Research on renewable energy trading’s algorithm

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Abstract. With the worsening of energy crisis and environmental pollution, the development and utilization of renewable energy have attracted more and more attention because of its remarkable social, economic and environmental benefits. As a populous country with rapid economic development, China's contradiction between energy supply and demand is increasingly prominent, and developing renewable energy vigorously is the inevitable choice for China's sustainable energy development in the future. This paper analyzes the existing renewable energy trading’s types, combines the situation of renewable energy resources in China and its development status, constructs the design of renewable energy quota trading model which is suitable for China, and designs the green certificate trading market based on quota system preliminarily.

1. Introduction

Since the new century, the transformation of energy with clean and low carbon as its main feature has become a common strategic choice for energy development in major countries. Major research institutions in Europe and America have proposed that in the next two or three decades, the main energy suppliers will gradually shift from traditional fossil energy such as coal, oil and gas to renewable energy such as wind power and photovoltaic power generation through technological progress and mechanism guarantee [1].

China started later than western countries in terms of the development and utilization of renewable energy, so the current policy system for promoting the development of renewable energy is not perfect. At the same time, existing research on renewable energy quota system is mainly focused on the demonstration of necessity and the promotion of renewable energy development. Also, there’s researchers study the existing obstacles and the insufficiency of related policies. The research on the in-depth analysis of certificate trading mechanism from the perspective of economic theory is relatively insufficient.

Therefore, we will study the design, implementation, and performance of the renewable energy quota system based on certificate trading in foreign countries, learn from the foreign countries’ successful experience about the development of renewable energy quota systems, and on this basis, put forward the implementation of our country's implementation of renewable energy power quota trading. The market-based mechanism will help China improve its renewable energy development policies and accelerate the cultivation of renewable energy markets.
2. Renewable energy transaction types
At present, domestic and foreign practice has mainly formed four kinds of renewable energy power system[2]: encouragement from electricity price, which is referred to as the Feed-in Tariffs for short; competition from the selection of developers, called the bidding system; and guarantee the amount of development, in combination with the market promotion role, which is referred to as the Renewables Portfolio Standard for short; the method of voluntary purchase by users is called the green electricity price system. Through the research on the types of renewable energy transactions, the paper makes a comparative analysis of the various systems in theory and practice, and then sorts out various transaction types.

2.1 Feed-in Tariffs
The Feed-in Tariffs is mainly used in European countries such as Germany, Denmark, Spain and Italy, which is the oldest and most widely used policy [3]. China's Feed-in Tariffs was promulgated in February 2005 as part of a comprehensive law to promote renewable energy. In the past few years, in countries with Feed-in Tariffs, the fixed electricity price policy has significantly increased technological innovation, increased investor interest, increased investment in renewable energy sources, and led to a rapid increase in renewable energy production. The Feed-in Tariffs vary from country to country, and some policies apply only to specific technologies or maximum capacity power generation technologies. Most policies usually set different subsidy policies for different technologies based on the cost of power generation.

The fixed price policy has two main features. First, it is mandatory to purchase and it guarantees a high purchase price for a long period of time. Guaranteed by the governmental agency for a longer period of time (for example, at least 10 or 15 years in France, at least 20 years in Germany), at a fixed price request to producers must purchase all new renewable within its service area Energy power. Second, it sets adaptive prices for different renewable energy technologies, so as to enrich the variety of renewable energy. The classification system for on-grid tariffs implemented in China determines the different on-grid tariffs according to different technology types and cost levels such as wind power generation, solar power generation, small hydropower, and biomass power generation.

2.2 Bidding online system of franchise bidding
The bidding policy for renewable energy power generation has been used in the United Kingdom and France until 2000. This type of policy is based on national renewable energy[4]. In the process of bidding on the Internet, the regulatory agency will give output of renewable energy power, and organize renewable energy producers to compete to distribute these outputs, and then force grid enterprises to purchase renewable energy power from the selected renewable energy producers.

2.3 Renewables Portfolio Standard (RPS)
The Renewables Portfolio Standard is based on legislation and is mandatory by law[5]. Any company that has not fulfilled the statutory quota obligation will be punished for the purpose of ensuring the realization of renewable energy development goals. The Renewables Portfolio Standard set the renewable energy development goal that should be achieved within a certain period of time. This goal can be either an absolute amount of renewable energy growth or a growth ratio. The purpose is to ensure that renewable energy has a fixed market demand in a certain period of time in the future. Quota obligations can be accomplished through the free trading of green certificates in the market. Green certificate trading facilitates competition among enterprises.

2.4 Tradable green certificates
Renewable energy is not only an ordinary energy source, but also has extra contribution to society, such as protecting the environment and ensuring energy security. The additional contribution of renewable energy is positive externalities in economics, which is a kind of market failure. The solution to positive externalities is to create markets and trigger voluntary transactions in addition to
government subsidies and other policies [6]. The tradable green certificate policy is one of tradable permit policies, which embodies Coase's theory that voluntary property right transactions can eliminate externalities. The voluntary trading of green certificates can internalize the externalities of renewable energy sources and achieve the optimal state of resource allocation. It is worth noting that the price of the green certificate itself does not include the price of renewable energy as an ordinary energy source, and it represents the market's compensation for the positive externalities of renewable energy sources. The tradable green certification policy was promulgated on the basis of the quota system.

3. Design of renewable energy quota trading model suitable for China

According to the present situation of renewable energy in our country, a green certificate trading model of renewable energy source quota system based on bilateral auction is formulated for China. The goal of the model is to maximize market profits under the constraints of government regulatory objectives.

Renewables Portfolio Standard is an overall goal set by regulators. As a participant, power producers must complete the indicators set by regulators, otherwise the regulators will punish them. Transactions between producers are allowed in the form of certificates, which are independent of conventional electricity transactions. The difference between mandatory internet access and quota system is that it can reduce the cost of power generation and promote technological progress by promoting competition among power producers [7]. The characteristic of this approach is that it requires less government regulation to intervene.

Through the above analysis of the quota trading system currently implemented in the worldwide, we can see that factors such as quota target, certificate price ceiling, punishment intensity, certificate limitation, target time limit, technical scope and geographical factors will all have an impact on the effective operation of the quota trading system, there also have many studies. On the basis of the previous discussion, this project builds a profit maximization model of power producers, discusses the influence of factors such as conventional energy power generation cost, renewable energy power generation cost, renewable energy power generation target set by the government, and the upper limit of transaction price of renewable energy power certificate on the renewable energy power output of power producers, and further discusses its influence on the transaction price of certificate market.

In the renewable energy power generation quota trading system, the regulator, that is the government, whose goal is to achieve a certain goal by the percentage of renewable energy power generation in the total power generation in a certain period. Therefore, regulators set targets for the power generation companies and adjust them gradually each year. For power producers, the goal is to maximize profits. Therefore, when manufacturers' own renewable energy power generation costs are too high or their own renewable energy power generation capacity is limited, they will choose to buy renewable energy power from other manufacturers, and this transaction is realized through certificates. The so-called tradable certificate, also known as green certificate, is a cost compensation for manufacturers using renewable energy power generation technology. Each certificate represents 1mw of electricity. In order to achieve the renewable energy and power targets set by regulators, power producers either generate electricity by themselves or purchase renewable energy and power certificates from other power producers. at the end of each year ( or the end of each period ), the certificates need to be submitted to the regulators. the certificates do not have a storage period and expire. If a power company's turnover is less than the government's target, it will be subject to government penalties. Based on the above elaboration, first of all, we will specify the factors involved in the quotas of renewable energy sources and their trading systems:

\[ P_e = \text{Market price of electricity (Yuan/MWh)} \]
\[ x_j = \text{Generator j's non-renewable energy power generation capacity (MWh)} \]
\[ y_j = \text{Generator j's renewable energy power generation capacity (MWh)} \]
\[ z_j = \text{Number of certificates handed over to generators by generator company j (MWh )} \]
\[ X_j = \text{Power producer j's Non-renewable energy power production capacity (MWh)} \]
\[ Y_j = \text{Power producer j’s renewable energy power production capacity (MWh)} \]
\[ P = \text{Price of certificate (Yuan/ Certificate)} \]
\[ P_e = \text{the maximum price of certificates set by regulators (Yuan)} \]
\[ c_j(x_j) = \text{Cost function of non-renewable energy power generation} \]
\[ k_j(y_j) = \text{Cost function of renewable energy power generation} \]
\[ r = \text{Total amount of renewable energy certificate transactions} \]
\[ r_{i\to j} = \text{The amount of certificates purchased by the generator i from j (MWh)} \]
\[ t = \text{Renewable energy power quota targets set by regulators (renewable energy power accounts for percentage of total power generation within each target period)} \]
\[ d_j = \text{Total power demand of generator j (MWh)} \]
\[ d = \text{Total electricity demand} \]

The above factors shall meet the following relations:

1. Electricity output from non-renewable energy sources
   \[ x_j \leq X_j \]

2. Electricity output from renewable energy sources
   \[ y_j \leq Y_j \]

3. The total power demand meet by Power producers
   \[ x_j + y_j = d_j \]

4. Number of certificates handed over to regulators
   \[ z_j = y_j + \sum_{i \neq j} (r_{j\to i} - r_{i\to j}) \geq 0 \]

5. Quota target constraints formulated by regulators
   \[ \sum_{j=1}^{n} z_j = \sum_{j=1}^{n} [y_j + \sum_{i \neq j} (r_{j\to i} - r_{i\to j})] \geq 0 \]

6. Constraints on the supply of manufacturer j’s certificates
   \[ \sum_{j=1}^{n} r_{ij} \leq y_j \]

7. Total demand for electricity
   \[ d = \sum_{j=1}^{n} d_j \]

Single generator \( j \) (\( j = 1, 2, \ldots, n \)) participate in the renewable energy power generation quota trading system, whose profit maximization goal is:

\[ \text{Max} \quad \pi_j \geq 0 \quad (1) \]

\[ \pi_j(x_j, y_j, r_{ij}) = P_e(x_j + y_j) - c_j(x_j) - k_j(y_j) + p_t \sum_{i=1, j \neq i}^{n} r_{i\to j} - p_t \sum_{i=1, j \neq i}^{n} r_{j\to i} \quad (2) \]

The constraints to be met by this profit maximization formula are:

\[ \sum_{j=1}^{n} z_j \geq td \quad (3) \]

Here, we assume that the production cost function \( c_j(x_j) \) is an increasing convex function, it satisfies \( c_j(0) = k_j(0) = 0 \). It also provides that:

\[ c_j(x_j) = \frac{1}{2} c_j \cdot x_j^2 \quad (4) \]
In addition, make \( r_{j\rightarrow j}, r_{j\rightarrow i} = 0 \) and \( \sum_{j=1}^{n} \sum_{i=1}^{n} r_{j\rightarrow i} - r_{i\rightarrow j} = 0 \), that is to say, each power producer is not only the buyer of the certificate, but also the seller of the certificate, and the total supply of the certificate is equal to the total demand. In the renewable energy quota trading system, the price of certificate transaction is influenced by both the supply and demand of certificate, that is, the price mechanism is discussed based on the conditions of market clearing. The price of certificate is an endogenous variable determined by the supply of certificate equal to the demand of certificate, that is, higher demand of certificate will drive the price of certificate to rise. At the same time, the transaction price of certificate is also limited by the upper limit of price stipulated by the government and the capacity of renewable energy power production, that is, the maximum transaction amount of certificate is the maximum renewable energy power generation, and the highest transaction price is the upper limit of price stipulated by the government.

By substituting \( x_j = d_j - y_j > 0 \) and \( y_j = z_j - \sum_{i=1}^{n} (r_{j\rightarrow i} - r_{i\rightarrow j}) \), the formula of profit maximization in the above text can be converted into the following form:

\[
\begin{align*}
\text{Max } \pi_j (z_j, y_j, x_j) &= p_s d_j - c_j (d_j - z_j + \sum_{i=1}^{n} (r_{j\rightarrow i} - r_{i\rightarrow j})) - k_j (z_j - \sum_{i=1}^{n} (r_{j\rightarrow i} - r_{i\rightarrow j})) + p_s \sum_{i=1}^{n} (r_{j\rightarrow i}) - p_i \sum_{i=1}^{n} (r_{i\rightarrow j}) \\
\end{align*}
\]

This profit maximization formula is subject to the following conditions:

\[
\begin{align*}
z_j - \sum_{i=1}^{n} (r_{j\rightarrow i} - r_{i\rightarrow j}) &\geq d_j - X_j \\
z_j - \sum_{i=1}^{n} (r_{j\rightarrow i} - r_{i\rightarrow j}) &\leq \min(Y_j, d_j) \\
\sum_{j=1}^{n} Z_j &\geq t \sum_{j=1}^{n} d_j
\end{align*}
\]

Based on the formula above, we can derive the total profit maximization function under the framework of the whole renewable energy power quota, that is:

\[
\begin{align*}
\text{Max } \pi &= \sum_{j=1}^{n} \pi_j + \lambda (\sum_{j=1}^{n} Z_j - t \sum_{j=1}^{n} d_j)
\end{align*}
\]

Where \( \lambda \) is Lagronia factor, which indicates the shadow price of the constraint condition of government regulation target, that is, the unit penalty price when manufacturers fail to achieve the regulation target, and \( \lambda^* \) indicates the Lagronia factor when the total profit maximization function reaches the optimal value.

4. Conclusion
With analyse of renewable energy transaction types and current situation, this paper constructs a market profit maximization model under the constraints of government objectives. Realizing the
renewable energy power generation goal set by the government is the purpose and constraint of implementing quota trading in the power system. On the premise of completing this constraint condition, the power producers achieve the purpose of maximizing their own profits. Therefore, it is particularly important for government to formulate related supporting policies, which guarantee the markets efficiency and the achievement of power generation goal. An extremely targets level will not be beneficial for the effective operation of the market. The price ceiling regulation will also affect the amount of renewable energy generated by the company and the volume of certificate transactions.

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