Research on the development mode of clean energy heating and its carbon emission reduction benefit in Beijing

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Abstract. Beijing has pledged to peak carbon dioxide emission by 2020. Promoting clean energy heating in winter is an important measure to reduce carbon emission, and Beijing government has given large policy support for clean energy heating. In this paper, the clean energy heating policy has been simulated and its carbon emission reduction benefit has been studied. Various typical clean energy heating technologies suitable for Beijing are presented and evaluated in the aspects of initial investment cost and running cost. Energy technology model is adopted to conduct a comprehensive optimization for heating technology path between 2015-2020 for Beijing under benchmark and policy scenarios. Model optimization results show that, comparing with benchmark scenario, the carbon emission reduction will reach 25 million tons for policy scenario. Under policy scenario, in 2020, the proportion of natural gas heating will reach 86%, while the electric heating will account 9%, among which air-source heat pump occupies 86%. Power consumption for electric heating will reach 4.9 billion kWh, and gas consumption for gas heating will reach 13.3 billion cubic meters.

1. Introduction
To increase the level of clean energy heating (Clean energy heating refers to the heating mode by the use of clean energy such as natural gas, electricity, geothermal, biomass, solar energy, industrial waste heat, clean coal (ultra-low emissions) and nuclear energy, and through high-efficiency system to achieve low emissions and low energy consumption) in the northern region and reduce the carbon and pollutant emissions, General Secretary Xi Jinping proposed the requirement of “promoting clean heating during winter in the northern region”. To speed up the construction of a first-class, harmonious and livable capital in the world, Beijing should take the lead in achieving clean heating. According to “Beijing's Energy Development Plan in the 13th Five-Year Plan Period”, by the year 2020 Beijing will basically achieve heating without coal in the plain area. Since clean energy heating developed rapidly recent years, lots of studies have been conducted on this topic [1-3], but they mainly focus on the economic analysis for several selected technologies, there are few studies on how to design the whole heating technology path and evaluate the carbon emission reduction benefit. This paper aims to conduct the comprehensive optimization for the heating technology by energy technology model, in which the policy can be simulated and the carbon reduction benefit can be computed from the global level. The results for the presented work can provide a global reference for the government to study and formulate the policy and technical route of clean heating.
2. **Comparative analysis of typical clean energy heating technologies in Beijing**

The clean energy heating technologies used in Beijing are mainly divided into natural gas heating and electric heating [4]. Natural gas heating includes gas-fired boilers and gas-fired combined heat and power generation. Electric heating includes electric heat storage boilers, regenerative electric heaters, ground-source heat pump and air-source heat pump. To promote the development of clean heating, the Beijing government has given a large amount of financial support. For the installation of air-source heat pump and ground-source heat pump, the subsidy can be 200 yuan per square meter. For heating with other clean energy equipment, the subsidy is 1/3 of the equipment acquisition cost. According to the analysis basing on the investigation on current heating situation in Beijing [5], the investment and operation cost for the following ten kinds of typical heating technologies (CHP means combined heat and power generation) are shown in Figure 1 and 2.

In terms of investment cost, the ground-source heat pump has the highest investment costs. The cost of investment for air-source heat pumps can be reduced to 60 yuan per square metre with the government subsidy. In terms of operation cost, heat pump technologies have lower operation cost due to higher energy efficiency, which is almost equal to the heating cost of central heating and dispersed coal burning. After considering the electricity price subsidy of the valley section, the operation cost of regenerative electric heating technology is the lowest, even lower than that of the heating mode by dispersed coal burning.

![Figure 1. Investment cost for various heating technologies in Beijing.](image1)

![Figure 2. Operation cost for various heating technologies in Beijing.](image2)
3. Optimization model for clean energy heating path in Beijing

This section uses the TIMES (The Integrated MARKAL-EFOM System) model as an analytical tool to construct a heating optimization model for Beijing. The TIMES model is generally used for the entire energy system, but there are also many applications on individual specific sectors, such as the transport sector [6].

3.1. Objective function in TIMES model

The TIMES model is a dynamic linear programming model, the optimization objective of which is to minimize the total cost of the energy system during the planning period under given energy demand and constraints. The specific objective function is as follows:

\[ OBJ(z)=\sum (1+d_y)^{R-y} \times ANNC(y) - SALV(z) \]  

(1)

Where \( obj(z) \) represents the total cost of the system, \( d_y \) represents the discount rate, \( R \) represents the discounted target year, \( ANNC(y) \) represents the technical cost of the year \( y \), and \( SALV(z) \) is the asset residue value. Technical cost \( ANNC(y) \) can be calculated as following:

\[ ANNC(y) = INVC(y) + INVT(y) + INVD(y) + FIXC(y) + FIXT(y) + VARC(y) + ELASTC(y) - LATER(y) \]  

(2)

Where \( INVC(y) \) represents investment cost; \( INVT(y) \) represents tax and supplement; \( INVD(y) \) represents dismantling fee, \( FIXC(y) \) represents fixed operation cost, \( FIXT(y) \) represents tax and supplement related to fixed operation cost, \( VARC(y) \) represents variable operation cost, \( ELASTC(y) \) represents cost of demand changes caused by price elasticity, \( LATER(y) \) represents recovery fee.

In the clean heating TIMES model of Beijing, the above ten kinds of typical heating technologies are defined according to the investment and operation cost. The carbon emission coefficient for various primary energy can be obtained from reference [7].

3.2. Heating demand forecast for Beijing

According to Beijing Statistical Yearbook statistics, the heating area for Beijing in 2015 was 780 million square meters, of which the central heating area was 585 million square meters, accounting for 75%. Beijing officially launched the electric heating reform project in 2003. By 2015, 310 thousand households in urban areas had been reformed for decentralized electric heating, while the Dongcheng and Xicheng districts had basically achieved "no coal". The electric heating reform project for the rural areas had started since 2013, and a total of 74.5 thousand households had been reformed for decentralized electric heating by 2015. In terms of heating energy sources, the coal heating was 259PJ, natural gas heating was 125PJ and electric heating was 11PJ. The proportion of clean heating was 34%.

The 13th Five-Year Plan of Beijing Energy Development proposes that by 2020 the heating area will reach 950 million square meters and the proportion of clean energy heating in the whole city will reach more than 95 percent. Based on the current proportion of central heating area and heating energy consumption level, the heating energy demand in 2020 is calculated to be 484PJ as shown in Table 1, of which the central heating demand will be 436PJ.

| Year | Heating area (unit: million m²) | Heating quantity (unit: PJ) |
|------|---------------------------------|-----------------------------|
|      | Total                          | Central heating             | Decentralized heating      |
|      | Total                          | Central heating             | Decentralized heating      |
| 2015 | 780                            | 585                         | 195                        | 395                          | 355                          | 40                          |
| 2020 | 950                            | 713                         | 237                        | 484                          | 436                          | 48                          |
4. Optimized analysis of clean heating development path in Beijing toward 2020

4.1. Scenario design

Benchmark scenario: Regardless of the policy constraints on the proportion of clean energy heating, the optimal calculation is based on the heating status in 2015 and the current technical and economic characteristics of various heating technology.

Policy scenario: Considering the constraint of clean heating ratio to be 95% in 2020, the user-designed constraints is added, which can be described as below.

\[ \sum Act_i(y) \leq 0.05 \times H(y) \]  

Where \( Act_i(y) \) represents the activity level of process, \( y \) represents the goal year (2020), \( i \) represents processes that use coal as the heating energy, including coal CHP, coal-fired boiler and coal furnace for bulk burning. \( H(y) \) represents the total heating demand.

4.2. Results analysis

(a) Carbon emission reduction benefit

The carbon emission and clean energy heating ratio under basic and policy scenarios can be calculated by model optimization, which is shown in Figure 3. It is shown that, policy plays a decisive role in the current clean energy heating development. Under the policy scenario, the carbon emission in 2020 is calculated to be 29.6 million tons, which is 12 million tons less than that in 2015. Comparing with benchmark scenario, the carbon emission reduction is up to 25 million tons.

![Figure 3. The carbon emission and clean energy heating ratio under basic and policy scenarios](image)

(b) Heating mode

Under policy scenario, to obtain the clean energy heating ratio goal in 2020, coal for heating will be largely be substituted by the natural gas central heating and electric decentralize heating. The natural gas heating ratio will reach 86%, and the electric heating ratio will be 9%, of which air-source heat pump occupies 86%, which can be shown in Figure 4.

According to the results, under policy scenario, in 2020, power consumption for electric heating will reach 4.9 billion kWh, with an increase of 2.9 billion kWh compared with that of 2015, and gas consumption for gas heating will reach 13.3 billion cubic meters, with an increase of 9.3 billion cubic meters.

(c) Heating cost

The heating cost mainly includes equipment investment cost, annual operation cost. According to the calculation results, the investment cost for Beijing heating in 2020 will reach 35 billion yuan and the operation cost will reach 27 billion yuan.
5. Conclusions
In this paper, the economic characteristics of typical clean heating technologies suitable for Beijing were comprehensively analysed, results show that after considering subsidy, air-source heat pump technology has lower investment cost, and regenerative electric heating technology has lower operation cost. The path optimization model of clean heating technology for Beijing was established by energy technology model, and optimized path of clean heating was proposed by model optimization. Model optimization results show that, comparing with benchmark scenario, the carbon emission reduction will reach 25 million tons for policy scenario. Under policy scenario, in 2020, the proportion of natural gas heating will reach 86%, while the electric heating will account 9%, among which air-source heat pump occupies 86%. Power consumption for electric heating will reach 4.9 billion kWh, and gas consumption for gas heating will reach 13.3 billion cubic meters. Total heating cost including investment and operation cost will be 62 billion yuan in 2020.

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