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Mechanism design and consumption certification of differentiated green electricity trading: A Zhejiang experience

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The carbon neutrality strategy marks that green electricity will replace fossil energy as the main power source in the future power system. The trading varieties in the electricity market will be more diverse, and the demand for green electricity by consumers will grow significantly. This paper innovatively proposes a provincial market framework for voluntary flexible trading of green electricity while elaborating on the conceptual design of differentiated green electricity trading processes in a systematic way for Zhejiang province. The proposed framework can not only reflect the carbon emission reduction attributes of green electricity but also fully exploit its commercial and social values. Moreover, the proposed green electricity trading certificate can realize the authoritative certification of green electricity consumption and help the construction of a carbon traceability mechanism. The proposed trading mechanism is expected to give rise to a new green electricity service industry and deepen the reform of the carbon and electricity synergy mechanism. The experience of green electricity trading in the Zhejiang province is expected to reveal the promotive impact of the electricity market on the carbon neutrality strategy.

KEYWORDS

electricity market, green electricity, differentiated trading, consumption certification, mechanism design

1 Introduction

In recent years, the issue of climate warming is continued to attract attention and a wave of global carbon emission reduction is rising. At the 75th session of the United Nations General Assembly, President Xi made an important commitment on behalf of China to the international community to "achieve peak carbon and carbon neutrality". In the process of realizing the carbon neutrality strategy, green electricity (i.e., non-water renewable energy) will become the main source of incremental energy supply in China and gradually transform into various market entities of energy supply, which requires corresponding technological and institutional innovation. As stated in gov (2021),

market-based construction is the key means to addressing the low-carbon transformation of the energy and power system. Nevertheless, how to build a differentiated green electricity trading mechanism with reasonable prices and high market satisfaction is the key challenge that has long plagued the effective synergy between the current electricity market reform and green electricity development.

At the same time, multinational enterprises and foreign trade enterprises are highly concerned about green electricity consumption in the whole industry chain, and the demand for relevant certifications is increasingly urgent. For example, internationally renowned enterprises such as Apple Apple (2020), Amazon (sustainability, 2020), and Facebook (sustainability) have also announced implementation plans for 100% green electricity supply and low-carbon emission reduction initiatives. As an eastern coastal province with a large scale of export-oriented enterprises, Zhejiang urgently needs to rely on the power trading platform to address the certification needs of corporate users to consume green electricity throughout the production and operation life cycle. Although power users should collaboratively assume the responsibility of consumption and the amount of consumption should correspond to the annual electricity consumption (zfxxgk.nea.gov, 2019), no clear green electricity quota approach and assessment methods have been introduced for power users, and no mention has been made of how to guide power users to actively participate in the consumption apportionment, and the huge user-side dormant resources have not yet been awakened. Therefore, the necessity of constructing an electricity market that can guide power users to participate in green electricity consumption is becoming more and more obvious.

Currently, some countries have initially implemented mechanisms related to green electricity trading. The United States has a variety of mechanisms to support the development of green electricity, and the system varies from state to state. The green electricity certificate mandatory trading market, or "green certificate market", promotes green electricity development through a mandatory quota system, which is essentially a secondary financial market for green electricity generation, i.e., a "separate certificate and electricity" trading mechanism. Some states have also established voluntary green electricity trading markets, and have opened a market model in which green electricity and green certificates are bundled and traded, i.e., a "certificate and electricity" system in which electricity users can voluntarily apply directly to electricity sellers or generating companies to purchase specified green electricity and obtain a "green certificate" at the same time (Overview of U.S., 2019). In addition, Europe has also established the Guarantees of Origins (GO) certificate mechanism to form a voluntary market for "green electricity", in which customers and power producers trade green electricity bilaterally across borders, and the price of electricity with GO certificates is slightly higher than that of electricity without certificates (Shi, 2019).

China has carried out an initial exploration of market-based trading of green electricity certificates ("green certificates"). 2017 saw the introduction of a voluntary subscription program for green certificates (nea.gov, 2017), and further, the introduction of a green electricity quota mechanism to promote green certificate trading (zfxxgk.nea.gov, 2019; nea.gov, 2020), which specifies that provinces and regions can allocate targets for green electricity consumption weights, and for provinces that cannot meet the quota requirements, they can purchase excess green electricity consumption from other provinces or purchase green certificates to supplement it. For provinces that cannot meet the quota requirements, they can purchase excess green electricity consumption in other provinces and regions or purchase green certificates to supplement and replace them. However, the existing green certificate mechanism is too expensive, the certification system is not yet sound, and the acceptance of users is not high, resulting in low transaction volume and making it difficult to play its proper role. Although the voluntary subscription of green certificates can guide consumers to green consumption, and to a certain extent can also alleviate the financial subsidy gap, from the fact that the difference between the amount of subscription and the amount of certification is large, the market regulation is very limited.

Furthermore, direct market-based electricity trading is an important means to promote green electricity consumption. Some scholars have conducted relevant research on green electricity trading, covering market mechanism design, trading decision optimization, green certificate accounting and issuance, market impact analysis, etc., but generally speaking, it is still in the initial stage. At the same time, the design of a green electricity trading mechanism involving the "unification of certificates and electricity" is still relatively small. In terms of the market mechanism, literature (Zhang et al., 2019a) proposed an electricity market system in the context of a renewable energy quota system; literature (He et al., 2020) proposed a market mechanism scheme in line with renewable energy quantity and price preservation, and discussed the interrelationship within the market mechanism; literature (Qian et al., 2020) explored in-depth the coordination mechanism of constructing national green certificate trading and provincial day-ahead electricity market; Literature (Shan et al., 2020) explored the construction of green electricity market from the perspectives of market mechanism and policy rules based on the experience of foreign electricity market construction; literature (Liu et al., 2020a) proposed the design of green certificate trading system for charging load aggregators. The literature (Li et al., 2019) analyzed and discussed the implementation problems and the reasons for the low trading volume of the green certificate mechanism in China and introduced the corresponding green certificate trading improvement model. In terms of market behavior decisions, literature (Zhou et al., 2020) investigated

the bidding strategies of the offering power producers in the context of the GO certificate and quota system; literature (An et al., 2017) modeled and analyzed the possibility of green electricity generators using market forces to pull up the price of green certificates in the green certificate trading market; literature (Wang et al., 2020) proposed a power insurance design scheme for power selling companies to reduce the impact of green certificate price fluctuations. The literature (Guo et al., 2020) proposes a market equilibrium model that integrates energy and green certificate trading, simulates the decision-making process of renewable energy generators, and analyzes and discusses their market behavior under different scenarios. In terms of green certificate tracking and issuance, literature (Cai et al., 2020) proposed a blockchain-based GO certificate trading platform implementation scheme to solve the green certificate tracking problem; literature (Liu et al., 2020b) further considered the calculation and allocation method of GO certificates. In terms of market impact analysis: literature (Feng, 2016) proposed a coupling model to portray carbon trading, electricity trading and green certificate trading, and analyzed the mutual influence among the three; literature (Yao et al., 2020) proposed an optimization model of electricity trading considering both green certificate market and carbon trading market, and simulated and measured the influence of carbon quota coefficient and green certificate ratio on the carbon emission reduction effect of power producers; The literature (Zhang et al., 2019b) explored the main influencing factors affecting the willingness to trade green certificates and analyzed the impact of relevant policies on green certificate pricing by constructing a marginal price dynamics model; the literature (Qu et al., 2020) established a medium- and long-term secondary trading model for green certificates under the quota system policy and measured and analyzed the national provincial green certificate market trading volume; The literature (Lin et al., 2021) constructed a market decision model considering green electricity quota system and discussed the impact of green certificate price and quota weight on market equilibrium point.

The construction of the provincial electricity market in China is still in its initial stage, and there is still a lack of effective market-based means to recover the investment costs of green electricity power plants and the supporting grid construction and operation costs, resulting in the low carbon value of green electricity not yet effectively explored, and the increasing pressure of government financial subsidies. In particular, the consumption rate of green electricity in China's receiving power system is generally low, and the market competitiveness of the relevant power generation entities is generally weak. In Zhejiang Province, for example, although green electricity is developing rapidly [expected to account for up to 26.05% in 2025 (Zhejiang Provincial Energy Adminis tration, 2021)], unit utilization hours are low [electricity generation in 2019 accounted for only 6.7% of the total social electricity consumption (gov.cn, 2020)], and green electricity units and conventional units have not been effectively distinguished in the regular market-based trading process, and the low carbon value of green electricity is seriously underestimated. In fact, Zhejiang Province needs to consume non-water renewable energy up to 7.5% of the total social electricity consumption in 2020 (nea.gov, 2020), however, due to the relative lack of utilization hours of green electricity units in the province, it is difficult to fully meet the green electricity consumption weighting target. In view of the objective status quo of green electricity scarcity in Zhejiang Province, the provincial green electricity market space in Zhejiang presents a situation of less supply than demand, which in turn has the economic foundation conditions for green electricity marketization, especially for customer-side bidding. 2020 pilot trading example in the Fan Meishan demonstration area was a complete success, which practically verified the feasibility and effectiveness of the market system for differentiated green electricity trading and laid the foundation for the official operation of the subsequent market opening. On 13 May 2021, Zhejiang Province launched the preparation of a pilot implementation plan for green electricity market-based trading, aiming to further stimulate market vitality and deepen the reform of green electricity market-based trading.

This paper provides the market design principles considering green electricity differentiated trading, constructs the corresponding trading framework system, and proposes derivative mechanisms such as green electricity trading certificates based on the operation practice and experience of Zhejiang Province. Our contributions aim to actively respond to the growing demand for green electricity consumption in the whole society, reasonably discover the value attributes of green electricity, and optimize the solution of the problem of the construction and operating costs of new power systems with renewable energy as the mainstay energy sources. The remaining contents of this article are as follows: Section 2 will introduce the green electricity market-oriented trading mechanism and market organization process; Section 3 will analyze the characteristics and connotations of green electricity differentiated trading by comparing the existing green certificate trading mechanism; Section 4 will discuss the value and extension of green electricity from the three aspects of commercial value, social value and carbon market cooperative operation; Section 5 will analyze the results in combination with simulation cases, and Section 6 will discuss practical experience and further market start-up implementation suggestions and expected results Section 7 summarizes the paper.

2 Design of green electricity differentiated trading framework

This paper follows the general idea of separating green electricity with gray electricity. Organizing differentiated trading to construct a framework system of provincial

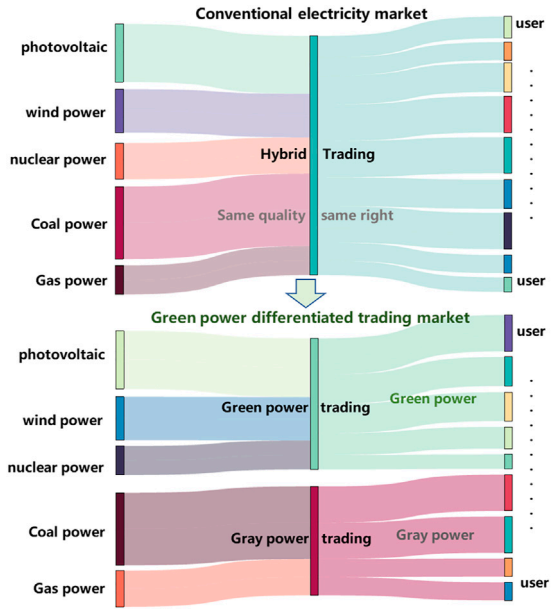

FIGURE 1
Comparison of traditional and differentiated trading.

voluntary differentiated green electricity trading market in conjunction with the actual situation in Zhejiang.

As shown in Figure 1, the conventional electricity market does not distinguish between power source categories, while power generation enterprises and consumers participate in the unified market, and all transactions are of the same quality and right, which makes it difficult to highlight the value of green electricity. Under the differentiated trading model, green electricity and traditional fossil power generation ("gray electricity") can be decoupled by setting the access conditions for market entities, and trade with consumers in batches, thus consumers' willingness can be meet to choose the quality of the purchasing power in a targeted manner, and the commodity attributes of green electricity can be fully reflected. Furthermore, the current main position of gray electricity trading can still follow the original market model. Differentiated green electricity trading is regarded as a new trading variety to open up a dedicated market module and an effective diversion of gray electricity without major adjustments to the original market system. The following parts discuss the design concept and market rules of differentiated green electricity trading.

2.1 Market access and trading mechanism

Market entities include power generation entities and consumer entities. In the initial stage of the differentiated trading market, the power generation entity is temporarily limited to green electricity power generation enterprises whose voltage and capacity meet certain conditions. Specifically, Solar, wind, and other green electricity power generation enterprises that have the national capital construction approval process and obtain or are exempt from the power business license (power generation) of 6,000 kW or above can participate in the differentiated green electricity trading as a market entity in Zhejiang province. Considering the technical constraints of metering, the consumer entities need to meet the grid access specifications, meet the technical requirements of grid security, open an independent account in the grid enterprise, separate metering and sign a formal power supply contract.

On this basis, the power trading center can regularly organize green electricity contract transactions based on market demand and transaction scale, taking annual, multi-month, and single month as the time scale, and adopting the mode of centralized bidding or listing transactions. Considering the scale and maturity of green electricity generation entities, it is more appropriate to adopt the unilateral centralized bidding model at the initial stage of the market in order to avoid collusion between power generation enterprises and keep the normal operation of the market (i.e., the demand-side entity submits the price and quantity while the generation-side entity only submits the quantity but not the price). Therefore, the following analysis only focuses on the green electricity differentiated trading model based on unilateral centralized bidding. The bidding model defaults to a unilateral centralized bidding model if no special instructions are given.

2.2 Bidding and clearing mechanism

Electricity consumers use the benchmark price of coal-fired power generation as the reference benchmark and declare the purchase price according to the market regularity. After the declaration is completed, the trading center will conduct market clearing according to the marginal price. Moreover, in the initial stage of the market, electricity consumers may not yet have the ability to make skilled market bidding decisions, and the prediction of the low carbon value of green electricity may significantly deviate. Power generation enterprises, as the recipients of the price, may have the risk of damage to their interests. Therefore, the trading center may set a price floor based on actual needs to protect the basic interests of power generation enterprises and promote the further development of the green electricity industry, while guiding consumers to discover the scarcity of the low-carbon value attached to the green electricity.

Take Zhejiang as an example, the declared price floor in annual trading is set at 10 CNY/MWh for the base price of coal-fired power generation on the grid, and the declared price floor $\underline{\rho}_m$ in monthly trading is set as follows:

$$\underline{\rho}_m = \rho_b + (\rho_c - \rho_b) \times \alpha \quad (1)$$

Where ρ_c is the annual transaction clearing price, ρ_b is the coal-fired power generation benchmark price, and α is the adjustment factor for the lower price limit. When α is 1, the lower price limit of the monthly trading declaration is the annual trading clearance price. When α is increased, the lower price limit is raised and the minimum value of green electricity is pulled up. To avoid the unintentional overvaluation of green electricity and low market participation on the demand side, it is not advisable to set too high a lower limit of the transaction price at the beginning of the market. Usually, α can be taken as 1.2, which means 1.2 times of the difference between the annual transaction clearing price and the benchmark price of coal-fired power generation feed-in price. Furthermore, when the market entities corresponding to the marginal price are not unique, the electricity quantity to be cleared in the marginal price segment is allocated in proportion to the electricity quantity declared by the market entities in that segment.

The market supply and demand balance analysis under unilateral centralized bidding by consumers is shown in Figure 2, where P_t is the benchmark feed-in price for coal-fired power generation, P_n is the ideal clearing price, and P_r is the minimum bid by consumers. The minimum bid limit is set to ensure that green electricity generators receive additional revenue corresponding to the low carbon value of green electricity (represented by the rectangular area of A + B in the figure). Moreover, the determination of the reasonableness of the minimum bid limit requires analysis and assessment based on the actual market bidding situation. Assuming that the market-clearing price is significantly higher than the set lower price limit, it indicates that the set price limit is more conservative and can ensure the smooth operation of the market in its initial stage to a certain extent. If the clearing price is close to the lower price limit for a long period of time, as shown in the bidding curve 1, it proves that the set minimum bid limit is too high and does not reasonably reflect the low carbon value of green electricity, and even inhibits the green electricity consumption demand. In this situation, if the price limit is released, the actual bid curve may shift into bidding curve 2, where the clearing price is lower than the lower price limit. The formed rectangular area of area B represents the real value of green electricity. Compared to the case of setting a price floor, the rectangular area of area A is reduced which indicates there is room for a price reduction for green electricity. In the future, under the condition that new energy subsidies are gradually withdrawn, the cost recovery of renewable energy power generation enterprises is limited, which is not conducive to promoting the healthy development of the renewable energy industry, and the willingness to promote the construction of supporting energy storage facilities may also be hindered. Therefore, setting the lower limit of the bid is conducive to guiding consumers to discover the price of green electricity and protecting the income of renewable energy generation enterprises. With the continuous development of renewable energy generation technology, the scarcity value of green electricity is gradually diluted, and green electricity will be gradually priced at parity. The price floor should be withdrawn at this time.

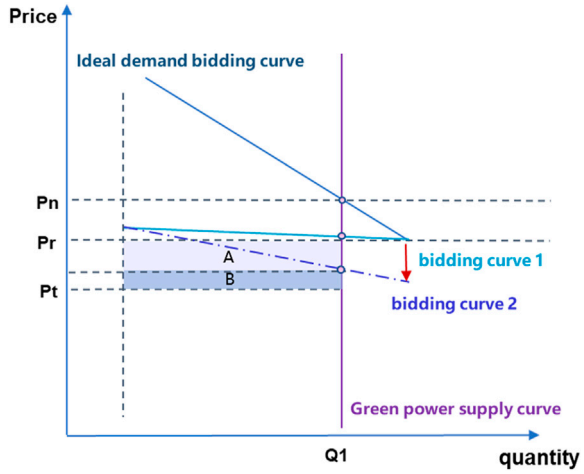

FIGURE 2
Analysis of market equilibrium under the one-sided customers' centralized bidding mode.

2.3 Settlement mechanism

The settlement of green electricity differential trading can be carried out in the way of "monthly settlement". Specifically, the uncompleted portion of the monthly contract power of each market entity will not be rolled over to the next month for settlement. The deviation will be settled according to the absolute value of the difference between the average price of the contract and the integrated price of coal-fired power generation on the grid. The actual monthly electricity generation and consumption of each market entity greater than the contracted electricity consumption are settled in accordance with the approved feed-in price and the consumer directory electricity price.

Taking Zhejiang as an example, the settlement price for consumers ρ_s^d is calculated as follows:

$$\rho_s^d = \rho_e + T + \rho_a + F \tag{2}$$

ρ_e is the green electricity clearing price, T is the transmission and distribution price (including line loss), ρ_a is the apportioned cost of auxiliary services, F is the governmental funds and surcharges. For customers with peak and valley time-sharing prices, the settlement of their time-sharing prices is based on the same range of increases or decreases in the difference between the settlement prices and catalog prices. The settlement price for power generation enterprises ρ_e is consistent with the clearing price,

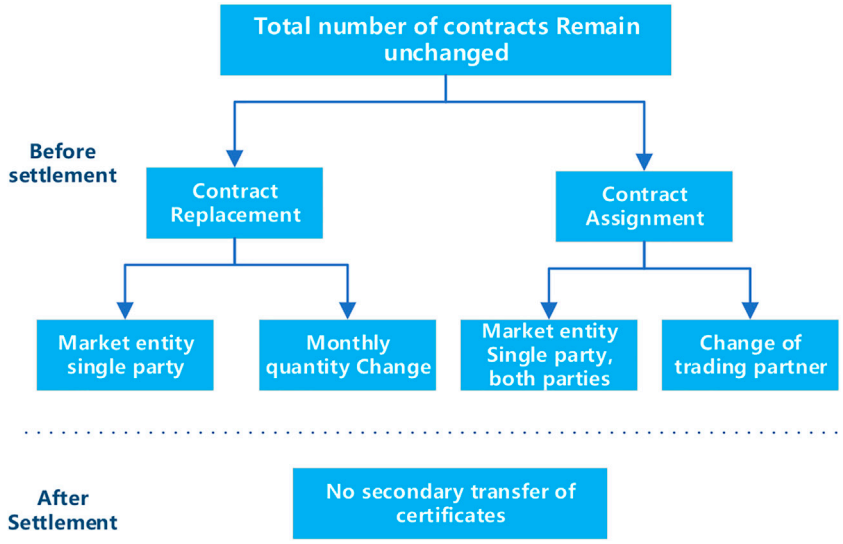

FIGURE 3
Deviation adjustment mechanism.

which includes the energy storage quota component and the discretionary income component, which is as follows:

$$\rho_e = \rho_k + G_1 \tag{3}$$

where G_1 is the unit power revenue formed by the price difference between the differentiated green electricity trading price and the benchmark feed-in price of coal-fired power generation in Zhejiang Province (converted by a proportional coefficient); ρ_k is the unit power revenue of the discretionary part of power generation enterprises. The special subsidy policy for clean energy has already provided policy subsidies to relevant power generation enterprises. If the entire share of differentiated green electricity trading is attributed to the power generation enterprises participating in the market, there is a risk of duplication of subsidies. Therefore, we should set a reasonable G_1 to guide the power generation enterprises to use part of the proceeds for the construction of energy storage quotas, and then build the positive cycle of "Take from the market, Benefit the society" on the basis of stimulating the willingness of green electricity enterprises to participate in the green electricity differentiated trading market.

2.4 Contract deviation adjustment mechanism

Market entities are required to bear the cost of deviation penalties when there are deviations in contract execution. To help market entities eliminate deviations and avoid deviation penalties, the market operation needs to consider a deviation adjustment mechanism to further improve the forecast accuracy of power generation and ensure the standardized rules.

The contract deviation adjustment mechanism is shown in Figure 3. Specifically, after reaching a green electricity transaction, market entities can adjust the transaction contract through market-based transactions including contract replacement and transfer on the premise that it does not affect the interests of related parties or the consensus of related parties. The purchase and sale of the two sides reach agreement and do not affect the implementation of other market entities' trading contract on the basis of the following month before the implementation of the transaction is allowed to adjust the subsequent months of the contract sub-month plan. However, the total number of differentiated green electricity trading contracts must remain unchanged. Based on the deviation adjustment mechanism set up, market entities can take the initiative to adjust the contract power deviation through ex-ante and ex-post contract replacement and contract transfer. However, it is worth pointing out that it is limited to contract replacement and transfer transactions before trade settlement.

2.5 Trading verification and authentication mechanism

After the green electricity transaction is completed and the contract is fulfilled, the trading center can issue the "Green electricity Trading Certificate" to the electricity consumers according to the settlement results. The certification process

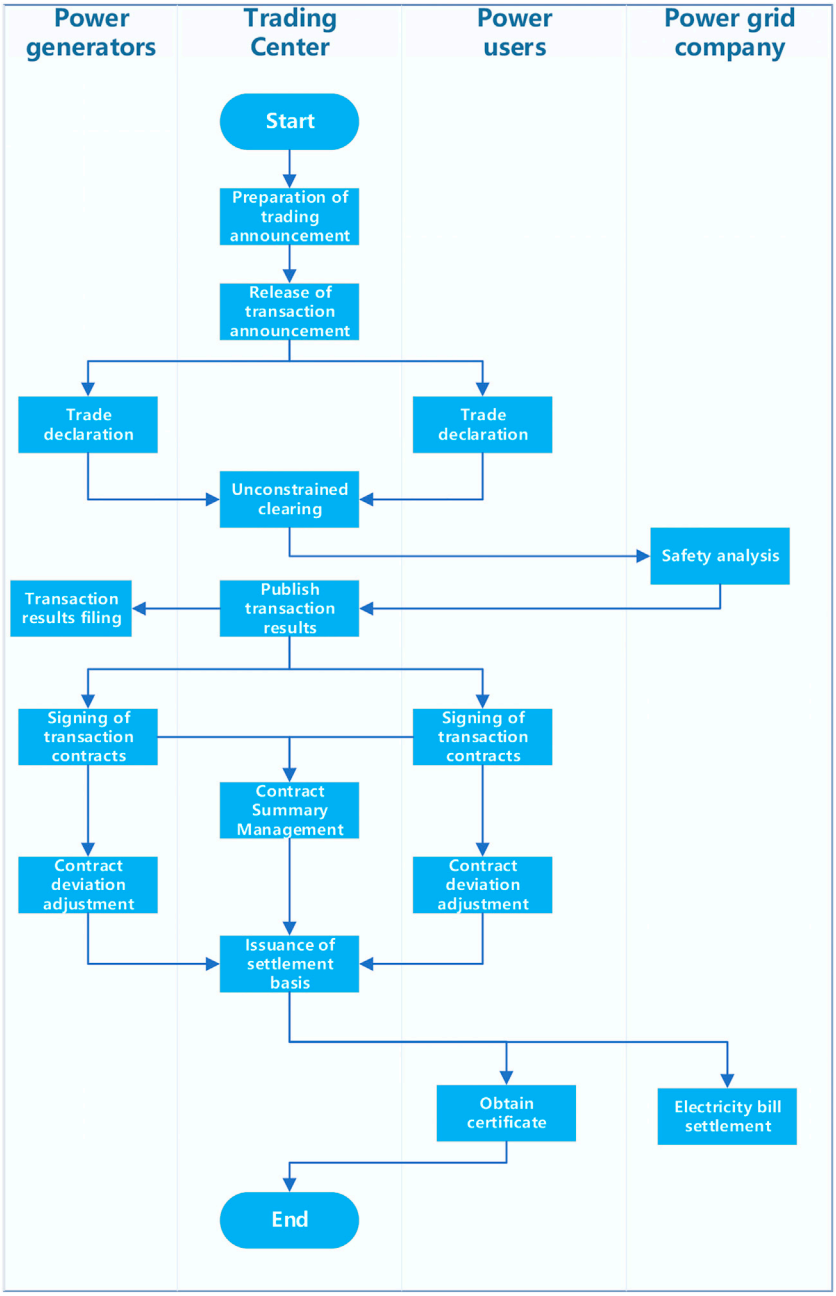

FIGURE 4
Process of market organization.

will be strictly in accordance with the settlement results record settlement power to ensure the uniqueness of the green attributes of each kilowatt-hour power purchased by the electricity consumers. It is worth pointing out that this type of certificate is mainly used to prove the authenticity of the consumer's consumption of green electricity, and cannot be transferred for secondary trading. With the gradual clarification of the principles of calculating carbon emission indicators for electricity consumption, such certificates are expected to be incorporated into the carbon emission indicator management system on their own initiative and used as the basis for reducing carbon emissions for consumers. At the same time, the issuance and certification of such certificates need to comply with the physical constraints of power balance and keep the synchronization of issuance and consumption.

Therefore, the power grid company must be deeply involved in the process of trade organization and execution of trade results, and guarantee the trade execution under the premise of ensuring the safe operation of the power grid. Especially in the initial stage of the market, the trading center and the power grid company should fully combine the actual needs of the market entities and consider the synergistic operation of the carbon market, which should play the following key roles:

1) Auxiliary role: provide a trading platform for green electricity power generation enterprises and electricity consumers, and guide market entities to discover the economic value attributes of green electricity.
2) Safeguarding role: providing power system security analysis services to safeguard the physical execution of the transaction, and strengthen the physical trading attributes of electricity.
3) Service role: it should play its own advantages in the construction of the carbon market to provide consumers with corresponding emission reduction services, and actively serve the needs of market entities to achieve their own emission reduction goals.

In summary, the organization process of green electricity differentiated trading can be summarized as shown in Figure 4. Power generation enterprises, electricity consumers, trading centers and power companies, and other multi-party entities collaborate to complete the financial settlement and physical delivery of green electricity, so as to realize the large-scale optimization of green electricity resources.

3 Differentiated trading features and connotations of green electricity

By effectively dividing the market-based trading process of green electricity and gray electricity, Green electricity differentiated trading can not only promote the zero-carbon power generation attributes of green electricity to be effectively quantified as market value but also reduce the design difficulty and reform cost of the electricity market mechanism. Moreover, the green electricity trading certificates delivered with power trading have the characteristics of traceability, which help clarify the rights and interests of green electricity consumers and stimulate the willingness of the whole society to reduce carbon emissions.

3.1 Inherent characteristics of green electricity trading certificates

Differentiated green electricity trading under the government's authorization and supervision, each market entity relies on the provincial power trading platform to bid and then produce the contract price. The trading results are physically executed, and the trading contract and settlement documents can form a strong evidence chain. On this basis, the trading center issues green electricity trading certificates to the settled green electricity based on credibility, which proves those market entities (especially consumers) have substantially participated in the green electricity trading. In turn, it is a more convenient and direct way to promote the concept of green electricity consumption to the whole society. Compared with the conventional green certificate "certification and electricity separation" mode, the green electricity trading certificate has obvious "certification and electricity unity" characteristics. In the trading process, the consumption of electricity can be traced, the footprint of carbon emission streams can be tracked, and the potential market acceptance space is large. Essentially, green electricity trading certificates are markers of the green electricity production and consumption process, which are by-products of green electricity differentiated trading. Green electricity trading certificates themselves have no additional value and cannot be separated from green electricity and traded. In contrast, the green certificate trading market is a secondary financial trading market. Taking the mandatory green certificate trading under the renewable energy quota system as an example, it lacks a mandatory binding relationship with the renewable energy power trading, but mainly stimulates the green electricity consumption demand of market entities by forming a matching relationship with the renewable energy quota system. It is worth pointing out that the differentiated green electricity trading mechanism has certain limitations in terms of flexibility in the use of certificates, which has constraints in terms of both consumption time and consumption quantity.

Table 1 presents a detailed comparison between green electricity trading certificates and conventional green certificates. On the one hand, green certificates are approved and issued on a monthly basis and are limited to onshore wind power projects and photovoltaic projects within the national renewable energy price surcharge fund subsidy catalog. The trading price of electricity corresponding to conventional green certificates is not allowed to be higher than the renewable energy price surcharge fund subsidy. Differentiated green electricity trading can be oriented to market demand and different uses, relying on the power trading platform to organize different time scales of market transactions. Differentiated green electricity trading can be also extended to biomass power generation, hydropower, and nuclear power as needed. Through market-based means, conduct reasonable pricing to a variety of clean energy carbon emission reduction values. On the other hand, the characteristics of green certificates "separation of certificates and electricity" make it difficult for consumers to strictly declare the green electricity consumption process. It is difficult for government departments and power grid enterprises to effectively track the carbon footprint, and consumers are not

TABLE 1 Comparison of green electricity trading certificates and green certificates.

Attribute	Green electricity trading certificates	Green certificates
Relying on electricity trading	Yes	No
Real power consumption	Certain	Uncertain
flexibility in the use of certificates	Limited	Flexible
Carbon-electric synergy tracking	Yes	No
Price range	Wider	Narrower
Range of market entities	Wider	Narrower
promoting the development of energy storage	Yes	No

highly motivated to participate. The green electricity trading certificate is only issued after the real delivery and settlement of electricity. The green electricity consumption and carbon emission reduction rights and interests are clearly defined. Moreover, differentiated green electricity trading based on unilateral centralized bidding by consumers can directly reflect the green electricity price level acceptable to the whole society and contribute to the integration of the electricity market and carbon trading market.

3.2 Merits of the differentiated trading mechanism

Differentiated green electricity trading explores the key role of green electricity in the process of achieving the carbon neutrality strategy through market-oriented and differentiated bilateral trading to stimulate the sustainable development of the green electricity industry after the withdrawal of government subsidies, specifically including:

1) Solve the problem that the traditional electricity market model cannot highlight the exclusive low-carbon value of green electricity. Through the establishment of a differentiated trading system, a reasonable green electricity price system will be gradually discovered and formed.
2) Promote the construction of supply capacity and cultivation of the consumption system of green electricity. Guide the flow of funds in the direction of increasing social welfare by enhancing the adaptability of the power system to green electricity.
3) Facilitate bilateral matchmaking of market entities. Discover the true value of green electricity through transaction price signals, relieve the pressure of the national green electricity subsidy funding gap, and provide a transition path for green electricity subsidy withdrawal.
4) Help enterprises to enhance their international competitiveness and social responsibility. Both foreign-funded enterprises, export-oriented enterprises, and high-energy-consuming enterprises can hedge their business risks under the pressure of carbon emission reduction in advance by participating in green electricity trading.

Green electricity differential trading is essentially a customized market mechanism for green electricity special trading in the medium and long-term electricity market environment. To realize the diversion of green electricity and gray electricity in the electricity market operation stage, its main differences from the traditional medium and long-term electricity market can be divided into three aspects: trading timing, market entities and trading methods, which are as follows:

1) Trading timing: differentiated green electricity trading in the total monthly electricity consumption of consumers has priority over ordinary direct trading and electricity sales market to conduct settlement, which aims to achieve the diversion of green electricity and gray electricity in the time scale.
2) Market entity: the traditional medium and long-term electricity market in the power generation entity, no restrictions on the type of power generation, coal power units, and gas units can participate. While the green electricity differentiated trading market has an entry threshold, limited to green electricity enterprises and electricity consumers to participate. The gray electricity represented by coal power is diverted to the traditional medium and long-term electricity market for trading, to realize the differentiation of market entities. It is worth emphasizing that, unlike ordinary direct trading policy price reductions that require considerable consumer access thresholds, green electricity is traded competitively with no thresholds required for consumers. Therefore, it is a truly voluntary market. As the market develops and matures, non-operating consumers including individuals can participate, which will greatly enrich the participation of green electricity trading, importing traffic for the market, and promoting market prosperity.

3) Trading method: the traditional medium and long-term electricity market in the centralized bidding trading method usually uses the seller and the buyer are both submit quantity and price, while the green electricity differential trading uses the demand-side submits quantity and price, the power generation enterprises only submit quantity for centralized clearing. Furthermore, Green electricity can be designed as a standard product and sold on the trading counter (OTC) with reference to the annual trading price according to market conditions. For example, for residential consumers, the price is increased by one cent per kWh, and 100 kWh is one trading unit, which can be bought and sold immediately. This will greatly reduce the complexity of trading and the threshold of participation to truly achieve the popularity of green electricity trading.

4 Value and outreach of differentiated green electricity trading

Market-oriented and differentiated intra-provincial green electricity trading is not only an effective transition for green electricity generation entities in the Zhejiang power system to participate in the electricity market, but also an important exploration to relieve the pressure of government financial subsidies. It has important commercial and social values to awaken the consensus of carbon neutrality strategy in the whole society and guide the transformation of the energy supply side.

4.1 The value space of green electricity trading

"Green, low-carbon, clean and environmental protection" will be the core competitiveness of multinational enterprises and foreign trade enterprises to participate in international trade under the pressure of global carbon emission reduction. For example, Europe has gradually implemented a carbon tax policy. Green electricity consumption can bring tangible economic benefits to enterprises. It is also an important step to enhance the image of enterprises' social responsibility. Important technology giants such as Apple and Facebook have already reaped wide acclaim for announcing and implementing green electricity programs. In this context, multinational and foreign trade enterprises that are in urgent need of environmental protection or carbon emission reduction recognition can participate in differentiated green electricity trading and obtain credible certification from provincial power trading centers, while being able to gain revenue or reduce corresponding expenses in the carbon emission market.

Currently, China has started to implement an enterprise-level carbon emission quota system, which has greatly increased the demand for lower carbon emissions from electricity consumers, implying a potentially broad market demand for green electricity with low-carbon attributes. In addition, China's Ministry of Ecology and Environment has made further regulation of national carbon emissions trading (Measures for the Administration, 2020). However, at present, China is still in the initial stage of carbon emission reduction process, and the carbon emission reduction technology of each market entity is not yet perfect, so carbon emission rights will have a large market demand. At the same time, in order to reduce carbon emissions of the power system to achieve the goal of carbon peak, it is still necessary to further cultivate green electricity enterprises and their supporting industrial construction. Therefore, it is especially important to lead and encourage the orderly development of the green electricity industry chain through market-based means, and further release low-carbon values to meet the carbon emission reduction needs of corporate consumers.

The differentiated green electricity trading mechanism is significantly different from that of gray electricity trading, which can play a positive incentive and guiding role in the development of the green electricity industry and further empower the whole society to make the low-carbon transformation. The differentiated green electricity trading highlights the added value of green electricity, which can not only broaden the profit channel of green electricity generation enterprises but also transfer the carbon emission reduction cost from the energy supply side to the demand side, thus helping to form a carbon neutrality strategy consensus in the whole society and forcing the structural transformation of the energy supply side. Furthermore, it can encourage green electricity power generation enterprises to help the construction of new power systems in a more active and forward-looking way by guiding the surplus funds of differentiated green electricity trading to be used for the construction of energy storage quota according to a certain proportion.

4.2 Cohesive and coherence with carbon emission allowances

The National Development and Reform Commission issued the "Corporate Greenhouse Gas Emissions Accounting Measures", which has explicitly included the carbon emissions embedded in the net purchased electricity of enterprises into the scope of corporate carbon emission calculation (ndrc.gov, 2013). However, the electricity carbon emission calculation of enterprises in China is still based on the emission factors of electricity consumption in their regions. Therefore, in order to further release the outward application value of green electricity trading certificates, it is necessary to differentiate the calculation of carbon emissions of electricity consumption of enterprise users, reflecting the low carbon benefits that users consuming

green electricity should have. Specifically, power users can choose to purchase relatively high-cost green electricity and relatively low-cost gray electricity, and the price difference between the two reflects the low carbon value obtained by power users. With the further establishment of a national carbon trading market, the carbon allowance system will stimulate companies to create a real demand for constraining their own carbon emissions.

In fact, green electricity production and consumption are natural measures of carbon emissions reduction. The corresponding differentiated green electricity trading can also accurately measure and calibrate the carbon reduction cost and contribution of the whole society. Moreover, green electricity trading certificates are effective proof of the physical delivery of green electricity for consumers. Compared to the consumption of gray electricity, it reduces the enterprise's own carbon emissions. With the continuous improvement of carbon trading, the purchase price difference based on green electricity and carbon emission rights may become one of the profit ways for electricity consumers. Specifically, consumers who switch from using gray electricity to using 100% green electricity or those who generate carbon surplus can trade their surplus carbon emission rights to gain economic benefits. However, the final revenue still depends on the price level of green electricity differentiated trading and carbon trading.

Theoretically, meeting carbon allowance requirements can be divided into indirect method and direct method. The indirect method refers to the market entity buying the remaining carbon emission allowances of other market entities by participating in the carbon market. The direct method refers to the direct adoption of emission reduction means by market entities to reduce their own carbon emissions. Green electricity differential trading is precisely to provide electricity consumers with new options in addition to the conventional carbon emission trading varieties. This means that consumers can not only indirectly meet carbon emission allowances by purchasing carbon emission rights but also directly reduce carbon emissions by purchasing green electricity.

In summary, as shown in Figure 5, promoting the use of green electricity consumption certification as a certification mechanism for cutting carbon emissions is conducive to encouraging the development of the green electricity industry and helps provide a channel for green electricity consumption certification for enterprises, which enhances the competitiveness of Zhejiang enterprises in green trade. It also helps to realize enterprise carbon verification to prove the carbon footprint of products. From the perspective of promoting the construction of a carbon market, promoting the construction of green electricity differentiated trading market is precisely a practical attempt to realize the synergistic operation of the electricity market and carbon market and jointly serve the carbon neutrality strategy, which is expected to release additional social and environmental values. Combined with Zhejiang's practical experience, two possible cohesive mechanisms are proposed as follows:

FIGURE 5
Applications of green electricity trading certificate.

1) Promote as soon as possible the transformation of green electricity trading certificates from common in Zhejiang province to national common certificates. At the same time, the international influence of China's green electricity certification will be enhanced to further promote the development of the green trade industry.
2) Scientifically design the mutual recognition and deduction mechanism between green electricity trading certificates and carbon emission management indicators (such as peer-to-peer conversion). The certificate can be directly calculated as carbon emission reduction by a certain factor.

5 Simulation analysis

In December 2020, the Zhejiang Provincial Power Trading Center organized the first pilot green electricity market-based trading in Ningbo Fan Meishan Highly Resilient Grid Demonstration Zone. Green electricity generation enterprise and power user complete green power trading through bilateral negotiations with the trading price for the feed-in tariff up 0.01 RMB/kWh. The scale of traded green electricity is about 14 million kWh from December 1st to 31st, 2020, which attracted wide attention from society and provided Zhejiang experience of green electricity trading.

Furthermore, to demonstrate in detail the process of green electricity differentiated trading based on unilateral centralized bidding by consumers, three scenarios are considered: 1) green electricity is in short supply; 2) green electricity is in oversupply

TABLE 2 Buyer's bidding behaviors of three scenarios.

Scenario name	Buyer entity	Price 1/CNY	Quantity 1/MWh	Price 2/CNY	Quantity 2/MWh	Price 3/CNY	Quantity 3/MWh
Scenario 1	A	380	2,000	387	1,000	401	1,000
	B	379	2,500	385	1,400	400	1,100
	C	376	2,000	385	2000	397	2000
	D	382	3,000	390	1,200	407	800
	E	374	4,000	379	2,800	389	1,200
	F	381	2,000	389	1,200	405	800
	G	375	3,000	382	1,500	390	500
Scenario 2	A	366	1,800	378	1,200	386	1,000
	B	357	2,000	375	1,600	382	1,600
	C	368	2,000	379	1,200	388	800
	D	355	2,000	365	1,400	379	1,200
	E	363	1,500	376	1,200	384	1,000
	F	356	1,500	372	1,500	381	800
	G	364	2,000	377	1,500	385	800
Scenario 3	A	346	1,500	353	1,200	368	1,000
	B	348	1,800	354	1,200	369	1,000
	C	346	1,500	351	1,500	366	800
	D	347	2,000	354	1,500	369	800
	E	348	2,000	355	1,200	372	800
	F	345	2,000	350	1,400	365	1,200
	G	346	2,000	352	1,600	367	1,600

with minimum price limit protection; 3) green electricity is in oversupply without minimum price limit.

5.1 Market declaration stage

Assuming the benchmark price of coal-fired power generation is 345 CNY/MWh and the minimum price limit is 10 CNY/MWh above the benchmark price of coal-fired power generation. There are 5 green electricity plants (including 2 wind farms and 3 photovoltaic farms). The seller entities of green electricity (power generation enterprises) participate in the market declaration by only submitting the quantity but not price. The buyer entities (power users) are 7 foreign trade enterprises (including textile group A, textile group B, refining group C, refining group D, electromechanical manufacturing group E, automobile group F, and automobile group G).

Scenario 1: The declared information by the buyer entities and their bids are shown in Table 2. The total quantity declared by the buyer is 37,000 MWh and the total quantity declared by the seller is 33,000 MWh. Since the market indicates that the demand for green electricity exceeds the supply, it is more likely that the power declared by the buyer entities will not all win the bid, and thus there may be a higher declared price. The highest bid of the seven buyer entities is 401 CNY/MWh, the lowest bid is 374 CNY/MWh, and the average bid price is 383.78 CNY/MWh.

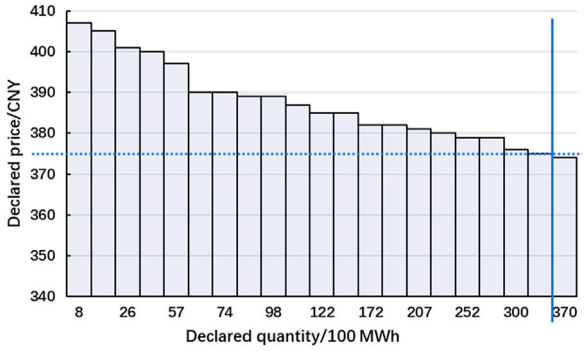

FIGURE 6
The results of clearing in the market of Scenario 1.

TABLE 3 Buyer's winning bid of Scenario 1.

Buyer entity	Declared quantity/MWh	Clearing quantity/MWh
A	4,000	4,000
B	5,000	5,000
C	6,000	6,000
D	5,000	5,000
E	8,000	4,000
F	4,000	4,000
G	5,000	5,000

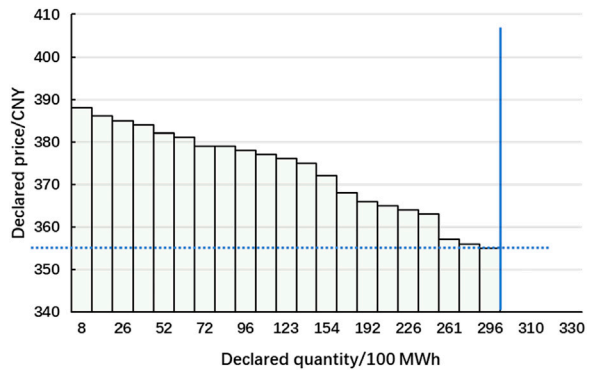

FIGURE 7
The results of clearing in the market of Scenario 2.

Scenario 2: the total declared volume of buyers is 29600 MWh and the total declared volume of sellers is still 33000 MWh. Due to the oversupply state of the market, the probability of not winning the bid for the buyer entities is relatively low. The highest declared price of seven buyer entities is $388/MWh and the lowest declared price is $355/MWh, which triggers the minimum price limit and the average declared price is 370.90/MWh.

Scenario 3: The total quantity of green electricity declared by buyers and sellers is the same as in Scenario 2, and the lowest declared price of the seven buyer entities is 345 CNY/MWh, the highest declared price is 372 CNY/MWh, and the average declared price is 353.69/MWh. Since green electricity is in oversupply and there is no protection of the lowest declared price limit, the buyer entities may use the market power to make the average declared price significantly lower compared with other scenarios.

5.2 Analysis of market clearing results

Scenario 1: As shown in Figure 6, the overall supply of green electricity is in short supply, the final traded volume is 33000 MWh, the clearing price is 375 CNY/MWh, and the market entity corresponding to the marginal electricity price is power user E. Table 3 is the specific winning bid of the buyer entities. As shown in Table 3, among the seven buyer entities, except for the power user E which has not won the bid in full, the rest of the power users' declared quantity of green electricity is fully traded.

Scenario 2: The total quantity of green electricity declared by the buyer entities is 29,600 MWh and the total quantity declared by the seller entities is 33,000 MWh, which indicates the green electricity oversupply. As shown in Figure 7, the final traded volume is 29,600 MWh, and the clearing price is 355 CNY/MWh, which is close to the lowest price limit. At this time, all buyer entities win the bids, while the winning bids of seller entities need to be allocated according to the declared quantity. The market clearing results are shown in Table 4.

Scenario 3: The green electricity still shows oversupply and the seller's clearing power allocation is consistent with Scenario 2. As shown in Figure 8, the final traded quantity is 29,600 MWh, and the corresponding unified clearing price is 345 CNY/MWh, which is close to the benchmark price of coal power. The clearing results show that the low carbon value of green electricity can hardly be effectively reflected in the oversupply scenario if the protection of the minimum bid limit is lost.

5.3 Market settlement

Without considering the transmission and distribution price (including line loss) and the apportionment cost of auxiliary services, the settlement of each market entity can be calculated and analyzed based on formula (2) and formula (3).

Scenario 1: Since the difference between the benchmark price of coal-fired power generation and the price of green electricity is 30 yuan/MWh, G1 should be 15 yuan/MWh (assuming that the proportion of allocated funds for energy storage priority construction is 50% and all electricity revenue paid to the power generation enterprise). The five seller entities received electricity revenue of 1.875 million yuan, 2.25 million yuan, 1.5 million yuan, 2.625 million yuan, and 4.125 million yuan

TABLE 4 Seller's winning bid of Scenario 2.

Seller entity	Declared quantity/MWh	Declared quantity percentage/%	Clearing quantity/MWh
A	5,000	15.15	4,484.85
B	6,000	18.18	5,381.82
C	4,000	12.12	3,587.88
D	7,000	21.21	6,278.79
E	11,000	33.33	9,866.67

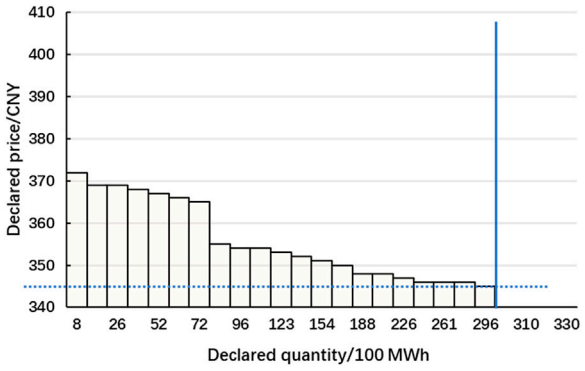

FIGURE 8
The results of clearing in the market of Scenario 3.

respectively, and the power generator obtained considerable income; while the 7 buyer entities spent 1.5 million yuan, 1.875 million yuan, 2.25 million yuan, 1.875 million yuan, 1.5 million yuan, 1.5 million yuan, and 1.875 million yuan respectively, and the detailed transaction situation and the allocation of energy storage priority construction funds are shown in Table 5.

Scenario 2: The settlement results are shown in Table 5. In the oversupply situation of green electricity, the buyer entity is less likely to not win the bid, which leads to a clearing price close to the minimum price limit. Although the revenue of seller entities decreases compared to the scenario of green electricity demand exceeding supply, they still earn additional revenue compared to the benchmark price of coal power, and the green electricity differentiated trading market is still attractive. Moreover, the settlement results also indicate that in the initial stage of the market, the scale of market entities should be expanded as much as possible. Power users should be actively cultivated and encouraged to participate in the green electricity differentiated trading market to promote the discovery of green electricity value for maintaining the stable market operation.

Scenario 3: The market settlement result is shown in Table 5. Without considering the minimum declared price limit, the low bid price of the buyer entity in the oversupply scenario may lead to serious damage to the interests of seller entities and weaken their driving force to participate in the green electricity differentiated trading, which is not conducive to the smooth start of the market. Therefore, if the scale of the buyer entities is significantly smaller than the seller entities, a minimum price limit should be established to protect the basic interests of seller entities and promote the expansion of the market scale of green electricity differentiated trading.

5.4 Pricing mechanism

The above clearing and settlement analyses all use the uniform clearing price mechanism. However, in terms of pricing mechanism, there are two mainstream models namely unified clearing pricing and pay-as-bid pricing. In the case of pay-as-bid pricing, the buyer entity is required to settle separately according to its price and the corresponding quantity, and the seller entity is required to settle in proportion to the amount of declared quantity because the seller entities don't offer price. Take Scenario 2 as an example, the market settlement using the pay-as-bid pricing mechanism is shown in Table 6.

As shown in Table 6, it can be seen that the adoption of the pay-as-bid pricing model can result in more additional green electricity benefits for the seller entity. However, it is also necessary to consider the possible impact of adopting the pay-as-bid pricing model on the bidding behavior of the buyer entity.

As the buyer entity needs to settle according to the declared price, compared with the unified pricing mechanism, the buyer entity's enthusiasm to achieve the full amount of the winning bid by increasing the bid price is inhibited. Therefore, the probability of a high bid price is relatively low. Especially in the situation of green electricity oversupply, the buyer entity may further depress the green electricity price level. In turn, it may cause the main interests of seller entities to be damaged, which is not conducive to the discovery of the low carbon value of green electricity. In addition, the adoption of the pay-as-bid pricing model as shown in Table 6 may result in the differences of green electricity purchase prices among buyer entities, which is not conducive to enhancing power users' recognition of the fairness of

TABLE 5 Settlement of the differentiated green electricity trading market of three scenarios.

Scenario name	Buyer entity	Electricity cost/ten thousand CNY	Seller entity	Electricity revenue/ten thousand CNY	Energy storage funds/ten thousand CNY
Scenario 1	A	150	A	187.5	7.5
	B	187.5	B	225	9
	C	225	C	150	6
	D	187.5	D	262.5	10.5
	E	150	E	412.5	16.5
	F	150			
	G	187.5			
Scenario 2	A	142	A	159.21	2.24
	B	184.6	B	191.05	2.69
	C	142	C	127.37	1.79
	D	163.3	D	222.90	3.14
	E	131.35	E	350.27	4.93
	F	134.9			
	G	152.65			
Scenario 3	A	127.65	A	154.73	0
	B	138	B	185.67	0
	C	131.1	C	123.78	0
	D	148.35	D	216.62	0
	E	138	E	340.40	0
	F	158.7			
	G	179.4			

TABLE 6 Settlement of market entity under the paid as bid mechanism.

Seller entity	Electricity revenue/ten thousand CNY	Revenue change/ten thousand CNY	Average electricity price CNY/MWh
A	166.34	+7.13	370.90
B	199.61	+8.56	370.90
C	133.07	+5.70	370.90
D	232.88	+9.98	370.90
E	365.95	+15.69	370.90

Buyer entity	Electricity cost/ten thousand CNY	Cost change/ten thousand CNY	Average electricity price CNY/MWh
A	149.84	+7.84	374.60
B	192.52	+7.92	370.23
C	150.12	+8.12	375.30
D	167.58	+4.28	364.30
E	137.97	+6.62	372.89
F	139.68	+4.78	367.58
G	160.15	+7.5	372.44

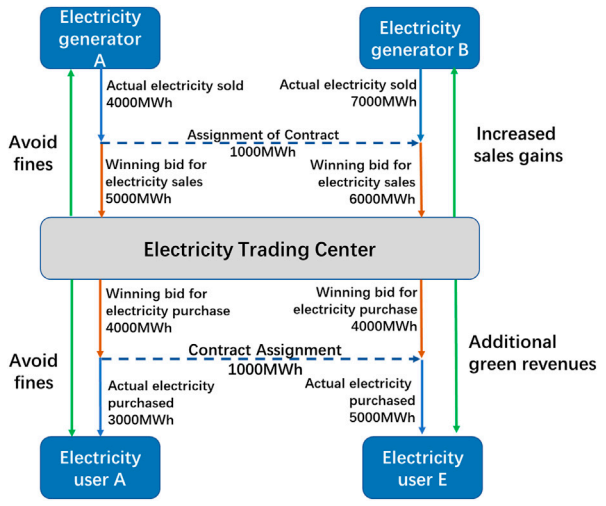

FIGURE 9
Case of contract deviation adjustment.

differentiated green electricity trading. Furthermore, users may pay higher fees which results in a poorer sense of market experience for users compared to the unified clearing pricing mechanism. Therefore, in the early stage of the green electricity differentiated trading market, it is more appropriate to adopt the uniform clearing pricing mechanism.

5.5 Deviation adjustment mechanism

Considering the randomness and volatility of green electricity generation, there may be deviations in the actual execution of the contract. Take Scenario 1 as an example. As shown in Figure 9, assume that power generator A forecasts its actual monthly green electricity generation to be 4000 MWh, which is lower than the contract quantity. Power generator B forecasts its actual green electricity generation to be 7000 MWh, which is higher than the contract quantity. According to the market rules, the over-generated portion can only be settled at the benchmark price of coal-fired power generation.

If power generator A and power generator B can transfer part of the contract power, then power generator A can avoid the annual settlement penalty of 30,000 CNY and power generator B makes an additional profit of 30,000 CNY (15,000 CNY of which can be used for supporting energy storage construction in priority) relative to the settlement at the base price of coal-fired power generation, achieving mutual benefit and a win-win situation. Another case considers there is a deviation in the green electricity consumption of users. Assuming that the actual electricity consumption of power user A is 3000 MWh, which is lower than the contract quantity of 1000 MWh, a penalty of 30,000,000 CNY shall be paid by power user A according to the market rules. However, if power user A transfers 1000 MWh to power user E, then power user E purchases additional green electricity in need, and power user A avoids paying the penalty. The total green electricity traded volume is not reduced severely by the change in actual power generation, thus realizing a win-win situation for the market operator, power users, and generators.

5.6 Analysis of implementation effect

Take Scenario 1 as an example as well. For the seller entity, the profit space is further enhanced (additional profit of 150,000 CNY, 180,000 CNY, 120,000 CNY, 210,000 CNY, and 330,000 CNY respectively) compared with the direct settlement based on the coal-fired power generation benchmark feed-in tariff. For the buyer entity, although it pays an extra cost of 30 CNY/MWh for green electricity, it can obtain green electricity trading certificates to enhance the competitiveness and honor of international trade. Furthermore, with the continuous improvement of the carbon emission index certification mechanism, the buyer entity has the opportunity to obtain additional benefits of carbon emission reduction. For instance, the formula for calculating the net purchased electricity carbon emissions of enterprises (ndrc.gov, 2013) indicates that net purchased electricity carbon emissions = net purchased electricity × electricity consumption emission factor in the region. It is possible that the electricity consumption emission factor corresponding to the part of green electricity purchased by users can be adjusted to 0, thus reducing the risk of purchasing carbon emission rights due to carbon emission overage. According to Scenario 1, the total CO2 reduction for customers is 13,200 tons assuming a carbon emission factor is 0.4tCO2/MWh. In terms of social welfare, a total of 495,000 CNY funds can be used for the green electricity storage quota construction project to continuously promote the low-carbon development of power systems.

6 Experiences and suggestions of differentiated green electricity trading

The successful implementation of the pilot trading in the Fan Meishan demonstration zone in Zhejiang Province means that the basic links and key processes of green electricity differentiated trading have been effectively verified. At present, the provincial electricity market still stays at the stage of promoting green electricity trading and consumption. In order to fully release the potential market value of green electricity and promote the formation of the environmental protection concept of “energy transition and green development”, the green electricity

differentiated trading mechanism needs to be further improved in the following aspects:

6.1 Market entity cultivation

It is recommended to conduct in-depth research on the needs of market entities. Through the digital training system and cloud training platform, providing training services for the whole process of differentiated green electricity trading operation, thereby improving the maturity, satisfaction, and sense of acquisition of market entities. Moreover, it should also fully draw on the experience of power demand-side response trial operation, actively guide eligible market entities to participate in the trial operation of green electricity differentiated trading through market invitation and participation incentives, etc.

6.2 Credit supervision and management

It is recommended to actively introduce third-party credit institutions and power trading platforms to supervise the signing of green electricity trading contracts and strengthen the credit supervision of market entities. In addition, the performance of market entities is included in the credit appraisal system. Adopt punitive measures for market entities with behaviors that disrupt market trading order and untrustworthy conduct following law and compliance, thereby ensuring orderly market operation. In addition, the introduction of blockchain technology is considered to build a security management mechanism for the whole life cycle of green electricity trading certificates covering issuance, maintenance, and audit functions to strictly prevent double counting and invalid issuance. The green electricity trading certificates adopts the issuance method of "one certificate and one code" to ensure the authenticity of green electricity consumption based on the technical advantage of blockchain technology of data traceability and anti-tampering. Furthermore, the security and trustworthiness of the blockchain-based consumer certification platform can further simplify the certification process of carbon emission reduction and reduce the cost of using the certificate.

7 Conclusion

This paper makes the mainly following contributions to meeting the growing demand for green electricity consumption in Zhejiang Province:

- This paper illustrates the design of a differentiated green electricity trading mechanism applicable to the Zhejiang objective situation and sustainable development needs combining the practical experience of electricity market reform with carbon neutrality strategy in Zhejiang province.
- This paper provides a market mechanism to support the low-carbon transformation of China's receiving-end power system and alleviate the pressure of government financial subsidies.
- The proposed derivative mechanisms such as green electricity trading certificates can meet the practical needs of power users for green electricity consumption certification and explore new paths to further enhance China's international trade image.

We hope that this paper and the related practice in Zhejiang Province can inspire more policymakers and researchers to further improve the green electricity market trading mechanism. Our next work aims to optimize the operation mode and product design to explore the path of market-oriented reform of the green power system.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

QX and SQ contributed to writing parts of the manuscript and the conceptual design of the market mechanism. HZ and RL contributed to the revision of manuscript and provided useful suggestions. XM contributed to writing parts manuscripts and designing the structure of manuscript. JG contributed to the improvement of the market mechanism design.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

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