Energy Engineering

Tech Science Press

DOI: 10.32604/EE.2021.014258

ARTICLE

Behaviours of Multi-Stakeholders under China's Renewable Portfolio Standards: A Game Theory-Based Analysis

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Received: 14 September 2020 Accepted: 11 January 2021

ABSTRACT

China has implemented both quantitative and policy incentives for renewable energy development since 2019 and is currently in the policy transition stage. The implementation of renewable portfolio standards (RPSs) is difficult due to the interests of multiple stakeholders, including power generation enterprises, power grid companies, power users, local governments, and the central government. Based on China's RPS policy and power system reform documents, this research sorted out the core game decision problems of China's renewable energy industry and established a conceptual game decision model of the renewable energy industry from the perspective of local governments, power generation enterprises and power grid companies. The results reveal that for local governments, the probability of meeting the earnings quota or punishments for not reaching quota completion are the major determinants for active participation in quota supervision. For power grid firms, the willingness to accept renewable electricity quotas depends on the additional cost of receiving renewable electricity and governmental incentives. It is reasonable, from the theoretical perspective, to implement the RPS policy on the power generation side. Electricity reform will help clarify the electricity price system and increase the transparency of the quota implementation process. Policy implications are suggested to achieve sustainable development of the renewable energy industry from price incentives and quantity delivery.

KEYWORDS

Renewable portfolio standards; power systems reform; game theory; stakeholder engagement; reward and punishment mechanism

1 Introduction

1.1 Development of China's Renewable Energy Industry

It is widely acknowledged that energy security, environmental protection and climate change are global challenges of international concern. Renewable energy development is an efficient measure to address these threats worldwide. First, with the continuous development of the economy and society, electric power will be increasingly in demand in daily life. The newly emerging source of electricity generation is mostly renewable energy. According to data from the International Renewable Energy Development Agency (IRENA), the global installed capacity of renewable energy in 2019 totalled 2.53 billion kilowatts [1], with 789 and

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284 million kilowatts from China and the United States, respectively [2]. China generated 1.84 trillion kilowatt-hours of electricity from renewable sources in 2018, ranking first in the world [2]. The renewable energy industry will still be prosperous in the future.

However, the imperfect policy framework of China's power market requires further improvements to be able to support the sustainable development of the renewable energy industry. With the medium-speed growth of China's economy in the new normal period and intensive environmental management, the Chinese renewable energy industry has transited from scale development to a wide range of incremental replacement and regional stock replacement stages. According to the 13th five-year plan for renewable energy development, China's commercial renewable energy consumption was 436 million tons of standard coal in 2015, accounting for 10.1% of the total primary energy consumption, and planned to be over 580 million tons of standard coal in 2020 [3]. With the rapid development of renewable energy, the electricity supply should not only be safe and economical but also environmentally-friendly and low-carbon. By the end of 2019, China's installed capacity of renewable energy power generation was 794 million kW, accounting for 39.5% of the total installed power generation capacity, while China's renewable energy generation was 2.04 trillion kWh, accounting for 27.9% of the total power generation [4].

Behind prosperous development, China's renewable energy industry has the following problems. First, the existing power operation mechanism does not meet the needs of the large-scale development of renewable energy. The fossil fuel-based traditional power system cannot fully meet the requirements of grid-connected operations of fluctuating renewable energy sources. There are still technical barriers to the large-scale grid connection of renewable electricity generation, and it is difficult to effectively implement the policy of fully purchasing renewable energy power. Second, the renewable energy industry is still dependent on policy incentives. It is necessary to further reduce the cost of power generation by promoting technological progress and establishing an efficient market competition mechanism. Third, stakeholders in the renewable energy industry have different interest demands, which restrict the sustainable development of the renewable energy industry. Apart from the high increase rate of installed renewable energy capacity, the utilization rate is relatively low because of the unclear responsibilities and obligations among the relevant stakeholders and the absence of a renewable electricity transmission channel grid. Therefore, stakeholder engagement is significant for the success of renewable energy engineering projects.

Renewable energy development requires joint teamwork with the participation of the central government, local government, power generation enterprises, power grid enterprises and electricity consumers. The implementation of renewable portfolio standards (RPS) is an effective approach to achieve quota targets for all provinces and power grid enterprises through mandatory policies. Fig. 1 shows regional renewable energy development goals for all provinces in 2020. In 2019, renewable energy power consumption was 1.99 trillion kilowatt-hours, accounting for 27.5% of the electricity consumption of all of China. Eight provinces (regions) receive more than 40% of their total electricity consumption from renewable energy sources, among which Tibet, Yunnan, Qinghai and Sichuan account for more than 80%. Fig. 2 shows the current situation of China's regional renewable energy power generation in 2019 [4].

The national renewable energy development system determines the overall trend of renewable energy, so the attitude of system makers to renewable energy development is very important to the implementation of the RPS. The national system urges the central government to vigorously promote the development of renewable energy. Second, the enthusiasm of power generation enterprises has played a fundamental role in the development of renewable energy because the final power generation responsibility still needs to be implemented by specific power generation enterprises. The collaborative participation of local governments and power grid enterprises will add wings to the implementation of renewable energy policy, which is also the key to the development of renewable energy.

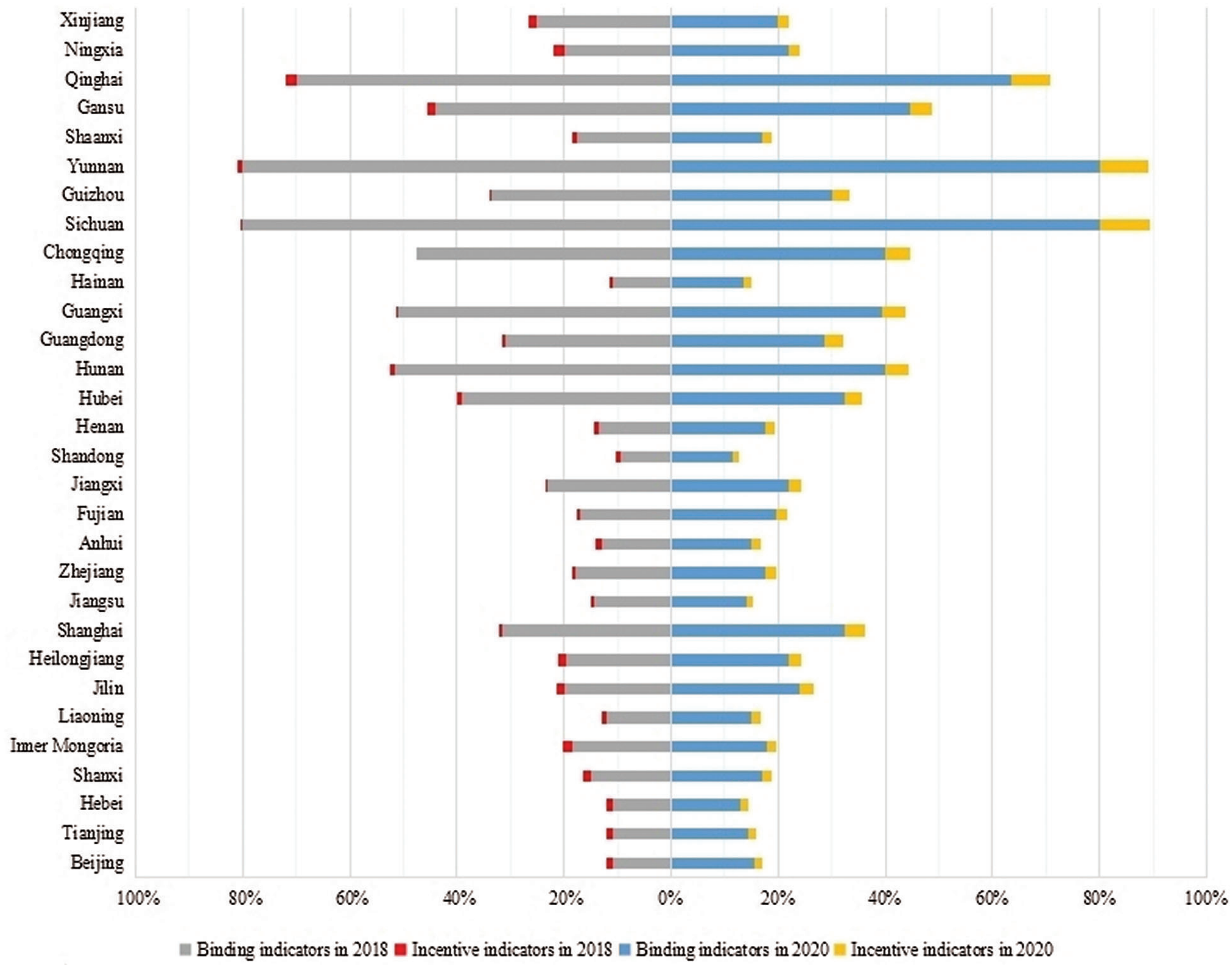

Figure 1: Regional renewable energy development goals for all provinces in 2020

In the future, public support for renewable energy development will have an important impact on RPS policy and even the whole renewable energy industry. Responsibility sharing and a system of rewards and punishments should be mandatory and flexible, and both incentives and punishments should be emphasized. The RPS policy needs to subdivide responsibility sharing. Especially when the central government issues regional quota targets, the local government should be responsible for detailed rules to measure the contributions of each participant within the policy framework. China has already polished numerous incentives for renewable energy development, such as feed-in tariff prices, auction electricity prices, fiscal subsidies, tax preferences and other policies [5]. Building the national carbon market and electricity system reform are also positive boons for further growth of the renewable energy industry. Therefore, it is necessary to assess the impacts of these incentives on the behaviours of stakeholders in the renewable energy market.

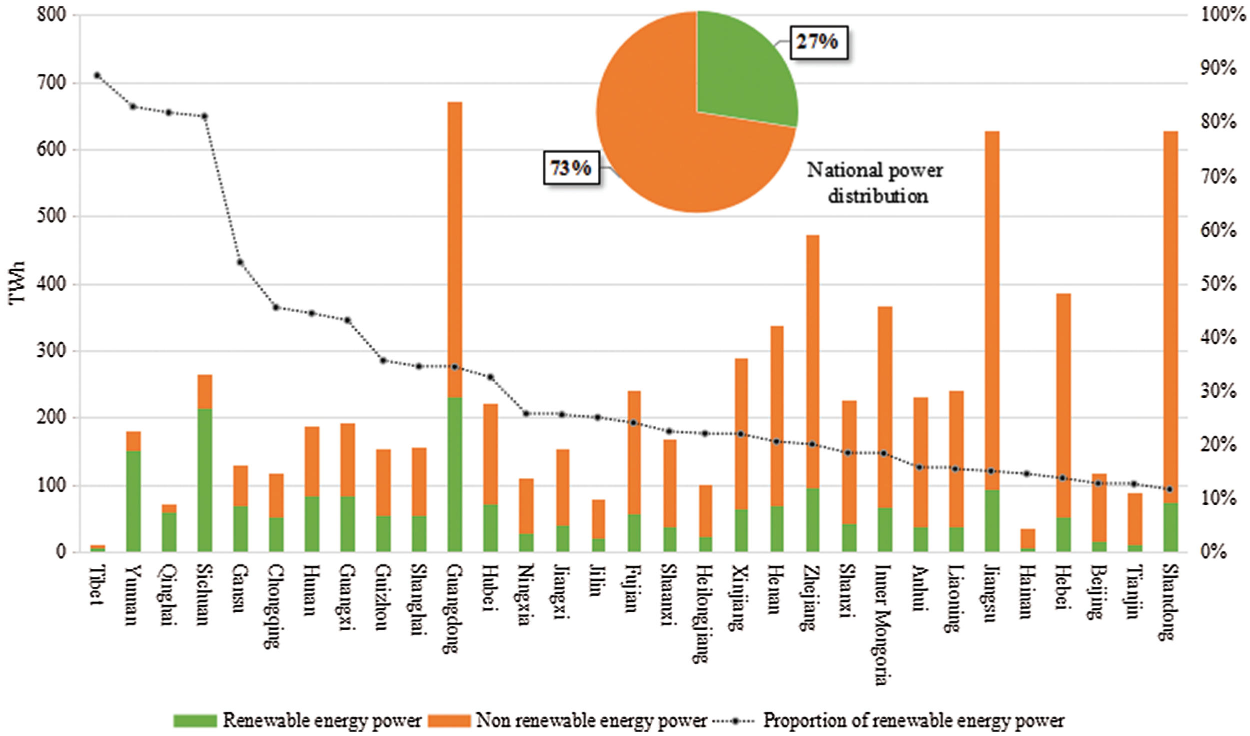

Figure 2: Current situation of China's regional renewable energy power generation in 2019

1.2 Literature Review

(1) The multi-Stakeholders' behaviours under RPS

Fan et al. based on the newly proposed provincial RPS for 2020, an integrated planning model composed of a multi-regression model and linear planning model was established to optimize the RE power installation plan for each province in 2020, it alleviates the waste of renewable energy and promotes the efficient utilization of renewable energy in China [6]. Zhang et al. used system dynamics (SD) to established models of long-term development of the renewable energy power industry under FIT and RPS schemes, and provided a case study of China's wind power industry by using scenario analysis method. The results show that the integrate implementation of FIT and RPS can promote long-term and rapid development of China's wind power industry given the constraints and actions of the mechanisms of RPS quota proportion, the tradable green certificates (TGCs) valid period, and fines [7]. Zhao et al. constructs an equilibrium model of power market under the overlapping regulation of carbon tax policy and RPS, studies the influence of RPS and carbon tax policy on the power market. The results show that the overlapping regulation can help to increase the proportion of renewable energy generation production in the power market and optimize the power supply structure [8]. Zhu et al. based on the background of Chinese renewable power industry, the scenario analysis method is employed to investigate the impacts of key parameters in relation with RPS scheme on stakeholders' strategy selections. The results show that, to basically ensure all the power sales companies comply with quota obligation, TGC price of different stages should maintain at desired levels, net profit of renewable power sales should be no less than that of conventional power sales, and incentive and punishment should be within a reasonable range [9].

(2) Multi-Stakeholders' behaviours under RPS by using game theory

Many previous studies used game model, Zhao et al. developed an evolution game model of power producers to analyze the symbiotic evolution between RPS and the electric producers' behaviour strategies, trading TGC could become the common belief of all power producers, with the scientific design of institutional parameters [10]. Zuo et al. applied evolutionary game theory and system dynamics (SD) model to examined electricity producers' strategies in this scheme context. The results show that, to ensure all the electricity producers willing to trade TGC, scheme parameters (subsidy, quota, and fine) should be within a reasonable range. Moreover, the stage descent mode of subsidy and higher level of fine will help the electricity producers accept the RPS scheme [11]. Fang et al. established an evolutionary game model of renewable power generation and transmission from the perspective of bounded rationality and multi-agents' game to analyze the necessity and effectiveness of strengthening relevant government regulation [12]. Feng et al. established an evolutionary game model of renewable power generation and transmission from the perspective of bounded rationality and a multi-agents' game [13]. Fang et al. studied the expected effect of the under-enforcement of RPS standards using an evolutionary approach, and created a regulatory evolutionary game model of RPS between the regulators and types of power companies based on cost structures. It shows that a dynamic subsidy and punishment mechanism not only helps achieve a better regulatory effect than a static mechanism, but also restrains the evolutionary oscillation [14].

Most of the previous studies used game model to study and analyze power generation companies, but few studies analyzed other stakeholders. This paper mainly analyzes the game and decision-making behaviour of various stakeholders under RPS, discusses the collaborative relationship between the quota system and the existing renewable energy incentive policies, and conducts an internal economic analysis of mechanism coordination, and the main research conclusions and implications are summarized.

1.3 The Aim of This Research

China's renewable energy development in the past 15 years has educated us that feed-in tariffs and other policies have promoted the expansion of the renewable energy market. Compared with other energy technologies, the competitiveness of renewable energy technologies is gradually increasing, but there is still a large gap between them [15]. In addition, large-scale development and the lag of power grid construction lead to hydropower, wind power and solar power abandonment problems, which have become the major obstacle to the sustainable development of China's renewable energy industry [16]. Compared with the mature TGC market abroad, China's TGC market is still in the cultivation period [17]. In addition, by October 02, 2020, the total number of TGCs issued was 27,502,207, and the total trading volume was 38,997, accounting for 0.142%. Among them, the total trading volume of wind power green certificates was only 0.141% and that of photovoltaic green certificates was only 0.001%. Therefore, it can be seen that the demand side lacks consumption momentum, the purchase demand for TGC is insufficient, the TGC market has a phenomenon of oversupply, overproduction and low market liquidity, and the market is in an inefficient state [17]. Therefore, the next step of China's renewable energy development focuses on the renewable electricity consumption side and the regulation of the responsibility sharing mechanism.

Based on the above literature review, the analysis of the game decision-making behaviours of various stakeholders in the RPS and the possible mobilization of the whole society to participate in renewable energy development can provide a basis for the success of a national RPS policy. Therefore, this research establishes a game decision model for analysing stakeholders' behaviours under RPS policy and finds the key factors that influence stakeholders' decisions. With the actual parameters, the modelling results would be meaningful to formulate the incentives and punishments for finishing renewable energy targets and to discuss the synergies between RPSs and existing renewable energy policies. Additionally, it is necessary to analyse the game behaviour of each participant and understand the demands of each interest group and the key factors affecting their participation in the RPS policy. This paper mainly focuses on the following three issues.

1. With the background of China's power system reform, how could this research simulate game behaviours under the framework of China's RPS?
2. Under the quota system, what are the driving factors for the game behaviour of each agent of interest?
3. What are the possible impacts of the ongoing power market reform on the game process?

2 Methodologies

2.1 Stakeholders in RPS

As a new policy to promote renewable energy development in China, the success of RPS implementation should consider all-in participation from agents of relevant interest. The evolutionary game and decision analyses in this context are policy regime issues from the view of the game body, game payoff and game circumstance. Fig. 3 denotes the theoretical framework for stakeholders' decisions under RPS policy and feed-in tariffs (FITs). The possible behaviours for different agents are analysed as follows. The evolutionary game theory is introduced because it is suitable for modelling the dynamic behaviour changes in the process of renewable electricity generation and consumption.

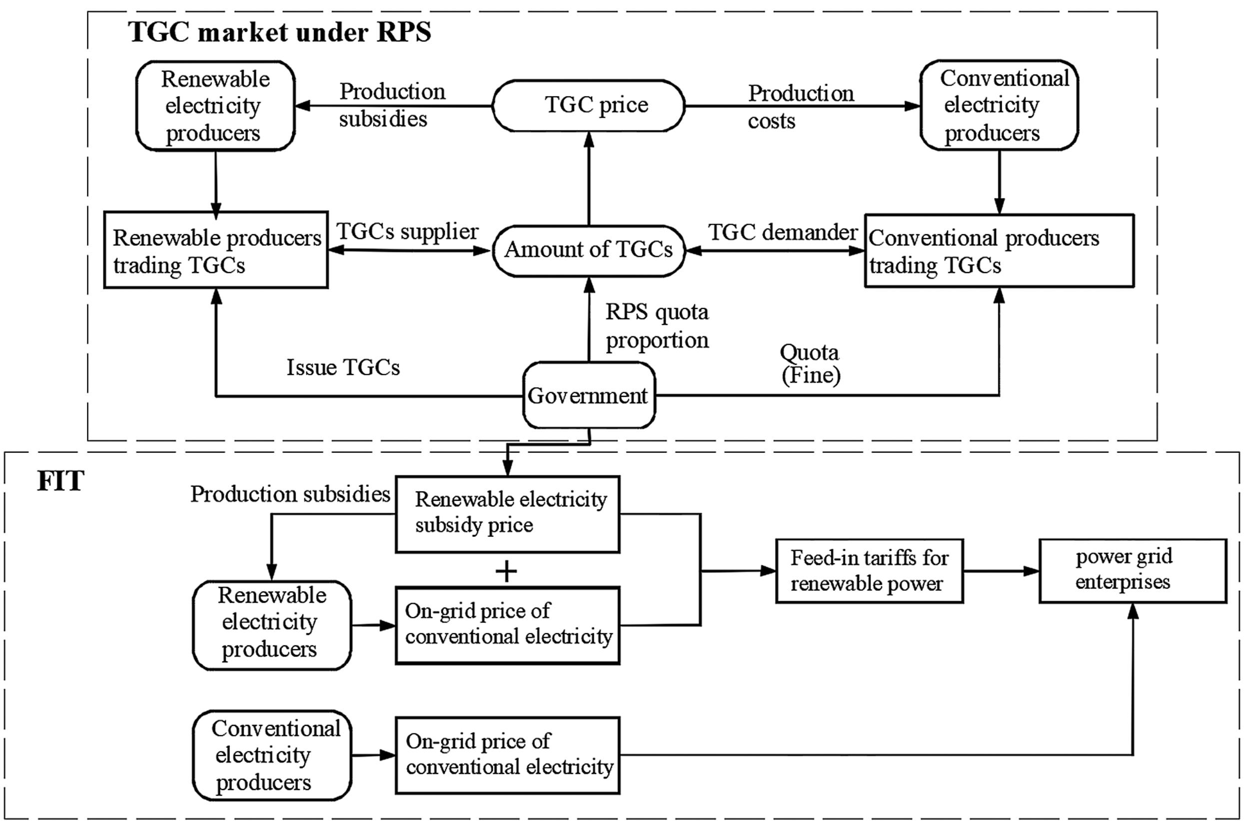

Figure 3: Theoretical framework for multi-agent decision analysis under different policy regimes

Power generation enterprises are responsible for the obligations of renewable power generation, but there are also competitive relationships among the power generation enterprises [18]. First, different renewable energy technologies used by power generation enterprises will lead to differences in renewable electricity production costs. Second, the entrance of renewable energy power generation companies at different times determines the existence of first-mover advantages and scale effects, which will also lead to differences in their respective competitiveness.

Power grids are central for the achievement of renewable quotas due to their significance in the purchase, transmission, dispatching, distribution and sale of electricity. Renewable energy consumption, therefore, depends largely on the support of the power grid [19]. When there is little difference between the benefits of renewable energy power transmission and traditional power, the power grid has a relatively strong willingness to transmit renewable electricity [20]. In addition, the grid needs a certain amount of additional market capacity to deal with the fluctuations of renewable energy power when dispatching renewable electricity. Grid companies thus play a key role in the implementation of the RPS scheme [21].

The government has the primary obligation to plan, manage and supervise the implementation of RPSs. At the local level, local governments are specifically responsible for the supervision and management of renewable energy procurement [22], and they are also supervised and evaluated by the central government. Local governments also have the ability to coordinate with local power grids. Therefore, the implementation of the regional quota system is completed under the supervision of local governments, which also plays a connecting role in the completion of the quota system.

Consumers of electricity accept renewable electricity consumption. However, the general public on the electricity demand side cannot freely choose power services [23]. This research does not analyse the game behaviour of power users separately. The central government is the top decision-maker of the quota system, and its behaviours are not included in this research due to its role in setting the rules.

The key determinant of the game decision of each interest group under the RPS policy lies in the cost and benefit mechanism in the process of completing the RPSs [24]. Specifically, it is important for power generation enterprises to determine whether and what they could obtain from renewable energy generation and whether their renewable electricity generation could be fully accessed through the grid. For power grid enterprises, it is essential to facilitate their willingness to transmit renewable electricity economically and efficiently. As macroscopic policymakers and industry regulators, local governments should actively participate in the implementation of RPSs. All decisions in the RPS process have a reference or information set for stakeholders, which is the traditional fossil-fuel electricity generation [25].

2.2 Conceptual Framework for Modelling Local Governments' Willingness to Participate in RPS

As electricity has the property of public goods, the consumption of renewable energy electricity requires the supervision of local government. The absence of supervision may lead to a lower willingness of power grid enterprises to accept renewable electricity [18]. Therefore, governmental participation is necessary to supervise the implementation of RPS effectively.

A cost-benefit analysis will be a key consideration in government regulation of RPS. The probability of government regulation (or the degree of regulation) is influenced by the cost of regulation (or the penalty in case of noncompliance) and the probability of quota completion. The government's participation in RPS implementation will expense certain management costs, including expenditures in the process of task design, supervision and assessment [22]. With intensive attention to climate change and environmental protection, government regulation can also increase the public's trust in the government and enhance the reputation of its actions.

If indicator $n > t$ in Tab. 1, it demonstrates that in the case of compliance, the additional benefits obtained by government regulation are greater than the recoverable economic gains obtained by government regulation from noncompliance. Tab. 1 demonstrates the parameters of the game model for the progress of local government regulation. Therefore, the gains and losses from local government regulation in different scenarios are shown by the avails matrix in Tab. 2.

Table 1: Parameters for local government's supervision in RPS

Indicator	Parameters
Probability of not reaching renewable quotas for local government	x
Probability of reaching renewable quotas for local government	$1-x$
Probability of local government's participation in RPS	y
Probability of local government's no participation in RPS	$1-y$
Costs for local government to supervise RPS	m
Reputation benefits of local government in RPS supervision	c
Recoverable gains by supervision when non-compliance	t
Punishments for local government when non-compliance	p
Extra benefits for local government when finish RPS targets	n

Table 2: Avails matrix for game decisions of local government in RPS

	Participation y	No participation $(1-y)$
Compliance $(1-x)$	$-m+c+n$	0
Non-compliance x	$-m+c+t-p$	$-c-p$

According to Tab. 2, the expected utility function of the local government can be shown in Eq. (1).

$$U(y,\ 1-y) = x \cdot [y \cdot (-m+c+t-p) + (1-y) \cdot (-c-p)] + (1-x) \cdot [y \cdot (-m+c+n) + (1-y) \cdot 0] \quad (1)$$

The correlation between the above utility and regulatory probability is discussed by the derivative for Eq. (1). The derivative result is shown in Eq. (2).

$$\partial U/\partial y = n \cdot (1-x) + c - m + (c+t) \cdot x \quad (2)$$

Therefore, when $n > \frac{m-c-(c+t)x}{(1-x)}$, $\partial U/\partial y > 0$. That is, there is a positive correlation between the expected utility of government participation and the probability of government regulation. In other words, when the additional benefits of the government from compliance with RPSs exceed a certain value, local governments tend to actively participate in completing RPSs. In contrast, the probability of supervision by local governments is reduced or they do not participate at all in quota management.

2.3 Impacts of Electricity System Reform on the Actions of the Power Grid Renewable Electricity Penetration

The game behaviour of power grid enterprises under RPS is based on the fact that renewable sources are intermittent for electricity generation, and the grid needs to pay extra costs in the process of renewable electricity access. Therefore, the grid connection of renewable electricity is more difficult than that of traditional power [26,27]. A conflict of interest is to balance the profit of the power grid enterprise and the responsibility of the power grid enterprise for renewable electricity access to the grid.

Power system reform would have an influence on the power grid game-decision process under the quota system. The first power reform in 2002 suggested the establishment of five major tasks. The power supply chain has achieved the separation of governmental function and enterprise economic performance, the separation of power plants and power grids, and the separation of primary businesses and subsidiary businesses [28]. The new reform in 2015 was designed for the separation of transmission and distribution and bidding for the power grid.

The most important task is the price adjustment and new settlement mechanism of power transmission and distribution. The electricity price includes the on-grid price (purchase price), transmission and distribution price, sales price, etc. After the electric power reform, the profit of the power grid may change from the difference between the purchase price and sale price of electricity to a price that includes operating costs and a reasonable profit. Therefore, the power grid will transition from the former profit-making unit to the public utility unit with a certain profit margin and only charge the transmission and distribution electricity price approved by the government, that is, the 'electricity toll price'. Based on the above analysis, this section establishes a power grid decision-making model under the quota system. The model assumes that the power transmission cost function of power grid enterprises is a linear function, and the model parameters are shown in Tab. 3.

Table 3: Decision-making model parameters of power grid and power generation enterprises

Indicators	Parameters
Electricity terminal sales price	P_c
Electricity transmission and distribution price	P_m
On-grid price of conventional electricity	P_e
Renewable electricity subsidy price	P_r
Feed-in tariffs for renewable power	$P_e + P_r$
Non-renewable electricity of power producer j	x_j
Renewable electricity of power producer j	y_j
The upper limit of non-renewable electricity production of electricity producer j	X_j
The upper limit of renewable electricity production of electricity producer j	Y_j
Non-renewable electricity production cost function of power producer j	$C_j(x_j)$
Renewable electricity production cost function of power producer j	$K_j(x_j)$
Quota proportion	t
Electricity supply from producer j	d_j
Power transmission cost of traditional power grid enterprises	$H(x)$
Additional cost of renewable power transmission in power grid enterprises	$F(y)$
Penalty function of incomplete quota system of power producer j from grid	$R_j(y_j)$

(1) Before the power reform, the profit price of the power grid is equal to the difference between the purchase price and sale price of electricity; that is, the difference between the grid price and the sale price is equal to $p_c - p_\varepsilon$ or $p_c - p_\varepsilon - p_r$. The income function of power grid enterprises is shown as follows:

$$\max \sum_{j=1}^{n} v_j(x_j,\ y_j)$$

where,

$$v_j(x_j,\ y_j) = (P_c - P_\varepsilon) \cdot x_j + (P_c - P_\varepsilon - P_r) \cdot y_j - H(x_j + y_j) - F(y_j) \tag{3}$$

According to the assumption that the power transmission cost function of power grid enterprises is a linear function, Eq. (2) can be described as follows:

$$\begin{aligned}\max v_j(x_j,\ y_j) &= (P_c - P_\varepsilon)\cdot x_j + (P_c - P_\varepsilon - P_r)\cdot y_j - H(x_j + y_j) - F(y_j)\\ &= (P_c - P_\varepsilon)\cdot x_j + (P_c - P_\varepsilon - P_r)\cdot y_j - a\cdot(x_j + y_j) - b\cdot y_j\\ &= (P_c - P_\varepsilon - a)\cdot x_j + (P_c - P_\varepsilon - P_r - a - b)\cdot y_j \end{aligned} \tag{4}$$

In Eq. (4), under the traditional electricity pricing mechanism, only if $P_c - P_\varepsilon - P_r - a - b > 0$, power grid enterprises will accept renewable energy power. If there is no policy incentive or public demand for clean power, grid enterprises have strong economic conditionality to actively access renewable energy electricity.

(2) Following the power reform, the profit price of the power grid is equal to the transmission and distribution cost and a reasonable profit. The government will be responsible for checking the operation cost of the power grid and determining the reasonable profit to set the transmission and distribution price p_m. The profit function of the power grid enterprise is shown as follows:

$$\max \sum_{j=1}^{n} v_j(x_j,\ y_j) = P_m \sum_{j=1}^{n}(x_j + y_j) - H\left(\sum_{j=1}^{n} x_j\right) - F\left(\sum_{j=1}^{n} y_j\right) + R\left(\sum_{j=1}^{n} y_i\right)$$

where,

$$v_j(x_j,\ y_j) = P_m(x_j + y_j) - H(x_j) - F(y_j) + R(y_i)$$

2.4 Game Behaviours of Electricity Supply Side under RPS

Power generation enterprises undertake the obligation of renewable electricity generation in the implementation of RPS targets [29]. Compared with traditional thermal power generation and hydropower generation, the cost of non-hydro renewable electricity generation is relatively high [30]. In addition, due to the existence of the scale effect and learning curve, the generation cost of enterprises that enter the renewable energy power field early will be lower than that of enterprises that enter later because of the entry cost [31]. Therefore, different participants who are treated with the same RPS have different competition strategies in renewable electricity generation.

2.4.1 Game Decisions of Electricity Supply Side under RPS

According to the parameters in Tab. 3, the constraints for power generation enterprises under the quota system are shown in Tab. 4.

Table 4: Constraints for power generation enterprises

Constraint condition	Constraints
Traditional power production restrictions	$x_j \le X_j$
Renewable energy power restrictions	$y_j \le Y_j$
Total power supply	$d_j = x_j + y_j$
Target completion of quota system	$\sum_{j=1}^{n} y_j \ge t\cdot\sum_{j=1}^{n} d_j$

If replacing the parameters of the total power supply formula $x_j = d_j - y_j \geq 0$, the efficiency function of electricity generation can be obtained as follows:

$$\max \pi_j(d_j, y_j) = P_\varepsilon \cdot (x_j + y_j) + P_r \cdot y_j - C_j(x_j) - K_j(y_j)$$
$$= P_\varepsilon \cdot d_j + P_r \cdot y_j - C_j(d_j - y_j) - K_j(y_j) \tag{5}$$

s.t $d_j - y_j \leq X_j$

$$y_j \leq \min(Y_j, d_j)$$

$$\sum_{j=1}^{n} y_j \geq t \cdot \sum_{j=1}^{n} d_j$$

Based on Rosen's conclusion [32], the shadow price of producer j is λ_j^*, that is, a Lagrange multiplier; then, it is an equilibrium solution [33] only if the KKT condition is satisfied [34,35].

Let $s^* = (y_1^*, y_2^*, \cdots, y_n^*)$, KKT conditions are shown in Eqs. (5) to (9).

$$d_j - y_j \leq X_j \tag{6}$$

$$y_j \leq \min(Y_j, d_j) \tag{7}$$

$$b(s^*) = \sum_{j=1}^{n} y_j^* - t \cdot \sum_{j=1}^{n} d_j \geq 0 \tag{8}$$

$$\lambda_j^* \cdot b(s^*) = 0 \tag{9}$$

$$\pi_j(s^*) \geq \pi_j(\mu_j | s^*) + \lambda_j^* \cdot b(\mu_j | s^*) \tag{10}$$

In Eq. (10), $\mu_j | s^*$ means that when j power producer takes μ_j and the strategy set of the other participants is unchanged, the final results from Eq. (10) reveal that player j cannot improve the profit when power producer j tries to change the behaviour of the optimal status quo.

Based on Rosen's method [32,36], the expression formula of shadow price λ_j^* is shown by Eq. (11).

$$\lambda_j^* = \frac{\lambda^*}{w_j} \tag{11}$$

where w_j is the weight of producer j, which can be understood as the discourse power of producer j, and λ^* is the shadow price of the joint income function.

$$\max_{d_j, y_j \geq 0} \pi^w(d_j, y_j) = \sum_{j=1}^{n} w_j \cdot \pi_j + \lambda \left(\sum_{j=1}^{n} y_j - t \cdot \sum_{j=1}^{n} d_j \right) \tag{12}$$

Eq. (11) reveals that the greater the evaluation weight, the smaller the shadow price (Lagrange multiplier), and the lighter the penalty when the quota is not achieved. Based on the above analysis, we can obtain the benefit function including the penalty.

$$\max \pi_j(d_j, y_j) = P_\varepsilon \cdot d_j + P_r \cdot y_j - C_j(d_j - y_j) - K_j(y_j) + R_j(y_j) \tag{13}$$

$$R_j(y_j) = \lambda_j^* \cdot \min\left(\sum_{j=1}^{n} y_j - t \cdot \sum_{j=1}^{n} d_j, 0 \right) \tag{14}$$

The above equation should satisfy conditions (4), (5), (7), and (8). The penalty Eq. (14) reveals the punishment to the power generation enterprises whether the quota is completed or not.

For the noncooperative game, that is, when each power producer maximizes its own revenue at the same time, under the given weight set $W = \{w_j | j = 1, 2, \ldots, n\}$, when the joint revenue function (12) is strictly concave, the equilibrium solution of the noncooperative game model is unique.

Specifically, the joint return function (12) is a strictly concave function for any two policy sets v and θ. There is $(v-\theta)^W(\theta)+(\theta-v)^W(v)>0$, where the joint revenue function $\pi^w(d_j, y_j)$ has the conjugate gradient.

If the joint revenue function is a concave function, power generation enterprises have greater control over their own revenue than do other power generation enterprises.

2.4.2 Case Study Analysis of the Behaviours of the Electricity Supply Side

In scenario 1, there is only one player on the electricity supply side. All power generation enterprises are alliances for power production with good cooperation. The enterprise decision function is shown in Eq. (14).

$$\max \pi_j(x_j, y_j) = P_\varepsilon \cdot x_j + (P_\varepsilon + P_r) \cdot y_j - C_j(x_j) - K_j(y_j) + R_j(y_j) \tag{15}$$

Eq. (15) shows that the parameters determining y_j are the grid price $(P_\varepsilon + P_r)$, the average cost function $K_j(y_j)$ of renewable energy generation, and the penalty $R_j(y_j)$.

In scenario 2, there are two or more players on the electricity supply side. The multiplayer game of power generation enterprises is the noncooperative game of power generation enterprises for pursuing the maximization of each player's interests. This research takes three players as an example and makes simplified assumptions on the cost function of power generation enterprises in the decision-making model, as shown in Eq. (16) and Eq. (17). Compared with the hypothesis in [37,38], this assumption is perfect for the fixed cost of renewable electricity generation.

$$C_j(x_j) = \frac{1}{2} c_{1j} \cdot x_j^2 + c_{2j} \cdot x_j + c_{3j} \tag{16}$$

$$K_j(y_j) = \frac{1}{2} k_{1j} \cdot y_j^2 + k_{2j} \cdot y_j + k_{3j} \tag{17}$$

where $c_{1j} > 0$, $k_{1j} > 0$, and i, j = 1, 2, 3. The above equation shows that the marginal cost of electricity production is increasing [33]. Generally, the marginal cost growth rate of renewable energy power is greater than that of traditional energy power. Therefore, it assumes that $K_j''(y_j) = k_{ij} > C_j''(x_j) = c_{ij}$, where i, j = 1, 2, 3. At the same time, each power generation enterprise is not homogeneous; that is, the marginal cost growth rate gap between renewable power and traditional energy power is not the same. This research assumes that there is $k_{11} - c_{11} > k_{12} - c_{12} > k_{13} - c_{13}$. The decision model in scenario 2 is shown in formulas (18) to (21).

$$\max_{d_1 \geq y_1 \geq 0} \pi_1(d_1, y_1) = P_\varepsilon \cdot d_1 + P_r \cdot y_1 - \left(\frac{1}{2} c_{11}(d_1 - y_1)^2 + c_{21}(d_1 - y_1) + c_{31}\right) \tag{18}$$

$$\max_{d_2 \geq y_2 \geq 0} \pi_2(d_2, y_2) = P_\varepsilon \cdot d_2 + P_r \cdot y_2 - \left(\frac{1}{2} c_{12}(d_2 - y_2)^2 + c_{22}(d_2 - y_2) + c_{32}\right) - \left(\frac{1}{2} k_{12} y_2^2 + k_{22} \cdot y_2 + k_{32}\right) \tag{19}$$

$$\max_{d_3 \geq y_3 \geq 0} \pi_3(d_3, y_3) = P_\varepsilon \cdot d_3 + P_r \cdot y_3 - \left(\frac{1}{2} c_{13}(d_3 - y_3)^2 + c_{23}(d_3 - y_3) + c_{33}\right) - \left(\frac{1}{2} k_{13} y_3^2 + k_{23} \cdot y_3 + k_{33}\right) \tag{20}$$

$$\text{s.t.} \sum_{j=1}^{n} y_j \geq t \cdot \sum_{j=1}^{n} d_j \tag{21}$$

According to the Rosen game model [32], the Lagrange function is shown in formula (22). First, the shadow price of $L = \pi_1 + \pi_2 + \pi_3$ is solved, as shown in formulas (23) to (26).

$$\begin{aligned} L = {} & P_\varepsilon \cdot (d_1 + d_2 + d_3) + P_r \cdot (y_1 + y_2 + y_3) - \left(\frac{1}{2}c_{11}(d_1 - y_1)^2 + c_{21}(d_1 - y_1) + c_{31}\right) \\ & - \left(\frac{1}{2}k_{11}y_1^2 + k_{21} \cdot y_1 + k_{31}\right) - \left(\frac{1}{2}c_{12}(d_2 - y_2)^2 + c_{22}(d_2 - y_2) + c_{32}\right) \\ & - \left(\frac{1}{2}k_{12}y_2^2 + k_{22} \cdot y_2 + k_{32}\right) - \left(\frac{1}{2}c_{13}(d_3 - y_3)^2 + c_{23}(d_3 - y_3) + c_{33}\right) \\ & - \left(\frac{1}{2}k_{13}y_3^2 + k_{23} \cdot y_3 + k_{33}\right) + \lambda[y_1 + y_2 + y_3 - t(d_1 + d_2 + d_3)] \end{aligned} \tag{22}$$

The derivation of the above equation can be given as follows:

$$\lambda[y_1 + y_2 + y_3 - t(d_1 + d_2 + d_3)] = 0 \tag{23}$$

$$\frac{\partial L}{\partial y_1} = P_r - (c_{11}(d_1 - y_1) \cdot (-1) - c_{21}) - (k_{11}y_1 + k_{21}) + \lambda = 0 \tag{24}$$

$$\frac{\partial L}{\partial y_2} = P_r - (c_{12}(d_2 - y_2) \cdot (-1) - c_{22}) - (k_{12}y_2 + k_{22}) + \lambda = 0 \tag{25}$$

$$\frac{\partial L}{\partial y_3} = P_r - (c_{13}(d_3 - y_3) \cdot (-1) - c_{23}) - (k_{13}y_3 + k_{23}) + \lambda = 0 \tag{26}$$

Let $t^* = \frac{1}{d}\left(\frac{c_{11} \cdot d_1}{c_{11} + k_{11}} + \frac{c_{12} \cdot d_2}{c_{12} + k_{12}} + \frac{c_{13} \cdot d_3}{c_{13} + k_{13}}\right)$; then, we can obtain the following shadow price:

$$\lambda^* = \begin{cases} 0, & t \le t^* \\ \dfrac{(t - t^*) \cdot d}{\sum_{i=1}^{3} 1/(c_{1i} + k_{1i})} - P_r, & t > t^* \end{cases} \tag{27}$$

Eq. (27) shows that the shadow price of the joint revenue function increases with the increase in the quota target. For example, in the case of power enterprise alliances, when the quota target is low, the change in the quota target has little impact on the income of the whole industry.

3 Results and Discussions

3.1 Local Government's Willingness to Participate in RPS

The essence of institutional change is the emergence of a high-efficiency system or the replacement of the original system by a more efficient system. According to the analysis of the above model, there are several alternative ways to improve local government participation in RPSs.

1. The most important is to increase the incentive measures formulated by the central government, that is, increase n in Tab. 1. To improve the probability of meeting the RPS targets, the authorities should emphasize the quota target setting to reasonably increase the value of $1 - x$ in Tab. 1. The implementation of RPSs can bring additional benefits, which is the motivation of institutional change.
2. The successful implementation of institutional change requires a sufficient number of people and nongovernmental organizations to recognize the change from the heart. To reduce the value of $m - c$ in Tab. 1, at the local government level, policymakers should improve public support for renewable energy development to increase the well-deserved reputation of local government participation. The other approach is to reduce the cost of RPS regulation.

3. Institutional change brings potential profit, and the profit is greater than the cost of institutional change. The government changes the existing institutional arrangements. The results suggest that when $n > 0$, it is a good incentive if $(1 - x) > (2c + t - m)/(c + t)$. If the probability of quota completion is greater than a certain value, the local government is willing to actively participate in the supervision of the quota system.
4. The final step is to increase the sum of $c + t$, where t is the difference between the government's efforts to participate in the quota system and its non-participation when the local government has implemented supervision but the quota is still not up to standard; and c is the reputation income of the government participating in the quota system.

Local governments play an important role in the implementation of the RPS. Local governments play a regulatory role with regard to other stakeholders, and they can also promote the likelihood that other stakeholders accept the RPS. In this study, there is no separate analysis of power users. Whether they accept the RPS largely depends on the promotion and publicity of the local government. When power users in a region are willing to accept renewable energy power, the local government can introduce incentives to encourage more users to accept renewable energy power, which provides a large number of potential customers for power producers and grid enterprises, ensuring that they can accurately evaluate future income and enhancing their willingness to accept RPS.

In the process of implementing RPS, the government plays the role of referee and carries out the functions of law-making and supervision. The implementation of RPS is a top-down reform that is proposed and promoted by the government. This reform can achieve its goals quickly. The government can promote the implementation of RPS by developing new technologies–those that modify the relative prices of production factors to promote the implementation of RPS and those that generate new benefits to promote the establishment of RPS. The government can harness human and material resources to develop new technologies to promote the implementation of RPS.

From the above analysis, it can be seen that, for local governments, the most important determinants of their decision regarding the intensity of quota supervision are the probability of quota compliance and the benefits they can obtain. These factors are also meaningful in improving the influence of the public on local government participation.

3.2 The Power Grid's Willingness to Participate in RPS

According to the linear function assumption between the transmission cost of power grid enterprises and power transmission, the acceptance of renewable energy power by power grid enterprises after the electric power reform is highly related to the state-specified transmission and distribution price, the comparison of the cost function between the acceptance of renewable energy and fossil fuel electricity, and the system of incentives and punishments established by the government. However, the existing performance assessment of RPS implementation at the local government level mainly focuses on the regulation of the reward and punishment system on the power generation side and seldom involves relevant reward and punishment policies for the power grid itself. This design is based on the premise that power grid enterprises can fully guarantee the consumption of renewable energy power in the implementation of provincial RPS, which is contrary to reality. Therefore, it is necessary to strengthen power grid enterprises' responsibility for the transmission and distribution of renewable electricity.

First, among the stakeholders involved in the RPS policy regime, power generation enterprises, power grid enterprises and local governments must coordinate to achieve win-win cooperation. However, the actual operation of RPS policy requires the high engagement of power grid enterprises with great responsibility. Second, in the three links of the quota system, the most important and critical player in the connections among RPS implementation is the power grid enterprise, largely because the power grid has the largest power access responsibility and the most onerous work in collecting and issuing the power surcharge. From the power management perspective, the grid is also responsible for distributing and selling power. Most importantly, access to grid connections and the management of renewable electricity also need the support of power grid enterprises.

However, it cannot be ignored that power grid companies in China are also enterprises in a market-oriented economic system with the purposes of independent operation and self-financing. With the dual challenges of responsibility and obligation, and operation and survival, power grid companies in China have also encountered insurmountable operational difficulties. The greatest difficulty for grid companies in RPS implementation is how to utilize renewable electricity efficiently and entirely. The current situation reveals that renewable power cannot be fully connected to the power grid or cannot be sold after being connected to the grid. The fundamental reason lies in the underdeveloped economy and small power demand in the regions rich in renewable energy sources, while the nearby consumption capacity for renewable electricity in these regions is insufficient. In addition, from the viewpoint of power security, renewable energy generation has a relatively large randomness, and the power grid must be equipped with backup units or capacity markets for security issues. This situation will undoubtedly increase the additional burden or cost of the power grid. Conclusively, the existing power system is insufficient to fully consume renewable energy power, and the government should therefore accelerate power system reform.

Power market reform has a significant influence on the grid's participation in the RPS. Before the electric power reform, the grid connection of renewable energy power had strong conditionality and the economic motivation for renewable electricity was weaker than that of traditional fossil fuel power. After the electric power reform, the conditional support of the power grid to renewable electricity increases considerably, and enthusiasm depends on the additional cost of renewable power connections and the system of incentives and punishments established by the government.

3.3 Electricity Supply Side Willingness to Participate in RPS

According to the results from Section 2.3, this research analyzes the game decisions of power generation enterprises from the supply side.

First, the three essential determinants for power generation enterprises to participate in the production of renewable electricity are the on-grid price of renewable electricity, the cost and benefit of traditional power production, and the enterprises' dominance in the power generation market. Under the circumstance that the government does not impose mandatory requirements on power generation enterprises by setting the proportion of renewable energy generation, some enterprises are willing to implement renewable energy generation due to the low cost of renewable energy generation, while others are unwilling to generate renewable electricity. In this case, the core problem of the multi-player games of power generation side lies in the judgment of the penalty of each power generation enterprise by the government when the quota target is not fulfilled. Therefore, the phenomenon of free riding is not easy to occur by the penalty.

Before the reform of electric power system, the performance of renewable energy generation obligations of power generation enterprises depends on the relationship among the average income function based on the on-grid price, the average cost function of renewable energy power generation, and the loss function of non-fulfillment of renewable power generation. It involves the game behaviours among the central government (quota target setting), local government (specific punishment measures), power generation enterprises (cost function), and power grid enterprises (renewable power consumption).

After the electric power reform, the state is primarily responsible for the control of formulating the transmission and distribution price, which changes the profit model of power grid enterprises. At the same time, power generation enterprise alliances can directly sign power contracts with large power users. In this case, the power generation enterprise alliance will adopt the means of promoting technological innovation and improving the management level, reduce the average cost of renewable energy generation, and directly negotiate with power users to complete the RPS as much as possible to pursue the profit of the alliance.

The results from scenario 1 suggest that the moment will be appropriate and ripe to implement the RPS policy after the implementation of power reform measures. Electricity reform will help clarify the electricity price system and increase transparency in the implementation of the quota system.

Second, it is necessary to establish a feasible incentive and punishment system to prevent some enterprises from free riding. As the specific decision implementers, local governments should include all regional power generation enterprises within the provincial domains or power generation enterprises with a scale above into the RPS. Specific incentives and penalties include the link to newly-installed power generation from fossil fuels in the next year, the carbon emissions quota distribution for the carbon trading market, and the interaction with regional energy conservation plans. The implementation of reward and punishment measures must be guided by governmental supervision or third-party assessment.

Profit seeking is the reason why power generation enterprises participate in RPSs. Compared with the government, power generation enterprises are more market-oriented organizations. Power generation enterprises have the initiative to implement RPSs. The development of renewable energy power generation technology can reduce transaction costs in the implementation of RPSs and fully show its advantages in promoting the implementation of RPSs.

To make power generation companies willing to accept RPSs, the government should set appropriate quota targets and fully consider the costs and benefits of power producers. In the TGC market, punishing those who fail to meet the standard can encourage power producers to buy TGCs. However, punishment alone is not enough, and the transaction costs of the TGC must be reduced. The government can give subsidies, but the subsidy price should be lower than the TGC price, and trading TGCs could become the common belief of all power producers.

4 Conclusions

From the perspective of the policy system of China's renewable energy development, the feed-in tariff policy has greatly promoted the renewable energy industry with increasing industrial competitiveness in the last 15 years. However, fiscal subsidy pressure has exceeded the sustainability of the policy regime. The renewable energy electricity surcharge has experienced an accelerated adjustment. It is fair to say that the development mechanism of the renewable energy industry is still not sound, and the development and utilization of renewable energy sources are facing difficulties in power grid access.

China's RPS policy was implemented in 2019 and will be assessed for regional achievement. The integration of FIT and RPS policies is undoubtedly a great boon for the renewable energy industry. The fully guaranteed acquisition stipulation in the Renewable Energy Law is also expected to be realized by this policy mix. However, there is still a long way to go in this process, and it is necessary to comprehensively consider the decision-making behaviours of various interest groups in the implementation of the quota system and mobilize the willingness to participate by all parties in RPS performance.

Based on the RPS framework, this research analyses the game decisions of different interest groups regarding participating in RPS, aiming to mobilize all stakeholders to actively participate in the RPS completion process and provide policy suggestions for the development of a reasonable and effective reward and punishment system for the RPS policy regime. This research also described the synergy mechanism and economic analysis between RPSs and other renewable energy incentives, which could provide suggestions for policy adjustments to solve the dilemma of an insufficient willingness to engage in renewable energy consumption. This paper draws some conclusions from the theoretical perspective.

1. For local governments, the target of the quota system should not be set too low or too high. It needs some effort to achieve this balance. It can set basic indicators and excellent indicators and provide incentive measures for excellent indicators. In addition, improving public support for renewable energy development can gain reputational benefits for local governments to participate in the RPS, which can help motivate local governments to participate.
2. Compared with traditional energy power, the current power transmission mechanism is not conducive to the grid accepting renewable energy power. Power system reform aimed at combining the price formation mechanism is expected to promote the grid to absorb renewable energy and truly realize the non-discriminatory and barrier-free access to renewable energy power. The research results show that, compared with traditional energy power, renewable energy power is highly conditional on grid acceptance, and power system reform is expected to reduce the difficulty of renewable energy power grids.
3. From the point of view of the generation side, which actually undertakes the quota generation task, it is useful to establish a system of sanctions to eliminate free riding in the process of completing the quota. Because China has implemented a fixed electricity price policy for renewable energy, the future implementation of the RPS needs to further consider its coordination and coordination with the on-grid price system.

However, this study only establishes the game decision-making conceptual model of each participant under the quota system. It would be meaningful to formulate a well-directed and practical reward and punishment system through case analysis. The game decision models established for different interest groups are isolated; designing a systematic game decision model for all stakeholders would determine the comprehensive influence of participants' decisions under the policy. In addition, the future national carbon market will likely have synergistic effects with the RPS policy on renewable energy development through the allocation of carbon quotas for the power industry.

Funding Statement: The authors received the financial support from the National Natural Science Foundation of China (No. 71704178), Beijing Excellent Talent Program (No. 2017000020124G133), and the Fundamental Research Funds for the Central Universities (Nos. 2021YQNY07 and 2021YQNY01).

Conflicts of Interest: The authors declare that they have no conflicts of interest to report regarding the present study.

References

1. IRENA (International Renewable Energy Agency). Regional Trends (2020). https://www.irena.org/Statistics/View-Data-by-Topic/Capacity-and-Generation/Regional-Trends.html.
2. IRENA (International Renewable Energy Agency). Country Rankings (2020). https://www.irena.org/Statistics/View-Data-by-Topic/Capacity-and-Generation/Country-Rankings.html.
3. NDRC (National Development and Reform Commission People's Republic of China). The 13th five years plan for renewable energy development (2016). https://www.ndrc.gov.cn/xxgk/zcfb/ghwb/201612/W020190905497880506725.pdf.
4. National Energy Administration (2020). Notice of national energy administration on monitoring and evaluation of renewable energy power development in China in 2019. http://zfxxgk.nea.gov.cn/2020−05/06/c_139059627.htm.
5. Li, R. (2019). *Multi-policy system synergic model and effect evaluation for carbon emission reduction of electric power industry (Ph.D. Thesis)*. North China Electric Power University.

6. Fan, J. L., Wang, J. X., Hu, J. W., Wang, Y., Zhang, X. (2019). Optimization of China's provincial renewable energy installation plan for the 13th five-year plan based on renewable portfolio standards. *Applied Energy, 254,* 113757. DOI 10.1016/j.apenergy.2019.113757.
7. Zhang, Y. Z., Zhao, X. G., Ren, L. Z., Zuo, Y. (2017). The development of the renewable energy power industry under feed-in tariff and renewable portfolio standard: A case study of China's wind power industry. *Cleaner Production, 9(4),* 532. DOI 10.3390/su9040532.
8. Zhao, X. G., Wu, L., Zhou, Y. (2020). How to achieve incentive regulation under renewable portfolio standards and carbon tax policy? A China's power market perspective. *Energy Policy, 143,* 111576. DOI 10.1016/j.enpol.2020.111576.
9. Zhu, C. P., Fan, R. G., Lin, J. C. (2020). The impact of renewable portfolio standard on retail electricity market: A system dynamics model of tripartite evolutionary game. *Energy Policy, 136,* 111072. DOI 10.1016/j.enpol.2019.111072.
10. Zhao, X. G., Ren, L. Z., Zhang, Y. Z., Wan, G. (2018). Evolutionary game analysis on the behaviour strategies of power producers in renewable portfolio standard. *Energy, 162,* 505–516. DOI 10.1016/j.energy.2018.07.209.
11. Zuo, Y., Zhao, X. G., Zhang, Y. Z., Zhou, Y. (2019). From feed-in tariff to renewable portfolio standards: An evolutionary game theory perspective. *Cleaner Production, 213,* 1274–1289. DOI 10.1016/j.jclepro.2018.12.170.
12. Fang, D. B., Zhao, C. Y., Yu, Q. (2018). Government regulation of renewable energy generation and transmission in China's electricity market. *Renewable and Sustainable Energy Reviews, 93,* 775–793. DOI 10.1016/j.rser.2018.05.039.
13. Feng, T. T., Yang, Y. S., Yang, Y. H. (2018). What will happen to the power supply structure and CO_2 emissions reduction when TGC meets CET in the electricity market in China? *Renewable and Sustainable Energy Reviews, 92,* 121–132. DOI 10.1016/j.rser.2018.04.079.
14. Fang, D. B., Zhao, C. Y., Kleit, A. N. (2019). The impact of the under enforcement of RPS in China: An evolutionary approach. *Energy Policy, 135,* 11021. DOI 10.1016/j.enpol.2019.111021.
15. Liu, Q., Zhao, Q. H. (2015). Policy impacts on power generation enterprises' decisions and optimization model. *System Engineering-Theory & Practice, 35(7),* 1717–1725. DOI 10.12011/1000-6788(2015)7-1717.
16. Huang, B. B., Zhang, Y. Z., Wang, C. X. (2020). New energy development and issues in China during the 14th five-year plan. *Electric Power, 53(1),* 1–9. DOI 10.11930/j.issn.1004-9649.201911140.
17. Zhou, Y., Zhao, X. G., Wang, Z. (2020). Demand side incentive under renewable portfolio standards: A system dynamics analysis. *Energy Policy, 144,* 111652. DOI 10.1016/j.enpol.2020.111652.
18. Pollitt, M. G., Yang, C. H., Chen, H. (2017). Reforming the Chinese electricity supply sector: Lessons from international experience. *Financial Minds, 2(4),* 5–83+140. DOI 10.1016/j.enpol.2020.111652.
19. Wang, B., Wei, Y. M., Yuan, X. C. (2018). Possible design with equity and responsibility in China's renewable portfolio standards. *Applied Energy, 232,* 685–694. DOI 10.1016/j.apenergy.2018.09.110.
20. Kong, L. C., Tu, G. G., Zhang, Y. H. (2018). Design of grid-connected renewable energy mechanism under asymmetric information. *Management Review, 30(5),* 249–261. DOI 10.14120/j.cnki.cn11-5057/f.2018.05.029.
21. Zhao, X. G., Feng, T. T., Yang, Y. S. (2014). Impacting mechanism of renewable portfolio standard on China's power source structure and its effect. *Power System Technology, 38(4),* 974–979. DOI 10.13335/j.1000-3673.pst.2014.04.023.
22. Wang, B. (2019). *Risk management of renewable energy systems: methods and empirical analysis*. Science Press, China.
23. Liu, S. J., Yang, J. (2017). The economic principles of electricity wholesale market design. *Electric Power, 50(9),* 1–10. DOI 10.11930/j.issn.1004-9649.201707123.
24. Wang, H., Chen, B. B., Zhao, W. H., Liao, K., Bao, X. J. T. (2019). Optimal decision-making of trans-provincial power transaction subjects under renewable portfolio standard. *Power System Technology, 43(6),* 1987–1995. DOI 10.13335/j.1000-3673.pst.2018.1836.
25. Ren, Y. (2019). Interpretation and development direction of China's renewable energy quota policy. *Sino-Global Energy, 24(3),* 15–20. DOI CNKI:SUN:SYZW.0.2019-03-004.

26. Freris, L., Infield, D. (2008). *Renewable energy in power systems*. Wiley Press, UK.
27. Boyle, G. (2009). *Renewable electricity and the grid. The challenge of variability.* Earthscan Publications, Ltd., UK.
28. Hu, H. H. (2018). What is the rationale for the functional orientation of business associations?–A Case of the Growth of Guangdong Province Electricity Trade Association. *Jinan Journal (Philosophy and Social Sciences), 40(12),* 19–34. DOI CNKI:SUN:JNXB.0.2018-12-003.
29. Zhang, X., Chen, Z., Ma, Z. M., Xia, Q., Dai, X. J. et al. (2019). Study on electricity market trading system adapting to renewable portfolio standard. *Power System Technology, 43(8),* 2682–2690. DOI 10.13335/j.1000-3673.pst.2019.1190.
30. Hu, H. T., Zheng, Z., He, Z. Y., Wei, B., Wang, K. et al. (2018). The framework and key technologies of traffic energy Internet. *Proceedings of the CSEE, 38(1),* 12–24+339. DOI 10.13334/j.0258-8013.pcsee.171969.
31. Zhou, D. Q., Xu, Q., Ma, J., Wang, Q. W. (2018). Research on incentive policy of photovoltaic industry based on evolutionary game theory. *Journal of Technical Economics and Management*, 114–119. DOI 10.3969/ j.issn.1004-292X.2018.03.021.
32. Tidball, M., Zaccour, G. (2009). A differential environmental game with coupling constraints. *Optimal Control Applications and Methods, 30(2),* 197–207. DOI 10.1002/oca.849.
33. Fuzhan, N., Georges, Z. (2010). Renewable portfolio standard policy: A game-theoretic analysis. *Infor Information Systems & Operational Research, 48(4),* 251–260. DOI 10.3138/infor.48.4.251.
34. Sumin, M. I. (2012). On the stable sequential kuhn-tucker theorem and its applications. *Applied Mathematics, 3,* 1334–1350. DOI 10.4236/am.2012.330190.
35. Karush, W. (2013). Minima of functions of several variables with inequalities as side conditions. *Traces and Emergence of Nonlinear Programming*, 217–245. DOI 10.1007/978-3-0348-0439-4_10.
36. Nabetani, K., Tseng, P., Fukushima, M. (2011). Parametrized variational inequality approaches to generalized nash equilibrium problems with shared constraints. *Computational Optimization and Applications, 48,* 423–452. DOI 10.1007/s10589-009-9256-3.
37. Krawczyk, J. B. (2005). Coupled constraint nash equilibria in environmental games. *Resource and Energy Economics, 27,* 157–181. DOI 10.1016/j.reseneeco.2004.08.001.
38. Krawczyk, J. B. (2007). Numerical solutions to coupled-constraint (or generalized nash) equilibrium problems. *Computational Management Science, 4,* 183–204. DOI 10.1007/s10287-006-0033-9.