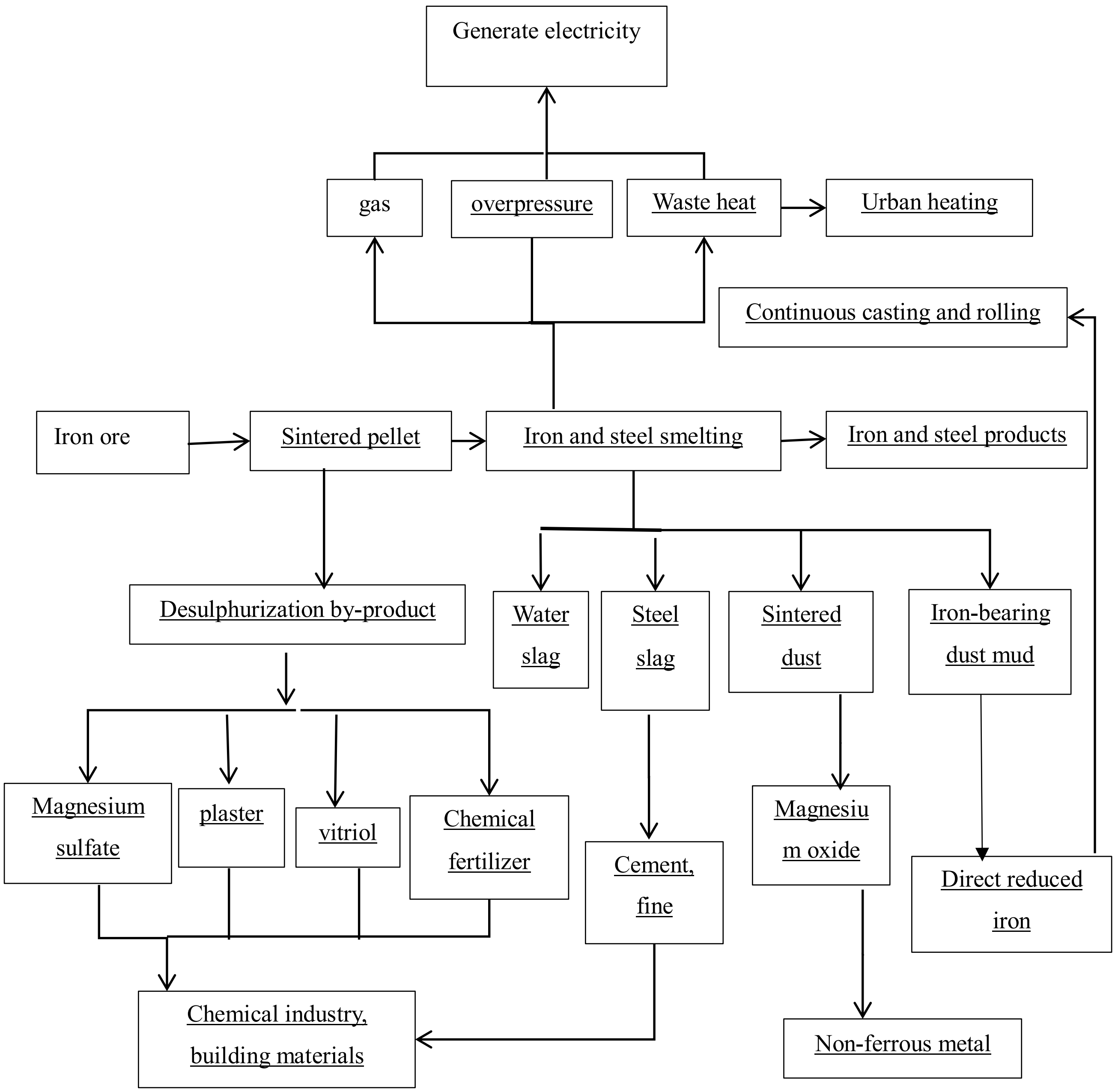

Fig. 3.6. Schematic diagram of circular economy industrial chain of new iron and steel industry

Source: Made by the author

(2) Xinyu Jinhua Coal Chemical Co., LTD

Founded in 2009, the company covers 1.021 million sqm, with a 2014 annual coke output of 3.3 million tons and output value of 4.075 billion yuan. It integrates production, supply, and marketing, leading China's production technology. Its technical and economic indicators, along with management level, are top in the industry. Adhering to 'advanced, applicable, reliable, eco-friendly, and economical' principles, the company uses advanced equipment and mature technology, aligning with coking industry trends.

The company closely collaborates with the new steel company, producing coal coke as its main product and transferring metallurgical coke via belt conveyor. Excess gas is supplied to the new steel company via pipelines, while auxiliary products like coke powder are sold externally. Chemical by-products like tar, crude benzene, ammonium sulfide, and gas are also produced and sold locally. Combining industrial chain, technological, and product advantages, the company has forged strong core competitiveness and significant industry advantages.

Xinyu Jinhua Coal Chemical Company reuses production waste through:

Industrial waste disposal by recycling tar residue and biochemical sludge back into coking processes; and industrial waste gas treatment by utilizing coke oven gas for combustion in heating processes and industrial dust removal.

Third, industrial wastewater treatment at Qianan Sinochemical Company involves recycling it for wet quenching coke and replenishing water after phenol cyanide treatment. The company adopts dry quenching and gas desulfurization technologies: dry quenching recovers coke sensible heat to produce clean energy electricity, used for steel removal to enhance energy efficiency; gas desulfurization reduces gas sulfur content, with sulfur products utilized by downstream enterprises. Currently, the park's coal chemical industry focuses on coking, aligned with its steel industry-based strategy. Existing enterprises can introduce new coal gasification or liquefaction as development directions, ensuring steel enterprises' energy needs while pursuing coal gasification and liquefaction projects. Based on market demand, various coal chemical primary and deep-processed products are produced, serving as final products like liquid fuel and gasoline, or raw materials for pesticides, pharmaceuticals, photographic materials, and chemical fibers, expanding the park's market space. Figure 3-7 outlines the coal chemical industry's circular economy industrial chain planning.

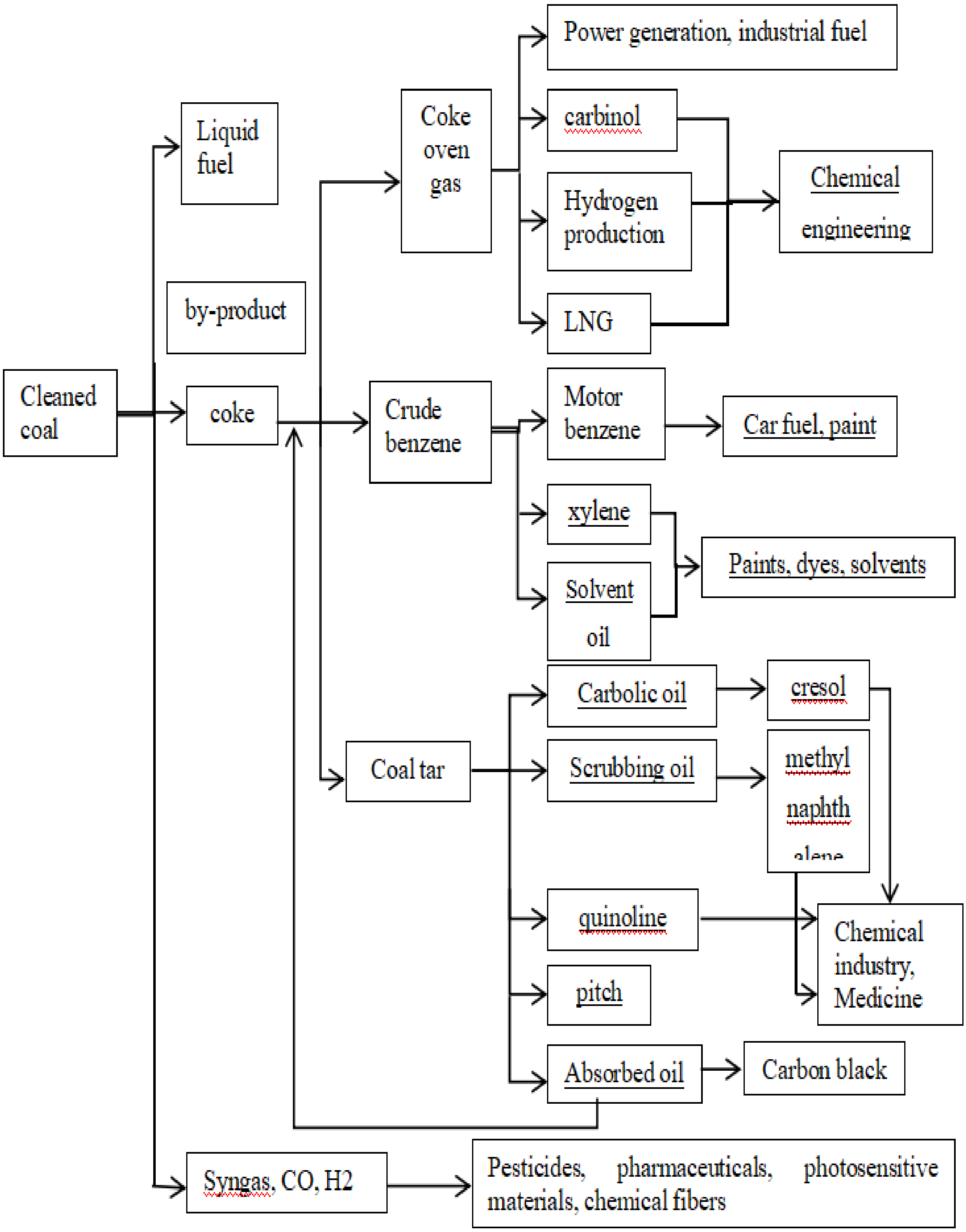

Fig. 3.7. Schematic diagram of circular economy industrial chain of coal chemical industry

Source: Made by the author

Based on the above cases, it can be seen that benchmarking plays a crucial role in Xinyu's circular economy practice. The following virtuous circle is formed：

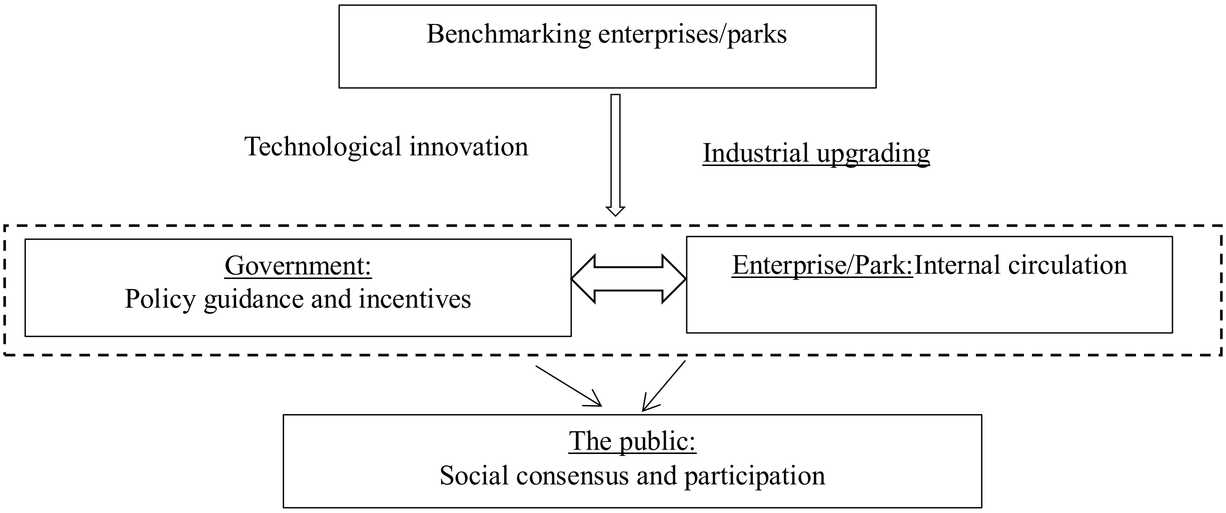

Figure 3.8. Clarification of the role of benchmarking in Xinyu's circular economy practice

Source: Made by the author

First of all, benchmarking provides Xinyu enterprises with clear goals and improvement directions by finding and studying the best practices of first-class companies in their peers. For example, Xinyu Iron and Steel Company through benchmarking management, the introduction of waste heat power generation equipment, to achieve efficient recycling of blast furnace gas, not only reduce environmental pollution, but also significantly improve economic benefits, become a model of circular economy in the industry. Benchmarking promotes Xinyu enterprises to learn and adopt advanced technologies and management models to promote technological innovation and industrial upgrading. It not only improves the efficiency of resource utilization, reduces energy consumption and emissions, but also promotes the cultivation and development of emerging industries, such as photovoltaic, new materials, and optimizes the industrial structure. Based on the results of benchmarking management, the Xinyu Municipal government has formulated relevant policies, such as setting up special funds for energy conservation, encouraging enterprises to implement environmental protection measures, etc., in order to guide and encourage enterprises to develop circular economy. These policies provide strong support for the implementation of urban sustainable development strategies. Benchmarking not only promotes the development of circular economy at the enterprise level, but also enhances the public's awareness of environmental protection and sustainable lifestyle through demonstration effects. This will help create a good atmosphere for the whole society to participate in sustainable development. Benchmarking encourages Xinyu City to pay attention to systematic planning and resource integration in circular economy practice, such as building "internal microcirculation of enterprises" and "large industrial circulation of the park", improving the utilization level of resources and energy, reducing production costs, and achieving a win-win situation of economic and environmental benefits.

In terms of optimizing resource utilization and improving utilization efficiency, Xinyu High-tech Zone companies have adopted a number of strategies in optimizing resource utilization. For example, through the implementation of waste heat power generation project, Xinyu Iron and Steel Company has successfully realized the efficient recovery and utilization of blast furnace gas, which not only reduces greenhouse gas emissions, but also significantly improves energy utilization efficiency. In addition, some enterprises in Xinyu City have also reduced energy consumption and improved production efficiency by introducing advanced energy-saving technologies and equipment, such as high-efficiency motors and energy-saving lamps. In terms of improving the efficiency of resource utilization, for example, the recycling industry of renewable resources in Xinyu City has realized the efficient recycling and utilization of waste materials by building a sound recycling network system. At the same time, some enterprises have also improved the comprehensive benefits of resource utilization by implementing circular economy models, such as scrap processing trade, industrial solid waste reduction and resource utilization.

Therefore, the following pattern has been formed in Xinyu High-tech Zone in terms of optimizing resource utilization and improving utilization efficiency (as shown in Figure 3.9)：

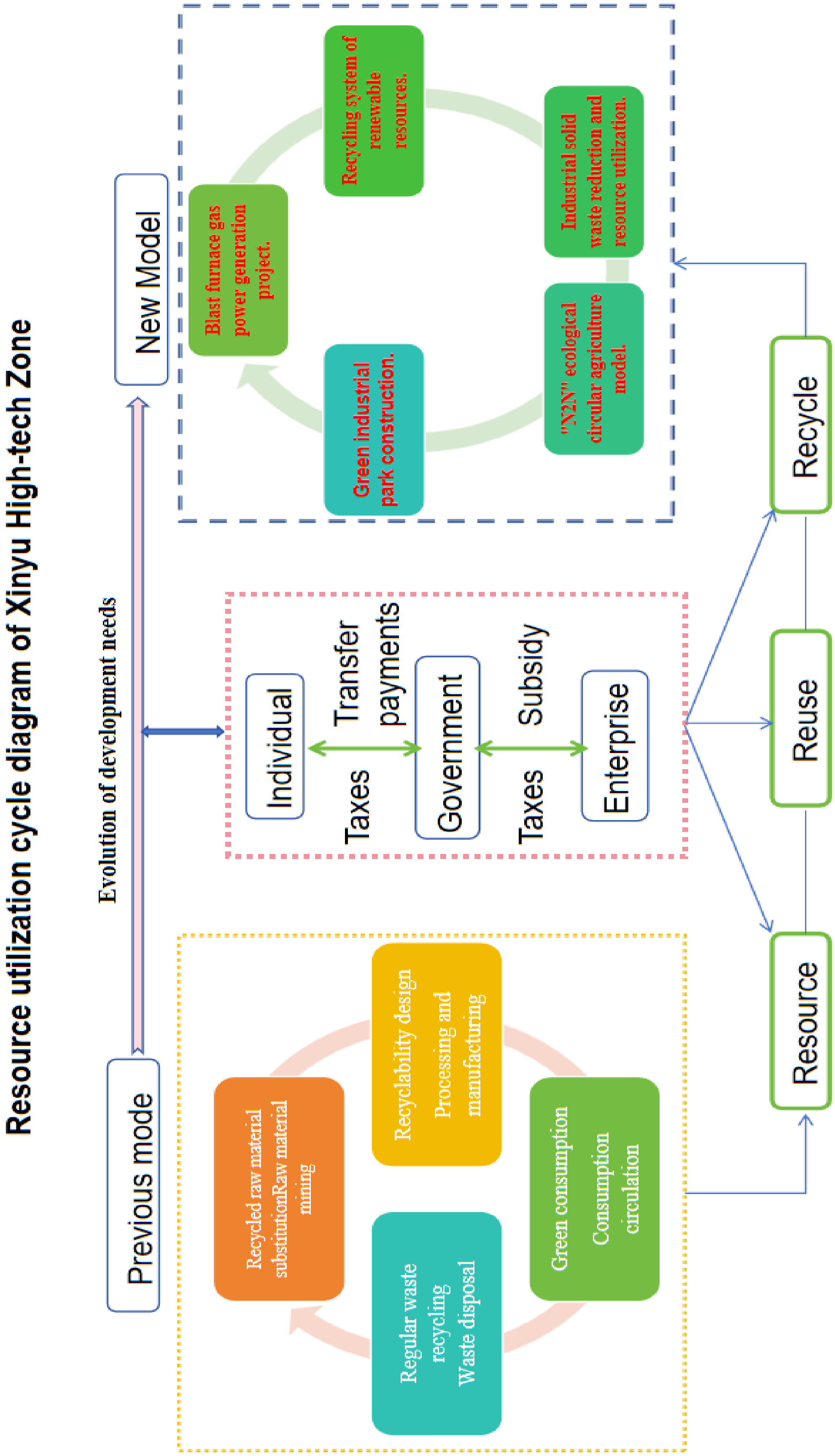

Figure 3.9. Resource utilization cycle diagram of Xinyu High-tech Zone

Source: Made by the author

At the same time, in the circular economy practice of Xinyu city, a series of innovative benchmarking models and practices have emerged, which have achieved remarkable results in optimizing resource allocation, improving resource utilization efficiency and reducing environmental pollution.

Blast furnace gas power generation project. Through the recycling of blast furnace gas for power generation, the project realizes the reuse of resources and reduces greenhouse gas emissions. Energy efficiency is improved, production costs are reduced, and new sources of income are provided for enterprises.

Recycling system of renewable resources. A perfect recycling network of waste materials has been built to realize the efficient classification, treatment and reuse of waste materials. It has significantly improved the efficiency of resource utilization, reduced the environmental pollution caused by landfill and incineration, and created a large number of employment opportunities.

Industrial solid waste reduction and resource utilization. Through technological innovation and process improvement, the production of industrial solid waste is reduced and the solid waste is transformed into reusable resources. It reduces the cost of solid waste treatment, improves the comprehensive utilization rate of resources, and promotes the development of circular economy.

"N2N" ecological circular agriculture model. This model realizes the positive cycle of agro-ecosystem through the combination of agriculture and animal husbandry, the return of straw to the field and the utilization of livestock and poultry manure. It has improved the utilization efficiency of agricultural resources, reduced the use of chemical fertilizers and pesticides, improved the rural ecological environment, and promoted the sustainable development of agriculture.

Green industrial park construction. In Xinyu industrial park, green production technology and environmental management concept have been promoted to realize the recycling of resources and the centralized treatment of pollutants in the park. It has improved the overall environmental quality of the industrial park, attracted more green investment and enterprises to settle in, and promoted the green development of the regional economy.

As an excellent enterprise performance management tool, benchmarking management has a positive and far-reaching impact on the economic competitiveness of Xinyu City. By learning from outstanding enterprises in the industry or outside the industry, enterprises in Xinyu can constantly find the gap between themselves and benchmark enterprises, and learn from their successful experiences, so as to improve their own business practices, improve operational efficiency, reduce costs, and ultimately improve economic performance. At the same time, circular economy practices have played a key role in Xinyu's efforts to balance economic growth with environmental sustainability. Circular economy emphasizes the recycling of resources, the reduction of environmental pollution and the improvement of economic benefits, which is highly consistent with Xinyu's pursuit of green and sustainable development goals. Through the implementation of circular economy, Xinyu has not only improved the efficiency of resource utilization and reduced production costs, but also promoted the development of green industries and injected new impetus into economic growth. At the same time, the practice of circular economy also helps to improve environmental quality, maintain ecological balance, and reduce excessive dependence on natural resources and environmental pollution. For example, Xinyu City has realized the recycling of resources and the effective treatment of pollutants by building a recycling system of renewable resources and promoting the reduction of industrial solid waste and the utilization of resources, providing a strong guarantee for the sustainable development of economy and society. This study evaluates how circular economy practices contribute to the balance between economic growth and environmental sustainability through the evaluation of industrial correlation degree of circular economy in Xinyu High-tech Zone.

Evaluation of industrial correlation degree of circular economy in Xinyu High-tech Zone: According to the general planning diagram of circular economy in high-tech zones (Figure 3-10), it can be seen that the product association (Lp) of industrial parks is 16, the industrial chain (Le) between industries is 11, and the total number of industries is 11.

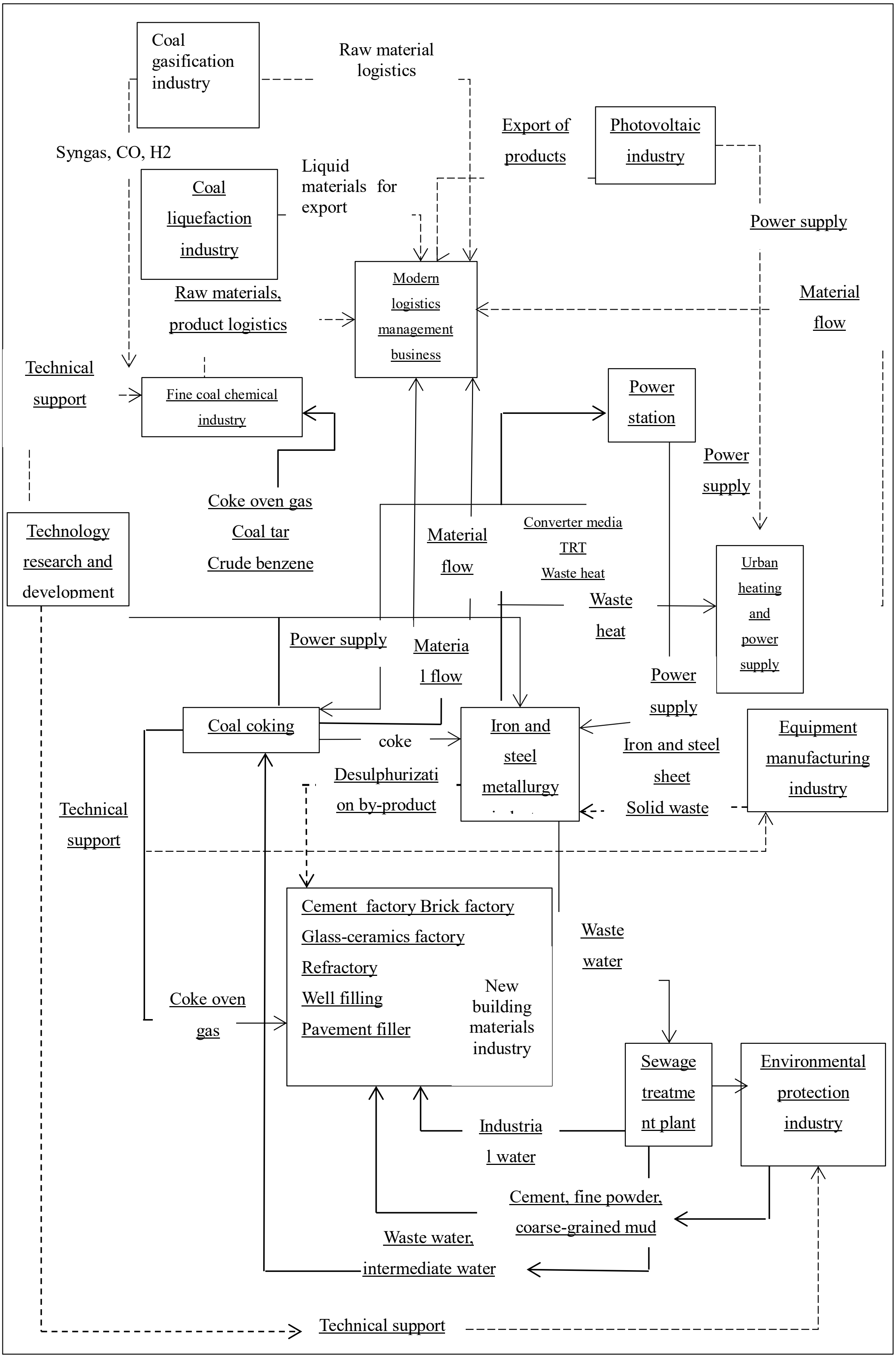

Fig. 3.10. Overall planning diagram of circular economy in high-tech zones

Source: Made by the author

According to the calculation formula of industrial park industrial correlation degree, the ecological industrial correlation degree among industries in Xinyu High-tech Park is as follows:

$$C_e = \frac{L_e}{S(s-1)} = \frac{11}{11\times(11-1)} = 0.1 \qquad (3.1)$$

The product correlation degree of Xinyu High-tech Park is:

$$C_p = \frac{L_e}{S(s-1)} = \frac{16}{11\times(11-1)} = 0.15 \qquad (3.2)$$

In Xinyu High-tech Zone, the product correlation degree (Cp) is 0.15, higher than the ecological industry chain correlation degree (Ce) of 0.10, resulting in a total correlation degree (Ct) of 0.25. This disparity is attributed to the zone's abundant natural resources, primarily iron ore, fine iron powder, washed coal, and limestone, fostering a dominant iron and steel metallurgy industry. Other industries closely align with this leading sector, forming a mature industrial park. The low Ce is due to internal digestion of sewage treatment, power generation, and environmental protection industries among enterprises. For instance, TRT residual pressure and waste heat power generation by Xinsteel, and coke oven gas power generation by Xinyu coal chemical industry, are solely for internal use. Similarly, some steel and coal chemical enterprises' sewage treatment is self-sufficient, lacking a unified park-wide sewage treatment system and environmental protection link. By-products and waste generated are too small-scale and limited in quantity for effective exchange and utilization within the park.

Fu Li and Chen Honghan (2011) calculated the total correlation degree of various industrial parks, referencing Kalenberg Ecological Industrial Park (Denmark, 1975-2007) and Choctaw Ecological Industrial Park (USA). To comprehensively assess China's industrial park correlations, this paper selects Kalenberg and Choctaw as foreign representatives, known for their circular economy success and typicality. It also includes Japanese Kokubo Industrial Park (Yamanashi), and Chinese parks in Nanhai (Guangdong), Guigang (Guangxi), Yueleang Bay (Fujian), and Lubei (Shandong). These foreign parks are frequently studied and characterized by diverse construction models: Kalenberg (spontaneous), Choctaw (new planning), and Kokubo (industry-school-government-people integration). Among the Chinese parks, besides the Qian'an case studied here, the other four are established, mature state-level ecological demonstration parks, reflecting China's general industrial park level. Table 3-4 presents the calculated industrial correlation degrees for each park.

Table 3.4

Industrial correlation index between Xinyu High-tech Industrial Park and domestic and foreign industrial parks

Nationality	Park name	Park type	Ct
1	**2**	**3**	**4**
Denmark	Karenburg Eco-Industrial Park (1975)	Enterprise consortium * Entity type	0.33
	Karenburg Eco-Industrial Park (1985)	Enterprise consortium * Entity type	0.27
	Karenburg Eco-Industrial Park (1995)	Enterprise consortium * Entity type	0.3
	Karenburg Eco-Industrial Park (2007)	Enterprise consortium * Entity type	0.36
America	Choctaw Ecological industrial park	Vein industry * Solid type	0.33
Japan	Kokubo Industrial Park in Yamanashi City	Comprehensive entity type	0.26
China	Shandong Lubei ecological Industrial Park	Industry (salt chemical) solid type	0.58
	Guangxi Guigang National ecological Industrial Park	Industry (sugar) entity type	0.21
	South China Sea National demonstration ecological Industrial Park	Comprehensive (environmental protection industry) entity + virtual type	0.17
	Moon Bay ecological Industrial Park	Entity type of enterprise association	0.29
	Xinyu high-tech Industrial Park	Enterprise combination type (energy electronic coal) entity type	0.25

Source: Made by the author

From Table 3.4, Xinyu High-tech Zone's total industrial correlation degree is 0.25. Compared to other Chinese parks, it surpasses Nanhai (0.17) and Guigang (0.21) but falls behind Yueleang Bay (0.29) and significantly under Lubei (0.58). When benchmarked against foreign parks like Choctaw (USA) and Kalenburg (Denmark), Xinyu High-tech Zone also lags, with lower degrees than Kalenburg (2007) (0.36) and Choctaw (0.33). In summary, Xinyu High-tech Zone has varying gaps in industrial correlation with both domestic advanced and foreign parks.

The table reveals that China's industrial parks generally have lower industrial correlation degrees compared to foreign ones. Yueleang Bay Ecological Industrial Park in China, similar to Karenburg in Denmark, has a lower degree (0.29 vs. 0.36). Guangxi Guigang's degree (0.21) is also lower than America's Choctaw Park (0.33). South China Sea National Demonstration Park's degree (0.17) falls below Japan's Kokubo Park (0.26). Field investigations confirm that Qian'an City's western industrial park has significant room for improvement in industrial correlation compared to developed countries.

3.2. Problems and prospects in the implementation of circular economy

Technical backwardness poses a significant bottleneck to regional circular economy development. Currently, China's circular economy technologies have considerable room for improvement, necessitating increased scientific and technological investment to drive progress and innovation.

Unreasonable energy structure: China's coal-based energy structure poses challenges to transitioning to circular economy. As the primary energy source, coal contributes significantly to carbon dioxide emissions, causing environmental issues like global warming, air, water, and land pollution. These problems threaten sustainable development and harm the global environment. Furthermore, coal use leads to resource waste and environmental destruction, hindering circular economy's emphasis on resource recycling and reduction. Implementing circular economy in coal mining and utilization is difficult due to the need for strong technical and financial support to address environmental issues simultaneously.

In summary, China's coal-based energy structure hinders its transition to a circular economy, imposing environmental strain and limiting further development. To facilitate regional circular economy, optimizing the energy structure, expanding clean energy, and reducing coal dependence are crucial. This necessitates collaborative efforts from government, enterprises, and society to bolster technological innovation and capital investment for energy structural transformation.

Over-exploitation of resources: Over-exploitation of resources poses a significant challenge to regional circular economy development. In pursuit of economic growth, China has faced high resource consumption and environmental pollution, leading to dwindling resource reserves and severe ecological damage. This not only threatens sustainable economic development but also impacts future generations. Over-exploitation also results in inefficient resource use and exacerbates resource supply-demand contradictions. Environmental destruction, including deforestation, soil erosion, land desertification, and biodiversity loss, further undermines ecosystems and human survival. To address this, the government must enforce strict resource management and environmental protection laws, promote sustainable resource use, and develop circular economy practices. Enterprises should adopt cleaner production and recycling technologies, while society should enhance environmental awareness and participation. Effective measures to strengthen resource management and environmental protection are crucial for sustainable resource use, ecological protection, and healthy regional circular economy development.

The deficiency of "hard law" guarantee of regional circular economy in China: From a new institutional economics perspective, institutions limit an agent's activity space, akin to a leash on a dog. Effective institutional design is crucial for agent behavior. Institutional support is vital for sustainable regional circular economy development. As formal systems, laws and policies play a pivotal role in safeguarding this development. Guided by the 18th National Congress report, China has vigorously promoted regional circular economy as a strategic priority. Existing laws like those on air and water pollution prevention, energy conservation, environmental protection, renewable energy, and clean production contribute positively. China has also signed international treaties and passed policies promoting regional circular economy, reflecting the government's commitment. However, challenges remain, including technological backwardness and a coal-based energy structure. Over-exploitation of resources poses significant pressure. Hence, there is no quick fix; China's regional circular economy is still in its nascent stage.

To overcome challenges and promote effective regional circular economy development, two strategies are key: enhancing eco-friendly and clean production technology, and strengthening legal frameworks. While technology growth and research projects are crucial, legal support is also vital, exemplified by amendments to the Energy Conservation Law. However, these "hard laws" often focus on supervision, legal scope expansion, and administrative coercion, neglecting market actors' will and market laws' compatibility. Experience shows that mandatory norms in "hard law" have limited effectiveness. In contrast, the subsequent "Clean Production Promotion Law" and "Circular Economy Promotion Law," with "soft law" attributes, offer valuable supplements, especially in sensitive and legislative bottleneck areas like environmental pollution, where national legitimacy is weakened.

Imperfect market mechanism: The development of circular economy relies on a well-functioning market mechanism for optimal resource allocation. However, current market mechanisms have flaws, such as information asymmetry, flawed pricing systems, and insufficient competition. Information asymmetry leads to uncertainty in market transactions, hindering resource utilization. The pricing system often ignores resource value and environmental costs, giving an unfair advantage to high-pollution products. Monopolies and administrative interventions further limit competition and resource efficiency, stifling innovation. To improve, measures must include enhancing information disclosure and supervision, revising pricing systems to include environmental costs, promoting fair competition, and encouraging cleaner production and resource recycling. Policies and international cooperation can also facilitate green industry growth and marketization of China's circular economy. In summary, addressing market mechanism flaws is crucial for circular economy advancement.

Insufficient public participation: The public plays a vital role in advancing circular economy, yet their awareness and participation remain low. Limited understanding stems from inadequate publicity and education, while engagement channels are narrow and lack diversity. To enhance public involvement, measures such as strengthening publicity, integrating circular economy education into schools, and providing diverse participation avenues are essential. These include encouraging community, business, and NGO activities like waste sorting, energy conservation, and green travel. Effective information feedback also boosts motivation. Addressing this issue is crucial for circular economy's sustainable development, aiming at resource conservation, environmental protection, and long-term growth. Industrial civilization's pursuit of efficiency has caused environmental issues, prompting recognition of circular economy as a harmonious, sustainable model ensuring economic progress without degrading natural resources.

Policy Support: Policy support is crucial for implementing the circular economy. Governments, as promoters, have provided significant policy backing through laws, regulations, and incentives. Future prospects for policy support are promising, with continued enhancements to promote sustainable circular economy development.

Firstly, governments will refine circular economy laws and regulations, clarifying responsibilities and regulating market behaviors to provide stronger legal guarantees. Enforcement against illegal activities will be intensified to combat resource waste and pollution, safeguarding market fairness and public interests. Secondly, financial support will increase, encouraging enterprises and the public to engage in circular economy practices through subsidies and tax incentives. Special funds for R&D and application of recycling, energy-saving, and emission-reduction technologies will be established. Tax breaks and subsidies for cleaner production and resource recycling enterprises, as well as for consumers of eco-friendly products, will stimulate market enthusiasm. Additionally, circular economy publicity and education will be strengthened, enhancing public environmental awareness and responsibility through various channels and activities, including school education. Governments will adopt scientific and democratic decision-making, seeking input from all parties, and will enhance international cooperation to draw on advanced experiences and technologies.

In summary, policy support remains vital for circular economy development. Future enhancements in legal frameworks, financial incentives, and public awareness will foster market enthusiasm, promote sustainable circular economy growth, and achieve a virtuous cycle of resource conservation, environmental protection, and economic and social development.

Technological innovation propels circular economy growth. Advances in science and technology enable new methods in resource utilization and environmental protection, offering vast potential for circular economy development. Waste reduction technology minimizes waste during production, enhances resource efficiency, and reduces environmental impact, as seen in clean production and process optimization. Waste resource utilization transforms waste into valuable resources through garbage classification, recycling, and reuse technologies, easing resource dependency and fostering economic growth. Energy recovery technology converts waste energy into usable forms, like waste heat recovery and solar utilization, aiding energy conservation and emission reduction. Future circular economy development hinges on technological breakthroughs. Governments, enterprises, and society must collaborate, invest in, and support innovation, enhancing public awareness and participation. International cooperation is crucial for addressing global resource and environmental challenges, jointly contributing to a sustainable planet. Thus, technological innovation is pivotal for circular economy progress, improving resource efficiency and waste management for sustainable development.

Market demand fuels the circular economy, escalating with consumers' heightened awareness of environmental protection and sustainable development. Future trends indicate:

Firstly, consumers increasingly prioritize eco-friendly and sustainable products, willing to pay more for those with lesser environmental impact. Hence, circular economy enterprises must focus on product sustainability to meet this demand. Secondly, green consumption will diversify, spanning daily goods, food, and transportation, offering broader market opportunities. Thirdly, government policies will bolster green markets through subsidies, tax incentives, and other measures, encouraging consumers and businesses to adopt green options.

As consumers' focus on environmental sustainability intensifies, market demand will remain a pivotal driver for circular economy growth. Enterprises must align with these trends, developing eco-friendly products and services to capture market share. Simultaneously, governments and societal sectors must enhance environmental awareness and action to collectively propel circular economy sustainability.

Social participation is crucial for circular economy development, offering support and momentum. Future prospects for social engagement broaden with heightened environmental awareness and circular economy advancements, evident in:

Firstly, broader environmental education integration into social systems. Schools, communities, and media will actively educate the public on environmental responsibilities and circular economy principles, fostering conscious participation. Secondly, social organizations will bridge government, enterprises, and the public, organizing environmental activities and promoting circular economy practices across sectors. Thirdly, enterprises will increasingly prioritize environmental responsibility and sustainable development, driving green transformations through innovation, recycling, and clean production. Fourthly, public involvement will escalate, with heightened participation in activities like garbage classification and energy conservation, providing vital support for circular economy growth.

Collectively, these efforts will foster a societal atmosphere conducive to circular economy engagement, promoting resource conservation, environmental protection, and socio-economic development. Enhanced cooperation among government and societal sectors will address global resource and environmental challenges, contributing to a healthier planet.

International cooperation: In globalization's context, international cooperation is crucial for circular economy development. It fosters resource and experience sharing, addressing global resource and environmental issues, and promoting sustainable development. Future prospects include: (1)Technological Innovation and Exchange: With circular economy advancements, countries will emphasize technological cooperation, jointly developing and applying advanced technologies. This will enhance resource utilization and environmental protection globally.(2)Policy Dialogue and Coordination: Governments will strengthen policy dialogue, formulating and implementing measures aligned with global sustainable development goals. This reduces trade and investment barriers, promoting circular economy cooperation and investment.(3)Capacity Building and Training: International cooperation will enhance national expertise through capacity building programs. Education and training will cultivate professionals, driving circular economy practice and innovation.(4)Demonstration Projects and Cooperation Platforms: Representative circular economy projects will share experiences and results, fostering technology and management innovation. Cooperation platforms will facilitate communication, resource integration, and coordinated development.(5)International Organizations and Multilateral Mechanisms: These entities will strengthen cooperation in circular economy, setting international standards and norms. They will help countries address global resource and environmental challenges, achieving sustainable development goals.

In summary, circular economy implementation faces challenges and opportunities. Governments, enterprises, and society must collaborate on policy, technology, market development, and social participation. Strengthening international cooperation is essential to tackle global resource and environmental issues, contributing to a better planet.

3.3. The model of the new circular economy model benchmarking

Currently, China is undergoing crucial industrial transformation and upgrading, with significant emphasis on the circular economy. However, our research and practice in this area are nascent, requiring time to mature. On the path of sustainable industrial cluster development through circular economy, China faces unique challenges, including system, policy, management, and technological issues. Thus, we must advance cautiously, grounded in national conditions and guided by reality. Therefore, this new economic development model is a new circular economic model and also an innovative economic development model.

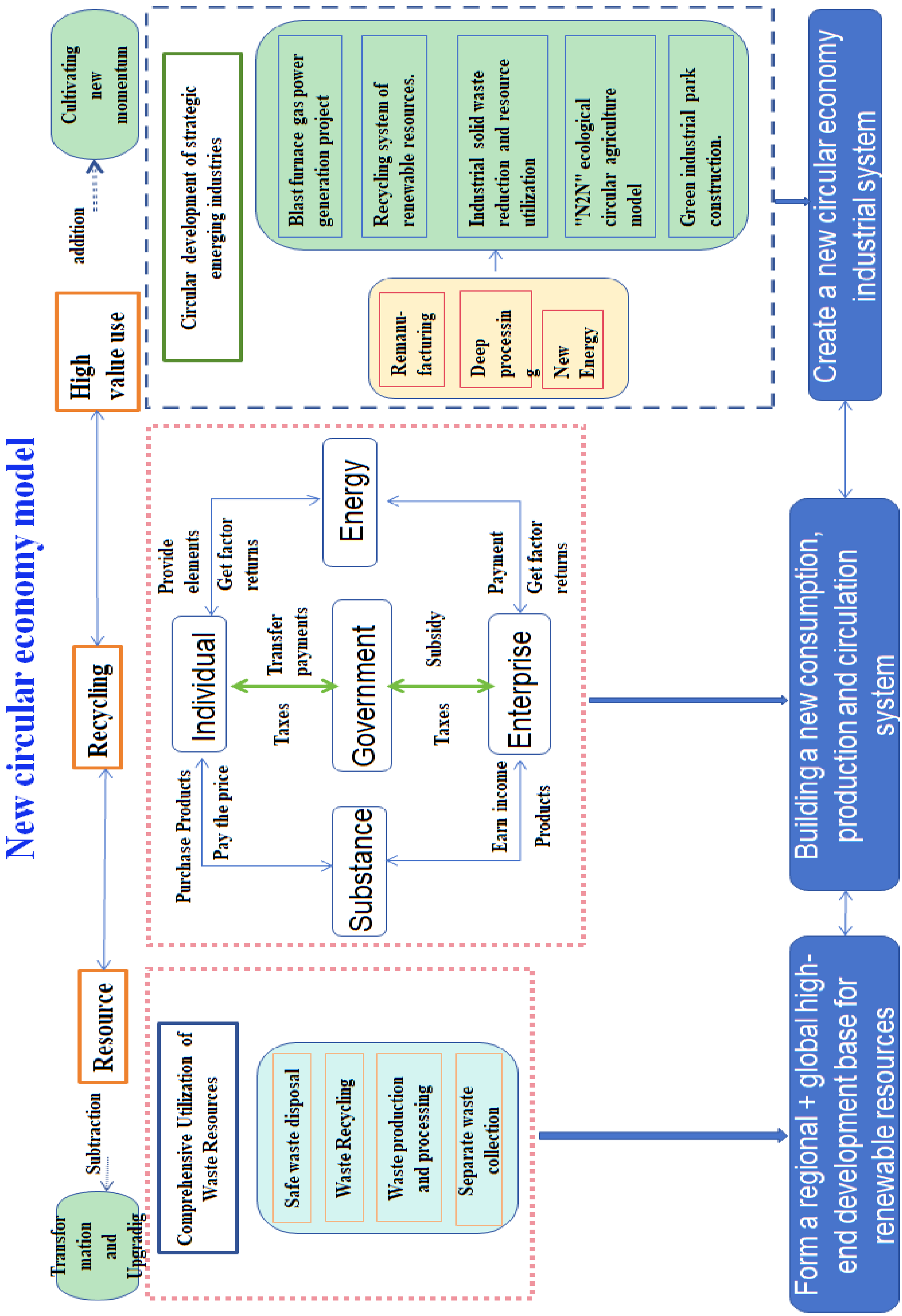

Figure 3.11. New circular economy model

Source: Made by the author

The new circular economy model main features and functions are as follows:

(1) The new circular economy model focuses on efficient resource use and environmental protection, aiming for sustainable economic and social development. Its core is "reduction, reuse, recycling," promoting coordinated economy-society-environment growth. In production, it emphasizes resource conservation and process optimization, requiring advanced technology and environmental management. In consumption, it advocates green and sustainable choices, urging consumers to select eco-friendly products and develop good habits. For waste recycling, a robust system is needed, with government policies, enterprise participation, and societal efforts ensuring resource conservation and environmental protection. In summary, this model, through comprehensive resource management and environmental optimization, fosters sustainable development and a better planet.

(2) The new circular economy model is characterized by resource management and environmental optimization in the whole process.The new circular economy model integrates resource management and environmental protection across economic and social operations. In production, it demands advanced technology, efficient resource use, and environmental management to reduce waste and pollution. Enterprises should also explore eco-friendly methods to enhance product quality and competitiveness. In consumption, it promotes green and sustainable choices, urging consumers to adopt eco-friendly habits and products. Governments and society must strengthen environmental education to foster green consumption. In waste recycling, a robust system is essential, supported by policies and active participation from enterprises and society. Effective management and supervision of the waste recycling industry ensure timely and safe waste handling. Overall, this model emphasizes holistic resource and environmental optimization, driving sustainable economic and social development for a better planet through collaborative efforts.

(3) The new circular economy model requires the joint participation and efforts of the government, enterprises and all social parties.In the new circular economy model, the government, enterprises, and society all play crucial roles. The government formulates supportive policies, strengthens supervision, and reduces enterprise costs through fiscal subsidies and tax incentives. Enterprises explore eco-friendly production methods to enhance product quality and competitiveness, while optimizing processes

and reducing waste. Society raises environmental awareness through education and media, promoting green consumption and waste classification. Collaborative efforts from all parties drive sustainable economic and social development.

With globalization and technological advancements, humanity has achieved remarkable success but faces resource and environmental challenges. Deforestation, water scarcity, and pollution signal the end of traditional production modes. Sustainable development has emerged as a global goal, leading countries to explore new production methods. Circular economy, emphasizing resource maximization and waste minimization, has garnered worldwide attention. Industrial clusters, formed under circular economy principles, optimize resource allocation, reduce costs, and foster industry interaction, promoting entire supply chain upgrades. Studying sustainable industrial cluster development guided by circular economy principles deepens our understanding of circular economy mechanics and provides scientific guidance for cluster evolution, aiding in addressing resource and environmental challenges and fostering sustainable development.

(1) Develop leading enterprises in industrial clusters under the condition of circular economy and gradually establish strategic alliances

To advance circular economy, we pursue a new economic model and philosophy, balancing growth with environmental protection and sustainable resource use. Achieving this necessitates selecting industries with robust foundations, forward-thinking visions, and innovative spirits capable of driving "reduce, reuse, recycle" initiatives. Leading enterprises, as industry pioneers, must leverage capital and technology, invest heavily in research, and innovate in production technology, products, processes, and organizational structures. Modern technology aids this transformation, enabling resource-based industrial clusters to align with sustainable development goals. Leading enterprises' circular technological shifts set examples, fostering cluster-wide low-carbon, high-tech advancements. To this end, we must build shared technology platforms facilitating inter-enterprise cooperation, knowledge sharing, and technology transfer. Constructing information networks and infrastructure fosters virtual industrial symbiosis, enabling closer ties and collective market resilience. Essential supporting facilities ensure stable cluster operations. In this environment, enterprise symbiosis integrates resources, promoting sustainable development. In summary, circular economy development is imperative for economic and social progress. By selecting strong industries, empowering leaders, harnessing technology, and building platforms and facilities, we steer industrial clusters towards greener, low-carbon, high-tech futures, contributing to a shared human destiny. This is both an economic contribution and a global promise.

(2) Embed the concept of circular economy into the industrial chain and gradually form an industrial ecological chain group

In traditional industrial clusters, each chain element from raw material mining to final product sales is tightly linked. However, resource and environmental pressures have made traditional production modes unsustainable. To address this, we must integrate complementary and circular chain enterprises to maximize resource use and minimize waste. Chain repair enterprises, vital for circular economies, convert traditional waste into valuable resources or energy. By embedding these enterprises, we reintroduce substances back into production, enabling resource recycling. Additionally, we need to boost R&D in recycling technology and innovate traditional processes with modern technologies like biotechnology, new materials, and information technology. These technologies enhance production efficiency, reduce costs, and mitigate environmental impact.

In industrial park construction, we should promote green procurement and encourage environmental cooperation among enterprises. By optimizing the product chain and extending the industrial chain vertically and horizontally, we achieve a virtuous park environment cycle. Implementing clean production auxiliary chains reduces waste generation, improves product quality, and boosts market competitiveness. For waste management, we should establish professional treatment centers to convert waste into resources or energy, minimizing environmental pollution. To further circular economy development, preferential policies and mechanisms, such as tax incentives and financial support, are essential. Creating a favorable industrial ecological environment, including improved regulations, stronger supervision, and heightened public environmental awareness, is also crucial.

In summary, by integrating supplementary and circular chain enterprises, investing in circular technology, innovating processes, promoting green procurement, optimizing product chains, implementing clean production, treating waste resourcefully, and establishing supportive policies, we can build a sustainable, resource-efficient industrial model. This will drive China's economic and social development and contribute to a shared future for humanity.

(3) Take circular economy as the responsibility to build a self-organizing mechanism and promote the mobilization and play of the long-term mechanism of industrial clusters

Industrial clusters, composed of interrelated enterprises, rely heavily on cooperation for resource recycling and sustainable production. To ensure voluntary adherence to resource-recycling principles and attract external enterprises, an effective mechanism is crucial, supported by strong government promotion. The circular economy model differs fundamentally from traditional economic development, offering significant positive externalities. While enterprises adopting this model benefit themselves, they also positively impact society and the environment. However, high initial investment and technical thresholds can discourage many. Thus, in the initial stage of transitioning industrial clusters to a circular economy, the government's macro-responsibility is vital, necessitating improved policy and management mechanisms to encourage enterprise participation.

The government can reduce transformation costs and risks through preferential policies like tax relief and financial support, and enforce resource recycling and environmental standards through legislation. It should also establish and refine circular economy supervision systems, rewarding outstanding performers and requiring corrective measures for non-compliant enterprises. By building information exchange platforms and fostering industry-university-research cooperation, the government can further promote enterprise exchanges and cooperation, facilitating widespread circular economy adoption.

With increasing focus on scarce resources, resource-based industrial clusters should align with national policies and explore low-carbon development. Government management mechanisms are pivotal here, utilizing market economy laws and economic tools like prices, taxes, finance, credit, fees, and insurance to regulate market participants and steer low-carbon development. Comprehensive environmental and economic policies, such as environmental taxes, ecological compensation, and emission trading, can incentivize enterprises to reduce pollution and improve resource efficiency.

In the low-carbon economy, local governments must adjust support for large enterprises beyond traditional methods like credit increases and tax relief. Instead, they should encourage mergers, acquisitions, and restructuring around core businesses to promote circular economy development. Pilot environmental and resource taxes, coupled with fiscal subsidies, tax incentives, green credit and insurance, and green procurement, can guide enterprises toward low-carbon technologies and circular production. Additionally, governments should guide energy consumption behavior and foster long-term low-carbon mechanisms, including industrial structure adjustments, encouraging advanced technologies and management models, improving energy efficiency, and reducing carbon emissions.

In summary, China's industrial clusters must adopt the circular economy concept, achieving reduction, reuse, and recycling of resources to form industrial ecological chains. Through policy support and guidance, model leading enterprises should be developed, enabling communication platforms and forming upstream-downstream alliances. Establishing and refining long-term industrial cluster mechanisms, with reasonable incentives and effective supervision, will drive regional economic harmonious development powered by circular industrial clusters.

Conclusion of Chapter 3

This chapter has provided a comprehensive analysis of benchmarking management implementation in Xinyu City, focusing specifically on the circular economy development in Xinyu High-tech Zone. Through detailed examination of benchmarking methods, including goal-setting, indicator selection, and plan formulation, we have gained insights into the operational process and its impact on circular economy development in the region.

Firstly, the chapter highlights the evolution of circular economy development path in Xinyu High-tech Zone, summarizing the general and specific laws governing its development. By establishing an evolution model, we aim to provide theoretical support and practical experience for circular economy development not only in Xinyu High-tech Zone but also in other similar regions. The benchmarking analysis at enterprise level, eco-industrial park level, and social level further enriches our understanding of circular economy practices in developed countries and their potential application in Xinyu.

Secondly, the chapter identifies several key problems and prospects in the implementation of circular economy in Xinyu High-tech Zone. Technical backwardness, unreasonable energy structure, over-exploitation of resources, and the deficiency of "hard law" guarantee are among the most significant challenges faced by the region. These issues highlight the need for increased scientific and technological investment, policy support, and market mechanism reform to drive progress and innovation in circular economy development.

Furthermore, the chapter evaluates benchmarking's effectiveness in promoting circular economy using both qualitative and quantitative methods. By analyzing typical enterprise cases, such as Xinyu Iron and Steel Co., LTD and Xinyu Jinhua Coal Chemical Co., LTD, we have demonstrated the positive role of benchmarking in fostering resource reduction, reuse, and recycling in the region. However, the chapter also reveals potential issues and areas for improvement, such as the need for more comprehensive indicator selection and plan formulation, as well as stronger policy support and guidance to ensure the long-term sustainability of circular economy practices.

In conclusion, this chapter underscores the importance of benchmarking management in promoting circular economy development in Xinyu City. By addressing both effectiveness and potential issues, the chapter provides valuable insights and recommendations for policymakers, practitioners, and researchers in the field. As the world increasingly turns to circular economy models to address environmental and economic challenges, the findings of this chapter offer a useful reference for regions seeking to adopt and refine benchmarking practices in their own circular economy development efforts.

CONCLUSIONS

The present study has delved into the benchmark management practices that underlie the formation of circular economy, aiming to identify effective strategies and mechanisms for promoting sustainable resource utilization and environmental protection. This paper discusses the development of circular economy in Xinyu City, China, and puts forward the countermeasures of circular economy development through systematic literature review, evaluation methods of circular economy, and comparison of domestic and international circular economy practices. Based on benchmarking theory, the paper constructs the evaluation index system and the evolution path of circular economy development. As a case of developing circular economy, this paper evaluates the development of circular economy in Xinyu City.

1. This study defines the nature of circular economy from multiple perspectives. From the Angle of comprehensive utilization of resources, circular economy emphasizes the maximum utilization of resources and the reduction of waste; From the perspective of environmental protection, it focuses on reducing pollution and protecting the environment; From the perspective of technology paradigm, circular economy emphasizes the key role of technological innovation in resource recycling. From the Angle of the relationship between man and nature, it pursues the harmonious symbiosis between man and nature; From the perspective of economics, circular economy aims to achieve a win-win situation of economic benefit and environmental benefit. In terms of the principles of circular economy, this study elaborates the principle of reduction, reuse and recycling, which provide guidance for the practice of circular economy. At the same time, this study also analyzes the implementation of circular economy at the enterprise level, including the construction of natural cycle subsystem, business cycle subsystem and "nature-economy" composite cycle system. This study discusses the evolution process of circular economy theory, from origin to development, and provides a clear framework for understanding the evolution of circular economy. At the same time, through the study of the index system of circular economy, this study puts forward the index system of all-round well-off society, the evaluation of circular economy index system and the application method of China's statistical index system, which provides a scientific basis for the evaluation and

monitoring of circular economy.

2. In terms of benchmarking management, this study deeply analyzes the world benchmark of circular economy, including the circular economy development practices of countries and regions such as the European Union, Germany, France, Japan and the United States. The successful experience of these countries and regions has provided valuable enlightenment and reference for our country's circular economy development. This study combined with the practice of China's circular economy, analyzed the current situation and problems of China's circular economy development, and put forward the corresponding countermeasures and suggestions. By referring to the international advanced experience and combining with China's national conditions, it can promote the sound development of China's circular economy.

3. The purpose and significance of regional circular economy development evaluation are clarified, and it is pointed out that it plays an important role in promoting regional sustainable development, optimizing resource allocation and improving environmental quality. On this basis, this study analyzed the characteristics of regional circular economy development evaluation index system, and combined with the current evaluation research status, built a comprehensive and scientific regional circular economy development evaluation index system. The system covers many aspects such as resource utilization, environmental protection, economic benefit and social progress, and provides an effective tool for comprehensive evaluation of regional circular economy development. This study deeply discusses the path evolution of regional circular economy development. By analyzing the dynamic mechanism of regional circular economy development, this study constructs a path evolution model, and evaluates and optimizes different development paths.

4. Taking Xinyu High-tech Zone of Jiangxi Province as an example, a detailed evaluation of circular economy development is carried out. By determining the benchmark of circular economy development and analyzing the index weight of evaluation system, this study obtained the status quo, experience and existing problems of circular economy development in Xinyu high-tech Zone cluster. On this basis, this study puts forward some countermeasures and suggestions to provide practical guidance for the development of circular economy in Xinyu City and similar areas. The

results show that the development of regional circular economy in China has achieved some results, but there are still some problems, such as low resource utilization efficiency and prominent environmental pollution. Therefore, we need to further strengthen theoretical research and practical exploration in the future, promote the in-depth development of circular economy, and achieve sustainable development of economy, society and environment.

5. In-depth analysis and evaluation are made on the development path of circular economy and the sustainable development of industrial clusters in Xinyu High-tech Zone. By constructing the development path evolution model, the paper systematically combs the evolution process of circular economy in Xinyu High-tech Zone, and reveals its development law and influencing factors. At the same time, combined with the actual situation of industrial clusters, the development of circular economy in Xinyu high-tech Zone is comprehensively evaluated, and the relevant problems and suggestions are put forward. In terms of the development path of circular economy, the research finds that Xinyu High-tech Zone has initially formed a circular economy development model with local characteristics, but there are still some problems, such as unreasonable energy structure and over-exploitation of resources. In order to promote the healthy development of circular economy in Xinyu High-tech Zone, the paper puts forward the prospect of strategic support, technological innovation, market demand, social participation and international cooperation.

6. In terms of the evaluation of circular economy development of industrial clusters, this study first clarified the benchmark of circular economy development of industrial clusters, then briefly introduced the industrial clusters in Xinyu High-tech Zone, and evaluated the industrial correlation degree of circular economy based on typical enterprise cases. The results show that the industrial clusters in Xinyu High-tech Zone have achieved certain results in the development of circular economy, but it is still necessary to further strengthen the coordination and correlation between industries and improve the efficiency of resource utilization.

7. In terms of the problems existing in the implementation of circular economy, this study has carried out an in-depth analysis from the perspectives of energy structure, resource development, legal protection, market mechanism and public participation. In

response to these problems, this study puts forward corresponding countermeasures and suggestions, such as optimizing energy structure, strengthening resource protection, improving laws and regulations, perfecting market mechanism and enhancing public participation. This paper analyzes the new circular economy model and provides a useful reference for the development of circular economy in Xinyu High-tech Zone and similar areas. At the same time, combined with the actual situation of industrial clusters, this study puts forward the path of sustainable development of industrial clusters under the background of circular economy, including strengthening industrial collaboration, promoting technological innovation, optimizing resource allocation, etc.

8. Xinyu High-tech Zone has a number of industrial clusters, which not only promote regional economic development, but also play an important role in the development of circular economy. By setting the benchmark of circular economy development of industrial clusters, we can objectively evaluate the industrial clusters in Xinyu High-tech Zone. These benchmarks include enterprise-level benchmarks, eco-industrial park level benchmarks, and social benchmarks. At the same time, we also introduce the industrial cluster of Xinyu High-tech Zone, including its industrial environment, infrastructure and so on, and select some typical enterprise cases for in-depth analysis. The successful experience of these enterprises and cases provides valuable reference for the circular economy development of Xinyu High-tech Zone and even other areas. Although Xinyu High-tech Zone has made some achievements in the development of circular economy, there are still some problems to be solved. First of all, the unreasonable energy structure and excessive dependence on traditional energy leads to low energy utilization efficiency and serious environmental pollution. Secondly, the over-exploitation of resources, some places in the pursuit of short-term economic interests, ignore the sustainable use of resources, resulting in resource waste and ecological damage. In addition, the lack of "hard law" protection of China's regional circular economy also restricts the in-depth development of circular economy. At the same time, problems such as imperfect market mechanism and insufficient public participation also affect the promotion and implementation of circular economy.

9.In view of the above problems, we put forward the implementation prospects and strategies of circular economy. First of all, the government should increase policy support, through the formulation of preferential policies, financial support and other ways to encourage enterprises to actively participate in the construction of circular economy. Second, strengthen technological innovation and research and development, promote advanced circular economy technology and management mode, improve resource utilization efficiency and reduce environmental pollution. At the same time, we will strengthen the construction of market mechanisms, improve the price formation mechanism and market access system, and promote the optimal allocation and recycling of resources. In addition, strengthen public education and publicity, improve the public's awareness of and participation in circular economy, and form a good atmosphere for the whole society to jointly promote the development of circular economy. The new circular economy model is an innovative economic development model, which emphasizes the effective use of resources and the protection of environment to achieve the sustainable development of economy and society. This model is characterized by the whole process of resource management and environmental optimization, through optimizing resource allocation, improving resource utilization efficiency, reducing environmental pollution and other ways to achieve the coordinated development of economy, society and environment. When Xinyu city promotes the development of circular economy, it should actively benchmark the new circular economy model, combine the local actual situation, and explore the development path of circular economy suitable for its own development.

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APPENDIX

Appendix I: List of national eco-industrial demonstration parks

1. List of parks approved as national eco-industrial demonstration parks		
NO.	Park name	Approval time
1	Suzhou Industrial Park	31 March 2008
2	Suzhou high-tech Industrial Development Zone	31 March 2008
3	Tianjin Economic and Technological Development Area	31 March 2008
4	Yantai Economic and Technological Development Zone	April 1, 2010
5	Wuxi New District (High-tech Industrial Development Zone)	April 1, 2010
6	Shandong Weifang Binhai Economic Development Zone	April 1, 2010
7	Shanghai Xinzhuang Industrial Zone	August 26, 2010
8	Rizhao Economic and Technological Development Zone	August 26, 2010
9	Kunshan Economic and Technological Development Zone	November 29, 2010
10	Zhangjiagang Free Trade Zone and Yangzijiang International Chemical Industrial Park	November 29, 2010
11	Yangzhou Economic and Technological Development Zone	November 29, 2010
12	Shanghai Jinqiao Export Processing Zone	April 2, 2011
13	Beijing Economic and Technological Development Zone	April 25, 2011
14	Guangzhou Development Zone	December 5, 2011
15	Nanjing Economic and Technological Development Zone	March 19, 2012
16	Tianjin Binhai Hi-Tech Industrial Development Zone Huayuan Science Park	December 26, 2012
17	Shanghai Caohejing Emerging Technology Development Zone	December 26, 2012
18	Shanghai Chemical Industry Economic and Technological Development Zone	February 6, 2013
19	Shandong Yanggu Xiangguang ecological industrial Park	February 6, 2013
20	Linyi Economic and Technological Development Zone	February 6, 2013
21	Jiangsu Changzhou Bell Tower Economic Development Zone	September 15, 2013
22	Jiangyin high-tech Industrial Development Zone	September 15, 2013
23	Shanghai Zhangjiang High-tech Park	January 10, 2014
24	Shenyang Economic and Technological Development Zone	March 20, 2014
25	Ningbo Economic and Technological Development Zone	March 20, 2014
26	Shanghai Minhang Economic and Technological Development Zone	March 20, 2014
27	Xuzhou Economic and Technological Development Zone	September 30, 2014
28	Nanjing high-tech Industrial Development Zone	September 30, 2014
29	Hefei high-tech Industrial Development Zone	September 30, 2014
30	Qingdao high-tech Industrial Development Zone	September 30, 2014
31	Changzhou National high-tech Industrial Development Zone	December 25, 2014
32	Changshu Economic and Technological Development Zone	December 25, 2014
33	Nantong Economic and Technological Development Zone	December 25, 2014
34	Ningbo high-tech Industrial Development Zone	July 31, 2015
35	Hangzhou Economic and Technological Development Zone	July 31, 2015
36	Fuzhou Economic and Technological Development Zone	July 31, 2015

37	Shanghai City Shibei high-tech service park	August 3, 2016
38	Jiangsu Wujin Economic Development Zone	August 3, 2016
39	Wujin National high-tech Industrial Development Zone	August 3, 2016
40	Nanjing Jiangning Economic and Technological Development Zone	August 3, 2016
41	Changsha Economic and Technological Development Zone	August 3, 2016
42	Wenzhou Economic and Technological Development Zone	August 22, 2016
43	Yangzhou Weiyang Economic Development Zone	August 22, 2016
44	Yancheng Economic and Technological Development Zone	August 22, 2016
45	Lianyungang Economic and Technological Development Zone	November 29, 2016
46	Huaian Economic and Technological Development Zone	November 29, 2016
47	Zhengzhou Economic and Technological Development Zone	November 29, 2016
48	Changchun Automobile Economic and Technological Development Zone	November 29, 2016

2. List of parks approved as national eco-industrial demonstration parks

1	National ecological industry (sugar) construction demonstration park - Guigang	14 August 2001
2	Lubei Enterprise Group Company	November 18, 2003
3	Nanchang high-tech Industrial Development Zone	April 1, 2010
4	Xi 'an High-tech Industrial Development Zone	August 26, 2010
5	Hefei Economic and Technological Development Zone	November 4, 2010
6	Dongying Economic and Technological Development Zone	December 25, 2010
7	Zhuzhou high-tech Industrial Development Zone	December 25, 2010
8	Taiyuan Economic and Technological Development Zone	April 2, 2011
9	Wuhan Economic and Technological Development Zone	October 10, 2011
10	Guiyang Economic and Technological Development Zone	October 10, 2011
11	Guangzhou Nansha Economic and Technological Development Zone	May 30, 2012
12	Zhaoqing high-tech Industrial Development Zone	September 3, 2012
13	Qingdao Economic and Technological Development Zone	February 5, 2013
14	Shenyang high-tech Industrial Development Zone	February 6, 2013
15	Wujiang Economic and Technological Development Zone	February 6, 2013
16	Changchun Economic and Technological Development Zone	February 6, 2013
17	Dongguan ecological Industrial Park, Guangdong Province	April 9, 2013
18	Shangyu Industrial Park, Hangzhou Bay, Zhejiang	April 18, 2013
19	Tianjin Port free Trade Zone and airport economic zone	April 18, 2013
20	Qingpu Industrial Park, Shanghai	December 20, 2013
21	Kunshan high-tech Industrial Development Zone	December 20, 2013
22	Ganzhou Economic and Technological Development Zone	December 20, 2013
23	Urumqi Economic and Technological Development Zone	December 20, 2013
24	Langfang Economic and Technological Development Zone	October 14, 2014
25	Xinfa Industrial Park, Eping Economic and Technological Development Zone, Shandong Province	October 14, 2014
26	Inner Mongolia Ordos Shanghai Temple Economic Development Zone	October 14, 2014
27	Maanshan Economic and Technological Development Zone	October 14, 2014
28	Ganzhou high-tech Industrial Park	October 14, 2014
29	Zhangjiagang Economic and Technological Development Zone	October 14, 2014
30	Zhuhai high-tech Industrial Development Zone	October 14, 2014
31	Chengdu Economic and Technological Development Zone	October 14, 2014
32	Lianyungang Xuwei New District	December 18, 2014
33	Wuhu Economic and Technological Development Zone	December 18, 2014
34	Weifang Economic Development Zone	December 18, 2014

35	Kunming Economic and Technological Development Zone	July 3, 2015
36	Shanghai Industrial Comprehensive Development Zone	July 3, 2015
37	Mengxi high-tech Industrial Park	July 3, 2015
38	Jiaxing Port Area	July 3, 2015
39	Hangzhou Qianjiang Economic Development Zone	July 3, 2015
40	Hangzhou Xiaoshan Linjiang high-tech Industrial Park	July 3, 2015
41	Xuzhou high-tech Industrial Development Zone	September 21, 2015
42	Xishan Economic and Technological Development Zone	September 21, 2015
43	Wuzhong Economic and Technological Development Zone	September 21, 2015
44	Tianjin Ziya Economic and Technological Development Zone	September 21, 2015
45	Changsha high-tech Industrial Development Zone	September 21, 2015

Appendix II: Circular economy development strategy and main indicators of The State Council

Index name	unit	2010	2015	2015 over 2010 (%)
The output rate of major resources increased	%	-	-	15
Energy production rate	Ten thousand yuan/ton standard coal	1.24	1.47	18.5
Water resource productivity	Yuan per cubic meter	66.7	95.2	43
The land yield of construction land has increased	%	-	-	43
Total output value of resource recycling industry	Trillion yuan	1	1.8	80
Total recovery rate of mineral resources	%	35	40	5
Comprehensive utilization rate of associated ore	%	40	45	5
Comprehensive utilization of industrial solid waste	tons	16.18	31.26	93.2
Comprehensive utilization rate of industrial solid waste	%	69	72	3
Total amount of major renewable resources recovered and utilized	tons	1.49	2.14	43.6
Recovery rate of main renewable resources	%	65	70	5
The main recycled non-ferrous metal production accounted for the proportion of total non-ferrous metal production	%	26.7	30	3.3
Effective utilization coefficient of agricultural irrigation water	%	0.5	0.53	6
Reuse rate of industrial water	%	85.7	＞90	＞4.3
Utilization rate of recycled water in urban sewage treatment facilities	%	＜10	＞15	＞5
Proportion of municipal solid waste resource utilization	%	-	30	-
Comprehensive utilization rate of straw	%	70.6	80	9.4
Comprehensive utilization of installed power generation capacity	megawatt	2600	7600	192.3
Proportion of municipal solid waste resource utilization	billion yuan / 10,000 tons	-	30	-
Output rate of main mineral resources	100 million yuan/tons of standard coal	0.02	0.024	0.03
Energy production rate	Tons of standard coal / 10,000 yuan	0.76	0.86	0.92
Energy consumption per unit of GDP	%	1.31	1.15	1.05
Water withdrawals per unit of GDP were lower than in 2010	Tons of standard coal/ton	-45.7	-53.86	-59.28
Comprehensive energy consumption per ton of steel	%	1.07	0.8	0.57
Comprehensive utilization rate of industrial solid waste	%	85	90	100
Reuse rate of industrial water	%	96.27	98	100
The intensity of sulfur dioxide emission decreased from 2010	%	-43.94	-48.98	-52.35
The intensity of COD emission decreased compared with 2010	%	-94.37	-94.71	-94.94