Renewable Energy and Power Quality Journal (RE&PQJ)
ISSN 2172-038 X, Volume No.22, September 2024

Analysis of the Psychological Willingness and Impact of Rural Residents to Use Clean and Renewable Energy Based on a Multiple Evaluation Model

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Abstract. Firstly, the basic structure of the rural integrated energy system is introduced. The supply and demand mode combining the integrated energy system, renewable energy and facility agriculture can improve the consumption capacity of renewable energy and realize the common energy supply and utilization of multiple energy sources, which is conducive to improving the low energy utilization rate and improving the flexibility of the system. The working principle of the energy supply side and the conversion side is analyzed, and the corresponding mathematical model is established. Considering the load side demand of the rural integrated energy system, taking a rural area in northern China in winter as an example, the electric and heat load values of each part of the load are calculated. Secondly, the life cycle assessment method is used to evaluate the carbon emissions of the rural integrated energy system. According to the principle of the carbon emission coefficient method, the industries in the rural integrated energy system are divided into four stages: raw material production stage, equipment installation stage, equipment operation stage and equipment demolition and recovery stage. On the premise of the consistency of the basic data of carbon emissions in each stage, the carbon emissions and energy consumption of each industry based on LCA are calculated, and then the independent carbon emission factors of each industry are calculated, and then the carbon emissions of the equipment can be calculated according to the power generation. Regardless of the photovoltaic power generation method, its gas emissions are smaller than conventional power generation. After adding photovoltaic power generation, gas emissions can be reduced by at least 89 %. For the analysis of photovoltaic power generation, the production and assembly of solar silicon panels is a key stage affecting its life cycle energy consumption and CO_2 emissions. Every 0.65 square meters of silicon panels will emit 80 kilograms of CO_2. The CO_2 emissions of trough and tower solar thermal power generation are 0.026 kg / kWh and 0.038 kg / kWh, respectively, indicating that their greenhouse gas emissions are small. The results show that the whole life cycle method is of practical significance for accounting for the carbon emissions of rural integrated energy systems.

Key words. Rural Energy, Renewable Energy, Multi-objective Optimization, Full Life Cycle Method, Operation Strategy.

1. Introduction

The manufacturing process of biomass energy involves multiple production and processing steps. By analyzing the energy consumption, resource consumption, and pollution emissions at each stage of the lifecycle, we can provide reference data for carbon cycle research and fully understand the environmental load and resource consumption at each stage, providing support for further ecological product design [1]. In foreign countries, the life cycle assessment method of biomass energy has been widely applied in fields such as biomass fuel ethanol, biodiesel, and biogas. Regarding biogas, a life cycle assessment method was used to evaluate the biogas power generation system in the Piedmont region of northern Italy, using different crops and manure as raw materials [2], [3]. The research results show that biomass energy is not always equivalent to sustainable energy, and there are significant differences in its environmental performance. The degree of greenhouse gas reduction largely depends on the substitution of non-renewable energy [4]. In the study of biodiesel, the life cycle assessment method was used to analyze the energy consumption, greenhouse gas emissions, and renewability of two different scenarios for the production of biodiesel by Jatropha Curcas [5], [6]. The research results indicate that both options have good energy and environmental benefits. In the field of fuel ethanol, a lifecycle assessment was conducted on cellulose fuel ethanol systems using straw as raw material. The research results show that fuel ethanol performs poorly in terms of fossil energy consumption, respiratory system effects, and carcinogenic effects, mainly due to the extensive use of hydrochloric acid and energy consumption in the production process. The life cycle energy evaluation method was used to evaluate the environmental benefits of Robinia pseudoacacia, fuel ethanol, and E10 gasoline [7], [8]. The environmental benefits of E85 blended gasoline as a transportation fuel were also evaluated, and compared with traditional gasoline. The evaluation results indicate that fuel ethanol and black locusts contribute to reducing global warming, acidification, eutrophication, and fossil fuel consumption [9]. The literature also proposes the optimal planting mode for Robinia pseudoacacia from an environmental perspective [10].

In terms of straw power generation, LCA evaluation software was used to evaluate the 4MW-e biomass gasification combined cycle power generation system using straw as raw material [11], [12], including environmental impact analogies such as non-renewable resource depletion potential, global warming, ozone layer depletion, and photochemical oxide formation in biomass gasification power generation systems [13]. The results indicate that biomass gasification power generation system is superior to coal gasification power generation system in terms of environmental impact [14]. Many scholars in China also use life cycle assessment methods to analyze and evaluate the development and utilization of biomass energy. To alleviate the insufficient energy supply in rural areas, an energy consumption model with biogas as the main source, complementary wind and solar energy, and multiple energy sources can be adopted. At the same time, promoting the conversion of coal to electricity in rural areas, improving the ecological environment, and reducing the living costs of farmers can be adopted. Utilize biogas as cooking energy, promote the use of solar energy, develop renewable energy, build a comprehensive rural energy system, and develop a multi-energy complementary system. A 25MW straw power generation system was studied using the life cycle assessment method, and the impact of the system on the environment was analyzed. The relationship between the improvement of key technologies and the reduction of environmental impact of biomass power generation systems was explored. A quantitative analysis was conducted on the entire lifecycle process of straw biomass briquettes from crop cultivation to fuel combustion using the life cycle assessment method [15]. The research results indicate that straw-shaped fuel has a good greenhouse gas emission reduction effect, and it is pointed out that reducing the use of nitrogen fertilizer during the planting stage is the key to reducing system energy consumption and greenhouse gas emissions [16]. By considering parameters such as resource depletion rate, energy return rate, environmental impact load, and life cycle cost, a comprehensive evaluation and comparative analysis of coal and straw briquettes were conducted from the perspective of the entire life cycle using the life cycle assessment method. A comprehensive EEE index combining energy, environment, and economy was established for evaluation.

2. Implementation of Multi-objective Optimization Algorithms for Renewable Energy Systems

A. Multi-objective Optimization of Systems Under the Environment-dominated Comprehensive Evaluation Model

The ultimate goal of the integrated energy system as an energy supply system is to provide energy to the user side, as shown in equation (1), based on the premise and guidance of the user side's multi-grade demand, to ensure real-time feedback for the system. The energy needs of users are closely related to the climate conditions, building structure characteristics, and local living habits of their location.

$$\mathrm{PER}^{\mathrm{TS}} = \frac{\mathrm{Q}_{\mathrm{output}}}{\mathrm{F}_{\mathrm{input}}^{\mathrm{TS}}} \tag{1}$$

Using DeST to simulate the hourly load of the energy-consuming end throughout the year, as shown in equation (2), determine the demand for domestic heat, electricity, cooling, gas, and other factors on the user side. Adjust the required time step by using the difference method with hourly intervals throughout the year.

$$\mathrm{PER}^{\mathrm{CES}} = \frac{Q_{\mathrm{output}}}{F_{\mathrm{input}}^{\mathrm{CES}}} \tag{2}$$

Distributed energy supply based on complementary multiple renewable energy sources is essentially a supply, storage, use, and control system based on multiple material and energy flows. As shown in equation (3), to ensure the stability of energy supply, the balance of dynamic loads of heat, electricity, and gas needs to be a necessary constraint.

$$Q_{\mathrm{output}} = E_{\mathrm{user}} + Q_{\mathrm{h}} + Q_{\mathrm{c}} + Q_{\mathrm{gas}} \tag{3}$$

As shown in equation (4), The total heat demand includes the total heat consumption of users and the system heat demand.

$$F_{\mathrm{input}}^{\mathrm{TS}} = F_{\mathrm{coal,h}}^{\mathrm{TS}} + F_{\mathrm{coal,e}}^{\mathrm{TS}} + F_{\mathrm{straw}}^{\mathrm{TS}} \tag{4}$$

The sum of the power generation of the system's driving equipment, photovoltaic power generation, and purchased electricity from the grid shall not be less than the total electricity demand. As shown in equation (5), the total electricity demand of the system includes the electricity demand of households, the accompanying electricity consumption of the system itself, and the electricity consumption of air source heat pumps.

$$F_{\mathrm{input}}^{\mathrm{CES}} = F_{\mathrm{coal}}^{\mathrm{CES}} + F_{\mathrm{ad}}^{\mathrm{CES}} + F_{\mathrm{b}}^{\mathrm{CES}} \tag{5}$$

The total amount of biogas purified by the system and the storage capacity of the gas storage device should not be less than the total gas demand. As shown in equation (6), the total gas demand of the system includes the amount of biogas consumed by internal combustion engines and the amount of biogas consumed by households for cooking.

$$\mathrm{PESR}=\frac{F_{\mathrm{input}}^{\mathrm{TS}}-F_{\mathrm{input}}^{\mathrm{CES}}}{F_{\mathrm{input}}^{\mathrm{TS}}}=1-\frac{F_{\mathrm{input}}^{\mathrm{CES}}}{F_{\mathrm{input}}^{\mathrm{TS}}}=1-\frac{\mathrm{PER}^{\mathrm{TS}}}{\mathrm{PER}^{\mathrm{CES}}} \tag{6}$$

B. Optimization Model Under Environmental Dominant Comprehensive Evaluation Indicators

As shown in equation (7), and the actual fuel mass flow rate and actual output power rate of the internal combustion engine are less than their maximum rate of change, the outlet temperature of the cooling water of the internal combustion engine does not exceed the maximum outlet temperature.

$$m_{\mathrm{CO_2}}^{\mathrm{TS}}=m_{\mathrm{CO_2,coal,e}}^{\mathrm{TS}}+m_{\mathrm{CO_2,coal,h}}^{\mathrm{TS}}+m_{\mathrm{CO_2,straw}}^{\mathrm{TS}} \tag{7}$$

At present, there is no relevant conclusion to prove that the solution obtained by multiplying more than a certain number of generations is optimal, as shown in equation (8). However, from the theoretical analysis of optimization algorithms, each iteration is an "evolution".

$$m_{\mathrm{NO}_x}^{\mathrm{TS}}=m_{\mathrm{NO}_x,\mathrm{coal},e}^{\mathrm{TS}}+m_{\mathrm{NO}_x,\mathrm{coal},h}^{\mathrm{TS}}+m_{\mathrm{NO}_x,\mathrm{straw}}^{\mathrm{TS}} \tag{8}$$

There are two ways to stop the reproduction frequency of optimization algorithms. One is to set a specified reproduction frequency, which is manually set and usually determined based on experience; One way is to look at the output solution and see if its value has changed after a period of iteration. For example, if the individual obtained after 30 consecutive iterations does not change, as shown in equation (9), it can be considered that the optimization algorithm has converged, and the solution obtained at this point can be considered the optimal solution.

$$m_{\mathrm{CO_2}}^{\mathrm{CES}}=m_{\mathrm{CO_2,gas}}^{\mathrm{CES}}+m_{\mathrm{CO_2,ice}}^{\mathrm{CES}}+m_{\mathrm{CO_2,coal,e}}^{\mathrm{CES}}+m_{\mathrm{CO_2,b}}^{\mathrm{CES}}-m_{\mathrm{CO_2,CH_4}}^{\mathrm{CES}} \tag{9}$$

The larger the population, the better the global search ability, which can better avoid getting stuck in local optima; The smaller the population, the slower it is to find the optimal solution, which may result in insufficient accuracy. As shown in equation (10), the population size can be determined by continuous attempts to determine an estimate.

$$m_{NO_x}^{CES}=m_{NO_x,coal,e}^{CES}+m_{NO_x,b}^{CES} \tag{10}$$

A comprehensive energy system with multiple complementary renewable energy sources uses cow manure and solar energy as the basic energy sources, as shown in equation (11), and coal corresponding to biomass briquette fuel and power grid replenishment as supplementary energy sources.

$$CESR=\frac{m_{CO_2}^{TS}-m_{CO_2}^{CES}}{m_{CO_2}^{TS}} \tag{11}$$

During the non-heating season, there is a situation of supplementing electricity and heating, as shown in equation (12). Due to the large heat demand in cold regions, the internal combustion engine operates at full load throughout the year, and the consumption of cow manure and biomass briquettes is greater than the other two operating modes.

$$NESR=\frac{m_{NO_x}^{TS}-m_{NO_x}^{CES}}{m_{NO_x}^{TS}} \tag{12}$$

3. Basic Structure and Mathematical Model of Rural Renewable Energy System

A. Overview of Rural Renewable Energy Systems

China's rural energy resources are rich in variety, but due to the scattered distribution and diversified demand of rural energy, the energy utilization rate is low, resources are wasted, and the economy needs to be improved [17], [18]. Therefore, this article proposes the construction of a comprehensive rural energy system, integrating multiple industry models such as new energy power generation, agricultural product planting, and animal husbandry, fully utilizing rural resource endowments, replacing traditional thermal power generation with renewable energy such as wind power, photovoltaic, biomass energy, anaerobic fermentation and biogas production, reducing environmental pollution and carbon emissions. The energy input side of the rural comprehensive energy system is determined by the abundant fermentable waste such as wind and solar energy, biomass energy, etc. in the countryside, including wind turbines, photovoltaic power plants, biomass energy power plants, and biogas power plants; On the energy conversion side, it includes heat pumps and electric to heat conversion equipment that convert electrical energy into thermal energy; On the energy storage side, the main consideration is thermal storage equipment; The load side considers the energy needs of rural vegetable greenhouses [19], animal husbandry, and residential households. This chapter analyzes the entire energy structure by establishing a rural comprehensive energy system model that responds to and regulates each other, in preparation for subsequent optimization scheduling research. Figure 1 shows the model diagram of the integrated energy system. The rural integrated energy system is essentially a micro energy grid, based on the theory of the integrated energy system, continuing its characteristics of mutual response and regulation, integrating diverse rural resources, considering the vast and sparsely populated land resources, idle roof resources, and unique and rich resources such as straw, kitchen waste, and feces in rural areas. It is centered around the power system, The micro energy grid system, which is composed of distributed new energy sources, energy storage devices, energy conversion devices, and residential and agricultural loads, is an extension of the energy internet in the agricultural field. It is an energy system that can operate in parallel with the external power grid or independently [20].

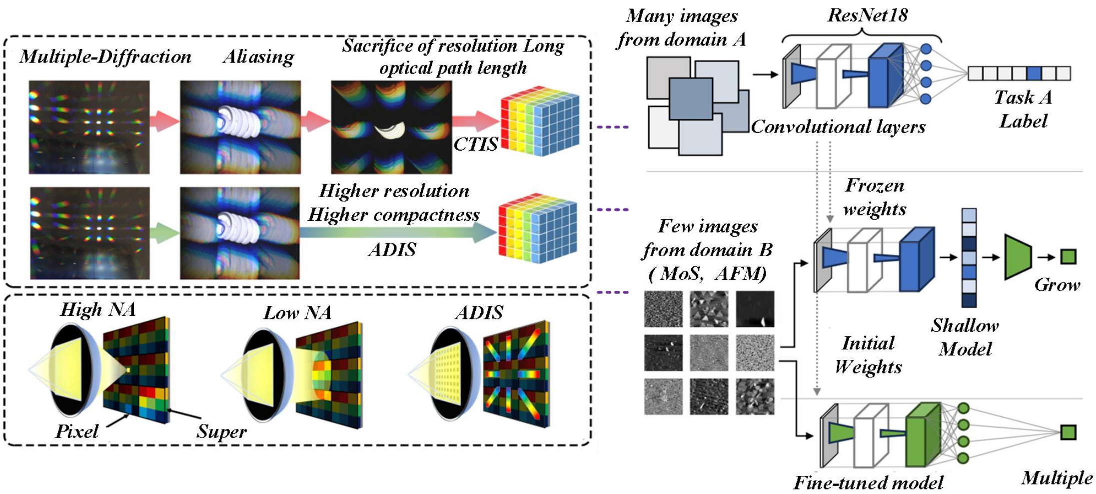

Figure 1. Integrated Energy System Model Diagram

Rural commodity energy consumption accounts for only about 75% of total energy consumption, while urban energy consumption is basically commodity energy. In rural household energy consumption, coal accounts for the highest proportion, followed by firewood, straw and electricity. In China, the remnants of deforestation are mostly used by farmers for cooking and heating. The energy utilization methods are relatively primitive, and the utilization level of biomass resources in their original form is low, which cannot be processed on a large scale. Straw is often burned casually in the fields, causing serious environmental pollution. In rural China, winter heating mainly relies on burning coal to meet the demand. The continuous growth of per capita housing area and the increasing per capita energy consumption has brought certain challenges to environmental protection. With the arrival of the heating season in the north, pollution problems are particularly evident, and haze control work should mainly focus on controlling loose coal. The inadequate rural power infrastructure, low load of township substations, and outdated transmission lines have led to low quality of rural power supply and services, as well as low levels of electrification. The consumption of renewable energy in rural areas mainly relies on the supply of small-scale photovoltaics and wind power, with small installed capacity and lower consumption of renewable energy. Overall, the energy consumption structure in rural areas needs to be optimized, and the energy quality is lower than that in cities [20], [21].

B. Main Equipment Models of Rural Renewable Energy Systems

Rural areas are vast, with few large buildings and abundant wind and solar energy resources. Crops such as straw, which are easily accessible in rural areas, can be used as biomass energy for gasification and energy supply. Poultry, livestock, human manure, and kitchen waste can enter the biogas digester to react and produce biogas [22]. This article adapts to local conditions and constructs an energy internet that is suitable for a rural area in northern China. It reasonably consumes new energy, effectively utilizes the abundant wind and solar energy in rural areas, as well as biomass energy such as straw, firewood, and animal manure [23], to meet the electricity and heat load of rural terminals and improve energy utilization efficiency. The input side of the rural comprehensive energy system mainly includes wind power generation, photovoltaic power generation, biomass power generation, and anaerobic fermentation biogas power generation. Among them, biomass power generation and biogas power generation have great advantages in rural areas. Their raw materials are convenient and easy to obtain, and they can also absorb some waste, which is conducive to the construction of a clean new countryside to a certain extent. By using energy conversion and storage devices, electrical energy can be converted into thermal energy to meet rural heat demand. The input side and energy conversion and storage equipment are collectively referred to as the energy system [24], [25]. The energy system inputs energy in the form of electricity and heat to meet rural electricity and heat loads. After agricultural production, it can produce waste such as straw and livestock manure. As mentioned earlier, this waste can be reasonably utilized and supplied to power generation equipment to maintain the operation of the energy system. This cycle reflects the complementarity of various parts in the rural comprehensive energy system, achieving a huge transformation from the traditional one-way energy flow mode to a more fully utilized circular energy flow mode. Figure 2 shows the optimization and scheduling diagram of the rural comprehensive energy system. Therefore, before establishing a wind turbine generation model, in order to reduce the error of power prediction, it is necessary to analyze its uncertainty. Photovoltaic power generation units convert solar energy into electricity and supply it to users. Rural areas not only have abundant solar energy, but also have large roof areas and sufficient idle space. Installing photovoltaic panels on the roofs of rural residents or livestock farms has sufficient available space, which not only meets certain energy supply needs but also generates corresponding benefits, which is conducive to the sustainable development of a low-carbon economy in rural areas. China is a major agricultural country, with abundant arable land and easily accessible mountain and forest resources in rural areas. Biomass energy is abundant, but in addition to a small amount used for feed, there is still a large amount of biomass resources that are treated as waste and cannot be effectively utilized [26].

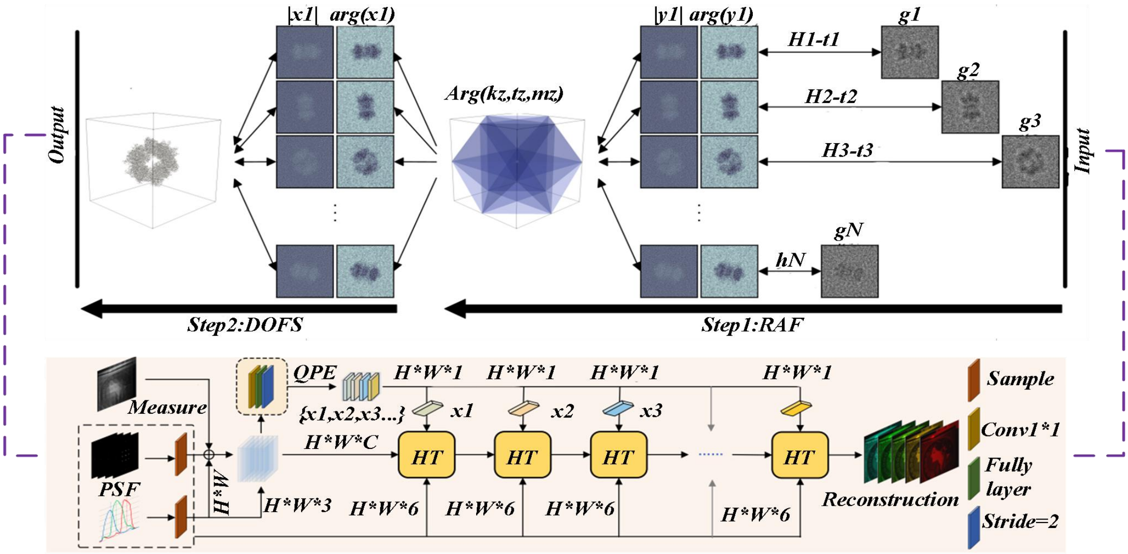

Figure 2. Optimization and Scheduling Diagram of Rural Comprehensive Energy System

4. Construction of Environmental Dominant Evaluation Model System for Comprehensive Energy System Based on Renewable Energy

A. Basic Framework of Environmental Dominant Evaluation Model System

In implementing rural revitalization construction, low-carbon development in rural areas must be considered, and reducing carbon emissions will also be one of the main goals of the rural comprehensive energy system. This chapter studies various power generation technologies in the rural comprehensive energy system. Based on the full life cycle assessment method, the carbon emissions and energy input and return rate of each equipment are used as the basis to consider the configuration capacity of each power generation equipment in the rural comprehensive energy system. Using the full lifecycle assessment method to calculate the carbon emissions of a system has become a mainstream idea. Using the carbon emission coefficient method to calculate the carbon emissions based on LCA, further determining the carbon emission factors of different equipment, and preparing for quantitative calculation of system carbon emissions. On this basis, calculate the energy input and return rate, and consider the economic feasibility of investing different new energy generation equipment in rural revitalization strategies. The full life cycle assessment method follows the principles of energy conservation and material conservation. Therefore, in order to quantitatively calculate the carbon emissions of a product, it is necessary to fully consider the carbon emissions throughout the entire process from "inception" to "retirement" and then to "dissipation". The so-called "nascent" refers to the carbon emissions from a series of activities such as raw material extraction, excavation, and transportation during the production process of products; From "retirement" to "dissipation", it refers to the carbon emissions from the recycling or complete dismantling of parts after the product no longer has useful value. Figure 3 shows the system diagram of the environmental dominant evaluation model [27], [28].

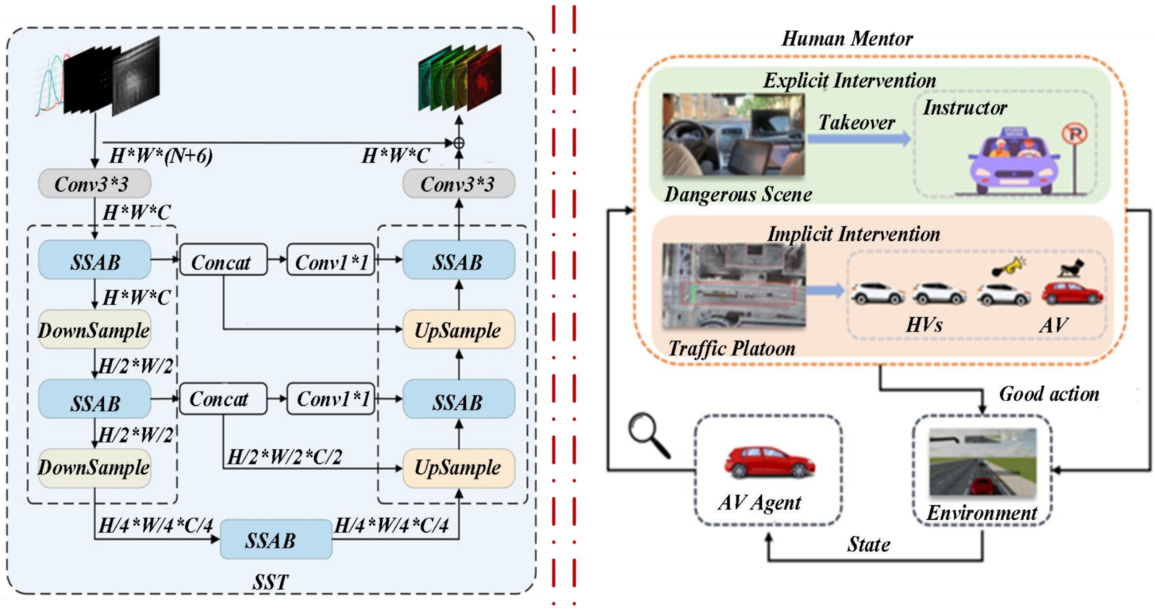

Figure 3. Environmental Dominant Evaluation Model System Diagram

During the four stages of equipment installation, operation, dismantling and recycling, the causes of carbon emissions in each stage are studied, and the specific amount and energy consumption of carbon-emitting substances are determined through tracking and tracing. Then, based on the carbon emission coefficient method, the carbon emissions are calculated by multiplying the material consumption in each stage of the entire life cycle of the equipment by the corresponding carbon emission factor. Finally, the total carbon emissions of each equipment are calculated Compare and analyze the accounting results of energy investment and return rate. This article selects a small wind turbine with the model ENEI-FIAT, an estimated annual power generation hour of 2145h, a lifespan of 20 years, and an installed capacity of 50kW. Determine the accounting boundary for wind power generation technology below. Boundary of wind power generation technology accounting. In the raw material production stage, the main raw materials include steel, copper, plastic pipes, lubricating oil and other raw materials. The main consumables for transportation are diesel and gasoline, and the driving sections are highways and railways. To calculate the above carbon emissions, it is necessary to consider the consumption of raw materials and the carbon emission factors of each material, and then calculate the total carbon emissions for this stage. Classify equipment with further practical value, and include dismantling, recycling, and landfill in the carbon emission calculation.

B. *Principles and Screening of Comprehensive Energy System Evaluation Indicators Under the Background of Carbon Neutrality*

It is necessary to evaluate the comprehensive energy system. Due to the diversity of energy input and output, the design types of integrated energy systems range widely. Due to the complexity of integrated energy systems, their evaluation process is not as simple and direct as simple power generation. To evaluate the feasibility and potential improvements of system technology, thermal analysis is required. In addition, the reserves of fossil fuels are also limited, so we need to use alternative fuel energy supply systems. Figure 4 shows the technical diagram of the evaluation system. Therefore, for comprehensive energy systems using diverse fuels, environmental benefit analysis is a necessary evaluation for testing the system in current social development. The research on environmental sustainability of the system is crucial for formulating policies on the use of renewable energy and carbon emissions. In order to demonstrate the benefits and sustainability of the system for the future global environment, it is necessary to conduct an environmental benefit analysis of the integrated energy system. Finally, the evaluation indicators may also be multidimensional, which can reveal the overall sustainability of the integrated energy system.

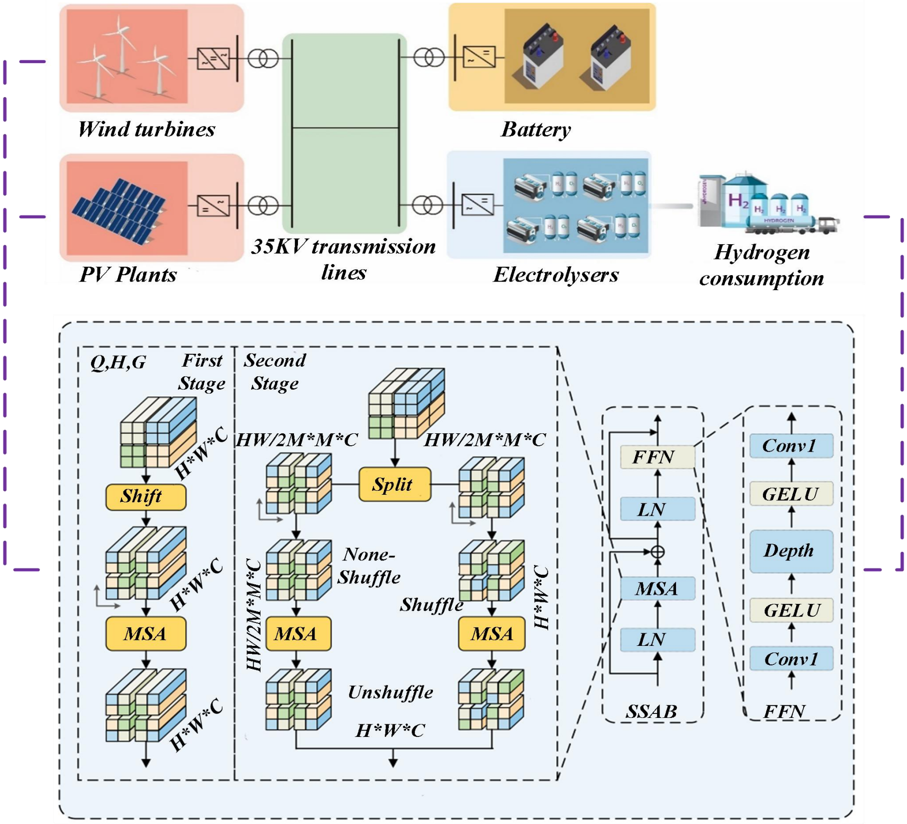

Figure 4. Evaluation System Technical Diagram

The first law of thermodynamics only focuses on the quantity of energy and does not include the mass of energy. Evaluate relevant integrated energy systems using energy efficiency and fire efficiency [29]. In order for a comprehensive energy system to be sustainable, its economic performance must be feasible and beneficial. The economic potential of a comprehensive energy system in India was analyzed using technical and economic analysis. Environmental benefit assessment is an important pillar for the sustainable development of the system and the achievement of the "dual carbon" goals. Elias et al. conducted research and evaluation on the environmental sustainability of a biomass-based integrated energy system in the UK, including the accumulation of fossil fuels and the assessment of the global warming index over its lifecycle. Conduct separate discussions and research on the environmental sustainability potential of integrated energy systems. Many scholars have also conducted multidimensional evaluations of the system. Propose a multidimensional evaluation system for the systematicity of integrated energy supply systems, and evaluate the energy [30], environment, and economy of the system. In recent years, some research has been conducted on the unilateral evaluation of integrated energy systems by scholars, which is more extensive compared to the multidimensional evaluation of systems. The actual demand of the international community for the global environment and the multi-dimensional evaluation model dominated by the environment have not been considered yet. A comprehensive energy system that complements biomass energy, solar energy, and air energy can fully utilize local biomass raw materials, solar energy, and other resources. It is a distributed energy supply system that utilizes energy cascading through driving devices, and combines power and heating units to stably provide the multi-level energy needs of residents for electricity, gas, heating, and hot water. Taking into account the diverse energy demands of the user side, local environmental conditions, and changes in meteorological parameters, as well as the dynamic performance changes and various influencing factors encountered during operation of major components such as internal combustion engines, solar photovoltaic power generation systems, and heat pump heating systems in different climates, this paper establishes a comprehensive energy system model based on complementary renewable energy. The biomass raw materials in the anaerobic reactor are subjected to anaerobic digestion, and the generated biogas is dehydrated, sulfur removed, and purified in a purifier before being stored in gas storage equipment. Part of the biogas directly meets the cooking needs of residential residents, while the other part is sent to internal combustion engines for distributed energy supply. The heat in the heat accumulator is used to heat the materials and reactants in the anaerobic reactor, ensuring that the temperature remains constant; On the one hand, it supplies residential buildings to meet their living water and heating requirements. When there is not enough heat in the heat accumulator, use an air source heat pump as a supplementary heating device; When the heat pump cannot meet the total heat demand, use biomass boilers to continue supplementing heat to ensure the stability of heat supply.

5. Experimental Analysis

We continuously attempted to optimize the system under various operating modes by setting different reproduction times and population sizes. Figure 5 shows a comparison of the increase in reproduction times, and we designed an optimization plan that combines multiple population numbers and reproduction iterations: 1) Population P=50, Algebra G=100; 2) Population P=100, Algebra G=100; 3) Population P=100, Algebra G=200.

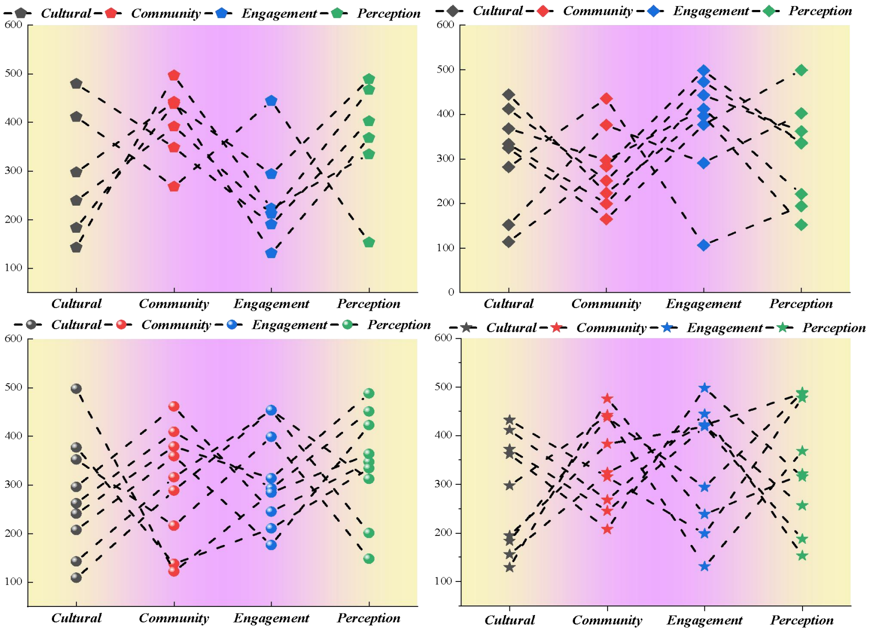

Figure 5. Comparison Chart of Increasing Reproduction Frequency

During the optimization process, the results obtained from internal combustion engines, photovoltaic panels, and air source heat pumps are all treated as floating-point numbers, and the optimization results are ultimately rounded. The number of anaerobic reactors remains constant at 2, assuming that their diameter and height remain consistent. Figure 6 shows the evaluation diagram of internal combustion engine cogeneration. During the optimization process, the number of internal combustion engines and the capacity of anaerobic reactors are randomly generated at the beginning, and it is necessary to meet the constraint conditions of the amount of biogas produced by reactor fermentation that can meet the consumption of internal combustion engine cogeneration.

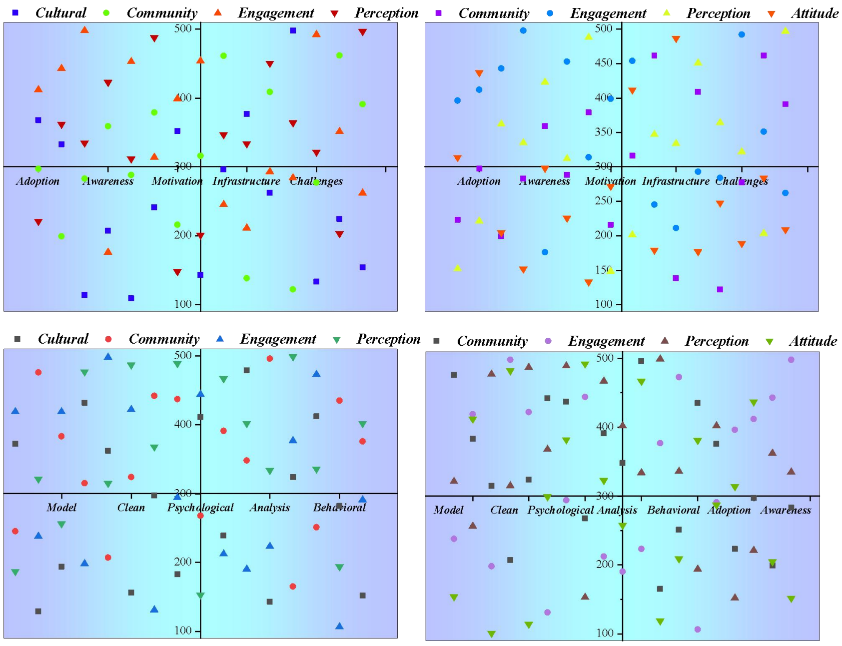

Figure 6. Internal Combustion Engine Cognition Evaluation Chart

Before and after optimization, the annual energy savings rate of the system is mostly greater than 0, with occasional occurrences below negative values, indicating that the comprehensive energy system saves primary energy consumption compared to the distribution system under the electric follow-up operation mode. Figure 7 shows a comparison of the system before and after optimization. Scheme 0 has a primary energy savings rate of 22.70%, while Scheme E1, E2, and E3 have optimized rates of 28.81%, 23.63%, and 25.18%, respectively. The primary energy savings rate has improved compared to before optimization.

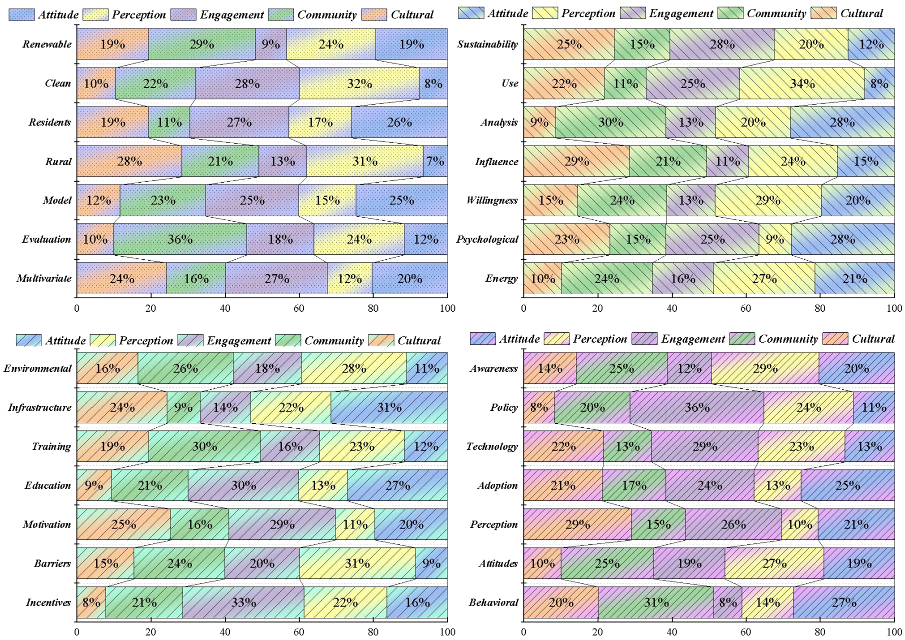

Figure 7. Comparison Diagram of the System Before and After Optimization

6. Conclusion

We have established a basic framework for a rural comprehensive energy system, studied the characteristics of wind energy, solar energy, biomass energy, and biogas power generation output, analyzed the working principles of heat pumps, electric heating equipment, and heat storage equipment, and established corresponding mathematical models. Finally, taking a rural area in northern China as an example, we calculated the electricity and heat loads of multiple industries during the heating period in the village. By using the full lifecycle assessment method, the carbon emissions and energy consumption of wind and solar power generation equipment, biomass power generation equipment, and biogas units were quantitatively calculated, and then the carbon emission factors, energy inputs, and return rates of the equipment were calculated. On this basis, calculations and comparisons were made for four power generation technologies, and the results showed that wind power generation technology had the lowest energy consumption and the best carbon reduction ability. Taking a rural area in northern China as the research object, a multi-objective optimization scheduling model considering the lowest energy cost and carbon emissions of the rural comprehensive energy system was established. PSO was introduced and improved. Combined with the output of various equipment during the winter heating period, simulation was conducted using typical daily electricity consumption, heat load, wind speed, and solar radiation data in winter. The optimization scheduling results under three configuration schemes were analyzed, the addition of new energy and heat storage equipment has a positive significance in reducing energy costs and carbon emissions.

Based on multi-objective optimization under different operating strategies, the corresponding optimization results are obtained by solving. On the basis of maximizing carbon dioxide emission reduction rate, annual cost savings rate, and primary energy savings rate, when the environmental weight factor is selected as 1/2 and the economic and thermal weight factors are both selected as 1/4, the comprehensive evaluation index CI of the mixed mode before optimization is the highest of 48.66% among the three operating modes; After optimization, the mixed mode operation strategy also achieved the highest comprehensive indicator CI among the three operation strategies, increasing to 52.30%; The environmental comprehensive index CEI of the mixed mode has increased from 75.90% to 82.53%, which is also the highest value among the different optimized settings of the three operating modes after optimization; And the proportion of all renewable energy inputs in the mixed mode increased from 93.48% before optimization to 99.14% in the optimized scheme M3, verifying the reliability of the multi-objective optimization model. Within the allowable range of other parameters remaining unchanged and calculation conditions, different settings for population size and reproduction frequency can be attempted. In theory, the larger the population size and reproduction frequency, the higher the optimization accuracy.

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