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Residual coal exploitation and its impact on sustainable development of the coal industry in China

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HIGHLIGHTS

- Pay attention to residual coal under changing energy-mix environment in China.
- Estimate residual coal reserves and investigate its exploitation mines.
- Discuss impacts of residual coal exploitation on delay of coal depletion in China.
- Discuss impacts on coal mining industry and residual coal exploitation technology.
- Give corresponding policy prescriptions.

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ABSTRACT

Although China owns large coal reserves, it now faces the problem of depletion of its coal resources in advance. The coal-based energy mix in China will not change in the short term, and a means of delaying the coal resources depletion is therefore urgently required. The residual coal was exploited first with a lower recovery percentage and was evaluated as commercially valuable damaged coal. This approach is in comparison to past evaluations when the residual coal was allocated as exploitation losses. Coal recovery rates, the calculation method of residual coal reserves and statistics of its mines in China were given. On this basis, a discussion concerning the impacts on the delay of China's coal depletion, development of coal exploitation and sustainable developments, as well as technologies and relevant policies, were presented. It is considered that the exploitation of residual coal can effectively delay China's coal depletion, inhibit the construction of new mines, redress the imbalance between supply and demand of coal in eastern China, improve the mining area environment and guarantee social stability. The Chinese government supports the exploitation technologies of residual coal. Hence, exploiting residual coal is of considerable importance in sustainable development of the coal industry in China.

1. Introduction

As China is the world's largest producer and consumer of energy, the fact that coal is considered as the primary energy source is not likely to change for a long time. In 2013, China's coal output was 3.68 billion metric tons (Gt), accounting for 47.4% of the world's coal output and 67% of the proportion of the national energy structure (Rühl, 2014). Over the past decade, the coal reserve-to-production (R/P) ratio has dropped from 131 (in 2001) to 35 (in 2014), in comparison to the global R/P ratio that exceeds 110 (National Bureau of Statistics of China, 2015; Lior, 2012; Rühl, 2014). The abrupt drop of the coal R/P ratio causes the advance depletion of China's coal resources. China's coal reserves and supply will have difficult satisfying the growing demand for coal (General Office of the State Council of China, 2014; Hao et al., 2015; Lin and Liu, 2010; BP p.l.c., 2016a; Wang et al., 2013b), even though China has been adjusting the energy mix and developing new energies.

The dominant position of coal will not be replaced by other energy, under changing energy-mix environment in China. The proportions of coal, natural gas and non-fossil energy in China's

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energy structure were 5.7%, 11.2% and 66%, respectively, in 2014 (National Bureau of Statistics of China, 2014). The proportions are projected to be 15%, 10% and 62% in 2020, according to the *Action Plans for Energy Development Strategy (2014–2020)* (General Office of the State Council of China, 2014). The proportion of coal in this mix would be further reduced to 47–51% in 2035 (BP p.l.c., 2016b). Many studies (Gao et al., 2014; Matsumoto, 2015; BP p.l.c., 2016b; Zou et al., 2016) have shown that the dependence on coal has been reduced with the adjusting of China's energy mix. However, the shortfall between supply and demand of coal cannot be replaced by the cleaner fossil energy and no-fossil energy (Wang et al., 2013b). In addition, coal imports cannot make up the balance completely, because of non-negligible geopolitical risks and price fluctuations (Matsumoto, 2015).

Higher coal reserves are necessary for meeting the future demand for coal. Energy demand is associated with multiple factors, but for the current China, economic growth is the main factor (Wang and Li, 2016). The coal demand would increase in the future with the widely predicted growth of China's economy (Hao et al., 2015; Lin and Liu, 2010; BP p.l.c., 2016a; Wang et al., 2013b). China's coal demand was forecast for 4.2–6.12 Gt in 2035 (Wang et al., 2013b). However, given the current positive energy mix adjustment and economic slowdown, China's coal demand would be approximately 4.4–4.8 Gt in 2035. Because coal production would be in the post-peak period at that time, the problem cannot be solved by increasing coal output. An additional coal reserve is the perfect solution, because it not only increases coal output but also delays the peak years and coal depletion. So an additional coal reserve of 20–30% is necessary, according to the current reserves of 114.5–133.7 Gt (Wang et al., 2013a).

Residual coal exploitation can help to solve the problem to some extent. The residual coal was defined as damaged coal that was originally exploited with a lower recovery percentage and was treated as part of exploitation losses. However, at present, this coal is being evaluated as commercially valuable coal. In the 1980s, in order to ease the oil crisis, residual coal exploitation was carried out temporarily in the United States and European countries (Environmental Protection Agency, 2000; Camm, 1983; Hawkins, 1994a, 1994b, 1995; Lei, 1982; Lu, 2010; Mauger et al., 2011). Residual coal began to be exploited in China as early as 1976 (Zaozhuang Mining Bureau, 1976), although its purpose was not to satisfy the demand of energy until approximately 2004. Compared with developed countries, the recovery percentage of the coal in China is rather low. For various reasons, the average recovery percentage of the state-owned coal mines is 30%, while that of the private coal mines is between 10% and 20% (Cui, 2007). Over the past several decades, the low recovery percentage led to ten trillion tons of residual coal. If this residual coal is successfully resumed from mining, it will help maintain the sustainable development of China's coal industry, and ease the demands for China's energy supplies.

Previous studies have proposed relevant and forward-looking policy prescriptions, including energy mix adjustment, new energy development and energy imports. However, China's coal depletion in advance causes an imbalance between coal supply and demand in the future, even if the energy mix has been adjusting. Meanwhile, many uncertain factors accompany the development of cleaner energy and renewable energy. Hence, residual coal exploitation may be a way of easing the coal supply crisis in the absence of a certain schedule of alternative energy sources to replace coal. This study seeks to provide fresh insights by focusing on residual coal exploitation and its impact on both the sustainable development of the coal industry and a sustainable supply of coal in China. The Hubbert model and survey were used to address the prediction of coal R/P ratio and the trend of residual coal exploitation.

The structure of this paper is as follows. In Section 2, we present coal recovery rates, the calculation method of residual coal reserves and R/P ratio, and statistics of residual coal mines in China. In Section 3, we analyze the impacts of residual coal on China's coal industry, including delaying the depletion of coal, the development of coal exploitation, and the sustainable development and the relevance between technologies and policies. In Section 4, the paper's conclusions are presented, outlining the relevant policy implications generated from the study.

2. Residual coal and its exploitation in China

2.1. Low recovery rates lead to residual coal

A low recovery rate of mining coal is the first essential reason for residual coal's being produced. The recovery percentage is also the most vital parameter for evaluating reserves of residual coal.

Detailed statistical data on the coal recovery percentage of different geological areas and exploitation methods is missing in China. Several studies suggested that the average coal recovery percentage was 30–35% in China (World Energy Council, 2013; Cui, 2007; Qian, 2010; Chang et al., 2007), which is lower than the 50–60% in the United States (Energy Information Administration, 2012; Rohrbacher et al., 1993). China's lowest recovery percentage was approximately 10% before 1949, while the highest average recovery percentage was 46% in 2004 (Shi, 2007). However, because of differences in political, economic and technical conditions, it is more reasonable to count China's coal recovery percentage during three stages with reference to different times and ownership (Table 1).

The first stage was between 1912 and 1948. During this period, the average recovery percentage was between 10% and 20% (Cui, 2007; Yue and Tian, 2010), and 15% was taken as the median. The second stage was between 1949 and 1998, when the average recovery percentage of the state-owned coal mines was approximately 45% and that of the private mines was 20% (Chang et al., 2007). In the third stage, between 1999 and 2013, the average recovery percentages of the state-owned coal mines and the private mines were 48% and 40% (Shi, 2007), respectively.

2.2. Reserves and R/P ratio of residual coal

Because of the large time span to be covered and the imperfect existing statistics, the reserves of residual coal cannot be precisely accounted for; they can only be estimated by considering the past

Table 1
Coal production, average initial recovery rate and recovery rate of residual coal.

	Cumulative production of coal (Gt)		Average initial recovery percentage (%)		Recovery percentage of residual coal (%)	
	State-owned coal mines	Private coal mines	State-owned coal mines	Private coal mines	State-owned coal mines	Private coal mines
1912–1948	10.3		15		41.2–52.9	
1949–1998	136.5	139.5	45	20	9.1–27.3	37.5–50.0
1999–2014	197.3	192.8	48	40	3.8–23.1	16.7–33.3
Total/average	676.4		34.5		23.7–39.0 (average:31.3)	

Note: The coal production data: (China National Coal Association, 2011) (Data before 2010), (National Bureau of Statistics of China, 2011, 2012, 2013, 2014, 2015) (2010–2014 data).