Flexible Investment Decision of BIPV Project Considering Green Certificate Policy

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Abstract: Promoting the investment and construction of BIPV projects is a non-negligible issue in the field of low-carbon buildings in the future. This paper investigates a flexible investment decision process problem for BIPV projects considering the green certificate policy, treating the investment opportunity as an American call option valid in a certain discrete time, and simulating it using least squares Monte Carlo simulation method with project data from Chongqing, China. The results show that the green certificate mechanism can significantly increase the project revenue, the project value considering the flexible investment decision is higher than that of the fixed investment decision, and the project value varies in the same direction with the volatility of the market price of electricity and the price of green certificates, and inversely with the volatility of the investment cost.

Keywords: Green Certificate; Flexible Investment Decision; BIPV

1. Introduction

Building Integrated Photovoltaics (BIPV) project is an emerging building form that integrates solar cell technology on the outside of the building, and it is a special distributed photovoltaic power generation project with "self-generation and self-consumption, and on-grid for residual power generation" as the operation mode. BIPV project.

Currently, the investment and construction of BIPV projects are facing many challenges. Firstly, the initial investment amount of the project is large and the investment process is irreversible. Secondly, the project will face many uncertainties during the investment process. Finally, distributed PV projects were officially included in August 2023 as certifiable green certificate projects. This indicates that BIPV projects are also able to obtain green certificates during operation and participate in the green certificate market for additional revenue. However, the price of photovoltaic green certificates in China is currently in a state of constant fluctuation due to a variety of objective conditions, which will further increase the uncertainty of the operation of BIPV projects.

To address the above challenges, investors can adopt flexible investment decisions when

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investing for BIPV projects, viewing the investment decision of a project as an American call option in a financial option. The flexible decision-making process enables decision makers to adaptively adjust investment decisions to changing environments within the effective period [1]. Commonly used flexible investment decisions include expanding investment, switching investment, delaying investment, etc. [2].The key difficulty of flexible investment decision-making in BIPV projects is how to accurately assess the project value under the multi-dimensional uncertain operating environment to support the decision maker's flexibility in adjusting the investment time and investment amount. Real options theory is widely used in the study of flexible investment decision making for renewable energy projects, and this theory can well utilize options to quantify the value of flexible investment, and common methods include bifurcation tree method [3], Monte Carlo simulation method [4], and so on. Since traditional valuation methods are unable to quantify multiple uncertainties, the Least-Squares Monte Carlo Simulation (LSMC) method developed by Longstaff and Schwartz expresses the option value as a linear combination of given state characteristics (i.e., a basis function) and combines it with dynamic programming to reverse the derivation to obtain the optimal strategy [5].

In this paper, with reference to the above method for the distributed photovoltaic feed-in tariff, unit investment cost, and green certificate price random fluctuations, the optimization problem of flexible investment decision for BIPV projects considering green certificate policy is solved by inverse dynamic planning technique and least squares Monte Carlo simulation method, which provides a reference for the investment decision of BIPV projects.

2. Construction of Flexible Investment Decision Model for BIPV Project

2.1. Problem description and assumptions

This paper investigates a flexible investment decision process problem for BIPV projects considering a green certificate policy. The investment for a BIPV project is regarded as an American call option valid for a certain discrete period of time. It is assumed that the investor can make a decision at an effective period$T$ At any point in time during the decision-making process, the investor can value a BIPV project with an operating life of$N$ of the BIPV project (as shown in Fig. 1). Throughout their life cycle, BIPV projects face a variety of uncertainties as mentioned before, such as fluctuations in unit installation costs, changes in distributed PV feed-in tariffs, and changes in green certificate policies. Therefore, in the process of evaluating the project, the investor can simulate the value of the uncertainty in time $T + N$and assess the value of the project at any time t within this period of time. In each simulation, the decision maker can compare the value of the project over the life of the investment, and then assess the value of the project through the K times simulations. The probability of occurrence of each simulated scenario is q^k. Assuming that the decision maker conducts$K$ times simulations, then the investor at each point in time$t$ makes an investment and keeps the project running smoothly for$N$ the project's value at the end of the year:

$$S_t = \sum_{k=1}^{k} q^k (\sum_{n=t}^{t+N} e^{-in} \cdot R_n^k - C_t^k) \tag{1}$$

R_n^k is the project's nth year's net income, theC_t^k is$t$ the one-time cost that needs to be invested at the moment, and$i$ is the discount rate. Through simulation, decision makers can choose the best timet^* to implement the investment decision, thus realizing the optimal valueS_t.

In this paper, a project value model will be constructed to help investors accurately assess the actual value of the project with the relevant assumptions:

(1) It is assumed that the decision maker can only make one investment decision during the validity period. And the investment project can be put into operation immediately after investing in it, without considering the time for project construction and installation of equipment, etc.

(2) Assuming that the capacity of the BIPV project is relatively stable during the operation period, the annual power generation of the project is measured using the average peak sunshine hours and effective utilization hours of the region where the project is located as simulation data.

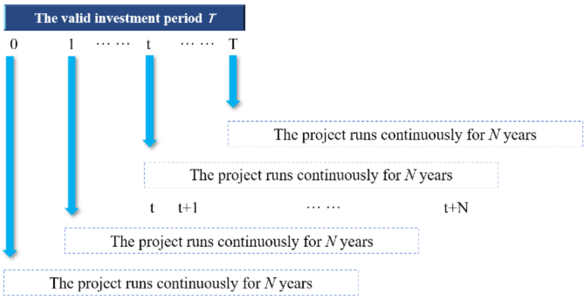


Fig. 1: BIPV project investment process

2.2. Analysis of the elements of uncertainty

In this paper, the operation of BIPV projects is modeled for three uncertainties: the green certificate price, the distributed PV feed-in tariff, and the unit installation cost. A large number of studies have been conducted to show that the changes in the green certificate price [6], distributed PV feed-in tariff [3], and unit installation cost [7] are subject to large uncertainties, which can be simulated by Geometric Brownian motion (GBM). The following equation describes the GBM stochastic process for the three uncertainties:

$$dPc = u_c \cdot Pc \cdot dt + \varphi_c \cdot Pc \cdot dz_c \tag{2}$$

$$dPe = u_e \cdot Pe \cdot dt + \varphi_e \cdot Pe \cdot dz_e \tag{3}$$

$$dCw = u_w \cdot Cw \cdot dt + \varphi_w \cdot Cw \cdot dz_w \tag{4}$$

Pc, Pe and Cw denote the green certificate price, distributed PV feed-in tariff and unit installation cost, respectively, and u_c, u_e, u_w denote their corresponding drift parameters, respectively, and $\varphi_c, \varphi_e, \varphi_w$ denote the volatility parameters, respectively, and the random variablesdz_c, dz_k anddz_w are the standard Wiener process increments.$dz = \varepsilon\sqrt{t}, \varepsilon \sim N(0,1)$. Equation (2) can be transformed according to Ito's Lemma:

$$dl\,n\,Pc = \left(u_c - \frac{\varphi_c^2}{2}\right) \cdot dt + \varphi_c \cdot dz_c \tag{5}$$

It can be approximated over a small discrete period of time:

$$l\,n\,Pc_{t+\Delta t} - l\,n\,Pc_t = \left(u_c - \frac{\varphi_c^2}{2}\right) \cdot \Delta t + \varphi_c \cdot dz_c \tag{6}$$

From this we can extrapolate the price of the green certificate at the momentP_{c_t} from the initial price:

$$Pc_t = exp\left[lnPc_0 + t \cdot \left(\left(u_c - \frac{\varphi_c^2}{2}\right) \cdot \Delta t + \varphi_c \cdot dz_c\right)\right] \tag{7}$$

The simulation of distributed feed-in tariffs and unit installation costs is similar to the process described above:

$$Pe_t = exp\left[lnPe_0 + t \cdot \left(\left(u_e - \frac{\varphi_e^2}{2}\right) \cdot \Delta t + \varphi_e \cdot dz_e\right)\right] \tag{8}$$

$$Cw_t = exp\left[lnCw_0 + t \cdot \left(\left(u_w - \frac{\varphi_w^2}{2}\right) \cdot \Delta t + \varphi_w \cdot dz_w\right)\right] \tag{9}$$

2.3. Cost-benefit modeling

The cost-benefit function of BIPV project under the mode of "self-generation and self-consumption, with residual on-grid" is constructed by applying the theory of the whole life cycle. The project value can be obtained from equation (1), and the cost-benefit function of the project investor at the$t$ The project value at the time of the project investor involves uncertainty parameters under multiple situations, which can be expressed as follows:

$$S_t = \sum_{k=1}^{k} q^k (\sum_{n=t}^{t+N} e^{-\pi n} \cdot [I_n^k(Pc_n^k, Pe_n^k) - c_n^k(Cw_t^k)] - C_t^k(Cw_t^k)) \tag{10}$$

Of these, the Pc_n^k, Pe_n^k and Cw_t^k are the uncertainties modeled by equations (2)-(9).$I_n^k(Pc_n^k, Pe_n^k)$ denotes the uncertainty of the project under scenario$k$. Under the scenario, the project's operating period in the nth year. The revenues includes the electricity cost savingsIb_n^k , green certificate trading revenueIc_n^k and the surplus electricity on-grid incomeIe_n^k:

$$I_n^k = Ib_n^k + Ic_n^k + Ie_n^k \tag{11}$$

$$Ib_n^k = \alpha \cdot E_n \cdot Pb \tag{12}$$

$$Ic_n^k = (1 - \alpha) \cdot E_n \cdot Pc_n^k \tag{13}$$

$$Ie_n^k = (1 - \alpha) \cdot E_n \cdot Pe_n^k \tag{14}$$

$$E_n = W \cdot H \cdot \eta^1 \cdot (1 - \eta_n^2) \tag{15}$$

Equations (12)-(14) denote the saved electricity cost, green certificate revenue and surplus electricity feed-in revenue, respectively, whereα denotes the proportion of self-generated and self-consumed electricity, andE_n denotes the power generation in the nth year of the operation period of the BIPV project, andPb denotes the price of electricity used by users, andPc_n^k, Pe_n^k denote the simulated green certificate price and distributed PV feed-in tariff in the nth year under the scenario$k$. H is the number of peak hours, and$Q$ is the amount of light irradiation per square meter, andη^1 is the overall efficiency of the PV system;η_n^2 is the attenuation rate of the PV system in the nth year.

$c_n^k(Cw_t^k)$ is the cost of the project in the nth year under the scenario$k$, including annual operating costsMg_n^k and bank interest costsCi_n^k:

$$c_n^k = Mg_n^k + Ci_n^k \tag{16}$$

$$Mg_n^k = W \cdot Cw_t^k \cdot R_g \tag{17}$$

$$Ci_n^k = W \cdot Cw_t^k \cdot ir \cdot r \tag{18}$$

In equations (17) and (18), the W denotes the total installed capacity of the system, and Cw_t^k represents the simulated value of the unit installation cost at time t under the scenario k , R_g is the annual operating rate, i_r is the loan ratio, and r is the annual loan interest rate.

$C_t^k(Cw_t^k)$ indicates the initial cost of the project at time t under the scenario k:

$$C_t^k = W \cdot Cw_t^k \tag{19}$$

During the lifetime of the investment T, the decision-maker estimates the value of the project by equation (10).

3. Model solving based on least squares Monte Carlo simulation methods

For the simulation of the investment process of the BIPV project, the solution of the optimal value of the project and the optimal investment time, this paper uses the least squares Monte Carlo simulation method for simulation. The estimation process starts with the generation of simulated scenarios, and the variation of uncertainty parameters in each simulation scenario is a random change under specific parameters. The value of the project S_t^k in each scenario can be calculated based on the formulas in the previous two subsections. At the end of the effective investment period, when the estimated project value S_T^k (i.e., the exercise value at T moment) is greater than 0, the decision maker's optimal strategy is to exercise the investment right; conversely, it does not exercise the investment right.

At $0 \leq t < T$ time, before the maturity date T before, the decision should be made by comparing the value of the project S_t^k (the value of exercising the option to invest immediately) and the value of holding H_t^k (the value of continuing to hold such an option) to determine the optimal decision at that moment. At that moment t , if the project value S_t^k is positive and greater than the holding value H_t^k , the optimal decision at this moment is to exercise the investment option.

The value of holding H_t^k at the moment t depends on the value of the execution option at the moment $t+1$. In order to evaluate the optimal decision at the current moment, it is necessary to predict the optimal decision in the future. In the least-squares Monte Carlo simulation method, the least-squares regression method is used to approximate the holding value H_t^k and the method uses a set of combinatorial functions approximate regression to obtain H_t^k.

In the process of inverse solving, the H_t^k only be estimated if S_T^k is greater than 0, because only this case is relevant to the decision to exercise the investment option. Once the H_t^k is estimated, then in the current scenario k at moment t the optimal decision is then updated. Then, the optimal decision state at each decision time point in the investment period under all scenarios is determined in turn.

In scenario k,the best time to invest t_k^* once determined, the project NPV formula can be used to calculate the optimal project value $S_{t_k^*}$under the scenario and finally calculate the optimal project value for all scenarios$K$.Optimal investment time t^* is is the most frequent optimal investment time t_k^* in all scenarios , the solution flowchart is like Fig. 2:

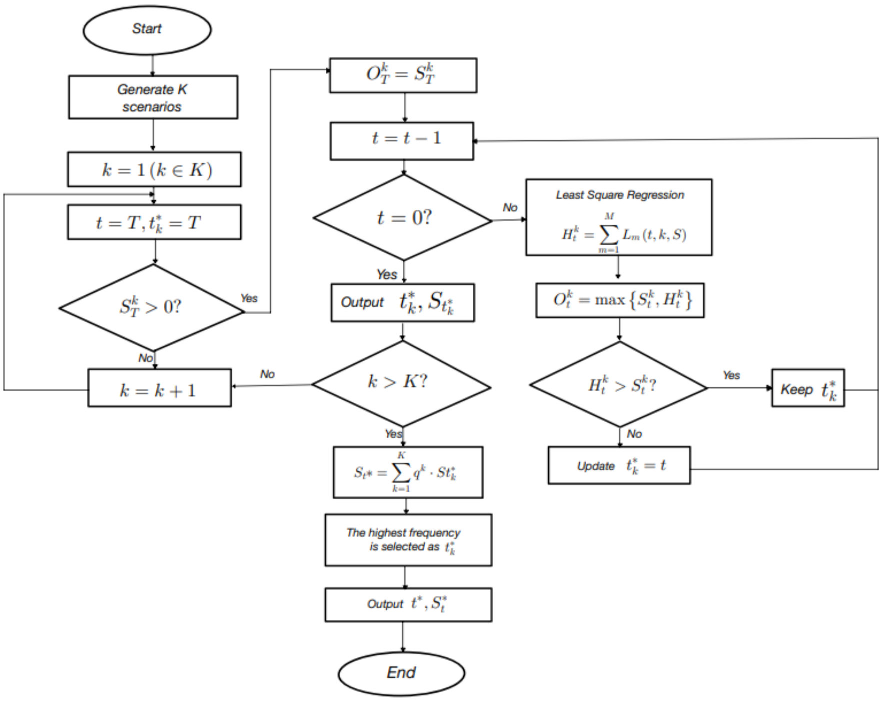


Fig. 2. Solution process of least squares Monte Carlo simulation method

4. Numerical analysis

In order to fully consider the realistic factors and test the effectiveness of the flexible investment decision model for BIPV projects constructed in this paper, this paper takes the BIPV projects in Chongqing, China, as the object of analysis, and carries out the simulation based on the photovoltaic resource parameters and other data in Chongqing. However, based on the current BIPV project situation construction and the decline of distributed PV subsidies, uncertainty under the conditions of the BIPV project value is underestimated, slow growth. This case combines the actual situation of Chongqing Municipality to set the model parameters and analyze the impact of the green certificate policy on the flexible investment of BIPV projects.

4.1. Parameterization

In the data selected for this study, the three main parts include project parameters, cost parameters and uncertainty-related parameters, which are mainly obtained through references, official release data and industry data projections. The three uncertainty factors selected in this paper can be simulated through equations (2)-(9), and Fig. 3 shows the simulation of the corresponding 100 simulation paths. Table 1 shows mainly the uncertainty parameters.

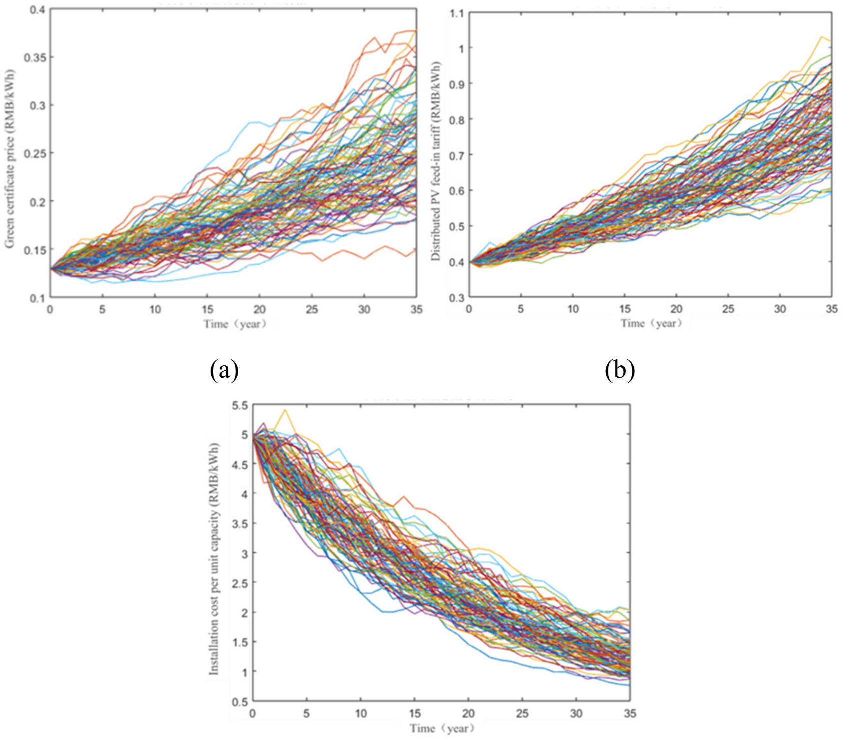
Table 1: Uncertainty parameters

parameters	descriptive	starting value	Sources and Remarks
Cw	Total installed cost per unit of capacity	4.94 RMB /W	China Photovoltaic Industry Association Data
u_w	Unit installed cost drift rate	-0.06	Calculated from data on changes in investment costs in China
φ_w	Unit installed cost volatility	0.04	
Pe	Distributed photovoltaic feed-in tariffs	0.396 RMB/kWh	Chongqing coal-fired benchmark tariff
u_e	Feed-in tariff drift rate	0.02	Estimated based on historical data of electricity prices in Chongqing
φ_e	Feed-in tariff volatility	0.02	
Pc	Green Certificate Price	0.1295 RMB/kWh	China Green Power Certificate Trading Platform Data
u_c	Green Certificates Price Drift Rate	0.02	Estimated based on historical data from China's green certificate trading platform
φ_c	Green Certificates price volatility	0.03	

While Table 2 shows the other technology parameters:

Table 2: Technology parameters

parameters	descriptive	starting value	Sources and Remarks
α	Proportion of self-consumption of electricity	50%	Initial analog value
H	Peak hours	686h	China Economic Database
η^1	Integrated efficiency	78%	China Economic Database
η_n^2	Attenuation rate for the year$n$	2.5%	0.66% for each subsequent year
Pb	sales tariff	0.52 RMB/kWh	According to the Chongqing Power Grid Sales Tariff Table
R_g	Annual running rate	10%	China Photovoltaic Industry Association Public Data
ir	Loan ratio	10%	Initial analog value
i	discount rate	8%	General discount rate
W	Total system capacity	100kW	Initial analog value
r	Annual loan interest rate	3.45%	People's Bank of China Lending Rate
N	Project life	25 years	General PV Project Lifetime
T	investment period	10	Base year is 2023



(a) (b)

(c)

Fig. 3. Solution process of least squares Monte Carlo simulation method

4.2. Simulation Results and Discussion

After taking into account the random variations of uncertainties that may be faced during the investment decision-making process for a BIPV project, the decision maker may choose to invest immediately or wait for more information about the investment in order to avoid the risk, and make an investment decision that maximizes the value of the investment among these choices.

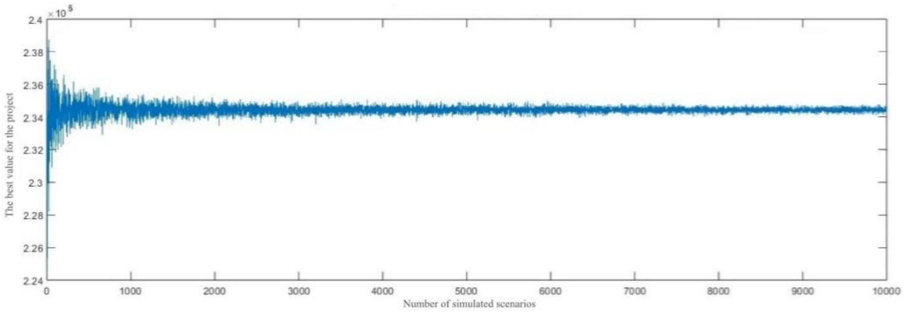


Fig. 4. Changes in project value with the number of simulated scenarios

This study uses MATLAB software to develop and solve the proposed flexible investment decision model for BIPV projects. In order to simplify the calculation process, the least squares regression in the solution process uses a power function and assumes that the probability of each simulation scenario is equal. As can be seen in Figure 4, the optimal project value based on flexible investment decision-making continuously tends to converge stably with the number of simulation scenarios and becomes robust after 3000 simulations. To ensure the reliability and stability of the results, the subsequent strategy comparison analysis and sensitivity analysis in this paper simulate 10,000 scenarios.

4.3. Comparative Analysis of Strategies

After analyzing the flexible investment problem using least squares Monte Carlo simulation, it is also necessary to compare the final simulation results with the fixed investment decision, as well as the optimal project value and the optimal investment time obtained with/without green certificate revenue. Based on this, the impact of adopting flexible investment decisions by decision makers is further explored. In this study, a fixed investment decision is one that allows investors to invest in a project at a fixed time $t = 0$ (base year), while a flexible investment decision is one that allows investors to flexibly choose the optimal investment time within the effective investment period T.

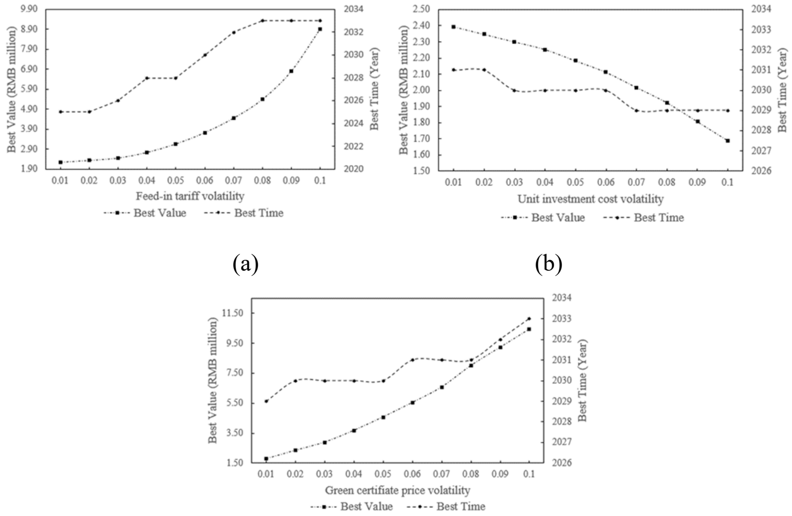
As shown in Table 3, the green certificate revenue greatly affects the decision maker's optimal investment decision and will advance the decision maker's optimal investment time. On the other hand, since the flexible investment decision gives the decision maker the power to flexibly choose the investment time under uncertainty, the decision maker can significantly increase the economic value of the project by delaying the investment and waiting for new market information, and this result further validates the importance of considering decision flexibility in the investment decision process of BIPV projects.

Table 3: Value of projects with different investment strategies, including green certificate income

Includes green certificate income or not	Investment decisions	Value of optimal project (RMB million)	Optimal investment time
no	Fixed	65.16	Invest Now
	Flexible	159.64	2030
Yes	Fixed	95.79	Invest Now
	Flexible	234.68	2028

4.4. Sensitivity analysis

As can be seen from Figure 5, with the increase of the volatility of the green certificate price, the investment value increases from 1.56 million to 9.8 million, while postponing the optimal investment time; the volatility of the PV feed-in tariff increases from 0 to 0.1, resulting in an increase of the project value from 1.93 million to 8.9 million, which drastically affects the investment value band of the BIPV project, and the optimal investment time is postponed; while the investment value is affected by the volatility of the unit investment cost is not significant, the project value always stays around 1.6-2.4 million dollars, and the optimal investment time is slightly pushed forward.



(a) (b)

(c)

Fig. 5. Sensitivity analysis

5. Conclusion

The analysis of the simulation results shows that, first, the uncertainty of multiple variables under the green certificate policy can have a significant impact on the investment decision of BIPV projects. Compared with the traditional NPV method, the flexible investment decision model based on the real options method takes the uncertainties in investment into account, does not underestimate the value of the investment, and encourages investors to make more strategic and flexible investment decisions. Second, for the arithmetic example presented in this chapter, the real options-based investment decision model is used to simulate the project value for different investment strategies, and the final calculations show that the net value of the BIPV project under a fixed strategy and no green certificate revenue is also greater than 0. However, when delayed investment decisions are considered, the project is more economically attractive. This is because by applying real options analysis, power generation companies, when faced with key uncertainties affecting investment returns under the green certificate policy, can mitigate the risk of the investment decision by delaying the exercise of the option until the uncertainty is resolved, thus maximizing the opportunity profit of the investment. Third, the sensitivity analysis for uncertainties illustrates the impact of considering multiple factors on investment value and optimal investment timing under the green certificate policy. In particular, the optimal investment time point is delayed as the volatility of the market price of electricity and the price of green certificates increases, and slowly pushed forward as the volatility of investment costs increases.

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References

[1] Hu, Junfei, Peng Guo, and Kim-Leng Poh.(2020) Generating decision rules for flexible capacity expansion problem through gene expression programming. Computers & Operations Research, 122: 105003.

[2] Hu, Junfei, et al. (2022) Optimal subsidy level for waste-to-energy investment considering flexibility and uncertainty.Energy Economics, 108. 105894.

[3] Kim, Kyeongseok, Hyoungbae Park, and Hyoungkwan Kim,(2017) Real options analysis for renewable energy investment decisions in developing countries. Renewable and Sustainable Energy Reviews, 75: 918-926.

[4] Denis Luis,de Oliveira, et al. (2014) Switching outputs in a bioenergy cogeneration project: a real options approach.Renewable and Sustainable Energy Reviews,36: 74-82.

[5] SONG Mingzhen,MA Teng,XIE Jiaping et al.2023 A study on wind power investment strategy considering double stochastic of green certificate price and power generation[J]. Price Theory and Practice,(03):156-160+207.

[6] Nadarajah, Selvaprabu, and Nicola Secomandi.(2023) A review of the operations literature on real options in energy. European Journal of Operational Research, 309.2: 469-487.

[7] Zhang, Mingming, et al. (2020) Valuing investment decisions of renewable energy projects considering changing volatility. energy Economics, 92. 104954.