Challenges and opportunities of coal-to-clean energy transition in China: a hard but long work

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Abstract. Coal-to-clean energy transition is a significant strategy for China to protect the environment and achieve sustainable development. This research reviews the present policy framework, targeted sector for this energy consumption reform and discusses the supply status of natural gas industry. The conditions for efficiently implementing the coal-to-clean energy projects are explored by literature review and data mining. The decision to choose a proper implementation schedule depends on the factors of economic, environment, infrastructure, technology and resources endowment. The possible impacts of coal-to-clean energy transition actions on the society of China are analysed from the changes of energy mix, challenges from stable energy supply and measures for safeguarding energy security. The results of this study could be helpful for the successful implementation of this transition in the other areas.

1. Introduction

1.1 Why should we implement coal-to-clean energy projects?
Based on increasingly serious energy shortage and environmental destruction, the development of clean energy plays an important role in environmental protection, energy security, and energy efficiency improvement. Coal-to-clean energy transition is a very significant part for this development. Therefore, China has gradually implemented coal-to-clean energy policies since 2013.

From the perspective of environmental protection, the pollution caused by coal consumption mainly includes three aspects: water pollution, dust and waste gas pollution, and solid waste pollution. Among them, the problem of waste slag discharge from coal combustion is one of the most serious aspects. Nevertheless, coal still accounted for more than half of China’s current energy production and consumption, while clean energy such as hydropower and natural gas accounted for only 17% and 9% of electricity generation, respectively. Furthermore, due to the safety problems of coal production and use, coal production safety becomes a public concern in recent years. During the first half of 2019, coal mine accidents happened frequently in Chongqing, Shaanxi, Yunnan, Fujian and other provinces. In terms of energy efficiency, per m³ of oilfield gas is equivalent to 1.33 kg of standard coal, and per m³ of
natural gas field is equivalent to 1.21 kg of standard coal. It can be seen that the energy efficiency is greatly improved when using natural gas compared with coal. Therefore, regarding environmental protection, coal mine safety and energy efficiency, the implementation of coal-to-clean energy is important for sustainable development of China [1].

1.2 Direction of coal-to-clean energy implementation

The current implementation directions of coal-to-clean energy transition include two major categories: coal-to-gas transition and coal-to-electricity transition. Coal-to-gas transition means that natural gas is the main source of energy instead of burning coal in energy consumption revolution. Coal-to-electricity transition is to replace the coal combustion with electricity. In addition, modern biomass energy is also an emerging and popular direction, but the support should be enhanced. The main directions are still coal-to-electricity and coal-to-gas in this revolution.

Overall, the focus of the coal-to-clean energy project implementation is mainly to comprehensively promote clean heating in winter and to adjust the energy consumption structure of industrial enterprises.

1.2.1 Residential sector. Many households in rural areas still have the habit of burning loose coal or traditional biomass in China. Due to the economic ability, coal-to-gas energy transition is one of the best ways to improve the cleanliness for urban citizens. When coal combustion is still the mainstream form of residential heating, air source heat pump (electricity) heating, however, has been adopted in recent years to implement coal-to-clean energy transition plan.

1.2.2 Industrial sector. For the traditional manufacturing industries, the main energy source is coal because of its lower price. It is a huge project to completely replace it. Local governments have proposed policies for replacing industrial boilers, and steadily advanced them. Original coal-fired industrial boilers have been replaced by gas-fired industrial boilers, or adopted more efficient electric-heated boilers. It reveals that the current mainstream of coal-to-clean energy transition is still coal-to-gas, mainly for the transformation of industrial boilers while coal-to-electricity transition is also one of the main methods for the heating in factories.

2. China’s natural gas industry and its impacts on energy transition

2.1 Natural gas security in China
from Australia and Qatar while pipeline natural gas imports are mainly from Turkmenistan, Uzbekistan. In addition, China has built four major natural gas import channels, including Central Asia Pipelines, China-Myanmar Pipelines, Sino-Russian Pipelines, and Coastal Imported LNG. The current status for China’s natural gas industry and external dependence from 2008 to 2017 are shown in Figure 1. When the annual increase of natural gas import is basically no less than 30%, the proportion of natural gas supply in China’s energy structure is getting higher and higher. Therefore, coal-to-gas transition may face the shortage bottleneck in the future because of the higher import dependence of natural gas. How to ensure the stable supply of natural gas may become a major problem in the implementation of the coal-to-gas process [3].

2.2 China’s natural gas development and application status

Rapid development of natural gas industry happened in 2008-2017. China’s natural gas import volume increased from 4.6 billion to 92 billion m³, with an average annual growth rate of 34.9%. In terms of production, China’s natural gas production in 2008 was 80.3 billion m³, and reached 148 billion m³ in 2017 with the average annual compound growth rate of 6.31% during this period, which was far lower than the growth rate of imports and consumption. With the continuous increase of imports, the external dependence of China’s natural gas industry has increased from 5.66% in 2008 to 38.77% in 2017. Therefore, the security of natural gas in China is not optimistic. Meanwhile, according to China’s natural gas resource endowment, the exploitation of unconventional natural gas should be increased and considered in the implementation process of coal-to-gas transition [4].

3. Conditions for the implementation of coal to clean energy

3.1 Economic factors

Residents’ expenditure on coal-to-clean energy mainly includes equipment, electricity price and gas price. The coal-to-electricity project mainly uses three types of clean heating equipment: regenerative electric heaters, water/ground source heat pumps, and air energy heat pumps. The price of coal-to-electricity equipment ranges from 2,000 to 5,000 RMB, while the price of natural gas boilers
ranges from 5,000 to 10,000 RMB. Different villages uniformly purchase the equipment according to the results of village committee bidding.

Taking Beijing as an example, per capita disposable income of rural residents was 2020 RMB per month in 2007. Due to the low income of rural households, municipal and district financial departments and village committees adopt subsidy policies to reduce the burden on rural families. In the village where the “coal-to-electricity” transition task is completed, households will enjoy a low price of 0.3 RMB/kWh from 21:00 to 6:00 pm, and the municipal and district financial departments will subsidize 0.1 RMB/kWh respectively. The limit is 10,000 degrees per household for each heating season. For the households who installed air energy heat pumps or non-whole village installs ground source heat pumps, the municipal financial department subsidizes the standard of 100 RMB per m² of heating housing area. The subsidy amount per household is up to 12,000 RMB. The district financial department can further increase subsidies to reduce the burden on residents. Households in rural areas that use compressed natural gas or liquefied natural gas for heating shall pay the fee at a price no higher than that of the municipal natural gas pipeline network. The price of CNG and LNG gas supply is higher than the price of gas supply from the municipal hot air pipe network. According to the municipal finance subsidies standard of up to 1,300 RMB per household in each heating season, the shortage is arranged by the district financial department and village committee. The financial supports from city, district and village committee are totally different regarding the situation of different villages. In addition, the different level of economic development results in different preferential deployment and satisfaction in different areas [5].

3.2 Energy infrastructure
As early as 2008, China has become the world’s first energy-producing country and the second energy-consuming country. It is obvious that energy infrastructure is the lifeblood of country. Energy infrastructure includes power production and supply system, gas production and supply system, heating production and supply system and other categories which can be divided into power generation facilities, substation and power distribution facilities, transmission facilities, natural gas stations, liquefied petroleum-gas stations, fuel transmission pipelines, heating stations, heating transmission pipelines.

As a high efficient and fast energy transporting channel and optimal allocation platform, power grid is a key link of sustainable development of energy and plays a pivotal role in the modern energy supply system and coal-to-clean energy projects. Since 2010, the scale of power grids has nearly doubled. With the construction of transmission lines, substations and transformers, large cross-provincial regional power grids have been formed. At present, the construction situation of power infrastructure in China is demonstrated as follows. The eastern region has basically achieved equal access to power supply services in both urban and rural areas; the gap between urban and rural power supply services in central and western regions has been greatly narrowed; and the rural power grid in poverty-stricken and remote areas has basically met the needs of production and living. The grid investment in the eastern region is obviously greater than that in the western region, and the investment in the urban power grid is greater than that in the rural area. Therefore, accelerating the construction of the power grid and expanding the scope of clean energy configurations are the basis for ensuring the power generation, transmission, transformation, distribution and electricity consumption, and also important ways to realize the coal-to-electricity project.

3.3 Regional resource endowment
The characteristics of China’s energy resource are that the total amount is abundant, but the per-capita average of energy resource is low, the distribution is uneven and exploitation is difficult. In 2017, newly increased coal reserves, oil reserves and other energy sources have a slow growth. The distribution of energy resources is wide but uneven. Coal resources are mainly distributed in North China and Northwest China, and hydropower resources are mainly distributed in Southwest China, oil and natural gas resources are mainly distributed in eastern, central and western China and sea areas. The main oil-bearing basins in the east have entered the middle and late stage of exploration and development [6].
The main energy consumption areas in China are concentrated in the economically developed southeast coastal areas, and there are obvious differences of territory between resource occurrence and energy consumption [4]. Large-scale and long-distance transportation of energy are the remarkable characteristics of China’s energy flow and the basic pattern of energy transport.

3.4 Environmental aspects

3.4.1 Policy environment and market mechanism. The implementation of coal-to-clean energy projects is inseparable from supporting policies of local governments. At present, Beijing, Tianjin, Hebei, Shanxi, Shandong, Henan and other “2+26” cities have issued a variety of policies on coal-to-clean energy transition, including electricity prices, equipment subsidies or implementation targets to ensure the rapid promotion of coal-to-clean energy projects.

At the same time, in terms of equipment for coal-to-clean energy transition, the enterprises are selected by the government through open bidding. The towns and villages draw part of them among the shortlisted enterprises to determine the equipment suppliers. In order to facilitate management and post-maintenance, every town should achieve “one village, one brand” in principle. Relevant departments of the People’s Government and the municipal government shall strengthen the management of the bidding for boiler procurement in the transition project and seriously implement the laws and regulations of bidding. Multiple enterprises must participate in the bidding, and implementing the principle of “openness, fairness and justice”. The bid invitation judges shall be composed of technical and economic experts from relevant fields (institutions or units). Fair competition in accordance with the principles of market economy, local enterprises products can be given priority in the case of equivalent conditions [1].

3.4.2 Natural environment. In principle, the first implementation of coal-to-clean energy transition should be arranged in cities which have colder weather and use bulk coal for heating. Besides, in view of the precious domestic natural gas resources, coal-to-clean energy projects should also be implemented firstly in cities with more serious air pollution.

3.5. The maturity of equipment technology

The technology of coal-to-gas mainly refers to the laying of natural gas pipelines, while the technology of coal-to-electricity mainly refers to the replacement of coal boilers with air source heat pumps [7]. At present, air source heat pumps have a strong technical force and advanced production technology, but the difficulty of laying natural gas pipelines remains a problem which cannot be underestimated in coal-to-gas transition.

The energy department of coal-to-gas villages should consider the location of municipal pipe network, regional planning and other conditions. The coal-to-electricity villages should consider the regional power supply load, lines and other infrastructures. Whether it is coal-to-electricity or coal-to-gas, actions must be discussed and approved by village committees. The township government reports to the district government for comprehensive consideration before unified planning and implementation. On one hand, due to the difficulty in laying natural gas pipelines and the high construction cost, the natural gas pipeline network in many northern regions is still not perfect. On the other hand, the consumption of natural gas in China is far greater than the supply of natural gas. The two deficiencies weaken the feasibility of coal-to-gas project while coal-to-electricity project is more feasible. Air heat pump is the representative equipment of coal-to-electricity project, which is not severely limited by natural gas resources. In rural areas, almost every household has access to electricity, and heat pumps rely on electricity to drive them. They can produce large amounts of hot water with only a small amount of electricity. Such characteristic makes the application and market of air source heat pumps broader than natural gas. Therefore, in the northern area, the application of coal-to-electricity is more popular than coal-to-gas.
4. Impacts of coal-to-clean energy transition actions on the society of China

4.1. Changes in supply, demand and infrastructure

Since the beginning of the 21st century, China’s natural gas consumption and imports have experienced rapid growth. With the progress of exploration technology, China’s natural gas exploration is still in the initial stage and natural gas output will remain in a low and stable growth trend. Only depending on domestic natural gas production cannot meet China’s growing natural gas demand. Therefore, China builds natural gas pipelines and LNG stations to meet the growth of natural gas consumption. China's natural gas imports are mainly from Turkmenistan, Australia, Qatar, and other countries. From 2010 to 2018, natural gas imports increased year by year. In recent years, the import speed of natural gas has also increased steadily along with construction of China’s four import channels which are northwest central Asia pipeline gas import channel, coastal LNG import channel, southwest Myanmar natural gas import channel, Northeast Russia natural gas import channel. At the same time, the aggressive push of the government for natural gas began to grow steadily, and imports have gradually increased. With the continuous promotion of coal-to-clean energy projects, China’s natural gas imports are increasing year by year, and the external dependence will continue to increase.

4.2 Changes in the proportion of supply sources

The empirical data shows that China imported 38 billion m$^3$ of pipeline gas and 343 billion m$^3$ of liquefied natural gas in 2016. About 22.3 billion m$^3$ of pipeline gas was imported from Turkmenistan, while 15.5 billion m$^3$ and 6.4 billion m$^3$ are from Australia and Qatar. Unconventional gas grew rapidly and shale gas production reached 7.88 billion m$^3$, with a year-on-year growth rate of 72%. About 4.5 billion m$^3$ of coalbed methane have been extracted from the ground, a slight increase compared with 2015. Coal-to-gas production reached 2.16 billion m$^3$, with a year-on-year growth rate of 15%. Although natural gas exploitation shows a high trend, the external dependence on natural gas has reached 38.7% by 2017. With the implementation of coal-to-clean energy projects, it is still expected to continue to go up in the future [8]. However, excessive dependence on foreign import is bound to bring safety risks. Therefore, it is urgent to increase the exploitation of unconventional natural gas and establish gas emergency reserves.

4.3 Security measures

With the continuous increase of China’s clean energy reform from coal, the external dependence of China’s natural gas import will also increase with the growth of the import quantity. The continuous increase of external dependence will pose a potential threat to China’s energy security. However, it is also an opportunity and challenge for China to develop low-carbon economy. Therefore, it is necessary to build diversified import channels, establish more stable strategic cooperative partnerships with other export countries, and expand China’s natural gas market to ensure the stable supply of natural gas. In addition, it is necessary to accelerate the construction of facilities for receiving, storing and transporting natural gas. China’s unconventional gas resources are abundant and have great exploration potential. When ensuring the external dependence of natural gas to develop at an appropriate speed, China should not only increase the exploitation and utilization of natural gas resources, but also rely on scientific and technological progress to enhance the development of unconventional natural gas dominated by coal bed methane, shale gas and methane hydrate. According to local conditions and energy endowment of the region, the effective use of wind, water and renewable energy power can meet the needs of different regions [9]. The awareness of resource conservation and the concepts of green environmental protection should be enhanced in the residential sector.

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