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Study on Electricity Substitution Plan for Civil Bulk Coal in Beijing-Tianjin-Hebei Region

JIN Ling, YAN Zhen, CHEN Xiaojun, TANG Qian, LEI Yu

Foreword »

Editor in Chief: Prof. WANG Jinnan

Since its opening-up and reform, China has been in the process of rapid economic development with its people enjoying an increasingly improved standard of life. Meanwhile accompanying this dramatic economic growth is the degradation of environment which has, to some extent, damaged the gains of the opening-up and reform and prevented the economy from a healthy and sustainable development. The Chinese government is increasingly aware of that without addressing the environmental issues it is facing now will jeopardize its long term goal of the great rejuvenation of the Chinese nation. Given the magnitude and complexity of the environmental issues in China, there is no easy way in addressing them and the solution to them entails an equal priority being given to environmental protection, ecological conservation and economic development or even higher than the latter by mainstreaming the former into the overall socio-economic decision-making process. As a matter of fact, China has been in the struggle against environmental pollution since the very beginning of its economic take-off and trying to explore a pathway that could help address China's environmental issues in the way most suitable to China's specific circumstances.

In recent years, especially since the 12th Five-Year Plan period, the enhanced measures including legislation, policy, regulatory and economic means have been taken by the Chinese government in dealing with environmental problems, of which environmental policies have played an important role in this regard. Corresponding to this situation and in meeting the demand of governments at different levels for environmental policy tools, the environmental policy research projects on topics of a wide range have been conducted by some Chinese environmental research institutions including the Chinese Academy for Environmental Planning (CAEP).

CAEP founded in 2001 is a research advisory body supporting governments in the development of key environmental planning, national environmental policies, and major environmental engineering projects. In the past more than 10 years, CAEP has accomplished the development of the overall planning of national environmental protection for the 10th, 11th and 12th Five-Year Plan periods; water pollution prevention and control planning for key river basins; air pollution prevention and control planning for key regions; soil pollution prevention and control planning; and some regional environmental protection plans. In the same period of time, CAEP also actively engaged in research on such topics as green GDP, environmental taxation, trading, ecological compensation, green financing, etc. By so doing, CAEP has become an indispensable advisory body in the environmental decision-making in mainland China. According to *2013 Global Go To Think Tanks Report and Policy Advice* published by University of Pennsylvania, CAEP was ranked 31 in the field of environment in the world. Many of CAEP's research results and project outcomes regarding environmental policies have drawn great attention of decision makers and international institutions, and have been utilized to contribute to the formulation of national environmental policies concerned.

The Chinese Environmental Policy Research Working Paper (CEPRWP) is a new internal publication produced by CAEP for the purpose of facilitating the academic exchange with foreign colleagues in this field, in which the selected research papers on environmental policies from CAEP are set out on the irregular basis. It is expected that this publication will not only make CAEP's research results on environmental policies be known by foreign colleagues but also serve as a catalyst for creating opportunity of international cooperation in the field of environmental policies, and environmental economics in particular, with a view of both the academic research and practical policy needs.

Beijing, Tianjin, Hebei and their surrounding areas are known as the most serious air pollution area in China. Relevant research showed that during heavy haze pollution episodes in winter, low source emissions, e.g. bulk coal combustion, contributed a lot to the concentration of $PM_{2.5}$.In order to promote civil bulk coal replacement and air quality improvement in Beijing-Tianjin-Hebei Region, CAEP research team have implemented this research to design the electricity substitution plan for civil bulk coal and analyze the corresponding economic costs and environmental effects, so as to provide decision-making reference for the government. This research was funded by the Energy Foundation. The project team carried out field visit to Beijing, Tianjin and Hebei Province, and investigated the basic status of civil coal using, the progress of energy substitution from coal to clean energy and the main obstacles. Three workshops on these issues were held in Beijing (in July 2016, March 2017 and August 2017 respectively), and relevant experts taking part in these discussions came from the Ministry of Environmental Protection, the National Energy Administration, Tsinghua University, Beijing Municipal Research Institute of Environmental Protection, Beijing Municipal Commission of Rural Affairs, Tianjin Development and Reform Commission and other relevant agencies.

Contents

1. INTRODUCTION

Bulk coal refers to the coal that is used in small coal furnaces or small coal-fired boilers other than that used in large industrial facilities (power generation, refinery works, etc.). Although the consumption of bulk coal is far below the coal consumption in large industrial facilities such as power plants, iron and steel plants, and construction materials industry, the pollutants discharge per unit of coal consumption contribute more to the air pollution than that of large coal-fired equipment. It is due to lack of pollution reduction facilities, poor quality of the coal and lower stack height. Therefore, air pollution derived from bulk coal combustion is a pressing problem that needed to be solved.

In order to replace the bulk coal for civil use and improve the air quality in the heating season, Beijing, Tianjin and Hebei have invested a lot and taken many comprehensive measures in recent years, and gained certain effect. Beijing is an exemplary city which started early in controlling bulk coal pollution and has made fast progress. By the end of 2016, 384,500 households had adopted electric heating instead of coal furnace, and nearly no coal used in core areas in Beijing. This report summarized the experience and lessons in “coal to electricity” project of Beijing, in order to provide reference for other cities. At present, main obstacles in the control of civil bulk coal in Beijing-Tianjin-Hebei Region include huge financial investment, insufficient electric grid infrastructures, significant difference between the prices of natural gas, electricity and coal for heating purposes, and difficulty in changing the living habits of residents.

There are many “coal to electricity” technologies applied at present. This report summarizes the current mainstream technologies, compare the costs, merits, drawbacks and suitable conditions of different electric heating technologies including separate air-source heat pump(including low-temperature air source hot-wind heat pump and low-temperature air source hot-water heat pump), ground source heat pump, thermal energy storage electric heater and direct electric heating technology. Cost is a main factor to consider in carrying out the “coal to clean energy” project in rural areas, we also compare the costs of different electric heating technologies and coal heating technologies. The heating costs mainly include initial investment, annual operation cost and maintenance cost.

In this report we also put forward the general guideline, principle and technology roadmap of “coal to electricity” policy. “Coal to electricity” is one of the important ways to control the using of bulk coal and should be implemented under the general guideline and framework of bulk coal control. Bulk coal should be controlled following the principles of “adjusting measures to local conditions, implementing the policy by categories, advancing the implementation step by step, and taking multiple measures”. The "coal to electricity" project mainly aims at those household users who burn bulk coal for heating and live in urban and suburban areas, and villages outside the coverage of gas and heat pipe networks.

In order to provide reference for policy making, we set two policy scenarios. There are self-defined objectives of each province in scenario 1, and more aggressive objectives in scenario 2. We have analyzed the scale and costs of implementing “coal to electricity” project in households in Beijing-Tianjin-

Hebei region during the "13th Five-Year Plan", and also analyzed the environmental, health and social benefit in different scenarios. At the end of this report, we make a few policy recommendations for the bulk coal control in Beijing-Tianjin-Hebei region.

2. BULK COAL CONSUMPTION AND AIR POLLUTION

2.1 The Definition and Types of Bulk Coal

Bulk coal refers to the coal that is used in small coal furnaces or small coal-fired boilers other than for the industrial centralized coal-fired facilities, e.g. power generators. According to its application fields, bulk coal can be subdivided into five categories: 1. bulk coal used in rural households, i.e., coal used by rural residents for heating and cooking; 2.bulk coal used in urban households, i.e., coal used by urban residents for heating and cooking;3.bulk coal for agricultural production, i.e. coal used for running agricultural greenhouses and breeding in rural areas;4.bulk coal used for commercial activities, i.e., coal used in catering, baths, etc. ; 4.bulk coal for enterprises and public institutions, i.e., coal used for heating and running canteens in schools and hospitals. Since over 80% of bulk coal was used in rural and urban households, this study focused on the pollution control of the first two types of bulk coal.

Although the quantity of civil coal consumption is far smaller than the coal consumption in the key industries such as power generation, iron and steel, and construction materials industry, the pollutants discharge per unit civil coal consumption contributes more to air pollution than that of coal consumption in large coal-fired equipment due to the lack of pollution reduction facilities and low pollutant discharge height. Therefore, reducing the air pollutants discharge from bulk coal combustion is essential.

2.2 Bulk Coal Consumption is the Main Source of Atmospheric Pollution in the North China in Winter

Since the implementation of the Action Plan on Prevention and Control of Air Pollution (hereinafter referred to as the "Action Plan") in China in 2013, pollution control measures and regulations have become stricter in the industry, transportation and other fields, which plays an important role in air quality improvement. The annual average concentration of $PM_{2.5}$ in key areas showed a decrease trend, however, frequent heavy pollution still occurred in winter and the air quality in the heating season was worse than the rest of the year. According to the data in the Green Book of Climate Change: Annual Report on Actions to Address Climate Change (2013), jointly issued by the Chinese Academy of Social Sciences and China Meteorological Administration, the hazy days in China showed obvious seasonal characteristics. The number of hazy days in winter accounted for 42.3% of the total hazy days all year around. According to the monthly monitoring data in Beijing, Tianjin, Hebei and the surrounding 45 cities from2013 to 2016, the concentrations of the four key pollutants, i.e., SO_2, NO_2, PM_{10} and $PM_{2.5}$, in the heating seasons (from November to February of the next year) were all higher than those in the non-heating seasons. The average concentrations of SO_2, NO_2, PM_{10} and $PM_{2.5}$ in heating season from2015 to2016 was 2.4, 1.4, 1.4 and 1.8 times of that in the non-heating season, respectively.

Figure 1 The Trend of Air Quality Average Concentration of 45 Cities Located in Beijing, Tianjin, Hebei, Henan and Shandong Areas between 2013 and 2016

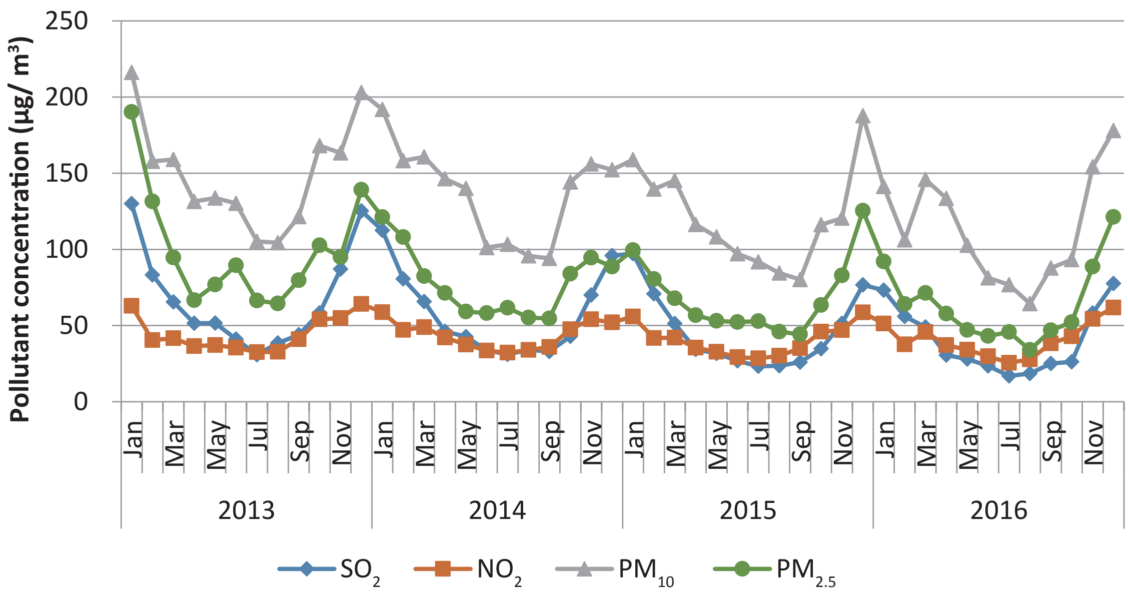
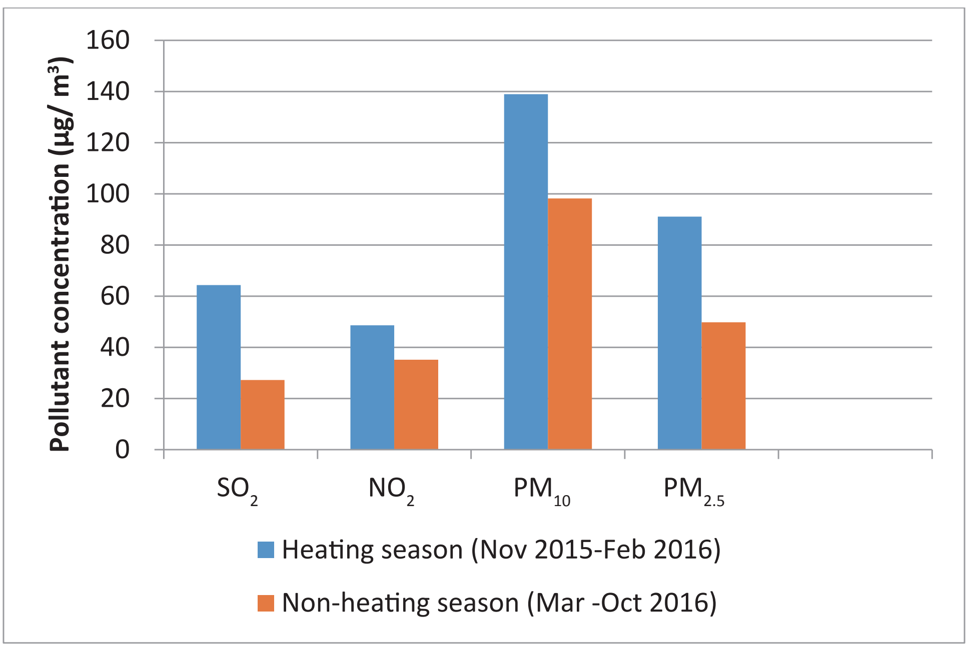


Figure 2 The Comparison of Air Quality between the Heating Season and Non-heating Season of 45 Cities Located in Beijing, Tianjin, Hebei, Henan and Shandong Areas



The study showed that coal-fired heating caused an increase inSO_2 and PM concentration, and in heating seasons, the contribution of coal combustion pollution in some northern cities even exceeded the industrial source and transportation source during certain periods, becoming the major pollution source. The analytical study on the pollution sources in the Beijing-Tianjin-Hebei region conducted by Tsinghua University showed that the residential source contributed 29% to the annual $PM_{2.5}$ concentration in this region in 2013, and this number rose to 48%[1] in winter. The residential source became the primary contributor to $PM_{2.5}$ in the Beijing-Tianjin-Hebei region in winter. In heavy pollution episodes, the automotive exhaust emission contributed less especially when taking some emergency measures such as driving restriction, but the coal combustion contributed much more.

2.3 The Heating Methods Need to be Upgraded

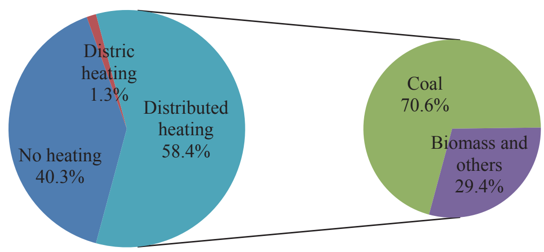
The percentage of district heating adoption in the urban areas of north China is about 76%, and that in cities and counties is higher (88%), but that in the towns is relatively low, only 20%.

Table 1 Areas Adopting District Heating in the Urban Areas in the North in 2013[2]

Unit: 10^8 m^2	Cities and counties	Towns	Total amount
Construction area	100	20	120
Area of district heating	87.8	3.9	91.7
The ratio of area adopting district heating to the total constructed area	88%	20%	76%

In terms of energy types used for heating in rural areas, among 160 million rural households in China, about 93 million[3] adopt distributed heating; 66 million households adopt coal heating and 27 million households adopt biomass heating or other methods. (See Fig. 3) Except for the Beijing-Tianjin-Hebei region where briquette is used at a higher rate, most rural areas in north China use raw coal for heating and the rate of using clean briquette is low.

Figure 3 Heating Methods and Structure of Energy Use in China's Rural Areas



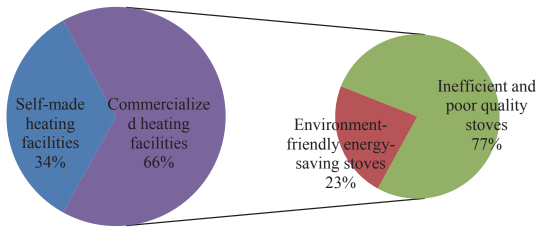
In terms of heating facilities, the majority of the residents in rural areas in north China use inefficient stoves, small boilers and 'home-made heating system'. Because the self-made heating facilities are still widely used, the inefficient and poor quality stoves have a big market share. The coal burned is mainly cheap poor quality bituminous coal, which aggravates air pollution.

[1] Li, X., Zhang, Q., Zhang, Y. et al., 2015. Source Contributions of Urban $PM_{2.5}$ in the Beijing-Tianjin-Hebei Region: Changes between 2006 and 2013 and Relative Impacts of Emissions and Meteorology. Atmospheric Environment. Vol,123: pp. 229-239.

[2] A Research Report on Annual Development of China's Building Energy Conservation 2015, China Architecture & Building Press. Notes: The data of areas adopting district heating provided by the statistical yearbook only includes operational areas adopting district heating, so the date of areas here includes non-operational areas adopting district heating, e.g. the army, universities and some large-scale enterprises have their own independent central heating systems.

[3] Report on Development of China's Heating Stove Industry 2016

■ **Figure 4 The Percentage of Existing Heating Facilities in China's Rural Areas**



In summary, controlling bulk coal and promoting cleaner heating methods in the north are important measures to alleviate air pollution in winter. On December 21, 2016, China's General Secretary XI Jinping pointed out in the speech at the 14th session of the Central Leading Group on Financial and Economic Affairs that promoting cleaner heating methods in winter in north China is related to a warm household for the masses in the north and the reduction of haze days. It is an important part of the revolution of energy production and consumption, and the revolution of rural life style. Enterprises should play the key role in promoting cleaner heating methods with supports from the government, finding more affordable heating methods for residents. They should utilize clean energy as much as possible to improve the percentage of heating supply powered by clean energy, such as natural gas or electricity whichever is suitable.

3. CURRENT POLLUTION CAUSED BY BULK COAL IN BEIJING-TIANJIN-HEBEI REGION AND THE RELATED CONTROL MEASURES

3.1 Current Consumption of Bulk coal and its Environmental Impacts on Beijing-Tianjin-Hebei Region

Bulk coal is a main form of energy used for heating in Beijing-Tianjin-Hebei region in winter. Taking Hebei province as an example, bulk coal, coal-fired district heating, natural gas, electricity and geo-thermal accounted for 58.6%, 30.4%, 4.7%, 2.4% and 2.1% of the total amount of energy used for heating in 2015,respectively,and the remaining was biomass. According to the investigation and estimation of the project team, in 2015, the consumption of bulk coal in households in Beijing, Tianjin and Hebei (including cities, towns and the countryside) were about 3.2 million tons, 1.42 million tons and 35.51 million tons respectively, a total of 40.13 million tons[4], accounting for 10.6% of the total coal consumption in these three municipal cities or province in 2015. The bulk coal consumption intensity per unit area in this region was 4.5 times of that in the country. Heavy pollution in winter was believed to be caused by huge amount of bulk coal consumption, poor coal quality and lack of pollution control measures.

According to our research, the emissions of SO_2, NO_x,PM_{10}, $PM_{2.5}$, CO and VOCs from bulk coal burning in Beijing-Tianjin-Hebei region in 2015 were 230,000 tons, 50,000 tons,320,000 tons, 255,000 tons, 4,422,000 tonsand109,000 tons, respectively, accounting for 18%[5] of the total smoke and dust emission, 16% of the total SO_2 emission and 3% of the total NO_x emission. The bulk coal burning contributed 9.9%, 11.9% and 13.2% to the atmosphere $PM_{2.5}$ concentration in Beijing, Tianjin and Hebei, respectively.

3.2 Bulk Coal Control Policies in Beijing-Tianjin-Hebei Region and Progress of their Implementation

In order to replace the bulk coal for civil use and to improve the air quality in the heating season, Beijing, Tianjin and Hebei have made heavy investment to promote clean coal and coal substitution in recent years. By the end of 2016, the ‘coal to electricity’ project had been comprehensively progressed in Beijing where 384,500 households had adopted electric heating, and almost no coal was used in the core areas in Beijing. Tianjin had made great efforts to popularize smokeless briquette and advanced civil stoves and had successfully replaced bulk coal with clean briquette. Wuqing district, Tianjin carried out ‘coal to electricity’ project and 196,200 tons of bulk coal had been replaced. Hebei Province designated 18 counties around Beijing in Baoding and Langfang as non-coal-using areas, where 318,700 households had replaced coal with electricity or gas. Households in central Handan had all replaced coal with gas and such cities as Shijiazhuang, Xingtai had set up a number of ‘coal to electricity’ and ‘coal to gas’ clean

[4] Calculated according to the data in the surveys of Beijing, Tianjin and Hebei.

[5] According to the compiling explanation of the Technical Guidance for Compiling Air Emissions Inventory of Civil Coal, in the emissions of particulate matters by the using of civil coal, PM_{10} accounts for about 90% of smoke and dust.

energy demonstration projects.

Beijing is a model city which started bulk coal control very early, and has made outstanding progress since 'coal to clean energy' project in 2003. By the end of 2015, the task of 'coal to clean energy' for 310,000 households in Dongcheng district and Xicheng district had been completed. In rural areas, 74,500 households had completed the transformation of 'coal to clean energy' since 2013. The release of a series of policies such as *Intensified Measures for Prevention and Control of Air Pollution in Beijing, Tianjin and Hebei (2016-2017), Work Scheme for Accelerating the Replacement of Civil Bulk Coal by Clean Energy in Beijing for the Period of 2016-2020 and the 2016 Guiding Opinions on Promoting the 'Coal to Clean Energy and Reduction and Replacement of Coal' Project in Villages in the Rural Areas of Beijing* has clarified the goal, deadline and direction of bulk coal control and driven the process of that efforts in Beijing. Beijing is making efforts to realize "non-coal-using" in its core areas and the plain areas in its four southern districts by the end of October 2017, and to completely adopt clean energy for heating in the rural plain areas of the whole city by 2020. **The guideline of controlling bulk coal in Beijing** is 'using various forms of energy; simultaneously implementing various measures; step by step'. It has divided the civil bulk coal pollution control measures into two categories: 'coal reduction' and 'coal replacement'. 'coal reduction' means replacing coal with such high-quality clean energy as electricity, natural gas, municipal heating power, solar energy and liquefied petroleum gas in the areas that meet the requirements. 'Coal replacement' means replacing the soft coal/bulk coal currently used by the residents with high-quality briquette of lower content of sulfur that emits fewer pollutants in the poor areas. Residents were encouraged to use systems such as low-temperature air sources pumps powered by geo-thermal and solar energy plus auxiliary energy which integrated different kinds of equipment based on the principle of 'using various forms of energy, combining various kinds of heating forms and unifying different sources'. The heating scheme for residents was based on local conditions, taking each rural household as an individual system and designing the heating plan for each household according to its requirements and actual conditions. Meanwhile, more financial subsidies were given to support the clean energy infrastructure construction. Taking the 'coal to electricity' project as an example, a series of policies were issued to support the promotion of the electric heating equipment, improving the insulation of farmer houses, external power and household wiring grid retrofit. For the retrofit of external power grid of 10kV or less for households, the State Grid Beijing Electric Power Company would pay 70% and the Municipal Development and Reform Commission will pay 30% for the fixed asset investment. For household wiring retrofit and peak-valley electricity meter connected to the heating equipment, cities and districts (counties) government would pay 60% and 40% respectively. For the heating equipment, the city and district (county) government would both one third of the total price. Residents who joined the 'coal to electricity' project would pay the electricity bills according to the peak-valley electricity price in the heating season, and the time for preferential electricity price is from 21:00 to 6:00 next day, during which users only need to pay 0.1 yuan/Kilowatt-hour after receiving subsidies. The cost of electric heating was basically equivalent to that of coal burning.

The practical experience for controlling bulk coal in the Beijing-Tianjin-Hebei region can be summed up as the following six points: (1) Set up a cooperation mechanism among government departments, including the Development and Reform Committee, Ministry of Energy, Ministry of Finance, Ministry of Housing and Urban-Rural Development, Ministry of Agriculture, Ministry of Environmental Protection and State Power Grid. (2) Strengthen the infrastructure construction, such as the power grid and natural gas pipeline network. (3) The special fund for prevention and control of air pollution played a key role in offering subsidies for electricity price, gas price, heating facilities, power grid construction and clean briquette, and the subsidies from governments at all levels were put in place. (4) Heating schemes were designed for each household according to local conditions following the principle of 'using various forms of energy, simultaneously implementing various measures, step by step'. (5) Standard relevant procedures and norms. Beijing released several guidelines for testing standards, bidding and tendering procedure, internal design and installation, choice of heating technology and requirement for maintenance. (6) Strengthen the supervision of the quality of bulk coal. In the Beijing-Tianjin-Hebei region, the sulfur content of the coal for civil use must not exceed 0.4%, and there are also requirements for its ash content and volatile matters.

The main problems in the bulk coal control at present include: (1) Lack of top-level design and unified planning; (2) Insufficient supporting capacity of the infrastructure; (3) Lack of effective, sustainable economic incentives and rewarding mechanisms, and to the government, financial subsidies are too high; (4) It is difficult for the masses to change their habit of using coal for heating, so there were phenomena of getting the subsidies by cheating and using coal again after adopting electric heating; (5) Bulk coal is heavily used in a wide range of facilities without effective supervision methods.

4. ANALYSIS OF THE MAINSTREAM TECHNOLOGY FOR 'COAL TO ELECTRICITY'

The forms of electric heating in winter are divided into district electric heating and distributed electric heating according to the heating scales. District electric heating includes such technology as centralized heating pump and heat accumulating electric boiler. Distributed electric heating includes separate air-source heat pump (including low-temperature air source hot-wind heat pump and low-temperature air source hot-water heat pump), ground source heat pump, thermal energy storage electric heater and direct electric heating technology. The merits and drawbacks of different distributed electric heating technology and comparison of their suitable conditions are shown in Table 2.

Table 2 Comparison of Distributed Electric Heating Technology

Description of technology	Merits	Drawbacks	Suitable conditions
Low-temperature air source hot-wind heat pump	High Coefficient of Performance (COP): (2.5—3.5), convenient to install and simple to control, can be opened at any time to use it, which can save energy, fast temperature increase and low failure rate.	Direct wind blowing makes poor customer experience.	Because it needs to be installed separately in each room and it is restricted by the limit of the outdoor power in rural residences; suitable for houses less than5 rooms or within 150 square meters. Upgrading of the power grid is needed for popularization of the technology in the whole village.
Low-temperature air source hot-water heat pump	High COP; heating the water and the floor, good customer experience.	Limited energy-conservation by behavioral habits. When using the automatic defrosting mode at low temperature, the water temperature will drop resulting in low indoor temperature. Electric heating is needed to raise temperature, causing a higher cost.	Suitable for rural residence who have a high demand for heating, more rooms or large area to be heated. Upgrading of the power grid is needed for popularization of the technology in the whole village.
Ground source heat pump	High COP (2.8- 3.8); lower demand for external power source and the heating source is steady; more comfortable and lower operation cost.	High initial investment, complicated technology and more concealed construction, restricted by the engineering, construction and hydro geological conditions, difficult to repair in case of malfunction, insufficient soil concurrent heating will shorten its service life.	Suitable for houses with large space areas and mobile underground geological structure in regions with stable geothermal resources.
Thermal energy storage electric heater	Simple to install, easy to operate, no outdoor equipment and no noise.	COP≤1, higher demand for power supply, when heat storage is insufficient, electricity at non-preferential price is needed, raising the operation cost. The exothermic property of heat-storing materials is fixed and not controllable, slow to raise indoor temperature.	Convenient to install but relies more on external power grid. It can be popularized in houses with lower rooms and small areas.
Direct electric heating technology	Simple to install and flexible to operate, no noise.	COP≤1; heavy energy consumption, high electricity bills, the electric capacity needs to be greatly expanded.	It is generally used by residents who cannot install heat pumps and users in "villages in the city". Beijing forbad its popularization in 2017.

Due to the lower level of economic development in rural areas, people consider the initial investment and operation costs more. Money-saving should be taken as the primary factor when carrying out the 'coal to clean energy' project in rural areas. The heating costs mainly include: (1) Initial investment: cost for purchasing the heating equipment and installation fee, not including the end facilities for heating; (2) Annual operation cost, namely the fees for electricity or natural gas used by the equipment, and the main influencing factors are living habits of the users and the insulating condition of the house; (3) Maintenance cost. Comparison of costs of electric heating and other heating methods are shown in Table 3.

Table 3 Comparative Analysis of Costs of Electric Heating and Other Heating Methods

Type of energy	Description of technology	Initial investment of each household	Operation cost for each household in the heating season (subsidies are not included)	Operation cost for each household in heating season (subsidies are included) [6]	Demand for electric power supply
		10,000 yuan/ Household	yuan/Household	yuan/Household	Kilowatt/ Household
Electricity	Low-temperature air source hot-wind heat pump	1.2-1.8	1600-3300	1000-1800	3.6-4.0
	Low-temperature air source hot-water heat pump	2.5-3.5	3200-4900	2000-2900	3.6-4.0
	Ground source heat pump	4.0-5.0	1300-1600	800-1000	3.1-3.6
	Electric floor-heating system	1.3-1.9	6500-9700	4100-5900	7.2-10.8
	Electric boiler	1.2-1.9	9700-13000	6000-8100	7.2-10.8
	Thermal energy storage electric heating(Compressed brick type)	0.7-1.0	4900-6500	3200-4200	7.2-18.0
	Air source heat pump +solar energy	3.0-4.0	1300-2400	800-1600	3.6-7.2
Natural gas	Wall-mounted gas boiler	0.6-0.8	4000-5600	2600-3500	/
Coal	Briquette	0.05-0.09	1200-2800	600-1200	/
	Bulk coal	0.01-0.05	550-950	/	/

Among the users' choices of technology for 'coal to electricity' in the rural areas of Beijing, air source heat pump was the mainstream technology.199,000 households in 574 villages in Beijing completed 'coal to electricity' in 2016, and among them,151,000 households adopted air source heat pump, accounting for 76.28% of the total number of households,44,300 households adopted thermal energy storage electric heater, accounting for22.30%, 2,139 households adopted ground source heat pump, accounting for1.07% and688 households adopted other types of electric heating facilities, accounting for 0.35%.

[6] Calculation was based on the subsidizing standard for electricity price in Beijing: the electricity price during valley period, which is from 21:00 to 6:00 the next day, is 0.1yuan/kWh after subsidizing and the price is 0.4883 yuan /kWh during other time period.

5. 'COAL TO ELECTRICITY' SCENARIOS AND THE RELEVANT COSTS IN BEIJING-TIANJIN-HEBEI REGION DURING THE 13TH FIVE-YEAR PLAN PERIOD

5.1 The General Guideline of Coal-to-Electricity

'Coal to electricity' is one of the important ways to control the using of bulk coal and should be implemented under a general guideline and framework. Bulk coal control is a systematic project, benefitting environmental protection, improving people's livelihood and energy optimizing. Bulk coal should be controlled following the principles of 'adjusting measures to local conditions, implementing the policy by categories, advancing the implementation step by step, and taking multiple measures'. In the Beijing-Tianjin-Hebei region, the bulk coal should be controlled step by step, considering the urgency of air pollution prevention and control, the difficulty in progress of work, and the residents' ability to shoulder economically. Beijing, Tianjin and eight cities in Hebei Province in the air pollution transmission channels[7] should be highlighted. Following the principle of 'urban areas first and then villages and towns', firstly adopt clean heating in urban areas, rural-urban continuums, industrial parks and key villages and towns, from plain areas to remote mountain areas,and then implement the project in villages and towns with good infrastructure conditions to other villages and towns.

5.2 Application Scope and Technological Routes of 'Coal to Electricity'

Coal-to-electricity conversion in households is targeted at users who burn bulk coal for heating in urban and suburban areas, and villages outside the coverage of gas and heat pipe networks. Priority should be given to developing district heating with combined heating and power generation and the heating supplied by industrial waste heat. In the regions where the two patterns mentioned above are hard to cover, distributed electric heating should be promoted upon the local conditions, prioritizing the popularization and use of air source heat pumps and ground source heat pumps with higher coefficient of performance (COP), and the use of energy-storage electric heaters should be restricted. Moreover, directly-heated electric heating should be used with care since its energy efficiency ratio is low.

5.3 'Coal to Electricity' Scenarios in Beijing-Tianjin-Hebei Region and their Costs

The scale and costs of implementing 'coal to electricity' conversion in households in the Beijing-Tianjin-Hebei region during the 13th Five-Year Plan were analyzed using a scenario analysis method, and the environmental, health and social benefits in different scenarios were also studied. With the indoor heating pollution reduction and atmospheric air quality improvement as the fundamental starting points, and considering the status quo of bulk coal consumption for civil use, energy resources and infrastructure conditions, air quality in different cities, and requirements on pollution control in

[7] The eight air pollution transmission channel cities in Hebei Province are Shijiazhuang, Langfang, Baoding, Tangshan, Cangzhou, Hengshui, Xingtai and Handan.

the Beijing-Tianjin-Hebei region, scenario plans for coal-to-electricity conversion in households in the Beijing-Tianjin-Hebei region during the 13th Five-Year Plan were set up. The 'coal to electricity' objective scenario plan in the Beijing-Tianjin-Hebei region in 2020 is detailed in Table 4, where Scenario 1 is a self-defined objective scenario ,that is objectives set by each province, and Scenario 2 is an intensified objective scenario.

Table 4 'Coal to Electricity' Objective Scenario Plans in the Beijing-Tianjin-Hebei Region in 2020

Region	Bulk coal consumption in 2015	Scenario 1: self-defined objective scenario	Scenario 2: intensified objective scenario
Beijing	3.20 million tons, and 1.1 million households	'Coal to electricity' is to be carried out for a total of 0.674 million households, with 60% complementation	'Coal to electricity' is to be carried out for a total of 0.75 million households, with 70% complementation
Tianjin	1.42 million tons, and approx. 0.60 million households	'Coal to electricity' is to be carried out for a total of 0.35 million households, with 58% complementation	'Coal to electricity' is to be carried out for a total of 0.4 million households, with 67% complementation
8 transmission channel cities in Hebei Province	29.47 million tons, and approx. 9.49 million households	'Coal to electricity' is to be carried out for a total of one million households, with 11% complementation	'Coal to electricity' is to be carried out for a total of1.8 million households, with 20% complementation
Zhangjiakou, Chengde and Qinhuangdao	6.04 million tons, and approx.1.94 million households	/	'Coal to electricity' is to be carried out for a total of 0.2 million households, with 10% complementation
Total	40.13 million tons, and approx.13.13 million households	'Coal to electricity' is to be carried out for a total of 2.02 million households, with 15% complementation	'Coal to electricity' is to be carried out for a total of3.15 million households, with 24% complementation

Costs for each 'coal to electricity' scenario plan include three parts: (1) initial investment in the heating equipment, which is about 21,000 yuan per household; (2) annual operation cost, which is about 3,300 yuan/year for each household, without considering subsides; (3) costs for electricity grid retrofit at all or different levels, which is about 50,000yuan per household according to research data from Beijing Power Grid. The results of the cost analysis for each 'coal to electricity' objective scenario plan in the Beijing-Tianjin-Hebei region in 2020 are detailed in Table 5.

Table 5 Cost Analysis of 'Coal to Electricity' Objective Scenario Plans in the Beijing-Tianjin-Hebei Region in 2020

Cost		Scenario 1: self-defined objective scenario of each province	Scenario 2: intensified objective scenario
Cost	Initial investment in heating equipment (100 million yuan)	425	662
	Annual operation cost (without subsidies) (100 million yuan/year)	67	104
	Investment in electricity grid retrofit (100 million yuan)	1012	1575

6. ANALYSIS OF ENVIRONMENTAL, ECONOMIC AND SOCIAL BENEFITS OF ‘COAL TO ELECTRICITY’ IN BEIJING-TIANJIN-HEBEI REGION

‘Coal to electricity’ project in the Beijing-Tianjin-Hebei region will bring benefits in environmental, health, economic, and social aspects, including: (1) Environmental benefit. It will reduce the emissions of major air pollutants and greenhouse gases, resulting in improved atmospheric and indoor air quality. (2) Health benefit. It will reduce the respiratory and cardiovascular diseases triggered by air pollution caused by bulk coal combustion, and the premature deaths related to air pollution. (3) Social benefit. It will improve the life quality of residents, and people are able to experience more comfortable and safer winter heating. It will increase electricity consumption, reducing the abandonment of wind and solar power, stimulate the development of related industries, including renovation of rural power network, and promoting the development of related electric transmission and transformation equipment and indoor electricity meter manufacture. Based on the scenario plans, the benefit of the ‘coal to electricity’ project in the Beijing-Tianjin-Hebei region will greatly outweigh its investment cost.

6.1 Environmental Benefits from Civil Bulk Coal Reduction

6.1.1. Air Pollutants Emission Reduction

Civil bulk coal consumption has a great impact on local air quality, due to the large amount of consumption, low combustion efficiency, no pollutant abatement facilities, and low stack height. The implementation of ‘coal to electricity’ project will reduce the emissions from civil bulk coal burning, which will have a significant effect on the improvement of air quality, especially in winter.

In scenario 1 and scenario 2, the quantity of civil bulk coal consumption would be reduced by 5.87 million tons and 9.26 million tons, respectively. The reduction potential of SO_2, NO_x,$PM_{2.5}$ and PM_{10} emission was estimated using an emission factor method. In scenario 1, SO_2, NO_x, $PM_{2.5}$ and PM_{10} would be reduced by 2.84×10^4tons, 0.59×10^4tons, 2.86×10^4tons and 3.61×10^4 tons, respectively, accounting for 12.4%, 11.7%, 11.3% and 11.2% of total emissions from civil bulk coal combustion (Table 6). In scenario 2, the quantity of SO_2, NO_x, $PM_{2.5}$ and PM_{10} reduction would be 4.76×10^4tons, 0.97×10^4tons, 5.03×10^4tons and 6.33×10^4 tons, accounting for 20.7%, 19.4%, 19.8% and 19.8% of total emissions from civil bulk coal combustion.

Table 6 Pollutants Emission Reduction in the Two Scenarios (10^4 tons)

Scenarios	Region	SO_2	NO_x	$PM_{2.5}$	PM_{10}
Scenario 1	Beijing	0.73	0.16	0.55	0.70
	Tianjin	0.32	0.07	0.24	0.31
	Hebei	1.79	0.35	2.07	2.60
	Total	2.84	0.59	2.86	3.61
	Reduction percentage %	12.4%	11.7%	11.3%	11.2%
Scenario 2	Beijing	0.81	0.18	0.61	0.78
	Tianjin	0.36	0.08	0.28	0.35
	Hebei	3.59	0.71	4.14	5.20
	Total	4.76	0.97	5.03	6.33
	Reduction percentage %	20.7%	19.4%	19.8%	19.8%

Considering the proportion of civil bulk coal to the total coal consumption (13.6%), $PM_{2.5}$ emission per unit bulk coal combustion (about 5 times of that in coal-fired power plants), the results of $PM_{2.5}$ source apportionment in Beijing-Tianjin-Hebei region, the contribution of civil bulk coal combustion to $PM_{2.5}$ concentration was estimated, and the decrease of $PM_{2.5}$ concentration caused by civil bulk coal reduction was calculated. The results showed that in scenario 1 and scenario 2, the reduction of $PM_{2.5}$ concentration in the Beijing-Tianjin-Hebei region would be 3.6μg/m^3 and 4.3μg/m^3, respectively.

In this research, we average the value of the $PM_{2.5}$ reduction caused by the reduction of civil bulk coal in the whole Beijing-Tianjin-Hebei region. However, 'coal to electricity' project is implemented mainly in rural areas, the concentration of $PM_{2.5}$ in rural areas will fall more than the urban area. In addition, the contribution of civil bulk coal burning in heavy pollution episodes is greater than in the normal days, therefore, the effect of the 'coal to electricity' project on $PM_{2.5}$ reduction in heavy pollution days should be greater.

Table 7 Annual Average $PM_{2.5}$ Concentrations in Different Regions in the Two Scenarios

Region	Annual average concentration of $PM_{2.5}$ μg/m^3	Contribution of coal combustion to Anuual Average $PM_{2.5}$ (in Heavy pollution episodes) %	Contribution of civil bulk coal to Anuual Average $PM_{2.5}$ (in Heavy pollution episodes) %	Decline of annual average concentration of $PM_{2.5}$ μg/m^3	
				Scenario 1	Scenario 2
Beijing	80.6	22.4 (32.2)	9.9 (14.2)	4.9	5.4
Tianjin	70.0	27.0 (30.8)	11.9 (13.6)	4.9	5.6
Hebei	77.0	30.0 (34.0)	13.2 (15.0)	1.1	2.0

6.1.2. Green House Gas Emission Reduction

(1) CO_2 emission reduction

The combustion of coal, oil and other fossil fuels produce SO_2, NO_x, PM_{10}, $PM_{2.5}$ and other pollutants which caused the deterioration of air quality. Huge amount of greenhouse gas are also emitted during the combustion process. 90% of greenhouse gas in China comes from fossil fuel combustion, of which 68% comes from coal combustion[8]. Therefore, strengthening the management of civil bulk coal and replacing it with cleaner and more efficient energy is important for carbon reduction.

In scenario 1, Beijing - Tianjin - Hebei region would reduce 641.2×10^4 tons of CO_2 emission, of which Beijing , Tianjin and Hebei would reduce 218.4 ×10^4 tons,82.9×10^{4}tons and 339.9×10^4 tons, respectively. In scenario 2, Beijing - Tianjin - Hebei region would reduce 1017.5×10^4 tons of CO_2 , of which Beijing , Tianjin and Hebei would reduce 243.0 ×10^4 tons, 94.8×10^{4}tons and 679.8×10^4 tons CO_2 respectively. (Table 8)

Table 8 CO_2 Reduction in the Two Scenarios

Scenarios	Region	CO_2 reduction (10^4 tons)
Scenario 1	Beijing	218.4
	Tianjin	82.9
	Hebei	339.9
	Total	641.2
Scenario 2	Beijing	243.0
	Tianjin	94.8
	Hebei	679.8
	Total	1017.5

[8] Zhu LIU. 2015. "China's Carbon Emissions Report 2015." Sustainability Science Program and Energy Technology Innovation Policy research group, Belfer Center Discussion Paper #2015-02. Harvard Kennedy School of Government, Cambridge, MA [R],2-3.

(2) Black carbon emission reduction

Black carbon is produced by incomplete combustion of fossil fuels and bio fuels, which is a particulate matter with strong light-absorbing and it is one of the main components of $PM_{2.5}$. Black carbon has a significant impact on climate change and human health, which is the second largest source of global warming. Civil bulk coal is the main source of black carbon emission[9], therefore to reduce black carbon emission, we must reduce the use of civil bulk coal firstly.

According to the related research[10], the black carbon emission coefficient from coal-fired power plants is 0.0013 g/kg, while the coefficient of civil bulk coal is up to 3.05 g/kg, which is more than two thousand times of that of power plant. In scenario1 and scenario 2 , the emission of black carbon in the Beijing - Tianjin - Hebei region would be reduced by 0.76×10^4 tons and 1.35×10^4 tons, as shown in Table 9.

Table 9 Black Carbon Reduction in the Two Scenarios

Scenarios	Region	Black carbon reduction (10^4 tons)
Scenario 1	Beijing	0.13
	Tianjin	0.06
	Hebei	0.57
	Total	0.76
Scenario 2	Beijing	0.15
	Tianjin	0.07
	Hebei	1.14
	Total	1.35

6.2 Health Loss Reduction

A lot of studies have shown that the combustion of coal, biomass and other household solid fuels is related to human health. Outdoor and indoor pollution caused by coal combustion is one of the important reasons for ischemic heart disease (IHD), stroke, lung cancer (LC), Chronic Obstructive Pulmonary Disease (COPD), children lower respiratory infection (LRI) and other cardiovascular and cerebrovascular diseases. In this research, based on Environmental Benefits Mapping and Analysis Program (BenMAP) and the analysis of grid population density, the health benefits of 'coal-to-electricity' in the two scenarios were assessed. The Poisson regression model was used to describe the relationship between air pollutant concentrations and human health exposure.[11 12]

$$E = E_0 \cdot \exp(\beta(C-C_0))$$

Where, β describes the relationship between $PM_{2.5}$concentration and premature death exposure, taking0.0067[13] (0.005 ~ 0.0083); C and C_0 are the actual concentration of $PM_{2.5}$ and the reference concentration of $PM_{2.5}$ ($\mu g/m^3$); E and E_0 are the premature death rate corresponding with C and C_0, E takes 0.006397[14], C_0 is the reference concentration of $PM_{2.5}$, and takes $10\mu g/m^3$ recommended by WHO[15].

The change of health risk caused by the change of $PM_{2.5}$concentrationis:

[9] IPCC (2007): Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. IPCC, Geneva, Switzerland, 104 pp; Bond, T. C. et. al. (2013), Bounding the role of black carbon in the climate system: A scientific assessment.

[10] ZHANG Nan, QIN Li, XIE Shaodong. Spatial distribution of black carbon emissions in China. Chin Sci Bull, 2013, 58, doi: 10.1007/s11434-013-5820-4.

[11] KAN Haidong, CHEN Bingheng Analysis of Exposure Response Relationships of Air Particulate Matter and Adverse Health Outcomes in China[J]. Environment and Health. 2002,19(6):422-424.

[12] HUANG Desheng, ZHANG Shiqiu. Health benefit evaluation for $PM_{2.5}$ pollution control in Beijing-Tianjin-Hebei region of China, China Environmental Science, 2013,33(1):166-174.

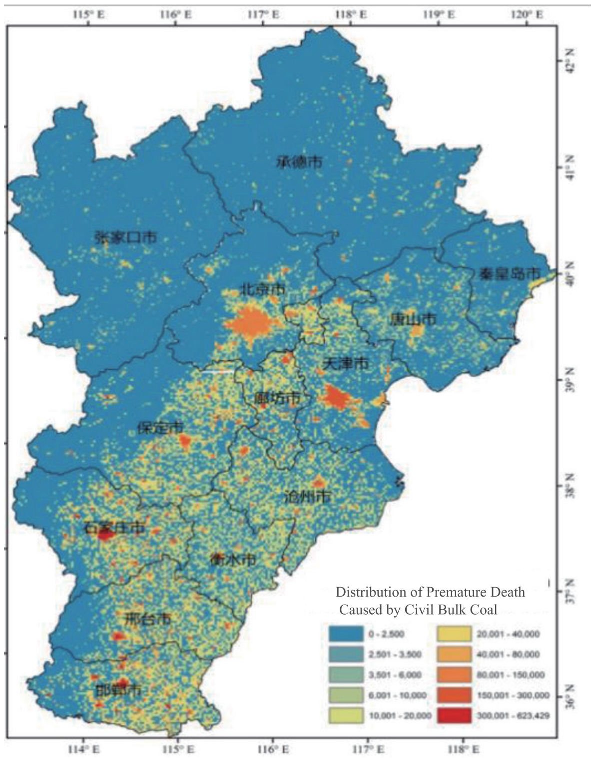
$$\Delta I = P(E - E_0) = P \cdot E \cdot \left(1 - \frac{1}{\exp(\beta(c - c_0))}\right)$$

WhereΔI is the change in the number of premature death caused by changes of $PM_{2.5}$ (person), P is the number of exposed people.

According to the population growth rates in Beijing, Tianjin and Hebei recent years, the population of Hebei, Tianjin and Hebei are expected to be 23.96million, 17.08million and 76.63 million, respectively in 2020. The reductions of the number of premature death in Beijing, Tianjin and Hebei in the two scenarios are shown in Table 10. In Beijing-Tianjin-Hebei region, the reduction of the number of premature deaths caused by civil bulk coal use will be11997 (8981~14817) and 15861 (11877~19585), respectively, and the distribution of premature death are shown in Figure 5.

The 'value of statistical life' (VSL) method was used to assess the economic value of the premature death reduction. Based on the results of GAO Ting et al[16]and the per capita disposable income and its growth trend in Beijing, Tianjin and Hebei recent years, The unit VSL of premature death caused by $PM_{2.5}$ was calculated (as seen in Table 10). The results showed that Beijing, Tianjin and Hebei would get considerable health benefits due to the reduction of civil bulk coal consumption. In scenario 1 and scenario 2, the total health economic benefits in Beijing-Tianjin-Hebei region would be 18.25 (13.66~22.53) billion yuan and 22.41 (16.79~27.66) billion yuan, respectively.

Figure 5 Distribution of Premature Death Caused by Civil Bulk Coal



[13] LI Pei, XIN Jinyuan, WANG Yuesi et al. Study on the Impact of Atmospheric Particulate Matter Pollution on Population Mortality in Beijing [J]. Chinese Meteorological Society,2012,5(1):2-11.

[14] National Health and Family Planning commission. Statistical Yearbook 2016 of China Health and Family Planning [M],Beijing:Peking Union Medical College Press, 2016.

[15] World Health Organization.Air quality guidelines for particulate matter, ozone, nitrogen dioxide and sulfur dioxide[R]//Global Update 2005.Summary of risk assessment. Switzerland: World Health Orgainzation,2006.

[16] GAO Ting, LI Guoxing, XU Meimei et al. Health economic loss evaluation of ambient $PM_{2.5}$ pollution based on willingness to pay [J]. Journal of Environment and Health,2015,08:697-700.

Table 10 The Reduction of Premature Death and the Health Economic Benefits

Scenarios	Region	Reduction of premature death (person)	VSL (million yuan)	Health economic benefits (billion yuan)
Scenario 1	Beijing	4941 (3702~6097)	2.12	10.50 (7.87~12.96)
	Tianjin	3500 (2623~4319)	1.37	4.82 (3.61~5.94)
	Hebei	3556 (2656~4402)	0.82	2.93 (2.19~3.63)
	Total	11997 (8981~14817)	——	18.25 (13.66~22.53)
Scenario 2	Beijing	5488 (4114~6769)	2.12	11.66 (8.74~14.38)
	Tianjin	3991 (2992~4922)	1.37	5.49 (4.12~6.77)
	Hebei	6382 (4771~7894)	0.82	5.26 (3.93~6.50)
	Total	15861 (11877~19585)	——	22.41 (16.79~27.66)

In this paper, we only chose one kind of health outcome, which was the premature death, because of its most serious consequence of health loss and economic loss. It was more than 90% of all kinds of health outcome, and the economic loss was easier to calculate. In addition to premature death, IHD, stroke, LC, COPD, LRI will cause treatment costs, and gas poisoning, fire hazard will result in huge loss of life and property. If the loss of these parts was taken into account, the economic health loss would have been greater.

6.3 Other Benefits

The 'coal-to-electricity' project will increase power consumption, reducing the wind power and solar power abandoning. At present, there is a problem of power surplus in China. From 2010, the growth rate of electricity consumption was declining, especially from 2013, thermal power utilization hours decreased significantly. Wind power, solar power and other renewable energy power utilization hours also showed a rapid decline trend. In 2015, the situation of wind power and solar power abandoning was deteriorated. The wind power abandoning rate in Hebei Province was 10%, and in Inner Mongolia, which is the main area for power supply to the North China, the abandoning rates of wind power and solar power were 18% and 10%, respectively, of which 86% occurred in winter.

'Coal to electricity' project in Beijing-Tianjin-Hebei region will greatly promote the development of the relevant industries, such as equipment manufacturing and related service industry. In scenario 1 and scenario 2, the 'coal to electricity' project will bring the economic benefits of 111.2 billion Yuan and 173.1 billion yuan, in the aspects of electric heating equipment manufacturing, equipment maintenance, building insulation and reinforcement and so on.

The 'Coal to electricity' project will improve the quality of life of rural residents. Switching to electricity heating, the room temperature is stable, and the rural residents don't have to take care of the coal stove in cold winter. The house is free of coal ash, and the rural residents will never be worried about gas poisoning, fire and other problems. The 'Coal to electricity' project will also make it easier for residents to live such as bathing and cooking. Rural residents will get more comfortable, safe, clean and convenient life experience.

7. SUGGESTIONS ON POLICIES OF BULK COAL CONTROL IN BEIJING-TIANJIN-HEBEI REGION

(1) Take the improvement of air quality as the primary goal to promote the 'coal to electricity' project in north China, and focus on minimizing the bulk coal consumption. In the next five years, according to the requirements of air quality improvement, priority should be given to places where are densely-populated, with poor air quality and large bulk coal consumption like the Beijing-Tianjin-Hebei region and the surrounding areas .

(2) Local governments should investigate the basic situations of bulk coal consumption as soon as possible to figure out the quantity of bulk coal consumption and other basic information in different regions such as rural-urban continuums, suburban areas, counties and villages, industrial parks etc.

(3) Make good top-level design. A systematic plan should be made, considering factors such as national oil and gas resources, electric power development plan, natural gas pipeline network retrofit and peak load regulation capacity, power network transmission and distribution capacity, urban heat supply network coverage, and energy saving reconstruction plan for residential buildings.

(4) Promote the 'coal to electricity' project step by step, give guidance by categories, and encourage the local residents to choose a suitable technical scheme on clean heating according to local conditions, e.g. availability of local energy resources, heating demands, and people's income level.

(5) The government should issue corresponding technological guidelines, standards and normative documents to standardize the design, model selection, installation and maintenance of the heating system. That is, using standard evaluation criteria to compare the technical indicators, prices, applicability of various clean energy heating equipments. In doing so, the government can guide the residents to choose and use clean energy heating technology and equipment well.

(6) Actively explore means of marketization, design and implement effective economic policies to attract residents to use clean energy for heating.

(7) Strictly control selling bulk coal of poor quality, improve the supervision mechanism of coal quality, and implement the regulatory responsibilities in coal mining, transportation, sell and use.

REFERENCE

1 Li, X., Zhang, Q., Zhang, Y. et al., 2015. Source Contributions of Urban $PM_{2.5}$ in the Beijing-Tianjin-Hebei Region: Changes between 2006 and 2013 and Relative Impacts of Emissions and Meteorology. Atmospheric Environment. Vol, 123: pp. 229-239.

2 A Research Report on Annual Development of China's Building Energy Conservation 2015, China Architecture & Building Press.

3 Report on Development of China's Heating Stove Industry 2016.

4 Technical Guidance for Compiling Air Emissions Inventory of Civil Coal.

5 Zhu LIU. 2015. "China's Carbon Emissions Report 2015." Sustainability Science Program and Energy Technology Innovation Policy research group, Belfer Center Discussion Paper #2015-02. Harvard Kennedy School of Government, Cambridge, MA [R], 2-3.

6 IPCC (2007): Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. IPCC, Geneva, Switzerland, 104 pp; Bond, T. C. et al. (2013), Bounding the role of black carbon in the climate system: A scientific assessment.

7 ZHANG Nan, QIN Li, XIE Shaodong. Spatial distribution of black carbon emissions in China. Chin. Sci. Bull, 2013, 58, doi: 10.1007/s11434-013-5820-4

8 KAN Haidong, CHEN Bingheng. Analysis of Exposure Response Relationships of Air Particulate Matter and Adverse Health Outcomes in China [J].Environment and Health. 2002, 19(6): 422-424.

9 HUANG Desheng, ZHANG Shiqiu. Health benefit evaluation for $PM_{2.5}$ pollution control in Beijing-Tianjin-Hebei region of China, China Environmental Science, 2013, 33 (1): 166-174.

10 LI Pei, XIN Jinyuan, WANG Yuesi et al. Study on the Impact of Atmospheric Particulate Matter Pollution on Population Mortality in Beijing [J]. Chinese Meteorological Society, 2012, 5 (1): 2-11.

11 National Health and Family Planning commission. Statistical Yearbook 2016 of China Health and Family Planning [M], Beijing: Peking Union Medical College Press, 2016.

12 World Health Organization. Air quality guidelines for particulate matter, ozone, nitrogen dioxide and sulfur dioxide[R]//Global Update 2005. Summary of risk assessment. Switzerland: World Health Organization, 2006.

13 GAO Ting, LI Guoxing, XU Meimei et al. Health economic loss evaluation of ambient $PM_{2.5}$ pollution based on willingness to pay [J]. Journal of Environment and Health, 2015, 08: 697-700.

Chinese Academy for Environmental Planning

8 Dayangfang, BeiYuan Road, Chaoyang District, Beijing 100012, China

Editor in chief: Prof. WANG Jinnan

President, Chinese Academy for Environmental Planning

Contact person: Mr. ZHANG Hongyu

Tel: 86-10-84917585

Fax: 86-10-84918581

E-mail: zhanghongyu@caep.org.cn

Web: www.caep.org.cn