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Provincial Renewable Energy Dispatch Planning and Assessment Based on RPS policy in China

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ABSTRACT

In order to stimulate clean energy consumption, the Chinese government issued a guarantee mechanism for the accommodation of renewable energy in May 2019. It stipulated the minimum accommodation responsibilities of the total amount of renewable energy power and non-hydropower in each province. However, China's electricity consumption and renewable energy resources are unevenly distributed. This will cause the mismatch problem between accommodation capacity and responsibility. So, each province has different levels of pressure to fulfill its responsibilities. We establish a renewable energy accommodation assessment model, which aims to propose a reasonable renewable energy optimal dispatch strategy to make full use of resources and complete the accommodation goal. First, we use support vector regression to predict power demand, and then establish a linear programming model to simulate renewable energy dispatch. Finally, an assessment index is constructed to estimate the level of pressure for each province to fulfill the accommodation responsibilities. The results show the flow of renewable energy across China in 2022. 347.7 and 86.4 TWh of hydropower and non-hydropower will be dispatched nationwide. Among them, 11 provinces face huge completion pressure.

Keywords: renewable energy, RPS policy, accommodation responsibilities, electricity demand forecast, dispatch planning

NONMENCLATURE

Abbreviations	
RPS	Renewable Portfolio Standard
RE	Renewable Energy
SVR	Support Vector Regress
LCOE	Levelized Cost of Energy
Symbols	
i, j	Provinces of China
$Th_{i,j}$	Hydropower transmitted from province i to j
$Tn_{i,j}$	Non-hydropower transmitted from province i to j
$Cost_i^h$	Hydropower LCOE in Province i
$Cost_i^{nhp}$	Non-hydropower average LCOE in Province i
$Cost_{i,j}^t$	Distance between province i and j
P_i^h, P_i^n	Hydropower and non-hydropower generation in province i
Rh_i, Rn_i	Hydropower and non-hydropower minimum accommodation responsibilities in province i
D_i	Electricity consumption in province i
C_i	Transmission line maximum capacity
M_i^{hp}, M_i^{nhp}	The pressure of hydropower and non-hydropower accommodation province i

1. INTRODUCTION

In order to promote the development of renewable energy, the Chinese government has adopted feed-in tariff (FIT) and RPS policy[1,2]. FIT has greatly promoted

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the growth of RE installed capacity. Therefore, China's RE installed capacity accounted for 39% of the total installed capacity in 2019. However, the difficulties in accommodation of RE has emerged. To alleviate this problem, China has set the specific provincial accommodation responsibilities and minimum proportion of RE accommodation in electricity consumption. The responsibilities include total amount of RE power and non-hydropower.

However, China's electricity consumption and RE resources are unevenly distributed. This will cause the mismatch problem between accommodation capacity and responsibility. So, each province has different levels of pressure to fulfill its responsibilities. Faced with this problem, it is urgent to coordinate and dispatch resources to ensure the optimal use of renewable energy.

Some scholars have studied the optimal path to achieve the target of renewable energy quota. For example, Geem et al. build an energy portfolio planning model with the goal of cost minimization. The development plan for all types of power generation installations from 2012 to 2030 has been formulated considering the RPS policy of South Korea [3]. Bird et al. simulated the evolution of power generation technology and the expansion of transmission lines in the U.S. power industry under the influence of the RPS policy based on the ReEDS model [4]. Farooq et al. used the bottom-up MARKAL model to analyze the development potential of various types of renewable energy power in Pakistan under different RPS policy scenarios [5]. These studies analyzed the policy characteristics of various countries and obtained the development plan of power generation technology in the power industry in order to realize the RPS policy. However, as each country's situation is different, their policy formulations are also quite different. Each state in the United States can set its own RPS goals [6]; there are other countries that have mostly set overall goals without specific distribution at the regional level, such as South Korea and Australia [3,7].

China's resource endowment and power grid structure are quite different from other countries. China has developed long-distance power transmission technology, and the scale of its power grid ranks first in the world, enabling power dispatch between regions with different resource endowments. This makes it a reality that all provinces cooperate to fulfill the responsibility of accommodation uniformly distributed by the country. Recently, some studies have analyzed China's RPS policy. Reference[8] studied the fairness of RE accommodation responsibilities in different provinces. However, the study did not provide specific inter-regional power transmission indicators. Reference[9] constructed an optimization model of China Southern Power Grid, but this study only considered the development plans of five provinces. Reference[10] assessed the pressure of China's provinces to achieve RPS goals in the past few years. Therefore, these studies on China's RPS policy lack foresight and integrity .

Previously, China announced the accommodation responsibility for 2018-2020. In order to provide the government with decision-making support for the setting of indicators in the next 3 years, we carry out the following research. First, we use SVR to forecast electricity demand. Then, we establish a renewable energy dispatch plan model. The future renewable energy power dispatch is simulated, and dispatch indicators for each province are obtained. Finally, we construct pressure assessment indicators to estimate the pressure of each provinces to fulfill accommodation responsibilities.

2. RE ACCOMMODATION ASSESSMENT MODEL

2.1 Electricity demand forecasting model

Vapnik proposed the support vector machine (SVM) theory, and its branch SVR is suitable for solving regression problems[11]. In addition, it shows good performance when the training data changes periodically.

In SVR model, $\{(x_i, y_i)\}_{i=1}^{N} \in R^m \times R$. x_i represents the input vector of the SVR model, y_i is actual output value, and N is the total number of data points. In this study, x_i is a 7-dimensional input vector, representing the GDP and population growth rate, the proportion of tertiary industry, per capita living area, humidity, temperature and rainfall. y_i represents electricity consumption. The goal of SVR is to train a model as follows:

$$f(x) = \omega^T \varphi(x) + b \quad (1)$$

ω is the weight vector. The function $\phi_i(x)$ is called feature, and the parameters b is deviations of training model. The SVR problem can be written in the form (2).

$$\min_{(\omega,b)} \frac{1}{2}\|\omega\|^2 + C\sum_{i=1}^{m} l_\varepsilon(f(x_i) - y_i) \quad (2)$$

Where C is the regularization constant, l_ε is the insensitive loss function.

$$f(x)=\begin{cases} 0, & \text{if}|z|\le\varepsilon \\ |z|-\varepsilon, & otherwise \end{cases} \quad (3)$$

The main idea of the SVR model is to map low-dimensional nonlinear functions to high-dimensional linear functions. At this time, the value of the kernel function is reflected. K is defined as the kernel function, then:

$$f(x)=\sum_{i=1}^{m}(\hat{\alpha}_i-\alpha_i)k(x,x_i)+b \quad (4)$$

In this study, the radial basis kernel(RBF kernel) is selected.

2.2 RE power dispatch model

We divide RE dispatch into two parts: hydropower and non-hydropower. Among them, the non-hydropower part includes wind power, photovoltaic and biomass power generation. The remaining non-hydropower (such as tidal energy, geothermal energy, etc.) has relatively small generation, and this study does not take it into consideration.

In objective function, the cost of power generation and transmission is minimized.

$$\min\sum_i\sum_j(Th_{i,j}\cdot(Cost_i^h+Cost_{i,j}^t)+Tn_{i,j}\cdot(Cost_i^{nhp}+Cost_{i,j}^t)) \quad (5)$$

The objective function is subject to the following constraints.

$$\sum_j Th_{i,j}\le P_i^h \quad (6)$$

$$\sum_j Tn_i \le P_i^n \quad (7)$$

$$\frac{P_i^h-\sum_j Th_{i,j}+\sum_j Th_{j,i}}{D_i}\ge Rh_i \quad (8)$$

$$\frac{P_i^n-\sum_j Tn_{i,j}+\sum_j Tn_{j,i}}{D_i}\ge Rn_i \quad (9)$$

$$\varphi_1\cdot\sum_j Th_{i,j}+\varphi_2\cdot\sum_j Tn_{i,j}\le C_i\cdot h_{ave} \quad (10)$$

$$Th_{i,j}\ge 0 \quad (11)$$

$$Tn_{i,j}\ge 0 \quad (12)$$

Where Eq.(6,7) are the provincial installed capacity constraints. Eq.(8,9) are the constraints of the province's accommodation responsibility. Eq.(10) are transmission line capacity constraints. Eq(11,12) are non-negative constraints. Due to technical limitations, the reasonable maximum proportion of UHV transmission of non-hydropower is 30%, so the value of φ_2 in equation (10) is set to 0.3. The value of φ_1 is 1.0.

2.3 Accommodation pressure assessment

According to the actual situation of hydropower and non-hydropower accommodation, the pressure for each province to fulfill its responsibilities is defined as follows.

$$M_i^{hp}=\frac{\sum_j Th_{j,i}-P_i^h}{D_i\cdot Rh_i} \quad (15)$$

$$M_i^{nhp}=\frac{\sum_j Tn_{j,i}-P_i^n}{D_i\cdot Rn_i} \quad (16)$$

2.4 Data resource

The socioeconomic and climate data used in the prediction model comes from National Bureau of Statistics of China[1,2]. The power data comes from the Wind database[3]. Transmission line data comes from powergrid construction planning[4]. The LCOE data comes from reference[12]. The province's RE accommodation responsibility weight comes from the China National Development and Reform Commission[5]. The growth rate of the weight of the accommodation responsibility is calculated based on the average annual growth rate. The planned RE installed capacity is derived from the forecast under the medium-speed scenario in reference [13]. The number of utilization hours of transmission lines is set to 5000.

3. RESULTS AND DISCUSSION

3.1 Demand forecast results

Due to space constraints, this article selects Shandong and Hunan provinces as examples to show the electricity demand forecast results, as shown in Fig.1. The R2 value of the model is distributed around 0.9, which reflects the good fitting degree of the model. The MAPE values were distributed between 4% and 9%, reflecting the good prediction accuracy of the model. Therefore, it can be seen that the prediction model has applicability and stability.

[1] Source: http://data.stats.gov.cn/easyquery.htm?cn=C01
[2] Source: http://www.stats.gov.cn/tjsj/ndsj/
[3] Source: https://www.wind.com.cn/newsite/edb.html
[4] Source: http://www.chinasmartgrid.com.cn/news/20191213/634440.shtml
[5] Source: http://www.nea.gov.cn/139105253_15910013573071n.pdf

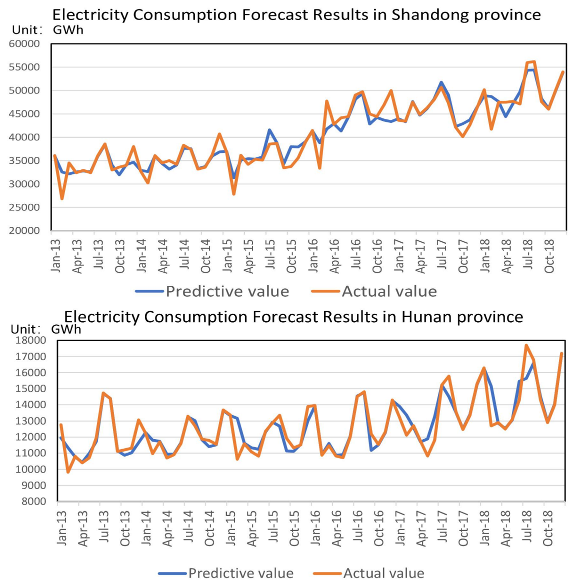

Fig 1 Comparison of electricity consumption forecast and actual value.

3.2 RE dispatch planning results

In this paper, Cplex is used to solve a this model, and the specific results are as follows. We selected 2022 as an example for analysis.

3.2.1 Hydropower dispatch

Fig.2 shows the amount of dispatchable, generated and demanded hydropower in each province. Among them, Yunnan, Sichuan, and Hubei have left 166.8, 103.2 and 75.1 TWh respectively after fulfilling their dispatching responsibilities. Guangdong, Shanghai and Jiangsu have large hydropower gaps, with 161.5 TWh, 44.8 TWh and 39.7 TWh respectively. A total of 17 provinces need to import hydropower 401.5 TWh.

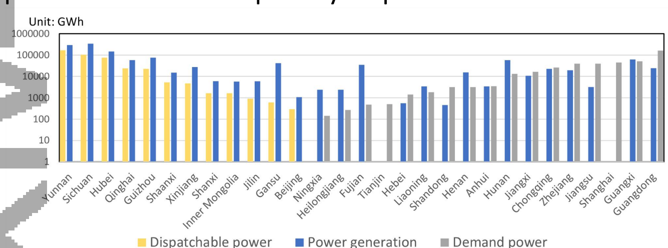

Fig 2 Dispatchable, generation and demand hydropower.

Figure 3 shows China's hydropower dispatch in 2022. In order to complete the target of accommodation responsibility, Jiangsu, Zhejiang, Shanghai, Jiangxi, Chongqing and other provinces in Central and East China have a large electricity shortage, and it is necessary to dispatch about 182.8 TWh of hydropower from Sichuan and Hubei. Due to the capacity limitation of the transmission lines from Yunnan to Guangxi and Guangdong in the Southern Power Grid region, we carry out economic dispatch of RE power to maximize power transmission. The results are also reflected in Figure 3. Guangdong and Guangxi are in serious power shortage, and about 158.4 TWh of hydropower is transferred from Yunnan and Guizhou. There will be a deficit of 53.8 TWh in this area. The Northeast and Northwest regions have less hydropower dispatching, requiring a total of 4.3 TWh electricity to be dispatched. It can be seen that the dispatching of hydropower is mainly concentrated in South, Southwest and East China, which is the result of uneven distribution of China's water resources.

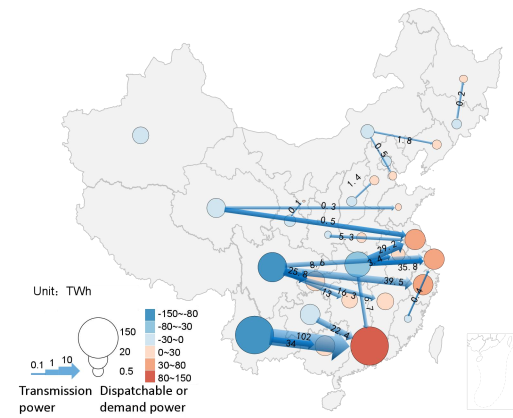

Fig 3 Hydropower dispatch in 2022.

3.2.2 Non-hydropower dispatch

Fig.4 shows the amount of dispatchable, generated and demanded non-hydropower in each province. After fulfilling the accommodation responsibility, the remaining dispatchable electricity in Xinjiang, Inner Mongolia and Gansu are 37.9, 22 and 15.3 TWh respectively. Beijing, Zhejiang, and Tianjin have large gaps for non-hydropower, with 22.2, 17.8 and 11.9 TWh respectively. In total, 10 provinces need to transmit non-hydropower from outside, and dispatch 86.4 TWh nationwide.

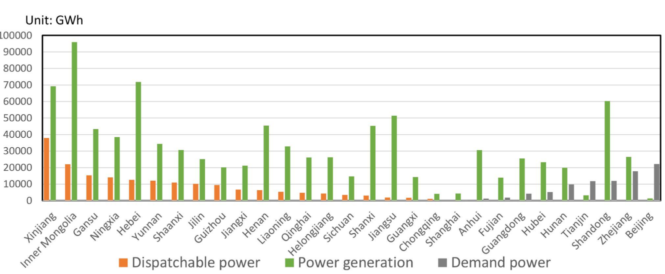

Fig 4 Dispatchable, generation and demand non-hydropower.

Figure 5 shows China's non-hydropower dispatch in 2022. Specifically, in order to fulfill non-hydropower accommodation responsibilities, Beijing, Tianjin, and Shandong have shortages, requiring dispatching about

34.4 TWh from Inner Mongolia, Hebei, and Liaoning. In East and Central China, Zhejiang, Hubei, Hunan and Anhui have large shortages, and most of the power from Xinjiang, Gansu, Ningxia and Guizhou needs to be dispatched about 55.4 TWh. The non-hydropower dispatched in the Southern region is relatively small, about 4.2 TWh.

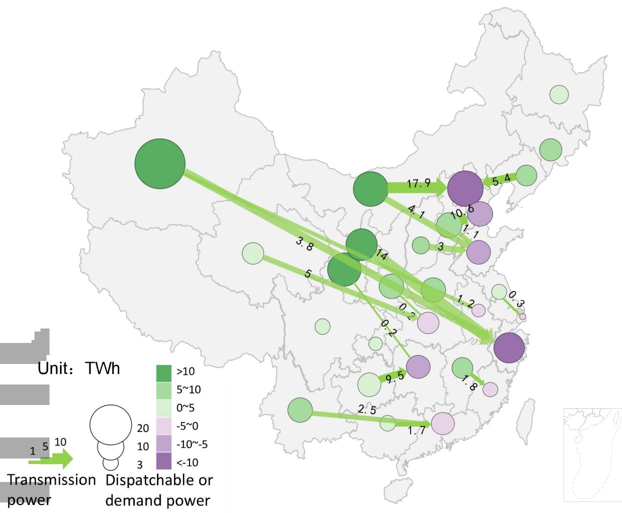

Fig 5 Non-hydropower dispatch in 2022.

3.3 Pressure assessment

We divide the pressure to fulfill the accommodation responsibility into three levels (0-0.3 is low, 0.3-0.5 is medium, and 0.5-1 is high). The specific values are shown in fig.6.

Among them, 11 provinces, including Tianjin, Zhejiang, Shanghai, etc. are under high pressure, mainly in East China, North China and South China. 9 provinces, including Chongqing, Guangxi, etc. are under moderate pressure, mainly in Northeast and Central China. 9 provinces, including Hubei, Inner Mongolia, Sichuan, etc. have lower pressures, mainly in the northwest and southwest China.

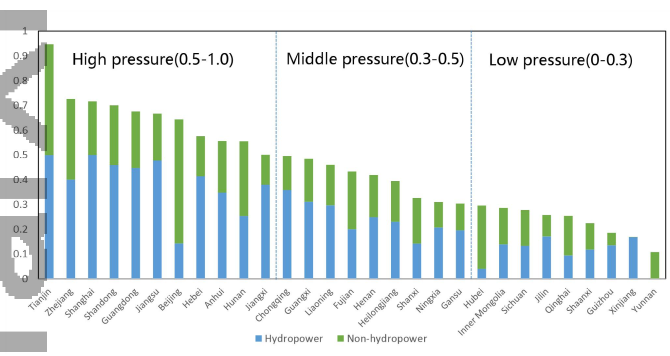

Fig 6 Non-hydropower dispatch in 2022.

4. CONCLUSION

We draw several key conclusions from the results. First, the average annual growth rate of China's total electricity demand from 2020 to 2022 is 4.0%. Second, in 2022, 347.7 and 86.4 TWh of hydropower and non-hydropower will be dispatched across China. Third, 11 provinces are under high pressure to fulfill the accommodation responsibilities.

Based on the results obtained, we make three recommendations. First, the provinces in southern China need to plan for hydropower dispatching to ensure the largest priority for hydropower accommodation. Second, actions should be taken to improve the flexibility on the non-hydropower supply side and expand the demand side accommodation space. Third, strengthening the interconnection of power grids could alleviate the pressure of accommodation responsibility.

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