Strategy Optimization and Simulation Analysis of Electricity-saling Companies under Renewable Portfolio Standard

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Abstract: In the context of energy supply constraint and ecological problems, governments have actively promoted the development and utilization of renewable energy and released a series of incentive policies, one of which is China's Renewable Energy Consumption Guarantee Scheme (RPS). Based on the RPS, this paper constructs an optimization model for the annual portfolio purchase strategy of power sales companies with the objective of studying how to optimize the portfolio purchase scheme and reduce the cost of power purchase. The simulation results show that, as RPS keeps developing and maturing, the subjects who do not complete their consumption responsibility will bear huge fines, so the optimal strategy is: when the price of renewable power is lower than that of conventional power, the purchase of renewable power should be given priority; if the consumption responsibility is still not fully satisfied at this time, the excess consumption of other subjects and the lower price of green certificates should continue to be purchased until the consumption responsibility is completed.

1 INTRODUCTION

Since global industrialization , traditional fossil energy sources have been heavily exploited and used, leading to energy resource constraints and environmental degradation. The key to addressing these problems lies in adjusting the energy structure and increasing the proportion of renewable energy sources (RES). China is in a critical period of socio-economic transformation and development, and facing the dilemma of development and environmental protection, the "decoupling" of economic growth and environmental problems has become a major issue in China's green development, of which the key lies in how to achieve a sustainable energy system transformation based on RES. At present, China's energy system transformation has indeed made substantial progress. In recent years, RES power generation and its installed capacity have maintained a high level of growth (see Figure 1 and Figure 2).

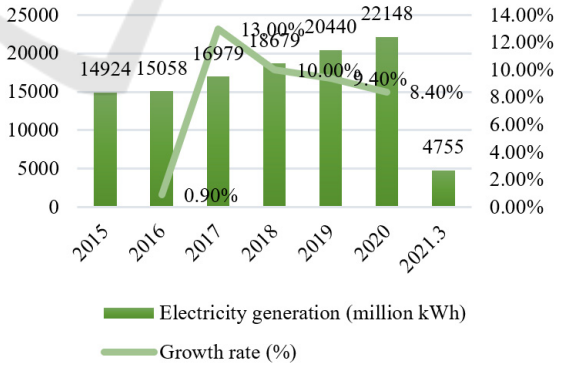

Figure 1: Renewable Energy Generation in China, 2015-March.2021.

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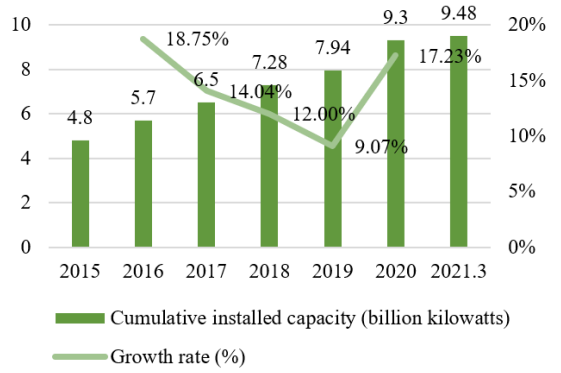


Figure 2: Cumulative Installed Capacity of Renewable Energy Generation in China, 2015-March.2021.

However, with the gradual expansion of the scale of RES, its consumption problem is increasingly prominent. 2018 the amount of China's annual "three abandoned" power was more than 100 billion kilowatt hours, equivalent to the annual power generation of the Three Gorges Power Station. Therefore, in order to improve the RES consumption rate and change the increasingly serious situation of the new energy subsidy gap, the National Development and Reform Commission and the Energy Bureau jointly issued the Notice on Establishing a Sound Renewable Energy Power Consumption Guarantee Mechanism (hereinafter referred to as "the Notice") on May 10, 2019, which set the RES power consumption responsibility weight for each provincial administrative region. In this context, power sales companies have been able to make a significant contribution to the development of the renewable energy market. In this context, it is important to study the trading strategy of power sales companies as the first type of market players who bear the responsibility of RES consumption.

2 REVIEW OF THE LITERATURE

2.1 Review of Renewable Energy Consumption Mechanism in China

Renewable energy power consumption guarantee mechanism, also known as renewable energy quota system (RPS), refers to a country or region mandatory requirement that a certain percentage (i.e., quota standard) of the power supplied by the power system must be RES. foreign research on RPS started earlier, the literature (Helgese 2018) established the electricity market and green certificate trading market equilibrium model, the study founds that the implementation of RPS not only improves production technology, but also can further improve social welfare. The feasibility of implementing RPS in China and its institutional design has been a research hotspot for scholars in China for many years: literature (Feng 2017) selected indicators such as obligation subject, operation mode, form of quota target, and degree of incentive, summarized and analyzed the practical experience of countries currently implementing RPS on the electricity sales side, and analyzed the feasibility of implementing RPS on the electricity sales side in China with our national conditions, and also designed the implementation of quota system on the electricity sales side in China The framework of RPS in China is designed.

The RPS is the product of a series of policy promotion. the *Notice* issued in May 2019 clearly decomposes the required RES power consumption to regional power sales companies and power consumers and assesses their completion; the *Notice on the Preparation Outline of the Implementation Plan for Provincial Renewable Energy Power Consumption Guarantee* (hereinafter referred to as the Outline) issued in March 2020 further clarifies the management mechanism and task division of labor (Zhang 2019) . The literature (Zhong 2020) argues that the RPS jointly established by the Notice and the Outline contains two main aspects.

1) The bearer of the consumption responsibility: There are two types of market participants, namely: ① grid enterprises, independent power sales companies, and power sales companies with the right to operate distribution grids, which supply (sell) electricity directly to power consumers; and ② power consumers and enterprises with self-provided power plants, which purchase electricity through the wholesale power market. The quota is to be borne by the electricity sales side rather than the generation side.

2) Market transaction mechanism for quota assessment: The quota system is designed with two sets of mechanisms to meet the weight of consumption responsibility through market-based transactions: (i) purchase the "excess" from market players who have exceeded the annual consumption volume, and both parties independently determine the transfer (or transaction) price; (ii) voluntarily subscribe to the "green certificate", and the RES power corresponding to the green certificate is recorded as the consumption volume.

2.2 Review of the Trading Strategies of Electricity-saling Companies

Foreign market-based reforms are earlier, and literature (Nojavan 2017) combines multiple power purchase paths such as RES and distributed power sources to propose a variety of pricing schemes for power sales companies for electricity contracts. In the domestic literature (Dai 2021), in order to analyze the impact of renewable energy consumption responsibility assessment on power sales companies, a power purchase portfolio investment model is established; the penalty mechanism of consumption responsibility assessment is introduced to realize the evaluation of the role of assessment strength. The literature (Zhou 2020) established a power purchase portfolio investment model in order to analyze the impact of renewable energy consumption responsibility assessment on power sales companies.

3 PROBLEM DESCRIPTION AND MODELING

3.1 Problem Description

1) Trading of Excess Consumption

After the electricity selling company and the customer have completed the corresponding consumption in the renewable energy trading market, the consumption beyond the quota obligation can be sold in the excess consumption trading market to gain revenue, and the shortage can also be bought in the market to realize the substitution of consumption between responsible entities.

2) Trading of Green Certificates

Green certificates themselves do not have any value, but under the quota system, their own price reflects the environmental value of RES generation - RES generators can sell their green certificate holdings in the green certificate trading market and receive additional green certificate proceeds, thus compensating for the portion of RES generation costs that exceed conventional energy generation, effectively reducing the government's financial burden.

3) Optimization problem of trading strategy for Electricity-Saling companies

The power seller needs to make decisions in the traditional spot market for electricity, the spot market for renewable energy, the spot market for excess capacity, and the spot market for green certificates, so as to minimize the cost of power purchase under the condition that the load demand and the minimum consumption weight of renewable energy are met (and bear the corresponding penalty when they are not met).

In this paper, we take the optimal purchase problem in the long-term phase (one year) as an example, and study how the power seller allocates the appropriate purchase ratio in the above markets to meet the electric energy demand and renewable energy quota requirements to maximize profit (with a fixed sales tariff, the minimum cost of power purchase can be used as an equivalent substitute for the maximum profit).

3.2 Problem Modelling

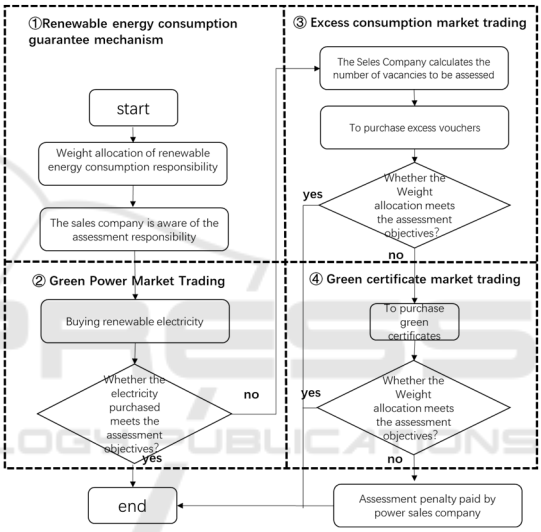


Figure 3: Renewable energy consumption market system framework.

In the above process, because the power sales company needs to ensure that the proportion of purchased RES power is not less than k (consumption weight), its transaction costs in carrying out power trading business can be specifically divided into power purchase costs and certificate costs: power purchase costs include both traditional power and green power, certificate costs include over-consumption voucher expenses and green certificate expenses (if the assessment target is not completed, the shortage part pays the corresponding penalties). The mathematical expressions are as follows.

$$min \quad \underbrace{C_{TE} + C_{RE}}_{Electricity\ purchase\ cost} + \underbrace{C_{ECC} + C_{GC}}_{Certificates\ purchase\ cost} + \underbrace{M \cdot max\{kQ - Q_R - Q_{EC} - Q_{GC}, 0\}}_{Pennalties} \tag{1}$$

In the above equation, C_{TE} and C_{RE} denote the power purchase cost for power sales companies to purchase conventional power and renewable energy power in the medium and long-term power market, respectively, C_{ECC} and C_{GC} denote the power purchase cost for power sales companies to purchase excess consumption vouchers and green certificates in the excess consumption trading market and green certificate trading market, respectively, and the last term is the penalty cost, M is the penalty for the assessed unit of electricity.

$$C_{TE} = p_T \cdot Q_T \quad (2)$$

$$C_{RE} = p_R \cdot Q_R \quad (3)$$

$$C_{ECC} = p_{ECC} \cdot Q_{EC} \quad (4)$$

$$C_{GC} = p_{GC} \cdot Q_{GC} \quad (5)$$

Q_T、Q_R、Q_{EC}、Q_{GC} indicate the purchase of traditional power, renewable power, excess consumption, and green certificates, respectively. In the actual trading process of excess consumption and green certificates, the subject of the transaction is the voucher, but a voucher is equivalent to 1MWh of renewable energy consumption, and in this paper, for the purpose of unifying the quantum of a variable, all of them are converted into units of electricity to express.

$p_T$denotes the price of thermal power purchased by the power selling company in the medium and long-term power market. Thermal power is basically stable in the current stage of the power market price, so this price is set in this paper as a value that fluctuates randomly within a small range, and considering the environmental cost of its generation, its price is bound to be higher than the market price of renewable power p_R; p_R is the transaction price of the power selling company in the RET market transaction; p_{ECC} and p_{GC} denote the license purchase price of the power selling company in the excess capacity market and the green license market, respectively.

Constraints of power purchase and consumption assessment for power sales companies:

$$Q = Q_T + Q_R \quad (6)$$

$$k \cdot Q \le Q_R + Q_{EC} + Q_{GC} \le Q \quad (7)$$

4 EXAMPLE ANALYSIS

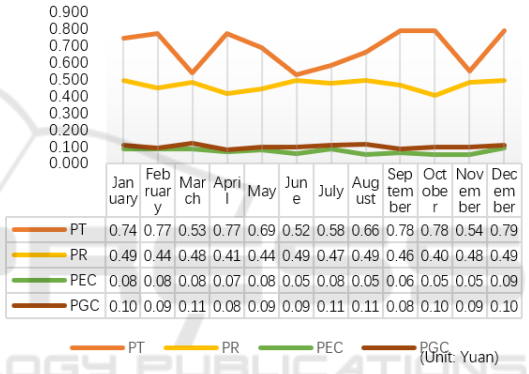
Electricity price fluctuations and market demand fluctuations are the risks that electricity sellers are bound to face when participating in monthly and annual centralized market bidding transactions. Therefore, in the setting of the relevant parameter values of this model, all kinds of electricity price fluctuations and electricity consumption fluctuations are considered, and the annual contracted electricity and renewable energy consumption are decomposed into each month, and the final combination forms an annual optimal power purchase strategy.

4.1 Setting of Parameter Values

Consider the elimination weight k=0.3250 (constant) and the unit penalty M=$10/unit (constant).

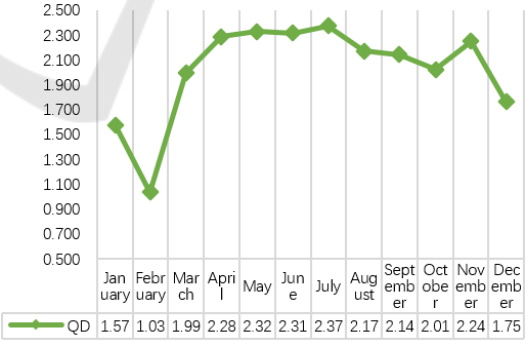
1）Fluctuations in electricity prices and electricity market demand by category

The fluctuation of various types of electricity prices with the market over the 12-month period is shown in Figure 4, and the QD (electricity market demand) also fluctuates with the market conditions, which is shown in Figure 5.



	January	February	March	April	May	June	July	August	September	October	November	December
PT	0.74	0.77	0.53	0.77	0.69	0.52	0.58	0.66	0.78	0.78	0.54	0.79
PR	0.49	0.44	0.48	0.41	0.44	0.49	0.47	0.49	0.46	0.40	0.48	0.49
PEC	0.08	0.08	0.08	0.07	0.08	0.05	0.08	0.05	0.06	0.05	0.05	0.09
PGC	0.10	0.09	0.11	0.08	0.09	0.09	0.11	0.11	0.08	0.10	0.09	0.10

Figure 4: Monthly average transaction price chart.



	January	February	March	April	May	June	July	August	September	October	November	December
QD	1.57	1.03	1.99	2.28	2.32	2.31	2.37	2.17	2.14	2.01	2.24	1.75

Figure 5: Electricity demand chart by month for power sales companies.

2）Monthly QR, QEC Caps

There is almost no oversupply in the thermal power market, so there is no cap constraint on QT (purchased conventional power). However, the RES market has lower prices due to the presence of

government subsidies and lower excess market prices relative to green certificates, so there are constraints on QR (purchased RES electricity power) and QEC (purchased excess). Their limits that fluctuate with the market are shown in Figure6.

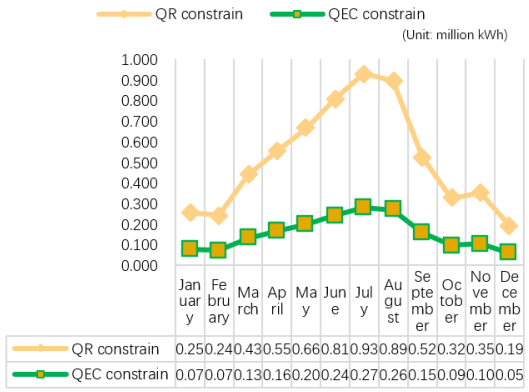


Figure 6: QR and QEC constrains..

4.2 Simulation Analysis

Using matlab to simulate and analyze the case, we get the purchase amount of each type of electricity and the percentage of each type of electricity to the total monthly electricity in 12 months under the optimal decision as shown below, and the minimum total cost under the optimal decision is RMB 15415676.76.

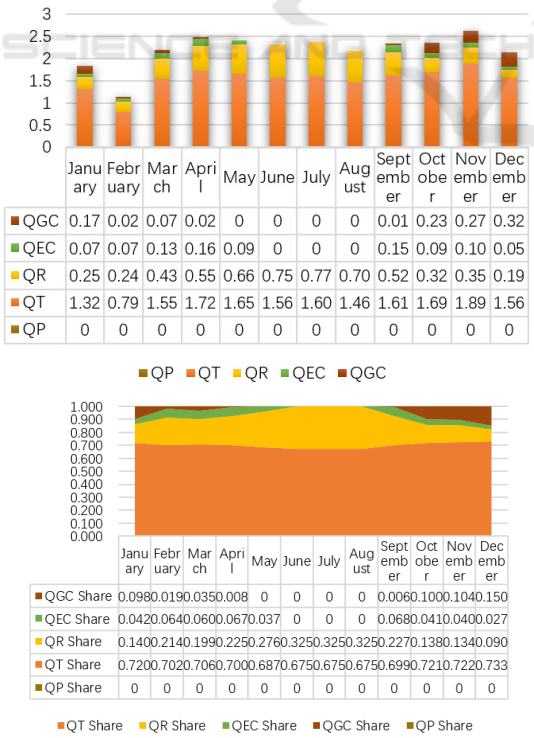


Figure 7: The chart of transaction results.

4.3 Analysis of Algorithm Results

1) Analysis of QP values

The annual QP is constantly 0. This is due to the fact that with the implementation of the national policy, the RPS is gradually maturing, so the penalty for the responsible body to complete the consumption volume is stronger, as shown by the unit penalty M of 10 yuan/unit - much higher than the unit price of other types of electricity.

2) Analysis of QR values

Throughout the year, QR reached the upper limit of the renewable energy limit constraint for the month. This is due to the existence of government financial subsidies, resulting in much lower RES electricity prices compared to conventional electricity prices, rational power sellers will prefer RES electricity, so in the premise that the demand for electricity on the sales side of the market is greater than the supply of RES electricity, RES electricity will be "snapped up".

3) Analysis of QEC values

From the simulation results, it can be seen that the QEC reaches the upper limit of the excess constraint for the month from January to April and from September to December. This is due to the fact that the price of "excess" is lower in this simulation compared to "green certificates", so a rational generator will give priority to purchasing excess to fulfill the consumption responsibility if the market demand is met and the consumption responsibility is not met. In May, because the unfulfilled consumption responsibility did not need to be satisfied by purchasing all the "excess", and the price of "excess" was still higher than that of "green certificates", only "Since the RES consumption responsibility has been fulfilled by QR from June to August, there is no longer a need for the "excess" or "green certificates".

4) Typical Month Analysis

a) December: QT and QGC both takes the largest share of electricity.

The QD (electricity market demand) in December is small, but the QR cap is also small, so in order to meet the QD, the remainder after all QRs are purchased has to be provided by QT, which results in the largest QT share in the 12 months; the small QR cap also results in the QR alone not being able to meet the consumption responsibility, so the excess or green certificates have to be purchased; unfortunately, the excess in December is exactly the smallest in the year, and all the excess It is also impossible to meet the remaining consumption responsibility. This results in the remaining part of the surplus needing to rely on "green certificates", and the remaining part is

relatively large, which explains why QGC accounts for the largest percentage of the year.

b) February: When QD is minimal, purchase decisions for all types of electricity are considered.

February QD is the smallest of the year, when the price of RES power is still lower than that of conventional power, so priority is still given to meeting market demand with all the RES power available for purchase, and the remaining unsatisfied portion is supplemented by conventional power. However, the QR cap in February cannot meet the consumption responsibility, so QEC and QGC still need to be purchased; at this time, the price of "excess" is still lower than that of "green certificates", so priority is given to the purchase of "excess ". However, the "Excess" cap in February is still unable to meet the remaining consumption responsibility, so finally, we still need to purchase 1.95% of the total monthly power QGC.

c) July: When QD is at its maximum, purchase decisions for all types of electricity are considered.

July QD is the largest of the year, and the RES power available for purchase is also the largest of the year, while the price of RES power is still lower than that of conventional power, so priority is still given to meeting the market demand with all the RES power available for purchase, and the remaining unsatisfied portion is supplemented by conventional power.

5 CONCLUSIONS

As the retail side of the grid continues to be liberalized and the RPS continues to be improved, it is critical that electricity sellers, as the obligated bearers of consumption responsibility, adopt an appropriate power purchase strategy to balance the cost and risk of power purchase. In this paper, we examine the combination of traditional, RES, "overage" and "green certificates" strategies of electricity sellers under the RPS on a monthly basis with minimum annual purchase costs.

(1) Since the existence of government subsidies keeps the price of renewable energy at a lower level than the price of conventional energy, electricity sellers should give priority to the purchase of renewable electricity to meet their consumption responsibilities.

(2) As the renewable energy quota system continues to develop and mature, the ability of power sales companies to meet their quotas will gradually increase, and they will no longer have to rely on the renewable energy contract market to meet their quota needs, as they did in the early stages of development. For fixed quota targets, purchases in the over-consumption and green certificate spot markets will also continue to increase as their prices fall.

(3) With the increase of renewable energy quota target, the purchase volume of power sales companies in renewable energy contract market, excess consumption and green certificate spot market will increase. The government can improve China's power supply structure by increasing the quota target, which will lead to a larger scale of renewable energy consumption, but it cannot be increased indefinitely, otherwise it will affect the operating efficiency of power sales companies, and the quota target should be reasonably set in accordance with the actual situation of each region.

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