

Research on Income evaluation of photovoltaic agricultural investment model based on fuzzy real option

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Abstract. With the proposal of emission peak and carbon neutrality, in view of the actual development of China's energy economy, photovoltaic agriculture becomes an important means to promote the economic development of poor and remote areas. Aiming at the investment modes of photovoltaic agriculture projects such as agricultural land leasing and farmers' participation in investment, this paper constructs a fuzzy real option investment model, and uses Monte Carlo simulation method to evaluate and analyze the income of both photovoltaic power generation project modes. The research shows that compared with the traditional real option income evaluation, the fuzzy real option model is more suitable for the investment evaluation of photovoltaic power generation project modes, and the project with farmers' participation has higher returns. The income evaluation results show that the best time to benefit from the photovoltaic power generation project is in the next seven years or so, which provides reference for policy guidance and investment decision-making, and helps to promote the development of photovoltaic agriculture projects.

Keywords: Photovoltaic agriculture; Fuzzy number; Real options; Project valuation; Investment decisions; Monte Carlo simulation.

1. Introduction

In the context of global warming and depletion of fossil energy, the development and utilization of renewable energy has attracted more and more attention from the international community. The goals of "emission peak" and "carbon neutrality" have also got people's attention. Countries and regions have successively issued relevant policies. Due to the differences in natural resources around the world, countries with sufficient light, such as China and the United States, prefer photovoltaic power generation. At the same time, with the gradual improvement of agricultural modernization, photovoltaic agriculture has become an important means to promote income growth and achieve agricultural modernization in poor areas. Therefore, the combination of photovoltaic power generation and agricultural development, focusing on the villages where light resources can be used, and jointly promoting the full utilization of resources and the improvement of farmers' living standards has become a crucial way to achieve the goal. photovoltaic agriculture model not only makes full use of clean energy and generates power generation income, but also provides new economic sources for farmers and helps rural revitalization.

However, China's photovoltaic power generation industry is still affected by many uncertain factors, such as high project investment cost, unstable technology development, long construction cycle, adjustment of supporting policies and so on. Therefore, it is very urgent and important to select an appropriate photovoltaic power generation project model and evaluate the uncertainty of investment income of photovoltaic power generation projects systematically and accurately. This paper will use the fuzzy real option theory to study the two modes of farmers' participation in investment and farmers' provision of land lease according to local conditions, and establish the comprehensive benefit analysis and evaluation model of photovoltaic power generation, so as to evaluate the investment projects more accurately, make the best decision and strive to achieve a win-win situation.

2. Literature review

2.1 Fuzzy real option theory

The concept of real option comes from the financial option theory developed by Black and Scholes (1973) [1] and Merton (1973) [2]. Real option, originally proposed by Stewart Myers (1977) [3], means that the profit created by the cash flow generated by an investment scheme comes from the use value of the assets currently owned plus the selection value of future investment opportunities. In the traditional DCF investment evaluation model, parameters such as cash flow and discount rate cannot be accurately estimated [4]. So, some scholars combine the theory of fuzzy uncertainty analysis with the real option model to analyze the investment decision. Wu (2004) [5] proposed the application of fuzzy set theory in Black-Scholes formula. On the basis of fuzzy interest rate, fuzzy volatility and fuzzy stock price, a fuzzy model of Black-Scholes formula and the parity relationship of call option are proposed. Zhao Zhenwu (2006) [6] et al. introduced the real option evaluation method of venture capital projects based on the analysis of traditional NPV method. The present value of expected cash flow and investment cost are assumed to be fuzzy numbers and the fuzzy real option method is used to make investment decision. Thiagarajah K (2007) [7] et al. adopted black-Scholes option pricing formula with quadratic adaptive fuzzy number for volatility parameters, interest rates, stock prices and other characteristics, and gave an example. Shiu-hwei Ho (2011) [8] et al., from the perspective of real options, proposed a fuzzy method for the valuation of investment projects in an uncertain environment, which overcomes the defects that DCF method cannot accurately estimate cash flow, discount rate and other parameters and cannot reflect the value of management flexibility in investment projects. The flexibility included in a project that may increase the value of the project is a real option. Young-chan Lee (2011) [9] et al., aiming at RFID and other advanced information technologies, which have high risks and choices of change, delay, delay and exit, used real option technology to carry out investment valuation. Meanwhile, they used trapezoidal fuzzy number fuzzy real option to obtain their mean and variance through numerical examples of RFID investment. An effective method for calculating fuzzy real option is proposed. Liu Xiaojing et al. (2015) [10] discussed the real option characteristics of enterprise design innovation from the perspective of economic management, and made a scientific evaluation on the flexibility of management decision-making. Yonggu Kim (2018) [11] et al. used real options with fuzzy logic to carry out valuation and give the best investment timing to support the decisions of investors with different investment tendencies. Wang Xiandong (2020) [12] used the fuzzy compound real option method to study the investment decision-making of R & D projects, established the fuzzy compound option model of value evaluation and investment decision-making, and gave the arbitrary level cut set of fuzzy value.

2.2 The application of fuzzy real option theory in renewable energy

With the rapid development of renewable energy, the analysis of renewable energy investment income based on fuzzy real option theory has gradually attracted the attention of scholars. Tian Lixin et al. (2013) [13] considered four uncertain factors: thermal power generation cost, wind power generation cost, carbon emission right price and government encouragement and subsidy. He established a decision-making value model to evaluate the development of wind power from the perspective of the government based on the real option theory. Zhang Mingming et al. (2014) [14] Based on real options, considering the uncertainty of market conditions, technical conditions and feed in price policy, the least square Monte Carlo simulation method is used to evaluate the investment of photovoltaic power generation projects in China. At the same time, through sensitivity analysis, the impact of market changes and technical changes on the investment value and optimal investment time of photovoltaic power generation is discussed. Lee H W (2014) [15] et al. proposed a volatility level estimated by real option valuation (ROV) based on Monte Carlo simulation, and compared ROV results of one-stage strategy with those of two-stage strategy by binomial case method, so as to quantify the benefits of improving management flexibility in this stage. Wang S (2016) [16] proposed a real option investment and evaluation model based on back propagation neural network, and

evaluated Chinese renewable energy enterprises. Passos A C (2017) [17] et al. proposed a dynamic model that simultaneously considered three types of uncertainties: renewable energy production of candidate resources and prices in spot and contract markets to design an optimal risk-averse investment strategy for complementary renewable energy portfolios for power generation companies in Brazil's power system. Lin Qing (2015) [8] and Yang Xiaoping (2021) [19] respectively evaluated the value of the fuzzy real option model in the biomass energy investment project and the energy storage investment project of lithium battery applied to wind power generation system, and analyzed the sensitivity of the uncertain factors of the model, so as to facilitate the decision-makers to correctly select the project investment direction and investment opportunity in the uncertain and competitive environment.

In recent years, fuzzy real option theory has also been widely used in photovoltaic power generation projects. Sarkin and Tamarkin (2008) [20] evaluated the investment of photovoltaic power generation projects under the uncertainty of electricity price and photovoltaic power generation technology. Huseyin yigit Ersen (2018) [21] made the fuzzy real option theory and its application in solar energy investment projects.

Photovoltaic agriculture is an important means to promote agricultural modernization in poor areas in China [12]. Facing the increasing investment demand of photovoltaic power generation and the uncertainty of its future, it is significant to use fuzzy real option method to systematically describe the characteristics of various uncertain factors and build a decision-making model to help investors make the best decision. Based on the existing research, this paper combines the economic benefits with the low-carbon benefits of photovoltaic power generation. We respectively study the two modes of the project, farmers participating in the investment and farmers only providing land lease, then establishes the comprehensive benefit analysis and evaluation model of photovoltaic power generation by using fuzzy real option theory. At the same time, we apply the proposed model to the case study of the actual photovoltaic power generation industry to verify the effectiveness of the proposed method.

3. Methodology

3.1 Fuzzy set theory

Fuzzy set was introduced by Zadeh (1965) [22] to deal with non-statistical uncertainty of data and information processing. Let A be a mapping of set X to $[0,1]$, $A: X \rightarrow [0,1]$, $X \rightarrow A(X)$, then X is called the fuzzy set on A , $A(X)$ is called the membership function of fuzzy set A , or $A(X)$ is the membership degree of X to fuzzy set A .

In order to objectively measure the fuzziness of things, we can take a real-valued function whose range is on $[0,1]$, $\mu_A(x)$, to represent the membership degree of x to the fuzzy set, which is called the membership degree of x . When $\mu_A(x)=1$, it means that the thing x completely belongs to the fuzzy set. When $\mu_A(x)=0$, it means that the thing x does not belong to the fuzzy set at all. The closer $\mu_A(x)$ gets to 1, the more x belongs to something. In this way, different fuzzy numbers can be expressed according to the different $\mu_A(x)$ functions.

Common fuzzy numbers include triangular fuzzy numbers and trapezoidal fuzzy numbers, which can be expressed as $\langle m, a, b \rangle$ and $\langle m, n, a, b \rangle$ respectively. Triangular fuzzy numbers are a special case of trapezoidal fuzzy numbers.

Assume that triangle fuzzy number $A = (a_1, a_2, a_3; 1)$, $B = (b_1, b_2, b_3; 1)$, then we can get the following rules. The operational rules can be listed as below.

$$A+B=(a_1+b_1, a_2+b_2, a_3+b_3; 1).$$

$$A-B=(a_1-b_1, a_2-b_2, a_3-b_3; 1).$$

Suppose that λ is a real number, then $\lambda A = (\lambda a_1, \lambda a_2, \lambda a_3; 1)$.

While for two triangular fuzzy numbers, it is not always possible to get the result of fuzzy numbers by direct multiplication and division. However, if the operation is carried out in the form of γ -truncated set, the following assumptions are made:

$$A=[a1(\gamma),a3(\gamma)]=[(1-\gamma)a1+\gamma a2,(1-\gamma)a3+\gamma a2]$$

$$B=[b1(\gamma),b3(\gamma)]=[(1-\gamma)b1+\gamma b2,(1-\gamma)b3+\gamma b2]$$

Then the multiplication and division algorithm operation can be defined as:

$$A \times B=[a1(\gamma)b1(\gamma),a3(\gamma)b3(\gamma)]$$

$$A \div B=[a1(\gamma)/b1(\gamma),a3(\gamma)/b3(\gamma)]$$

3.2 Real option theory and model

Real option is derived from financial option, and its corresponding underlying asset is a specific investment project. To be specific, it can be understood as follows: Suppose there is a completely irreversible investment project at present, and the value of the project comes from the cash flow generated in the future, then the real option contained in the project can be analyzed as follows:

We can think of the act of investing in the project as the exercise of an option. Assuming that the investment of a project is divided into several stages, the investment in the last stage can be regarded as the execution of the real option. The option fee comes from the input of the project in the previous stage, and the change of the project value caused by the fluctuation in the future is the future price of the project.

The pricing of real options generally includes three methods: Black-Scholes-Merton formula, binary tree method and least square Monte Carlo simulation method. The first method is only applicable to European options, that is, the value of options that cannot be exercised in advance before the expiration date; The latter two methods are mainly solved in reverse, so both European and American options can be evaluated. The least square Monte Carlo simulation method is used in this paper.

The least square Monte Carlo simulation method is modified on the basis of monte Carlo simulation method so that it can be used to solve the value of American options. The least square Monte Carlo simulation method is a probabilistic and random numerical calculation method. When using Monte Carlo simulation method, it is assumed that the underlying assets obey a certain geometric distribution, so that the random path of the price in a certain time can be simulated by computer, and the value of the project under this path can be calculated. Repeating the simulation many times can obtain all possible outcomes for the underlying asset price at the same time point in a certain period of time. At this time, different from the traditional Monte Carlo simulation method, the least squares Monte Carlo simulation method is mainly used to evaluate the price of American options that can be exercised at any time before the expiration date. Therefore, when exercising exercise, it is necessary to consider the magnitude between the intrinsic return of exercising the option at that time and the expected return of continuing to hold the option, namely:

$$f_i(S_i)=\max\{I_i(S_i),E[e^{-r\Delta t}f_{i+1}(S_{i+1})|S_i]\}$$

Among them, $f_i(S_i)$ is the value of the option at time i , $I_i(S_i)$ means the intrinsic value of the option at time i , $E[e^{-r\Delta t}f_{i+1}(S_{i+1})|S_i]$ represents the discount of the future expected value of the option at time $i+1$ under asset prices at time i .

And to calculate $E[e^{-r\Delta t}f_{i+1}(S_{i+1})|S_i]$ we need to know the future exercise strategy. To this end, add the least squares method to calculate $E[e^{-r\Delta t}f_{i+1}(S_{i+1})|S_i]$:

$$E[e^{-r\Delta t}f_{i+1}(S_{i+1})|S_i] \approx \alpha + \beta_1 S_i + \beta_2 S_i^2$$

Using the price at time i under the sample path as the X value and the price of the underlying asset at time $i+1$ as the Y value, α , β_1 and β_2 can be calculated.

In order to find the optimal execution time and value of the option, we can work backwards from the expiration date. At expiration time T , the intrinsic value of the option is $\max[X-ST, 0]$ (assuming the option is A put option). For time $T-1$, if $X > ST-1$, it is unable to directly choose whether to exercise the option. It is necessary to compare the option income at time T (that is, the income from

the option held to the expiration date). If $[X - S_{T-1}] < e^{-r\Delta t}[X - S_T]$, the option cannot be exercised. For the expected return of holding options, regression can be used to solve:

$$E[y_{T-1}] = e^{-r\Delta t} \max\{X - S_{T-1}, 0\} \approx \alpha + \beta_1 S_{T-1} + \beta_2 S_{T-1}^2$$

Based on this, we can compare and calculate whether we exercise at time T-1, and calculate the option holding period return at time T-2, T-3, ..., 0 in the same way. The final value of the option is:

$$f = e^{-r\Delta t} \max[X - S_i]$$

Finally, all the simulation results are regarded as a set of random samples, and the expected value of the option at a particular moment can be obtained by taking the average of all the samples.

3.3 Investment characteristics of photovoltaic agriculture projects

Photovoltaic power generation is a way to convert light energy into solar energy. It is the key technology of new energy power generation in China. At present, photovoltaic power projects in our country mainly include two kinds, one is distributed photovoltaic power and the other is centralized photovoltaic power. Because distributed photovoltaic power generation is only partially connected to the grid, and the distribution is relatively scattered, it is difficult to conduct unified value evaluation, and the accuracy cannot be guaranteed. Therefore, the investment value evaluation in this paper is only for centralized photovoltaic power generation projects.

In order to make better use of rural resources and increase farmers' income, this paper considers investing in photovoltaic power generation projects in rural areas, and puts forward two investment modes. The first mode is that farmers only rent land for power generation manufacturers to build power generation and do not participate in the investment and construction of power generation projects. At this time, for power generation manufacturers, the land rent of renting farmers' land is part of the cost, and other expected income is owned by the manufacturers themselves. The second mode is the photovoltaic power generation mode in which farmers participate in investment. At this time, farmers, as a member of investors, will also receive the benefits of photovoltaic power generation projects, that is, farmers' agricultural production electricity is borne by photovoltaic power generation manufacturers. At the same time, the combination of photovoltaic power generation projects and agricultural production is conducive to the production of specific crops, increasing crop output and farmers' income. Finally, the new jobs created by the construction of photovoltaic power generation projects can be given priority to farmers participating in investment.

As the photovoltaic agriculture project is affected by many uncertain factors, such as benchmark on grid price, initial investment expenditure and green card transaction price, so its investment has strong irreversible characteristics. Once invested, it will be transformed into sunk cost. Therefore, it is very suitable to use the real option method for investment evaluation. The real option method can make up for the defects of the traditional valuation theory and better quantify the option value brought by uncertainty. However, in practice, decision makers are often unable to accurately obtain parameter values, resulting in a large degree of ambiguity in the measurement of uncertainty. Therefore, fuzzy number can be introduced to fuzzify the parameters and obtain the uncertain value in the fuzzy environment, so as to evaluate the investment project more accurately and help investors make the optimal decision.

4. Fuzzy real options modelling : assessing the option to delay

4.1 Assumptions of the model

When evaluating photovoltaic power generation projects, the most commonly used method is the net present value method. However, the net present value method does not take into account the impact of uncertain factors of photovoltaic power generation projects on the investment value. Therefore, we give the value evaluation model of photovoltaic agriculture project based on fuzzy real option method. In the construction of the model, this paper makes the following assumptions:

The project construction cycle is ignored, that is, after the project chooses investment and construction at the beginning of the year, it can get income at the end of the year.

(1) The project will maintain full load operation within the working life, regardless of shutdown and accidents.

(2) The power generation efficiency of power generation projects decreases linearly year by year.

(3) Investors make only one investment in the investment cycle.

4.2 The establishment of photovoltaic project investment assessment

4.2.1 Fuzzy real option investment model of photovoltaic agriculture project based on land lease

Based on the above assumptions for photovoltaic agriculture projects, this paper can establish a real option income model of photovoltaic agriculture projects based on land lease:

$$R_t = V_t + V_s - I_t - C_t - H_t, 0 \leq t \leq t_v \quad (1)$$

$$V_t = \sum_{i=t}^{t+t_s} F_t \times g_i^r \times D_i \quad (2)$$

$$F_t = P_t^d \quad (3)$$

$$g_i^r = AOT \times Scale \times Ge_t \times (1 - r^e) \quad (4)$$

$$Ge_t = Ge_{t-1} \times d^r \quad (5)$$

$$D_i = \exp(-r) \quad (6)$$

$$V_s = N_s \times P_g \times D_i \quad (7)$$

$$C_t = \sum_{i=t}^{t+t_s} O_i \times g_i^r \times D_i \quad (8)$$

$$H_t = H_t^{vat} + H_t^{cit} \quad (9)$$

$$H_t^{vat} = \sum_{i=t}^{t+t_s} P_t^d \times g_i^r \times R_i^{vat} \times D_i \quad (10)$$

$$H_t^{cit} = \sum_{i=t}^{t+t_s} \left[(P_t^d - g_i^r) \times (1 - R_i^{vat}) - O_i \times g_i^r \right] \times R_i^{cit} \times D_i \quad (11)$$

Of which, V_t is the income from power generation, V_s is the income from energy conservation and emission reduction, I_t is the initial investment cost, C_t is the operation and maintenance cost, H_t is tax. F_t is the benchmark on grid price, g_i^r is the on grid power of each year, D_i is the discount factor. P_t^d is the on grid electricity price for desulfurization, AOT represents the annual operation time of photovoltaic power station, $Scale$ represents the installed capacity of photovoltaic power station, Ge_t is the annual photovoltaic power generation efficiency, d^r represents the annual reduction in efficiency, r^e represents the self-consumption rate of power in the power plant. r is the discount rate. The benefits of energy conservation and emission reduction are measured by green card trading, N_s is the number of green certificates, P_g is the unit price of green certificate. O_i is the unit operating expenditure. H_t^{vat} is value added tax, H_t^{cit} is income tax. R_i^{vat} is the VAT rate, R_i^{cit} is the income tax rate.

Based on the idea of real option, due to the existence of uncertain factors and management flexibility, in the effective investment cycle, investors can choose the time when they can obtain the maximum investment benefit according to the real-time market information. In this cycle, when the income of immediate investment is greater than that of delayed investment, investors will choose to invest, otherwise they will continue to wait for the best time to invest. Investors will only make one investment in the whole investment validity period, and the value of investment at this time is the maximum value of the whole power generation project.

According to the above description, the investment value of photovoltaic agriculture project can be obtained in this paper as follows:

$$F = MAX_t \left(\max(R_t, 0) \right), 0 \leq t \leq t_v \quad (12)$$

The income of farmers under the land lease mode:

$$Revenue = 0.2R_t \quad (13)$$

4.2.2 Fuzzy real option investment model of photovoltaic agriculture projects with farmers' participation

For photovoltaic agriculture projects invested by farmers, farmers, as a member of investors, will have some new income types under this mode:

Income from agricultural production

Using the agricultural light complementary technology combining solar photovoltaic power generation and agricultural planting, photovoltaic power generation is used above the ground, and some shade loving and salt tolerant cash crops are planted on the ground to realize the cross utilization of light and land. At the same time, relevant equipment can be configured to achieve the ideal temperature, shorten the planting cycle, realize multi-season planting and give full play to the maximum benefits of the land.

Social security benefits

Photovoltaic power generation projects can create jobs for the society and improve farmers' income, which is expressed in terms of operation and maintenance costs to farmers.

Based on the above two new income types, the fuzzy real option income model of photovoltaic power generation project invested by farmers is obtained:

$$R_t = V_t + V_s + V_f - I_t - C_t - H_t, 0 \leq t \leq t_v \quad (14)$$

$$V_f = (Q'_f - Q_f) \times p \times D_i \quad (15)$$

Among them, the meaning represented by V_t , V_s , I_t , C_t , H_t , D_i is the same as the fuzzy real option income model formula of photovoltaic power generation project based on land lease, but the power generation contained in V_t can be used by farmers first, and the rest can be used for Internet access, which indirectly brings power value to farmers. V_f represents the income of agricultural production, Q'_f represents the output of agricultural products after photovoltaic power generation, Q_f represents the original output, and P represents the unit price of agricultural products. At this time, the operation and maintenance costs indicated by C_t will be returned to farmers in the form of wages to increase farmers' income and obtain social benefits.

Similar to the previous model, investors will choose the best investment time within the effective investment cycle.

The investment value at this time is:

$$F = MAX_t \left(\max(R_t, 0) \right), 0 \leq t \leq t_v \quad (16)$$

Farmers' income under the mode of farmers' participation in investment:

$$Revenue = 0.2R_t + C_t \quad (17)$$

4.3 4.3 Fuzzy processing of uncertain power generation project factors

The impact of uncertainties on the value of photovoltaic agriculture projects is considered below. The following three uncertain factors are mainly considered: benchmark on grid price, initial investment expenditure and green card transaction price. And when the real option method is used to evaluate the value of photovoltaic agriculture projects, there is a high demand for the accuracy of the initial input parameters. For example, the parameters in the model include benchmark on grid price, initial investment cost, green card transaction price and discount rate. They all use historical data, which has a great impact on the accuracy of the evaluation value of the model. In order to solve this

problem, this paper introduces the concept of fuzzy number and uses triangular fuzzy number to fuzzify the above parameters, so as to achieve more accurate value evaluation.

Benchmark on grid price and fuzzy processing

With the development of China's economy and the continuous progress of photovoltaic power generation technology, the future electricity price of photovoltaic agriculture projects is still in an uncertain state of change. Therefore, this paper assumes that the future benchmark on grid price of power generation project follows geometric Brownian motion, that is:

$$dp^d = \alpha_d p^d dt + \sigma_d p^d dz_t \quad (18)$$

Among them, dz_t represents Wiener process, $dz_t = \varepsilon_t^g \sqrt{dt}$, ε_t^g is the standard normal distribution with mean value of 0 and variance of 1, α_d is the instantaneous expected drift rate of feed in price, and σ_d is the instantaneous standard deviation of feed in price. Among them, the estimation of σ can be carried out in the following steps [7][a]: assume that $l+1$ is the number of observations; S_i is the variable value at the end of i time interval ($i=0,1,2,\dots,l$); Δt indicates the length of the time interval in years. First, calculate according to the historical sample data: $\mu_i = \ln(S_i/S_{i-1})$, ($i=1,2,3,\dots,l$). Second, calculate the general estimated value of the standard deviation S of μ_i :

$S = \sqrt{\frac{1}{l-1} \sum_{t=1}^l \left(\mu_t - \bar{\mu} \right)^2}$ or $S = \sqrt{\frac{1}{l-1} \sum_{t=1}^l \mu_t^2 - \frac{1}{l-1} \left(\sum_{t=1}^l \mu_t \right)^2}$, where $\bar{\mu}$ is the mean value of μ_i and the final volatility is $\sigma = S / \sqrt{\Delta t}$.

Assuming that the benchmark on grid price p^d is a fuzzy number, the following formula is satisfied

$$(P^d)_\gamma = [(P^d)_\gamma^-, (P^d)_\gamma^+] = [P_0^d - (1-\gamma)\alpha_{p^d}, P_0^d + (1-\gamma)\beta_{p^d}] \quad (19)$$

Where, P_0^d represents the core value, that is, the current benchmark on grid price; γ Represents the confidence level under the triangular fuzzy number, that is, the membership degree of the fuzzy electricity price to P^d . α_{p^d} and β_{p^d} represent the left and right expansions respectively. $P_0^d - \alpha_{p^d}$ and $P_0^d + \beta_{p^d}$ are the upper and lower bounds of the triangular fuzzy number.

Initial investment expenditure and fuzzy processing

The initial investment expenditure of photovoltaic power generation project is closely related to the development of photovoltaic power generation technology. With the development of current photovoltaic power generation technology, its initial investment expenditure also has great uncertainty. Therefore, we propose a hypothesis that the initial investment expenditure of the power generation project in the future follows the geometric Brownian motion, that is:

$$dI_t = \alpha_I I_t dt + \sigma_I I_t dz_t \quad (20)$$

Where dz_t is the Wiener process, $dz_t = \varepsilon_t^g \sqrt{dt}$, ε_t^g is the standard normal distribution with mean value of 0 and variance of 1, α_I is the instantaneous expected drift rate of the initial investment unit price, and σ_I is the instantaneous standard deviation of the initial investment unit price.

Assuming that the initial investment expenditure I_t is a fuzzy number, the following formula is satisfied:

$$(I_t)_\gamma = [(I_t)_\gamma^-, (I_t)_\gamma^+] = [I_{t0} - (1-\gamma)\alpha_{I_t}, I_{t0} + (1-\gamma)\beta_{I_t}] \quad (21)$$

Where, I_{t0} represents the core value, that is, the current initial investment expenditure; γ Represents the confidence level under the triangular fuzzy number, that is, the membership of the fuzzy investment cost to I_t . α_{I_t} and β_{I_t} represent the left and right extensions respectively. $I_{t0} - \alpha_{I_t}$ and $I_{t0} + \beta_{I_t}$ are the upper and lower bounds of the triangular fuzzy number.

Green card transaction price and fuzzy processing

Green certificate refers to the electronic certificate with unique code identification issued by the information center to qualified renewable energy power generation enterprises through the renewable energy power generation project information management platform of the National Energy

Administration in accordance with relevant national management regulations and based on the on grid power of renewable energy. It records which onshore wind farm or photovoltaic centralized power station the specific 1000 kwh on grid power comes from in the country. Green card can be traded and cashed into monetary income, which is an indicator to confirm the mode of renewable energy power generation.

In order to promote the development of renewable energy, China has implemented green card trading since 2017. At present, China's green card trading market is in the stage of voluntary subscription, which is expected to be improved with the popularization of the concept of carbon neutrality in the future. Based on the current development of the green card trading market, the government is also in the exploratory stage of how to implement the green card policy, and the green card trading price has great uncertainty. Therefore, this paper assumes that the green card trading price follows the geometric Brownian motion, that is:

$$dp^g = v_g p^g dt + \sigma_g p^g dz_t \quad (22)$$

Where dz_t represents Wiener process, $dz_t = \varepsilon_t^g \sqrt{dt}$, ε_t^g is the standard normal distribution with mean value of 0 and variance of 1, v_g is the instantaneous expected drift rate of green certificate unit price, and σ_g is the instantaneous standard deviation of green certificate unit price.

Assuming that the green card transaction price p^g is a fuzzy number, the following formula is satisfied:

$$(p^g)_\gamma = [(p^g)_\gamma^-, (p^g)_\gamma^+] = [P_0^g - (1 - \gamma)\alpha_{p^g}, P_0^g + (1 - \gamma)\beta_{p^g}] \quad (23)$$

Where, P_0^g represents the core value, that is, the current green card transaction price; γ Represents the confidence level under triangular fuzzy number, that is, the membership degree of fuzzy green card transaction price to p^g . α_{p^g} and β_{p^g} represent the left and right development respectively. $P_0^g - \alpha_{p^g}$ and $P_0^g + \beta_{p^g}$ are the upper and lower bounds of triangular fuzzy number.

fuzzy processing of discount rate

If the discount rate R is a fuzzy number, the following formula is satisfied:

$$(\tilde{r})_\gamma = [(\tilde{r})_\gamma^-, (\tilde{r})_\gamma^+] = [r_0 - (1 - \gamma)\alpha_r, r_0 + (1 - \gamma)\beta_r] \quad (24)$$

Where, r_0 represents the core value, i.e. the current discount rate; γ Represents the confidence level under the triangular fuzzy number, that is, the membership of the fuzzy discount rate to r_0 . α_r and β_r represent the left and right extensions respectively. $r_0 - \alpha_r$ and $r_0 + \beta_r$ are the upper and lower bounds of the triangular fuzzy number.

4.4.4 Fuzzy Real Option Model of photovoltaic agriculture project

Based on the above conclusions, we can get the investment value fuzzy real option model of photovoltaic agriculture project based on land lease:

$$(R_t)_\gamma = [(R_t)_\gamma^-, (R_t)_\gamma^+] \quad (25)$$

$$(R_t)_\gamma^- = (V_t)_\gamma^- + (V_s)_\gamma^- - (I_t)_\gamma^- - C_t - H_t \quad (26)$$

$$(R_t)_\gamma^+ = (V_t)_\gamma^+ + (V_s)_\gamma^+ - (I_t)_\gamma^+ - C_t - H_t \quad (27)$$

Among them, $(R_t)_\gamma^-$ is a conservative estimate of the income of the photovoltaic power generation project, that is, the minimum value of the project, and $(R_t)_\gamma^+$ is a positive estimate of the photovoltaic power generation project, that is, the maximum value that the project can achieve.

We can also get the investment value of fuzzy real option model of photovoltaic agriculture project with farmers' participation:

$$(R_t)_\gamma = [(R_t)_\gamma^-, (R_t)_\gamma^+] \quad (28)$$

$$(R_t)_\gamma^- = (V_t)_\gamma^- + (V_s)_\gamma^- + V_b + V_f + E_f - (I_t)_\gamma^- - C_t - H_t \quad (29)$$

$$(R_t)_\gamma^+ = (V_t)_\gamma^+ + (V_s)_\gamma^+ + V_b + V_f + E_f - (I_t)_\gamma^+ - C_t - H_t \quad (30)$$

5. Case study

5.1 Project background

This paper selects the photovoltaic agriculture project with an installed capacity of 50MW (occupying about one square kilometer of land) and a life cycle of 10 years as the analysis object, and uses two different methods of real option and fuzzy real option to evaluate and compare the project value of the above two photovoltaic agriculture models, in order to provide investors with more accurate decision-making opinions.

5.2 Fuzzy real option evaluation method

This paper considers the value contained in three risk factors, namely market electricity price, green card transaction price and initial investment cost. In order to prevent subjective error in initial parameter selection, triangular fuzzy number is introduced to modify the evaluation method on the basis of real option, so as to evaluate the investment of photovoltaic power generation project more comprehensively.

5.2.1 Parameter estimation

Table 1. Parameter estimation

parameter	interpretative statement	data	Company	data sources
<i>Scale</i>	Installed capacity of photovoltaic power station	50	MW	
<i>N</i>	Life cycle of power generation project	10	year	
<i>AOT</i>	Annual operation time of photovoltaic power station	1800	h	
<i>d^r</i>	Annual reduction degree of power generation efficiency	2%		Development roadmap of China's photovoltaic industry in 2020
<i>F_t</i>	Benchmark on grid price	0.469	yuan	Jiangsu Provincial Development and Reform Commission
<i>F_f</i>	Agricultural electricity price	0.5090	yuan	State Grid
<i>Ge_t</i>	Photovoltaic annual power generation efficiency	83%		China photovoltaic Association
<i>α_d</i>	Instantaneous expected drift rate of on grid price	0.018		Calculated according to a
<i>σ_d</i>	Instantaneous expected volatility of feed in price	0.026		Calculated according to a
<i>v_g</i>	Instantaneous expected drift rate of green card unit price	1.593		Calculated according to a
<i>σ_g</i>	Instantaneous expected volatility of green card unit price	0.43		Calculated according to a
<i>r</i>	Discount rate	0.08		Energy observation network
<i>R_i^{vat}</i>	VAT rate	13%		PV power generation VAT Policy
<i>R_i^{cit}</i>	Income tax rate	20%		Photovoltaic power generation income tax policy
<i>O_i</i>	Unit operating expenses	0.05	yuan/W	China Energy Network
<i>α_I</i>	Instantaneous expected drift rate of initial investment unit price	0.011		Calculated according to a
<i>σ_I</i>	Instantaneous expected volatility of initial investment unit price	0.0073		Calculated according to a
<i>I</i>	Initial investment cost	3390	yuan	China photovoltaic Association
<i>P</i>	Crop unit price	10	yuan/kg	China News Network

5.2.2 Solving process

The real option constructed in this paper is an American option that can be executed at any time before the expiration date. For this kind of option, the traditional B-S formula can not price it directly. Generally, it is mainly composed of binomial method, finite difference method and Monte Carlo simulation method. In view of the fact that this paper constructs the options of three different underlying assets, using the first two methods for valuation will greatly increase the number of nodes in the process, and ultimately can not obtain accurate value. Therefore, this paper will use Least Squares Monte Carlo simulation to evaluate the constructed real options.

Least Squares Monte Carlo simulation is to simulate the future price of the underlying asset by using the simulation method based on the characteristic that the underlying asset obeys geometric Brownian motion. The more simulation paths, the closer the state is to the future price trend of the underlying asset. Therefore, this paper will use the existing target parameters to realize the future price simulation of the target asset through MATLAB, with 5000 times of simulation. At the same time, variance reduction technology is used to reduce the fluctuation of simulation data and make the simulation more accurate. The final results are as follows:

Mode 1: land leasing photovoltaic agriculture project

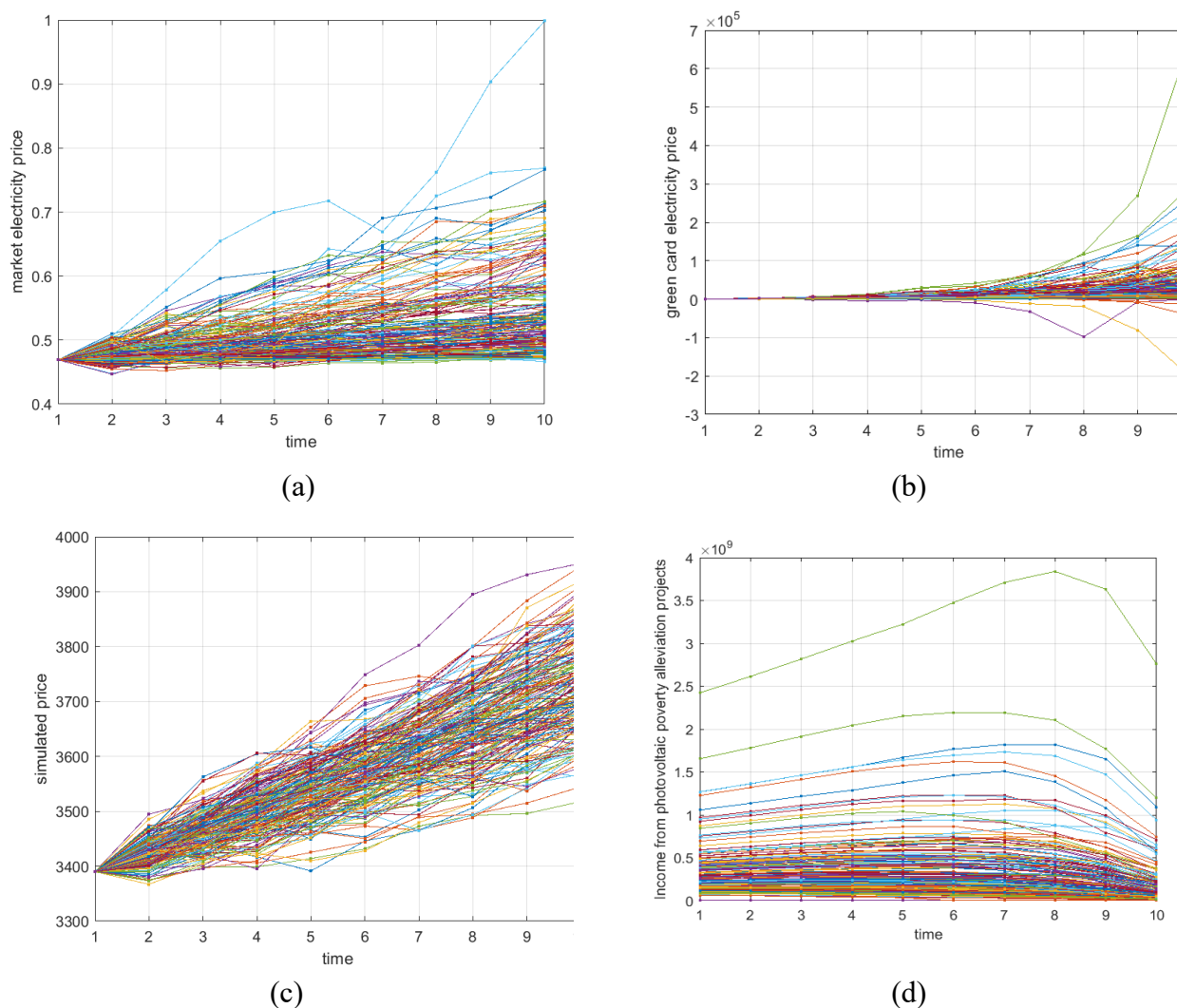


Fig. 1 (a) Simulated price of the first 200 times of market electricity price in mode 1, (b) Simulated price of green card electricity price for the first 200 times of mode, (c) Simulated price of the first 200 cost investments in mode 1, (d) Income simulation diagram of photovoltaic agriculture project in mode 1

The figure shows the price trend of three uncertain factors in the next 10 years. Based on the above simulated price, the future income of the project is calculated under different project execution time, as shown in the above figure.

Based on this, we take the price income simulated in each phase as the dependent variable and use the least square method to inversely solve the correlation coefficient, so as to obtain the expected function of the project income in the next phase and bring it back to the solution. At the same time, by comparing the expected return at the next time with the simulated return at that time, choose whether to implement the investment. By analogy, the optimal execution value of the project on one path is finally solved, and the initial maturity is discounted as the optimal value of the project. Finally, the optimal price of the project on the simulated 200 paths is averaged to obtain the project option value under the real option model.

Mode 2: photovoltaic agriculture projects invested by farmers

Similarly, the price trend chart and project income of the three uncertain factors in mode 2 in the next 10 years are as follows:

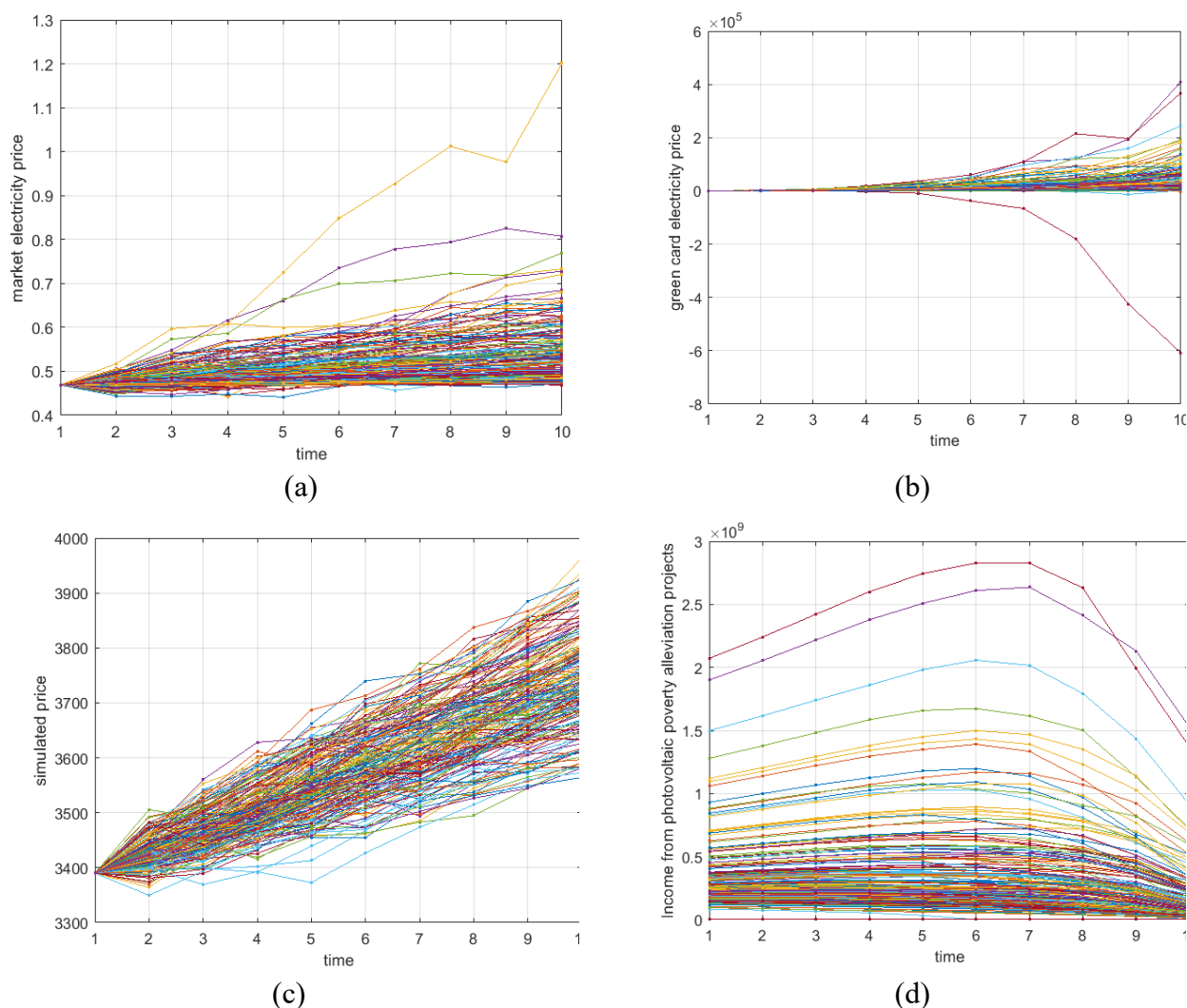


Fig. 2 (a) Simulated price of the first 200 times of market electricity price in mode 2, (b) Simulated price of green card electricity price for the first 200 times of mode 2, (c) Simulated price of the first 200 cost investments in mode 2, (d) Income simulation diagram of photovoltaic agriculture project in mode 2

5.2.3 Evaluation results

Based on the above cases, this paper selects the confidence level γ the value range of the two modes of photovoltaic agricultural project is solved by using MATLAB software and least square Monte Carlo simulation method as follows:

Table 2. Evaluation results of fuzzy real option method

entry name	Project value (unit: 10000 yuan)	investment decision
Land leasing photovoltaic agriculture project	[204360,226840]	Choose investment
Farmers' participation in photovoltaic agriculture project	[212800,231400]	Choose investment

As can be seen from the results in the table, the project value is an interval and much greater than 0, indicating that the project is worthy of investment. The project value of Model 1 under conservative and positive conditions is 2.0436 billion yuan and 2.2684 billion yuan respectively, while the project value of model 2 under conservative and positive conditions is 2.128 billion yuan and 2.314 billion yuan respectively. Even under conservative conditions, the return of farmers' participation in investment is higher than that of land leasing.

6. Conclusions

Under the background of "emission peak" and "carbon neutrality", photovoltaic power generation projects are in a good state of development, it is particularly important to focus on the characteristics of "photovoltaic +" industry and give investors appropriate value evaluation methods. Combined with the characteristics of photovoltaic power generation projects, this paper explores the new development idea of combining photovoltaic and agriculture, helps rural revitalization, introduces the fuzzy real option theory into the investment value evaluation of projects, puts forward two modes of land leasing photovoltaic agricultural projects and farmers' participation in photovoltaic power generation projects, constructs two investment value evaluation models of photovoltaic agriculture projects, and substitutes parameters for case analysis. Finally, according to the evaluation results, the evaluation methods and the benefits of the two models are compared, and relevant conclusions are drawn.

Fuzzy real option method shows investors the range of project investment value in the results of project evaluation, so as to help investors with different risk preferences make the most suitable investment choice according to their own risk preferences. The results of the project evaluation of the two modes show the feasibility and broad prospects of the photovoltaic agriculture project, and also show that the participation of farmers makes the project more valuable and the poverty alleviation effect better, further expand the application field of photovoltaic, and give project investors more accurate and reasonable investment opinions; At the same time, according to the income curve, the best benefit time of photovoltaic agriculture projects will reach the peak in the next seven years or so, which provides a strong reference value for policy construction and enterprise layout. The above conclusions have important significance for the scientific decision-making of photovoltaic enterprise investment and the policy guidance of renewable energy and agricultural development industry in China.

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