Sustainable development of coal-based circular economy park: a case study

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Abstract. China is one of the world's largest producing and consuming countries of coal. In decades, the coal-based resource type cities of China are facing economic reduction and environment degradation, because of the rapid resource exhaustion and single industrial structure. However, as a policy instrument for sustainable development, a nationwide circular economy model has been implemented at the strategic plan of new coal mines to succeed in the future dilemmas of economic depression, energy shortage, and environmental pollution. Generally, most of the coal resources are buried in the underdeveloped north-western areas with a more vulnerable eco-environment, which means a great distance between the energy supply source and the demand markets as well. Therefore, through comparing and analysing several successful coal-based circular industry chains, and discussion and evaluation of a new model of the circular economy park (CEP), this paper aims to enhance the understanding of coal mine sustainable development and shed light on the relationship between resource exploitation and local economic development.

1 Introduction

Primary energy resources are crucial to both economic prosperity and social development. In 2018, the global consumption of primary energy grew rapidly, besides the carbon emissions rose at the highest rate in seven years [1]. As a high-speed developing country, China leads both the production and consumption of coal all over the world (as shown in Figure 1), and more than 66% of the electricity countrywide is generated by coal in 2018, which means the excavation and utilization of coal have made crucial importance and irreplaceable contributions to China's industrial development and economic prosperity [2].

However, the traditional coal mining and utilization models generally ignored the comprehensive and effective utilization of resources and only focused on the output of raw ore by predatory exploitation, leading to substantial negative impacts such as accelerated resource depletion, high casualty rate and environment deterioration [3-5]. These models can be considered as

linear economy which is a 'take, make and dispose' type of tradition coal industry process.

In the last ten years, the coal industry authorities realized the negative effects and started to reduce the outdated capacity and curb new projects with over capacity [6]. Meanwhile, recognizing the clear use of coal resources is the principal way to reduce carbon emissions, a series of successful practices have been carried out on many coal bases in China and try to achieve the sustainable development of ecology and economy. In 2008, China's most famous major coal-producing district, Shanxi province, first carried out mergers and acquisitions of coal enterprises, building up a batch of large coal enterprise groups. Thanks to the social responsibility and technology ability of these state-owned enterprises, more effective and cleaner coal mining and utilization methods have the chance to be developed and took into practice, which is also a strong foundation of sustainable development of the coal industry.

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Owing to the highly efficient exploitation and recycling of resources, the model of circular economy park has been widely implemented in new large-scale coal enterprises to overcome the dilemma among economic depression, energy shortage, and environmental pollution, also as a policy instrument for sustainable development [7]. From the view of the circular economy [8], coal mining is the origin of the industry chains. Intending to realize the circular of power and materials, the integration of downstream industries and the comprehensive utilization of all kinds of resources from every production process in one place is a main option to prolong the industry chain with added-values and reduced emissions [9].

2 Mining circular economy

The mining circular economy evolves from circular economy practice, which has been developed and extended in the mining industry. Under the guidance of the circulation economic theory, mining circular

economy takes the development model and the basic principles by following the ecology, systematics, and sustainable development theory as the foundation [10]. The environmental-friendly technology leads to the mining circular economy technique, and its characteristics are reasonable utilization of resources, less pollution emissions, recycling more waste, and taking the environment acceptable way to dispose of the remnants.

In the coal-based CEP, because of the most use and transfer of the materials and the largest scale of energy flow, coal mine is the foundation of the industry community and has abilities to drive and regulate the downstream industries. Simultaneously, as the source of the largest amount of waste and energy in the industry chain, coal mine has the longest lateral chain and reflects the character of the CEP. So, the construction of coal-based CEP is the process of developing and integrating downstream industries around the core industry, i.e. coal mining.

Nowadays, three main development models of coal mining enterprises are frequently used [11]. The first one is to take electricity as intermediary, development of high energy consumption industries like construction material, metallurgical refinery, and electrolytic aluminum. The second is the coal direct conversion mode which includes coal coking, coal gasification or liquefaction and coal chemical industries. The third is the development and utilization of coal associated mineral resources.

3 A case study of coal mine based circular economy park

This paper shows a typical practice of coal-based CEP in northwest of Shanxi province. In the park area, the main mineral resources include coal and bauxite, and the recoverable reserves reach 549Mt and 160Mt respectively.

The CEP uses the '1+4' model, which is based on coal mine, and combined power plant, electrolytic aluminum, sewage treatment plant and construction material industries. The products and wastes from upstream industries can be used as raw materials for downstream

industries. Some of the downstream products can be returned to the source of the industry chain. Therefore, the circular of materials and power is eventually achieved (see Figure 2).

Figure 2. Industry chain of the circular economy park.

3.1 Modernized coal mine

Relying on two large-scale modernized coal mines, the CEP's annual raw coal production can reach 20 million tons. At present, after 9 years' preparation and construction, the bigger one of the two coal mine has successfully finished the joint commissioning and its first-stage production capacity is 5 million tons per year. And the annual capacity will reach 10 million tons after the second-stage extension.

The longwall top-coal caving method is adopted in coal mining. The average seam thickness of the coal seam is 7.75m and the caving ratio is 1:1.2, which is defined as the cutting height over caving height. Meanwhile, the coal mine is also rich in methane, thus the utilization of methane resources is one of the development directions of the industry chain shortly, although the plan has not been made yet for the time being.

The capacity of the matched coal preparation plant is 10 million tons per year, and produce clean coal for sale and low calorific value coal, like middling coal, slime coal, gangue and peat for downstream industries' utilization.

3.2 Low calorific value coal power plant

Low calorific value coal means low calorific value of resources after the clean process of raw coal, including gangue, slime, etc. In the traditional coal industry, these by-products are generally abandoned or buried as coal mining wastes. The total quantity of low calorific value coal in Shanxi reached one billion tons, which leads to

not only air pollution and water contamination, but also spontaneous combustion. In recent years, the development of ultra-supercritical air-cooled units realized the recycle and reuse of these buried resources. In 2016, the government of Shanxi province invested 30 billion yuan to support the low calorific value coal power projects, as the provincial-level key projects, and CEP's power plant is one of them.

The total installed capacity of the power plant is 2×660MW, which is composed of an indirect air condensing steam turbine generator set and two ultra-supercritical boilers (1980t/h for each). The investment of this plant is 6 billion yuan. Assuming 0.38 yuan per kilowatt-hour, the annual revenue of the plant is 2.76 billion yuan. The waste of the plant, such as fly ash and slag, can be reused in the downstream cement factory as raw materials.

The design and construction of the plant follow the Shanxi government's ultra-low emission standard, i.e. the strictest and most advanced among the national thermal power emission standard. Once the plant starts to operate, the emission of 1210t NO_x, 1573t SO₂ and 605t smoke can be reduced. Besides, as an important part of the CEP's industry chain, the power plant can serve as an effective link between the upstream and downstream industries. To conclude, the power plant indicates that coal-electricity integration has realized, and the basic framework of the CEP has been built.

3.3 Aluminum industry

The area's bauxite mineral resources reach 8.96 billion tons and have great potential for future development. A bauxite mine, which designed capacity is 2 million tons

of ores per year, is in planning. The matched alumina production line uses the Bayer & Sintering Process. Owing to the advantages of CEP's power supply, the electrolysis and processing of aluminum can efficiently prolong the industry chain.

The total investment of the aluminum industry in the CEP reaches 6 billion yuan, and the annual sales revenue and profit after the operation will reach 18.5 billion yuan and 3.2 billion yuan, respectively. The aluminum industry will significantly improve the diversity and product added value of the CEP.

3.4 Construction material factory

With the recycle of upstream industries' waste resources, the construction material factory is one of the downstream industries in the CEP two main projects included. The first is the cement factory. By recycling the abundant local limestone resources, fly ash and slag from power plant and red mud from aluminum manufacturer, the production of cement factory could reach 1 million tons per year and achieve sales revenue of 300 million yuan by the new dry process technique (or NSP). The second is the standard brick factory. With the recycle of upstream wastes, such as gangue, fly ash and slag, 0.2 billion standard bricks can be produced for self-use or trade-in market.

As the source of materials is mineral resources in CEP, the construction material industry is the tail end of the material flow, which indicates that all the materials in the CEP have been fully used regardless of the resources or wastes. Meanwhile, the demand for local development could be entirely satisfied by the construction materials.

3.5 Benefits summary

The investment and benefit statistics of pillar industries of the CEP's model are listed in Table 1.

Table 1. Investment and benefit statistics (billion yuan).

Name	Capacity	Investment	Revenue	Tax
Coal mine	20Mt/a	11.70	12.00	1.60
Power plant	2×66MW	6.00	2.76	0.22
Aluminum industry	1Mt/a	6.00	18.50	2.80
Construction material	1Mt/a cement	0.50	0.30	0.06
	0.2 billion bricks	0.10	0.05	0.01
total	-	24.30	33.61	4.69

After completion, the CEP can yield a total state tax of 4.69 billion yuan and profit of 7.66 billion yuan, not to mention the creation of employment opportunities and promotion of the economic development for local residents [12-13].

4 Discussion

The case of CEP, as the national key construction project of the mining industry in the 11th Fiver-Year Plan and the key construction project of Shanxi province in the

12th Fiver-Year Plan, has received great support from the local government. It shows that the perfection of the large coal-based CEP is an extremely complicated and multi-element integrated system that needs more than decades of effort. Currently, the transformation of the traditional coal mining industry from low quality, low added value and low efficiency to high quality, high added value and high benefit, has generally been achieved.

However, there is a home truth that the national excess of coal production and electricity becomes a major problem in China and the energy resources structural imbalance between supply and demand is more and more obvious [14]. The solution includes two aspects. For the first one, since the out-dated energy capacity has long been a major part of the national capacity structure, it takes a much longer time to transfer the out-dated capacity to concentrated capacity. Although the current condition is not promising, efforts should be made to insist on the sustainable development of the mining industry, especially on the construction of modern coal-based CEP.

The second is the perfection of the transportation system. In other words, the connection of supply sources and demand markets should keep pace with the capacity growth, such as using the ultra-high voltage power transmission system. This way, the supply of energy resources can meet the demand market effectively to concur with the structural imbalance.

In general, there is no doubt that the future development of the mining industry cannot thrive without the circular economic model, and the coal-based industry must persist in the direction of sustainable development. The specific industrial structure program should adjust measures according to the local conditions and obtain sufficient supports from the government for investment. Only in this way can promote real 'Green Mining'.

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