Multi-scenario comparison analysis on nuclear power development in China

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Abstract. In the future, nuclear power will play a much greater role in promoting energy transition, and people are retrieving their confidence of nuclear power since Fukushima nuclear accident. However, there’re many parameters will affect nuclear power development scale. In view of nuclear power investment cost increase, policy constraint of nuclear power scale and power demand rise, this paper has done sensitivity analysis on relevant indexes, such as such as power supply structure and distribution, power generation, power flow, environmental benefits and regional nuclear plant sites resource utilization rate, by use of a multi-region multi-scenario medium and long-term electric power planning model. The result shows that, nuclear power cost, power demand, carbon tax and policy guidance will affect future development scale of nuclear power.

1. Introduction
China has clearly established a clean low-carbon, safe and efficient modern energy system in the literature [1]. Nuclear power, as an important component of China's non-fossil energy supply, plays an important and strategic role in the deep substitution of conventional fossil energy sources and the continuous optimization of energy supply structure in literature [2] and [3]. However, now’s researches of nuclear power mostly focus on the description and analysis of its functions, which lack of quantitative studies of nuclear power scale. Therefore, it is necessary to study the demand for nuclear power in energy power systems and the scale distribution of nuclear power in future national development.

In order to study the important factors affecting the development of nuclear power, combined with China's overall goal of energy development and green transition strategy in the literature [4], this paper studies the power system development plan for 2030 and 2050, gives the comparison of power installation, power generation, power flow and planning period cost under four scenarios. At the same time, this paper makes a detailed sensitivity analysis on the two important parameters of carbon tax and nuclear power investment, and compares and analyzes the scale and layout of nuclear power development under different influencing factors.

2. Models and parameters
The multi-region multi-scenario medium and long-term electric power planning model used in this paper refer to the literature [5], as its framework shown in Figure 1. After which we set three
sensitivity scenario based on the base scenario refer to the literature [5], and the difference between sensitivity scenarios and base scenario is shown in the table below.

![Figure 1. Multi-region multi-scenario medium and long-term electric power planning model.](image)

### Table 1. Scenarios design.

| Scenario            | Difference from base scenario                                                                 |
|---------------------|-----------------------------------------------------------------------------------------------|
| Base scenario       | Future nuclear power investment: remain at 16,000 RMB/kW. Power demand: 9.0 trillion kWh in 2030 and 11.7 trillion kWh in 2050. |
| High investment     | Future nuclear power investment: increase from 16,000 RMB/kW now to 20,000 RMB/kW in 2050.       |
| 5800 scenario       | Stop approving new nuclear power in the future, and nuclear power capacity will maintain 58 million kW after 2022. |
| High demand scenario| Power demand: 10.3 trillion kWh in 2030 and 13.3 trillion kWh in 2050.                         |

3. **Scenario comparison**

In this paper, the results of three sensitivity scenario and base scenario are compared and analysed from the aspects of the size and structure of the installed capacity, power flow, total cost during planning period and the change of carbon price.

3.1. **Installed capacity comparison**

According to the energy production and consumption revolution strategy (2016-2030), "non-fossil energy consumption accounts for half of primary energy consumption in 2050," this paper sets a constraint of 80% of non-fossil energy power generation in 2050 as the basis for power planning.

As shown in Figure 2, under the three sensitive scenario, the total installed capacity will increase by 10% to 14% in 2035 and the total installed capacity by 10% to 23% in 2050. Under high investment scenario and 5800 scenario, since 80% of the non-fossil energy electricity share is restricted in 2050, the reduction in the scale of nuclear power under both scenarios will be met by other non-fossil energy power generation, and considering the limited resources of hydropower and biomass power generation, the planned scale of these two types of power supply in 2050 under the base scenario has basically reached the upper limit of development potential, so the gap is basically made up of wind power, solar power generation. In addition, due to the large increase of intermittent power sources such as wind and light, flexible resources such as gas-electric, pumped-storage and electric energy storage need to be added.
3.2. Comparison of power generation in various schemes

The results showed in Figure 3, that conventional non-fossil energy power generation (including nuclear power and hydropower), new energy power generation (including wind, light and biomass) accounted for about 40 per cent of the total electricity generation under the base scenario, the share of new energy generation under 5800 scenario rose to about 60 per cent, and the new energy generation under the other two sensitive scenarios fell between base scenario and 5800 scenario.

In the future, as the proportion of intermittent power sources such as wind power and solar energy increases, the positioning of coal power will gradually change from base-load power supply to regulated power supply, and the utilization hours will gradually decrease from 4209 hours in 2017 to 3800 hours in 2030, 3700 hours in 2035 and 2200 hours in 2050; the utilization hours of nuclear power will remain at about 7800 hours; the utilization hours of hydropower and biomass power remained at about 3650 hours and 5500 hours; with the adoption of various technical measures, the problem of abandoning wind and light will be solved gradually, and the utilization hours of wind power and solar energy will remain at about 2100 and 1200.

![Figure 3. Comparison of Power Generation Mix under Various Scenarios in 2050.](image-url)

3.3. Power flow comparison

As the main resources of wind power and solar power generation are distributed in the western and northern regions, under scenarios 2 and 3, more wind and light are distributed in resource-rich regions, while local absorptive capacity is smaller. Therefore, more cross-zone channels are needed to be sent.
out to load centers in eastern and central regions. The scale of the power flow for the three horizontal years under various scenarios is shown in Figure 4.

![Figure 4. National trans-regional power flow for various scenarios (billion kW).](image)

3.4. Planning period costs
The total costs for the planning period under the four scenarios are shown in Figure 5. Compared to base scenario, the High investment scenario results in a reduction in both installed capacity and output of nuclear power. Under the constraint of 80 per cent of non-fossil energy generation in 2050, the shortfall in nuclear power generation will be supplemented by other non-fossil energy sources (wind, light and water) that do not consume fuels, so that fuel costs will be slightly reduced. At the same time, the rising cost of nuclear power will bring the competitiveness of other power sources with slightly higher investment costs, and the installation of other non-fossil energy sources will also increase, resulting in an increase in investment costs. Under the "5800 scenario", the development scale of economically competitive nuclear power is fixed at 58 million kW, and under the constraint of 80 per cent non-fossil energy generating capacity, the installed scale of other non-fossil energy generating power will be greatly increased, resulting in a larger increase in investment costs. Under high demand scenario, overall cost of the planning period was the highest in all scenarios, as demand increased by more than 15% per cent compared to other scenarios.

![Figure 5. Comparison of total costs during planning period.](image)

4. Sensitivity analysis for carbon price and nuclear power investment
4.1. Influence of carbon price on non-fossil energy power generation
Taxing or charging for carbon emissions is considered to be one of the effective ways to reduce future carbon emissions. This topic analyses the impact of imposing different standard carbon prices on the
development of non-fossil energy sources. As shown in Figure 6, under the parameters set in this model, and without the constraint of the fossil energy share, when no carbon price is imposed, the non-fossil energy power-generating capacity will reach about 65% in 2050; when the carbon price is 100 RMB/ton, the non-fossil energy power-generating capacity will account for 80%; when the carbon price is 200 RMB/ton, the non-fossil energy power-generating capacity will account for 90%; when the carbon price is higher than 300 RMB/ton, there is a limited effect on the proportion of non-fossil energy generating capacity.

Figure 6. Effect of different carbon price on the proportion of non-fossil energy generation in 2050.

According to the structure change of the specific electric power, the coal-fired machine will be reduced continuously with the increase of carbon price as shown in Figure 7 and Figure 8. In 2030, coal-electricity prices still have a clear advantage over other power sources, so when the carbon price increases from 0 RMB/ton to 200 RMB/ton, the power structure changes relatively small. Later, when the carbon price increases again, the reduction of coal-fired power units increases, and the number of alternative non-fossil energy units increases. In 2050, the price advantage of new energy relative to coal power appears, and the impact of rising carbon price on installed coal power units is obvious. However, considering that the coal generator in some areas still needs to take the important system reserve and the adjustment function, after the carbon price exceeds 200 RMB/ton, the marginal effect of increased carbon price on the reduction of installed coal power units will be gradually reduced to a minimum. With the rise in carbon prices, non-fossil energy power supply installed will rise rapidly to make up for the reduction of coal-electricity supply gap.

Figure 7. Power capacity in 2030 under different carbon prices.

Figure 8. Power capacity in 2050 under different carbon prices.

In 2050, as the price of carbon rose from 0 RMB/ton to 300 RMB/ton, the overall cost of fossil energy power increased dramatically, with the share of coal-fired power down from 17% to 8% and gas-electric power down from 4% to 1%. As the development of nuclear power and hydropower resources is constrained by the upper limit, the power supply of alternative coal is mainly wind power, solar power and other new energy sources, the proportion of wind power installed from 28% to 42%, the proportion of solar power installed from 30% to 33%.

4.2. Influence of the change of nuclear investment cost on the scale of nuclear power
Overall, when the investment cost per kilowatt of future nuclear power is increased from 14,000 RMB/kW to 22,000 RMB/kW, the scale of nuclear power development will be reduced from about
400 million kW to 200 million kW in 2050, as shown in Figure 9. The above results show that the scale of nuclear power development decreases rapidly with the increase of the investment per kilowatt, and it is sensitive to the investment per kilowatt of nuclear power when the objective of power planning is to minimize the cost of the system. Considering the high proportion of investment cost in the cost of nuclear power generation, in order to improve the scale of nuclear power development and the proportion in the overall power supply, we should try to improve the economy of nuclear power and reduce investment cost in nuclear power plants.

![Figure 9. Influence of nuclear power investment cost on nuclear power scale in the future.](image)

5. Conclusion

Through the comparison and analysis of multi-schemes, we can find that nuclear power cost, electricity demand, carbon tax carbon price, policy guidance and other factors will affect the future development scale of nuclear power. Considering the important role of nuclear power in China's energy system, we should promote the large-scale development of nuclear power and reduce the investment of nuclear power units rapidly. According to the current general prediction of the industry, with the batch and standardized construction of the three generations of nuclear power units, engineering design will be basically mature, equipment manufacturing problems will be overcome, supplemented by the upgrading of the proportion of domestic and engineering management level, the economy of the three generations of nuclear power will be significantly improved, the cost will be less than 16,000 RMB/kW.

References

[1] Xi Jinping 2017 the 19th session of chinese National Congress of the CPC
[2] Qi Enran 2005 Consideration on nuclear power development in China Electric Power 38(4)16–19
[3] Wang Yongping Zhao Shoufeng, Jiang Linli 2008 Understanding on issues of China nuclear power development strategy Nuclear Power Planning 1 182-88
[4] Revolutionary strategy for energy production and consumption (2016-2030), 2016, http://www.ndrc.gov.cn/zcfb/zcfbtz/201704/t20170425_845284.html, 2018-10-10
[5] Wang Yaohua, Jiao Bingqi, Zhang Fuqiang, Feng Junshu, Wu Shengyu 2017 Medium and Long-term Electric Power Development Considering Operating Characteristics of High Proportion of Renewable Energy Automation of Electric Power System 41(21) 9–16
[6] 2017 State Grid Energy Research Institute, China's medium and long-term electricity demand outlook and forecast model research