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# MODELLING AND OPTIMISATION OF GREEN ENERGY SYSTEMS BASED ON COMPLEMENTARY INTEGRATION OF RENEWABLE ENERGY

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## Abstract

This paper proposes a green energy system modelling and optimisation based on complementary integration of renewable energy, constructing an energy system model using solar energy, air energy, biomass energy, and distributed functional systems. And the objective optimisation function is constructed based on environmental friendliness, profitability, and energy utilisation efficiency as indicators. The results show that in mixed mode, the average annual environmental evaluation indicators of $F$ before optimisation were 75.91%, while the average annual environmental evaluation indicators of M1, M2, and M3 after optimisation were 81.77%, 81.82%, and 82.53%, respectively. Research has shown that green energy system modelling and optimisation methods based on complementary integration of renewable energy can effectively solve energy and environmental problems, improve energy utilisation efficiency and environmental friendliness, and provide strong support for comprehensive decision-making of all parties in the power supply system.

## Key Words

Renewable energy, energy complementarity, photovoltaic panels, biomass energy, energy supply optimisation

## 1. Introduction

In the past few decades, the global demand for renewable energy has been continuously increasing, which is mainly focused on environmental protection and sustainable energy development [1]. The energy crisis may lead to an increase in energy prices, exacerbating economic recession, triggering geopolitical tensions, and exacerbating environmental issues, with serious impacts on the global economy. The traditional energy system has the problem of emitting large amounts of greenhouse gases and relying on limited fossil fuels, which has prompted people to shift towards the use of renewable energy [2]. However, due to the intermittency and volatility of renewable energy, the utilisation of a single energy source is difficult to meet stable energy needs [3]. Renewable energy refers to the energy continuously generated in nature, such as solar energy, wind energy, hydro energy, geothermal energy, and bioenergy. Compared with traditional energy, renewable energy has the characteristics of being renewable, environmentally friendly, and widely distributed. The utilisation of renewable energy is of great significance in addressing energy pressure and environmental issues. It can reduce dependence on traditional energy, reduce greenhouse gas emissions, promote sustainable development, and create employment opportunities. Therefore, integrating multiple renewable energy sources (RES) and establishing a comprehensive energy system has become an important solution. Relevant research work has made some progress in modelling and optimising integrated energy systems. For example, researchers have used multi-objective optimization (MOO) algorithms to determine the optimal energy configuration and operational strategies to achieve efficient system performance [4]. Other studies have focused on establishing comprehensive evaluation models that comprehensively consider indicators, such as thermodynamic performance, environmental benefits, and economic performance to evaluate the performance of comprehensive energy systems [5]. However, there is currently a lack of comprehensive research on modelling and optimisation of green energy systems (GES) based on complementary integration of renewable energy. Therefore, this study aims to fill this research gap by establishing models and optimisation methods, providing a theoretical basis for the development and application of comprehensive energy systems, and achieving efficient, stable, green, and

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energy-saving operation of the system. The paper has four parts. The first part is a summary of the existing energy system and optimised design; the second part is the optimisation design of GES modelling combined with RES complementary integration (RES-GES); the third part is about the analysis of the optimisation results of RES-GES; the fourth part is a summary of the entire study. The aim of this study is to provide energy demand for local residents and achieve efficient, stable, green, and energy-saving operation through a comprehensive energy system based on renewable energy. By constructing an evaluation index system and considering the complementary relationship between renewable energy, the system capacity configuration is optimised to achieve the optimal operating strategy. Taking a certain village and town as an example, verify the reliability of the model, summarise the research significance, provide a theoretical basis for the development of renewable energy systems, and promote energy transformation and renewable energy utilisation.

## 2. Related Works

The energy system is the entire process of transforming natural energy resources into effective energy required for human social production and life. Acar's team proposes the design of an independent solar hydrogen hybrid energy system consisting of photovoltaic panels, electrolytic cells, storage tanks, and fuel cell stacks to meet the energy needs of residents. The power of components in this system is affected by other components [6]. Zhen *et al.* proposed an optimisation modelling for energy water linkage and carbon emission reduction coupling, combining credibility constrained programming models, and economic cost optimisation goals to achieve constraints on water resources and carbon emissions. Carbon reduction helps decision-makers manage energy systems [7]. Zhang *et al.* proposed a comprehensive model to describe the integrated energy system of cold cogeneration. Its objective function is optimal economic performance. The method is effective in solving constraints according to safety and operation requirements [8]. Liu *et al.* proposed a unified modelling framework based on a fourth-order tensor generalised interval type 2 fuzzy neural network, which analyses the seasonal energy supply characteristics of energy systems by combining the input output and differential changes of various energy media. The prediction results of this method are more flexible than traditional distributed energy systems [9]. Tercan *et al.* proposed a method to extend the lifespan of distributed energy systems, which combines energy storage systems to improve energy utilisation flexibility, thereby improving power quality and achieving the goal of reducing line costs. This method can reduce the total cost by 65% and reduce system losses by 34% [10].

Energy optimisation refers to the optimal allocation of energy structure to determine the optimal energy supply system solution. Abdellatif *et al.* proposed a MOO method for independent hybrid RES systems in combination with linear programming, and took time span and household consumption into consideration to reduce power consumption. This method can reduce energy consumption by 10% [11]. Sharma *et al.* proposed an optimisation method for hybrid power system, and used Aquila algorithm and particle swarm optimisation algorithm (PSO) to obtain the model optimisation results. This method can provide the optimal solution with the minimum energy cost [12]. Li *et al.* proposed a modelling and MOO method for an independent photovoltaic wind turbine hydrogen battery hybrid energy system based on hysteresis bands. It combines the net annual value of the system and the remaining electricity to construct an objective optimisation function, and uses the non dominated sorting genetic algorithm (GA) to solve the objective function, which can reduce the probability of power loss to 0.92% [13]. Sun *et al.* reviewed the latest research on power system network security and proposed solutions to enhance grid security, including smart grid technology surveys, power industry practices and standards, solutions to network security issues, and unresolved issues [14]. The Moradi research group proposed a random zero sum Nash strategy solution based on deep $Q$-learning, and demonstrated its universality and effectiveness in ensuring the safe operation of modern power grid systems through empirical research in large-scale power grid systems [15].

In summary, many researchers have conducted different research and designs on energy system modelling and optimisation, but the applicability of these models and methods still needs to be improved. Therefore, this study proposes an optimisation design based on RES-GES, aiming to enhance the green economy of energy supply.

## 3. RES-GES Optimisation Design

The green energy system with complementary integration of renewable energy improves energy efficiency, reduces dependence on traditional energy, and achieves sustainability and stability of energy supply by combining multiple renewable energy technologies, thereby reducing carbon emissions and environmental pollution.

### 3.1 Modelling of RES-GES

RES-GES can form different types of integrated energy systems based on different forms of driving devices, input energy, and output energy [16]. This study aims to model an energy system composed of solar energy, air energy, biomass energy, and distributed energy for subsequent analysis and optimisation. The green energy system model based on complementary integration of renewable energy is shown in Fig. 1 [17].

The system contains a variety of green energy, manifested as solar energy, air energy, and biomass raw materials, which helps to reduce the use of fossil fuels, improve the richness of energy structure, and promote green environmental protection [18]. The methane volume production rate (MVPR) of the anaerobic reactor is calculated as (1).

$$\gamma_V = \frac{BS_0}{\theta} = \frac{B_0 S_0}{\theta}\left(1 - \frac{K}{\theta/\theta_m - 1 + K}\right) \qquad (1)$$

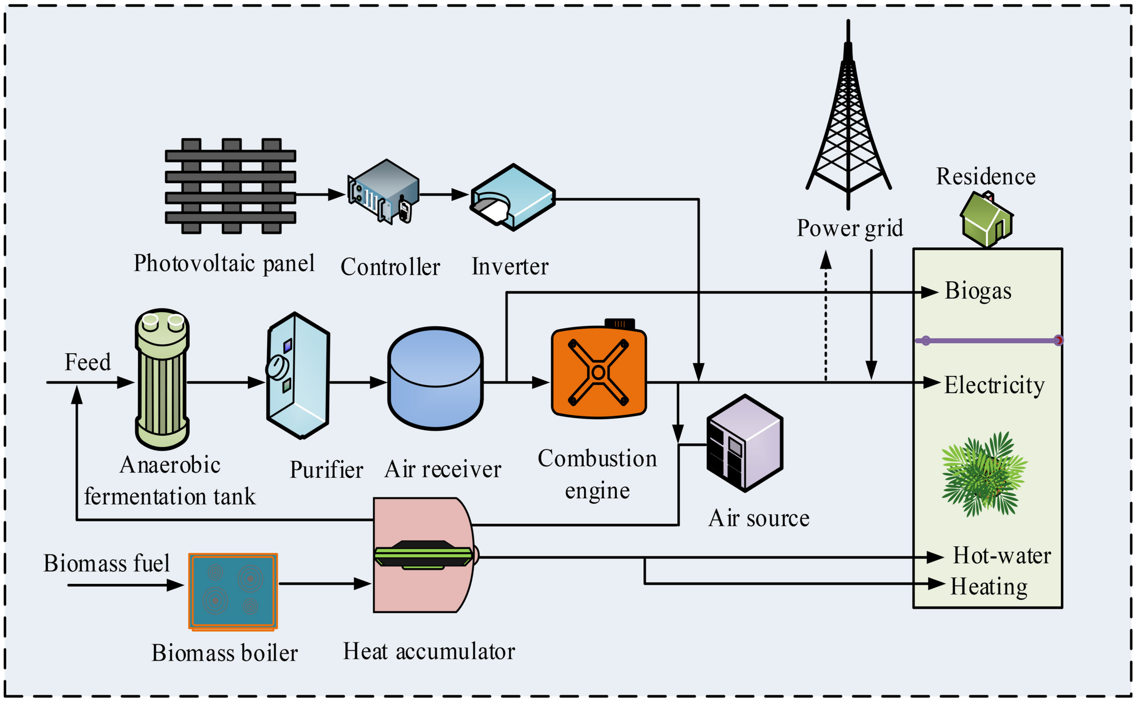


Figure 1. A GES model based on complementary integration of RES.

In (1), MVPR is $\gamma_V$. The hydraulic retention time and its minimum value are represented by $\theta$ and $\theta_m$, respectively. The methane yield and extreme value of organic matter fermentation are $B$ and $B_0$, respectively. The concentration of organic matter in the feed is $S_0$. The dynamic parameter is $K$. The heat dissipation loss (HDL) of the anaerobic reactor is (2).

$$Q_{\text{ad,loss}} = k_o A_o (t_{\text{ad}} - t_a) \tag{2}$$

In (2), $Q_{\text{ad,loss}}$ is the HDL of anaerobic reaction. $k_o$ is the comprehensive Heat transfer coefficient of the outer wall. $A_o$ is the outer wall area of the reactor. $t_{\text{ad}}$ is the anaerobic fermentation temperature of microorganisms. $t_a$ is the ambient temperature. The heat consumption for increasing the temperature of the feed is (3).

$$Q_{\text{ad,new}} = c_{p,\text{in}} M_{\text{cow,in}} (t_{\text{ad}} - t_a) \tau_{\text{ad,new}} \tag{3}$$

In (3), $Q_{\text{ad,new}}$ represents the heat consumption. $c_{p,\text{in}}$ is the feed specific heat capacity. $M_{\text{cow,in}}$ is the quality of the incoming material. $\tau_{\text{ad,new}}$ is the feeding onset time. The efficiency of the internal combustion engine model is (4).

$$\begin{cases} \eta_e = f_1(P_{\text{ice}}, m_{\text{cw}}, t_{\text{cw}}) \\ \eta_q = f_2(P_{\text{ice}}, m_{\text{cw}}, t_{\text{cw}}) \end{cases} \tag{4}$$

In (4), the electrical efficiency and thermal efficiency are $\eta_e$ and $\eta_q$, respectively. The mass flow rate and temperature of cooling water are $m_{\text{cw}}$ and $t_{\text{cw}}$. The output power of the unit is $P_{\text{ice}}$. The solar photovoltaic power generation (SPPG) is (5).

$$E_{\text{PV}} = k P_{\text{AS}} I / G_S \tag{5}$$

In (5), SPPG is represented by $E_{\text{PV}}$. The comprehensive design coefficient is $k$. The total output energy of the solar photovoltaic panel (SPP) in the testing state is $P_{\text{AS}}$. The radiation received by the solar panel is $I$, and its standard radiation is represented by $G_S$. The total output electrical energy of SPP is (6).

$$P_{\text{AS}} = P_{\text{MS}} N \tag{6}$$

In (6), the electrical energy release of the solar panel under test conditions is $P_{\text{MS}}$. The number of solar panels is $N$. The unit coefficient of performance of air source heat pump is COP, as (7).

$$COP = Q_{\text{hp}} / E_{\text{hp}} \tag{7}$$

In (7), the output thermal power of the heat pump is $Q_{\text{hp}}$. The power consumption of the heat pump is $E_{\text{hp}}$. The one-time energy consumption of the boiler is $F_b$ as (8).

$$F_b = Q_b / \eta_b \tag{8}$$

In (8), the output heat of the boiler is $Q_b$. The thermal efficiency of the boiler is $\eta_b$. The structure of RES-GES is complex, so this study focuses on the operation of the system in electric fixed heat, thermal fixed point, and hybrid modes, with the aim of improving the operational performance of the system configuration.

### 3.2 MOO Design of GES

This study establishes a MOO mathematical model for RES-GES to achieve optimal configuration of operating modes, including decision variables, optimisation objectives, constraint conditions, and optimisation algorithms.

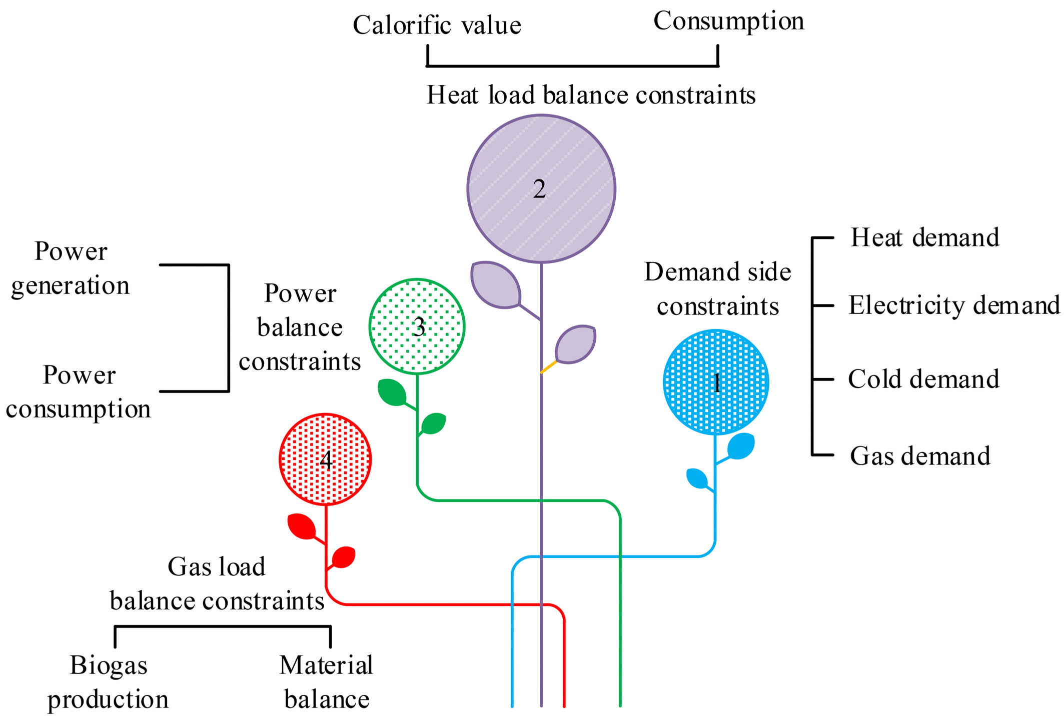


Figure 2. Specific content of constraints.

The optimisation objective is (9).

$$\{\mathrm{CESR_{max}}, \mathrm{ACSR_{max}}, \mathrm{PESR_{max}}\} \tag{9}$$

In (9), the environmental friendliness index is CESR. The indicator of good returns is ACSR. The energy utilisation efficiency is PESR. The ultimate goal of optimisation is to achieve the optimal results of these three indicators. Figure 2 shows the details of the constraint conditions.

User side energy supply is the ultimate goal of energy systems. The paper predicts the demand for heat, electricity, cooling and gas through the annual load of the user side, and takes the dynamic equilibrium of the load of heat, electricity, and gas as the demand side constraint condition. The expression of the thermal load balance constraint is (10).

$$Q_{\mathrm{ice}}^{t} + Q_{\mathrm{hp}}^{t} + Q_{b}^{t} + Q_{\mathrm{ha}}^{t-\Delta t} \geq Q_{\mathrm{user}}^{t} + Q_{\mathrm{loss}}^{t} \tag{10}$$

In (10), the heat storage capacity of the heat accumulator in the previous step of time $t$ is $Q_{\mathrm{ha}}^{t-\Delta t}$. The heat generation of the internal combustion engine and air source heat pump at time $t$, as well as the boiler makeup heat, are represented by $Q_{\mathrm{ice}}^{t}$, $Q_{\mathrm{hp}}^{t}$, and $Q_{b}^{t}$, respectively. At moment $t$, the user's heat load and device heat dissipation are combined with the consumption of $Q_{\mathrm{user}}^{t}$ and $Q_{\mathrm{loss}}^{t}$. The constraint of electric energy balance is (11).

$$E_{\mathrm{ice}}^{t} + E_{\mathrm{PV}}^{t} + E_{\mathrm{grid}}^{t} \geq E_{\mathrm{user}}^{t} + E_{p}^{t} + E_{\mathrm{hp}}^{t} \tag{11}$$

In (11), the internal combustion engine and photovoltaic power generation as well as the purchased electricity at time $t$ are $E_{\mathrm{ice}}^{t}$, $E_{\mathrm{PV}}^{t}$, and $E_{\mathrm{grid}}^{t}$. The user's electricity demand, internal system power consumption, and operational energy consumption of air source heat pumps at time $t$ are $E_{\mathrm{user}}^{t}$, $E_{p}^{t}$, and $E_{\mathrm{hp}}^{t}$. The constraint conditions for gas load balance are (12).

$$B_{\mathrm{con}}^{t-\Delta t} + B_{\mathrm{clean}}^{t} \geq B_{\mathrm{ice}}^{t} + B_{\mathrm{user}}^{t} \tag{12}$$

In (12), the purification amount of biogas at $t$ is $B_{\mathrm{clean}}^{t}$. The gas storage capacity of the step before $t$ is $B_{\mathrm{con}}^{t-\Delta t}$. The amount of biogas required by the internal combustion engine and users at $t$ is $B_{\mathrm{ice}}^{t}$ and $B_{\mathrm{user}}^{t}$. The material balance of anaerobic digestion is (13).

$$\begin{aligned} M_{\mathrm{manure}}^{t} + M_{\mathrm{water}}^{t} + M_{\mathrm{slurry,back}}^{t} \\ = M_{\mathrm{slurry}}^{t} + M_{\mathrm{residue}}^{t} + M_{\mathrm{biogas}}^{t} \end{aligned} \tag{13}$$

In (13), the biomass feed rate, water input quality, and biogas slurry reflux rate at $t$ are $M_{\mathrm{manure}}^{t}$, $M_{\mathrm{water}}^{t}$, and $M_{\mathrm{slurry,back}}^{t}$, respectively. The amount of biogas slurry and biogas residue produced by anaerobic fermentation at $t$ is $M_{\mathrm{slurry}}^{t}$ and $M_{\mathrm{residue}}^{t}$. The amount of biogas produced by anaerobic fermentation is $M_{\mathrm{biogas}}^{t}$. This study used the non-dominated sorting GA II (NSGA-II) algorithm for MOO. Figure 3 shows the process of NSGA-II.

The objective function used in this study is a benefit type indicator, with larger values indicating better benefits. The weighted standardised decision matrix is (14).

$$S_{\mathrm{ij}} = W_{j} \frac{r_{\mathrm{ij}}}{\sqrt{\sum_{i=1}^{P} r_{\mathrm{ij}}^{2}}} \tag{14}$$

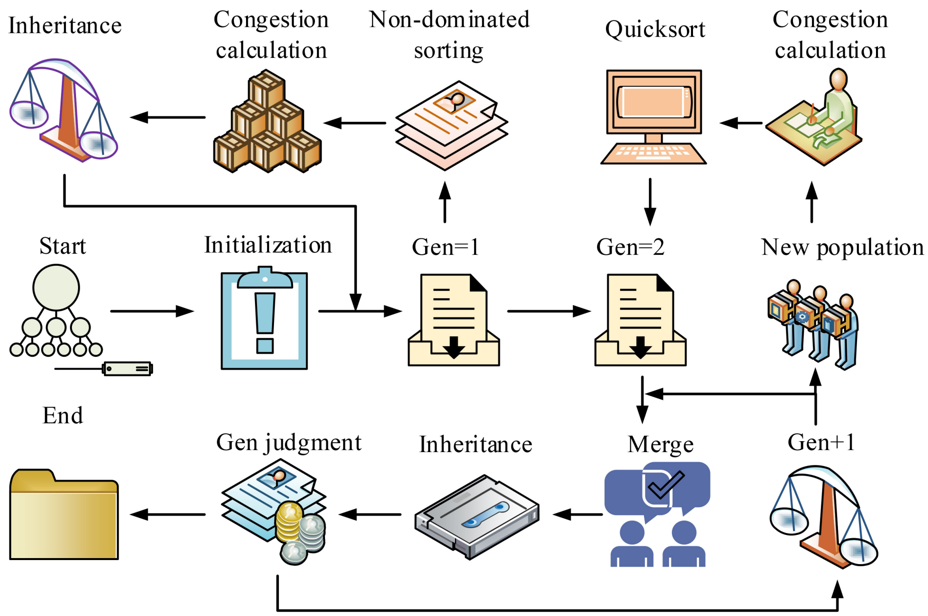


Figure 3. NSGA-II algorithm process.

In (14), the weighted standardised decision matrix is $R = (r_{\mathrm{ij}})_{P\times n} = \begin{bmatrix} r_{11} & \cdots & r_{1n} \\ r_{21} & \cdots & r_{2n} \\ \vdots & \vdots & \vdots \\ r_{P1} & \cdots & r_{\mathrm{Pn}} \end{bmatrix}$. The weight of the $R = (r_{\mathrm{ij}})_{P\times n} = \begin{bmatrix} r_{11} & \cdots & r_{1n} \\ r_{21} & \cdots & r_{2n} \\ \vdots & \vdots & \vdots \\ r_{P1} & \cdots & r_{\mathrm{Pn}} \end{bmatrix}$ goal is $R = (r_{\mathrm{ij}})_{P\times n} = \begin{bmatrix} r_{11} & \cdots & r_{1n} \\ r_{21} & \cdots & r_{2n} \\ \vdots & \vdots & \vdots \\ r_{P1} & \cdots & r_{\mathrm{Pn}} \end{bmatrix}$. The normalised attribute value of the $R = (r_{\mathrm{ij}})_{P\times n} = \begin{bmatrix} r_{11} & \cdots & r_{1n} \\ r_{21} & \cdots & r_{2n} \\ \vdots & \vdots & \vdots \\ r_{P1} & \cdots & r_{\mathrm{Pn}} \end{bmatrix}$ scheme on the $R = (r_{\mathrm{ij}})_{P\times n} = \begin{bmatrix} r_{11} & \cdots & r_{1n} \\ r_{21} & \cdots & r_{2n} \\ \vdots & \vdots & \vdots \\ r_{P1} & \cdots & r_{\mathrm{Pn}} \end{bmatrix}$ target is $R = (r_{\mathrm{ij}})_{P\times n} = \begin{bmatrix} r_{11} & \cdots & r_{1n} \\ r_{21} & \cdots & r_{2n} \\ \vdots & \vdots & \vdots \\ r_{P1} & \cdots & r_{\mathrm{Pn}} \end{bmatrix}$. The number of populations, *i.e.* the number of schemes, is $R = (r_{\mathrm{ij}})_{P\times n} = \begin{bmatrix} r_{11} & \cdots & r_{1n} \\ r_{21} & \cdots & r_{2n} \\ \vdots & \vdots & \vdots \\ r_{P1} & \cdots & r_{\mathrm{Pn}} \end{bmatrix}$. The weighted decision matrix (WDM) needs to be calculated by combining the decision matrix with the weighted weight factors of the objective function, and the final decision results and changes are influenced by the set values. The original indicator data matrix $R = (r_{\mathrm{ij}})_{P\times n} = \begin{bmatrix} r_{11} & \cdots & r_{1n} \\ r_{21} & \cdots & r_{2n} \\ \vdots & \vdots & \vdots \\ r_{P1} & \cdots & r_{\mathrm{Pn}} \end{bmatrix}$ in the calculation of entropy weight method is (15).

$$R = (r_{\mathrm{ij}})_{P\times n} = \begin{bmatrix} r_{11} & \cdots & r_{1n} \\ r_{21} & \cdots & r_{2n} \\ \vdots & \vdots & \vdots \\ r_{P1} & \cdots & r_{\mathrm{Pn}} \end{bmatrix} \tag{15}$$

In (15), the number of evaluation indicators is $n$. The weight of each evaluation indicator $W_j$ is (16).

$$W_j = \frac{1 - e_j}{n - \sum_{j=1}^{n} e_j}, 0 \le W_j \le 1, \sum_{j=1}^{n} W_j = 1 \tag{16}$$

In (16), the entropy value of each indicator is $e_j$. The weight of evaluation indicators refers to the importance of each indicator in the overall evaluation in multi indicator decision-making or evaluation. Weights can be expressed in numerical terms, usually as proportional values between 0 and 1. The higher the weight, the greater the importance of the indicator in the overall evaluation. The lower the weight, the smaller the impact of the indicator on the overall evaluation. The traditional Topsis method of distance between superior and inferior solutions is difficult to determine the weight of evaluation indicators, and its applicability is relatively limited. Therefore, this study uses

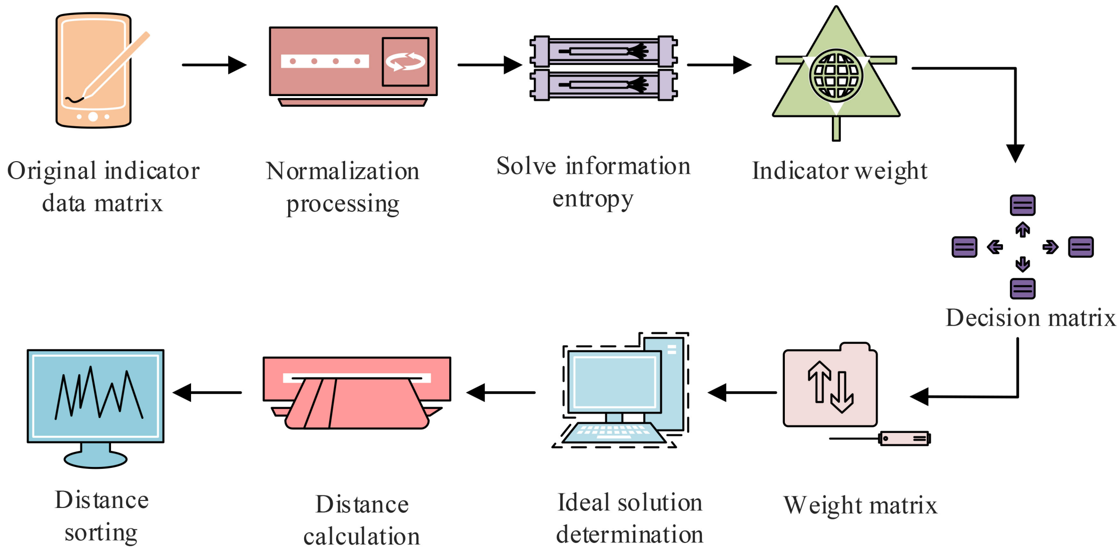


Figure 4. EWTop calculation process.

the entropy weight Topsis method (EWTop) to calculate the optimal configuration, and the calculation process is Fig. 4.

In EWTop, firstly, entropy weight method is used to calculate the objective weight, and the statistical dispersion of the evaluation index is combined to give a reasonable value. Then, the WDM is constructed by the Topsis method. At this point, it is necessary to use the optimised data and entropy weight reconstruction WDM, combined with the optimised solution set to determine the positive and negative ideal solutions, and calculate their distances to each scheme. Finally, the optimal solution is determined through distance comparison ranking.

The MOO design of GES includes the following steps: establishing a mathematical model, determining optimisation objectives and constraints, selecting optimisation algorithms for solution, conducting decision analysis, sensitivity analysis, and feasibility analysis. Through these steps, the design of GES can be achieved with environmental friendliness, good returns, and optimal energy utilisation efficiency.

## 4. Optimisation Analysis of Integrated Green Energy System

This chapter analyses the optimisation results of RES-GES. The first section is about the configuration of energy supply objects and capacity, as well as the optimisation parameter settings; the second section is the optimisation analysis of GES.

### 4.1 Energy Supply Objects and Capacity Configuration, as well as Optimisation Parameter Settings

Rural households face the problems of unstable energy supply and heavy energy burden, and research can explore solutions to improve the reliability and economy of energy supply. Rural households in Qinghai province are distributed in remote areas, and it is of great significance to study the application of renewable energy systems in these areas and solve energy problems. The study selected 50 rural households in Qinghai province as the functional objective, which helps to promote the optimisation and sustainable development of the green energy system. Figure 5 shows the annual load demand of 50 households.

In Fig. 5, there are significant seasonal differences in this area, resulting in significant differences in cold and hot demand. The required cooling capacity in summer is less than that in winter, and the cooling load in summer is negligible. January is the maximum period required for annual heat load, with a maximum of 6, 529.81 kWh. The annual electricity load does not change much, and the biogas load remains consistent throughout the year, at 90 $m^3$ per day. This study sets relevant parameters for different energy units based on the energy demand of residents, and optimises the parameter as listed in Table 1.

In Table 1, the electric following schemes are E1, E2, and E3, the thermal following schemes are H1, H2, and H3, and the hybrid mode schemes are M1, M2, and M3. The number of decision variables, number of objective functions, selection rate, crossover rate, and mutation rate for all options are the same, which are 4, 3, 0.85, 0.85, and 0.06, respectively. The different variables of different schemes under the same following method are population size and reproduction algebra, with population size of 50, 100, and 100, and reproduction quantity of 100, 100, and 200, respectively.

### 4.2 Analysis of Optimisation Results for GES

This study optimises the system benefits, thermal performance and economic performance under different schemes according to the objective optimisation model. Combining the population distribution and entropy weight, the optimisation results of different schemes are obtained, as displayed in Table 2.

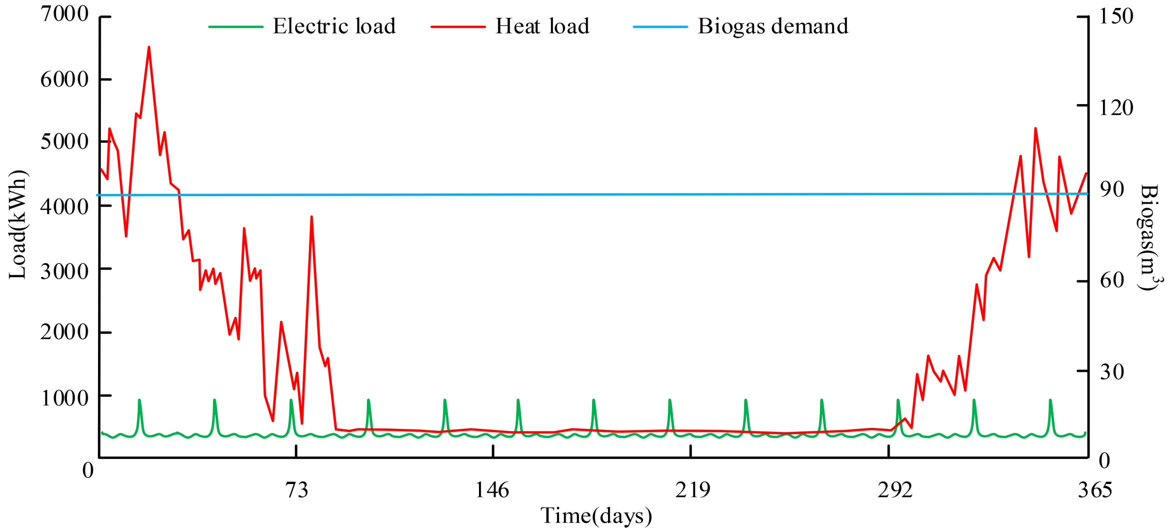


Figure 5. Annual load demand of 50 households.

Table 1
Optimize Parameter Design

| Parameter | E1 | E2 | E3 | H1 | H2 | H3 | M1 | M2 | M3 |
|---|---|---|---|---|---|---|---|---|---|
| Number of decision variables | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Population size | 50 | 100 | 100 | 50 | 100 | 100 | 50 | 100 | 100 |
| Generative algebra | 100 | 100 | 200 | 100 | 100 | 200 | 100 | 100 | 200 |
| Number of objective functions | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| Selection rate | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 |
| Crossover rate | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 |
| Mutation rate | 0.06 | 0.06 | 0.06 | 0.06 | 0.06 | 0.06 | 0.06 | 0.06 | 0.06 |

Table 2
MOO Results Under Different Schemes

| Optimal results | E1 | E2 | E3 | H1 | H2 | H3 | M1 | M2 | M3 |
|---|---|---|---|---|---|---|---|---|---|
| Internal combustion engine (sets) | 6 | 7 | 7 | 5 | 4 | 4 | 6 | 5 | 5 |
| Photovoltaic panels (blocks) | 1791 | 1562 | 1839 | 1291 | 1674 | 1876 | 1878 | 1561 | 1678 |
| Air source heat pump (sets) | 9 | 5 | 6 | 8 | 9 | 10 | 7 | 6 | 7 |
| Diameter and height of anaerobic fermentation tank (m) | 7.43 | 7.62 | 8.01 | 7.76 | 7.63 | 7.81 | 7.92 | 7.73 | 8.12 |
| Biomass boiler capacity (kW) | 166 | 165 | 173 | 156 | 158 | 163 | 153 | 151 | 156 |

Table 2 shows the number of internal combustion engines, photovoltaic panels, air source heat pumps, as well as the diameter and height of anaerobic fermentation tanks and biomass boiler capacity optimised for different schemes. This study combines the $CO_2$ emission reduction rate, green energy contribution rate, and nitrogen oxide emission reduction rate into an environmental assessment indicator (labelled as CEI), as shown in Fig. 6.

Figure 6(a)–(c) shows the annual changes in CEI (AC-CEI) indicators under three modes. In Fig. 6(a), the mean annual CEI index (MA-CEI) of $F$ before optimisation was 67.81%, while the MA-CEI of E1, E2, and E3 after optimisation were 76.88%, 79.84%, and 80.14%, respectively. In Fig. 6(b), the MA-CEI of $F$ before optimisation was 76.64%, while the MA-CEI of H1, H2, and H3 after optimisation were 79.87%, 80.18%, and 80.79%. In Fig. 6(c), the MA-CEI of $F$ before optimisation was 75.91%, while the MA-CEI of M1, M2, and M3 after optimisation were 81.77%, 81.82%, and 82.53%, respectively. By comparison, it can be seen that the

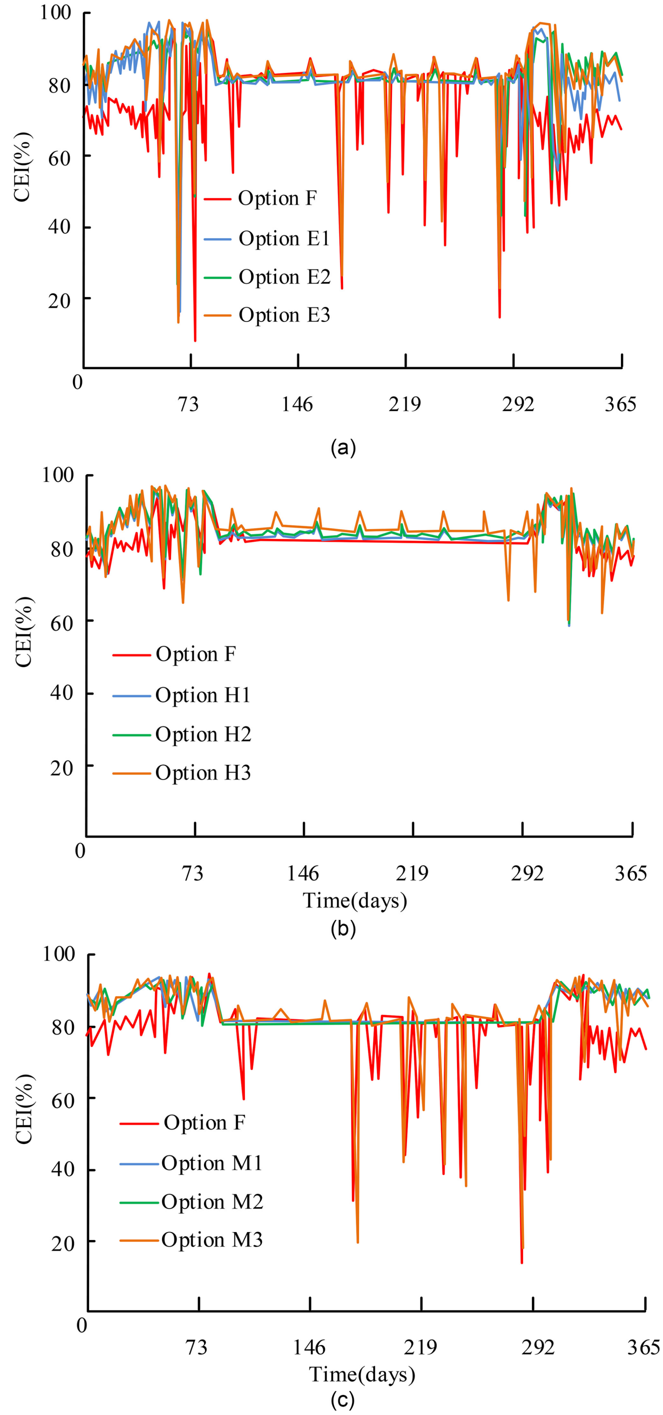


Figure 6. AC-CEI indicators under three modes: (a) annual CEI of the integrated energy system under electric following mode; (b) annual CEI of integrated energy system under thermal following mode; and (c) annual CEI of integrated energy system in hybrid mode.

optimised average value of CEI indicators in mixed mode is the highest.

## 5. Conclusion

With increasing attention to the environment and climate change, the importance of renewable energy has been widely recognised. To achieve sustainable development, a balanced approach that takes into account environmental and economic factors is necessary to ensure the stability, economic feasibility, and social acceptability of energy supply, while creating multiple benefits, such as job opportunities, improving energy security, and reducing carbon emissions.

The study conducted modelling and optimisation of a GES based on RES integration. The integrated energy system included solar energy, air energy, biomass energy, and distributed functional systems. A MOO mathematical model was used to achieve the optimal configuration of operating modes. In the mixed operation mode, the MA-CEI of the optimised scheme $F$ was 75.91%, while the MA-CEI of the optimised schemes M1, M2, and M3 were 81.77%, 81.82%, and 82.53%, respectively.

The research data demonstrated that the proposed RES-GES modelling and optimisation could reduce the utilisation rate of disposable energy and improve the environmental friendliness of the energy supply system. It is important to note that the sample data analysed in this study was specific to a household energy supply system in a certain area of Qinghai province. Further analysis of systems in other regions would be beneficial to expand the scope of the study quent study can consider analysing systems in other regions to further expand the scope of analysis.


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