Research on Inter-provincial Power Generation Rights: a Case Study of a Province in Eastern China

Cheng Fang¹, *, Ting Pan¹, Xinying He¹, Jiahua Hu², Wen Zhao², Erdong Zhao¹, Ming Zeng¹

¹ North China Electric Power University, Beijing, China
² State Grid Zhejiang Economic Research Institute, Hangzhou, China

*Corresponding author e-mail: 120192206981@ncepu.edu.cn

Abstract. Trans provincial generation rights trading is an effective means to increase the consumption of renewable energy. In this paper, taking a province in East China as the research object, considering the constraints of environmental protection, generator output, transmission line maximum load and other constraints, the inter provincial generation right model is constructed. Finally, through the model, the influence of transmission channel selection and bundling ratio on generation right potential space is analyzed.

1. Introduction
Renewable energy power generation right trading can effectively guide the low energy consumption system with alternative energy power generation, renewable energy generation right trading on the one hand can provide renewable energy units with larger Internet space given to promote renewable energy, on the other hand to reduce the pollutant emissions and high energy consumption unit through market-oriented means to provide a certain amount of economic compensation, the optimization of the power structure in our country and the policy of energy conservation and emissions reduction has a very good role [1-3].

At present, the research of domestic and foreign scholars on the trading of renewable energy power generation rights mainly focuses on the trading model design, mechanism optimization and market bidding strategy. Literature proposed hydropower and thermal power unit to generate power trading, and agent model, the transaction mode of power generation right trading model is divided into easy and total utility model, and compared the two modes, verify the power generation right trading can improve the level of social surplus in the power market, has practical significance[4]. In paper[5], the transaction theory of power generation right based on energy saving and emission reduction is put forward, and the bilateral transaction mode and centralized bidding trading mode of power generation right transaction were studied. The literature adopts the idea of dynamic game, combines the stakeholder theory with the generation right trading model, and divides the authority of the two parties in the generation right trading model, which provides a research idea for solving the information asymmetry problem in the generation right trading [6].

Combined with the existing studies, this paper conducts potential measurement of inter-provincial power generation right trading, and through the construction of inter-provincial power generation right trading model, conducts quantitative measurement of inter-provincial power generation right trading.
potential space, studies the important factors affecting the trading space, and provides theoretical
guidance for the start of inter-provincial power generation right trading market.

2. Basic principles of power generation right trade
The essence of power generation right trade is the redistribution of power generation share among units. In
addition to having the characteristics of a general trade, the following conditions must be met before
the trade can be conducted.
(1) Both parties to the power generation rights transaction need to meet the minimum environmental
protection standards set by the market.
(2) Power generation rights can only be traded on the premise of ensuring system security, and power
generation rights transactions between entities must not harm the security of the power grid.
(3) Power generation right trading parties need to obtain the corresponding income, the transaction
can be motivated.
(4) Power generation rights should be traded in a certain direction to ensure compliance with the
requirements of energy conservation and emission reduction.

3. Research on spatial constraint boundary of interprovincial power generation rights trading potential

3.1. Environmental benefits boundary of power generation rights trading
After the trading of power generation rights, the carbon emission of the entire power system cannot be
higher than before the trading of power generation rights. Therefore, the boundary of environmental
benefits is as follows:

$$\sum_{i=1}^{m} \sum_{j=1}^{n} Q_{ij}(e_i - e_j) \geq 0$$

Where, \(m\) and \(n\) are the total number of units of the transferor and transferee participating in the
power generation right transaction; \(Q_{ij}\) is the transaction quantity of transferred unit \(i\) and accepted
unit \(j\) MWh; \(e_i, e_j\) are carbon emission intensity per unit of unit \(i\) and unit \(j\), t/MWh.

3.2. Economic benefit boundary of power generation rights trading
(1) Economic benefit boundary of power generation right transferor
In the transaction of power generation right, if the opportunity cost is not considered, only if the
profit of the unit of the transferor is greater than 0, can it be motivated to participate in the transaction
of power generation right.
The transaction price of the power generation right transferor shall meet:

$$R_{sell\_i} - P_{ij} > \frac{C_{ij}}{2}$$

Where, \(R_{sell\_i}\) is the local feed-in tariff of the power generation right transferor, yuan /MWh; \(P_{ij}\) is
the power generation rights trading price yuan /MWh; \(C_{ij}\) is the transaction cost of power generation
right, which is Shared equally between the transferor and transferee, yuan /MWh.
Therefore, only when the trading price of generating right is lower than the bottom line of the price,
the trading transferor of generating right can make profits from the trading of generating right.
(2) Economic benefit boundary of the transferee of power generation right
The transaction price should meet the following formula:
Where, \( C_{\text{buy}, j} \) is the KWH cost of the transferee of power generation right, yuan /MWh.

Among them, the KWH cost includes the power generation cost and transaction cost of the transferee of power generation right. The cost of KWH is as follows:

\[
C_{\text{buy}, j} = C_{\text{buy}} + P_r
\]

Where, \( C_{\text{buy}} \) is the unit power generation cost, yuan /MWh, \( P_r \) is the unit transaction cost, yuan /MWh.

3.3. Market boundary of power generation rights trading

Power generation right transaction will not change the existing balance point between supply and demand in the power market:

\[
\sum_{i=1}^{m} \sum_{j=1}^{n} Q_{ij} \leq Q_0
\]

Where, \( Q_0 \) is the original supply and demand balance of the power market (receiving end) with a point of electricity, MWh.

From the perspective of the power generation right transferor, the subject matter of power generation right transaction is the planned electricity quantity already distributed by the transferor, so the power generation right transaction space of the transferor \( i \) should meet the following electricity quantity constraint:

\[
\sum_{j=1}^{n} Q_{ij} \leq Q_{i,0}
\]

Where, \( Q_{i,0} \) is the total amount of electricity allocated by the transferred subject \( i \) at a time, MWh.

3.4. Device load boundary of power generation rights trading

(1) Regional transaction channel constraints

When the power generation right transaction changes the output of the unit, it will change the change of the injected power of the system node and cause the change of the system flow. Therefore, the transaction of power generation rights must be restrained to ensure the safe and stable operation of the system. Therefore, the power constraint of the transmission line is:

\[
P_{ij,\text{min}} \leq P_{ij} \leq P_{ij,\text{max}}
\]

Where, \( P_{ij,\text{max}} \), \( P_{ij,\text{min}} \) is the maximum and minimum power limit of \( ij \) inter-branch transmission.

(2) Unit active power output constraints

When the unit's climbing speed is ignored and the unit's active power is adjusted, only the maximum power limit \( P_{iG,\text{max}} \) and the minimum power limit \( P_{iG,\text{min}} \) of the unit are considered. Where, \( P_{iG,\text{max}} \) take the unit's active power output rating, \( P_{iG,\text{min}} \) is determined by the generator set technical requirements. The safety constraint of the unit's active power output is:

\[
P_{iG,\text{min}} \leq P_{iG} + \Delta P_{iG} \leq P_{iG,\text{max}}
\]

4. Empirical study on the potential of inter-province power generation rights trading

Taking the transaction of power generation rights in northwest power grid of a province in east China as an example, the relevant data are taken from the historical data of this province in 2018, and the specific setting is as follows.
4.1. Scenario simulation

(1) The basic setting of the trading party of power generation right

1) The trading volume can be set by the transferor. Based on the annual utilization hours of units of various capacity levels in the province, and combined with the information of the thermal power plant, the upper limit of the total amount of tradable electricity of the transferor can be calculated. The Annual generating capacity of coal-fired units below 300MW, 300MW, 600MW, and 1000MW is 973.21*10^5 MWh, 1159.66*10^5 MWh, 713.93*10^5 MWh and 125.16*10^5 MWh.

2) Power consumption parameters of the unit. When considering the opportunity cost, the difference between the KWH cost of the transferor of power generation right and the cost of the trading of power generation right is the economic benefit space for the transferor to participate in the inter-provincial trading of power generation right. Therefore, KWH cost is an important basis for the quotation of the transferee. In addition, there is an important relationship between KWH cost and unit capacity and operation level, so the average coal consumption parameters of coal-fired units of each capacity level are sorted out to calculate KWH cost. The average coal consumption of coal-fired units below 300MW, 300MW, 600MW, and 1000MW is 337.13 g/kWh, 312.88 g/kWh, 300.49 g/kWh and 285.31 g/kWh.

3) Relevant parameter setting. Coal-fired unit price is 560 Yuan/t, the ratio of the cost of coal in the cost of electricity is 70%, the trading commissions is 0.5 Yuan/MWh, benchmark price is 391 Yuan/MWh.

(2) Basic setting of transferee for power generation right transaction

1) Installation of renewable energy units and data of electric quantity of wind, solar and hydro curtailment. The water and light abandoning power of the power generation right transferee province is the upper limit of power generation right transferee. In 2018, the Northwest Power Grid's "Three abandonment" power are 214.52*10^5 MWh

2) Cross-provincial and cross-regional transaction scenario and data setting. At the present stage, the construction of interregional channels in China's regional power grid is as follows, transaction channel fees are shown in attached table 1.

**Table 1.** Transmission province and Jiangsu power generation right transaction channel fees

| Transferee Item | Electricity price including line loss (Yuan/MWh) | Transferor |
|-----------------|--------------------------------------------------|------------|
| Provinces of transmission termial | | |
| Transferee province | Transmission cost of the province | 30 | Transferee province |
| | Transmission cost across provinces | 20 | Transferee province |
| | Lingshao dc transmission cost | 71.4 | East China power grid |
| | Jiquan dc transmission cost | 82.9 | East China power grid |
| | Tianzhong dc transmission cost | 65.8 | Central China power grid |
| | Lingbao dc transmission cost | 42.6 | Central China power grid |
| | transmission cost across provinces | 10 | Central China power grid |
| | Ge nan dc transmission cost | 60.0 | Central China power grid |
| | Longzheng dc transmission cost | 74.0 | East China power grid |
| | Yihua dc transmission cost | 74.0 | East China power grid |
| | Lin feng dc transmission cost | 47.1 | East China power grid |
| Central China power grid | Transmission cost across provinces | 10 | Jiangsu |
| East China power grid | | |

4
3) Other related parameter setting.

Average coal consumption of thermal power is 0.31 t/MWh, Electricity-coal price of transferee province is 460 Yuan/t, the ratio of the cost of coal in the cost of electricity is 70%, The trading commissions is 0.5 Yuan/MWh.

(3) Basic setting of power generation rights trading market

1) Setting 1: The timing sequence of the transaction in the potential calculation stage is set as "the province can give priority to the replacement of fossil fuels for fossil fuels, next to the replacement of fossil fuels by interprovincial renewable energy, and last to the replacement of fossil fuels with efficient fossil fuels for inefficient fossil fuels".

2) Setting 2: The high-low matching mechanism is adopted in the power generation right trading market.

(4) Setting of influencing factors of power generation right transaction

1) Transmission line selection. Spanned across the province electricity trade fair, in transmission between provinces, due to the transmission distance is far, besides can produce larger line loss also will be sent by the province for trading main body in the geographical position is different to the provincial power grid companies need trading main body and regional power grid companies to deliver a certain transmission cost, this part of the line loss and transmission cost accounting will serve as a transaction costs as ground electricity price in the end, thus affect the power generation rights of licensor economic boundary, will affect the potential of the power generation right trading between province space. The transmission cost of inter-provincial power generation right can be expressed as:

\[ P_{tr} = P_{tr,buy} + P_{tr,t1} + P_{tr,t2} + P_{tr,sell} \]  

(9)

Where, \( P_{tr,buy} \) is the price of power transmission sent out by the transferee of power generation right, yuan /MWh; \( P_{tr,t1} \) is the inter-provincial transmission price of power generation right transferee, yuan /MWh; \( P_{tr,t2} \) is the transmission price of trans-regional power transmission project, yuan /MWh; \( P_{tr,sell} \) is the inter-provincial transmission price of power generation right transferee, yuan /MWh.

2) Binding ratio setting. Unit of electricity transaction costs are as follows:

\[ C_{buy} = (1 - \sum_{j=1}^{n} b_j) \cdot C_{buy,coat} + \sum_{j=1}^{n} b_j C_{re,j} + P_{tr} \]  

(10)

Where, \( C_{buy} \) is the cost of unit electricity after bundling, yuan /MWh; \( b_j \) is the baling ratio of thermal power and j renewable energy; \( C_{buy,coat} \) is the variable cost of KWH production of thermal power units at the place where the power right transferor is located, yuan /MWh; \( C_{re,j} \) is the variable cost of KWH generation of the JTH renewable energy of the power right transferor, yuan /MWh.

4.2. Results and analysis

According to the scenario set out above, according to the constraint boundary in chapter 3, the quotation limit and declared electricity limit of the power generation right transferee and transferee participating in the power generation right transaction are calculated. The results are shown in table 2.
Table 2. Results of potential trading space of power generation right under the guarantee mechanism of renewable energy power consumption.

| line            | Baling ratio | Inter-provincial transaction power (10^8MWh) | Provincial transaction power (10^8MWh) | Considering opportunity cost Inter-provincial transaction power (10^8MWh) | Provincial transaction power (10^8MWh) |
|-----------------|--------------|---------------------------------------------|---------------------------------------|-----------------------------------------------------------------------|---------------------------------------|
| Tianzhong - Genan | 1.5:1        | 357.5                                       | 603                                   | 0                                                                     | 839.1                                 |
|                 | 1:1          | 429                                         | 603                                   | 0                                                                     | 839.1                                 |
|                 | 1:1.5        | 536.3                                       | 603                                   | 0                                                                     | 839.1                                 |
|                 | 1:2          | 650                                         | 603                                   | 0                                                                     | 839.1                                 |
| Tianzhong - Longzheng/Yihua | 1.5:1.       | 357.5                                       | 603                                   | 0                                                                     | 839.1                                 |
|                 | 1:1          | 429                                         | 603                                   | 0                                                                     | 839.1                                 |
|                 | 1:1.5        | 536.3                                       | 603                                   | 0                                                                     | 839.1                                 |
|                 | 1:2          | 650                                         | 603                                   | 0                                                                     | 839.1                                 |
| Tianzhong - Linfeng | 1.5:1.       | 357.5                                       | 603                                   | 125                                                                   | 713.9                                 |
|                 | 1:1          | 429                                         | 603                                   | 0                                                                     | 839.1                                 |
|                 | 1:1.5        | 536.3                                       | 603                                   | 0                                                                     | 839.1                                 |
|                 | 1:2          | 650                                         | 603                                   | 0                                                                     | 839.1                                 |
| Lingbao - Genan | 1.5:1.       | 357.5                                       | 603                                   | 125                                                                   | 713.9                                 |
|                 | 1:1          | 429                                         | 603                                   | 0                                                                     | 839.1                                 |
|                 | 1:1.5        | 536.3                                       | 603                                   | 0                                                                     | 839.1                                 |
|                 | 1:2          | 650                                         | 603                                   | 0                                                                     | 839.1                                 |
| Lingbao - Longzheng/Yihua | 1.5:1.       | 357.5                                       | 603                                   | 125                                                                   | 713.9                                 |
|                 | 1:1          | 429                                         | 603                                   | 0                                                                     | 839.1                                 |
|                 | 1:1.5        | 536.3                                       | 603                                   | 0                                                                     | 839.1                                 |
|                 | 1:2          | 650                                         | 603                                   | 0                                                                     | 839.1                                 |
| Lingbao - Linfeng | 1.5:1.       | 357.5                                       | 603                                   | 360                                                                   | 603                                   |
|                 | 1:1          | 429                                         | 603                                   | 125                                                                   | 713.9                                 |
|                 | 1:1.5        | 536.3                                       | 603                                   | 0                                                                     | 839.1                                 |
|                 | 1:2          | 650                                         | 603                                   | 0                                                                     | 839.1                                 |
| Lingshao dc     | 1.5:1        | 357.5.5                                     | 603                                   | 357.5                                                                 | 603                                   |
|                 | 1:1          | 429                                         | 603                                   | 429                                                                   | 603                                   |
|                 | 1:1.5        | 536.3                                       | 603                                   | 125.16                                                                | 713.94                                |
|                 | 1:2          | 650                                         | 603                                   | 0                                                                     | 839.1                                 |
| Jiquan dc       | 1.5:1        | 357.5.5                                     | 603                                   | 357.5                                                                 | 603                                   |
|                 | 1:1          | 429                                         | 603                                   | 125.16                                                                | 713.94                                |
|                 | 1:1.5        | 536.3                                       | 603                                   | 0                                                                     | 839.1                                 |
|                 | 1:2          | 650                                         | 603                                   | 0                                                                     | 839.1                                 |

The effects of baling ratio and channel scheme on the transaction benefits of power generation rights are shown in Figure 1:

![Fig. 1 Influence of different baling ratio and transmission channel on transaction price difference](image-url)
As can be seen from the above figure, when the baling ratio is fixed, different channel selection schemes have a significant impact on the economic benefits of power generation right transaction, among which the maximum benefit difference between different schemes can reach 30 yuan /MWh. When the channel selection scheme is fixed, the price difference of power generation right transaction will decrease with the increase of the ratio of thermal baling.

Set in accordance with the high and low power generation right transaction matching mechanism, follow the "raw energy alternative thermal power is preferred, can be in the province between renewable energy instead of thermal power, efficient thermal power in the province to replace inefficient thermal power finally" transactions timing, power of the thermal power unit of Jiangsu province in accordance with the acceptable by descending order (kWH) cost, transfer price between the province and the thermal power unit in the province would be acceptable to the transeree of electricity (transaction costs) ascending order, the intersection of two line for the balance of supply and demand, namely power generation right trading market potential, is calculated under different transmission channel scheme and the ratio of baling northwest power grid and power generation in Jiangsu province trading potential results as shown in figure 2 and figure 3.

![Graph 2](image2.png)  
**Fig. 2** Potential trading space of power generation rights between provinces excluding opportunity cost.

![Graph 3](image3.png)  
**Fig. 3** Consider the potential trading space of inter-provincial power generation rights with opportunity cost.
5. Conclusion
This paper mainly calculates the potential space of inter-provincial power generation rights trading, and first defines the basic principles of power generation rights trading. Secondly, the factors influencing the transaction of power generation right are analyzed from the two dimensions of standard power generation right transaction and inter-provincial power generation right transaction. Finally, the market potential of interprovincial power generation right transaction between Jiangsu province and northwest power grid is evaluated through a case study. The result of the example shows that there is a huge market space for inter-provincial power generation right transaction in Jiangsu province, and the ratio of transmission channel and renewable energy bundle is an important factor affecting inter-provincial power generation right transaction space.

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