

# Research on the paths and mechanisms of a circular economy empowering the "Dual Carbon" strategy

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**Abstract.** Circular economy represents a crucial development domain for China to promote energy conservation and emission reduction, as well as to efficiently advance carbon peaking and carbon neutrality. This study aims to explore the implementation paths and practical effects of circular economy empowering the "Dual Carbon" strategy, with the Circular Economy Industrial Park in Quetang Town, Hunan Province as the research object. By comprehensively applying the Analytic Hierarchy Process (AHP), fuzzy comprehensive evaluation and case study methods, this research systematically analyzes the energy conservation and emission reduction mechanisms of the secondary aluminum industry. The findings indicate that circular economy can significantly reduce energy consumption and carbon emission intensity of traditional energy-intensive industries through three major paths: resource recycling and reuse, clean energy substitution, and collaborative optimization of the industrial chain. Meanwhile, it lessens the dependence on primary resources and drives regional green and low-carbon transformation. The conclusions demonstrate that circular economy is one of the core paths to achieve the "Dual Carbon" goals. Its large-scale promotion can provide a replicable practical paradigm for industrial upgrading and sustainable development, which carries important policy reference significance.

**Keywords:** circular economy, Dual Carbon strategy, Analytic Hierarchy Process (AHP), fuzzy comprehensive evaluation, secondary aluminum

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## 1. Introduction

On September 22, 2020, President Xi Jinping of the People's Republic of China announced at the 75th session of the United Nations General Assembly that China would strive to peak its carbon dioxide emissions before 2030 and achieve carbon neutrality before 2060. To implement the "Dual Carbon" strategy, the central government has successively issued the *Opinions of the Central Committee of the Communist Party of China and the State Council on Fully, Accurately and Comprehensively Implementing the New Development Concept and Doing a Good Job in Carbon Peaking and Carbon Neutrality* and the *Action Plan for Carbon Peaking Before 2030*, providing solid policy support for the development of the circular economy. The National Development and Reform Commission and the Standardization Administration have established circular economy standardization pilot projects in multiple provinces and cities across China, which have achieved remarkable results to date.

As an important province in central China and a key ecological barrier and industrial undertaking hub in the middle reaches of the Yangtze River Economic Belt, Hunan Province faces the dual challenges of high energy consumption and high emissions. In response to the rigid constraints of carbon reduction, Hunan Province has actively responded to the national "Dual Carbon" strategy, innovatively constructing a "1+N" circular economy policy matrix, and issuing a series of policy documents such as the *Strategic Plan for the Development of Circular Economy in Hunan Province*. It has launched circular economy pilots in Miluo, Yongxing and other places within the province, accelerating the green and low-carbon transformation of the industrial structure.

The Quetang Circular Economy Industrial Park, located in Xinshao County, Shaoyang City, Hunan Province, was once trapped in difficulties due to disorderly waste recycling and prominent environmental pollution. In recent years, through promoting the transformation to a circular economy, the park achieved a total output value of 7.76 billion yuan in 2024, successfully transforming from a "garbage town" to a new green and environmentally friendly industrial city, and becoming a demonstration benchmark for "increasing greenery and reducing carbon" and "turning waste into treasure". The industrial park has been listed as a national circular economy standardization pilot project, and its formed "Quetang Wisdom" transformation paradigm is being promoted in similar parks nationwide. Meanwhile, relying on its characteristic industries, the park has effectively alleviated employment difficulties and fiscal pressure in Xinshao County. Taking the non-ferrous metal-secondary aluminum enterprises in the park as an example, the project provides 400 direct jobs, drives more than 500 indirect jobs, and contributes an annual tax revenue of over 25.63 million yuan, accounting for 2.88% of Xinshao County's total tax revenue in 2023.

## 2. Literature review

Literature related to this study can be generally summarized into the following aspects. The first category concerns research on the connotation and evaluation indicators of the circular economy. The circular economy serves as an important approach to resolving the contradiction between consumption growth and carbon emissions. Through various effective measures, it aims to achieve maximum economic output and minimal waste discharge with the least resource consumption and environmental impact [1]. For China, developing the circular economy is a fundamental requirement for sustainable economic development. It can address the extensive use and waste of resources, and help reduce carbon emissions embodied in resources throughout their entire life cycle [2]. The origin of the circular economy is mainly rooted in fields such as Industrial Ecology (IE) and Ecological Economics (EE). At present, research on the circular economy has been and remains largely grounded in industrial ecology, focusing on analyzing the physical flows of energy and materials between industrial systems and natural systems [3].

Since the 1990s, Chinese scholars have conducted extensive research on the connotation, indicator evaluation, development paths and current status of the circular economy. Wu and Cao [4] argued that the connotation of the circular economy lies in applying ecological laws to restructure social and economic activities into a circular flow of "resources-products-renewable resources". Regarding the indicator system for circular economy development, Zhang and Huang [5] established an evaluation system oriented toward planning and management based on the 3R principles. Its control layer consists of five dimensions: social and economic development, resource reduction potential and level, pollution emission reduction, resource recycling, and ecological environment quality, which jointly govern and assess the construction and development level of the circular economy. The circular economy evaluation indicator system can be divided into two major parts: indicators for evaluating circular economy innovation and indicators for evaluating the

effects of circular economy innovation. The former includes three sub-indicators: green development concept, scientific and technological support, and institutional and organizational guarantee; the latter comprises six sub-indicators: resource output, resource consumption, comprehensive resource utilization, waste emission, ecological environment, and socio-economic development [6].

In terms of development paths, some scholars have pointed out problems in China's circular economy development, such as backward key technologies and insufficient effectiveness of supporting policies, and accordingly put forward policy suggestions including strengthening policy and financial support and promoting green technological innovation [7]. Regarding development status, some scholars took Jiangsu Province, a national circular economy pilot province, as an empirical case and found that the circular economy development index of Jiangsu had shown an S-shaped dynamic trend over the recent decade. Although the overall level of circular economy development improved significantly, development was unbalanced, and the performance of comprehensive resource utilization and waste discharge was relatively unstable [8]. Some scholars noted that characteristics of the circular economy, such as closed-loop operation and improved resource efficiency, are highly beneficial to Small and Medium-sized Enterprises (SMEs), for instance by reducing material costs, creating competitive advantages and opening up new markets. However, small enterprises face various barriers in the transition to a circular economy, including weak corporate environmental culture, insufficient capital, lack of government support or effective legislation [9].

In addition, the evaluation system of the circular economy is also an important part of the research. Based on the narrow-sense circular economy theory, the National Bureau of Statistics and relevant scholars have built a macro-level circular economy evaluation system. The framework covers five categories of core indicators such as resource utilization efficiency, clarifies the specific meaning and calculation method of each indicator, analyzes the main gaps in statistical data in the system construction, and puts forward targeted short-term and long-term implementation suggestions for the improvement of the statistical system [10]. Zhao and Guo [11] constructed a dynamic comprehensive evaluation method to depict the level of green, low-carbon and circular development in each province, and conducted inter-provincial comparison and cause analysis. It is concluded that the level of inter-provincial circular economy development in China is uneven, there is an echelon division phenomenon. Based on the development status at home and abroad and the theory of systems science, Feng, Liu and Zhou [12] proposed three types of eco-industrial park development models under the circular economy paradigm. Then they analyzed the characteristics of the development model of eco-industrial parks under the circular economy. Finally, they put forward an evaluation indicator system for the circular economy development of eco-industrial parks, which reflects the level of circular economy development of eco-industrial parks from two aspects: the industrial system and the support system of eco-industrial parks. Some researchers [13] further expanded the connotation of the circular economy and proposed the "4R" principles including Reduce, Reuse, Recycle, and Remove to meet the needs of the "Dual Carbon" strategy.

The second category concerns research on the "Dual Carbon" strategy. Implementing the "Dual Carbon" strategy is an inherent requirement of China's economic and social development at a certain stage and an inevitable choice for achieving common prosperity. It provides a solid material foundation for common prosperity, promotes the transformation of growth models and driving forces, helps establish a modern green financial system, creates more employment opportunities for the public, reduces various risks and disasters caused by the large-scale exploitation and use of fossil energy [14]. Domestic and international studies on the "Dual Carbon" goals mainly focus on theoretical backgrounds, implementation paths, effectiveness evaluation and other aspects. In terms of theoretical background, the development of carbon peaking and carbon neutrality can be traced back to the reflection of Western developed countries on the traditional development model and the rise of the sustainable development trend. Humanity began to recognize the impact of human

activities on the ecological environment and the need to pursue environmental and economic balance. Subsequently, theoretical concepts such as sustainable development and ecological economy emerged [15].

In terms of implementation paths, scholars at home and abroad have put forward various strategies and suggestions. Some scholars evaluated the carbon emission reduction effect of the carbon trading market scale using panel data of 30 Chinese provinces from 2006 to 2017 and the continuous difference-in-differences method. They proposed that expanding the carbon trading market helps reduce carbon emissions in pilot regions, which is achieved by lowering total energy consumption, optimizing the energy consumption structure, promoting low-carbon technological innovation, and adjusting the industrial structure [16]. Some scholars used the Institutional Analysis and Development (IAD) framework to analyze the policy and institutional logic and economic impacts of China's pursuit of carbon neutrality, as well as the government's role in carbon neutrality governance [17]. Based on China's provincial panel data from 2011 to 2019, some scholars empirically examined the impact and mechanism of the digital economy on green development under the "Dual Carbon" context. They found an inverted U-shaped relationship between the digital economy and green development with significant regional heterogeneity (more pronounced effects in central and western regions), where technological innovation plays a partial mediating role and environmental regulation exerts a substitution effect [18]. In addition, the digital economy can significantly suppress carbon emission intensity and per capita carbon emissions; it can also help optimize the energy structure and thus substantially reduce carbon emissions [19]. At present, the trend of "carbon-energy decoupling" in China has become increasingly clear, providing an effective path for coordinating development and pollution control while addressing climate change. A modern industrial system featuring green and low-carbon production processes and efficient utilization of resource factors has become a necessary condition and inevitable choice for achieving the "Dual Carbon" goals and building a Beautiful China [20]. Regarding effectiveness evaluation, energy structure restructuring under the "Dual Carbon" constraint exerts both drag and pull effects on economic growth. Only the active promotion of non-fossil energy substitution can balance economic growth and energy structure optimization goals. Meanwhile, high-carbon industries will face challenges such as production restrictions, intensified differentiation, and credit shocks [21].

The third category concerns research on the circular economy empowering the "Dual Carbon" strategy. The Circular Economy (CE) approach offers a sustainable alternative by promoting material circulation, reuse and recycling, in which resources and energy are optimized and conserved throughout the economic cycle. Energy conservation and emission reduction aim to extend resource service life and minimize waste through efficient resource design and utilization [22]. Some scholars recently have explored the internal connections and interaction mechanisms between the circular economy and the "Dual Carbon" goals from economic, environmental, social and other perspectives. The circular economy is a critical pathway for China to achieve its "Dual Carbon" objectives. It functions through a "trilogy" of pathways: reducing emissions in hard-to-abate sectors, securing the supply of key raw materials for energy transition, and enhancing the climate resilience of the social economy. Meanwhile, collaborative governance between the circular economy and climate action should be advanced in five dimensions including design optimization and resource management to unlock its carbon reduction potential and provide a Chinese solution for global green transition [23]. Some scholars have examined the dual-value context of economic circulation under the "Dual Carbon" goals, namely the mutual promotion and unification of economic value and ecological value. They point out that circular low-carbon development and low-carbon circular development are important pathways to realize such goals, and emphasize the significance of systematic thinking and top-level design [24]. Other scholars argue that the high-quality development of the circular economy under the "Dual Carbon" context faces dilemmas such as lagging energy transition, imperfect regulatory systems and lack of practical carriers, while enjoying

advantages including an early transition start and a small gap in green technologies. Efforts should be made to improve laws and policies, establish emission reduction evaluation systems, strengthen technological innovation and pilot practices, and promote low-carbon transformation of industries and cities, so as to support the circular economy in empowering the implementation of the "Dual Carbon" strategy [25].

Existing studies have accumulated rich achievements in the circular economy, the "Dual Carbon" strategy, and their synergistic empowerment. However, there are deficiencies in exploring the integration mechanisms of emerging factors such as digital technology and green finance, and the research on the causes of regional development and differentiated strategies is not in-depth. Research on the "Dual Carbon" strategy mostly focuses on the evaluation of emission reduction through a single path, lacking research on the conflicts of multi-policy coordination, industrial transformation paths, and risk prevention and control. The cross-research between the two is mainly based on qualitative macro-analysis, with weak research on quantitative and dynamic mechanisms as well as industry-specific and region-specific adaptation paths. To address these gaps, this study analyzes the connotation and practice of the circular economy, explore its paths to empower the "Dual Carbon" goals.

### **3. Analysis of the current situation of circular economy in Quetang Town**

This study focuses on the Quetang National Circular Economy Standardization Pilot, supplemented by surveys conducted in other regions including Changsha City, Yueyang City and Shaoyang City. A total of 3,020 questionnaires were distributed, with 2,752 valid responses finally collected. A comparative analysis was performed between the survey results and the actual conditions of Quetang Town. The survey mainly covers three core areas: the current implementation of circular economy policies, the dilemmas faced in the application of circular economy products, and the development level of the circular economy.

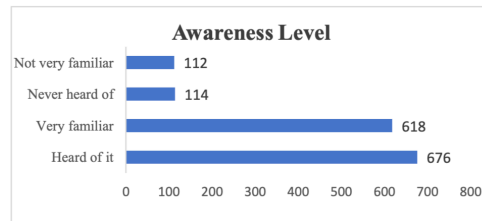
#### **3.1. Analysis of the current situation of circular economy policy implementation**

To further investigate the policy implementation effectiveness of the national circular economy standardization pilot, the research team first conducted a survey in the more economically developed districts of Changsha City, Hunan Province, including Furong District, Tianxin District, and Yuelu District. The team then visited Shaoyang City, the prefecture-level city where the Quetang Circular Economy Industrial Park is located, as well as the urban area of Shaoyang (see Appendix 1 for the questionnaire). Given the large economic gap between the surveyed areas of Changsha and Shaoyang, and to ensure data quality, the research team included Yueyang City for comparative analysis. Finally, surveys were carried out in towns including Quetang Town, where the industrial park is situated.

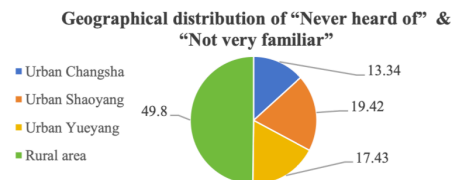
Online questionnaires were distributed in Changsha, Shaoyang, and Yueyang. A total of 1,700 questionnaires were issued, and 1,520 valid responses were collected, including 507 from Changsha, 507 from Shaoyang, and 506 from Yueyang. Selected statistical results of the questionnaire are presented as follows:

##### *3.1.1. Public understanding of the circular economy*

The general level of respondents' awareness of the concept of "circular economy" is as follows, see Figure 1 and Figure 2.



**Figure 1.** Survey on residents' awareness of the circular economy

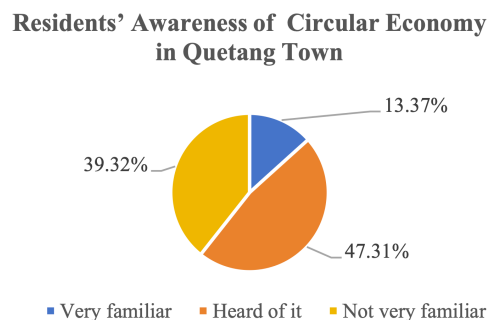


**Figure 2.** Geographical distribution of respondents with "never heard of" or "not very familiar" of the circular economy

According to the results of this survey, among the 1,520 respondents, 226 (approximately 14.8%) had never heard of the circular economy or knew very little about it. This reflects, to a certain extent, obvious deficiencies in the intensity of policy publicity and the coverage of public education. Based on the analysis in Figure 5, the findings further reveal that awareness of the circular economy is generally low in economically underdeveloped areas, remote regions, and areas with weak policy implementation. Data from the two figures indicate that public understanding of the circular economy still has considerable room for improvement, and the problem of unbalanced regional development is particularly prominent.

### 3.1.2. Understanding of the circular economy among residents in Quetang Town

Considering the professional nature of relevant issues and the educational level of local residents, the research team adopted a field sampling survey method for the study area, Quetang Town. A total of 900 paper questionnaires were distributed. After excluding respondents who refused to participate, 812 valid questionnaires were recovered, with a response rate of over 80%. A stratified random sampling method was applied, taking the industrial park as the center and dividing its surrounding areas into four circular zones. A total of 200 sample units were surveyed in each zone, with reasonable proportions ensured in terms of occupation, gender and age, so that the questionnaire results could fully reflect the opinions of most residents in Quetang Town. Some typical questionnaire samples are selected below as the reference basis for this study, see Figure 3.

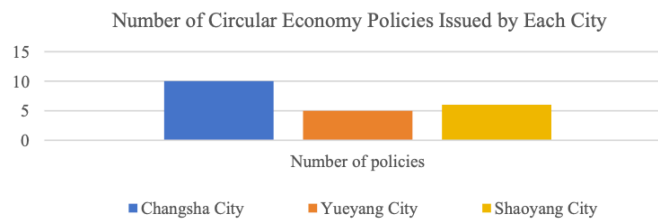


**Figure 3.** Survey on awareness of the circular economy among residents in Quetang Town

The research team found that although Quetang is a relatively remote and underdeveloped area, local residents' awareness of the circular economy is higher than the provincial average. Further investigation revealed that most local residents participate in collecting waste paper boxes, discarded bottles and other recyclables to earn income, and all residents are familiar with the local circular economy industrial park.

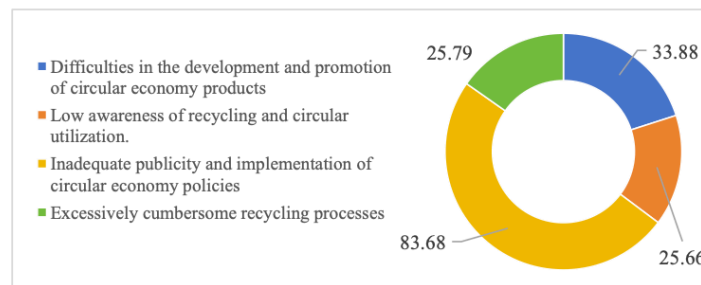
### 3.1.3. Analysis of relevant policies in various regions

Through interviews with staff of relevant government departments and database retrieval, we found that all urban areas have introduced precise and efficient policies, and initially formed a circular economy development pattern with rational layout, interactive coordination and coordinated promotion. The survey results on the policy implementation status in Changsha, Yueyang and Shaoyang (see Figure 4) show that, generally speaking, all regions have formulated step-by-step carbon peaking action plans based on their own energy and economic development conditions, and are steadily advancing the carbon peaking and carbon neutrality goals. However, the implementation effect of policies varies across regions.



**Figure 4.** Number of circular economy policies issued in Changsha, Yueyang and Shaoyang cities

The survey results regarding respondents' views on the constraints facing the current development of circular economy in China are as follows, see Figure 5:



**Figure 5.** Statistical chart of constraints on the development of the circular economy

According to the survey results, 83.68% of respondents identified insufficient publicity and policy implementation of the circular economy as key constraints. Field interviews with government departments revealed that although relevant

policies for promoting the circular economy and building a resource-conserving and environment-friendly society are relatively complete in all regions, their actual implementation still faces difficulties, a problem that is particularly pronounced in economically less developed areas.

### 3.1.4. Analysis of relevant policies in Quetang Town

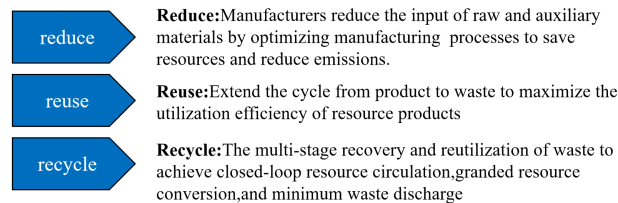
During the field investigation, the research team found that policy implementation in Quetang Town was more efficient than in the other three regions. In terms of policy publicity, residents of Quetang Town showed a

higher level of understanding of the circular economy. Regarding policy implementation, grassroots participation was also higher in Quetang Town.

Through communication with local government staff, we learned that the main reasons can be summarized into two points. First, the demonstration effect of the circular economy industrial park has attracted a large number of cadres to conduct research and inspections, which has played a certain role in supervising policy implementation. Second, local residents have a high enthusiasm for participating in circular economy development, can keenly perceive policy changes, and exert a supervisory role.

### 3.2. Analysis of dilemmas faced by circular economy products in Quetang Town

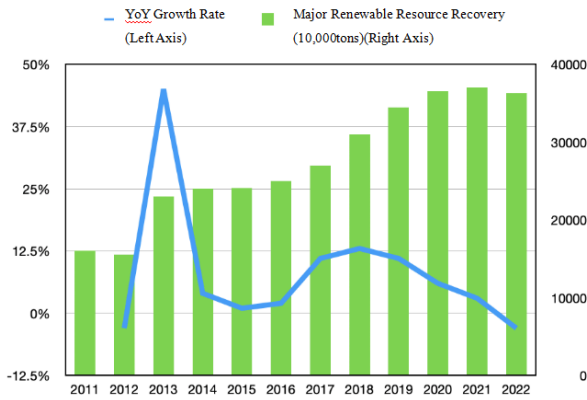
Based on the core concept of the circular economy, three basic evaluation principles can be summarized (namely the "3R" principles, as shown in Figure 6. The research team visited enterprises in the Quetang Circular Economy Industrial Park and conducted an in-depth analysis of the dilemmas facing circular economy products by combining interviews with more than 100 professionals, literature review, and questionnaire surveys. Respondents generally reported that many factories were facing closure or operational difficulties, mainly affected by the overall macroeconomic conditions. To further explore the causes of this "macroeconomic environment" phenomenon, this part of the investigation focuses on Hunan Province and conducts a detailed analysis around three aspects: difficulties in product recycling, difficulties in product manufacturing, and difficulties in product consumption.



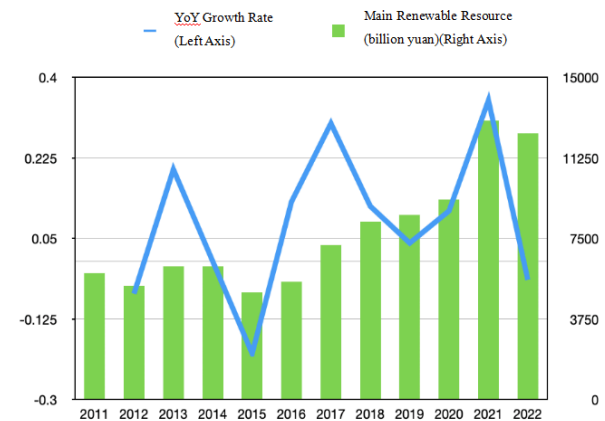
**Figure 6.** The "3R" principles of the circular economy

#### 3.2.1. Difficulties in recycling circular economy products

Through data retrieval from the Wind database, China Materials Recycling Association and other public sources, we recognize that the development of the circular economy is closely related to the renewable resources recycling industry, which has shown a growing trend to a certain extent. According to the data, from 2011 to 2022, the total recovery volume of major renewable resources in China increased from 165 million metric tons to 371 million metric tons, with a Compound Annual Growth Rate (CAGR) of 7.78%. Over the same period, the total value of recovered renewable resources rose from 576.39 billion yuan to 1,314.05 billion yuan, representing a CAGR of 7.66%. The relevant trends are shown in Figure 7 and Figure 8:



**Figure 7.** Volume and growth rate of renewable resources recovery in China (Left)



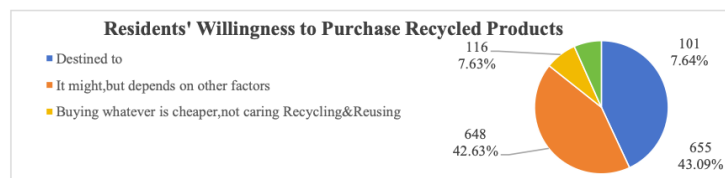
**Figure 8.** Value (100 million yuan) and growth rate of major renewable resources recovery in China (Right)

Survey results indicate that in 2022, affected by multiple factors such as domestic and international economic conditions and fluctuations in raw material prices, the combined effects of the COVID-19 pandemic and the Ukraine crisis drove a sharp rise in global energy and food prices. Advanced economies adjusted their monetary policies one after another, leading the global economy into a state of high inflation, high interest rates, high debt, high costs and low growth. This has clouded the global economic outlook and raised mounting risks of recession. As a result, both the volume and value of major renewable resources recovered in China experienced a temporary decline.

Under this backdrop, the total recovery volume of China's top ten renewable resource categories reached approximately 371 million metric tons in 2022, down 2.62% year-on-year. Among them, waste glass, waste textiles, and Waste Electrical and Electronic Equipment (WEEE) recorded the most significant drops, falling by 15.4%, 12.6% and 10.4% respectively. In addition, due to lower recycling prices, the total recovery value of renewable resources decreased by 4.05% year-on-year in 2022.

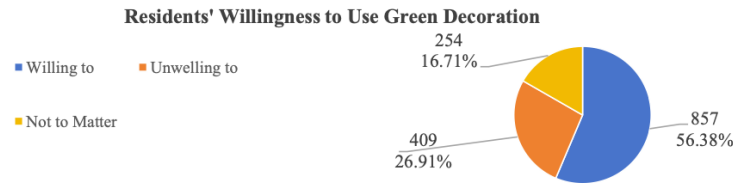
### 3.2.2. Sales dilemmas of circular economy products

To investigate respondents' willingness to purchase circular economy products, we designed the question: "If discounts or reward points are offered for buying recyclable and reusable products, would you be willing to purchase such products?" (see Subjective Question 5 in Appendix 1). Four options were provided: "Destined to", "It might, but depends on other factors", "Buying whatever is cheaper, not caring about recycling and reusing", and "Will Not Purchase". The survey results are as follows, see Figure 9:



**Figure 9.** Residents' willingness to purchase recyclable products

The following (see Figure 10) presents the survey results on residents' willingness to use green furniture and eco-friendly decoration under the condition of slightly higher prices (Question 7 in Appendix 1).



**Figure 10.** Residents' willingness to use green decoration

The above data show that with the diversification of consumption patterns, the concept of green and circular consumption has gradually taken root among the public. Given preferential conditions, a large number of consumers—1,303 people, accounting for 85.72%—expressed willingness to buy circular products. However, if circular and green products are priced higher than conventional ones, the number of willing buyers drops significantly to only 857, or 56.38%. In response to this pattern, the research team further analyzed the challenges in pricing circular economy products.

First, enterprises face a difficult trade-off between energy conservation and cost control. From a corporate perspective, the application cost of low-carbon technologies does not always correlate positively with improved economic benefits. Firms must bear the financial pressure of adopting decarbonization technologies, making it difficult to promote such initiatives based solely on environmental protection and social responsibility. Second, current government policies mainly encourage the application of low-carbon technologies rather than mandating them. Without clear and binding requirements, enterprises lack motivation and initiative in implementation. In addition, enterprises show low confidence in domestic energy-saving and emission-reduction technologies. Given the relatively short development period of such technologies in China, they are still in the process of improvement and face certain technical bottlenecks, resulting in low willingness to adopt them. Finally, high energy consumption has become embedded in the existing interest structure of industrial enterprises. Energy-saving and emission-reduction retrofits would disrupt established interest chains.

### 3.3. Assessment of circular economy development in quetang town

The circular economy industry is an industrial organization model centered on the recycling of resources, covering waste recovery, renewable resource utilization, energy conservation and environmental protection, among other sectors. In this study, the construction of the indicator system followed five principles: scientificity, integrity, independence, feasibility, and dynamism. Based on these principles, the relevant indicator system was established from four dimensions.

For the development status assessment, the survey respondents included residents who had lived in Quetang Town for more than ten years with a certain level of education, as well as experts with in-depth knowledge of the town's relevant conditions. Participants scored the corresponding questionnaires (see Appendix 2 for details), yielding a total of 20 valid questionnaires. Data analysis was conducted using statistical software such as SPSS.

#### 3.3.1. The Analytic Hierarchy Process (AHP)

The Analytic Hierarchy Process (AHP) is a systematic and hierarchical decision-making method that combines qualitative and quantitative analysis. It is widely used to address complex decision-making problems. The basic steps of this method include establishing a hierarchical structure model, constructing pairwise comparison matrices, calculating weight vectors and conducting consistency checks, and finally deriving the comprehensive weight vector. This paper adopts the AHP method to determine the weights of each indicator, with detailed procedures and steps provided in Appendix 4. Only the indicator framework and partial calculation results are presented in this section.

### 3.3.1.1. Establishment of the hierarchical structure model

The AHP model adopted in this paper is divided into three levels: the target layer, the first-level indicator layer, the second-level indicator layer, and the third-level indicator layer. The specific hierarchical framework is shown below, see Table 1.

**Table 1.** Evaluation index system for circular economy in Quetang Town

target layer	First-level indicator layer	Second-level indicator layer	Third-level indicator layer
Evaluation Index System for Circular Economy Development in Quetang Town <i>M</i>	Economic Indicators <i>A1</i>	Comprehensive Economic Indicators <i>B1</i>	Per capita GDP (yuan/person) <i>C1</i>
			Consumer Price Index (CPI) <i>C2</i>
			Fixed-asset Investment Price Index <i>C3</i>
			Expenditure on Energy Conservation and Protection (10,000 yuan) <i>C4</i>
			Proportion of tertiary industry output value in GDP (%) <i>C5</i>
			Economic Structure Indicators <i>B2</i>
			Proportion of employees in tertiary industry (%) <i>C6</i>
			Growth rate of tertiary industry GDP (%) <i>C7</i>
			Reduction Indicators <i>B3</i>
			Energy consumption per unit GDP (kWh/10,000 yuan) <i>C8</i>
			Water demand per unit GDP <i>C9</i>
			Comprehensive utilization rate of industrial solid waste <i>C10</i>
			Resource Indicators <i>A2</i>
Reuse Indicators <i>B4</i>			
Comprehensive utilization volume of industrial solid waste (10,000 tons) <i>C11</i>			
Increase in daily harmless treatment capacity of domestic waste <i>C12</i>			
Increase in daily sewage treatment capacity (10,000 m <sup>3</sup> ) <i>C13</i>			

**Table 1.** Continued

Evaluation Index System for Circular Economy Development in Quentang Town <i>M</i>	Environmental Indicators <i>A3</i>	Pollution Emission Indicators <i>B5</i>	Total industrial wastewater discharge (10,000 tons) <i>C14</i>
			Smoke and dust emission (tons) <i>C15</i>
			Industrial dust emission (tons) <i>C16</i>
			Green coverage rate of built-up areas (%) <i>C17</i>
		Social Development Indicators <i>B6</i>	Annual per capita disposable income of urban residents (10,000 yuan) <i>C18</i>
	Social Indicators <i>A4</i>	Social Stability Indicators <i>B7</i>	Engel' s coefficient (%) <i>C19</i>
		Average wage of employed population (yuan) <i>C20</i>	

### 3.3.1.2. Calculation results

Calculation results are presented below, see Table 2, Table 3 and Table 4.

**Table 2.** Calculation results of first-level indicators (M)

<i>M</i>	<i>A1</i>	<i>A2</i>	<i>A3</i>	<i>A4</i>	Weight	$\lambda_{max}$	CI	CR
<i>A1</i>	1	1.9584	1.5651	1.5868	0.3558	4.0237	0.0079	
<i>A2</i>	0.5106	1	0.6119	0.5989	0.1576			0.0089 < 0.1
<i>A3</i>	0.6389	1.6342	1	0.717	0.2229			Consistency test:passed
<i>A4</i>	0.6302	1.6697	1.3946	1	0.2637			

**Table 3.** Calculation results of second-level indicators (A1)

<i>A1</i>	<i>B1</i>	<i>B2</i>	Weight	$\lambda_{max}$	CI	CR
<i>B1</i>	1	1.6945	0.6289	2	0	0 < 0.1
<i>B2</i>	0.5901	1	0.3711			Consistency test:passed

**Table 4.** Calculation results of third-level indicators (B1)

<i>B1</i>	<i>C1</i>	<i>C2</i>	<i>C3</i>	<i>C4</i>	Weight	$\lambda_{max}$	CI	CR
<i>C1</i>	1	1.2884	1.4881	1.1822	0.3016	4.0088	0.00294	
<i>C2</i>	0.7762	1	1.1943	0.6844	0.2194			0.0033 < 0.1
<i>C3</i>	0.672	0.8373	1	0.6743	0.1929			Consistency test:passed
<i>C4</i>	0.8459	1.4612	1.483	1	0.286			

By summarizing the above calculation results, the relative weights of each indicator are obtained. The comprehensive weights are derived by multiplying the relative weights level by level, representing the hierarchical ranking of the bottom-level indicators with respect to the overall goal. The detailed results are shown in the following Table 5:

**Table 5.** Results of comprehensive weights

target layer	First-level indicator layer	Relative Weight	Second-level indicator layer	Relative Weight	Third-level indicator layer	Relative Weight
<i>M</i>	<i>A1</i>	0.36	<i>B1</i>	0.63	<i>C1</i>	0.30
					<i>C2</i>	0.22
					<i>C3</i>	0.19
					<i>C4</i>	0.29
	<i>A2</i>	0.16	<i>B2</i>	0.37	<i>C5</i>	0.36
					<i>C6</i>	0.30
					<i>C7</i>	0.33
					<i>C8</i>	0.60
					<i>C9</i>	0.40
					<i>C10</i>	0.35
					<i>C11</i>	0.20
	<i>A3</i>	0.22	<i>B3</i>	0.38	<i>C12</i>	0.23
					<i>C13</i>	0.22
					<i>C14</i>	0.24
					<i>C15</i>	0.27
					<i>C16</i>	0.27
					<i>C17</i>	0.22
<i>A4</i>	0.22	<i>B4</i>	0.62	<i>C12</i>	0.23	
				<i>C13</i>	0.22	
				<i>C14</i>	0.24	
<i>A5</i>	0.22	<i>B5</i>	1.00	<i>C15</i>	0.27	
				<i>C16</i>	0.27	

**Table 5.** Continued

			<i>B6</i>	0.45	<i>C18</i>	1.00
<i>M</i>	<i>A4</i>	0.26	<i>B7</i>	0.55	<i>C19</i>	0.40
					<i>C20</i>	0.60

### 3.3.2. Fuzzy comprehensive evaluation

The basic idea of the fuzzy comprehensive evaluation method is based on fuzzy mathematics theory. It decomposes the evaluation objective into a fuzzy set composed of multiple sub-indicators to process uncertain information. The specific process includes: establishing an evaluation factor set, a comment set, determining membership functions, and constructing a fuzzy evaluation matrix. The fuzzy comprehensive evaluation method generally follows the steps below:

#### 3.3.2.1. Establishment of fuzzy evaluation factor set

The evaluation factor set in this paper is divided into four levels: the target level, the first-level indicator level, the second-level indicator level, and the third-level indicator level.

#### 3.3.2.2. Establishment of comment set

This paper sets the comment set for indicators as  $V = \{Good, Fairly\ good, Medium, Relatively\ poor, Poor\}$ , and constructs the scoring vector according to the median of each evaluation grade interval:  $V = \{90, 70, 50, 30, 10\}$ . This scoring interval is adopted to determine the evaluation results of the target comments, with details shown in Appendix 5.

#### 3.3.2.3. Establishment of fuzzy evaluation matrix

In this study, several evaluators were invited to score each indicator based on the comment set. After quantifying the scores, the membership degree of each factor corresponding to each evaluation grade was obtained. The membership degree  $F_{ij}$  represents the membership degree of the  $i$ -th factor under the  $j$ -th evaluation grade, calculated as the ratio of the number of evaluators who gave that grade to the total number of participants. Thus, the fuzzy relation matrix is constructed.

#### 3.3.2.4. Calculation of membership degree

When calculating membership degree, this paper adopts the weighted average operator to multiply the weight  $W_i$  of indicators at each level with the corresponding fuzzy matrix  $F_{ij}$ , obtaining the membership degree matrix  $Z_{ij}$  of the second-level indicator layer. Furthermore, the weight  $W_i$  of the second-level indicator layer is multiplied by the membership degree matrix  $Z_{ij}$  to obtain the membership degree matrix  $Z_{ij}$  of the first-level indicator layer. Finally, the membership degree  $Z$  of the target layer is obtained by multiplying the weight  $W_i$  of the first-level indicator layer with the membership degree matrix  $Z_{ij}$ . The specific formulas are as follows, see Table 6:

**Table 6.** Fuzzy evaluation factor set

Evaluation Factor Set	Set Elements
Target Layer Factor Set	$S = \{A1, A2, A3, A4\}$
First-level Indicator Layer	$S_{A1} = \{B1, B2\}$
	$S_{A2} = \{B3, B4\}$
	$S_{A3} = \{B5\}$
	$S_{A4} = \{B6, B7\}$

**Table 6.** Continued

Second-level Indicator Layer	$S_{B1} = \{C1, C2, C3, C4\}$
	$S_{B2} = \{C5, C6, C7\}$
	$S_{B3} = \{C8, C9\}$
	$S_{B4} = \{C10, C11, C12, C13\}$
	$S_{B5} = \{C14, C15, C16, C17\}$
	$S_{B6} = \{C18\}$
	$S_{B7} = \{C19, C20\}$

3.3.2.5. Establishment of fuzzy evaluation weight set

Convert the relative weights calculated above into a weight set. See Table 7.

**Table 7.** Weights of evaluation indicators

Evaluation Weight Set	Set Elements
Target Layer Weight Set	$W = \{0.36, 0.16, 0.22, 0.26\}$
First-level Indicator Layer Weight Set	$W_{A1} = \{0.63, 0.37\}$
	$W_{A2} = \{0.38, 0.62\}$
	$W_{A3} = \{1.0\}$
	$W_{A4} = \{0.45, 0.55\}$
	$W_{B1} = \{0.3, 0.22, 0.19, 0.29\}$
	$W_{B2} = \{0.36, 0.3, 0.33\}$
	$W_{B3} = \{0.6, 0.4\}$
Second-level Indicator Layer Weight Set	$W_{B4} = \{0.35, 0.2, 0.23, 0.22\}$
	$W_{B5} = \{0.24, 0.27, 0.27, 0.227\}$
	$W_{B6} = \{1.0\}$
	$W_{B7} = \{0.4, 0.6\}$

**Table 8.** Score interval of evaluation grades

Evaluation Index	Good	Fairly Good	Medium	Relatively Poor	Poor
Median	90	70	50	30	10
Score Interval	(80-100]	(60-80]	(40-60]	(20-40]	[0-20]

Evaluation matrix is shown as follows (see Formula (1)).

$$F_{ij} = \begin{bmatrix} F_{i1}^{j1} & F_{i1}^{j2} & \dots & F_{i1}^{j5} \\ F_{i2}^{j1} & F_{i2}^{j2} & \dots & F_{i2}^{j5} \\ \dots & \dots & \dots & \dots \\ F_{in}^{j1} & F_{in}^{j2} & \dots & F_{in}^{j5} \end{bmatrix} \tag{1}$$

The weighted score calculation formula is shown as follows (see formula (2)).

$$Z_{ij} = W_i * F_{ij} = [z_{ij}^1 z_{ij}^2 z_{ij}^3 \dots z_{ij}^n] \quad (2)$$

### 3.3.2.6. Score calculation

The score corresponding to indicators at each level shall be calculated by multiplying the membership degree by the comment set of the indicator. The formula is as follows (see formula (3)):

$$Y_{ij} = [z_{ij}^1 z_{ij}^2 z_{ij}^3 \dots z_{ij}^n] \times [9070503010]^T \quad (3)$$

The calculated score corresponds to the above Score Interval of Evaluation Grades (Table 8), which serves as the final fuzzy evaluation result for indicators at all levels.

### 3.3.2.7. Calculation process (see Appendix IV, V)

### 3.3.2.8. Evaluation results

According to the membership degree results of first-level, second-level and third-level indicators, the fuzzy comprehensive evaluation results of each indicator can be obtained, as shown in Table 9 below:

a. Corresponding comments and scores of the target layer are as follows (see Table 9):

**Table 9.** Corresponding comments and score set of the target layer

Target Layer	Final Score	Evaluation Criterion
<i>M</i>	60.78	<i>Fairly good</i>

b. Corresponding comments and scores of the first-level indicator layer are as follows (see Table 10):

**Table 10.** Corresponding comments and scores of the first-level indicator layer

First-level Indicator Layer	Final Score	Evaluation Criterion
<i>A1</i>	49.10	<i>Medium</i>
<i>A2</i>	73.41	<i>Fairly good</i>
<i>A3</i>	79.87	<i>Fairly good</i>
<i>A4</i>	53.04	<i>Medium</i>

c. Corresponding comments and scores of the Second-level indicator layer are as follows (see Table 11):

**Table 11.** Corresponding comments and scores of the second-level indicator layer

Second-level Indicator	Final Score	Evaluation Criterion
<i>B1</i>	55.68	<i>Medium</i>
<i>B2</i>	37.89	<i>Relatively poor</i>
<i>B3</i>	57.80	<i>Medium</i>
<i>B4</i>	82.97	<i>Good</i>
<i>B5</i>	79.87	<i>Fairly good</i>
<i>B6</i>	57.00	<i>Medium</i>
<i>B7</i>	49.80	<i>Medium</i>

d. Corresponding comments and scores of the Third-level indicator layer are as follows (see Table 12):

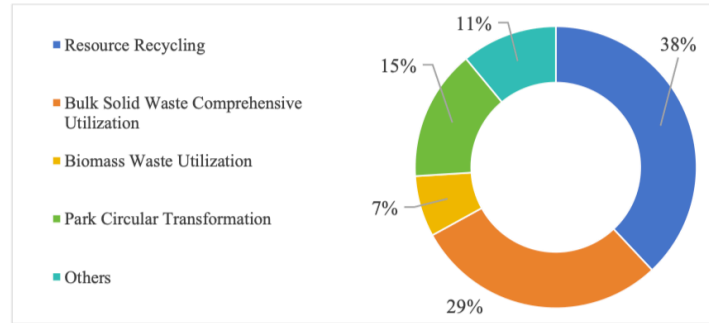
**Table 12.** Corresponding comments and scores of the third-level indicator layer

Third-level indicator layer	Final Score	Evaluation Criterion
<i>C1</i>	39.00	<i>Relatively poor</i>
<i>C2</i>	58.00	<i>Medium</i>
<i>C3</i>	59.00	<i>Medium</i>
<i>C4</i>	69.00	<i>Fairly good</i>
<i>C5</i>	37.00	<i>Relatively poor</i>
<i>C6</i>	39.00	<i>Relatively poor</i>
<i>C7</i>	39.00	<i>Relatively poor</i>
<i>C8</i>	57.00	<i>Medium</i>
<i>C9</i>	59.00	<i>Medium</i>
<i>C10</i>	87.00	<i>Good</i>
<i>C11</i>	86.00	<i>Good</i>
<i>C12</i>	78.00	<i>Fairly good</i>
<i>C13</i>	79.00	<i>Fairly good</i>
<i>C14</i>	85.00	<i>Good</i>
<i>C15</i>	87.00	<i>Good</i>
<i>C16</i>	86.00	<i>Good</i>
<i>C17</i>	58.00	<i>Medium</i>
<i>C18</i>	57.00	<i>Medium</i>
<i>C19</i>	39.00	<i>Relatively poor</i>
<i>C20</i>	57.00	<i>Medium</i>

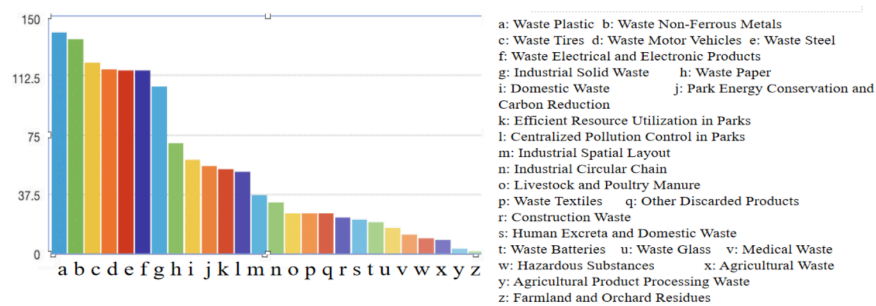
#### **4. Effectiveness analysis of circular economy empowering the "Dual Carbon" strategy: taking recycled aluminum as an example**

Through questionnaires, interviews and empirical data analysis, the research team has basically grasped the current development status of circular economy in Quetang Town, and explored the key factors for its coordination with the "Dual Carbon" strategy. Subsequently, combined with residents' opinions and focusing on four major circular economy fields, 400 targeted questionnaires were distributed and collected among residents aged 20–35 in Quetang Town (see Appendix III), and the results were visualized.

According to the survey results, among fields of Resource Recycling, Bulk Solid Waste Comprehensive Utilization, Biomass Waste Utilization, and Park Circular Transformation, Resource Recycling and Bulk Solid Waste Comprehensive Utilization have larger weights (see Figure 11). The resource recycling industry in the town mainly includes waste steel, waste tires, waste non-ferrous metals, etc. In terms of comprehensive utilization of bulk solid waste, it mainly involves the treatment and reuse of industrial solid waste and domestic waste (see Figure 12).



**Figure 11.** Analysis of carbon emission reduction contribution in major fields of Quetang Town



**Figure 12.** Analysis of carbon reduction contribution of circular industries in Quetang Town

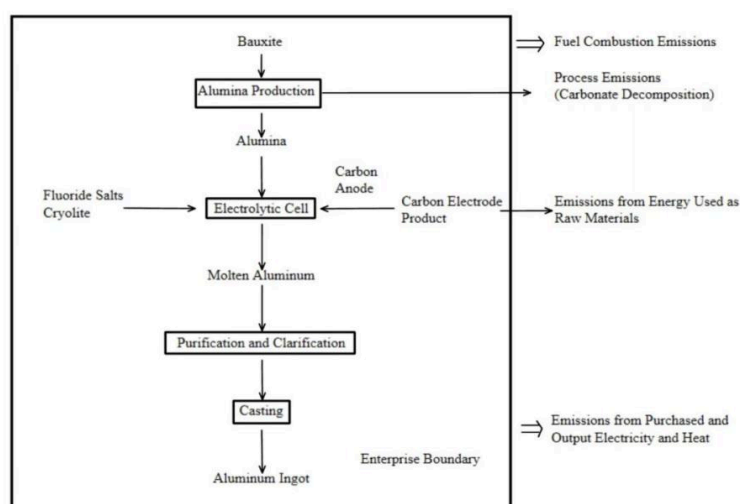
Combined with the advantageous industries of Quetang Town and the leading enterprises in its circular economy industrial park, to evaluate the actual contribution of the circular economy to the "Dual Carbon" strategy, the research team selected the recycled aluminum industry as the research object, adopted a scientific calculation model, comprehensively analyzed relevant data, and drew conclusions through model calculation and result discussion. The following is a detailed description of the calculation method, boundary setting and research process.

#### 4.1. Selection of calculation model

The main calculation methods for carbon emissions include three commonly used approaches: the emission factor method (IPCC method), mass balance method, and actual measurement method. As the most widely adopted carbon accounting method, the emission factor method estimates greenhouse gas emissions through standardized emission factors and is applicable to both macro and micro-level carbon accounting. The mass balance method calculates greenhouse gas emissions by analyzing material flows in the production process, making it suitable for production with continuous raw material input, such as aluminum smelting. The actual measurement method obtains emission data through on-site or off-site monitoring; although it has high accuracy, its application is limited due to high costs and implementation difficulties. Considering data availability and accuracy comprehensively, this study adopts the emission factor method (IPCC method) as the calculation model to ensure the accuracy and comparability of results and fully reflect carbon emissions in the implementation of the "Dual Carbon" strategy.

## 4.2. Calculation boundary

In the greenhouse gas accounting of aluminum smelting enterprises, the calculation boundary mainly covers the following emission sources: First, carbon dioxide emissions from fuel combustion. In the smelting process, the combustion of energy fuels is a key source of greenhouse gas emissions, which is quantified by combining fuel consumption and carbon dioxide emission. Second, the use of energy as raw materials also generates carbon emissions, especially carbon dioxide emissions from the consumption of carbon anodes, which shall be quantified according to the consumption ratio. For process emissions, certain chemical reactions in the smelting process produce greenhouse gases, such as perfluorocarbon emissions caused by anode effects and carbon dioxide released during carbonate decomposition, both of which shall be included in the calculation. Finally, indirect carbon emissions from purchased electricity and heat are calculated based on different power sources (e.g., thermal power or renewable energy) to determine the corresponding carbon dioxide emissions (see Figure 13).



**Figure 13.** Schematic diagram of greenhouse gas accounting boundary for aluminum smelting enterprises

## 4.3. Calculation steps and accounting methods (see Appendix VI)

### 4.4. Case analysis—taking hongteng aluminum industry, a leading enterprise in Quetang Circular Economy Industrial Park, as an example

Hunan Hongteng Aluminum Co., Ltd. located in the core area of Quetang Circular Economy Industrial Park in Shaoyang City, Hunan Hongteng Aluminum Co., Ltd. is one of the core enterprises of the park. Established in June 2020, the company covers a total plant area of 70 mu with a total investment of 360 million RMB. As a private enterprise, its main business covers the recycling, processing and reuse of waste aluminum products. Hongteng Aluminum's main products include aluminum rods, aluminum alloy round ingots, aluminum profiles, etc., all of which are important basic materials in the aluminum products industry. Relying on its outstanding performance in industrial transformation and green production, Hongteng Aluminum has successively won the honorary title of "Excellent Private Enterprise" of Xinshao County in 2023 and the "Outstanding Contribution Enterprise" award for high-quality development of the year. It holds an important position in regional economic development and has made positive contributions to promoting green and sustainable development and achieving the goals of the "Dual Carbon" strategy. Through the recycling and reprocessing of waste aluminum products, Hongteng Aluminum has played an active role in reducing resource

waste, improving resource utilization efficiency and promoting sustainable economic development, and is of exemplary significance in promoting circular economy and implementing the "Dual Carbon" strategy.

#### 4.4.1. Carbon emission boundary of Hongteng Aluminum

During the investigation of Hongteng Aluminum, the research team conducted a detailed analysis of the company's comprehensive utilization and deep processing project with an annual output of 150,000 tons of recycled aluminum, and determined the greenhouse gas emission boundary of the project (see Table 13). According to the production process and operation flow, the following emission sources are included in the accounting scope: First, since no carbonate materials such as limestone or soda ash are used in Hongteng Aluminum's production process, process emissions therefrom are excluded. Second, the project does not involve heat purchase or power output, so no relevant emissions need to be calculated. The main sources of greenhouse gas emissions are:

**Direct emissions:** Carbon dioxide emissions from the combustion of natural gas fuel, which require key attention and quantification.

**Indirect emissions:** Carbon dioxide emissions from purchased electricity, which shall be calculated based on the energy structure of the power source (e.g., thermal power generation or renewable energy power generation).

By clarifying these emission boundaries, the research team has provided theoretical support and data basis for evaluating the project's contribution to achieving the "Dual Carbon" goals.

**Table 13.** Carbon emission source identification

Emission Type		Specific Facilities	Greenhouse Gas Type					
			CO <sub>2</sub>	CH <sub>4</sub>	N <sub>2</sub> O	HFCs	PFCs	SF <sub>6</sub>
Direct Emissions	Fuel Combustion	Smelting Furnace, Refining Furnace	√		*			
		Aging Furnace, Aluminum Rod Heating Furnace	√					
Indirect Emissions	Purchased Electricity	Fans, Pump Systems and Other Electrical Equipment	√					

#### 4.4.2. Calculation results

The calculation results are shown in Table 14.

**Table 14.** Total greenhouse gas emissions

Item	Carbon Emissions from Fuel Combustion	Total Carbon Emissions from Purchased Electricity	Total
Whole Plant	23,027.73	21,038.15	44,065.88

#### 4.4.3. Discussion on results

To further explore the application of recycled aluminum in energy conservation and emission reduction, the research team consulted a large number of relevant documents and conducted in-depth interviews with industry experts, and drew the following conclusions: Compared with primary aluminum production, the energy consumption per ton of recycled aluminum is only about 5% of that from bauxite-based aluminum

production, with lower production costs and less investment required. With continuous technological progress and the expansion of application fields, recycled aluminum has been gradually applied in construction, communications, electronics, packaging and other industries. Especially in the automotive industry, innovative applications of recycled aluminum are constantly driving industrial development.

The recycling, separation, sorting and regeneration of waste aluminum can not only effectively alleviate the problems of resource shortage and energy tension, but also help reduce environmental pollution and promote the development of circular economy. The development of the recycled aluminum industry has important practical and strategic significance for achieving the goals of the "Dual Carbon" strategy and promoting the transformation of the economy toward green, low-carbon and sustainable development. With continuous technological innovation and improvement, the recycled aluminum industry not only has huge development potential, but also provides an important solution for the efficient utilization of global resources and environmental protection.

## **5. Countermeasures and suggestions for circular economy empowering the "Dual Carbon" strategy**

### **5.1. Optimize resource acquisition channels to ensure stable raw material supply**

Enterprises should obtain raw materials through diversified channels to avoid over-reliance on a single source. They can cooperate with local governments, waste recycling companies, industry associations and other institutions to establish a waste recycling and reuse network, ensuring the continuity and stability of raw material supply. In addition, the government should promote the marketization of resource recovery, establish a standardized waste recycling market, and encourage enterprises to form long-term partnerships with waste treatment companies and recyclers. Guided by market mechanisms and supported by policies, the commercialization level of waste resource utilization will be improved.

### **5.2. Improve production efficiency and management level of enterprises to enhance market competitiveness**

Circular economy enterprises should adopt advanced technologies, optimize production processes, improve energy efficiency, and reduce costs. Increasing R&D investment and introducing digital-intelligent equipment helps cut energy waste, enhance efficiency, and boost product competitiveness. Enterprises should strengthen management innovation and lean production to improve operational efficiency, realize real-time production monitoring via information systems, reduce resource waste, and optimize supply chain to lower inventory and logistics costs.

In terms of products, enterprises should enhance innovation for key products such as recycled aluminum to improve added value and quality to meet the growing demand for green products.

### **5.3. Two-way improvement of industrial chain and policies to promote the implementation of the "Dual Carbon" strategy**

Achieving the "Dual Carbon" goals requires joint efforts, closer industrial chain coordination, and stronger policy support. All links should be closely connected to ensure efficient resource circulation and reuse. Enterprises in the circular economy chain should strengthen cooperation and share information and resources. For example, waste treatment and renewable resource enterprises can cooperate to realize efficient waste recovery and recycling.

The government should further improve circular economy policies, enhance support for green industries, and offer tax incentives and subsidies to promote corporate green transformation. Detailed implementation rules for the "Dual Carbon" strategy should be issued to provide clear guidance, and an effective supervision mechanism should be established.

## 6. Conclusion

This study takes the Circular Economy Industrial Park in Quetang Town, Hunan Province as the research object, and systematically explores the paths and mechanisms of circular economy empowering the "Dual Carbon" strategy by comprehensively applying the Analytic Hierarchy Process (AHP), fuzzy comprehensive evaluation and case study method. The evaluation results show that the overall development of circular economy in Quetang Town is at a fairly good level. Among them, resource recycling and environmental emission reduction achieve outstanding effects, while the economic structure and social indicators still need to be improved. The calculation based on recycled aluminum enterprises shows that the energy consumption per ton of recycled aluminum is only about 5% of that of primary aluminum. Through three core paths: resource recycling, clean energy substitution and collaborative optimization of industrial chain, it can significantly reduce energy consumption and carbon emission intensity, with remarkable effects of energy conservation and carbon reduction. The study confirms that circular economy is a crucial path to promote the green transformation of energy-intensive industries and help regions achieve the "Dual Carbon" goals. In the future, the low-carbon development potential of circular economy can be further released by optimizing resource supply, improving the technological and management level of enterprises, and perfecting the industrial chain coordination and policy support system.

## Funding project

National Students' Platform for Innovation and Entrepreneurship Training Program (202510542060).

## References

- [1] State Council of the People's Republic of China. (2005). Several opinions on accelerating the development of circular economy. *Gazette of the State Council of the People's Republic of China*, (23), 10–14.
- [2] Lin, B. (2022). China's high-quality economic growth in the process of carbon neutrality. *Economic Research Journal*, 57(1), 56–71.
- [3] Bruel, A., Kronenberg, J., Troussier, N., & Guillaume, B. (2019). Linking industrial ecology and ecological economics: A theoretical and empirical foundation for the circular economy. *Journal of Industrial Ecology*, 23(1), 12–21. <https://doi.org/10.1111/jiec.12714>
- [4] Wu, J., & Cao, Y. (2021). Circular economy promotes high-quality development of industrial system in the context of the new pattern of "domestic circulation and dual circulation". *Environmental Protection*, 49(5), 11–14.
- [5] Zhang, B., & Huang, X. (2005). Research on circular economy development indicator system and demonstrable assessment. *China Population, Resources and Environment*, (3), 22–25.
- [6] Wang, M., & Feng, Z. (2012). Research on evaluation index system of circular economy innovation. *China Population, Resources and Environment*, 22(4), 163–166.
- [7] Li, J. (2022). Opportunities, challenges and strategies for the development of circular economy under the "dual carbon" background. *Modern Management Science*, (4), 15–23.

- [8] Liu, J., & Li, M. (2018). Empirical analysis on the development of recycling economy in Jiangsu Province in the transitional period. *Ecological Economy*, 34(9), 81–87.
- [9] Rizos, V., Behrens, A., van der Gaast, W., Hofman, E., Ioannou, A., Kafyeye, T., Flamos, A., Rinaldi, R., Papadelis, S., Hirschnitz-Garbers, M., & Topi, C. (2016). Implementation of circular economy business models by small and medium-sized enterprises (SMEs): Barriers and enablers. *Sustainability*, 8(11), Article 1212. <https://doi.org/10.3390/su8111212>
- [10] Research Group of "Circular Economy Evaluation Index System" from National Bureau of Statistics, Li, D., & Zhang, W. (2006). The research of system of indicators to evaluate cycling economy. *Statistical Research*, (9), 23–26.
- [11] Zhao, H., & Guo, C. (2020). Research on dynamic comprehensive evaluation of green, low-carbon and circular development in Chinese provinces. *The World of Survey and Research*, (4), 39–48.
- [12] Feng, Z., Liu, Y., Zhou, C., Luo, Y., & Yu, L. (2008). Research on development mode of circular economy eco-industrial parks in China. *China Soft Science*, (4), 1–10.
- [13] Zhou, H., Huo, L., Guan, Y., Li, C., & Zhou, C. (2021). Carbon circular economy: Connotation, practice and its far-reaching impact on carbon neutrality. *Ecological Economy*, 37(9), 13–26.
- [14] Tang, R., & Fan, S. (2022). On the value concept, internal mechanism and path choice of "double carbon" strategy to promote the realization of common prosperity. *Journal of Guizhou Normal University (Social Sciences Edition)*, (6), 78–90.
- [15] Wang, Z., & Peng, F. (2022). *Research on global carbon neutrality strategy* (pp. 1–2). Shanghai Academy of Social Sciences Press.
- [16] Xue, F., & Zhou, M. (2021). Research on the emission reduction effect of the scale of China's carbon trading market. *East China Economy Management*, 35(6), 11–21.
- [17] Zhou, C., Zhang, R., Loginova, J., Sharma, V., Zhang, Z., & Qian, Z. (2022). Institutional logic of carbon neutrality policies in China: What can we learn? *Energies*, 15(12), Article 4397. <https://doi.org/10.3390/en15124397>
- [18] Feng, Z., Cheng, S., Qu, G., Cui, Y., & Ye, J. (2023). Research on theoretical mechanism and promotion path of digital economy driving China's green development under "double carbon" background. *International Journal of Environmental Research and Public Health*, 20(1), Article 437. <https://doi.org/10.3390/ijerph20010437>
- [19] Liu, L., & Wang, M. (2024). Digital economy empowers "dual carbon" goals: Influence mechanism and implementation path. *Climate Change Research*, 20(4), 440–453.
- [20] Zheng, X., Zhang, Y., Zhao, Z., & Lu, M. (2025). Promoting high-quality development to solidify the foundation for basically realizing socialist modernization: Special articles for studying and implementing the spirit of the fourth plenary session of the 20th CPC central committee. *Economic Perspectives*, (11), 5–22.
- [21] Yan, Y., Yuan, H., Zhang, L., & Wang, Q. (2022). Impact of dual carbon targets on China's economic growth and risk challenge. *Exploration of Financial Theory*, (2), 10–18.
- [22] Hendrianto, F. C., Negara, K. P., & Devia, Y. P. (2024). Analyzing critical success factors for implementing a circular economy in East Java's construction industries using fuzzy synthetic evaluation. *Civil and Environmental Engineering*, 20(2), 1077–1094. <https://doi.org/10.2478/cee-2024-0001>
- [23] Chen, L., & Wen, Z. (2025). Provide systematic solutions to achieve carbon neutrality. *China Sustainability Tribune*, (Z1), 26–29.
- [24] Chen, J. (2022). Economic circulations under the "carbon peaking and carbon neutrality" goals: Low-carbonization of economic circulations and circulation of low-carbon industries. *Economist*, (9), 78–87.
- [25] He, H. (2024). *Problems and countermeasures for the high-quality development of circular economy under the "dual carbon" strategy background*. In Proceedings of the symposium on social and economic sustainable development in the new era (pp. 4–5). China Wisdom Engineering Association.

## Appendix I. Questionnaire on the understanding of circular economy

Gender \_\_\_\_\_ Date of Birth \_\_\_\_\_ Family Size \_\_\_\_\_ Occupation \_\_\_\_\_ Education \_\_\_\_\_

Please tick or write your answer in the brackets; multiple choices are allowed.

1. How well do you understand the circular economy? ( )
  - A. Very familiar B. Heard of it C. Not very familiar D. Never heard of it
2. [Multiple choices] What does the circular economy mean to you? ( )
  - A. Conserving resources B. Reusing certain resources circularly C. Considering environmental impacts in development D. Maximizing the circulation and utilization of resources
3. What important fields of the circular economy do you know? [Multiple choices] ( )
  - A. Utilization of renewable metal resources such as scrap steel
  - B. Production of solid waste-based cementitious materials to replace cement
  - C. Clean energy utilization of biomass waste such as domestic waste and kitchen waste in various forms
  - D. Recovery of waste heat and residual energy from industrial sectors such as electric power, metallurgy, building materials and chemical industry
  - E. Circular linkage between leading industries and venous industries
  - F. Remanufacturing as an alternative to new original products
  - G. Others
4. Do you think it is necessary to popularize knowledge about the circular economy to promote its development? ( )
  - A. Very necessary B. Necessary C. Ordinary, not very useful D. Unnecessary
5. Would you be willing to buy recyclable and reusable products if they are offered with discounts or reward points? ( )
  - A. Destined to B. It might, but depends on other factors C. Buying whatever cheaper, not caring Recycling&Reusing D. Will not purchase
6. Can you repair damaged items for reuse to extend their service life? ( )
  - A. Yes B. Sometimes C. Never
7. Would you choose green furniture and eco-friendly decoration if their prices are slightly higher? ( )
  - A. Willing to B. Unwilling to C. Not to matter
8. [Multiple choices] What do you think are the constraints on the development of the local circular economy? ( )
  - A. Difficulties in the development and promotion of circular economy products B. Insufficient awareness of circular utilization C. Inadequate publicity and policy implementation of the circular economy D. Cumbersome recycling process E. Others
9. [Multiple choices] What do you think are the key factors for developing the circular economy? ( )
  - A. Publicizing its connotation and policies B. Government support C. Public consciousness D. Innovation of circular products E. Others
10. In which aspects do you think the local circular economy can most affect the national "carbon peaking and carbon neutrality" strategy?

## Appendix II. Questionnaire on the weight of circular economy indicator system

**Table A1.** Scoring criteria

No.	Scale Meaning	Ratio
1	When comparing element i with element j, i is equally important to j	$a_{ij} = 1$
2	When comparing element i with element j, i is slightly more important than j	$a_{ij} = 3$
3	When comparing element i with element j, i is obviously more important than j	$a_{ij} = 5$
4	When comparing element i with element j, i is strongly more important than j	$a_{ij} = 7$
5	When comparing element i with element j, i is absolutely more important than j	$a_{ij} = 9$
6	The importance of element i relative to j lies between the above judgments	$a_{ij} = 2, 4, 6, 8$
7	If the relative importance scale of i to j is $a_{ij}$ , then the scale of j to i is $a_{ji} = 1/a_{ij}$	Reciprocal

Judgment example: If you think that A4 International Market Share in the first column is much more important than A5 R&D Capability in the second column in the table below, fill in 7 in the corresponding comparison cell; conversely, the value of A5 relative to A4 is 1/7. (For brevity, the variable names from A1 to C20 are referred to Table 1 in the main text.)

### 1. Importance comparison of first-level indicators with respect to the target layer

**Table A2.** Judgment on the importance of first-level indicators for circular economy in Quetang Town

<i>M</i>	<i>A1</i>	<i>A2</i>	<i>A3</i>	<i>A4</i>
<i>A1</i>	1			
<i>A2</i>		1		
<i>A3</i>			1	
<i>A4</i>				1

### 2. Importance comparison of second-level indicators with respect to first-level indicators

**Table A3.** Judgment on the importance of each indicator to A1

<i>A1</i>	<i>B1</i>	<i>B2</i>
<i>B1</i>	1	
<i>B2</i>		1

**Table A4.** Judgment on the importance of each indicator to A2

<i>A2</i>	<i>B3</i>	<i>B4</i>
<i>B3</i>	1	
<i>B4</i>		1

**Table A5.** Judgment on the importance of each indicator to A4

<i>A4</i>	<i>B6</i>	<i>B7</i>
<i>B6</i>	1	
<i>B7</i>		1

## 3. Importance comparison of third-level indicators with respect to second-level indicators

**Table A6.** Judgment on the importance of each indicator to B1

<i>B1</i>	<i>C1</i>	<i>C2</i>	<i>C3</i>	<i>C4</i>
<i>C1</i>	1			
<i>C2</i>		1		
<i>C3</i>			1	
<i>C4</i>				1

**Table A7.** Judgment on the importance of each indicator to B2

<i>B2</i>	<i>C5</i>	<i>C6</i>	<i>C7</i>
<i>C5</i>	1		
<i>C6</i>		1	
<i>C7</i>			1

**Table A8.** Judgment on the importance of each indicator to B3

<i>B3</i>	<i>C8</i>	<i>C9</i>
<i>C8</i>	1	
<i>C9</i>		1

**Table A9.** Judgment on the importance of each indicator to B4

<i>B4</i>	<i>C10</i>	<i>C11</i>	<i>C12</i>	<i>C13</i>
<i>C10</i>	1			
<i>C11</i>		1		
<i>C12</i>			1	
<i>C13</i>				1

**Table A10.** Judgment on the importance of each indicator to B5

<i>B5</i>	<i>C14</i>	<i>C15</i>	<i>C16</i>	<i>C17</i>
<i>C14</i>	1			
<i>C15</i>		1		
<i>C16</i>			1	
<i>C17</i>				1

**Table A11.** Judgment on the importance of each indicator to B7

<i>B7</i>	<i>C19</i>	<i>C20</i>
<i>C19</i>	1	
<i>C20</i>		1

### Appendix III. Questionnaire on the specific situation of circular economy in quetang town

Gender \_\_\_\_\_ Date of Birth \_\_\_\_\_ Family Size \_\_\_\_\_ Occupation \_\_\_\_\_ Education \_\_\_\_\_

Please tick or write your answer in the brackets; multiple choices are allowed.

1. [Multiple choices] Which aspect of the town do you think has the greatest impact on achieving carbon emission reduction? ()

A. Resource recycling B. bulk solid waste comprehensive utilization C. biomass waste utilization of D. park circular transformation E. Remanufacturing of waste products F. Others G. Not familiar

2. [Multiple choices] What types of products are mainly involved in the resource recycling and reuse of the town? ()

A. waste steel B. Waste non-ferrous metals C. Waste plastics D. Waste paper E. Waste tires F. Waste electrical and electronic products G. End-of-life vehicles H. Waste textiles I. Waste glass J. Waste batteries K. Other scrapped products L. Not familiar

3. [Multiple choices] What are the main aspects of the comprehensive utilization of bulk solid waste in the town? ()

A. Domestic waste B. Industrial solid waste C. Hazardous substances D. Medical waste E. Agricultural waste F. Construction waste G. Not familiar

4. [Multiple choices] What are the main aspects of biomass waste utilization in the town? ()

A. farmland and orchards residues B. Livestock and poultry manure C. agricultural product processing waste D. Human excreta and domestic waste E. Not familiar

5. [Multiple choices] What are the main aspects of the circular transformation of the town's industrial park?

A. Industrial spatial layout B. Industrial circular chain C. Energy conservation and carbon reduction in the park D. Efficient resource utilization in the park E. Centralized pollution control in the park F. Not familiar

### Appendix IV. Calculation process of analytic hierarchy process

1. Construction of the Analytic Hierarchy Process (AHP) model

(1) Establish the judgment matrix

$$A = \begin{bmatrix} a_{11} & a_{12} & \cdots & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & \cdots & a_{2n} \\ \cdots & \cdots & a_{ij} & \cdots & \cdots \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ a_{n1} & a_{n2} & \cdots & \cdots & a_{nn} \end{bmatrix}$$

In the matrix,  $a_{ij}$ , represents the relative importance of element  $A_i$  over element  $A_j$ , If the former is more important, then  $> 1$ , if the two are equally important, then = 1.

(2) Judgment of matrix element importance

**Table B1.** Elative importance scale

Scale	Meaning
1	Two factors are equally important
3	The former factor is slightly more important than the latter
5	The former factor is obviously more important than the latter
7	The former factor is strongly more important than the latter
9	The former factor is extremely more important than the latter
2, 4, 6, 8	Intermediate values between adjacent scales
Reciprocals of the above values	The reciprocal value when comparing two factors in reverse order

(3) Calculation of the indicator weight vector

Steps of the Normalization Method:

First, Normalize the judgment matrix using the following formula (1):

$$\bar{a}_{ij} = \frac{a_{ij}}{\sum_{i=1}^n a_{ij}} \quad (i, j = 1, 2, \dots, n) \tag{1}$$

Second, Sum the elements in the normalized matrix (2).

$$\bar{w}_i = \sum_{j=1}^n \bar{a}_{ij} \quad (i, j = 1, 2, \dots, n) \tag{2}$$

Third, Further normalize the weight vector  $\bar{w}_i$  obtained above (3):

$$w_i = \frac{\bar{w}_i}{\sum_{i=1}^n \bar{w}_i} \quad (i = 1, 2, \dots, n) \tag{3}$$

Finally, Calculate the maximum eigenvalue of the judgment matrix A (4).

$$\lambda_{max} = \frac{1}{n} \sum_{i=1}^n \frac{(Aw)_i}{w_i} \tag{4}$$

(4) Consistency test

The consistency test is performed on the previously obtained weight vector and eigenvalue. If the test is passed, the judgment matrix is considered reasonable and interpretable.

Let CI denote the consistency index. The calculation formula is as follows (5):

$$CI = \frac{\lambda_{max} - n}{n - 1} \tag{5}$$

**Table B2.** Random consistency index RI

N	RI
1	0
2	0
3	0.52
4	0.89
5	1.12
6	1.24
7	1.32
8	1.41
9	1.45
10	1.49
11	1.51

The RI value can be determined based on the value of n, and then the Consistency Ratio (CR) is calculated as  $CR = \frac{CI}{RI}$

The consistency test is passed when  $CR < 0.1$ .

## 2. Construction of judgment matrix and calculation of weights

### (1) Weight analysis of first-level indicators

**Table B3.** Weight analysis of first-level indicators

	<i>A1</i>	<i>A2</i>	<i>A3</i>	<i>A4</i>	Weight
<i>A1</i>	1	1.9321	1.6558	1.5559	0.3582
<i>A2</i>	0.5176	1	0.6389	0.6208	0.1614
<i>A3</i>	0.6039	1.5651	1	0.7167	0.2175
<i>A4</i>	0.6427	1.6108	1.3952	1	0.2629

CR = 0.0075

### (2) Weight analysis of second-level indicators

All the tables below have passed the consistency test.

**Table B4.** Weight analysis of second-level indicators

	<i>B1</i>	<i>B2</i>	Weight
<i>B1</i>	1	1.7271	0.6333
<i>B2</i>	0.579	1	0.3667

**Table B5.** Weight analysis of second-level indicators

<i>A2</i>	<i>B3</i>	<i>B4</i>	Weight
<i>B3</i>	1	0.6163	0.3813
<i>B4</i>	1.6226	1	0.6187

**Table B6.** Weight analysis of second-level indicators

<i>A3</i>	<i>B5</i>	Weight
<i>B5</i>	1	1

**Table B7.** Weight analysis of second-level indicators

<i>A4</i>	<i>B6</i>	<i>B7</i>	Weight
<i>B6</i>	1	0.8215	0.451
<i>B7</i>	1.2173	1	0.549

(3) Weight analysis of third-level indicators (results display)

**Table B8.** Weight summary

Target Layer	First-level Indicator Layer	Relative Weight	Second-level indicator layer	Relative Weight	Third-level indicator layer	Relative Weight	Comprehensive Weight	Overall Weight
M	<i>A1</i>	0.3582	<i>B1</i>	0.6333	<i>C1</i>	0.3016	0.0684	18
					<i>C2</i>	0.2166	0.0491	12
					<i>C3</i>	0.1927	0.0437	8
					<i>C4</i>	0.2891	0.0656	17
					<i>C5</i>	0.361	0.047	10
					<i>C6</i>	0.305	0.0401	7
	<i>A2</i>	0.1614	<i>B2</i>	0.3667	<i>C7</i>	0.3335	0.0438	9
					<i>C8</i>	0.5965	0.0367	6
					<i>C9</i>	0.4035	0.0248	4
					<i>C10</i>	0.3491	0.0349	5
					<i>C11</i>	0.1995	0.0199	1
					<i>C12</i>	0.2266	0.0226	3
					<i>C13</i>	0.2248	0.0224	2

**Table B8.** Continued

				<i>C14</i>	0.241	0.052	13
				<i>C15</i>	0.270	0.058	16
<i>A3</i>	0.2175	<i>B5</i>	1	<i>C16</i>	0.267	0.058	15
<i>M</i>				<i>C17</i>	0.220	0.047	11
		<i>B6</i>	0.451	<i>C18</i>	1	0.118	20
<i>A4</i>	0.2629	<i>B7</i>	0.549	<i>C19</i>	0.395	0.057	14
				<i>C20</i>	0.6044	0.0872	19

## Appendix V. Calculation process of fuzzy comprehensive evaluation

To determine the evaluation grades of indicators at the third-level indicator layer, 20 experts were invited to evaluate the third-level indicators. After the experts submitted their questionnaires, the results were sorted out and presented in Table C1.

**Table C1.** Summary of evaluation grades for the third-level indicators

Third-level Indicators	Good	Fairly Good	Medium	Relatively Poor	Poor
<i>C1</i>	0	3	4	12	1
<i>C2</i>	4	4	9	2	1
<i>C3</i>	5	4	7	3	1
<i>C4</i>	7	7	4	2	0
<i>C5</i>	0	4	3	9	4
<i>C6</i>	0	4	4	9	3
<i>C7</i>	0	3	7	6	4
<i>C8</i>	5	2	9	3	1
<i>C9</i>	6	3	7	2	2
<i>C10</i>	18	1	1	0	0
<i>C11</i>	17	2	1	0	0
<i>C12</i>	12	5	2	1	0
<i>C13</i>	13	4	2	1	0
<i>C14</i>	16	3	1	0	0
<i>C15</i>	18	1	1	0	0
<i>C16</i>	17	2	1	0	0
<i>C17</i>	3	5	10	1	1
<i>C18</i>	4	5	7	2	2
<i>C19</i>	0	3	6	8	3
<i>C20</i>	4	5	7	2	2

By calculating the summarized data: the number of experts evaluating each grade for each indicator divided by the total number of experts yields the membership degree table of the third-level indicators.

**Table C2.** Membership degree of the third-level indicator layer

Third-level Indicators	Good	Fairly Good	Medium	Relatively Poor	Poor
<i>C1</i>	0.0000	0.1500	0.2000	0.6000	0.0500
<i>C2</i>	0.2000	0.2000	0.4500	0.1000	0.0500
<i>C3</i>	0.2500	0.2000	0.3500	0.1500	0.0500
<i>C4</i>	0.3500	0.3500	0.2000	0.1000	0.0000
<i>C5</i>	0.0000	0.2000	0.1500	0.4500	0.2000
<i>C6</i>	0.0000	0.2000	0.2000	0.4500	0.1500
<i>C7</i>	0.0000	0.1500	0.3500	0.3000	0.2000
<i>C8</i>	0.2500	0.1000	0.4500	0.1500	0.0500
<i>C9</i>	0.3000	0.1500	0.3500	0.1000	0.1000
<i>C10</i>	0.9000	0.0500	0.0500	0.0000	0.0000
<i>C11</i>	0.8500	0.1000	0.0500	0.0000	0.0000
<i>C12</i>	0.6000	0.2500	0.1000	0.0500	0.0000
<i>C13</i>	0.6500	0.2000	0.1000	0.0500	0.0000
<i>C14</i>	0.8000	0.1500	0.0500	0.0000	0.0000
<i>C15</i>	0.9000	0.0500	0.0500	0.0000	0.0000
<i>C16</i>	0.8500	0.1000	0.0500	0.0000	0.0000
<i>C17</i>	0.1500	0.2500	0.5000	0.0500	0.0500
<i>C18</i>	0.2000	0.2500	0.3500	0.1000	0.1000
<i>C19</i>	0.0000	0.1500	0.3000	0.4000	0.1500
<i>C20</i>	0.2000	0.2500	0.3500	0.1000	0.1000

1. Calculation results of membership degree for the second-level indicator layer

**Table C3.** Membership degree of the second-level indicator layer

Second-level Indicators	Good	Fairly Good	Medium	Relatively Poor	Poor
<i>B1</i>	0.193	0.2285	0.2835	0.2595	0.0355
<i>B2</i>	0	0.1815	0.2295	0.396	0.183
<i>B3</i>	0.27	0.12	0.41	0.13	0.07
<i>B4</i>	0.766	0.139	0.0725	0.0225	0
<i>B5</i>	0.6975	0.1315	0.149	0.011	0.011
<i>B6</i>	0.2	0.25	0.35	0.1	0.1
<i>B7</i>	0.12	0.21	0.33	0.22	0.12

2. Calculation results of fuzzy membership degree for the first-level indicator layer

**Table C4.** Membership degree of the first-level indicator layer

First-level Indicators	Good	Fairly Good	Medium	Relatively Poor	Poor
<i>A1</i>	0.1216	0.2111	0.2635	0.31	0.0901
<i>A2</i>	0.5775	0.1318	0.2007	0.0634	0.0266
<i>A3</i>	0.6975	0.1315	0.149	0.011	0.011
<i>A4</i>	0.156	0.228	0.339	0.166	0.111

### 3. Fuzzy comprehensive evaluation of the target layer

By summarizing the membership degree of the first-level indicator layer, the fuzzy comprehensive evaluation matrix of the target layer can be obtained. The fuzzy matrix  $F$  and weight set  $W$  are as follows (6):

$$F = \begin{bmatrix} 0.1216 & 0.2111 & 0.2635 & 0.31 & 0.0901 \\ 0.5775 & 0.1318 & 0.2007 & 0.0634 & 0.0266 \\ 0.6975 & 0.1315 & 0.149 & 0.011 & 0.011 \\ 0.156 & 0.228 & 0.339 & 0.166 & 0.111 \end{bmatrix} \quad (6)$$

$$W = [0.36 \quad 0.16 \quad 0.22 \quad 0.26]$$

Calculate the membership degree of the circular economy development evaluation index system  $M(7)$ .

$$Z = F \times W = [0.3302 \quad 0.1853 \quad 0.2479 \quad 0.1673 \quad 0.068] \quad (7)$$

Calculate the score of the circular economy development evaluation index system  $M(8)$ .

$$Y = Z \times V = [0.3302 \quad 0.1853 \quad 0.2479 \quad 0.1673 \quad 0.068] \times \begin{bmatrix} 90 \\ 70 \\ 50 \\ 30 \\ 10 \end{bmatrix} = 60.78 \quad (8)$$

## Appendix VI. (Excerpted from requirements for greenhouse gas emission accounting and reporting)

The content of this appendix is excerpted from the national standard GB/T 32151.4-2015 Requirements for Greenhouse Gas Emission Accounting and Reporting—Part 4: Aluminum Smelting Enterprises.

## Appendix VII. Collection of emission data of hongteng aluminum

**Table D1.** Collection of emission data of hongteng aluminum

No.	Parameter Symbol	Parameter Name	Unit	Value	Remarks
1		Natural gas			
1.2	$FC_{\text{natural}}$	Natural gas consumption	$10^4 \text{Nm}^3/\text{a}$	1,065	
1.2	$NCV_{\text{natural}}$	Average net calorific value	$\text{GJ}/10^4 \text{Nm}_3$	389.31	See Table a
1.3	$OF_{\text{natural}}$	Carbon oxidation rate	%	99	See Table a
1.4	$CC_{\text{natural}}$	Carbon content per unit calorific value	$\text{tC}/\text{GJ}$	$15.3 \times 10^{-3}$	See Table a
1.5	$EF_{\text{natural}}$	$\text{CO}_2$ emission factor of natural gas	$\text{tCO}_2/\text{GJ}$	0.05554	See Table b
1.6	$AD_{\text{natural}}$	Activity data of natural gas	GJ	414,615.15	Calculated
1.7	$E_{\text{combustion}}$	$\text{CO}_2$ emissions from natural gas combustion	$\text{tCO}_2\text{e}/\text{a}$	23,027.73	Calculated
No.	Production Workshop	Production Process	Fuel	Consumption	$\text{CO}_2$ Emissions from Natural Gas Combustion ( $\text{tCO}_2\text{e}/\text{a}$ )
1	Aluminum Bar Production Workshop	Smelting and refining	Natural gas	$930 \times 10^6 \text{Nm}^3/\text{a}$	20,108.72
2	Aluminum Alloy Forming Workshop	Aluminum bar heating&aging	Natural gas	$135 \times 10^6 \text{Nm}^3/\text{a}$	2,919.007
		Total			23,027.73