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A review on coal-to-electricity policies into practice in northern China

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Abstract. China has been promoting clean energy heating in an all-around way since recent year to reduce air pollution and energy consumption as a result of using coal for winter heating. Supported by a series of Chinese government policies, a coal-to-electricity project become a significant measure for clean energy heating in Beijing-Tianjin-Hebei region and the surrounding areas, which has obviously improved air quality in northern China. The coal-to-electricity project can involve engagement from multiple levels of government and social companies, wherein government is uniquely positioned to provide leadership. However, factors contributing or hindering policies into practice are largely unexplored. This paper presents a review on coal-to-electricity policies into practice through summarizing government policies and practical investigation, including its planning, scope, funding, process, and technical types analysis. In addition, a prospect of coal-to-electricity project in northern China is also given. It is found that the coal-to-electricity project holds a meaningful contribution and promising potential of development given the urgent need for clean energy heating in large areas of northern China. Government financial subsidy is driving force and efficient technical types are carrier. It was further demonstrated that a large amount of government financial subsidy and the application of efficient technology will contribute to the implementation of coal-to-electricity project, which may provide reference for transition of other energy and low carbon policies into practice.

1. Introduction

As the world's second-largest economy, rapid industrialization and urbanization in China has caused significant air pollution [1-2]. The mean annual PM_{2.5} concentration in China's major cities reported to be 43 µg/m³, had exceeded 4 folds based on the threshold of 10 µg/m³ annual mean concentration set by the World Health Organization in 2017, and the Air Quality Index (AQI) has been in "red alerts" for multiple consecutive days [3-5]. The sources of PM_{2.5} mainly include town coal heating boilers, rural coal heating, coal-fired power plants and automobile exhaust [6], many studies indicated that the large amount of coal-fired heating in winter were the main cause of the poor air quality. The annual air quality report released by the Ministry of Environmental Protection of China in 2014 showed that cities



requiring heating had an average of 168.3 days during which the air quality standard was not reached, which was 59.8 % higher than that of cities which did not require heating [7]. ALMOND et al. evaluated TSP concentration in 76 cities in China and observed that the average value of TSP concentration in heating cities was 300 mg/m^3 higher than that in non-heating cities [8]. Zhang et al. reported that the contribution of coal-fired district heating to $\text{PM}_{2.5}$ concentration in winter was up to 53 % [9]. As seen, although the high $\text{PM}_{2.5}$ concentration in China is synthetically caused by industrial, domestic, traffic, and heating emissions, during the heating season, coal-fired heating emissions are the main cause of the poor environmental quality. Therefore, in northern China, where heating is commonly needed in winter, air pollution caused by coal-fired emissions would be more severe as a result of tremendous rising in building space and residential heating demand.

Air quality of northern China during heating season in 2013 has been monitored and shown in Figure 1. As seen, large-scale air pollution in northern China, especially in Beijing-Tianjin-Hebei region and its surrounding areas, has become an urgent issue that jeopardized the health of residents. Many studies have proven that $\text{PM}_{2.5}$ has serious adverse effects on the human health. Because of its small particle size, $\text{PM}_{2.5}$ can reach the lungs and alveolar regions [10], and there are positive and statistically significant relationships between the short-term exposure to $\text{PM}_{2.5}$ and cardiovascular and respiratory diseases [11]. To this end, the Chinese government has begun to call for clean energy heating and established a series of policies to alleviate air pollution. Various provinces and municipalities in northern China have adopted different alternative energy sources according to local conditions. At present, a coal-to-electricity project has become a main measure of clean heating conversion in Beijing-Tianjin-Hebei region, which has played a positive role in improving air quality. The coal-to-electricity is a project of transforming the users who use coal-fired heating into those who use electric drive equipment such as air source heat pump (ASHP), ground source heat pump (GSHP), solar energy, electric heater and so on. It is a complex engineering that requires a lot of manpower, financial resources and technical support, involving engagement from multiple levels of government and social companies. However, due to differences in policy guidance among regional governments, the implementation effect of coal-to-electricity project was different in northern China. Therefore, to ensure the better promotion of the coal-to-electricity project, it is necessary to explore the factors that contribute or hinder the policies of the coal-to-electricity project into practice. As a result, a review on coal-to-electricity policies into practice about its planning, scope, funding, process, and technical types were detailed in this paper. Followed by a prospect of coal-to-electricity project in northern China. Finally, a conclusion is given.

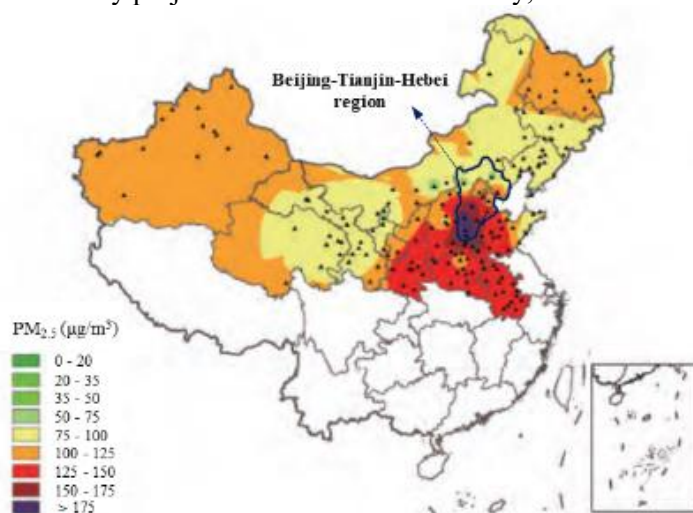


Figure 1. Air quality of northern China during heating season in 2013

2. Policies of coal-to-electricity project

The coal-to-electricity project is an effective measure taken by the Chinese government based on macro-requirements of clean energy heating in northern China and relevant policies have been introduced in

succession. The contents of coal-to-electricity policies in various regions will be sorted out based on the background of clean energy heating, and specific objectives are also listed in this section.

2.1. Background

2.1.1. Heating Status in northern China. By the end of 2016, the heating area of buildings in northern China was about 20.6 billion square meters. Among them, the heating area of urban buildings was 14.1 billion square meters, while that of rural buildings was 6.5 billion square meters. Coal was the main energy for heating and coal-fired heating area accounted for 83 % of the total heating area, resulting in annual consumption reached about 400 million tons of standard coal. The proportion of clean energy heating in northern China was lower, as shown in Figure 2.

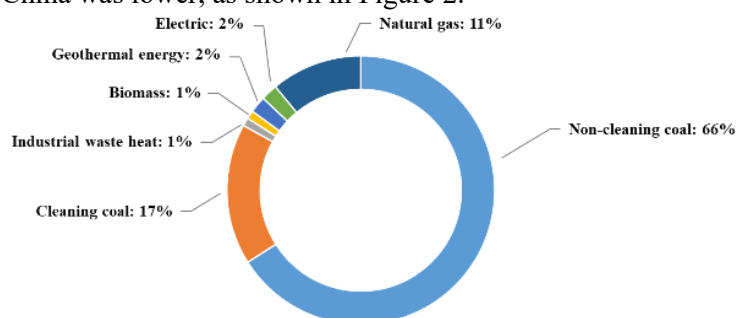


Figure 2. Distribution of heating sources in northern China in 2016

2.1.2. Development process of clean energy heating. Before 2016, the development of clean energy heating was sluggish in northern China, and there was a lack of overall planning and management. Except for the support measures introduced in the Beijing-Tianjin-Hebei region, most of the regional support policies were few.

On December 21, 2016, President Xi Jinping proposed to speed up the increasing of the proportion of clean energy heating, so that the work of heating conversion has received extensive attention. On March 5, 2017, Premier Li Keqiang reported that all levels of government should devote themselves to the planning route of clean energy heating, emphasizing the importance of "Defending the blue sky". At this point, cleaning energy heating have become China's key livelihood project, which have been highly valued by the government. Subsequently, the government promulgated <the Clean Energy Heating Plan for Winter in North China (2017-2021)>. This plan required that the goal of clean energy heating rate in northern China will reach 70% by 2021, and heating sources should be selected according to local conditions, including clean energy such as electric, solar and geothermal energy. The conversion project will start from the Beijing-Tianjin-Hebei region and expands to its surrounding areas. Meanwhile, the government has put forward 36 key cities and invested a lot of money to ensure the implementation of clean energy heating conversion, as shown in Table 1.

2.2. Subsidies of coal-to-electricity policies

The coal-to-electricity project has become a main measure of clean energy heating conversion in Beijing-Tianjin-Hebei region due to the policies guidance of the government, and will reach the goal of 500 million square meters of electric heating in northern China in 2021. Coal-fired heating was mainly used in rural areas, in thus **Beijing** has issued the <Plan for Clean Energy Heating in Winter in Rural Areas of Beijing in 2018>, which proposes to realize "coal-free" in plain areas of the whole city by 2019. **Tianjin** has issued the <Tianjin Residents' Winter Clean Energy Heating Program> and planned to implement clean energy heating conversion for 1.23 million residents, including a total of 543,000 coal-to-electricity. **Hebei Province** promulgated <Hebei Province Winter Clean Energy Heating Program in 2018> that 400,000 households were converted from coal to electricity. Shanxi, Shandong and Henan provinces have also introduced relevant policies and Table 2 shows the subsidies for coal-to-electricity project in key cities of northern China.

Table 1. Key Cities and Funding of clean energy heating in norther China

Beijing-Tianjin-Hebei region atmospheric transmission channel	Key cities	Beijing; Tianjin; Shijiazhuang; Tangshan; Langfang; Baoding; Cangzhou; Hengshui; Xingtai; Handan; Taiyuan; Yangquan; Changzhi; Jincheng; Jinan; Zibo; Jining; Dezhou; Liaocheng; Binzhou; Heze; Zhenzhou; Kaifeng; Anyang; Hebi; Xinxiang; Jiaozuo; Puyang
	Funding	Municipality directly under the Central Government: 1 billion RMB per year ; Provincial capital city: 700 million RMB per year ; Prefecture-level city: 500 million RMB per year .
	Promulgation date	17/02/2017
First batch of central financial support cities	Key cities	Tianjin; Shijiazhuang; Tangshan; Langfang; Baoding; Hengshui; Taiyuan; Jinan; Zhenzhou; Kaifeng; Hebi; Xinxiang
	Funding	Central Finance: 20.1 billion RMB ; Local Finance: 69.5 billion RMB ; Social Capital: 211.6 billion RMB .
	Promulgation date	05/06/2017
Second batch of central financial support cities	Key cities	Handan; Xingtai; Zhangjiakou; Cangzhou; Yangquan; Changzhi; Jincheng; Jinzhong; Yuncheng; Linfen; Lvliang; Zibo; Jining; Binzhou; Dezhou; Liaocheng; Heze; Luoyang; Anyang; Jiaozuo; Puyang; Xi'an; Xianyang
	Funding	Central Finance: 30.4 billion RMB ; Local Finance: 65.3 billion RMB ; Social Capital: 221.4 billion RMB .
	Promulgation date	22/08/2018

Table 2. Subsidies for coal-to-electricity project in key cities of northern China

City	Technology	Equipment subsidy (RMB/household)	Tariff subsidy
Beijing	ASHP; GSHP	100 yuan/m ²	20:00 – 8:00
	Others	12,000	0.1 RMB/kWh
Tianjin	Electric radiator	1200 – 4400	21:00 – 6:00
	ASHP	25000	0.2 RMB/kWh
Shijiazhuang	---	7400	0.2 RMB/kWh
Baoding	---	7400	0.2 RMB/kWh
Langfang	---	7400	0.2 RMB/kWh
Chengde	---	25000	2000 RMB/household
Hengshui	---	7400	0.2 RMB/kWh
Taiyuan	ASHP	27400	0.2 RMB/kWh
	Electric boiler; Electric radiator	14400	
Datong	---	8000	0.2 RMB/kWh
Lvliang	---	24000	2000 RMB/household
Yuncheng	---	2000	0.21 RMB/kWh

2.3. Analysis of coal-to-electricity policies

The coal-to-electricity policies introduced in the Beijing-Tianjin-Hebei region was more clear than other cities, in terms of conversion target. These policies have formulated the area of coal-to-electricity project and the number of converted households. Under the mandatory goal, the progress and efficiency of coal-to-electricity was higher. On the other hand, subsidies for Beijing, Tianjin, and Hebei were higher so that residents can basically buy clean energy heating equipment for free. Meanwhile, the subsidies of local governments on electricity prices have reduced the operating costs of heating equipment, making it easier for residents to accept conversion.

3. Practice of coal-to-electricity project

The coal-to-electricity project has reached the final stage of the Beijing-Tianjin-Hebei region, where the air quality has improved significantly. The application of various technologies makes electric heating more efficient and energy-saving however the practical effect was different. In this section, the practice of various technologies in coal-to-electricity project was detailed though field measurement and data investigation.

3.1. Application Technology of Coal-to-Electricity project

In <the Clean Energy Heating Plan for Winter in North China (2017-2021)>, the types of electric heating technology were also defined, including electric radiator, ASHP, GSHP and so on. In order to investigate the practical application of coal-to-electricity project, a total of nearly 20,000 coal-to-electricity households have been monitored, in terms of their equipment operation cost and performances.

3.1.1. Economy of technology. Each technology can satisfy the requirements of residents' comfort in winter and the main difference was reflected in the cost. Figure 3 shows original investment and operating cost for different technologies. As seen, the original investment of combination of ASHP and solar energy system was the largest due to its complex forms while the simplest electric heating technology has the smallest investment. The original investment of ASHP was in the middle. On the other hand, the cost trend has changed in practical operation, the combination of ASHP and solar energy system was the lowest and the electric heating technology was the largest. Taking 120 square meters of households as an example, the electricity cost of ASHP (Air/Air) was 13.2 RMB per square meter, and the total cost of heating season was 1584 RMB. The operating cost of electric heating, electric radiator, electric boiler, solar energy, GSHP and ASHP-Solar system were 3468, 2220, 3360, 1812, 1656 and 972 RMB in heating season, respectively. Taking into account the original investment, the economic advantages of the ASHP were obvious. Meanwhile, the ASHP was recognized by 97% of users in the survey of user satisfaction and thus it became the main utilization technology of coal-to-electricity project in northern China.

3.1.2. performances of technology. ASHP has the advantages of environmental protection, energy-saving and flexibility, but there were still inevitable problems in its application, which influenced the operation efficiency of the ASHP. The practical operation performances of the ASHP in coal-to-electricity project was monitored and the average *COP* of heating season in Beijing from 2016 to 2018 was 2.19, 2.24 and 2.2, respectively. The *COP* distribution of the ASHP in 2017 is shown in Figure 4, during which the ambient air temperature was averaged at -1.1 °C and the relative humidity was averaged at 36.7%. It can be seen that only 27% of the ASHP was in a good performances range during the whole heating season. Wang et al. reported that frosting will occur on an outdoor coil of a space heating ASHP when its outdoor coil metal surface temperature is below both air dew-point temperature and freezing temperature of water, which lead to the output heating capacity of the ASHP unit decreased by 30 % to 57 %, the *COP* decreased by 35 % to 60 %. Furthermore, mal-defrosting will also lead to a significant drop in the output heating capacity and operating efficiency of ASHPs [12-13]. Therefore,

developing good technologies to improve the operation efficiency of the ASHP is an effective way to promote the practice of coal-to-electricity policies.

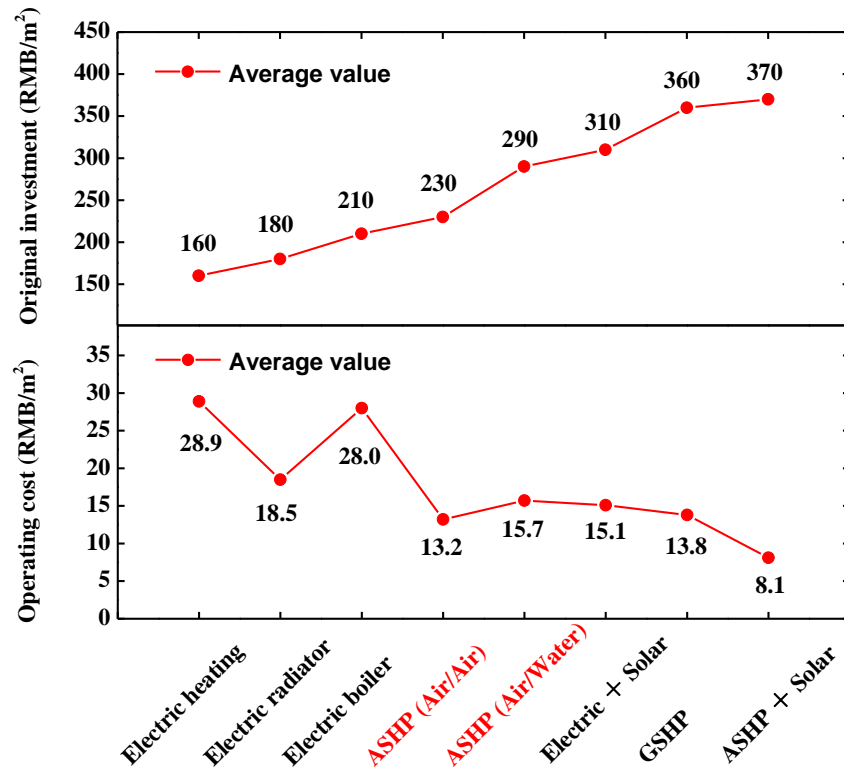


Figure 3. Original investment and operating cost for different technologies

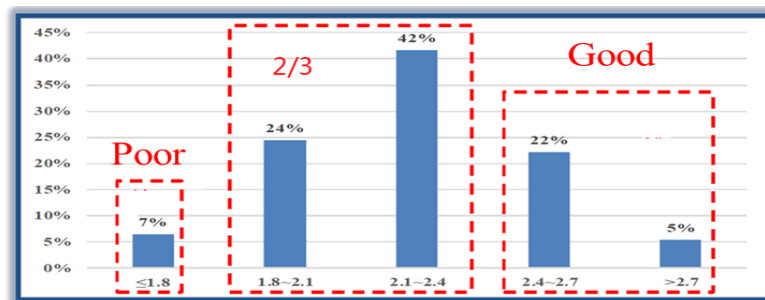


Figure 4. The COP distribution of the ASHP in heating season in 2017

3.2. Effect of coal-to-electricity project

From 2016 to 2018, more than 3 million households were converted from coal to electricity in northern China. The proportion of coal consumption decreased by 8.1%, and that of clean energy consumption increased by 6.3%. The conversion of 700 villages in Beijing has been completed, reducing coal-fired emissions by 900,000 tons and PM_{2.5} by about 1,260 tons per year. Air quality of northern China during heating season in 2017 is shown in Figure 5. As seen, at the beginning of the implementation of the coal-to-electricity project, the environmental pollution during heating season in northern China has been significantly improved. In addition, according to the data of Ministry of Environmental Protection, the average concentration of PM_{2.5} in 12 cities supported by first batch of central financial such as Tianjin and Baoding et al. decreased by 33% in the heating season of 2017, and the number of heavy pollution days decreased by 57% compared with last year. A number of data showed that coal-to-electricity project is an effective way to alleviate air pollution in northern China.

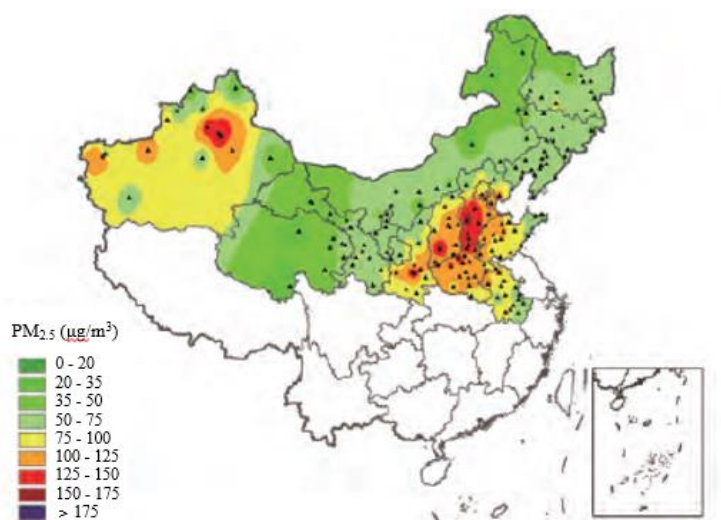


Figure 5. Air quality of northern China during heating season in 2017

4. Prospect of coal-to-electricity project in northern China

Clean energy heating was still the key implementation project of the Chinese government. In 2019, it will increase 15 billion RMB for clean energy heating. Coal-to-electricity project was rapidly being implemented in the surrounding areas of Beijing-Tianjin-Hebei region, and the Fenwei Plain will be the focus of conversion in the government's planning. It can be inferred that the coal-to-electricity project holds promising potential of development given the urgent need for clean energy heating in large areas of northern China.

The development of commercial ASHP was also predicted and shown in Figure 6. As the continues to increase in demand for urban building conversion, the ASHP were in thus vigorously promoted. The concomitant problem was how to improve the operating performances of equipment so that it can be used efficiently in coal-to-electricity project. To solve these problems, it is necessary to give play to the joint role of universities and enterprises to carry out technical research and the technology must be adapted to local conditions.

Finally, the experience of coal-to-electricity project in Beijing-Tianjin-Hebei region should be fully used for reference, and local governments should speed up the introduction of policies. Defining the target, scope and financial subsidy of coal-to-electricity policies can actively promote conversion.

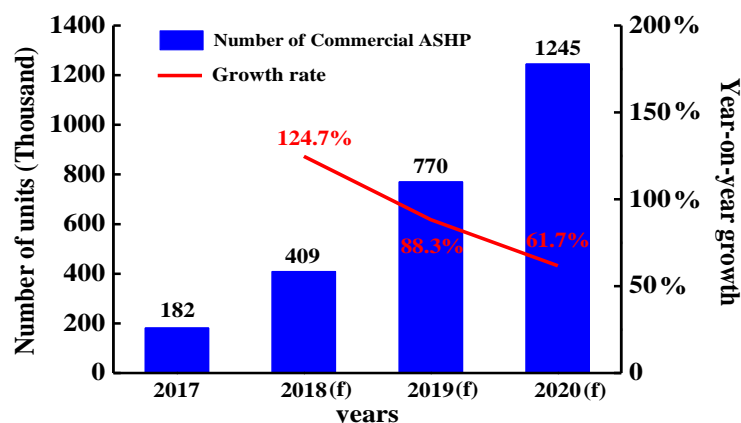


Figure 6. Development forecast of commercial ASHP in China

5. Conclusions

In this paper, a review on coal-to-electricity policies into practice is reported. Its planning, scope, funding, process, and technical types are analyzed in detail and a prospect of coal-to-electricity project

in northern China is also given. It is found that the coal-to-electricity project has become a main measure of clean energy heating conversion in Beijing-Tianjin-Hebei region and holds a meaningful contribution and promising potential of development. Meanwhile, due to the advantages of energy-saving and environmental protection, ASHPs has become the main utilization technology of coal-to-electricity project, which could be recommended for large-scale application in northern China. Lacking of policy subsidies and technical deficiencies are the factors that hinder the coal-to-electricity policies into practice and should be given attention in coal-to-electricity project in different regions. With clear funding policies by government and further research on suitable technology by social companies, it is contributing to the coal-to-electricity project and providing reference for transition of energy and low carbon policies into practice.

Acknowledgements

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