Coal Mine Based Circular Economy Park: A Case Study

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Abstract: With decades of development and exploitation of coal resources, the first batch of coal-based cities in China are faced with the challenge of economic shrinkage and environment deterioration due to the rapid resource exhaustion and single industrial structure. Nowadays, as a policy instrument for sustainable development, a nationwide circular economy mode has been implemented during the design and planning of new coal mines to address the challenges arising from economic depression, energy shortage and environmental pollution. It should be mentioned that several national coal bases and most of constructing and planning coal mines are located in the underdeveloped areas in the Midwest of China which means that the distance between supply source for energy resources and the demand market is significantly increased. Moreover, the eco-environment vulnerability in these rural areas should be taken into serious consideration. Therefore, after comparison and analysis with several successful coals based and diversified circular industry chains, this paper presents a case study on the circular economy park (CEP) in the northwest of Shanxi Province. Through discussion and evaluation of ‘1+3’ mode in the CEP, this paper aims to enhance the understanding of coal mine sustainable development and shed light on the relationship between resources exploitation and local economic development.

Keywords: sustainable development, circular economy park, coal mine, multi-industry structure, underdevelopment areas

1. Introduction

Earth's fossil energy resources are crucial to both economic prosperity and human well-being. Taking coal mining and consumption as an example, coal has been widely used to generate electricity since the 1880s, and more than 40% of the electricity globally is provided by coal nowadays. However, as one of the largest worldwide anthropogenic sources of carbon dioxide releases (39% of global CO₂ emissions), the extensive excavation and utilization of coal have brought a series of side effects to both natural environment and human health (Wikipedia 2017).

As the largest coal producer and consumer in the world, China is leading the list over the past decade (as shown in Figure 1) (BP 2016). The excavation and utilization of coal resources have made a crucial impact and irreplaceable contributions to China's industrial development and economic prosperity (Long and Zhang 2009). However, most of the air pollution in China are also attributed to the simplified and extensive exploitation of coal resources, e.g., 90% of SO₂, 67% of NO, 70% of smoke ashes, and 70% of CO₂ in 2016. In recent years, most of North China and the developed coastal areas were wreathed by smog due largely to the oversimplified extensive utilization of coal, suggesting that the development patterns of coal utilization need to be reshaped so that both the biosphere and humanity could thrive equally.

Figure 1. Production and consumption of coal by country (top 5) and year (million tons oil equivalent).

The major environmental issue that comes with coal-based energy structure lies in the way that the waste produced during coal exploitation is properly processed. At the start of this century, small-scale coal mines in villages and towns sprung up like mushrooms, owing to the low entrance threshold and technical requirements of the traditional coal mining in China. The majority of these coal mines have made a large contribution to the country's supply of energy (Andrews-Speed et al 2003). However, they have ignored the

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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 (He et al 2017, Min et al 2009, Yang et al 2015). Such a mining model can be considered as a linear economy which is a 'take, make and dispose' model of traditional coal production.

In the last ten years, the Chinese government realized the negative effects and started to reduce the outdated capacity and curb new projects with overcapacity (Wang et al 2017). For example, in 2008, Shanxi, one of the China's most famous major coal-producing provinces, carried out mergers and acquisitions of coal enterprises, building up a batch of large coal enterprise groups. The industrial concentration has improved the labor productivity and increased the market share. More importantly, because of their social responsibility, large-scale coal enterprises have the ability and aspiration to make some changes, such as to develop more effective and cleaner coal mining methods and to replace the previous industry pattern that has less efficiency and negative environmental impact.

Nowadays, the model of circular economy park (CEP), with the core of a highly efficient resources exploitation and recycling, has been widely implemented in new large-scale coal enterprises to address challenges arising from economic depression, energy shortage and environmental pollution, also as a policy instrument for sustainable development (Batterham 2017). From the view of circular economy (Boulding 1966), coal mining is just the origin of the industry chains. Only by the integration of downstream industries and comprehensive utilization of all kinds of resources from every production processes (Gao 2012), the coal industry chain can be prolonged with added-value and reduced emissions.

2. Mining Circular Economy

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, a mining circular economy takes the development model and the basic principles by following the ecology, systematics, and sustainable development theory as the foundation (Feng and Yan 2007). The environmentally-friendly technology leads to the mining circular economy technique, and its characteristics include the reasonable utilization of resources, less pollution emissions, recycling more waste, and taking the environmentally acceptable way to dispose of the waste (Guo et al 2007).

In the coal based CEP, because of the most use and transfer of the materials and the largest scale of energy flow, coal mines are the foundation of the industry community and have the ability to drive and regulate the downstream industries. Simultaneously, as the source of the largest amount of waste and energy in the industry chain, coal mines have the longest lateral chain and reflect the characteristics of the CEP (Choi 2014). So the construction of coal-based CEP

is the process of developing and integrating of downstream industries around the core industry, i.e. coal mining.

Nowadays, three main development models of coal mining enterprise are frequently used (Franklin-Johnson et al 2016). The first one is to consider electricity as an intermediary step for the development of high energy consumption industries like construction materials, metallurgical refineries and electrolytic aluminium. 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.

Here are several completed representative examples of large-scale, diversified and coal-based CEPs in the Shanxi province with their own characteristics.

3. Tashan CEP of Datong Coalmine Group Co.

Tashan CEP is the first integrated project following the rule of circular economy in the mining industry with the approval of the state. After several years of construction, starting from 2003, it has achieved an integrated industry chain based on coal and combined with electricity, construction materials and the chemical industry.

As the headstream of the industry chain, the super-huge coal mine, Tashan coal mine, could afford 15 million tons of high quality power coal per year to downstream industries, which formed two primary circular chains, i.e. 'coal-electricity-construction' and 'coal-chemical industry'. A total of ten projects are integrated and optimized in the CEP, which achieved the expected goals, i.e. the least influences on the eco geological environment and the best comprehensive exploitation of mineral resources.

One of the major advantages of this park is the salient stakeholders (Dong et al 2014), such as China Datang and Guangzhou Development Industry Holdings Co., who guaranteed the source of funds, talents and technology, and benefit to swiftly and efficiently prolonging of the industry chains.

4. Lu'an Group's Diversified CEPs

Different to the high-quality power coal excavated from the Jurassic coal measures of the Tashan coal mine, the major coal resources of the Lu'an coal area are fat coal, lean coal and coking coal, which are hosted in the Carboniferous and Permian stratum. This feature has determined that Lu'an group's major downstream products are from the chemical industries, such as coal-based compound fuel oil, nitro fertilizer, p-nitrobenzoic acid, caustic soda and so on.

There are four CEPs which have been constructed and put into operation during the 11th Five-Year Plan period and as much as six divested industries' sales revenue reached to more than 50 billion RMB. With the synthetic coordinated utilization of every CEP's resources, the diversified industry chains of the Group have been extended and industrial categories have been developed. High value-added products gradually took the place of raw coal export and produced more profits with the minimal impacts to eco-environment.

The characteristics of four CEPs are given in Table 1.

Table 1. Characteristics of four typical CEPs.

Name	Model	Characteristics
Tunliu	Coal-oil	Coal-based compound fuel oil; Gasification & generation (IGCC)
Gaohe	Coal-electricity	Comprehensive generation of both gas and low calorific value coal
Lucheng	Coking-chemical	Coal coking; Tar and benzene processing
Donggu	Electricity-chemical	Calcium carbide plant; Caustic soda plant

5. Model of New Constructed CEP

The model choice of coal-based CEP must take all the factors into consideration, which includes not only the natural resource conditions, but also social conditions such as government policy and product transportation.

The current situation is, that after decades of mining, the shallow coal resources in eastern China are generally exhausted and the deep mining technology of coal is developing. The new planned national large-scale coal bases are mostly located in the middle-west underdeveloped provinces, and the traditional energy supply sources are far away from the demand market in the middle-east and coastal areas (Li et al 2010). This situation determines that the transport efficiency of coal-based energy should receive more concerns and research as well as resources exploitation. One of the current solutions is coal-electricity integration combined with ultra-high voltage power transmission. This means that the power plant and power transmission system should become parts of a new modern coal-based CEP that will be built in rural areas.

On the other hand, the complete circular industry chain shows that more added-value products can be produced with less waste discharge. However, without a combination of existing industries, the perfection of large-scale CEP needs at least twelve years. All of the new planned coal-based CEPs started from coal mines and are only combined with the power plant. Thus, the primary framework of CEP has just taken shape. As a result, in the near future, it can be said that a basic pattern of new constructed coal-based CEP is coal-electricity integration. It is also a major trend in the circular economy model in mining areas.

6. Practice at the Wangjialing (WJL) CEP

This paper shows a typical practice of coal-based CEP, the Wangjialing Circular Economy Demonstration Park in northwest of Shanxi province, northernmost of Hedong coalfield. The CEP is affiliated to Baode County, and is invested and constructed by Jinneng Group, which is one of the world's top 500 largest companies and famous of its coal mining and power industries.

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+3' model, which is based on coal mines, and combined electricity, aluminum and construction material industries. The products and waste 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 economy of materials and energy is eventually achieved (see Figure 2).

Figure 2. Industry chain of WJL circular economy park.

7. Coal Mine

Relying on two large-scale modernized coal mines (WJL coal mine and Baijiagou coal mine), the CEP's annual raw coal production can reach 20 million tons. At present, after 7 years of preparation and construction, the WJL coal mine has successfully finished the joint commissioning and its first-stage production capacity is 5 million tons per year. The annual capacity will reach 10 million tons after the second-stage extension.

The longwall top-coal caving method is adopted to mine the No.4 coal seam. The average seam thickness is 7.75m and the caving ratio is 1:1.2, which is defined as the cutting height over caving height. The major equipment in the longwall face is all domestically manufactured and are shown in Table 2.

Table 2. Major mining equipment's technical characteristics.

	Model	Characteristics
Shearer	MG650/1630-WD	Cutting height: 2.25~4.6m; Capacity: 4000t/h; Control system: electronic Total power: 1630kW Weight: 92t
Drag conveyor	SGZ1000/2×855	Capacity: 2500t/h; Total power: 1710kW Slot size: 1750×1000×367mm
Hydraulic support	ZF16000/23/43D; ZFG16000/26/43H	Support scope: 2.3~4.3m Working resistance: 16000kN Control: electro-hydraulic Weight: 47t
Reversed loader	SZZ1200/700	Capacity: 3500t/h; Total power: 700kW

The WJL coal mine is also rich in methane, thus the utilization of methane resources is one of the development directions of the industry chain in the near future. Note that such plans are not currently in place.

The washing capacity of the matched coal preparation plant of the WJL coal mine is 10 million tons per year, which will meet the requirements for all raw coal washing, and will produce clean coal for sale and low calorific value coal, like middling coal, slime coal, gangue and peat for downstream industries' utilization.

8. Low Calorific Value Coal Power Plant

Low calorific value coal means low calorific value of resources after the coal mining and washing process, including gangue, slime, middling coal, etc. In a traditional coal industry, these by-products are generally abandoned or buried as coal mining waste. The total quantity of low calorific value coal in Shanxi reached one billion tons (Lu 2016), which leads to not only air pollution and water contamination, but also spontaneous combustion. In recent years, the development of an ultra-supercritical air-cooled unit realized the recycling and reuse of these buried resources. In 2016, the government of Shanxi province invested 30 billion RMB to support the low calorific value coal power projects, as the provincial-level key projects, and WJL power plant is one of them.

The total installed capacity of the WJL 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 important parameters for the WJL power plant are shown in Table 3. The investment for this plant is 6 billion RMB. Assuming 0.38 RMB per kWh, the annual revenue of the plant is 2.76 billion RMB. The waste of plant, such as fly-ash and slag, can be reused in the downstream cement factory as raw materials.

Table 3. Main parameters of WJL power plant.

WJL power plant	Value
Capacity	2×660MW
Operating hour	5500h per year
Coal consumption	5.28 million tons per year (above 3500 kcal/kg)
Energy output	7.26 billion kWh per year
Investment	6 billion RMB
Revenue	2.76 billion RMB per year

The design and construction of the plant follows the Shanxi government's ultra-low emission standards, i.e. the strictest and most advanced among the national thermal power emission standards. 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

been achieved and the basic framework of the CEP has been built.

9. Aluminum Industry

The area's bauxite mineral resources reach 8.96 billion tons and have great potential for future development. A bauxite mine is in planning, which can excavate 2 million tons of ore every year matching the alumina production line using the Bayer & Sintering Process. Owing to the advantages of CEP's power supply, the electrolysis and processing of aluminium can efficiently prolong the industry chain.

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

10. Construction Material Factory

With the recycling of the upstream industries' waste resources, the construction material factory is one of the downstream industries in the CEP. Two main projects are included. The first is the cement factory. By recycling the abundant local limestone resources, fly ash and slag from the power plant and red mud from aluminium manufacturer, the production of the cement factory could reach 1 million tons per year and achieve a sales revenue of 300 million RMB by the new dry process technique (or NSP). The second is the standard brick factory. With the recycling of upstream waste, 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 the 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 of local development could be entirely satisfied by the construction materials.

11. Brief Summary

The investment and benefit statistics of pillar industries of WJL CEP's '1+3' model are listed in Table 4.

Table 4. Investment and benefit statistics (billion RMB).

Name	Capacity	Investment	Revenue	Tax	Profit
Coal	20Mt/a	11.70	12.00	1.60	1.80
Electricity	2×66MW	6.00	2.76	0.22	2.54
Aluminium	1Mt/a	6.00	18.50	2.80	3.20
Construction material	1Mt/a cement	0.50	0.30	0.06	0.10
	0.2 billion bricks	0.10	0.05	0.01	0.02
Total	-	24.30	33.61	4.69	7.66

After completion, the CEP can yield a total state tax of 4.69 billion RMB and a profit of 7.66 billion RMB, not to mention the creation of employment opportunities and promotion of the economic development for local residents (Geng et al 2012, Zhou et al 2009).

12. Discussion

The WJL CEP, as the national key construction project of mining industry in the 11th Five-Year Plan and the key construction project of the Shanxi province in the 12th Five-Year Plan, have received great support from the local government. However, this project has slowed down a little bit for some time due to capital shortage and policy changes. It shows that the perfect operation of the large coal-based CEP is an extremely complicated and multi-element integrated system which needs more than a decade of efforts. 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 truth in that the national excess of coal production and electricity becomes a major problem in China and the structural imbalance between supply and demand regarding energy resources is more and more obvious (Levesque et al 2014). The solution includes two aspects. For the first one, the outdated energy capacity has long been a major part in the national capacity structure, it will take a much longer time to transfer the outdated 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 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 the energy resources can meet the demand market effectively to mitigate the imbalance between supply and demand.

In general, there is no doubt that the future development of the mining industry cannot thrive without the circulation economic model, and also must persist in the direction of sustainable development. The specific industrial structure programme should adjust measures according to the local conditions and obtain sufficient supports from government for investment. This is the only way to promote real 'Green Mining' in the Chinese coal mining industry.

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