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Sustainability Evaluation of Modern Photovoltaic Agriculture Based on Interval Type-2 Fuzzy AHP-TOPSIS and Least Squares Support Vector Machine Optimized by Fireworks Algorithm

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ABSTRACT

Photovoltaics (PV) has been combined with many other industries, such as agriculture. But there are many problems for the sustainability of PV agriculture. Timely and accurate sustainability evaluation of modern photovoltaic agriculture is of great significance for accelerating the sustainable development of modern photovoltaic agriculture. In order to improve the timeliness and accuracy of evaluation, this paper proposes an evaluation model based on interval type-2 Fuzzy AHP-TOPSIS and least squares support vector machine optimized by fireworks algorithm. Firstly, the criteria system of modern photovoltaic agriculture sustainability is constructed from three dimensions including technology sustainability, economic sustainability and social sustainability. Then, analytic hierarchy process (AHP) and technique for order preference by similarity to an ideal solution (TOPSIS) methods are improved by using interval type-2 fuzzy theory, and the traditional evaluation model based on interval type-2 Fuzzy AHP-TOPSIS is obtained, and the improved model is used for comprehensive evaluation. After that, the optimal parameters of least squares support vector machine (LSSVM) model are obtained by Fireworks algorithm (FWA) training, and the intelligent evaluation model for the sustainability of modern photovoltaic agriculture is constructed to realize fast and intelligent calculation. Finally, an empirical analysis is conducted to demonstrate the scientificity and accuracy of the proposed model. This study is conducive to the comprehensive evaluation of the sustainability of modern photovoltaic agriculture, and can provide decision-making support for more reasonable development model in the future of modern photovoltaic agriculture.

KEYWORDS

Modern photovoltaic agriculture; sustainability evaluation; interval type-2 fuzzy numbers; AHP; TOPSIS; FWA; LSSVM

1 Introduction

In recent years, the application field of photovoltaic renewable energy is expanding and the application depth is deepening [1]. Photovoltaic power generation technology has expanded from

the simple use of solar power to the field of agriculture. It has been popularized in many fields of agriculture, such as power generation, planting, breeding, fishery, tourism, biological protection and so on. The concept of photovoltaic agriculture is gradually accepted by the professionals in the photovoltaic field and agricultural field [2]. The healthy and sustainable development of photovoltaic agriculture can not only accelerate the pace of agricultural transitory development, provide green and sustainable energy for agricultural production, but also solve the development dilemma of photovoltaic industry, alleviate the overcapacity problem of photovoltaic industry, and increase the proportion of renewable energy utilization [3]. However, the sustainable development of photovoltaic agriculture still faces some problems, which has badly affected the construction and operation of modern photovoltaic agriculture. How to solve the difficulties and problems encountered in the development of photovoltaic agriculture, promote the better and deeper combination of photovoltaic power generation and agriculture development, so as to truly realize the sustainable development of photovoltaic agriculture, is well worthy of study. Therefore, in order to solve the problem of sustainable development of modern photovoltaic agriculture, this paper will evaluate the sustainability of modern photovoltaic agriculture, find out the problems in its development timely and accurately, and take more targeted measures.

According to existing literature, it can be found that no scholars have carried out the sustainability evaluation of modern photovoltaic agriculture. The researches about modern photovoltaic agriculture mainly focus on the influencing factors of the development of photovoltaic agriculture [4], the operating mode of photovoltaic agriculture [5] and the technical design of photovoltaic agriculture [6,7]. Li et al. [4] showed that technical training had a significant positive impact on farmers' construction and operation of photovoltaic agricultural projects, while photovoltaic investment cost had a significant negative impact. Yeoh et al. [5] introduced the application modes of photovoltaic agriculture, such as photovoltaic agricultural greenhouse, photovoltaic breeding, photovoltaic wastewater purification, photovoltaic pumping and new rural solar power station. At the same time, they believed that more theoretical research and practical exploration were needed to achieve the optimal combination of photovoltaic power generation and agricultural planting. For photovoltaic agriculture, Chen [6] designed KNT-SPV02 photovoltaic power generation inverter system, and studied the application of unipolar control mode SPWM in photovoltaic power generation inverter system. Yang et al. [7] proposed using modular design method to design and develop a multi-functional power supply system of agricultural internet of things based on solar power generation. The functions of power generation, storage, display, protection and remote control were designed in the system, which can provide reliable power for users, and can also increase the extension functions such as automatic day-to-day tracking and anti-theft alarming based on the actual demand. From the above researches, we can find that photovoltaic agriculture is getting more and more attention, and some existing research results can provide references for us to build a sustainable evaluation index system of photovoltaic agriculture, but there is a lack of systematic and multi-dimensional quantitative evaluation of the sustainability of photovoltaic agriculture. Therefore, this paper intends to make a qualitative and quantitative analysis on the sustainability evaluation of photovoltaic agriculture, build a scientific and reasonable evaluation index system of photovoltaic agriculture sustainability, and select appropriate methods to carry out the quantitative analysis of photovoltaic agriculture sustainability.

Considering that no scholars have carried out evaluation research on the sustainability of photovoltaic agriculture, this paper combs other research methods of sustainability evaluation [8–12]. At present, the main methods used in sustainable evaluation research include data

envelopment analysis (DEA), network analysis process (ANP), matter-element extension method, analytic hierarchy process (AHP) and technique for order preference by similarity to an ideal solution (TOPSIS). Among them, AHP is a multi-criteria analysis method, which can deal with qualitative problems quantitatively. AHP has been one of the most commonly used multi criteria decision-making methods because of its scientific hierarchy construction and clear logical structure [13]. TOPSIS is another traditional multi criteria decision-making model. It is a method of ranking according to the gap between the evaluation objects and the ideal solutions, so as to determine the quality of the evaluation objects [14]. Because AHP and TOPSIS methods cannot deal with semantic variables with strong fuzziness and uncertainty effectively, interval type-2 fuzzy numbers are introduced in this paper to improve AHP and TOPSIS, respectively [15], and the traditional evaluation model of modern photovoltaic agriculture sustainability based on interval type-2 fuzzy AHP-TOPSIS is constructed. By combining fuzzy set theory with AHP-TOPSIS analysis method, we can better deal with the uncertainty involved in the problem and form pairwise comparison, and ensure the consistency of the ranking made by decision makers [16].

The above evaluation methods belong to the traditional evaluation methods, which are mature and accurate, but the calculation process is very complex. Intelligent evaluation methods can process data quickly and accurately [17], so this paper intends to use artificial intelligence methods to complete the sustainability evaluation of modern photovoltaic agriculture. Modern intelligent evaluation methods mainly include back propagation neural network (BPNN), support vector machine (SVM) and least squares support vector machine (LSSVM) evaluation methods [18–20]. LSSVM chooses the least square linear system as the loss function, which avoids the process of quadratic programming. At the same time, the kernel function is used to transform the prediction problem into the solution of equations, and the inequality constraint is transformed into the equality constraint, which increases the accuracy and the speed of prediction. Considering that LSSVM theory is relatively mature, and it is widely used [21], this paper uses LSSVM model for intelligent evaluation. However, in view of the blind selection of key parameters of LSSVM, it is necessary to select appropriate intelligent algorithm to optimize it [22]. Inspired by the phenomenon of fireworks exploding in the air, fireworks algorithm (FWA) is a new swarm intelligence algorithm with explosive search mechanism for global optimization. It shows excellent performance and high efficiency in solving complex optimization problems [23]. Therefore, this paper applies FWA to optimize the parameters of LSSVM.

The main contributions of this paper are as follows:

(1) The criteria system of modern photovoltaic agriculture sustainability is constructed from three dimensions including technology sustainability, economic sustainability and social sustainability.
(2) AHP and TOPSIS are improved by using interval type-2 fuzzy theory, and the traditional evaluation model based on interval type-2 Fuzzy AHP-TOPSIS is obtained.
(3) The optimal parameters of LSSVM model are obtained by Fireworks algorithm training, and the intelligent evaluation model for the sustainability of modern photovoltaic agriculture is constructed to realize fast and intelligent calculation.

Above all, this paper constructs the sustainability evaluation index system of modern photovoltaic agriculture, and establishes sustainability evaluation models of modern photovoltaic agriculture based on interval type-2 fuzzy AHP-TOPSIS and FWA-LSSVM. The rest of this paper is arranged as follows: Section 2 designs the evaluation index system of modern photovoltaic agriculture sustainability from three aspects including technological sustainability, economic sustainability and social sustainability; Section 3 introduces the main theories of the evaluation methods used in this paper, including interval type-2 fuzzy AHP, interval type-2 fuzzy TOPSIS, LSSVM model and fireworks algorithm, and constructs modern photovoltaic agriculture sustainability evaluation models based on these theories; Section 4 outlines the case study to verify the accuracy and effectiveness of the proposed model; and Section 5 summarizes the research results of this article.

2 Constructing an Evaluation Criteria System of Modern Photovoltaic Agriculture

In order to construct the sustainability evaluation criteria system of modern photovoltaic agriculture, we need to understand the connotation of modern photovoltaic agriculture. Modern photovoltaic agriculture is a new type of agriculture which widely applies solar power generation to many fields, such as modern agricultural research, planting, breeding, irrigation, pest control and agricultural machinery power supply [24]. In fact, photovoltaic agriculture means that photovoltaic power generation and agricultural production are carried out at the same time and in the same place. On the same land, it cannot only be used to build photovoltaic power station, but also to carry out agricultural production activities, such as planting, breeding, tourism and so on. Specifically, photovoltaic agriculture is the application of photovoltaic technology in the field of agriculture, which integrates photovoltaic power generation and agricultural production. By erecting solar panels, the current generated by the photovoltaic power generation system is connected to the nearest substation for grid-connected generation, the power generated by solar panels can also solve the problems of irrigation, lighting, heat preservation and temperature rise in agriculture, and play the role of biological insecticidal lamp, nutrient solution circulation system and plant protection facilities. It accomplishes the perfect combination of agriculture and photovoltaic new energy power generation, so as to achieve the effect of clean photovoltaic power generation and efficient agricultural development [25].

Modern photovoltaic agriculture includes many aspects, which are high systematic and hierarchical. Following the principles of comprehensiveness, independence, measurability and guidance is conducive to the sustainable evaluation of modern photovoltaic agriculture. According to the above construction principles, combined with the actual development of modern photovoltaic agriculture, this paper constructs the sustainable evaluation criteria system of modern photovoltaic agriculture.

As the future direction of agricultural development, modern photovoltaic agriculture plays a positive role in cost saving, environmental protection, social development and technological innovation. With the increasing concern for sustainable development, modern photovoltaic agriculture has already started to seek the coordinated development of economy, society and technology instead of the simple pursuit of economic growth in the past. Therefore, the sustainability evaluation of modern photovoltaic agricultural technology is conducive to a profound and comprehensive understanding of the impact from various aspects. On the basis of the index selection criteria, the objective environment of projects and the difficulty of data acquisition are fully considered, and the criteria system of modern photovoltaic agriculture sustainability is constructed. The criteria system mainly includes technology sustainability, economic

sustainability and social sustainability. And the criteria system for sustainability evaluation of modern photovoltaic agriculture consists of 15 s level indexes, as shown in Table 1. According to the connotation of modern PV agriculture and the principles of comprehensiveness, independence, measurability and orientation, these indicators are selected in this paper.

Table 1: The criteria system for sustainability evaluation of modern photovoltaic agriculture

Target layer	Criterion layer	Scheme layer	Index type I	Index type II
Sustainability evaluation of modern photovoltaic agriculture	Technology sustainability	Installation and operation level of photovoltaic system	Qualitatively	Cost index
		Light radiation resource condition	Qualitatively	Cost index
		Intelligent level of the greenhouse	Qualitatively	Cost index
		The stability of greenhouse architecture	Qualitatively	Cost index
		The energy saving property of greenhouse building	Qualitatively	Cost index
	Economic sustainability	The net present value	Quantitatively	Profit index
		The internal rate of return	Quantitatively	Profit index
		The return on total assets	Quantitatively	Profit index
		The asset liability ratio	Quantitatively	Cost index
		The total assets turnover	Quantitatively	Cost index
	Social sustainability	Energy saving and emission reduction	Quantitatively	Profit index
		The improvement of energy outcomes	Qualitatively	Profit index
		The promotion of employment	Qualitatively	Profit index
		Ecological efficiency	Quantitatively	Profit index
		The impact on vegetation	Qualitatively	Profit index

3 Methodology

3.1 Interval Type-2 Fuzzy AHP Model

The sustainability evaluation of modern photovoltaic agriculture is complicated, the evaluation process is affected by a variety of complex factors, with a certain degree of uncertainty. And the method of interval type-2 fuzzy numbers is effective to deal with many uncertain factors and obtain robust results. Interval type-2 fuzzy numbers have been widely used in many fields [26].

AHP is a multi-criteria analysis method which can deal with qualitative problems quantitatively. AHP is one of the most commonly used multi criteria decision-making methods because of its scientific hierarchy construction and clear logical structure [27]. By combining the fuzzy set theory with AHP analysis method, we can better deal with the uncertainty involved in the problem and form pairwise comparison, and ensure the consistency of the ranking made by decision makers. Therefore, this section applies the interval type-2 fuzzy AHP model to evaluate the sustainability of modern photovoltaic agriculture to calculate the weight of the indexes.

The calculation process of interval type-2 fuzzy AHP model is as follows:

(1) Combined with interval type-2 fuzzy numbers theory, pairwise comparison matrix is established for indexes of different levels and types.

Decision makers usually use semantic form to evaluate the objects in the measurement analysis of research projects. But it is difficult for decision-makers to define interval type-2 fuzzy numbers directly. Therefore, according to the semantic expression given by the decision-maker, it needs to be transformed into interval type-2 fuzzy numbers.

(2) Test the consistency of comparison matrix

The interval type-2 fuzzy numbers are calculated with Eq. (1), and then the consistency of the matrix can be tested.

$$Defuzzified(\widetilde{\widetilde{A}}_i) = \frac{1}{2} \left\{ \begin{array}{l} \frac{1}{4}\left[\left(a_{i4}^U - a_{i1}^U\right) + (H_1(\tilde{A}_i^U) \times a_{i2}^U - a_{i1}^U) + (H_2(\tilde{A}_i^U) \times a_{i3}^U - a_{i1}^U)\right] + a_{i1}^U \\ + \frac{1}{4}\left[\left(a_{i4}^L - a_{i1}^L\right) + (H_1(\tilde{A}_i^L) \times a_{i2}^L - a_{i1}^L) + (H_2(\tilde{A}_i^L) \times a_{i3}^L - a_{i1}^L)\right] + a_{i1}^L \end{array} \right\} \tag{1}$$

The consistency index (CI) of the weight matrix of the object to be measured is tested, and the calculation process is shown in Eqs. (2) and (3).

$$CI = \frac{(\lambda_{max}( ))}{(m-1)} \tag{2}$$

$$Aw = \lambda_{max} \tag{3}$$

where $\lambda_{\max}$ is the maximum eigenvalue of the weight matrix of the object to be measured, w is the maximum eigenvector corresponding to $\lambda_{\max}$. The consistency ratio (CR) of comparison matrix can be calculated with Eq. (4).

$$CR = \frac{CI}{RI} \tag{4}$$

where RI is the average random consistency index of the judgment matrix. When CR value is less than 0.1, the consistency of weight comparison matrix is determined. Otherwise, the relevant elements in the matrix need to be adjusted to make it consistent.

(3) Integrate the interval type-2 fuzzy number comparison matrix by geometric average method

The interval type-2 fuzzy number comparison matrix of the object to be measured can be integrated according to Eq. (5).

$$\widetilde{\widetilde{A}}_{ij} = \left[\widetilde{\widetilde{A}}^1 \otimes \widetilde{\widetilde{A}}^2 \otimes \cdots \otimes \widetilde{\widetilde{A}}^n \right]^{\frac{1}{n}} \tag{5}$$

(4) Calculate the fuzzy weight of each index

The fuzzy weight of each index of the object to be measured can be calculated by Eq. (6).

$$\widetilde{\widetilde{w}}_i = \widetilde{\widetilde{r}}_i \otimes (\widetilde{\widetilde{r}}_1 \oplus \widetilde{\widetilde{r}}_2 \oplus \cdots \oplus \widetilde{\widetilde{r}}_m)^{-1} \tag{6}$$

where $\widetilde{\widetilde{r}}_i$ is the geometric average of each row of the comparison matrix after integration.

3.2 Interval Type-2 Fuzzy TOPSIS Model

TOPSIS is one of the traditional multi criteria decision-making models. It is a method to rank based on the distance between the evaluation objects and the ideal solutions, so as to determine the quality of the evaluation objects [28]. For interval type-2 fuzzy TOPSIS model, the elements in the decision matrix will be calculated with interval type-2 fuzzy method.

Assuming that there are m items to be evaluated, N indexes and T experts in related fields to score, the main steps of interval type-2 fuzzy ideal point method are as follows:

(1) Transform semantic variables into interval type-2 fuzzy numbers

There are both quantitative and qualitative indicators in the index system. It is difficult to realize the horizontal comparison of semantic expression of different types of indexes, so it is necessary to standardize them and transform semantic variables into interval type-2 fuzzy numbers. Then the interval type 2 fuzzy decision matrix of expert k can be expressed by Eq. (7).

$$D^k = (\widetilde{\widetilde{d}}^k_{ij}) = \begin{bmatrix} \widetilde{\widetilde{d}}^k_{11} & \widetilde{\widetilde{d}}^k_{12} & \cdots & \widetilde{\widetilde{d}}^k_{11} \\ \widetilde{\widetilde{d}}^k_{11} & \widetilde{\widetilde{d}}^k_{11} & \cdots & \widetilde{\widetilde{d}}^k_{11} \\ \vdots & \vdots & \ddots & \vdots \\ \widetilde{\widetilde{d}}^k_{11} & \widetilde{\widetilde{d}}^k_{11} & \cdots & \widetilde{\widetilde{d}}^k_{11} \end{bmatrix} \tag{7}$$

(2) Integrate interval type-2 fuzzy matrix

Collect the measurement score data of all objects to be measured for input, and then the integrated interval type-2 fuzzy decision matrix can be determined as Eqs. (8) and (9).

$$\overline{\overline{D}}(\widetilde{\widetilde{d}}_{ij})_{m \times n} = \begin{bmatrix} \widetilde{\widetilde{d}}_{11} & \widetilde{\widetilde{d}}_{12} & \cdots & \widetilde{\widetilde{d}}_{1n} \\ \widetilde{\widetilde{d}}_{21} & \widetilde{\widetilde{d}}_{22} & \cdots & \widetilde{\widetilde{d}}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \widetilde{\widetilde{d}}_{m1} & \widetilde{\widetilde{d}}_{m2} & \cdots & \widetilde{\widetilde{d}}_{mn} \end{bmatrix} \tag{8}$$

$$\approx\atop{d_{ij}} = \frac{(\overset{\approx 1}{\tilde{d}_{ij}} \oplus \overset{\approx 2}{\tilde{d}_{ij}} \oplus \cdots \oplus \overset{\approx t}{\tilde{d}_{ij}})}{t} \tag{9}$$

where $\tilde{\tilde{d}}_{ij}$ denotes interval type 2 fuzzy number, $1 \leq i \leq m$, $1 \leq j \leq n$, $1 \leq k \leq t$.

(3) Construct weighted normalized fuzzy decision matrix

The weighted normalized fuzzy decision matrix of the object to be measured can be calculated by Eqs. (10) and (11).

$$\overline{Y} = (\tilde{v}_{ij})_{m \times n} = \begin{bmatrix} \overset{\approx k}{v_{11}} & \overset{\approx k}{v_{12}} & \cdots & \overset{\approx k}{v_{1n}} \\ \overset{\approx k}{v_{21}} & \overset{\approx k}{v_{22}} & \cdots & \overset{\approx k}{v_{2n}} \\ \vdots & \vdots & \ddots & \vdots \\ \overset{\approx k}{v_{m1}} & \overset{\approx k}{v_{m2}} & \cdots & \overset{\approx k}{v_{mn}} \end{bmatrix} \tag{10}$$

$$\overset{\approx}{\tilde{v}}_{ij} = \overset{\approx}{\tilde{w}}_i \otimes \overset{\approx}{\tilde{d}}_{ij} \tag{11}$$

where, $1 \leq i \leq m$, $1 \leq j \leq n$.

(4) Determine fuzzy positive and negative ideal solutions

The positive ideal solution and the negative ideal solution are expressed as $x^+ = (v_1^+, v_2^+, \cdots, v_m^+)$ and $x^- = (v_1^-, v_2^-, \cdots, v_m^-)$, respectively. v_i^+ and v_i^- can be calculated by Eqs. (12) and (13).

$$v_i^+ = \begin{cases} \max_{1 \leq j \leq n} \{Def(\tilde{v}_{ij})\}, f_i \in F_1 \\ \min_{1 \leq j \leq n} \{Def(\tilde{v}_{ij})\}, f_i \in F_2 \end{cases} \tag{12}$$

$$v_i^- = \begin{cases} \min_{1 \leq j \leq n} \{Def(\tilde{v}_{ij})\}, f_i \in F_1 \\ \max_{1 \leq j \leq n} \{Def(\tilde{v}_{ij})\}, f_i \in F_2 \end{cases} \tag{13}$$

where F_1 is the set of profit indexes, and F_2 is the set of cost indexes, $1 \leq i \leq m$.

(5) Calculate the distance between each alternative and the fuzzy positive and negative ideal solutions

The calculation formulas of the distance between the measurement score of each index of the object to be measured and the positive and negative ideal solutions are shown in Eqs. (14) and (15), respectively.

$$d^+(x_i) = \sqrt{\sum_{i=1}^{m}(Def(\tilde{v}_{ij}) - v_i^+)^2} \tag{14}$$

$$d^-(x_i) = \sqrt{\sum_{i=1}^{m}(Def(\tilde{v}_{ij}) - v_i^-)^2} \tag{15}$$

(6) Calculate and sort the similarity coefficients of each alternative

The similarity coefficients of each alternative can be calculated with Eq. (16).

$$C(x_i) = \frac{d^-(x_j)}{d^+(x_j) + d^-(x_j)} \tag{16}$$

where $1 \leq j \leq n$, and the larger the index value $C(x_i)$ is, the better the measurement result is.

3.3 Least Squares Support Vector Machine

Least squares support vector machine (LSSVM) is an improvement of standard support vector machine (SVM). LSSVM uses equality constraints instead of inequality constraints of SVM, and uses kernel function to transform the prediction problem into solving equations, which can greatly improve the accuracy and speed of evaluation [29].

It is supposed that the given sample set is $T = \{(x_i, y_i)\}_{i=1}^N$, and N is the total number of samples. The regression model of the sample is as follows:

$$y(x) = w^T \bullet \phi(x) + b \tag{17}$$

where $\phi(x)$ is a high dimensional space projected by training samples, w is the weighted vector, b is the bias.

For LSSVM, the optimization problem changes into the following:

$$min \frac{1}{2} w^T w + \frac{1}{2} \gamma \sum_{i=1}^N \xi_i^2 \tag{18}$$

$$s \cdot t \ y_i = w^T \phi(x_i) + b + \xi_i, i = 1, 2, 3, \cdots, N \tag{19}$$

where γ is the penalty coefficient, which is used to balance the complexity and accuracy of the model, ξ_i is the estimation error.

In order to solve the above problems, Lagrange function is established as below:

$$L(w, b, \xi_i, \alpha_i) = \frac{1}{2} w^T w + \frac{1}{2} \gamma \sum_{i=1}^N \xi_i^2 - \sum_{i=1}^N \alpha_i [w^T \phi(x_i) + b + \xi_i - y_i] \tag{20}$$

where α_i is Lagrange multiplier.

Take a derivation of each variable of the function and make them have a value of 0, as shown in Eq. (21).

$$\begin{cases} \dfrac{\partial L}{\partial w} = 0 \rightarrow w = \sum_{i=1}^{N} \alpha_i \phi(x_i) \\[2mm] \dfrac{\partial L}{\partial b} = 0 \rightarrow \sum_{i=1}^{N} \alpha_i = 0 \\[2mm] \dfrac{\partial L}{\partial \xi} = 0 \rightarrow \alpha_i = \gamma \xi_i \end{cases} \tag{21}$$

$$\dfrac{\partial L}{\partial \alpha} = 0 \rightarrow w^T + b + \xi_i - y_i = 0$$

Eliminate w and ξ_i, and turn the problem into Eq. (22):

$$\begin{bmatrix} 0 & e_n^T \\ e_n & \Omega + \gamma^{-1} \times I \end{bmatrix} \times \begin{bmatrix} b \\ a \end{bmatrix} = \begin{bmatrix} 0 \\ y \end{bmatrix} \tag{22}$$

where,

$$\Omega = f^T(x_i) f(x_i) \tag{23}$$

$$e_n = [1, 1, \ldots, 1]^T \tag{24}$$

$$\alpha = [\alpha_1, \alpha_2, \ldots, \alpha_n] \tag{25}$$

$$y = [y_1, y_2, \ldots, y_n]^T \tag{26}$$

By solving the above linear equations, the following results are obtained:

$$y(x) = \sum_{i=1}^{N} \alpha_i K(x_i, x) + b \tag{27}$$

where $K(x_i, x)$ is the kernel function satisfying Mercer condition.

Considering that the RBF kernel function has a wide range of convergence and application, this paper chooses it as the kernel of LSSVM. The expression is as follows:

$$K(x_i, x) = \exp\{-\|x - x_i\|^2 / 2\sigma^2\} \tag{28}$$

where σ^2 represents the width of the kernel, it reflects the characteristics of the training data set and has an impact on the generalization ability of the system.

3.4 Fireworks Algorithm

By analyzing the relevant theories of LSSVM, we can see that the difficulty of establishing LSSVM model is determining kernel function parameter σ^2 and the penalty parameter γ. Selecting appropriate parameters is essential to improve the learning and generalization ability

of the model [30]. Considering that FWA has excellent local search capability and the self-adjusting mechanism of global search capability [31], this paper selects FWA to optimize these two parameters.

FWA is a simulation of the whole process of fireworks explosion. When fireworks explode, a large number of sparks will be generated, which can continue to explode and produce new sparks, thus it will make beautiful and colorful patterns. In the FWA, each firework can be regarded as a feasible solution in the solution space of the optimization problem, so the process of fireworks explosion can be regarded as the process of searching for the optimal solution. In the specific optimization problem, FWA involves the number of sparks produced by fireworks explosion, the radius of explosion, and how to select a group of optimal fireworks and sparks to carry out the next explosion [32].

In the FWA, the number of sparks and explosion radius of fireworks are different. The fireworks with poor fitness have larger explosion radius, which makes them have greater exploration ability, while the fireworks with good fitness have smaller explosion radius, which makes them have greater excavation ability. In addition, the introduction of Gauss mutation sparks can further increase the diversity of the population [33].

Therefore, we can know that the three most important parts of FWA are explosion parameters, mutation parameters and selection strategy [34].

(1) Explosion parameters

In the explosion parameters, the number of sparks and explosion radius of fireworks are calculated according to the fitness value of fireworks. For firework x_i $(i = 1, 2, \cdots, N)$, the formulas to calculate the number of sparks S_i and the explosion radius R_i are as follows:

$$S_i = M \times \frac{y_{\max} - f(x_i) + \varepsilon}{\sum_{i=1}^{N}(y_{\max} - f(x_i)) + \varepsilon} \tag{29}$$

$$R_i = \hat{R} \times \frac{f(x_i) - y_{\min} + \varepsilon}{\sum_{i=1}^{N}(f(x_i) - y_{\min}) + \varepsilon} \tag{30}$$

where $y_{\max}$ is the maximum fitness value and $y_{\min}$ is the minimum fitness value in the current population; $f(x_i)$ is the fitness value of firework x_i; M is a constant which is used to adjust the number of explosive sparks; $\hat{R}$ is a constant which is used to adjust the explosion radius of fireworks; ε is the minimum quantity of the machine, which is used to avoid no operation.

(2) Mutation parameters

The setting of mutation parameters is to increase the diversity of explosion spark population. The mutation sparks in FWA generate Gaussian mutation sparks by Gaussian mutation. Suppose that firework x_i is selected for Gaussian variation, the Gaussian variation operation with K dimensions is as follows: $\hat{x}_{ik} = x_{ik} \times e$, where $\hat{x}_{ik}$ is the firework with K dimensions, e is a Gaussian distribution following $N(1, 1)$.

In FWA, the explosion sparks and mutation sparks generated by explosion parameters and mutation parameters may exceed the boundary range of feasible region, so they must be mapped to a new location by mapping rules by Eq. (31).

$$\hat{x}_{ik} = x_{LB,k} + |\hat{x}_{ik}| \% (x_{UB,k} - x_{LB,k}) \tag{31}$$

where $x_{UB,k}$ and $x_{LB,k}$ are the upper and lower boundary of the solution space with K dimensions.

(3) Selection strategy

In order to transmit the information of excellent individuals to the next generation, it is necessary to select a certain number of individuals as the fireworks of the next generation from the explosion sparks and variation sparks.

Suppose that there are K candidates and the population number is N. The individuals with the best fitness value in the candidate set will be identified as the next generation fireworks. And the remaining $N-1$ fireworks are selected according to probability method. For firework x_i, the probability formulas of being selected are as follows:

$$p(x_i) = \frac{R(x_i)}{\sum_{x_j \in K} x_j} \tag{32}$$

$$R(x_i) = \sum_{x_j \in K} d(x_i - x_j) = \sum_{x_j \in K} \|x_i - x_j\| \tag{33}$$

where, $R(x)$ is the sum of distances between all individuals in the current candidate set. In the candidate set, if the individual density is high, that is, there are other candidates around the individual, the probability of the individual being selected will be reduced.

Based on the previous description, the specific steps of FWA are as follows [35,36]:

Step 1. Randomly select N fireworks in the solution space and initialize their coordinates.

Step 2. Calculate the fitness value $f(x_i)$, the blast radius R_i and the spark number S_i. The coordinate with the K dimensions are randomly selected to update, and the update formula is as follows:

$$\hat{x}_{ik} = x_{ik} + R_i \times U(-1, 1) \tag{34}$$

Step 3. Generate M Gauss mutation sparks, randomly select spark x_i, and M Gauss mutation sparks $\hat{x}_{ik}$ are calculated according to Gauss mutation formula, then save them in Gauss mutation spark population.

Step 4. From the fireworks, explosion sparks and Gauss mutation spark population, N individuals are selected as the fireworks for next generation iterative calculation by using probability selection Eqs. (32) and (33).

Step 5. Judge the stop condition. If the stop condition is satisfied, jump out of the program and output the optimal result; if not, return to Step 2 to continue the loop.

3.5 Sustainability Evaluation Model of Modern Photovoltaic Agriculture Based on Interval Type-2 Fuzzy AHP-TOPSIS and FWA-LSSVM

In this section, on the basis of the evaluation model of modern photovoltaic agriculture sustainability based on interval type-2 Fuzzy AHP-TOPSIS, the intelligent evaluation model of modern photovoltaic agriculture sustainability based on FWA-LSSVM is proposed, that is, the index value of modern photovoltaic agriculture sustainability evaluation index system is taken as the input, and the LSSVM is optimized by FWA, so as to obtain the optimal value of LSSVM,

finally, the sustainability evaluation results of modern photovoltaic agriculture can be obtained and analyzed. The flow chart of the proposed model is shown in Fig. 1.
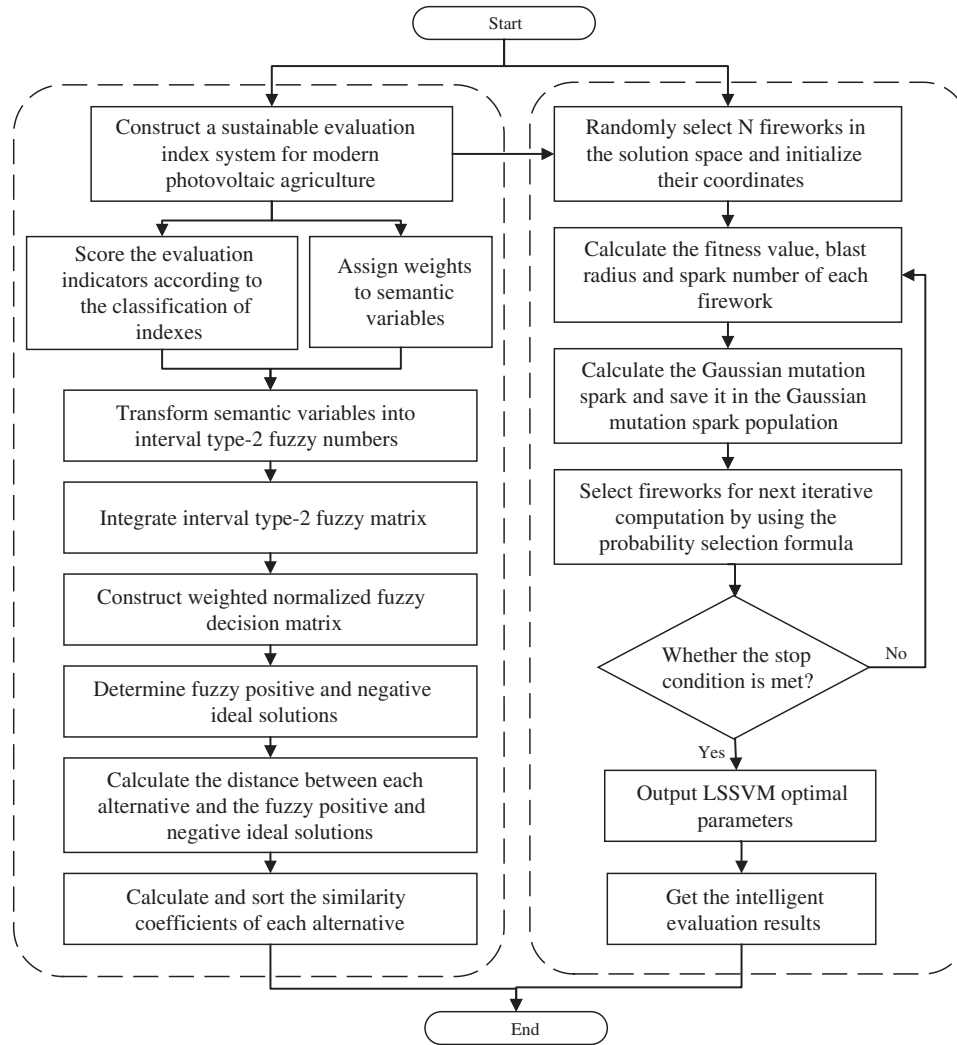

Figure 1: The flow chart of the evaluation

The specific steps are as follows:

Step 1. Construct a sustainable evaluation index system for modern photovoltaic agriculture.

Step 2. Score the evaluation indexes according to the classification of indexes and assign weights to semantic variables.

Step 3. Transform semantic variables into interval type-2 fuzzy numbers, integrate interval type-2 fuzzy matrix and construct weighted normalized fuzzy decision matrix.

Step 4. Determine fuzzy positive and negative ideal solutions, calculate the distance between each alternative and the fuzzy positive and negative ideal solutions, then calculate and sort the similarity coefficients of each alternative.

Step 5. Initialize the parameters of LSSVM and FWA, optimize the parameters of LSSVM model with FWA, then output and analysis the intelligent evaluation results.

4 Example Analysis

4.1 Determination of the Index Set

In order to achieve the hierarchical measurement of different levels of indexes, it is necessary to classify different indexes on the basis of the level differences, that is, to define the index set. Here, according to the evaluation index system, we divide the indexes into different levels, including the first level indexes and the second level indexes.

(1) Set of the first level indexes

The set of the first level indexes can be expressed as Eq. (35).

$$U = \{U_1, U_2, U_3\} \tag{35}$$

where U_1 stands for technical characteristic index; U_2 stands for economic characteristic index; U_3 stands for social characteristic index.

(2) Set of the second level indexes

The set of the first level indexes can be expressed as follows:

a. Technical characteristic index

$$U_1 = \{u_{11}, u_{12}, u_{13}, u_{14}, u_{15}\} \tag{36}$$

where u_{11} is the level of installation and operation of photovoltaic system; u_{12} is the light radiation resource condition; u_{13} is the intelligent level of the greenhouse; u_{14} is the stability of greenhouse architecture; u_{15} is the energy saving property of greenhouse building.

b. Economic characteristic index

$$U_2 = \{u_{21}, u_{22}, u_{23}, u_{24}, u_{25}\} \tag{37}$$

where u_{21} is the net present value; u_{22} is the internal rate of return; u_{23} is the return on total assets; u_{24} is the asset liability ratio; u_{25} is the total assets turnover.

c. Social characteristic index

$$U_3 = \{u_{31}, u_{32}, u_{33}, u_{34}, u_{35}\} \tag{38}$$

where, u_{31} is the effect of energy saving and emission reduction; u_{32} is the improvement of energy outcomes; u_{33} is the promotion of employment; u_{34} is the ecological efficiency; u_{35} is the impact on vegetation.

4.2 Determination of the Evaluative Language

Due to the differences in various aspects of the projects to be measured, the measurement results also have the characteristics of diversity. Through the integration of semantic variables,

the corresponding set of comments V is established, as shown in Eq. (39).

$$V = \{v_1, v_2, v_3, v_4\} \tag{39}$$

All possible states of the objects to be measured should be fully included in the set of comments. The reasonable construction of the comments set will have an important impact on the accuracy and scientificity of the measurement results. Therefore, we should define the comments set on the basis of full investigation and expert advice.

(1) Comments set of the interval type-2 fuzzy AHP model

There are five semantic variables in the comments set of the interval type-2 fuzzy AHP model. They are absolutely strong (AS), very strong (VS), fairly strong (FS), slightly strong (SS) and equal (E). The expression is shown in Eq. (40).

$$V_1 = \{AS, VS, FS, SS, E\} \tag{40}$$

The correspondence between semantic variables of interval type-2 fuzzy AHP model and interval type-2 fuzzy numbers can be shown in Table 2.

Table 2: The correspondence between semantic variables and interval type-2 fuzzy numbers

Semantic variables	Interval type-2 fuzzy numbers	The reciprocal of interval type-2 fuzzy numbers
Absolutely strong (AS)	((7, 8, 9, 9;1, 1), (7.2, 8.2, 8.8, 9;0.8, 0.8))	((0.11, 0.11, 0.12, 0.14;1, 1), (0.11, 0.11, 0.12, 0.14;0.8, 0.8))
Very strong (VS)	((5, 6, 8, 9;1, 1), (5.2, 6.2, 7.8, 8.8;0.8, 0.8))	((0.11, 0.12, 0.17, 0.2;1, 1), (0.11, 0.13, 0.16, 0.19;0.8, 0.8))
Fairly strong (FS)	((3, 4, 6, 7;1, 1), (3.2, 4.2, 5.8, 6.8;0.8, 0.8))	((0.14, 0.17, 0.25, 0.33;1, 1), (0.15, 0.17, 0.24, 0.31;0.8, 0.8))
Slightly strong (SS)	((1, 2, 4, 5;1, 1), (1.2, 2.2, 3.8, 4.8;0.8, 0.8))	((0.2, 0.25, 0.5, 1;1, 1), (0.21, 0.26, 0.45, 0.83;0.8, 0.8))
Equal (E)	((1, 1, 1, 1;1, 1),(1, 1, 1, 1;1, 1))	((1, 1, 1, 1;1, 1),(1, 1, 1, 1;1, 1))

(2) Comments set of the interval type-2 fuzzy TOPSIS model

There are seven semantic variables in the comments set of the interval type-2 fuzzy TOPSIS model. They are very low (VL), low (L), medium low (ML), medium (M), medium high (MH), high (H), very high (VH). The expression is shown in Eq. (41).

$$V_1 = \{VL, L, ML, M, MH, H, VH\} \tag{41}$$

The correspondence between semantic variables of interval type-2 fuzzy TOPSIS model and trapezoidal interval type-2 fuzzy numbers can be shown in Table 3.

Table 3: The correspondence between semantic variables and trapezoidal interval type-2 fuzzy numbers

Semantic variables	Trapezoidal interval type-2 fuzzy numbers
Very low (VL)	((0, 0, 0, 1;1, 1),(0, 0, 0, 0.05;0.9, 0.9))
Low (L)	((0, 0.1, 0.1, 0.3;1, 1),(0.05, 0.1, 0.1, 0.2;0.9, 0.9))
Medium low (ML)	((0.1, 0.3, 0.3, 0.5;1, 1),(0.2, 0.3, 0.3, 0.4;0.9, 0.9))
Medium (M)	((0.3, 0.5, 0.5, 0.7;1, 1),(0.6, 0.7, 0.7, 0.8;0.9, 0.9))
Medium high (MH)	((0.5, 0.7, 0.7, 9;1, 1),(0.6, 0.7, 0.7, 0.8;0.9, 0.9))
High (H)	((0.7, 0.9, 0.9, 1;1, 1),(0.8, 0.9, 0.9, 0.95;0.9, 0.9))
Very high (VH)	((0.9, 1, 1, 1;1, 1),(0.95, 1, 1, 1;0.9, 0.9))

4.3 Calculation and Analysis Based on Interval Type-2 Fuzzy AHP-TOPSIS Model

4.3.1 Weight Calculation Based on Interval Type-2 Fuzzy AHP Model

In order to comprehensively evaluate the sustainability of modern photovoltaic agriculture, this paper selects five modern photovoltaic agricultural projects for research. The basic information of the five projects is shown below:

(1) A1: The installed photovoltaic capacity is 75 MW, with an estimated annual average power generation capacity of 98.86 million kWh. 50 new vegetable greenhouses, 25 flower greenhouses and 20 Chinese herbal medicine greenhouses are arranged in the field with steel structure.

(2) A2: This project is a fishery-photovoltaic complementary photovoltaic power plant project. The installed PV capacity is 200 MW, and the average annual power generation is expected to be 257.86 million kWh. The project covers an area of 3,333,300 square meters. In addition, 22 vegetable greenhouses are arranged in the field with steel structure.

(3) A3: This project is a distributed photovoltaic power plant for cowshed. The installed PV capacity is 20 MW, with an estimated annual average power generation capacity of 27.12 million kWh. The cowshed covers an area of 666,700 square meters.

(4) A4: The installed photovoltaic capacity is 50 MW, with an estimated annual average power generation capacity of 63.92 million kWh. 60 new vegetable greenhouses are arranged in the field with steel structure.

(5) A5: This project is a water conservancy PV model. The installed capacity of photovoltaic is 35 MW, and the average annual power generation is expected to be 45.02 million kWh. The PV is used to supply power to farmland drainage and irrigation, water-saving irrigation and its control system. 16 flower greenhouses are arranged in the field with steel structure.

30 experts are invited from photovoltaic industry, agricultural development and energy economy to form a decision-making group to score the alternatives, so as to judge the advantages and disadvantages of the sustainability of modern photovoltaic agricultural projects.

Based on the established sustainability evaluation index system of modern photovoltaic agriculture, experts evaluated this five modern photovoltaic agricultural projects. The scoring results evaluated by experts are shown in Table 4.

Table 4: Semantic scores of the modern photovoltaic agricultural projects to be evaluated

Scheme	Expert	u_{11}	u_{12}	u_{13}	u_{14}	u_{15}	u_{21}	u_{22}	u_{23}	u_{24}	u_{25}	u_{31}	u_{32}	u_{33}	u_{34}	u_{35}
A1	E_1	VL	L	VL	L	VH	H	H	MH	M	H	ML	H	MH	MH	M
	E_2	ML	L	VL	L	M	M	L	L	ML	L	H	M	H	ML	L
	......															
	E_{30}	ML	M	L	ML	ML	ML	M	H	L	L	M	ML	ML	L	L
A2	E_1	L	ML	L	VL	M	ML	L	L	MH	H	H	L	M	M	ML
	E_2	MH	VH	L	ML	MH	H	M	ML	L	MH	L	MH	MH	H	H
	......															
	E_{30}	H	ML	ML	H	L	VL	L	L	VH	H	MH	M	ML	L	M
A3	E_1	L	L	L	ML	VL	L	H	M	L	L	H	VL	H	H	M
	E_2	MH	VH	L	L	M	MH	L	ML	H	M	H	H	H	L	M
	......															
	E_{30}	M	MH	M	L	MH	M	H	M	M	ML	L	ML	L	M	MH
A4	E_1	L	VH	MH	VL	VL	L	H	H	VL	L	ML	MH	MH	ML	L
	E_2	VH	MH	M	L	L	ML	H	L	MH	M	M	M	ML	MH	VL
	......															
	E_{30}	ML	ML	L	H	MH	MH	M	ML	ML	ML	MH	VH	H	H	M
A5	E_1	H	ML	VL	MH	H	M	L	L	M	H	H	M	L	ML	H
	E_2	M	H	ML	M	ML	ML	M	M	ML	L	M	L	MH	M	L
	......															
	E_{30}	L	H	VL	L	L	L	ML	H	L	L	L	ML	M	ML	M

According to the corresponding relationship between semantic variables and interval type-2 fuzzy numbers in Table 3, the semantic variables are transformed into corresponding interval type-2 fuzzy numbers. After that, each expert compares the importance of each modern photovoltaic agricultural sustainability index and establishes a pairwise comparison matrix of semantic variables. The comparison results are shown in Tables 5–8.

Table 5: Comparison of the importance of the first level indexes

	u_1	u_2	u_3
u_1	[E, E, E]	[1/FS, FS, 1/VS]	[VS, VS, 1/SS]
u_2	[FS, 1/FS, VS]	[E, E, E]	[VS, VS, FS]
u_3	[1/VS, 1/VS, SS]	[1/VS, 1/VS, 1/FS]	[E, E, E]

Table 6: Comparison of the importance of technology sustainability indexes

	u_{11}	u_{12}	u_{13}	u_{14}	u_{15}
u_{11}	[E, E, E]	[1/VS, 1/FS, SS]	[1/VS, FS, VS]	[1/VS, 1/FS, VS]	[1/SS, FS, VS]
u_{12}	[VS, FS, 1/SS]	[E, E, E]	[1/FS, FS, FS]	[1/FS, FS, VS]	[FS, VS, VS]
u_{13}	[VS, 1/FS, 1/VS]	[FS, 1/FS, 1/FS]	[E, E, E]	[FS, 1/FS, SS]	[VS, SS, SS]
u_{14}	[VS, FS, 1/VS]	[FS, 1/FS, 1/VS]	[1/FS, FS, 1/SS]	[E, E, E]	[FS, 1/FS, 1/FS]
u_{15}	[SS, 1/FS, 1/VS]	[1/FS, 1/VS, 1/VS]	[1/VS, 1/SS, 1/SS]	[1/FS, FS, FS]	[E, E, E]

Table 7: Comparison of the importance of economic sustainability indexes

	u_{21}	u_{22}	u_{23}	u_{14}	u_{25}
u_{21}	[E, E, E]	[SS, E, 1/FS]	[VS, VS, FS]	[1/VS, 1/FS, VS]	[VS, VS, FS]
u_{22}	[1/SS, E, FS]	[E, E, E]	[SS, FS, FS]	[1/FS, FS, VS]	[VS, VS, VS]
u_{23}	[1/VS, 1/VS, 1/FS]	[1/SS, 1/FS, 1/FS]	[E, E, E]	[FS, 1/FS, SS]	[E, SS, SS]
u_{14}	[VS, FS, 1/VS]	[FS, 1/FS, 1/VS]	[1/FS, FS, 1/SS]	[E, E, E]	[FS, 1/FS, 1/FS]
u_{25}	[1/VS, 1/VS, 1/FS]	[1/VS, 1/VS, 1/VS]	[E, 1/SS, 1/SS]	[1/FS, FS, FS]	[E, E, E]

Table 8: Comparison of the importance of social sustainability indexes

	u_{31}	u_{32}	u_{13}	u_{14}	u_{35}
u_{31}	[E, E, E]	[1/SS, 1/SS, 1/SS]	[1/VS, FS, VS]	[1/VS, 1/FS, VS]	[SS, 1/FS, E]
u_{32}	[SS, SS, SS]	[E, E, E]	[1/FS, FS, FS]	[1/FS, FS, VS]	[FS, 1/SS, 1/FS]
u_{13}	[VS, 1/FS, 1/VS]	[FS, 1/FS, 1/FS]	[E, E, E]	[FS, 1/FS, SS]	[VS, SS, SS]
u_{14}	[VS, FS, 1/VS]	[FS, 1/FS, 1/VS]	[1/FS,FS, 1/SS]	[E, E, E]	[FS, 1/FS, 1/FS]
u_{35}	[1/SS, FS, E]	[1/FS, SS, FS]	[1/VS, 1/SS, 1/SS]	[1/FS, FS, FS]	[E, E, E]

Similarly, based on the corresponding relationship between semantic variables and interval type-2 fuzzy numbers in Table 2, the semantic variables in Tables 6–8 are transformed into corresponding interval type-2 fuzzy numbers. The consistency of the transformed results is checked and calculated by using Eqs. (1)–(4). The calculation results of consistency ratio of indexes at all levels are shown in Table 9.

Table 9: The test results of consistency ratio of indexes at all levels

Index		CR_1	CR_2	CR_3
Index of the first level		0.0325	0.0933	0.0763
Index of the second level	Technology sustainability	0.0384	0.0940	0.0721
	Economic sustainability	0.0940	0.0882	0.0788
	Social sustainability	0.0876	0.0933	0.0733

From the data in Table 9, it can be seen that the CR values of all levels of index comparison matrix of modern photovoltaic agriculture sustainability are less than 0.1, and the judgment matrix meets the calculation requirements, with good consistency.

The geometric average decision matrix of sustainability evaluation indexes of modern photovoltaic agriculture is obtained by Eq. (5), and the calculation results are shown in Table 10.

According to the data in Table 10, the fuzzy weight of each index is calculated with Eq. (6), and the calculation results of fuzzy weight matrix of each index are shown in Table 11.

4.3.2 Sustainability Evaluation of Modern Photovoltaic Agriculture Based on Interval Two Type Fuzzy TOPSIS Model

According to the interval type-2 fuzzy TOPSIS model, the positive and negative ideal solutions of interval type-2 fuzzy numbers are calculated, as shown in Table 12.

Table 10: Geometric average decision matrix of sustainability evaluation index of modern photovoltaic agriculture

Index	The numerical value of geometric average decision matrix
u_1	((1.23, 1.11, 2.43, 1.04;1, 1),(1.28, 2.33, 2.21, 2.18;0.9, 0.8))
u_2	((1.28, 1.8, 3.53, 3.86;1, 1),(2.32, 2.22, 1.23, 3.89;0.8, 0.8))
u_3	((1.23, 1.73, 2.26, 2.51;1, 1),(1.51, 1.79, 2.21, 2.46;0.8, 0.8))
u_{11}	((1.32, 1.23, 2.41, 2.74;1, 1),(1.41, 1.8, 2.34, 2.67;0.8, 0.8))
u_{12}	((2.08, 2.48, 3.21, 3.58;1, 1),(2.16, 2.55, 3.14, 3.5;0.8, 0.8))
u_{13}	((1.31, 1.61, 2.17, 2.46;1, 1),(1.38, 1.67, 2.11, 2.4;0.8, 0.8))
u_{14}	((0.3, 0.38, 0.58, 0.76;1, 1),(0.32, 0.4, 0.55, 0.71;0.8, 0.8))
u_{15}	((1.91, 2.34, 3.11, 3.48;1, 1),(2, 2.42, 3.04, 3.41;0.8, 0.8))
u_{21}	((0.28, 0.3, 0.39, 0.47;1, 1),(0.28, 0.31, 0.37, 0.44;0.8, 0.8))
u_{22}	((0.37, 0.46, 0.67, 0.84;1, 1),(0.39, 0.48, 0.64, 0.79;0.8, 0.8))
u_{23}	((0.39, 0.48, 0.65, 0.79;1, 1),(0.41, 0.5, 0.63, 0.75;0.8, 0.8))
u_{24}	((0.52, 0.64, 0.96, 1.28;1, 1),(0.55, 0.66, 0.91, 1.19;0.8, 0.8))
u_{25}	((1.04, 1.43, 2.08, 2.4;1, 1),(1.13, 1.5, 2.02, 2.33;0.8, 0.8))
u_{31}	((1.25, 1.53, 2.04, 2.31;1, 1),(1.31, 1.59, 1.99, 2.25;0.8, 0.8))
u_{32}	((2.22, 2.43, 3.47, 3.88;1, 1),(2.31, 2.74, 3.39, 3.79;0.8, 0.8))
u_{33}	((1.31, 1.65, 2.28, 2.64;1, 1),(1.38, 1.71, 2.22, 2.56;0.8, 0.8))
u_{34}	((1.45, 1.98, 2.39, 2.68;1, 1),(1.52, 1.84, 2.33, 2.62;0.8, 0.8))
u_{35}	((2.01, 2.43, 3.21, 3.62;1, 1),(2.1, 2.51, 3.14, 3.53;0.8, 0.8))

Table 11: Fuzzy weight matrix of sustainability evaluation index of modern photovoltaic agriculture

Index	Fuzzy weight matrix
u_1	((0.21, 0.3, 0.57, 0.82;1, 1),(0.23, 0.32, 0.53, 0.76;0.8, 0.8))
u_2	((0.17, 0.28, 0.58, 0.86;1, 1),(0.19, 0.31, 0.54, 0.78;0.8, 0.8))
u_3	((0.09, 0.13, 0.27, 0.46;1, 1),(0.09, 0.13, 0.24, 0.4;0.8, 0.8))
u_{11}	((0.03, 0.04, 0.07, 0.10;1, 1),(0.03, 0.04, 0.06, 0.09;0.8, 0.8))
u_{12}	((0.13, 0.19, 0.37, 0.52;1, 1),(0.14, 0.21, 0.35, 0.48;0.8, 0.8))
u_{13}	((0.04, 0.06, 0.12, 0.18;1, 1),(0.05, 0.07, 0.11, 0.17;0.8, 0.8))
u_{14}	((0.23, 0.32, 0.56, 0.76;1, 1),(0.25, 0.34, 0.53, 0.71;0.8, 0.8))
u_{15}	((0.03, 0.04, 0.09, 0.14;1, 1),(0.03, 0.05, 0.08, 0.13;0.8, 0.8))
u_{21}	((0.14, 0.2, 0.36, 0.51;1, 1),(0.16, 0.21, 0.34, 0.47;0.8, 0.8))
u_{22}	((0.24, 0.33, 0.58, 0.79;1, 1),(0.26, 0.35, 0.55, 0.74;0.8, 0.8))
u_{23}	((0.22, 0.2, 0.53, 0.73;1, 1),(0.24, 0.32, 0.5, 0.68;0.8, 0.8))
u_{24}	((0.04, 0.05, 0.09, 0.13;1, 1),(0.04, 0.05, 0.08, 0.11;0.8, 0.8))
u_{25}	((0.14, 0.19, 0.32, 0.42;1, 1),(0.15, 0.2, 0.3, 0.39;0.8, 0.8))
u_{31}	((0.23, 0.3, 0.51, 0.66;1, 1),(0.25, 0.32, 0.48, 0.62;0.8, 0.8))
u_{32}	((0.17, 0.23, 0.38, 0.51;1, 1),(0.19, 0.24, 0.36, 0.48;0.8, 0.8))
u_{33}	((0.04, 0.06, 0.11, 0.15;1, 1),(0.06, 0.1, 0.14;0.8, 0.8))
u_{34}	((0.14, 0.2, 0.37, 0.52;1, 1),(0.15, 0.21, 0.34, 0.48;0.8, 0.8))
u_{35}	((0.15, 0.19, 0.35, 0.48;1, 1),(0.15, 0.21, 0.33, 0.45;0.8, 0.8))

Table 12: Ideal solutions of interval type-2 fuzzy numbers for the sustainability of modern photovoltaic agriculture

Ideal solution	Fuzzy value
x^+	(0.012, 0.0854, 0.0126, 0.015, 0.14, 0.1456, 0.0253, 0.0007, 0.0423, 0.023, 0.0561, 0.0222, 0.028, 0.0146, 0.0049)
x^-	(0.002, 0.1055, 0.0551, 0.0344, 0.0016, 0.0943, 0.0324, 0.0911, 0.0376, 0.0446, 0.0455, 0.0127, 0.0121, 0.0109, 0.0837)

Combined with the positive and negative ideal solutions, the distance between modern photovoltaic agricultural projects and the positive and negative ideal solutions can be obtained, as shown in Table 13.

Table 13: Calculation results of distance between evaluation performance and ideal solutions of modern photovoltaic agricultural projects to be evaluated

	A1	A2	A3	A4	A5
d^+	0.0856	0.0768	0.2389	0.1243	0.0945
d^-	0.2830	0.1593	0.0032	0.0987	0.0432

Finally, the similarity coefficient of sustainability of each modern photovoltaic agricultural project is calculated. The calculation results are shown in Table 14 and Fig. 2.

Table 14: Calculation results of similarity coefficient of modern photovoltaic agricultural projects

	A1	A2	A3	A4	A5
C	0.5900	0.7022	0.1029	0.3597	0.5107
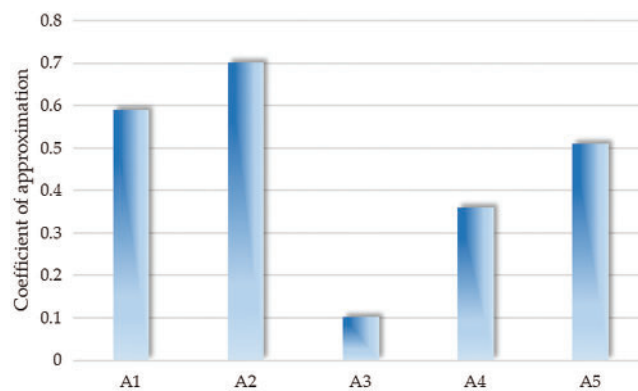
Figure 2: Calculation results

From the sustainability evaluation results, we can see that the order of sustainability of the five modern photovoltaic agricultural projects is as follows: C(A2)>C(A1)>C(A5)>C(A4)>C(A3). It can be concluded that the sustainability evaluation result of modern photovoltaic agricultural project A2 is the best.

4.4 Calculation and Analysis Based on FWA-LSSVM Model

In this paper, the sustainability evaluation model of modern photovoltaic agriculture based on interval type-2 Fuzzy AHP-TOPSIS method is used to get the objective and accurate results of 5 samples of modern photovoltaic agriculture sustainability evaluation. However, according to the above calculation, it can be found that the calculation of the model is more complex, the efficiency is low, and the workload is large. When facing the massive data of modern photovoltaic agriculture projects, this method is bound to be difficult to quickly and effectively calculate the sustainability evaluation results of modern photovoltaic agriculture. Therefore, this paper will further use the FWA-LSSVM model constructed above for research. The other 15 samples are selected as the training set, and the existing 5 samples are used to complete the sustainability evaluation of the modern photovoltaic agriculture. After that, the intelligent evaluation results are compared with the evaluation results in the previous section to verify the effectiveness of the FWA-LSSVM model.

The parameters of FWA are set as follows: the maximum number of iterations *Maxgen* is 500, the population number *PopNum* is 30, the determination constant of spark numbers M is 100, the determination constant of explosion radius $\hat{R}$ is 150. Matlab software is used for model calculation.

In order to verify the effectiveness of the intelligent evaluation model proposed in this paper, this part continues to use the above 5 photovoltaic agricultural projects for empirical analysis, taking these five photovoltaic agricultural projects as test samples, and selecting another 15 photovoltaic agricultural projects as training samples. FWA-LSSVM, PSO-LSSVM, LSSVM and SVM models are applied to the sustainability evaluation of modern photovoltaic agriculture projects for comparative experiments. The calculation results are shown in Table 15 and Fig. 3.

Table 15: Comparison of evaluation results of test samples

Modern photovoltaic agriculture projects	Approximate coefficient of sustainability evaluation	FWA-LSSVM	PSO-LSSVM	LSSVM	SVM
A1	0.5900	0.6136	0.6431	0.6726	0.7098
A2	0.7022	0.6741	0.7794	0.8122	0.8146
A3	0.1029	0.1065	0.0926	0.1217	0.0836
A4	0.3597	0.3795	0.3201	0.3120	0.2913
A5	0.5107	0.4750	0.4698	0.4557	0.6021

Fig. 3 shows the maximum and minimum relative distances of the intelligent evaluation results. In SVM model, the maximum and minimum relative distances are 0.1198 and 0.0193, respectively; while in LSSVM model, the maximum and minimum relative distances are 0.1100 and 0.0188 respectively. The two distance values of LSSVM are less than that of SVM, which indicates that the evaluation accuracy of LSSVM is higher than that of SVM. In the

PSO-LSSVM model, the maximum and minimum relative distances are 0.0772 and 0.0103, respectively. The deviation between the maximum and minimum relative distance is 0.0669, which is smaller than that of LSSVM and SVM, showing that the stability of PSO-LSSVM model is higher than that of LSSVM and SVM. In FWA-LSSVM model, the maximum relative distance is only 0.0357, the minimum relative distance is 0.0036, and the deviation between the maximum and minimum relative distance is only 0.0321. Compared with the other three models, the three values of FWA-LSSVM model are smaller, which shows that the proposed FWA-LSSVM model has higher accuracy and higher stability.
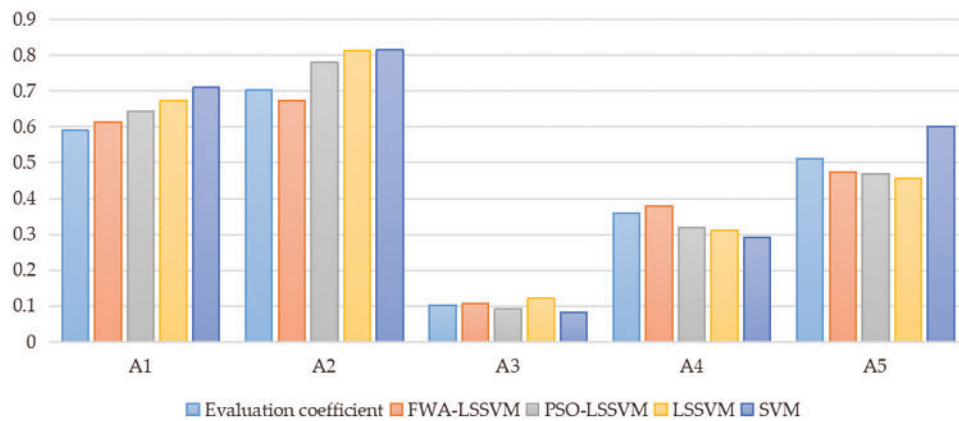
Figure 3: Comparison of evaluation results

Mean absolute percentage error (MAPE), root mean square error (RMSE) and average absolute error (AAE) are used to compare the evaluation errors of each intelligent evaluation model. Fig. 4 shows the MAPE, RMSE, and AAE for each model.
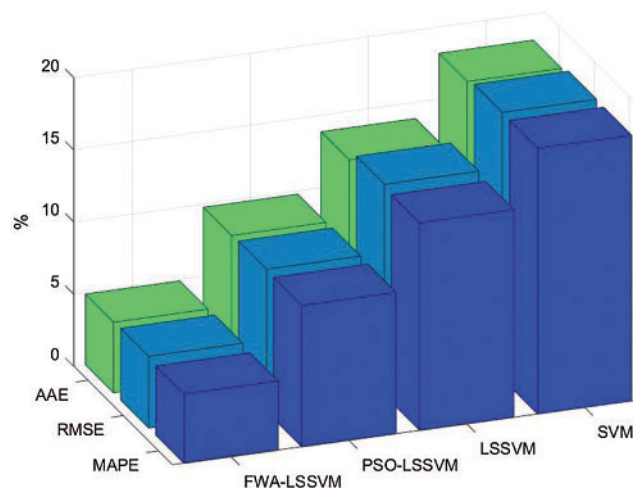

Figure 4: Comparison of the model errors

It can be seen from Fig. 4 that the sustainability evaluation results of modern photovoltaic agriculture calculated by FWA-LSSVM have the highest accuracy, and the MAPE, RMSE and

AAE are 4.80%, 4.97% and 4.89%, which are the optimal values. The MAPE, RMSE and AAE of PSO-LSSVM are 9.80%, 9.87% and 9.76%, respectively. The MAPE, RMSE and AAE of standard LSSVM are 14.39%, 14.61% and 13.86%, respectively. The MAPE, RMSE and AAE of standard SVM model are 18.40%, 18.45% and 18.15%, respectively. It shows that the error of the evaluation results of the proposed FWA-LSSVM model is the smallest, and the overall accuracy of the evaluation is the highest. Compared with PSO-LSSVM model, FWA has better optimization performance for LSSVM model. Compared with the original LSSVM model, the generalization ability and classification accuracy can be improved by optimizing the parameters of LSSVM. Compared with SVM model, LSSVM model can use kernel function to transform the prediction problem into the solution of equations and greatly improving the accuracy of evaluation. Overall, the evaluation performance of FWA-LSSVM model is the best.

Therefore, the results of the example analysis show that the proposed FWA-LSSVM model can evaluate the sustainability of modern photovoltaic agriculture scientifically and effectively. On the basis of interval type-2 fuzzy AHP-TOPSIS evaluation method, the intelligent algorithm is introduced, and expert knowledge is obtained by intelligence learning to generalize the expert scoring process in comprehensive evaluation. Then, the sustainable evaluation results of modern photovoltaic agriculture are obtained through FWA-LSSVM model, finally achieve the purpose of fast calculation and supporting relevant decision-making.

5 Conclusions

The healthy and sustainable development of modern photovoltaic agriculture can reduce the consumption of non-renewable energy in agriculture, improve the utilization rate of renewable energy, and significantly promote the efficiency of agricultural development. In order to realize the healthy and sustainable development of photovoltaic agriculture, this paper designs a set of modern photovoltaic agriculture sustainability evaluation system, mainly including an evaluation index system and a new hybrid evaluation method. Firstly, the evaluation index system of the sustainability of modern photovoltaic agriculture is constructed from three aspects, including technology sustainability, economic sustainability and social sustainability, and it solves the problems in which aspects the sustainability of modern photovoltaic agriculture is mainly reflected. Then, based on the interval type-2 fuzzy AHP-TOPSIS method, the comprehensive evaluation is carried out after the evaluation indexes are scientifically weighted, and the evaluation results are obtained from the perspective of traditional evaluation methods. After that, FWA is chosen to optimize the parameters of LSSVM, and finally the FWA-LSSVM model of modern photovoltaic agriculture sustainability is constructed, and the evaluation results are obtained from the perspective of modern intelligent evaluation method. Through the analysis of an example, the scientificity and accuracy of the evaluation model proposed in this paper are verified. The traditional evaluation model can get accurate results, while the intelligent evaluation model can achieve the purpose of fast calculation and supporting relevant decisions. To sum up, the research conclusions of this paper can provide decision-making support for putting forward a more reasonable development mode for modern photovoltaic agriculture. The application of the model proposed in this paper to other fields is an important direction for future research.

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

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