Study on the optimization of transregional transmission scale for coal and power electricity under the background of coal capacity reduction

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Abstract. The coal capacity reduction policy has made great impact on the pattern of coal transportation and power transmission across regions. In this paper, the total coal consumption control and renewable energy quota constraint target were decomposed into regional constraints for the multi-region power generation energy development and transmission model, which was constructed by the energy technology model. Then the baseline and intensive scenarios were designed for coal and power transmission optimization, while the whole country was divided into seven regions according to the sending and receiving relationships. The results show that, under the background of coal capacity reduction, the power transmission scale will continue to increase quickly, with the ratio between coal and electricity transmission declining, to be 3.3 in 2020, 1.8~2.0 in 2030 and 1.2~1.5 in 2050 for different scenarios.

1. Introduction
The regional imbalance in the distribution of energy resources and energy demand in China determines that long-distance energy transmission will exist for a long time. Coal transportation and power transmission are important components of long-distance energy transmission. Comparison of coal transmission and power transmission has long been carried out by scholars from different aspects [1-4], such as technical reliability, economic and environmental benefits. Driven by the national policy of air pollution prevention and control, total coal consumption control has become the focus in recent years. The total coal consumption control, especially in the east and middle regions, is bound to have a new impact on the pattern of coal and power transmission regions. Based on the multi-region power generation energy development and transmission model with new energy generation, this topic optimizes the total power generation energy and its structure in each district at the level of power generation energy balance. What’s more, comprehensive optimization research on coal and power transmission is conducted, and the proportion of coal and power transmission in the future is proposed.

2. Analysis on influencing factors of coal and power transmission
2.1 Total coal consumption control
The “13th Five-Year Plan for Controlling Greenhouse Gas Emissions” proposes to control the total amount of coal consumption, which will be controlled at around 4.2 billion tons in 2020. This will promote negative growth in coal consumption in areas and cities with severe smog after 2017. The “13th Five-Year Plan for Energy Development” proposes that the total coal consumption in 2020 will
be controlled within 4.1 billion tons. Considering that coal consumption may reach its peak in 2020, the total coal consumption control targets for 2030 and 2050 are expected to be 4.0 and 3.8 billion tons.

From the perspective of coal consumption, under the promotion of intensive clean utilization and electric energy replacement, the coal consumption of building materials and steel has gradually declined. The coal consumption of thermal coal and modern coal chemical industry still has room to rise, mainly replacing bulk coal burning. It is proposed that the proportion of coal used for power generation will increase to more than 55% by 2020. However, with the economic improvement of renewable energy power generation technology, and the introduction of the external environmental cost of power generation, and the gradual maturity of the power market mechanism, the marginal cost advantage of renewable energy becoming more apparent. The average annual growth rate of coal for thermal power after 2020 will be less than that in the “Thirteen-Five” period, which will be 1.2%. It is expected that by 2030, the proportion of coal for power generation will increase to about 65%, and in 2050, the proportion will increase to about 70%.

2.2 Renewable energy quota constraint

According to “Guiding Opinions on Establishing a Target Guidance System for Renewable Energy Development and Utilization”, the national non-fossil energy accounted for 15% of the total primary energy consumption in 2020, the national non-hydropower renewable energy generation should reach more than 9% of the total power generation. According to the status of renewable energy resources and energy consumption in various regions, and the national medium- and long-term total renewable energy development and utilization targets, the non-water renewable energy power consumption of provinces (autonomous regions, municipalities) and the whole society has been developed. “Revolutionary Strategy for Energy Production and Consumption (2016-2030)” proposes that non-fossil energy of primary energy consumption accounts for 20% in 2030 and 50% in 2050. As the future development of hydropower and nuclear power in China is relatively certain, preliminary estimates are made to achieve the above objectives. The national non-hydropower renewable energy generation capacity should reach 15% in 2030 and 45% in 2050 of the total power generation.

3. Construction of the multi-region power generation energy development and transmission model

The multi-regional energy system optimization model constructed in this study is based on 2015 and the planning period is 2015-2050. The energy carriers not only consider conventional fossil energy such as coal, oil and gas, but also consider new energy and renewable energy such as nuclear energy, hydro energy, wind energy, solar energy, geothermal energy, biomass energy, and hydrogen energy. Energy mining mainly considers coal, oil, natural gas, coalbed methane and so on. Processing conversion technology mainly includes coal washing, coking, oil refining, coal liquefaction, coal gasification, power generation, and heat supply. The power sector has fully considered the current mature and current power technologies which are in the development stages of R&D and demonstration.

3.1 Objective function

The objective function of the energy system optimization model is to minimize the total energy supply cost of the energy system during the planning period under various energy requirements. The total energy supply cost includes the exploitation and import and export costs of various resources, various processing techniques and Conversion technology and investment in demand equipment, fixed and variable operating costs, energy and power transmission costs, etc. At the same time, the objective function of the model incorporates the residual value of the assets to compensate the investment value of the remaining life at the end of the planning period. The total energy supply cost consists of three parts: investment cost, annual cost and recovery cost.
3.2. Constraint equation
The energy supply and demand balance model includes the following types of constraint equations: flow balance constraints for fossil fuels, nuclear energy and renewable energy; seasonal and day-night supply and demand balance constraints; basic load constraints of power; peak load constraints of power; seasonal heat load balance constraints; regional heating peak load constraint; cross-time capacity transfer constraint; technical capacity growth constraint; energy cumulative total constraint; energy resource growth constraint; demand balance constraint; power production capacity constraint; regional heating production capacity constraint; processing technology capacity constraint; conversion technology plan maintenance; processing technology output variable balance; total investment growth constraints; conversion technology production constraints; emission constraints; modeler custom constraints, and so on.

3.3. Decision variables
The model includes four endogenous variables: energy resource activity levels, investment levels, technology capacity, and technology production. These variables characterize the various forms of energy carriers, energy resources, energy technology capacity and their level of activity from energy resources to energy services.

The energy resource activity variable represents the annual activity level of different resource energy carriers, which includes the collection of mining, import, export, renewable resources and inventory.

The technical capacity variable represents the installed capacity of the time period technology. The technical investment variable represents the new capacity of the technology. The new added capacity value for each time period is equal to the investment.

The technical yield variable is mainly used to describe the energy processing and conversion technology (the other descriptive variables of the technology are investment variables, capacity variables, utilization factors, etc.), since energy exploitation is described by resource activity variables. Energy conversion technology has both power generation and heat generation. Each power generation technology divides the electricity output by season and day-night. Each thermal plant divides the low-temperature heat and high-temperature heat production in each season.

4. Comparative analysis of transregional coal and power transmission

4.1 Regional division scheme
According to the relationship between the national coal and electricity transmission and receiving end, the national power grid is divided into seven regions such as Mengxi, Northeast (including Mengdong), Shanxi, Northwest, East Central receiving areas (13 provinces), Chuanyuzang (Sichuan, Chongqing and Xizang), and the Southern region. The topological relationship between the major regions is shown in Figure 1.
4.2 Scenario setting

Scenario design should be typical and representative. It should refer to the national energy-related development plan, taking full account of the actual level of development, and the various uncertainties that may exist. In this study, two representative scenarios were selected for analysis. For the baseline scenario, non-fossil energy sources such as hydropower, nuclear power, wind power, and solar power generation have all reached the expected development scale. The coal-fired power grid layout continues the regional equilibrium situation. This scenario is also a benchmark for comparison with other scenarios. The second is intensive scenario. The concept is that the environmental policy orientation is obvious, the coal power layout is further optimized and adjusted, new energy and electric energy replacement technologies are accelerated, and non-fossil energy is developing at a high speed.

Intensive scenario setting. With reference to relevant national coal consumption total control, renewable energy quota and other related policy objectives, adding sub-regional coal consumption total control, renewable energy quota target constraints based on the baseline scenario.

Table 1. Total coal consumption control target (10² million tons).

| Region       | 2020    | 2030    | 2050    |
|--------------|---------|---------|---------|
| Chuanyuzang  | 0.82    | 0.80    | 0.76    |
| East Central | 18.06   | 17.62   | 16.74   |
| Mengxi       | 3.90    | 3.80    | 3.61    |
| Northeast    | 3.56    | 3.47    | 3.30    |
| Northwest    | 6.00    | 5.85    | 5.56    |
| South        | 4.84    | 4.72    | 4.49    |
| Shanxi       | 3.82    | 3.73    | 3.54    |
| Total        | 41.00   | 40.00   | 38.00   |

According to the above-mentioned total target of non-hydrogen renewable energy generation, and the status of renewable energy resources and energy consumption in each region, the non-hydopower renewable energy generation ratio in each region is obtained as a renewable energy quota policy scenario.

Table 2. Non-hydopower renewable energy generation constraint (%).

| Region       | 2020 | 2030 | 2050 |
|--------------|------|------|------|
| Chuanyuzang  | 8%   | 12%  | 36%  |
| East Central | 8%   | 11%  | 33%  |
| Mengxi       | 13%  | 20%  | 60%  |
| Northeast    | 13%  | 20%  | 60%  |
| Northwest    | 12%  | 18%  | 54%  |
4.3 Power generation technical and economic parameters

Refer to “China Power Industry Annual Development Report”, “Firepower Engineering Quota Design Reference Cost Index”, “China Wind Power Construction Statistical Evaluation Report” and other data, the national average level values of various types of power supply technical economic parameters in 2015 are shown as following.

Table 3. Main technical and economic parameters of various types of power supplies

| Types       | Power generation efficiency | Cost (yuan/kW) | Fixed operating expenses as percentage of investment | Variable operating cost (yuan/ton standard coal) | Lifetime (year) |
|-------------|-----------------------------|---------------|-----------------------------------------------------|-----------------------------------------------|-----------------|
| Biomass     | 0.43                        | 10000         | 0.02                                                | 8                                             | 20              |
| Coal        | 0.54                        | 3156          | 0.04                                                | 1545                                          | 40              |
| Gas         | 1                           | 3963          | 0.04                                                | 5122                                          | 25              |
| Hydro       | 1                           | 11272         | 0.02                                                | 8                                             | 100             |
| Nuclear     | 1                           | 18083         | 0.02                                                | 8                                             | 25              |
| Solar       | 1                           | 8225          | 0.01                                                | 0                                             | 25              |
| Wind        | 1                           | 9324          | 0.01                                                | 0                                             | 25              |

4.4 Results analysis

According to the model calculation, the coal and power transmission scale of the East Central regions are shown as below.

In the medium and long term, the national power flow still presents the overall pattern of "West-East power transmission" and "South-North power transmission". The receiving end for East Central areas mainly receive the coal-fired and new energy power from Shanxi, Mengxi, Northwest and Northeast, as well as hydropower from Sichuan, Chongqing and Xizang.

Table 4. Scale of coal and power transmission for East Central receiving regions under baseline scenario (units: million tons)

| Sending region | 2020  | 2030  | 2050  |
|----------------|-------|-------|-------|
| Coal transportation |       |       |       |
| Mengxi          | 35.6  | 0     | 0     |
| Northeast       | 35.8  | 0     | 0     |
| Northwest       | 6.8   | 0     | 0     |
| Shanxi          | 158.1 | 198.6 | 178.1 |
| Power transmission |      |       |       |
| Chuanyuzang     | 14.9  | 16.8  | 20.6  |
| Mengxi          | 20.7  | 30    | 36    |
| Northeast       | 7.5   | 22.5  | 28.6  |
| Northwest       | 17.1  | 23.8  | 14.1  |
| Shanxi          | 25.6  | 23.1  | 41.6  |

Due to air pollution, carbon emissions and other national targets, the coal consumption especially in the eastern central region will be strictly controlled, and coal consumption will enter the saturation and even negative growth stage. The future cross-regional coal transport scale will also be limited. According to the model calculation results, in 2020, 2030, 2050, the coal transportation scale for east central region is 240, 200, 180 million tons of equivalent coal.
Due to the rapid development of power transmission, the integrated transportation system of coal transportation and power transmission will basically form by 2020. The power transmission proportion for main energy base is rising. For the four large coal sending regions of Shanxi, Mengxi, Northwest and Northeast, the proportion for coal transportation and power transmission is 3.3:1, 2.0:1 and 1.5:1 respectively in 2020, 2030 and 2050 under baseline scenario. For intensive scenario, the ratio will be 3.3:1, 1.8:1 and 1.2:1 respectively in 2020, 2030 and 2050.

5.Conclusions
Under the background of coal consumption control and large-scale development of renewable energy, the power transmission scale will be increasing in the future, and the scale of coal transportation will have limited increase. By 2020, the integrated energy transportation system of developing coal transportation and power transmission simultaneously will basically form, with coal and power transmission ratio to be 3.3:1. After 2020, the proportion of power transmission will be further improved. By the year 2030 and 2050, the proportion of coal and power transmission will reach 2.0:1 and 1.5:1, respectively for the benchmark scenario. Under the intensified scenario, the proportion of transmission is higher, and the ratio will be 1.8:1 and 1.2:1 respectively.

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