Modeling energy system transformation policy in 2020 and 2030: A case study of Shandong Province

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Abstract. In recent years, Shandong Province has actively adopted policies and measures to reduce fossil energy consumption and achieve clean and low-carbon development. In order to explore the future energy system transformation and upgrading in Shandong Province, this paper use EnergyPLAN model to construct Shandong Province’s 2020 and 2030 energy structure standard scenarios and simulation scenarios for analysis. The results show that: under BAU (business-as-usual) scenario, in 2020, non-fossil energy consumption accounts for 7% of primary energy consumption, but it can only reach 8.67% by 2030, which is far from the policy goal (18%); to achieve the energy consumption goal promulgated by government, three alternative scenarios are then studied. Finally, this paper compares and analyzes the above two scenarios and proposes policy recommendations for the transformation of energy systems in Shandong Province.

1. Introduction

1.1. Research background
The present energy system in Shandong Province Currently, the world is working together to address climate change, reduce greenhouse gas emissions, and promote clean energy development. Shandong Province is facing the opportunities and challenges in the transformation of energy systems. Shandong’s energy system is in a state of transition known as the Shandong Energy Medium and Long-Term Development Plan (SEMLTDP) targeting by 2020 and 2030, (i) the total energy consumption of the province will be controlled at 420 million and 485 million tons of standard coal respectively, (ii) the proportion of non-fossil energy consumption will increase from the current 3% to 7% and 18%. (iii) the installed capacity in the province reached 137 million and 195 million kilowatts respectively. The three central strategies are to increase the share of renewable energies and to decrease the primary energy demand, i.e., efficiency improvements. Therefore, summarizing and analyzing the energy system policy background of Shandong Province, constructing future energy application scenarios, assessing the comprehensive effects of existing policies and future development, and proposing specific application measures that can achieve the goals of policy planning are necessary for Shandong Province to comply with the changes of the times and achieve an effective way to transform and upgrade the energy system. The article will establish an energy system planning model of Shandong Province, simulate the standard and simulation scenarios of future energy systems, and compare the results of the relevant energy policies, and propose relevant policy recommendations.
In the context of global climate change, promoting energy structure adjustment and technological progress is an important way to control smog and achieve green development. An exponentially rising number of studies are working on how to realize energy structure optimization and upgrading to achieve green and low carbon development, including reviewing the resource potentials and situation of energy system transformation (Alizadeh et al. 2016; Weaver et al. 2019) [1,2], using energy system model to analyze the role of different technologies in improving energy efficiency and energy conservation (Su et al. 2016) [3], and exploring the impact of government policy on the energy system (Panula-Ontto et al. 2018; Liu et al. 2019) [4,5].

This article first introduces the present energy system in Shandong Province, including the status quo of energy supply and demand and the status quo of energy utilization structure, then build reference indicators to verify the accuracy of the model. Subsequently, standard scenarios and simulation scenarios for the energy system of Shandong Province in 2020 and 2030 were established, and in the 2030 simulation scenario, three scenarios were considered. Finally, based on the comparison of model simulation results and related policy documents, relevant policy recommendations for achieving policy objectives are proposed.

1.2. The current energy system in Shandong province

1.2.1. Background. Shandong province is a major province of energy consumption and with the rapid development of the economy, energy demand is increasing. In 2016, the province’s primary energy consumption was 387.23 million tons of standard coal, accounting for 8.88% of the national energy consumption. The province’s import volume was 331.32 million tons of standard coal, and the import volume was 89.48 million tons of standard coal. Coal consumption accounted for 76.87% of the province’s primary energy consumption, oil consumption accounted for 16.27%, is the main energy consumer goods; total energy production is 136.78 million tons of standard coal, accounting for 3.95% of the country. Therefore, it is difficult to meet consumer demand, and this phenomenon bring some pressure to the development of clean energy in Shandong Province.

1.2.2. Current status of energy structure in Shandong province. Shandong Province is an important energy base of the country. Fossil energy reserves such as coal and petroleum are abundant, clean energy resources are widely distributed and its development conditions are superior. The accumulated proven coal reserves in the province are more than 40 billion tons, accounting for about 3% of the country. The petroleum resources are mainly distributed in the north and southwest. The Shengli Oilfield in the province is the second largest oil production base in China and the main natural gas production base. The new energy and clean energy equipment industry started early, and the industrial energy consumption system continued to improve.

In order to improve the current energy structure and achieve a successful transformation and upgrading of the energy system, Shandong province has promulgated the Energy Medium and Long-Term Development Plan (hereinafter referred to as the Plan) to set the proportion of non-fossil energy consumption in primary energy consumption to 7% in 2020, and to 18% in 2030. Clean energy is the main improvement target, the power industry is the main reform department, and for non-fossil energy, combined with the actual situation of Shandong Province, the main research objects are wind energy, solar energy, water energy and biomass energy, in the China Energy Statistics Yearbook. In this classification, Shandong province does not have a formed nuclear power system either, so it is not considered in this article. These energy sources are mainly used in the power industry, and in the China Energy Statistics Yearbook, thermal power, wind power, solar photovoltaic power generation and hydropower are unified in the power classification. Therefore, the proportion of clean energy generation to total power generation is studied to represent non-fossil energy consumption. From the standard scenarios and simulation scenarios in 2016, this is representative and reliable.
2. Methodology

2.1. Energy system simulation tool

The article uses the EnergyPLAN model to construct a future energy system scenario in Shandong Province. The model is applied to analyse energy system simulation scenarios in many countries around the world due to its powerful database, detailed data simulation and extensive departments. It is widely used in China and involved in the construction of future policy implementation scenarios in multiple energy fields such as electricity, new energy, and heat supply (Liu et al. 2011; Hong et al. 2013; Xiong et al. 2015) [6-8]. European countries are relatively mature and in-depth in applying the model[9]. Through the analysis of the entire energy system, including the synergies generated by the integration of various sectors, covering all demand side (heating and cooling demand, flexible and inflexible power demand, fossil fuel transportation demand, power demand and synthetic fuel demand), cleaning Energy power plants (onshore and offshore wind power, photovoltaic power, river hydropower, hydropower, geothermal power), clean energy heating equipment, energy conversion technology (personal and district heating fuel boilers, electric boilers, heat pumps, solar collectors) Heaters and cogeneration units (condensing mode power plants, electrolyzers and synthetic fuel producers) and energy storage technologies (individual and district heating connections for heat storage, power storage, vehicle to grid, compressed air storage, hydrogen and other fuel storage). On the other hand, it is also an aggregation model. Different types of generation, transformation and consumption units are aggregated into fewer units for integration analysis.

2.2. Modeling the reference scenario

The EnergyPLAN model performs an hourly simulation with a one-year timeframe to analyze the entire energy system. Taking hydropower as an example, the input value is determined based on the hourly distribution of water inflow \( W_{H_{\text{Hydro}}} \), water storage capacity \( S_{H_{\text{Hydro}}} \), installed capacity \( C_{H_{\text{Hydro}}} \), and efficiency \( \mu_{H_{\text{Hydro}}} \), and based on such input, the potential output is calculated by the following procedure. First, the average hydropower generation \( e_{H_{\text{Hydro}}-ave} \) is expressed as the average water supply (annual water supply divided by 8784 hours/year):

\[
e_{H_{\text{Hydro}}-ave} = \mu_{H_{\text{Hydro}}} \cdot W_{H_{\text{Hydro}}} / 8784
\]

The program then performs hourly modeling of the system by storing the distribution of fluctuations in the content. In addition, the hydropower generation \( e_{H_{\text{Hydro}}} \) is adjusted in the following manner based on generator capacity, water supply distribution, and storage capacity:

\[
\text{Hydro storage content}' = \text{Hydro storage content} + W_{H_{\text{Hydro}}}
\]

\[
e_{H_{\text{Hydro}}} = \text{MAX}\left[ e_{H_{\text{Hydro}}-ave}, (\text{Hydro storage content}' - S_{H_{\text{Hydro}}} \cdot \mu_{H_{\text{Hydro}}}) \right]
\]

\[
e_{H_{\text{Hydro}}} \leq C_{H_{\text{Hydro}}}
\]

Table 1. Comparison of electricity production of Shandong Province in 2016 and the EnergyPLAN simulation (TWh).

| energy        | actual 2016 | Energy PLAN 2016 | Difference | Difference(%) | Correction factors |
|---------------|-------------|------------------|------------|---------------|--------------------|
| wind power    | 1.47        | 1.469            | 0.001      | 0.0681%       | -0.5               |
| solar power   | 0.31        | 0.31             | 0          | 0.0000%       | -0.04              |
| biomass       | 0.919       | 0.919            | 0          | 0.0000%       | -0.72              |
| hydroelectric | 0.139       | 0.139            | 0          | 0.0000%       | -0.63              |
| thermal power | 46.71       | 46.741           | -0.031     | -0.0663%      | -0.93              |

Due to differences in stored content at the beginning and end of the calculation cycle, errors may occur in the calculation. In order to correct these problems, the above calculation process may cause the last stored content to be the same as the stored content at the beginning, that is, after the first
calculation, the new content covers the previous initial calculation result, thereby obtaining the output value of the hydropower generation amount.

In order to verify the accuracy of the model, the article compares the 2016 simulation results with the actual values, as shown in Table 1.

Different future wind turbine configurations will result in lower or higher yields under the same wind conditions, and similar problems are encountered in other clean energy generation processes. Therefore, you can choose to specify the correction factor to change the distribution and correct the annual production, which is between plus and minus 0-1. By this method, the amount of power generated is corrected so that the product takes values between zero-output or full-output conditions, while other values are relatively stable:

\[
e_{\text{res}}' = \frac{e_{\text{res}}}{1 - F A C_{\text{res}} * (1 - e_{\text{res}})}
\]

Where \(e_{\text{res}}\) indicates the amount of power generation, \(e_{\text{res}}'\) indicates the amount of power generation after adjustment, and \(F A C_{\text{res}}\) is the correction factor.

The correction factors of wind power, hydropower, solar photovoltaic power generation, biomass power generation and thermal power in the table are: -0.50, -0.63, -0.04, -0.72, -0.93. It can be seen that the difference between the simulated value and the actual value is small, and the model can be considered to accurately simulate the future energy structure and be used for subsequent analysis.

3. Results and discussion

3.1. Standard scenario for 2020 and 2030

In the standard scenario, the distribution data, correction factor and other relevant data are calculated on the basis of 2016. First, under the existing energy scenario, according to the requirements of “the Plan”, it is assumed that the installed capacity of hydropower, wind power, solar photovoltaic power generation and biomass power generation in 2020 (2030) will be respectively 1.1 GW (7.9 GW), 14 GW (23 GW), 10 GW (25 GW) and 2.3 GW (5 GW), and based on the existing macro policy and the requirements of Shandong Province for clean energy development, the growth rate of thermal power installed capacity is unchanged, therefore, the calculated total installed capacity in 2020 and 2030 is 126.84 GW and 205.44 GW respectively. Input the above data into the EnergyPLAN model to simulate the 2020 and 2030 energy power generation standard scenarios (2020-S, 2030-S) under the current implementation of the policy, as shown in Table 2.

| Year | Wind power | Solar power | Biomass | Hydroelectric power | Thermal power | Proportion of clean energy generation |
|------|------------|-------------|---------|---------------------|---------------|--------------------------------------|
| 2020-S | 25.41      | 6.82        | 11.79   | 1.41                | 621.5         | 6.93%                                |
| 2030-S | 40.3       | 17.05       | 25.62   | 10.15               | 1006.6        | 8.67%                                |

According to the formula, the proportion of clean energy consumption in 2020 is 6.8%, which is similar to the target of 7% predicted in the Plan. It can be seen that with a reasonable correction factor, according to the estimated installed capacity, combined with the existing power generation distribution and power generation efficiency, the requirements can be met. In 2030, the proportion of clean energy consumption is 8.7%, which is far from the target value of 18%.

3.2. Governmentally proposed scenario for 2020 and 2030

3.2.1. Governmentally proposed scenario for 2020. First, for the 2020 energy high-level scenario (2020-M0), after the correction factor is adjusted to 0, the installed capacity of thermal power is adjusted from the initial estimate of the equilibrium growth rate of 126.84 GW to 115 GW, and the thermal power installed capacity will no longer continue to grow steadily. Instead, the installed
capacity of thermal power is increased at a lower growth rate; the installed capacity of clean energy is consistent with the standard scenario. The total power generation thus simulated is 742.63 TWh, far exceeding the power generation of the standard scenario of 655.14 TWh, and the proportion of clean energy power generation is 7.12%, reaching the level of 7% required by the Plan.

However, this is only an ideal scenario. To achieve the optimal efficiency of the power generation process and the negative growth scenario of thermal power installation is almost impossible under the existing equipment conditions and technologies, for the reason that the next low-level scenario analysis is needed. In the low-level scenario (2020-M1), the correction factor under the standard scenario is restored, and the installed capacity of each energy is consistent with the high-level scenario. The results of the simulation are shown in Table 3. The proportion of clean energy generation reaches 7.57%, which is higher than the level of both high-level scenario and standard scenario. However, the total power generation is only 600.75 TWh, which is far lower than the total power generation in the standard scenario. It can be seen that although the low-level scenario is the most feasible, the power generation is difficult to meet the estimated electricity consumption demand.

Although thermal power development is limited by environmental factors, it has to be acknowledged that thermal power is still the main force of power generation in the next decade. It is difficult to maintain the current installation of thermal power thermal power or even decrease it in a short period of time, considering that current clean energy technologies are difficult to generate quickly to cover social needs, the main source of power generation for society is still thermal power. Therefore, in the medium-level scene (2020-M), the installed capacity of thermal power increased from 1.50 GW in high-level and low-level scenes to 1.2 GW. At the same time, with the rapid development of clean energy technology and the further improvement of transportation efficiency in recent years, the correction coefficient of thermal power and biomass power generation has been revised to 0.7, and other input values remain unchanged. On this basis, the total generated power generation becomes 651.38 TWh, which is very close to the power generation of the standard scene, and the proportion of clean energy power generation reaches 6.99%, which is very close to the level of 7%. From this, it is concluded that the medium-level scene meets the actual development speed and the electricity demand in 2020.

### Table 3. Governmentally proposed scenario of electricity production in 2020 (TWH).

|          | wind power | solar power | biomass | hydroelectric power | thermal power | Proportion of clean energy generation |
|----------|------------|-------------|---------|---------------------|---------------|---------------------------------------|
| 2020-M0  | 30.02      | 6.96        | 14.08   | 1.79                | 703.86        | 7.12%                                 |
| 2020-M1  | 25.41      | 6.82        | 11.79   | 1.48                | 567.04        | 7.57%                                 |
| 2020-M   | 25.41      | 6.82        | 11.84   | 1.48                | 617.67        | 6.99%                                 |

3.2.2. Governmentally proposed scenario for 2030. The 2030 model is more complex than in 2020, as the proportion of clean energy generated in the standard scenario is only 8.67%, far less than the 18% required in the Plan. The installed capacity of each energy needs to be re-adjusted. Shandong Province has the most abundant wind energy resources. Therefore, wind power is used as an example to calculate the maximum feasible penetration rate of wind power under simulated scenarios, which can more accurately establish and evaluate future energy system scenarios.

The subsequent analysis is similar to the 2020 high-level scenario, assuming a 2030 high-level simulation scenario with a correction factor of 0 (2030-M0). However, unlike 2020-M0, in order to achieve the Plan, the installed capacity of thermal power needs to be adjusted to 86.5 GW, even lower than the installed thermal power capacity of 95.4 GW in 2016. At the same time, the total power generation capacity of the thermal power installed capacity is 609.02 TWh, which is far less than the total power generation in the standard scenario (2030-S), and only 200 TWh more than in 2016.

It is necessary to comprehensively consider the installed capacity of each energy generation and optimize the input value to increase the proportion of each clean energy generation. In the next step,
the installed capacity of wind power, solar power, hydropower and biomass power generation capacity will be increased to 41 GW, 35 GW, 14 GW and 10 GW respectively. The simulation results are shown in Table 4. The total power generation of the simulated 2030 high-level scenarios (2030-M0) is 1,083.78 TWh, which is similar to the standard scenario of 107.4 TWh, and the clean energy generation ratio is 18.11%, meeting the requirements of the Plan.

However, this is still an ideal scenario. Therefore, in 2030, the low-level scene (2030-M1), the installed capacity of wind power, solar power, hydropower, and biomass power generation is the same as that of the high-level scene (2030-M0), and the correction coefficients are adjusted to -0.1, 0, -0.7, and -0.2 respectively. The installed capacity of thermal power is the same as the maximum penetration rate of wind power, reaching 155 GW by 2030, and the correction factor is -0.7, which is the same as the correction factor of biomass power generation. At this time, clean energy generation accounted for 19.50%, reaching an ideal level. However, it encountered the same contradiction as the low-level scenario of 2020 (2020-M1), that is, the total power generation was only 927.11 TWh, far less than the 10741 TWh under the 2030 standard scene (2030-S), which is supposed to be the basic direction of development.

Therefore, in the next medium-level scenario (2030-M), the structural importance of thermal power is taken into account, the installed capacity of thermal power will be increased from 155 GW in high-level and low-level to 175 GW, the installed capacity of wind power, solar photovoltaic power, biomass power, and hydropower generation is adjusted to 15 GW, 46 GW, 40 GW and 10 GW respectively. The correction factor of thermal power and biomass power generation is adjusted to -0.5, and other input values are unchanged. The output results are shown in Table 4.

Table 4. Governmentally proposed scenario of electricity production in 2030.

|               | wind power | solar power | biomass | hydroelectric power | thermal power | Proportion of clean energy generation |
|---------------|------------|-------------|---------|---------------------|---------------|--------------------------------------|
| 2030-M0       | 87.93      | 24.36       | 61.21   | 22.81               | 948.68        | 18.11%                               |
| 2030-M1       | 83.97      | 24.36       | 51.47   | 20.96               | 797.82        | 19.50%                               |
| 2030-M        | 94.21      | 27.84       | 53.87   | 22.46               | 942.71        | 18.25%                               |

After the final adjustment, the relatively realistic 2030 medium energy scene (2030-M) analog output value is obtained. The proportion of clean energy power generation reached 18.25%, which is in compliance with the requirements of the Plan; the total power generation is 1,087.22 TWh, which is similar to the power generation in the 2030 standard scenario (2030-S). Therefore, the analog output value can be considered for future energy scenario construction and policy effectiveness assessment.
3.3. **Comparison between the standard and governmentally proposed scenarios**

The simulation of the standard scenario can represent the energy system in 2020 and 2030 under current development speed and technology level, see Figure 1. It can be seen that if the current policy is effectively implemented, the non-fossil energy will account for 7% of the primary energy consumption in 2020, fully fulfilled the conditions, but it is very difficult to achieve 18% of the standard scenario by 2030. In the simulation scenario, the data input and output results of the low, medium, and high level scenarios in 2020 are not much different; in the optimal scenario of 2030, wind power, solar photovoltaic power, biomass power, and hydropower installed capacity are respectively increased 100%, 60%, 100% and 89.87% year-on-year; and are 3.89 times, 6.69 times, 11.99 times and 4.57 times more than 2016, which requires high development speed for clean energy installation. Correspondingly, the installed capacity of thermal power is reduced by 14.82% compared with the Plan, which is 0.62 times higher than that of 2016, and is far lower than the current growth rate of thermal power installed capacity.

Through analysis and adjustment of data, we can find that in order to increase the proportion of clean energy power generation, in addition to simply increasing the installed capacity of clean energy and reducing the installed capacity of thermal power, we must fully consider the actual situation, considering clean energy cannot fully compensate for the thermal power generation gap. At the same time, the prior art is difficult to meet the requirement of a correction factor of 0. The distribution data will not be greatly adjusted in a short period of time, because the climate zone and geographical distribution of Shandong Province cannot be changed, and its 8684 hours of light and wind speed throughout the year will not be very different, etc. Therefore, it is only possible to synthesize the actual situation and the future clean energy generation ratio target to simulate an actual structure of the energy generation system that is relatively in line with the government requirements.

4. **Conclusions**

In this article, an Energy PLAN model for Shandong Province has been developed. Firstly, a reference model based on actual 2016 data has been established, and the simulated output value and actual value of the energy generation system in 2016 are compared. It is considered that the model can accurately simulate the energy generation structure considering the error between them is small. Therefore, according to relevant policy documents and data, the standard energy power generation structure scenarios in 2020 and 2030 (2020-S, 2030-S) are simulated respectively. It can be seen that under the current development speed and technical level, the Plan target can be basically achieved by 2020, that is, clean energy generation accounts for 7% (analog value is 6.93%). However, the proportion of clean energy generation in the standard scenario is only 8.67% by 2030, which is quite different from the target of 18%. From this, it can be considered that it is difficult to achieve the planning goal by 2030 under the existing development speed and technical level. In addition, the article continues to optimize the power distribution and correction factor, so that the total power generation will reach the expected level by 2020 and 2030 and the clean energy generation will continue to increase, that is, the proportion of non-fossil energy consumption in total primary energy consumption will increase in order to approach the expected level.

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