Benefit Evaluation of Energy Substitute Terminal Energy Project

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Abstract. In recent years, China's economic growth is faced with increasingly severe resource constraints and environmental problems, especially environmental problems, which have become an important factor limiting economic development. Although the Chinese government has introduced a series of policies to promote the absorption and utilization of clean energy and alleviate the problem of monotonous energy consumption structure, there are few studies on the transformation of energy conservation and emission reduction into economic benefits. In this paper, a calculation model of the environmental benefit to economic benefit of electric energy replacement is established, and a comparative calculation of pollutant emission reduction and economic efficiency is made for the replacement of coal (loose coal and boiler coal) by natural gas and electric heat storage in Tianjin. The results show that electric heat storage and heating has more advantages.

1. Introduction

Since the beginning of the 21st century, non-renewable energy has been gradually reduced in China. More and more people have proposed to use clean energy to replace non-renewable energy, and countries around the world have begun to pay more attention to the use of new energy [1, 2]. With the continuous development of science, technology and industry, energy shortage on the one hand is restricting economic development, on the other hand, the massive use of fossil energy has caused the problem of environmental pollution that affects human existence. As the driving force and guarantee of rapid economic development, the amount of fossil energy consumption in China is also increasing. According to relevant data of BP statistical review of world energy (2016), China's total energy consumption in 2015 was 2.972 billion tons of oil equivalent, ranking the first in the world, and accounting for 23% of the total energy consumption of all countries and regions in the world [3-5]. For a long time, China's energy structure has been dominated by non-renewable fossil energy. In 2013, China's coal consumption accounted for 67% of the total energy consumption, and oil accounted for 17%. Studies show that fossil energy consumption accounts for about 80 percent of global carbon dioxide emissions, which contribute more than 80 percent to the greenhouse effect, and most emissions of sulfur dioxide are from coal. This kind of energy consumption structure, which is dominated by coal and oil, has brought serious negative effects on China's ecological environment. In addition, the excessive consumption of fossil energy to produce a large amount of air pollutants such as sulfur dioxide,
nitrogen oxides, dust, cause haze weather in China in recent years, many cities and regions in PM2.5 extraordinary, since January 2013, more than 30 provinces, autonomous regions and municipalities in the serious fog weather, the world's most polluted by seven out of 10 cities from China, and the most of the cities in the Beijing-Tianjin-Hebei region. Persistent haze pollution, such as the London smog incident, has brought huge impacts on people's life, especially physical health. It is imperative to replace non-renewable fossil energy with clean energy [6].

For example, literature [5] combined specific examples to analyze the economic and environmental benefits brought about by power replacement with comprehensive evaluation method, and carried out index quantification to more intuitively show the correlation between energy structure transformation and environmental pollution. Literature [6] by using the model of a dynamic optimization method to establish cost utility, under the condition of the coal and electricity price relevance has carried on the example analysis, get the power to replace coal discharge threshold of positive factors and negative factors, from the perspective of the discharge threshold, the alternative energy and the environment and economic sustainable development. Literature [7, 8] analyzed the significance of improving energy efficiency and improving energy structure to improve environmental quality by building a standard system framework for layered design of power replacement in the fields of architecture, transportation, industry, mining and agriculture. In literature [9], the environmental load model of power generation replacement is established, which USES wavelet neural network and decoupling theory to conduct multi-scenario simulation analysis, and the trend of energy transformation and power generation replacement is predicted.

Overall, both at home and abroad are mainly concentrated on the study of electrical energy to replace in the urban areas "to the coal electricity generation" and "electricity generation oil" two aspects and the research on economic and environmental benefits, or for power instead of index system and comprehensive evaluation on have more in-depth research, but the domestic and foreign experts in power instead of comprehensive, concreteness research is very few, the study of electrical energy to replace confined to a local, and are still rarely beneficial to domestic energy alternative policies and mechanisms, especially for the main energy alternative mode of technical economic and environmental benefits of quantitative research is very few, Research in the literature is limited to some opinions and Suggestions on the future development direction and policies. The study on the technical economy and environmental economy of power to replace other energy sources in the environment of energy conservation and emission reduction provides a necessary theoretical supplement for promoting power replacement and solving urban haze problems, and makes contributions to the construction of a new low-carbon, energy-saving and harmonious society with sustainable development.

2. Methodology

2.1. Power substitution benefit analysis model

2.1.1. Economic benefits model. Considering the initial investment and annual operating costs, taking the full life cycle economic costs as the comprehensive index, and comparing the economic benefits before and after electricity replacement with output value unchanged.

\[
P_{\text{C fuel}} = \sum_{i=1}^{n} I_{\text{fossil} - i} + \sum_{i=1}^{n} C_{\text{fossil} - i} \times \frac{1}{r \times (1+r)^{N_t}}
\]  

(1)

Where: \(P_{\text{C fuel}}\) is the total life cycle cost when using fossil fuel equipment; \(I_{\text{fossil} - i}\) is the initial investment of I fossil fuel equipment (10,000 yuan); \(r\) is the base discount rate; \(N_t\) refers to the service life of fossil fuel equipment; \(C_{\text{fossil} - i}\) is the annual operating cost of I fossil fuel equipment (ten thousand yuan).

\[
C_{\text{fossil}, i} = L_{\text{fossil} - i} \times P_{\text{fossil} - i}
\]  

(2)
Where, $L_{\text{fossil}_{-i}}$ is the actual annual fuel consumption (ton, m3) of I fossil fuel equipment; $P_{\text{fossil}_{-i}}$ is the price of I fossil fuel (yuan/ton, yuan/cubic meter).

Full life cycle economic costs of power equipment

$$\text{PC}_e = I_e + C_e \times \frac{(1+r)^{N_e}}{r \times (1+r)^{N_e}}$$

Where: $\text{PC}_e$ is the total life cycle cost of power equipment; $I_e$ is the initial investment of power equipment (ten thousand yuan); $r$ is the base discount rate; $N_e$ is the service life of power equipment; $C_e$ is the annual operating cost of power equipment (ten thousand yuan).

$$C_e = Q_e \times P_e$$

Where $Q_e, P_e$ for electric power equipment in the actual power consumption (10^4kWh); $P_e$ is the electricity price (yuan/kWh). The difference of peak and valley electricity price is considered in the calculation process.

Electricity replaces annual economic benefits

$$\text{AC} = \text{AC}_{\text{fossil}} - \text{AC}_e$$

Electric energy replaces whole life cycle cost economy benefit

$$\text{PC} = \text{PC}_{\text{fossil}} - \text{PC}_e$$

2.2. Environmental benefit model

2.2.1. Pollutant discharge tax. According to the above economic benefit analysis model, the annual pollutant emission equivalent before the user chooses electricity to replace is

$$E_{\text{NO}_X,f} = \sum_{i=1}^{n} L_{\text{fossil}_{-i}} \times \eta'_{\text{NO}_X} \div 0.95$$

$$E_{\text{SO}_2,f} = \sum_{i=1}^{n} L_{\text{fossil}_{-i}} \times \eta'_{\text{SO}_2} \div 0.95$$

$$E_{\text{TSP},f} = \sum_{i=1}^{n} L_{\text{fossil}_{-i}} \times \eta'_{\text{TSP}} \div 2.18$$

$$E_{\text{CO},f} = \sum_{i=1}^{n} L_{\text{fossil}_{-i}} \times \eta'_{\text{CO}} \div 16.7$$

where $\eta'_{\text{NO}_X}, \eta'_{\text{SO}_2}, \eta'_{\text{TSP}}, \eta'_{\text{CO}}$ respectively I fossil fuel unit of nitrogen oxides, sulfur dioxide and fuel dust, carbon monoxide emissions from fossil fuels.

Electricity replaces the previous year’s environmental tax

$$T_{\text{PDT},f} = P_{\text{NO}_X} \times E_{\text{NO}_X,f} + P_{\text{SO}_2} \times E_{\text{SO}_2,f} + P_{\text{TSP}} \times E_{\text{TSP},f} + P_{\text{CO}} \times E_{\text{CO},f}$$

Where, $P_{\text{NO}_X}, P_{\text{SO}_2}, P_{\text{TSP}}, P_{\text{CO}}$ is the local unit equivalent nitrogen oxides, sulfur dioxide, dust, carbon monoxide tax payable.

Cost of pollutant emission tax for the whole life cycle of equipment

$$\text{PT}_{\text{PDT},f} = T_{\text{PDT},f} \times \frac{(1+r)^{N_t}}{r \times (1+r)^{N_t}}$$
After electrical energy is replaced, the emission equivalent $NO_X, SO_2$ and dust emission equivalent are:

$$E_{NOX,e} = L_e \cdot \tau \times \rho \times \mu \times \eta_{NOX} \div 0.95$$  \hspace{1cm} (13)$$

$$E_{SO2,e} = L_e \cdot \tau \times \rho \times \mu \times \eta_{SO2} \div 0.95$$  \hspace{1cm} (14)$$

$$E_{TSP,e} = L_e \cdot \tau \times \rho \times \mu \times \eta_{TSP} \div 2.18$$  \hspace{1cm} (15)$$

$$L_e \cdot \tau = \frac{q_e \cdot \tau}{(1-\delta)}$$  \hspace{1cm} (16)$$

In the equation: $L_e \cdot \tau$ is the total amount of electricity generated and transferred after replacing electrical energy; $\delta$ is the transmission line loss in the province; $\rho$ is the share of electric power online in thermal power; $\mu$ is the standard coal consumption for power supply in thermal power plants; $\eta_{NOX}$, $\eta_{SO2}$, $\eta_{TSP}$ are nitrogen oxides, sulfur dioxide and soot emissions per unit of coal in thermal power plants.

Electricity replaces environmental tax for the next year

$$T_{PDT,e} = P_{NOX} \times E_{NOX,e} + P_{SO2} \times E_{SO2,e} + P_{TSP} \times E_{TSP,e}$$  \hspace{1cm} (17)$$

Where, $P_{NOX}$, $P_{SO2}$, $P_{TSP}$ are the unit equivalent nitrogen oxide, sulfur dioxide, dust tax payable

The cost of pollutant emission tax in the whole life cycle of power equipment

$$PT_{PDT,e} = T_{PDT,e} \times \frac{(1+f)^{Ne}}{r \times (1+r)^{Ne}}$$  \hspace{1cm} (18)$$

Electric power replacement equipment whole life cycle pollutant emission saves benefit

$$PT_{PDT} = PT_{PDT,f} - PT_{PDT,e}$$  \hspace{1cm} (19)$$

2.2.2. The carbon tax. since 2013, seven provinces and cities, including Beijing, Shanghai, Tianjin, Chongqing, Hubei, Guangdong and Shenzhen, have successively carried out carbon trading pilot work, providing rich practical experience for China to establish a national uniform carbon market. Electricity replaces carbon dioxide emissions from the burning of fossil fuels

$$E_{CO2,f} = L_{fossil,\text{sum}} \times H_f \times F_{chf} \times F_{oxf} \times \frac{44}{12}$$  \hspace{1cm} (20)$$

Where, $E_{CO2,f}$ is the carbon dioxide emission generated by fossil fuel combustion; $H_f$ is the status heating value of the fuel, and $F_{chf}$ is the carbon content per unit calorific value of the fossil fuel, and $F_{oxf}$ is the carbon oxidation rate of the fossil fuel.

Carbon dioxide emissions generated during the generation and transmission of electricity after electricity replacement

$$E_{CO2,e} = L_e \cdot \text{sum} \times \rho \times \mu \times H_f \times F_{chf} \times F_{oxf} \times \frac{44}{12} + E_{CO2,pp}$$  \hspace{1cm} (21)$$

Where, $E_{CO2,pp}$ is the amount of carbon dioxide generated by the flue gas desulfurization treatment of thermal power plants.

$$E_{CO2,pp} = L_e \cdot \text{sum} \times S \times \lambda \times \frac{44}{32}$$  \hspace{1cm} (22)$$
Where, S is the received base total sulfur of the standard coal, and λ is the wet desulphurization efficiency of limestone and gypsum.

Electricity replacement reduces carbon dioxide emissions each year

\[
\Delta E_{CO_2} = E_{CO_2,f} - E_{CO_2,e}
\]  

(23)

Trade at the market price of carbon emission rights

\[
CTR = \sum_{j=1}^{N_e} \frac{P_{j,CO_2} \times \Delta E_{CO_2}}{(1+r)^t}
\]  

(24)

Where, \(P_{j,CO_2}\) is the j-th annual average carbon transaction price.

3. The example analysis

The water storage electric heating project of a commercial building in south Tianjin city was selected as an example, and the building area of the commercial building was 10000m². The setting of the parameters of the model is shown in table 1.

At present, the heating price of commercial buildings in Tianjin is charged according to general industrial and commercial electricity, and the price and time period are shown in table 2.

| Table 1. Model parameter setting |
|-------------------------------|
| variable | The numerical | unit |
| Heating area | 10000 | m² |
| The heating time | 120 | Day |
| Coal calorific value | 29308 | KJ/kg |
| Unit power consumption of coal | 283 | g/kWh |
| The discount rate | 3 | % |
| Coal prices | 355 | Yuan/t |
| Line loss | 3 | % |
| Desulphurization efficiency of thermal power plant | 95 | % |
| Denitration efficiency of thermal power plant | 80 | % |
| Fossil fuel power generation | 93.5 | % |
| Taxes on air pollutants | 8 | Yuan/pollution equivalent |
| Carbon trading prices | 50 | Yuan/t |

| Table 2. Time-of-use electricity price of general industry and commerce in Tianjin |
|-------------------------------|
| Period of time | The peak time | off-peak | Period of at ordinary times |
| Electricity prices | 8:00-11:00, 18:00-23:00 | 1.3458 | 23:00-7:00 | 0.4748 | 7:00-8:00, 11:00-18:00 | 0.9003 |

It can be seen from table 3 that compared with coal-fired/gas-fired boilers, regenerative electric boilers have less one-time investment. In addition, regenerative electric boilers also have advantages such as no need of external pipe network, high energy conversion efficiency, unattended operation, automatic operation and clean environmental protection. The building area of this case is about 10000m², the heating heat index is 50W/m², and the maximum hourly heat load is \(=50 \times 10000/1000=500\)kW; The project property is the office building, and the normal heating time is from 8:00 to 19:00, for a total of 11h. Heating is calculated on the basis of 120 days. According to the statistics, the total amount of heat storage is realized for 60 days. For the remaining 60 days, except for heat storage during the peak period, 1h electric boilers shall be operated during the peak period of daytime to meet the heating demand.
electricity consumption per square meter in each heating season is about 66kWh, of which 60.4kwh is the trough electricity. According to the environmental benefit and economic benefit model, the economic benefit, environmental benefit and life-cycle cost of the electric heat storage system and the coal-fired gas boiler system are calculated, as shown in table 3, table 4 and table 5.

### Table 3. Comparison of economic benefits between electric heat storage systems and coal-fired/gas-fired boilers

| Heating type             | The initial investment (yuan/m²) | Annual operating cost (yuan/m²) | Full life cycle economic costs (yuan/m²) |
|--------------------------|----------------------------------|---------------------------------|----------------------------------------|
| Gas fired boiler heating | 225                              | 50.3                            | 754.16                                 |
| Coal fired boiler heating| 225                              | 30                              | 540.6                                  |
| Electric heat storage    | 153                              | 21.56                           | 379.81                                 |

### Table 4. Comparison of environmental benefits between electric heat storage system of unit heating area and coal/gas boiler

| Heating type             | Energy consumption | Pollutant discharge(kg) | Annual pollution tax (yuan/m²) | Total life cycle pollution tax (yuan/m²) | Total life cycle carbon emission cost (yuan/m²) |
|--------------------------|--------------------|-------------------------|-------------------------------|----------------------------------------|-----------------------------------------------|
| Gas fired boiler heating | 13m³/m²            | 0.002 0.008 0.003       | 24.51                         | 0.1                                    | 1.05                                          |
| Coal fired boiler heating| 21.5kg/m²          | 0.43 0.17 0.21          | 44.29                         | 6.04                                   | 63.54                                         |
| Electric heat storage    | 66kwh/m²           | 0.06 0.10 0.00          | 168.34                        | 1.21                                   | 12.80                                         |

### Table 5. Comparison of total life cycle cost between electric heat storage system and coal-fired/gas-fired boiler

| Heating type             | Full life cycle costs(yuan/m²) |
|--------------------------|--------------------------------|
| Gas fired boiler heating | 768.1                          |
| Coal fired boiler heating| 633.77                         |
| Electric heat storage    | 481.16                         |

According to the above analysis, the total life cycle cost of electric regenerative boiler heating is 152.64 yuan/m², and it is 286.97 yuan/m² less than that of coal-fired boiler heating. The lowest cost of whole life cycle of electric heat storage boilers, reflects the strong superiority, look from whole life cycle cost, electric heat storage is 379.81 yuan/m², is lower than coal-fired boiler heating and gas boiler heating, respectively, 160.79 yuan/m², 374.35 yuan/m², due to the electric heat storage, heat storage with low at night, and can better reflect economy, and can promote the peak power load cutting and economic stability of power grid operation also to have certain positive role. From the perspective of the total life-cycle environmental cost, the electric heat storage is 8.15 yuan/m² higher than that of coal-fired boilers, and 87.38 yuan/m² higher than that of gas-fired boilers. With the increase of the proportion of clean energy generation, the difference will gradually decrease.

Sensitivity analysis
Figure 1. The influence of the change of the proportion of thermal power on the total life cycle cost of electric heat storage and heating

According to the analysis in figure 1, as the proportion of thermal power decreased from 93.5% to 40%, the total life cycle cost of electric thermal storage and heating would decrease from 481.13 yuan/m² to 417.71 yuan/m². When the proportion of thermal power is 92.5%, the total life cycle environmental benefit of electric thermal storage is equal to that of coal-fired boiler heating. It can be seen that the higher the proportion of clean energy, the greater the advantage of electric heating. In addition, electric heat storage and heating not only have advantages in energy conservation, emission reduction and economic benefits, but also can promote peak load cutting and valley filling of electric power load and promote the safe and stable economic operation of power grid.

4. Conclusion
Electric regenerative heating boiler heating unit heating area life cycle cost is 521.2 yuan, gas boiler heating in remote area; the replacement of electric regenerative boiler or gas boiler for the original coal-fired heating system can reduce the cost of pollutant emission. However, China is an energy country with "rich coal, poor oil and low gas". The use of natural gas for heating is not only costly in operation, but also affects the energy security of China. Therefore, electric heat storage and heating have more advantages. According to the sensitivity analysis of the thermal power factor, the higher the proportion of clean energy, the greater the advantage of electric heat storage.

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