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CLEAN ENERGY CONSUMPTION BASED ON TIME-SHARING CARBON MEASUREMENT MODEL

Shuai Yan,* Mingchun Hou,* Lei Luo,* Dali Xiao,* Bingyuan Tan,* Xiong Xiao,* and Wenguang Wu**

Abstract

Clean energy can directly generate electricity for production and life. It does not emit pollutants, has low carbon characteristics, and conforms to the requirements of the United Nations Framework Convention on Climate Change. Therefore, its power generation is increasing, which has caused the problem that it cannot be absorbed by users. This paper analyzes the current research situation of clean energy power generation consumption, studies the two main factors that affect the scenario energy consumption, namely the consumption measures and the power system flexibility supporting mechanism, and proposes a clean energy consumption method based on carbon measurement. This method is based on the integration and complementarity of clean energy and traditional thermal power. The paper introduces the mathematical model, constraints, and algorithm flow of this method. The example analysis of clean energy represented by photovoltaic power generation shows that compared with the traditional energy consumption method, the clean energy consumption method based on carbon measurement can save 9.1% of the operating cost, reduce carbon emissions by 11.7%, and improve the consumption rate by 7%.

Key Words

Clean energy, carbon measurement, absorption, carbon emission, power system

1. Introduction

Clean energy is the energy that does not emit pollutants and can be directly used for production and life, including nuclear energy and renewable energy [1]. Although the use of nuclear energy will produce radioactive substances, it will not cause carbon emissions, so it is classified as clean energy. Renewable energy, including wind energy, water energy, solar energy, tidal energy, geothermal energy, etc., are classified as clean energy. The use of these energy sources will not cause carbon emissions.

The United Nations Framework Convention on Climate Change, a national voluntary commitment and national independent contribution mechanism with common, but differentiated responsibilities for greenhouse gas emissions of States parties, requires States parties to regularly prepare and submit national inventories of anthropogenic emissions by sources and removals of greenhouse gases using a uniform and comparable method [2]. In the process of measuring, accounting, statistics, and reporting greenhouse gas emissions, we should follow the basic principles of using internationally recognized reference data, avoiding omission and repeated calculation, and verifiable comparison based on the results of measured data, and in accordance with the internationally accepted technical standards and specifications, uniformly convert them into carbon dioxide equivalent statistical reports, so as to enhance the consistency and comparability of greenhouse gas inventory measurement methods and reporting methods between countries and regions. Improve the credibility and mutual recognition of the results, and facilitate the relevant statistics, analysis, comparison, observation, and other management and research work.

The growth rate of carbon in nature is limited, which is almost an order of magnitude lower than the current rate of carbon emissions. Therefore, using clean energy to reduce carbon emissions from the source is the main research direction at present. The biggest problem with the use of clean energy is that the electricity based on clean energy cannot be completely consumed. At present, the important way to solve the problem of clean energy consumption is building group sharing on the user side. It can also further help building enterprises alleviate the pressure of carbon emission assessment through the consumption of photo voltaic green electricity [3]. The traditional measurement method of carbon emissions on the user side usually uses a fixed factor for accounting all day. In fact, the composition of power generation units

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on the energy supply side at different times of the day has certain differences, which makes the corresponding equivalent carbon emissions measurement on the user side different. Therefore, it is of great significance to study the clean energy consumption technology that comprehensively considers the time-sharing carbon emission measurement model.

This article proposes a clean energy consumption algorithm based on carbon measurement. This algorithm takes into account two main factors that affect scenario energy consumption: 1) consumption measures and 2) flexible support mechanisms in the power system. Compared with traditional energy consumption methods, clean energy consumption algorithms based on carbon measurement can save operating costs, reduce carbon emissions, and improve consumption rates.

2. Clean Energy Consumption

2.1 Research Status

At present, scholars have done a lot of research in the field of clean energy consumption optimization. Literature [4] proposes a sharing strategy of user collaborative optimization, which effectively reduces the user's operating costs. Literature [5] proposes a centralized power sharing scheme in a cooperative environment. Users aggregate and trade with the grid through aggregators. Both aggregators and users can benefit from power sharing. Literature [6] studies the power sharing scheme between users under centralized management mode. Although the sharing mode of centralized management can achieve multi-agent power sharing to the maximum extent, it also brings a huge risk of privacy disclosure to all sharing users. In recent years, the two sharing modes of local market and alliance cooperation have also received widespread attention. The above documents mainly focus on electricity sharing, and building carbon emission rights sharing under the future carbon emission assessment cannot be ignored.

Literature [7] has constructed a full-life cycle carbon cost accounting model under the two cost systems of building cluster carbon emission rights sharing and carbon emission tax. Literature [8] establishes a multi-objective decision-making model for building clusters under the two policies of low carbon emission technology and carbon emission rights sharing, and obtains the optimal sharing scheme of internal carbon emission rights. The above documents only propose the sharing of carbon emission rights among building clusters, without considering that clean energy and carbon emission rights can be shared among building clusters at the same time. Literature [9] analyzes the feasibility of sharing renewable energy and carbon emission rights among building clusters. Literature [10] through the carbon emission rights sharing mechanism of "total emission control and trading", it promotes the consumption of clean energy among buildings and improves the economy of building operation. Literature [11] proposes a carbon emission right sharing mechanism for building clusters based on multiple collaborative policies. The above documents have conducted in-depth research on the sharing of clean energy and carbon emission rights among building clusters, but the differences in the composition of power generation units at the energy supply side in different periods of time have not been taken into account in the sharing process. All the carbon emissions generated by the building clusters are measured with fixed factors throughout the day, which reduces the low carbon value of clean energy sharing among the building clusters and fails to reflect the fairness of electricity and carbon coupling sharing.

2.2 Influence Factor

Quantitative assessment of the impact factors and measures of renewable energy consumption: the technical route in this direction is devoted to quantitative analysis and comparison of the implementation effects and implementation costs of different flexible consumption measures [12]. The research focuses on the measurement of the contribution degree of the absorption influencing factors and the evaluation of the absorption capacity. The research idea is generally based on the analysis of the contribution degree of various absorption influencing factors. Through the simulation of the real power system, the evolution of the absorption capacity under different policy scenarios is analyzed to evaluate the system's absorption capacity.

The grid-connected consumption of clean energy grid involves local governments, grid enterprises, new energy owners, equipment manufacturers, and other entities, with a long management chain and great difficulty in promotion. We should establish the concept of harmony and win-win, and promote the information exchange, sharing, and coordination of all stakeholders on the basis of fully understanding their expectations and demands. First, adhere to multi-party coordination. Strengthen internal and external linkage, establish a multi-party coordinated organizational guarantee and multi-dimensional linkage working mechanism, actively connect with local government departments, actively serve new energy owners, actively communicate with equipment manufacturers, establish a multi-party linkage mechanism between the government, power grid enterprises, new energy owners, and equipment manufacturers, promote mutual coordination and cooperation among all parties, and maximize the absorption capacity of regional power grids for distributed power, cooperate to promote the full consumption of distributed power and achieve win-win cooperation. Second, adhere to demand-oriented. Guided by problems and demands, and driven by business demands, technological innovation, tackling three key technologies of large-scale distributed new energy planning and design, key terminal equipment, and cluster control, breaking through the transmission and distribution coordination technology, implementing distributed power coordinated optimization scheduling, realizing the nearby consumption of distributed power generation, achieving the optimal control of regional power grid and the maximum consumption of distributed power generation, and further integrating new methods, new equipment, new technologies. The R&D achievements of the new system are converted into a series of technical standards [12]. Formulate the distributed new energy development plan and project development plan scientifically, promote the coordinated and orderly development of power supply and power grid, and ensure the orderly access of the distributed power supply. According to the new energy planning and construction information, traditional power supply situation, power grid status, load forecast, geographical location, resource conditions, etc., take into account the needs of all parties, and realize the maximization of the comprehensive benefits of new energy development by optimizing and improving the power grid structure, orderly developing new power projects and other measures.

3. The Time-Sharing Carbon Metering and Absorption Method

3.1 Measurement Standard

There are many carbon measurement standards. In 2002, the International Organization for Standardization (ISO) established the Technical Committee on Environmental Management (TC207) and the Subcommittee on Standardization of Greenhouse Gas Management (SC7) in 2007. At present, 11 standards have been issued and six are under revision [13]. The ISO issued the ISO 14064 series standards and the ISO 14067 series standards in 2006 and 2013, respectively, and the Air Quality Standards Committee (ISO/TC146) issued the ISO 19694 series standards of "Fixed Source Emissions - Determination of Greenhouse Gas Emissions from Energy-intensive Industries" in 2014. At present, countries in the world are also building relevant standard systems. The design standard of this paper is the 2006 IPCC Guidelines for the National Greenhouse Gas Inventories developed by the Intergovernmental Panel on Climate Change (IPCC). This standard is the most widely used carbon measurement and accounting standard in the world and will be revised in 2019 [14].

3.2 The Absorption Model

This paper proposes a clean energy consumption model considering time-sharing carbon emission measurement, as shown in Fig. 1. If users operate independently, some high-emission buildings will cause economic losses due to excessive carbon emissions. When these users form an alliance to operate, the internal electricity and carbon emission rights are priced according to the real-time electricity and carbon emission rights supply and demand of each building in the alliance, and then the users adjust their energy use plans according to the price signals transmitted by the alliance sharing platform, and obtain the optimal operation plan of the alliance through interactive sharing iteration, meet the diversified needs of users, and reduce the cost of the entire alliance to purchase electricity from the superior power grid, It has improved energy efficiency and economy.

As a virtual entity to realize power sharing within the alliance, the alliance sharing platform provides an internal

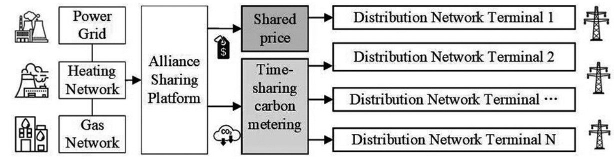

Figure 1. Time-sharing carbon metering structure model.

power trading price, carbon emission trading price, and fee settlement services for user terminal groups. As a non-profit public platform, the operation and maintenance costs of the alliance sharing platform are shared by the internal user terminals of the alliance.

3.3 The Absorption Algorithm

Measurement essentially refers to the amount of carbon dioxide emissions generated when users produce, transport, use, recycle, and process various products. At present, most of the measurement methods used are fixed carbon emission factors given by the IPCC. The traditional fixed factor fails to fully consider the impact of the future electricity carbon market coupling on the carbon measurement of electricity purchase. This paper believes that the change of carbon price and electricity price depends on the structural factors, such as the generation capacity of generating units, power demand level, and so on. This paper takes into account the differences in the composition of different power generation units in different periods of energy, and measures the carbon footprint of group power purchase in a time-sharing manner, so as to deepen the sharing potential of clean energy among groups and improve the economy of active distribution network operation [15].

Combined with the division method of the blocked time period of new energy absorption, the active distribution network multi-load coordinated and optimized dispatching model to improve the new energy absorption capacity and improve the new energy absorption capacity, the power grid dispatching strategy based on time-sharing carbon measurement is comprehensively obtained, which includes four parts. The active distribution network dispatching layer establishes the upper layer modified coordination optimization model and solves it to obtain the final optimized dispatching plan of wind and solar power, and the interaction power with the main network tie line. The flow chart is shown in Fig. 2.

The specific process is as follows: obtaining the predicted value of solar and solar power output, the predicted result of the non-adjustable load in the active distribution network basic data, such as day-ahead power consumption plan and cluster adjustment model parameters, are reported by various multi-load cluster agents; Calculate the blocked time period and the blocked new energy power. The active distribution network dispatching control center establishes the time-sharing carbon metering optimization dispatching model based on the current division of the blocked time period and the boundary information of the cluster power and cumulative consumption reported by each cluster agent; A nonlinear particle swarm optimization

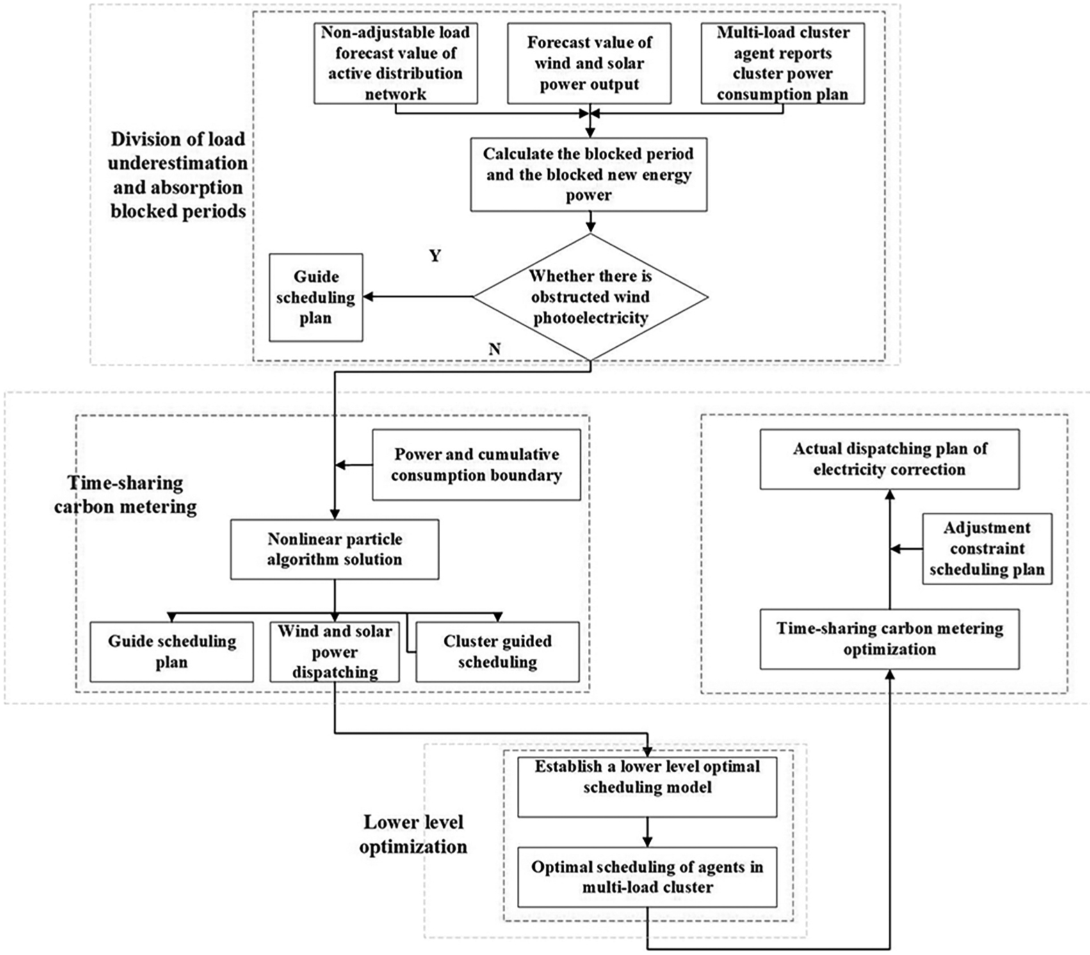

Figure 2. Time-sharing carbon metering new energy consumption optimization scheduling strategy flow chart.

algorithm based on the worst solution of particle history is adopted to solve the upper optimization model; The guiding dispatching plan for outputting solar and solar power, various multi-load cluster agents, and outgoing power with the main network interconnection line. Each multi-load cluster agent obtains the guiding dispatching plan issued by the upper layer, and each cluster follows the guiding dispatching plan issued by the active distribution network dispatching control center [16]. According to the operation and regulation constraints of the individual within the cluster agent, the lower layer optimization model is established with the objective of minimizing the overall optimization cost of the cluster agent; The improved particle swarm optimization algorithm is used to solve the model, and the optimal scheduling plan of the individual in the cluster agent is obtained, which is transferred to the active distribution network scheduling layer; Based on the optimized dispatching plan reported by each cluster agent.

At this time, it is assumed that the power generation of non-clean energy is large, and the power generation of clean energy is small, but it is rising, and the carbon emission intensity on the power generation side increases slowly; Considering that there are certain differences in the composition of power generation units on the energy supply side during different time periods, it is divided into three different time periods to measure the carbon emissions of electricity purchased by the superior power grid. According to the peak and valley periods of electricity consumption on the user side, time period I (23:00-07:00) is defined as the period when the proportion of low-carbon emissions in electricity purchases is low. At this time, the power generation of thermal power units decreases, and the carbon emission intensity on the power generation side significantly decreases; Time period II (11:00-19:00) is defined as the period when the proportion of carbon emissions in electricity purchases is high. At this time, the power generation of thermal power units is relatively high, but the power generation of clean energy units has also increased, and the carbon emission intensity on the power generation side has slightly increased; Time period III (07:00-11:00, 19:00-23:00) is defined as the period when the proportion of high carbon emissions from purchasing electricity is high. At this time, the proportion of thermal power generation is relatively high and the generation of clean energy units is low, resulting in a significant increase in carbon emission intensity on the power generation side. Considering the operation and maintenance costs of the generator units on the power generation side, buildings also need to measure certain carbon emissions when purchasing clean energy from the superior power grid. The time-sharing model for measuring carbon emissions from electricity purchases by superiors is formula (1):

$$W^E = \varepsilon^j P^B \tag{1}$$

$$\begin{bmatrix} \varepsilon^I \\ \varepsilon^{II} \\ \varepsilon^{III} \end{bmatrix} = \begin{bmatrix} R_1^I & R_2^I & R_3^I \\ R_1^{II} & R_2^{II} & R_3^{II} \\ R_1^{III} & R_2^{III} & R_3^{III} \end{bmatrix} \begin{bmatrix} \chi^S \\ \chi^{\mathrm{PV}} \\ \chi^H \end{bmatrix} \tag{2}$$

Where: W^E is the equivalent carbon emission of electricity purchase from the superior power grid; ε^j is the measurement factor of carbon emissions per unit of power purchase for period A, B, and C; P^B is the purchased power of the superior power grid; R_1^j, R_2^j, and R_3^j are the actual power generation ratio of thermal power generation unit, photo voltaic power generation unit, and water turbine unit in time period j, respectively; χ^S, χ, χ^{PV}, χ^H are the carbon emission measurement factor of unit power generation of thermal power unit, photo voltaic power unit, and hydraulic turbine unit.

Formula (2) has two constraints, the electric-carbon coupling constraint and the energy storage constraint.

Because in the intelligent terminal group, terminals have different characteristics of load, follow the mode of building autonomous operation, and consume different power in different periods. The constraint conditions of electro-carbon coupling are as follows (3):

$$\begin{cases} -\phi(V^d - V^{\mathrm{CO}_2}), V^{\mathrm{CO}_2} \le V^d \\ e^{d_1}(V^{\mathrm{CO}_2} - V^d), V^d < V^{\mathrm{CO}_2} \le (V^d + d) \\ e^{d_1}d + e^{d_2}(V^{\mathrm{CO}_2} - V^d - d), \\ \quad (V^d + d) < V^{\mathrm{CO}_2} \le (V^d + 2d) \\ (e^{d_1} + e^{d_2})d + e^{d_3}(V^{\mathrm{CO}_2} - V^d - d), \\ \quad (V^d + 2d) < V^{\mathrm{CO}_2} \le (V^d + 3d) \\ \qquad \vdots \end{cases} \tag{3}$$

V^{CO_2} is the terminal load power and net demand carbon emission right; V^d is the variable of terminal purchase and sale of carbon emission rights. d is the length of carbon emission intervals for stepped emissions; e^{d_1}, e^{d_2}, and $e^{\mathrm{d}3}$ are the carbon prices of excess emissions of stepped carbon dioxide. ϕ is the reward coefficient for saving per unit of carbon emissions.

4. Example and Analysis

4.1 Application Scenario

Power grid terminal with industrial intelligent building cluster, which is equipped with high energy consumption and high carbon emission equipment, such as combined heat and power (CHP), gas boiler (GB), and so on. Its decision-making model aims to minimize the total operating cost [17]. The total operating cost includes the cost of purchasing and selling electricity with the superior power grid, the cost of purchasing and selling electricity and carbon emission rights with other buildings, the cost of purchasing gas from the natural gas network, and the cost of purchasing heat from the superior heating network equipment operation and maintenance costs, carbon reward, and punishment costs. Schematic diagram of the scene is shown in Fig. 3.

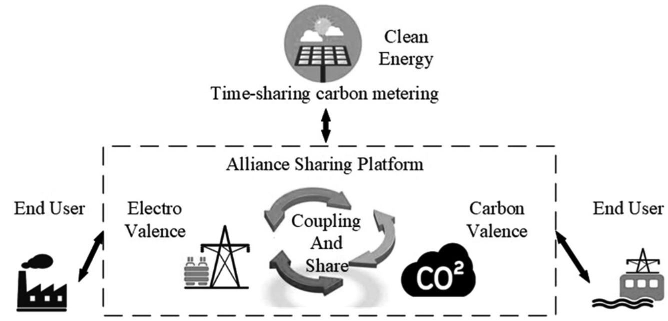

Figure 3. Time-sharing carbon metering application scenario.

The user load data comes from the measured data. The terminals are installed with smaller distributed optical storage systems, and the peak power of photo voltaic power generation is 5700 kW. The transaction scenario is a typical day in summer, so only the cluster has thermal load. Building 1 is installed with CHP equipment and GB equipment, and the price of natural gas is 1.150 CNY/m3. The rated capacity of energy storage is 300 kWh, and the cost coefficient of energy storage charge and discharge loss is 0.2. The predicted deviation of the set transferable load is ±10%, and the on-grid price of photovoltaic residual power is 0.421 CNY/(kWh). The electricity purchase price of the power grid is calculated according to the peak and valley price of single manufacturing industry and commerce. According to the carbon emission quota of buildings for one year, this paper assumes that the carbon emission quota of building 1 is 4t/day, the carbon emission quota of building 2 and 3 is 2T/day, and the cluster optimization cycle is t=24; time interval $\Delta\ t$=1.

Take a comprehensive high-rise building as the research object. Its area is 300 W square meters, and the main power generation loads are residential electricity, commercial electricity, and public electricity. The average load demand coefficient is 0.26. The entire building adopts a circular website structure, with low voltage dual incoming lines, one incoming line for operation and one incoming line for backup, meeting the requirements of secondary load. Set the load curve of building as shown in Fig. 4.

The power supply of the residential area comes from clean energy generation. The output period of clean energy power generation is from 5 a.m. to 20 p.m. The maximum output of clean energy is 600 Kw and the power prediction curve of clean energy generation as shown in Fig. 5.

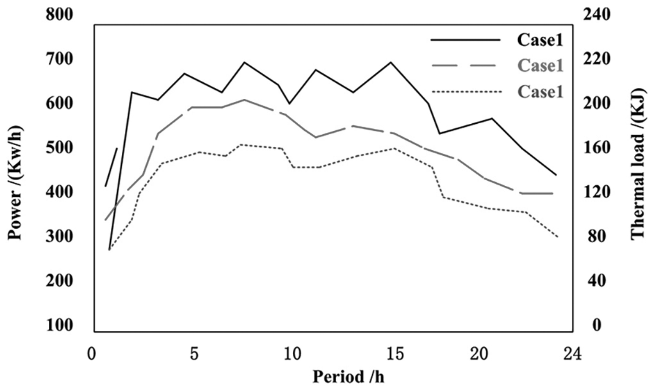

Figure 4. Load curve of building.

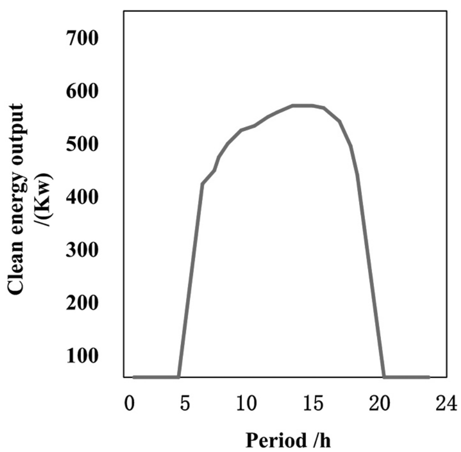

Figure 5. Prediction curve of clean energy power generation.

4.2 Result and Analysis

According to Table 1, the new energy consumption based on carbon time-sharing measurement is beneficial to the purchase price of electricity in the alliance, which is less than the purchase price from the superior grid, the price of selling electricity to the alliance is higher than that to the superior power grid, therefore, the operating cost of its cost can be reduced. According to Table 1, under the operation mode of the traditional supply-demand ratio sharing strategy, the operation cost of new energy consumption based on carbon time-sharing measurement is reduced by 9.1% compared with non-alliance operation, and the new energy consumption strategy based on carbon time-sharing measurement proposed in this paper is reduced by 11.7% compared with non-alliance operation.

The operation results of the energy consumption rate of the whole system are shown in Fig. 6. The buildings will store the remaining electric energy after meeting their own load demand in the period of low electricity price in the ESS, and supply the electric energy in the ESS equipment to their own load in the period of high electricity price to reduce the building operation cost. The building can store the remaining electric energy after meeting its own load demand or purchase the remaining electric energy of other buildings, and store it in the ESS. When other buildings have a shortage of electric energy, the electric energy will be released from the ESS and sold to other building entities for more profits.

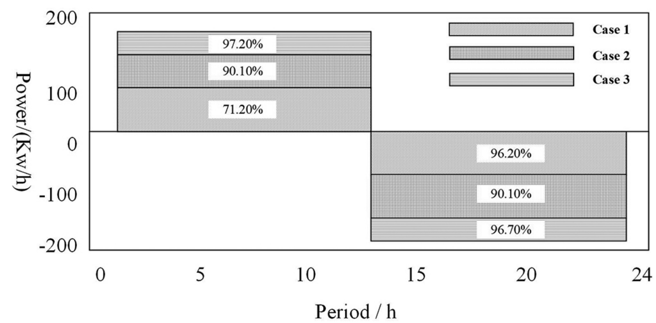

Figure 6. Proportion of new energy consumption.

From Fig. 6, it can be seen that for the above calculation example, the time-sharing carbon metering algorithm used in this article has the best effect on clean energy consumption, reaching 97.2% in the morning period (0:00–12:00). In the afternoon and evening periods (12:00–23:00), due to the high output of clean energy, the difficulty of consumption increases, and the consumption rate slightly decreases compared to the morning period, but it can still reach 96.7%, far superior to other algorithms.

The energy storage equipment stores the remaining electric energy after meeting its own load demand or purchases the remaining electric energy of other building entities during the period of medium and low carbon proportion, releases the electric energy to meet its own load or sells it to other buildings during the period of high carbon proportion, and gains profits while reducing the total carbon emissions of the entire user terminal alliance. The new energy consumption method considering time-sharing carbon measurement proposed in this paper can increases the output of clean energy and further achieve the goal of emission reduction.

4.3 Application Examples

The China State Grid Jiangsu Electric Power Company, relying on the Jiangsu Energy Cloud Network platform, has launched carbon emission data products for key energy consuming units in the province, targeting more than 3000 energy efficiency monitoring users who have settled on the platform. The system aims to improve comprehensive energy efficiency for the whole society and build an open and shared comprehensive energy service platform, targeting the diverse needs of different user groups, such as energy customers, energy service providers, and government agencies, provide precise carbon emission enquiry, and energy efficiency services. The carbon emission data product adopts the emission factor accounting method to calculate and analyze the carbon dioxide emissions generated by energy activities of energy consuming units, ultimately achieving the goal of saving costs and reducing carbon dioxide emissions.

Table 1
Comparison of Operating Costs

Scene	Cluster 1 Cost (CNY)	Cluster 2 Cost (CNY)	Cluster 3 Cost (CNY)	Total (CNY)	Economy
Case 1	6100.7	2712.2	1170.0	9982.9	-
Case 2	5633.4	2651.3	963.1	9247.8	Better
Case 3	5231.5	2600.1	912.7	8744.3	Best

5. Conclusion

Aiming at the problem of how user terminals can promote the interactive sharing of clean energy, this paper constructs a clean energy consumption method based on time-sharing carbon measurement. Through example analysis, the following conclusions are drawn:

(1) Compared with the traditional non-cooperative operation mode, the clean energy consumption method based on time-sharing carbon measurement proposed in this paper saves 11.7% of the cost, which proves its economy.

(2) The clean energy consumption method based on time-sharing carbon measurement has changed the working hours of flexible resources, such as energy storage and HVAC, and can effectively improve the new energy consumption rate by 7%.

(3) The carbon reward and punishment mechanism has a significant impact on the consumption of new energy. If we consider the planning scheme of a tiered carbon reward and punishment mechanism, carbon emissions will be significantly reduced. However, when considering a tiered carbon reward and punishment mechanism, the planning cost of consumption will increase, proving that the tiered carbon reward and punishment mechanism will sacrifice some economic benefits in exchange for carbon emission reduction performance.

(4) The comprehensive demand response function during the new energy dispatching period makes the energy consumption curve more gentle, which proves the effectiveness of the comprehensive demand response combined with the ladder carbon reward and punishment mechanism in energy conservation and emission reduction, which can further tap the absorption potential of new energy.

The clean energy consumption method based on time-sharing carbon measurement will slightly increase carbon emissions, but it has an obvious effect on reducing carbon missions for user terminals with excessive carbon emissions. At the same time, all buildings in the alliance will gain benefits after responding to carbon emissions reduction, proving that the clean energy consumption method based on time-sharing carbon measurement has a reduction effect on carbon emissions.

Data Availability Statement

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Conflicts of Interest

The authors declared that this article is free of conflict of interest.

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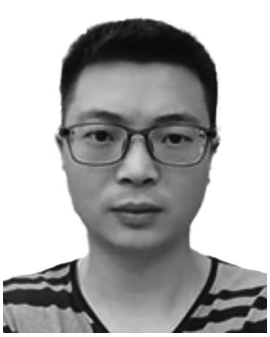

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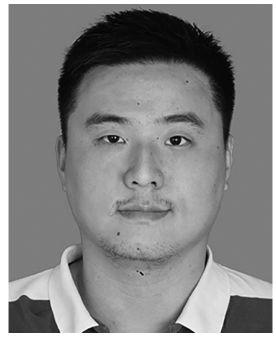

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