Research on Long-term Nuclear Power Development Scenario in China under the Background of Re-electrification

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Abstract. In the future, nuclear power will play a much greater role in achieving national non-fossil energy targets and greenhouse gas emission reduction commitments. Based on building medium and long-term (2030 and 2050) power system development scenario, this paper defines clean energy resources and development potential, key technical economic parameters of generating units, and the boundary conditions such as non-fossil energy ratio in primary energy consumption. Then, by use of power planning software GESP-III solving, scenario results, such as power supply structure and distribution, power generation, power flow, environmental benefits and regional nuclear plant sites resource utilization rate, were analysed.

1. Introduction
China has clearly established a clean low-carbon, safe and efficient modern energy system. Nuclear power, as an important component of China's non-fossil energy supply, plays an important role in the deep substitution of conventional fossil energy sources and the continuous optimization of the energy supply structure. Therefore, it is necessary to study the demand for nuclear power in the energy power system and the layout of the scale of nuclear power in the future national development.

Based on the forecast of China's power demand in 2030 and 2050, combined with the overall goal of energy development and the green transformation strategy in China, this paper studies the development plan of China's power system in 2030 and 2050, and gives the development scale and layout of nuclear power.

2. Methodologies
This paper takes into account the demand for electricity, energy resources for power generation and cross-district and cross-provincial transmission channels. The goal is to meet the balance of power and electricity in each region. By coordinating energy structure adjustment, supply side structural reform, pollutant emission reduction, greenhouse gas emission control and other factors, and according to the requirements of efficient development and utilization of clean energy and air pollution treatment, adapting to scale distributed power supply, this paper presents a multi-region and multi-scene long-term power planning model. The model is optimized according to the principle of lowest total cost of power supply, and solved by GESP-V software developed by National Energy Institute of Power Network, and finally, the national power flow and power supply configuration scheme is obtained.
3. Main boundary conditions

3.1. Power Demand Forecasting
The total electricity consumption and the maximum load of the whole country and eight districts in 2030 and 2050 are shown in the figure below \(^1\). Overall, although the new round of the Northeast revitalization strategy and the effect of industrial transfer has become more prominent, and the proportion of electricity consumption in the West and Northeast has further increased, the position of North, East, Central and South China as national load centers has remained unchanged. The proportion of total electricity consumption in the four regions fell from 74% in 2017 to 2030 in 70% and 65% in 2050.

3.2. Resource situation and development potential

3.2.1. Hydro energy. The theoretical storage capacity of hydro energy is 750 million kW, the technical development capacity is 572 million kW and the economic development capacity is 404 million kW.
3.2.2. Uranium resources and nuclear power plant sites. Natural uranium will not be a constraint to the large-scale development of nuclear power in China. Nuclear power plant site resources range from 440 million to 5.0 billion kW, with coastal resources ranging from 180 million to 210 million kW.

3.2.3. Natural gas and electricity. In the case of comprehensive consideration of domestic development and foreign imports, China will form a natural gas supply capacity of 665 billion to 800 billion cubic meters in 2030, which can support the installation of gas and electricity from 400 million to 480 million kW.

3.2.4. Wind energy. The technical capacity of wind energy resources at 70 m on land is 2.6 billion kW (196 million kW in the central and southern regions) and the installed capacity of offshore is about 200 million kW.

3.2.5. Solar energy. The potential for photovoltaic power generation is about 6 billion kW, with a potential capacity of about 1.4 billion kW for photothermal.

3.3. Unit parameters

3.3.1. Investment

According to the forecasts of relevant organizations [2-4], the investment cost per kilowatt of all kinds of power supply units in 2016-2050 is shown in the following figure. The investment cost of nuclear power is mainly considered in the following two aspects: On the one hand, the mass and autonomous construction of nuclear power technology will push the cost down, on the other hand, the increase of the safety redundancy of nuclear power will bring the cost increase. Considering both positive and negative factors, the cost of nuclear power will remain unchanged by 16280 yuan/kW.

![Figure 3. Investment of different units](image)

3.3.2. Fuel costs for power generation

According to the forecast of the relevant institutions [5-6], the fuel cost of various types of power supply is forecasted as shown in the table below.

|                  | RMB/kWh | 2017  | 2030  | 2050  |
|------------------|---------|-------|-------|-------|
| Coal power       | 0.10~0.23| 0.15  | 0.17  |       |
| Gas power        | 0.44    | 0.44  | 0.44  |       |
| Nuclear power    | 0.076   | 0.076 | 0.076 |       |
| Biomass          | 0.50    | 0.50  | 0.50  |       |
Among them, the unit power cost of nuclear power is calculated at 0.076 yuan / kWh, of which 0.05 is the cost of nuclear fuel conversion and 0.026 is the spent fuel reprocessing fund for nuclear power plants.

3.3.3. Emission parameters
The cost of pollutant emissions in each region is averaged over the current regional collection. At present, the provinces have imposed three types of air pollutant taxation standards as shown in the following table.

| Coal power | 0.47 | 0.43 | 0.09 | 730-901 |
| Gas power  | 0.01 | 0.43 | 0    | 434     |
| Biomass    | 0.03 | 0.27 | 0.23 | 0       |

3.3.4. Unit operating parameters
The technical constraints of each type of unit during operation are shown in the table below. According to domestic and foreign experience, nuclear power plants generally do not participate in starting and stopping peak regulation, and therefore do not involve the minimum continuous shutdown time, minimum continuous opening time, thermal starting cost and other parameters.

| Minimum output rate | Climbing rate (%/min) | thermal starting cost (RMB/time) | minimum continuous shutdown time (h) | minimum continuous opening time (h) |
|---------------------|------------------------|---------------------------------|--------------------------------------|------------------------------------|
| Coal power          | 350 MW, 50%; 660 MW, 45%; 1000 MW, 40% | <1000 MW, 3.5%; ≥1000 MW, 5% | 350 MW, 200000; 660 MW, 30000; 1000 MW, 600000 | 350 MW, 4; 660 MW, 5; 1000 MW, 8 |
| Nuclear power       | 0% 20% | 80000 | 2 | 3 |
| Biomass             | 50% 1% | 50000 | 2 | 2 |

4. Development scenario analysis

4.1. Power supply structure and layout
China's total installed capacity of electric power continues to grow rapidly, reaching 2.93 billion kW in 2030, 3.29 billion kW in 2035, and about 5 billion kW in 2050. The installed structure has the following characteristics: (1) hydropower, biomass power generation and gas power basically maintain a relatively stable growth rhythm; (2) wind power, solar power generation and nuclear power show a slow and then fast pace of development; and (3) coal power increases first and then decreases.
China’s installed nuclear power capacity will reach 130 million, 170 million and 340 million kilowatts in 2030, 2035 and 2050 respectively, and the annual investment and operation rhythm is gradually accelerating, from an average annual investment of 6 units before 2030 to an average annual investment of 10 units after 2035. The layout of nuclear power is still dominated by areas such as eastern, southern and northern China, with the combined share of nuclear power in the three regions accounting for 83 percent and 70 percent of the country in 2035 and 2050 respectively. Around 2035, the central China region needs to start laying out inland nuclear power, which will account for 20% of the country by 2050.

4.2. Power generation
In terms of electricity generation, non-fossil energy generation increased from about 30 percent in 2017 to around 50 percent in 2033 and about 80 percent in 2050, with the corresponding non-fossil energy consumption accounting for more than 50 percent, becoming the main power source and main energy source. The share of electricity generated by nuclear power rose from less than 4 percent in 2017 to 10.0 percent in 2030, 13.5 percent in 2035 and 22.1 percent in 2050. The contribution to the optimization of the energy consumption structure increased from 1.6 percent of total primary energy consumption by nuclear energy in 2017 to 4.5 percent in 2030, 6.5 percent in 2035 and 12.5 percent in 2050.
4.3. Power flow
In terms of power flow, under the baseline scenario, cross-district power flow across the country will reach 400 million kW in 2030, 440 million kW in 2035 and 550 million kW in 2050.

4.4. Environmental benefits
Electricity carbon emissions have fallen from around 5bn tonnes in 2017 to 3.85bn tonnes in 2030, 3.57bn tonnes in 2035 and 1.66bn tonnes in 2050, a reduction of more than 65 percent compared with 2017.

5. Conclusion
Different from the traditional method of "energy-power-nuclear power", which is used to calculate the space for nuclear power development by queuing various power supply priorities or supply capacity, a multi-region and multi-scene medium and long-term power planning model is used to study the development and layout optimization of nuclear power in the medium and long term from the point of view of optimal economy. The results show that the scale of nuclear power development is expected to reach 131 million and 169 million kW in 2030 and 2035, with the share of electricity generation reaching 10.0% and 13.5%. In the long run, the scale of nuclear power development in 2050 will exceed 335 million kW and the share of electricity generation will reach 22.1%. The layout of nuclear
power is mainly in East, South and Central China, and inland nuclear power needs to be started in time. In particular, from the perspective of ensuring the continuity and sustainability of nuclear power technology development, it is recommended that the pace of nuclear power development remains stable. It is proposed to maintain a production scale of about six units per year until 2030, and about eight units per year between 2031 and 2050. A stable rhythm is also conducive to stabilizing the expectations of the nuclear power and related industries, and a rational allocation of resources is conducive to reducing the cost of nuclear power construction.

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