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Research on Carbon Neutral Grid Enterprises' Low Carbon Transition Strategies and Benefit Assessment

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Abstract. In the context of achieving the dual-carbon goal, the power sector is actively exploring ways to make a low-carbon transition. The transformation of traditional thermal power involves the safety and reliability of electricity supply in the power system, and the low-carbon transformation involves changes and transformations in various aspects, which requires huge investments and costs. Therefore, it is of great significance to study the low-carbon transition strategy of power grid enterprises and assess the benefits generated by low-carbon transition of power grid enterprises. This paper first analyzes the background and transformation objectives of the low-carbon transformation of the power industry. Then it analyzes the potential of low-carbon development on the power generation side, puts forward the path of low-carbon transformation on the power generation side according to the development potential, and analyzes the role mechanism of low-carbon technology to generate low-carbon benefits, and constructs the assessment model based on system dynamics according to the role mechanism of low-carbon benefits. Simulation analysis is carried out through actual data, and the results show that the low-carbon transition strategy can produce more economic and environmental benefits, and can provide suggestions for subsequent development for reference.

1 Introduction

The power sector, as the main source of coal consumption, is the main source of carbon emissions in China, accounting for about 40% of China's total carbon emissions, most of which come from large coal-fired power plants. Data from the National Bureau of Statistics (NBS) show that as of the end of 2021, the country's installed power generation capacity was 2.377 billion kilowatts (kW), of which the installed thermal power generation capacity was 1.297 billion kW, accounting for 54.6% [1]. According to the study of China's 14th Five-Year Plan for Energy Development, by 2035, the total installed capacity of power plants in China is expected to reach 4.37 billion kW, of which coal-fired power generation accounts for 21% of the installed capacity [2]. The large installed capacity of coal-fired power generation in China has a high environmental impact, so it is important to complete the transition of the past 15 years and develop new energy systems as soon as possible. In the future, as the proportion of new energy increases, coal power will gradually reduce its proportion in the power generation structure as soon as possible, and transform from the role of the main body of power generation to the basic safeguard and system regulation power supply [3]. Power transformation is a complex decision-making problem that requires scientific methods to support its completion. China's coal power unit volume is huge, the overall operating life is small, there are differences in the characteristics of the unit, and even in the transition process, need to "one machine, one policy" to be discussed separately. For example, through the flexibility transformation to reduce the minimum output of the unit, increase the peak shifting capacity, so that the unit can participate in the depth of peak shifting, improve the flexibility of the power system; large-capacity, high-parameter advanced coal power units, to take the provision of heat, steam, water and other integrated energy services to enhance its energy efficiency; high-carbon coal-fired power plants should adopt carbon-reducing technologies to complete the conversion of coal-fired power plants to low-carbon, carbon-free and carbon-negative facilities; the operation of the longer small-capacity, aging coal power units, the longer the operating life, the older units, the longer the operating time, the lower capacity and older units. Longer operating years of small-capacity, old units are shifted to standby and auxiliary service units or gradually withdrawn from the market [4]. Different regions have their own advantages and disadvantages in terms of resource endowment, and the pace of coordinated development of new energy and coal power varies, which leads to different transformation pressures on coal power units in different regions. The low-carbon development of the power generation side will bring long-term and diversified benefits to the relevant subjects. The scientific evaluation of these

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benefits will help the main bodies to carry out systematic investment analysis, enhance their investment enthusiasm, and thus improve the scientificity and sustainability of the investment in the decarbonized power system [5].

To this end, this paper studies the background and objectives of the low-carbon transformation of the power generation side of the electric power industry, analyzes the potential of low-carbon transformation and puts forward the response strategy of power grid enterprises in the context of the development of low-carbon transformation, analyzes the mechanism of the role of the low-carbon benefits and establishes an evaluation model according to the proposed strategy.

2 Analysis of the background and objectives of power transformation

At present, China's social economy still relies on traditional fossil energy sources such as coal, oil, gas, etc., and the consumption demand continues to increase, and the coupling between the social economy and carbon emissions from energy consumption is high [3]. In China's industrial sector, the form of energy conversion is mainly based on combustion, fossil energy combustion CO2 accounted for up to 88%, of which 41% of CO2 emissions generated by the electric power industry production, transmission and consumption of electricity. As can be seen from Table 1, By the end of 2020, the country's installed power generation capacity will reach 220,058,000 kilowatts, of which 124,517,000 kilowatts, or 56.6%, will be coal-fired.

Table 1. National installed power generation data at the end of 2022

Electricity energy	Installed capacity/ 10^4KW	Growth rate (%)
Thermal power	124517	4.7
Hydropower	37016	3.4
Nuclear power	4989	2.4
Wind Power	28153	34.6
Photovoltaic	25343	24.1
Others	40	12.6
Total	220058	9.5

According to the conversion relationship between fossil energy and electric energy, the amount of CO2 emitted by thermal power units from the whole process of electric energy production, transportation to consumption can be deduced as:

$$C_Z = N_B W \cdot h \qquad (1)$$

Where C_Z is the total carbon emission from fossil energy; N_B is the carbon production coefficient of fossil energy, which is 0.4; W is the installed capacity of thermal power; and h is the number of hours of power generation.

Assuming that China's thermal power units generate electricity at full capacity, the CO2 generated annually is about 1.6 billion tons. It can be seen that China's electric power industry CO2 emission reduction tasks and challenges are very arduous. However, in the face of global climate deterioration caused by high CO2 emissions, the proposed "four revolutions, a cooperation" energy security strategy for China's power energy transformation and development has pointed out the direction. As a power grid enterprises should promote the production and use of clean power, build a green, environmentally friendly and low-carbon power energy system, and actively deepen, take the initiative and lead the low-carbon transformation of power energy.

Beginning in 2015, China began to adjust its electric energy structure, boosting the penetration rate of power sources such as wind power, photovoltaic and hydropower, and gradually reducing the combustion of fossil energy for power generation. By the end of 2020, China's power energy composition of non-fossil energy generation capacity and installed capacity of the proportion of the increase is obvious. According to the "carbon peak, carbon neutral" action program released by the state grid, China's power carbon emissions peaked in 2030, is expected to reach "carbon neutral" in 2060. Since power grid enterprises play a leading role in the transmission, distribution and consumption of electric energy, and profoundly influence the mode and structure of energy production on the power supply side, therefore, in the context of energy restructuring and low-carbon transformation, power grid enterprises not only have to ensure the demand for electric energy for the rapid development of the national economy, but also have to contribute to the realization of the goal of "Carbon Neutral" within the scope of their responsibilities, functions and capabilities. The goal of "carbon neutrality" should be realized within the scope of their responsibilities, functions and capabilities.

3 Analysis of Low Carbon Development Potential in the Electricity Sector

The power generation industry, as an important basic industry for the development of the national economy, has a large proportion of both energy consumption and greenhouse gas and pollutant emissions, and is an important area for energy conservation and carbon reduction in China [6]. Although energy saving and carbon reduction in the power generation industry has made relatively significant achievements, the potential is still very large.

3.1 Clean coal power generation

Adopting advanced power technology to improve energy efficiency of power generation and reduce carbon dioxide emission intensity is one of the ways to develop clean coal power generation technology, including overall coal gasification combined cycle technology, high-efficiency coal power generation technology, high-efficiency natural gas power generation technology, supercritical and ultra-supercritical large-scale high-efficiency coal-fired units, and so on. Low-carbon power generation technology is mainly used to indirectly reduce the intensity of carbon emissions from power generation by improving the energy efficiency of power generation and reducing the amount of coal consumption. It is estimated that if thermal power units reduce coal consumption by 1 gram per kWh, the power industry will save 3.41 million tonnes of standard coal and reduce greenhouse gas emissions by 9.46 million tonnes. If the energy efficiency of ultra (supercritical) units is increased by 1 per cent, greenhouse gas emissions will be reduced by 3 per cent [7].

3.1.1. Critical power generation technology

This technology is a coal-fired power plant that operates at high temperatures and employs an advanced steam cycle to achieve higher thermal efficiencies and lower gas emissions than conventional coal-fired power plants. Supercritical and ultra-supercritical units refer to the pressure of the work mass in the boiler. Boiler mass are water, water critical pressure is: 22.115MP, critical temperature is 374.15 ℃; At this pressure and temperature, the density of water and high-temperature water vapour is the same, known as the critical point of water, the furnace pressure is less than this pressure is known as sub-critical boilers, higher than this pressure for the supercritical boiler, the furnace temperature of high-temperature water vapour is not less than 593 ° C or the pressure is not less than 31MPa is known as ultra-supercritical. In the project is also often more than 25MPa called ultra-supercritical [8]. Ultra-supercritical, ultra-supercritical thermal power units have significant energy savings and improve the environment, improve the efficiency of coal-fired generating units, so that the amount of coal combustion is relatively reduced, the amount of pollutants emitted is also relatively reduced; power generation efficiency increased by 1%, carbon dioxide emissions reduced by 2% to 3%, compared with supercritical units, ultra-supercritical units have higher thermal efficiency and can save 0.6 million tonnes of standard coal a year.

3.1.2. Integrated Gasification Combined Cycle Power Generation (IGCC) Technology

IGCC technology includes coal gasification, purification, and gas-steam combined cycle, which is a clean coal power generation technology combining coal gasification and combined cycle power generation, and is known as the "cleanest coal power" [9], and some people use "old energy, new methods" to describe IGCC technology. IGCC technology also uses traditional coal resources as energy source, with high thermal efficiency, currently up to 43%~45%; low environmental pollution: sulfur can be recycled; NOx emission is less than 25mg/m3, dust emission is less than 10mg/m3; CO2 after the conversion of water vapor reaches a high concentration, easy to realize the zero emission; IGCC power plant's water consumption is only about half of the conventional coal-fired power plants. Therefore, IGCC integrates high efficiency power generation and environmental protection performance, which not only makes up for the shortcomings of single technology of coal utilization that is difficult to satisfy the efficiency, cost and environment at the same time, but also has the same long-term sustainable development goal of cutting carbon dioxide emission, which is the most effective way of clean coal utilization technology, and it will also become the main direction of high-tech development of clean coal utilisation in China.

3.2 Renewable Energy Power Generation

China is endowed with abundant solar energy resources, of which about 70 per cent of the area has more than 2,200 hours of sunshine per year, and the total amount of solar radiation exceeds 5,000 megajoules per square metre per year, which provides good conditions for the use of solar energy. Tibet, Qinghai, Xinjiang, Gansu, Ningxia, Inner Mongolia Plateau, the total amount of sunshine and the number of hours of sunshine are higher, is one of the world's solar energy resource-rich areas. China's land surface receives solar energy equivalent to 4,900 billion tons of standard coal each year, about the sum of tens of thousands of Three Gorges Project power generation. Solar power generation potential. According to the China Meteorological Administration census results, the country's land 10 meters above the ground at a height of 4.35 billion kilowatts of total reserves of wind energy resources, technology can be developed for about 300 million kilowatts, the sea can be exploited about 750 million kilowatts of wind energy. Our country has abundant wind resources, with average wind speeds of more than 3 metres per second in most areas, and even more than 5 metres per second in the highland areas and coastal areas. Half of the year in these areas are windy days. Therefore, China has good potential for wind power generation and can vigorously develop the wind power industry in the future.

4 Implementation Path of Low Carbon Transition in Power Sector

In response to the above analysis of the potential for low-carbon development, the implementation path for low-carbon transition on the power generation side of the power industry includes thermal low-carbon power generation technologies and clean energy generation.

4.1 Cleaner Coal Power Generation

In the context of low-carbon development, coal power generation is made cleaner through the transformation of coal power units and the application of low-carbon technologies to realize the decarbonization development of the power generation side. The first is to adopt efficient and clean combustion technology to reduce pollutant emissions from coal combustion by improving combustion efficiency and reducing emissions. For example, the use of advanced combustion equipment and pulverized coal combustion technology can reduce sulfur dioxide, nitrogen oxides and particulate emissions from coal-fired power plants. The second is the promotion of cogeneration technology. Cogeneration technology improves energy efficiency and reduces CO2 emissions through the combined operation of thermal power plants and gas turbines.The technology enables the coal power industry to maintain high power generation efficiency while cleaning up. The last is the development of coal power carbon capture utilization and storage technology, which is a method of capturing, utilizing and storing carbon dioxide generated during the coal combustion process. By separating, compressing and storing carbon dioxide gas, greenhouse gas emissions in the atmosphere can be reduced. The technology can effectively reduce carbon emissions from the coal power industry and provide a viable solution for carbon reduction in the power sector [10].

4.2 Clean Energy Power Generation

To cope with the global greenhouse effect and power energy transition, the power system has begun to vigorously develop wind, light, water and other clean energy. However, wind and light energy power has strong volatility and instability, and large-scale access to the grid will have a certain impact on the operation, management and security of the grid. Obviously, the power grid enterprises on the one hand to ensure that clean energy and new energy equipment can be safe, reliable and stable access to the power grid, on the other hand, to deal with the development of the relationship between clean energy and fossil energy. First of all, power grid enterprises should provide technical support for the access of new energy power plant (station), and increase the proportion of new energy power generation in scheduling, and gradually reduce the traditional fossil energy power generation. Secondly, on the user side, they should improve the service level of the distribution network to meet the diversified power needs of distributed power sources, mobile energy storage devices, electric vehicles and other new energy-using devices, and lead the energy-using mode of electric energy substitution, gradually replacing the traditional conventional energy-consuming devices such as oil, gas and coal, so as to keep the power system running at a low carbon level throughout the whole process of power production, transmission and consumption. Once again, accelerate scientific and technological innovation, provide technical guarantee for the green economic operation of each link of source, network, load and storage, help supply-side energy structure adjustment through accurate prediction and scientific regulation, meet the diversified demand for electricity on the demand side, solve the problem of "double-high, double-peak" of the grid, and comprehensively promote the low-carbon, safe and high-efficiency utilization of clean energy.

5 Constructing a Benefit Assessment of Low-Carbon Transition in the Power Sector

5.1 Mechanisms of low-carbon benefits

The benefits of power decarbonization development can be divided into economic and environmental benefits. Among them, economic benefits refer to the effect of cost saving or revenue increase: environmental benefits usually include the benefits brought by the reduction of many kinds of greenhouse gases, and this paper specifically refers to the benefits of reducing CO2 emissions.

In power generation, the use of cleaner energy sources, such as wind and solar, has replaced traditional fossil energy sources, thus reducing CO2 emissions on the one hand and bringing significant environmental benefits, and on the other hand, it reduces the demand for fuels such as coal and oil, which further reduces the fuel cost and generates economic benefits. In addition, low carbon technologies such as clean and low-carbon coal power generation technologies and biomass gasification power generation technologies have also improved energy efficiency [5], reduce the peak load demand and the operation and maintenance costs of power generation enterprises, and generate environmental and economic benefits. This is shown in Figure 1 below:

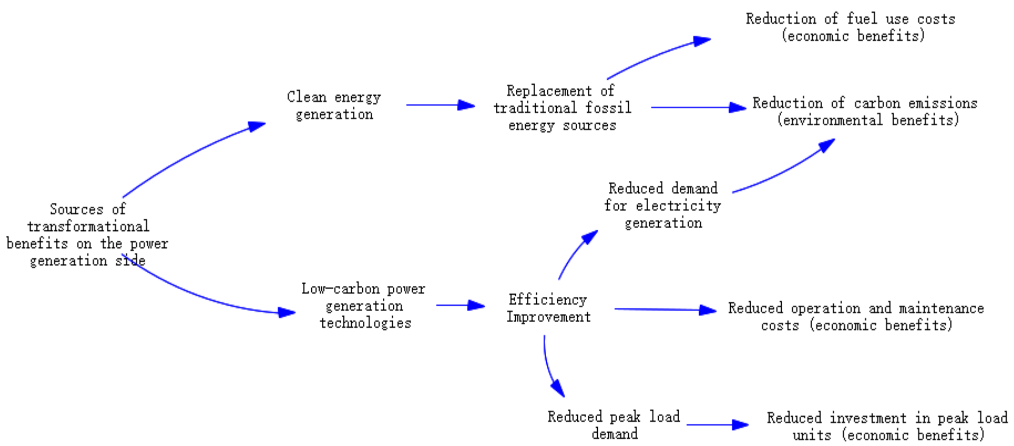

Fig. 1. Mechanism of low carbon benefits on the power generation side

5.2 Modeling

System dynamics is a system simulation method using computer for simulation proposed by Prof. Forrester J W of MIT in 1956 [11]. Based on the simulation software VENSIM, the benefit flow stack diagram is drawn according to the low-carbon benefit action mechanism, as shown in Figure 2. Since the benefit flow stack diagram is based on the causal relationship to establish the loop, it cannot show the mathematical relationship between the variables in the system. Therefore, it is also necessary to establish the system structure equation that supplements the relationship of variables, as shown in Table 2.

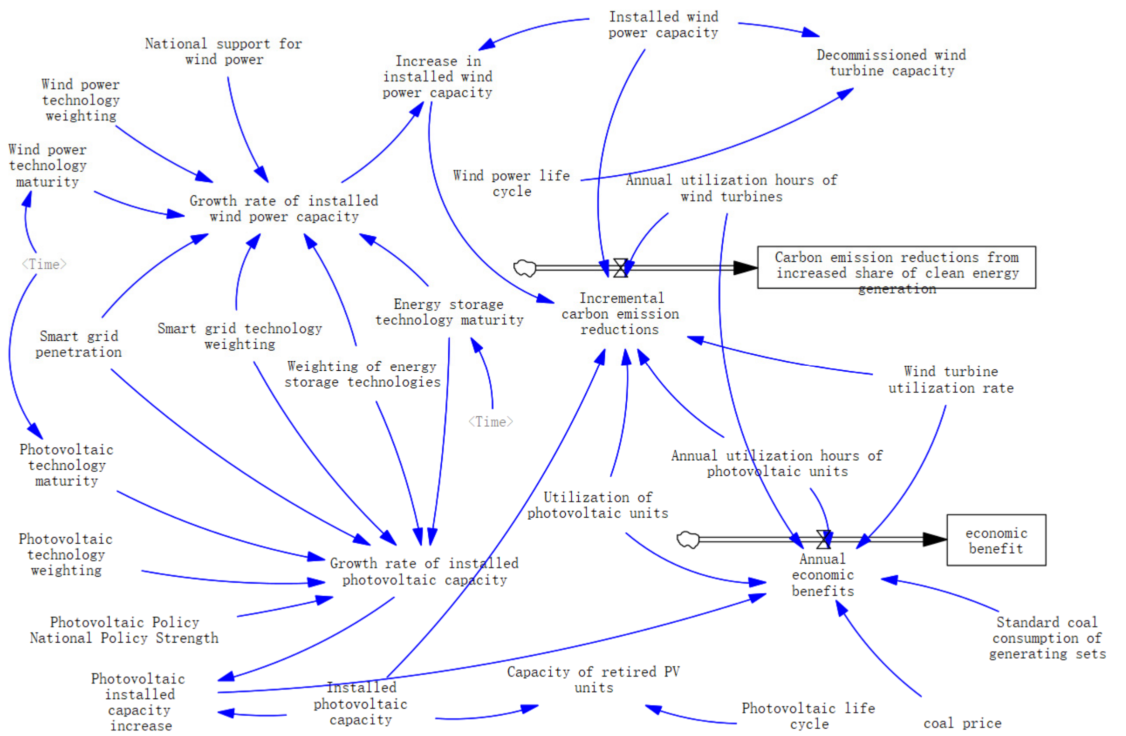

Fig. 2. Generation-side low-carbon benefit stack diagram

Table 2 System structure equations for the generation side

Number	System structure equation
1	Installed wind power capacity =INTEG(installed wind power capacity * installed wind power capacity growth rate - retired wind power capacity, initial value)
2	Installed PV capacity =INTEG(installed PV capacity * installed PV capacity growth rate - Capacity of retired PV units, initial value)
3	Wind power installed capacity growth rate =INTEG(smart grid penetration * smart grid technology weight + energy storage technology maturity * energy storage technology weight + wind power technology maturity * wind power technology weight)/(smart grid technology weight + energy storage technology weight + wind power technology weight)
4	Pv installed capacity growth rate =INTEG(smart grid penetration rate * Smart grid technology weight + energy storage technology maturity * energy storage technology weight + photovoltaic technology maturity * photovoltaic technology weight)/(smart grid technology weight + energy storage technology weight + photovoltaic technology weight)
5	Decommissioned wind turbine capacity = installed wind power capacity/wind power life cycle
6	Capacity of decommissioned PV units = PV installed capacity/PV life cycle
7	Carbon emission reduction generated by the increase in the proportion of clean energy generation =[installed wind power capacity * annual utilization hours of wind power units *(1- utilization rate of wind power units)+ installed photovoltaic capacity * annual utilization hours of photovoltaic units *(1- utilization rate of photovoltaic units)]* Carbon emission reduction intensity of benchmark technology
8	Economic benefit =(installed capacity of wind power * annual utilization hours of wind power units + installed capacity of photovoltaic units * annual utilization hours of photovoltaic units)*(standard coal consumption of generator units * coal price - average cost per unit of clean energy unit capacity)

5.3 Example analysis

Taking the development of Baiyin area in Gansu Province as an example, the data and parameters of low-carbon transition benefit assessment on the power generation side are shown in Table 3.

Table 3 Evaluation data of low-carbon transition benefit on power generation side

Content	Argument
Generating unit utilization rate (%)	73
Line loss ratio (%)	1.19
Coal price (Yuan /t)	800
Feed-in Tariff Adjustment Time (a)	1
Standard coal consumption for power generation (gce/kWh)	320
Annual utilization hours of equipment (h)	4289
Ratio of thermal power fuel cost to total cost (%)	75
Photovoltaic installed capacity (10,000 kW)	1300
Wind power installed capacity (10,000 kW)	220

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The above data is brought into the model for simulation, and the evaluation results are shown in the figure below:

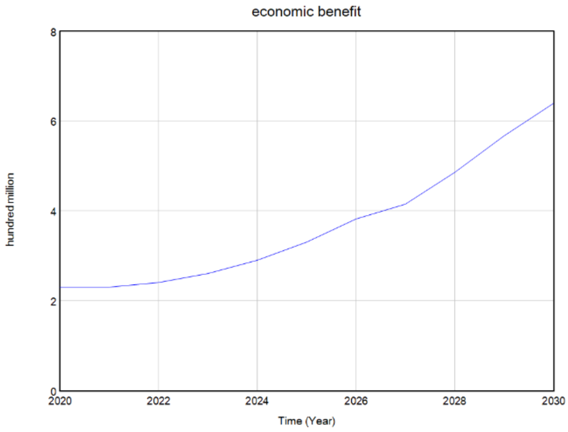

Fig. 3. Economic benefits of new energy generation

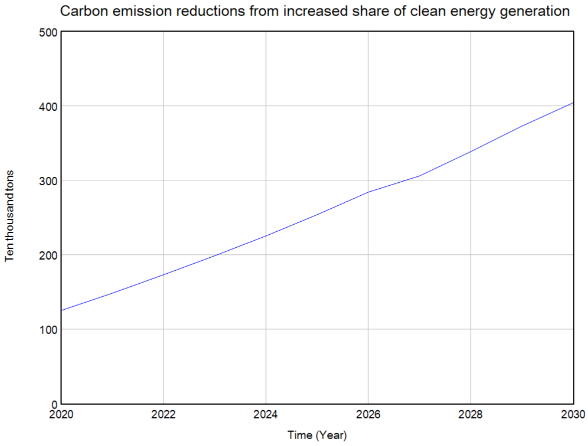

Fig. 4. Carbon reduction from increasing the proportion of clean energy generation

On the power generation side, the use of clean energy such as wind and solar energy replaces traditional fossil energy, which on the one hand reduces the emission of greenhouse gases such as carbon dioxide and brings significant environmental benefits, and on the other hand reduces the demand for fuels such as coal and petroleum, alleviates the energy crisis, reduces the cost of fuels and generates economic benefits. Moreover, the application of coal power clean-up technology improves the combustion efficiency of gas turbines and the power generation efficiency of units, and effectively reduces the emission of pollutants such as sulfur dioxide, nitrogen oxides and particulates, as well as the impact on the environment.

According to the low carbon transition implementation path proposed in this paper, we analyze the mechanism of low carbon benefits, and construct a benefit assessment model according to the mechanism of low carbon benefits. The simulation results are shown in Figure 3-4, according to the proposed low-carbon transition implementation path, the new energy generation generates economic benefits of 331 million yuan in 2025, and 639 million yuan in 2030, and the increase in the proportion of clean energy generation in 2025 indirectly reduces 2.537 million tons of carbon emissions, and in 2030 reduces 4.039 million tons of carbon emissions. This is because with the increase in the proportion of clean energy power generation, the transformation of coal power generation, and the cleaner coal reduces the amount of coal consumption required for power generation, thus reducing carbon emissions and generating economic and environmental benefits. Therefore, the power generation chain can achieve a series of environmental and economic benefits, such as improving energy utilization efficiency, reducing operation and maintenance costs, realizing carbon dioxide emission reduction, and stimulating the development of related industries through the integration of clean energy into the grid and the use of low-carbon power generation technologies.

6 Conclusion

Through the grid-connection of clean energy and the use of low-carbon power generation technology, the power industry can achieve a series of environmental, economic and social benefits such as improving energy utilization, reducing operation and maintenance costs, achieving carbon dioxide emission reduction, and stimulating the development of related industries.

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