Study on Performance and Economic Efficiency of Solar Power on Agricultural Land: A case study in Central Region, Vietnam

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Abstract- Vietnam is an agricultural country with about 35% of the land devoted to agricultural production and has a solar energy source with average radiation of about 4-5 kWh/m^2/day. A combination of agricultural production and solar power can ensure support for rural economic development. However, these projects have not been evaluated in detail by Vietnamese investors. In the paper, the economic efficiency of a typical solar power project on agricultural land in Gia Lai province, Central Region, Vietnam is analyzed by using RETScreen financial-economic efficiency analysis software. This study shows that the payback time of a typical solar power system on agricultural land in Gia Lai province is about 8 years. Moreover, the results also help investors understand more the benefits to encourage investment and develop the combination of agriculture and solar energy in Vietnam.

Keywords - Photovoltaic; agriculture; solar power; economic efficiency.

Nomenclature

PV	Photovoltaic
DC	Direct current
AC	Alternating current
GHG	Greenhouse gas
IRR	Internal rate of return
NPV	Net present value
N	Project life in years
C_n	Cash flow for year n
ALCS	Annual life cycle saving
PCF	Positive year cash flow
B-C	Profit-cost ratio
r	Discount rate

1. Introduction

At present, solar power develops very fast and becomes an important renewable power source [1,2] in the power system of many countries in the world to ensure energy security [3,4,5] and combat climate change.

In Vietnam, the traditional energy sources are increasingly exhausted, the development of renewable energy and solar power will contribute to ensuring energy security [6]. Photovoltaic (PV) system construction with preferential incentive mechanism [7] attracted domestic and foreign investors, thereby reducing pressure on arranging capital for the investment of power source projects. Therefore, PV development will contribute to reducing national electricity shortages, enhancing electricity supply security, and reducing pressure in power system operations. By the end of 2020, the total capacity of solar power in Vietnam reached about 16,500 MWp [8]. This capacity scale exceeds the expected solar power development scale of 850 MWp in the adjusted national power planning [9].

In addition to the positive contributions of the solar power system, the explosion and concentration of PV power projects in several rural areas in Vietnam have become a major concern for the development of agricultural land and the daily life of local people. Thus, the application of the PV power system should be carefully calculated for mutual benefits to ensure the long-term benefits of the people and avoid insignificant damage.

The combination model of solar power in agricultural production was launched in Germany [10] in 2010. Recently, more and more large-scale PV agriculture commercial projects have been applied in countries such as China, Japan, Italy, France [11,12,13]. The outstanding advantage of PV agriculture is the improvement of land use efficiency because it is possible to resolve conflicts in land use between solar energy development and agricultural production by combining the two activities in the same agricultural area. Besides, it also gives many socio-economic benefits for the community such as saving energy costs, increasing income for local farmers, improving promotion opportunities and competitiveness, developing agricultural production practices, reducing energy demand and CO_2 emissions.

In this study, the economic efficiency of a typical solar power project on agricultural land in Gia Lai province, Central Region, Vietnam is analyzed by using RETScreen financial-economic efficiency analysis software. The research results help to accurately assess the advantages of land areas where solar power projects can be deployed for agricultural, economic, and social development. By which, it contributes to support the efficient and sustainable agriculture development in rural areas in Vietnam.

2. PV agriculture system

The PV agriculture technology generates electricity from solar power without taking away arable land resources for agricultural production. The PV agriculture system can protect plants and soil against negative environmental impacts, contribute to climate protection. Moreover, the actual PV agriculture projects [10,13] have determined that the agricultural land use efficiency increases after using solar power as shown in Figure 1 and Figure 2.

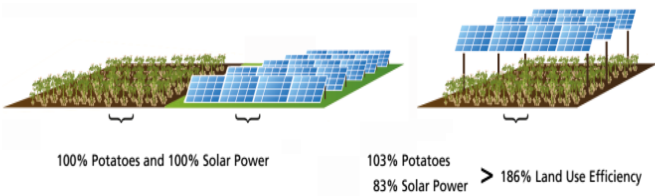


Fig. 1. Land use efficiency with PV agriculture [10]

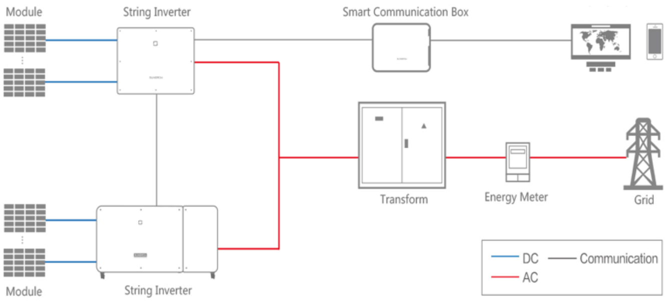


Fig. 3. Diagram of grid-connected PV system [14]

The grid-connected PV agriculture project includes main equipment such as solar panels, grid-connected string inverter, transformer station, and transmission line as can be seen in Figure 3. The string inverters [15] convert DC power from the PV array [16] to AC power and supply the electricity to the utility grid with the support of the transformer station and transmission line.

3. Methodology

The RETScreen international clean energy project analysis software is used around the world to evaluate energy production efficiency, life cycle costs, and greenhouse gas emissions reductions for renewable energy technologies and energy-saving [17,18,19]. The investors can evaluate projects and make decisions based on the data and financial indicators are analyzed by the user.

- Internal rate of return (IRR) [20]

The IRR is the discount factor that makes the net present value (NPV) of the project zero. The IRR is calculated by the following formula:

$$0=\sum_{n=0}^{N}\frac{C_n}{\left(1+IRR\right)^n} \quad (1)$$

C_0 is the project's equity minus incentives and subsidies. This is the cash flow for year 0.

The before-tax IRR is calculated by using the pre-tax cash flow, while the after-tax IRR is calculated by the after-tax cash flow. The IRR is not determined under certain

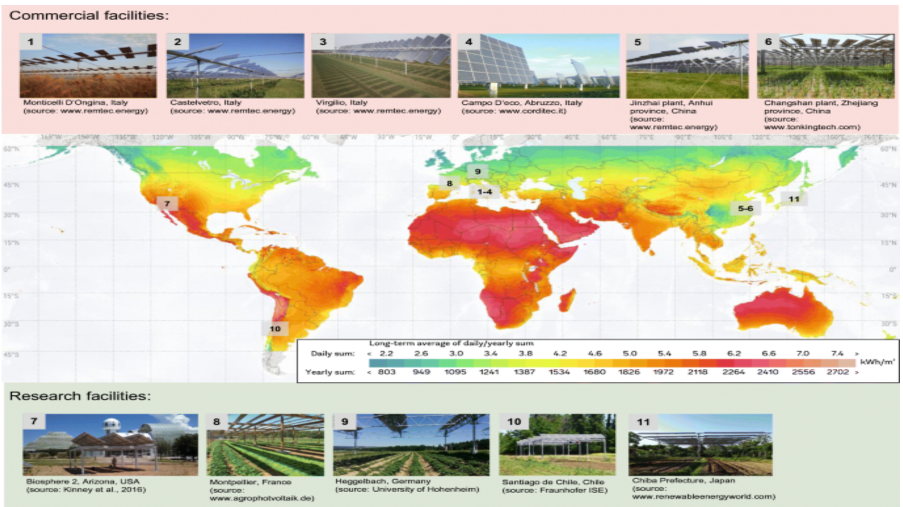


Fig. 2. PV agriculture projects in the world [13]

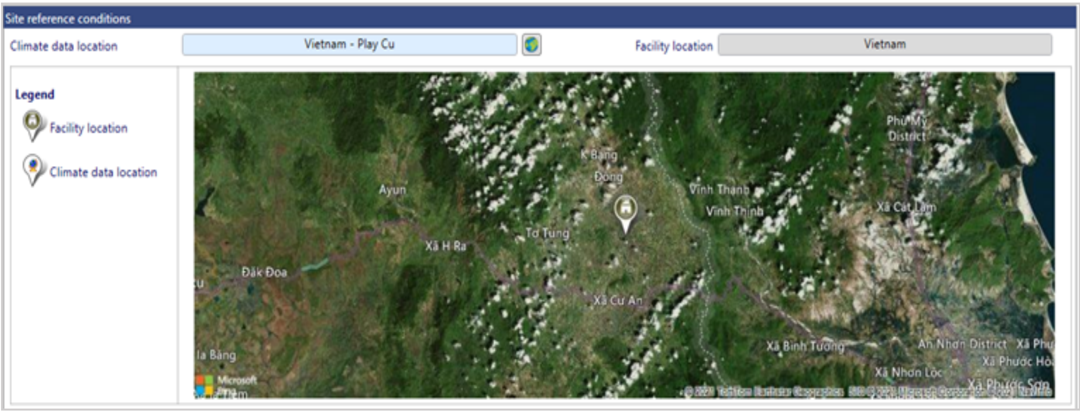


Fig. 4. Location of PV agriculture project in Kbang district

Month	Air temperature	Relative humidity	Precipitation	Daily solar radiation - horizontal	Atmospheric pressure	Wind speed	Earth temperature	Heating degree-days 18 °C	Cooling degree-days 10 °C
	°C	%	mm	kWh/m²/d	kPa	m/s	°C	°C-d	°C-d
January	21.2	73.3%	22.01	5.12	95.9	2.5	21.3	0	347
February	22.8	68.5%	8.40	5.88	95.8	2.4	22.9	0	358
March	24.9	64.8%	15.50	6.18	95.7	2.2	25.1	0	462
April	27.0	62.9%	19.80	6.12	95.5	1.8	27.2	0	510
May	27.2	68.1%	57.97	5.43	95.4	1.6	27.4	0	533
June	26.6	72.1%	52.50	4.82	95.2	1.9	26.7	0	498
July	26.4	71.3%	44.02	4.64	95.2	2.0	26.5	0	508
August	26.0	73.8%	74.09	4.33	95.2	2.1	26.1	0	496
September	25.3	77.7%	141.30	4.47	95.4	1.5	25.4	0	459
October	24.3	79.5%	235.60	4.42	95.6	1.9	24.3	0	443
November	23.0	78.8%	170.40	4.26	95.7	2.5	23.0	0	390
December	21.4	76.9%	72.54	4.38	95.9	2.7	21.5	0	353
Annual	**24.7**	**72.3%**	**914.13**	**5.00**	**95.5**	**2.1**	**24.8**	**0**	**5,359**
Source	NASA	NASA	NASA	NASA	NASA	NASA	NASA	NASA	NASA
Measured at					m	10	0		

Fig. 5. Monthly solar radiation value in Kbang district

circumstances, especially if the project yields an immediate positive cash flow in year 0.

➢ Positive year cash flow (Return on equity) [20]

The positive year N_{PCF} is the first year that the cumulative cash flow for the project is positive. It is calculated by the following equation:

$$0 = \sum_{n=0}^{N_{PCF}} \tilde{C}_n \qquad (2)$$

➢ Net present value (NPV) [20]

The net present value of the project is the value of all cash flows in the future discounted at a discount rate. It is calculated by discounting all cash flows in the following formula:

$$NPV = \sum_{n=0}^{N} \frac{\tilde{C}_n}{(1+r)^n} \qquad (3)$$

➢ Annual life cycle saving (ALCS) [20]

The annual life cycle savings are nominal annual savings converted to projects of the same life and net present value. It is calculated by the following formula:

$$ALCS = \frac{NPV}{\frac{1}{r}\left(1 - \frac{1}{(1+r)^N}\right)} \qquad (4)$$

➢ Profit-cost ratio (B-C) [20]

The profit-cost ratio, B-C, represents the profitability of the project. It is calculated as the ratio of the present value of annual sales minus the annual cost to equity of the project.

$$B-C = \frac{NPV + (1-f_d)\,C}{(1-f_d)\,C} \qquad (5)$$

➢ Cost of energy production [20]

The cost of energy production is the cost of energy that returns net present value to zero. Hence, the cost of energy production is calculated by the equation:

$$0 = \sum_{n=0}^{N} \frac{\tilde{C}_n}{(1+r)^n} \qquad (6)$$

➢ The cost of reducing greenhouse gas emissions [20]

The cost of GHG emission reduction GRC is the equal nominal cost of generating per ton of avoided greenhouse gas. It is calculated by the equation:

$$GRC = -\frac{ALCS}{\Delta_{GHG}} \qquad (7)$$

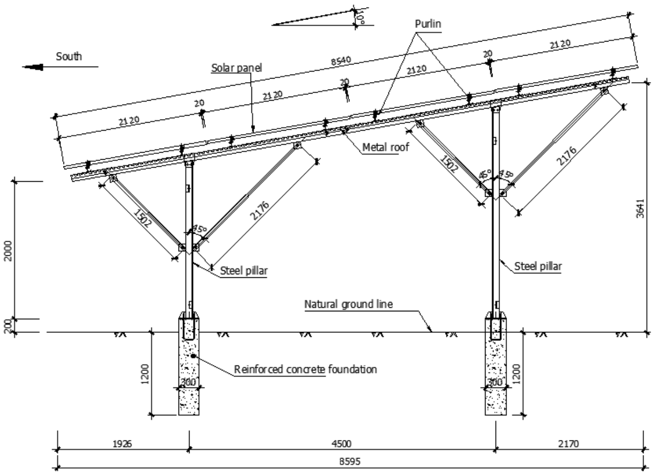
4. Site selection

Kbang district, Gia Lai province in Figure 4 has good solar energy potential with an average annual solar radiation of 5 kWh/m^2.day. As can be seen in Figure 5, the period from August to December has the lowest daily average solar radiation value from 4.26 kWh/m^2.day to 4.47 kWh/m^2.day while the daily average solar radiation in the period from January to May has the best value from 5.12 kWh/m^2.day to 6.18 kWh/m^2.day.

The PV agriculture project in Kbang district uses 2,286 solar panels (435 Wp per panel) with a total power of 994.4 kWp and 8 grid-tied inverters (110kVA per inverter). The main parameters of the solar panel and inverter of the PV agriculture system are presented in Table 1.

Table 1. Main equipment of PV power system

No	Parameter	Quantity	Unit
1	Solar panel - Maximum power: 435Wp - Open circuit voltage: 51.61V - MPP voltage: 43.55V - Short circuit current: 10.67A - MPP current: 9.99A	2286	module
2	Grid-tied Inverter - Max input voltage: 1100V - MPPT voltage range: 200V - 1000V - Min input voltage: 200V - Max MPP input current: 26A - Rated power: 110kVA - Rated AC voltage: 400V - Frequency: 50Hz - 3 phases	8	unit



Note: Dimension in mm.

Fig. 6. Structural drawing

PV modules are installed on the metal roof of the structure with a slope angle of 10^0 and azimuth angle of 0^0 to get the highest power conversion efficiency (Figure 6).

The solar panel structure is mainly made of aluminum profiles and galvanized steel to ensure stable structure and anti-corrosion conditions. The height of the supporting frame system is eligible for the construction of a PV agriculture project because sunlight can still ensure the growth of the tree.

The solar panel support system in the project is combined into modules of 4x18 panels as shown in Figure 7.

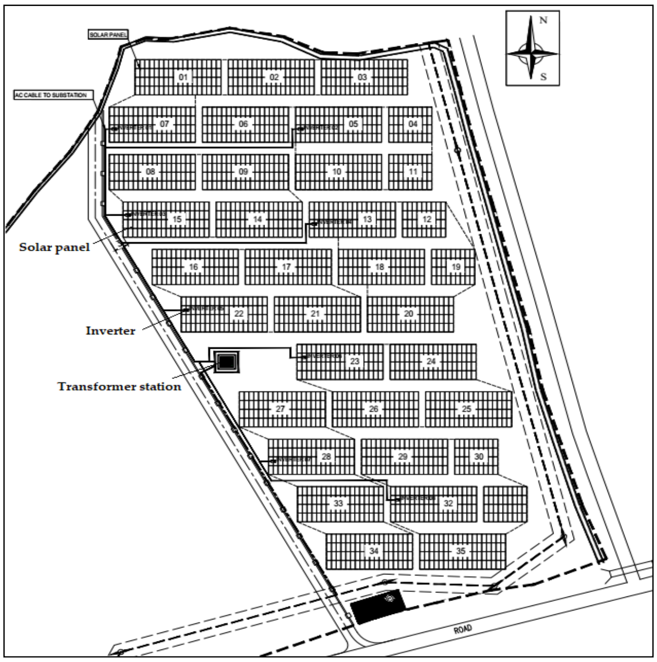


Fig. 7. Plan drawing

5. Result and discussion

The latest fuel and electricity prices have been updated into the project's energy model in Figure 8.

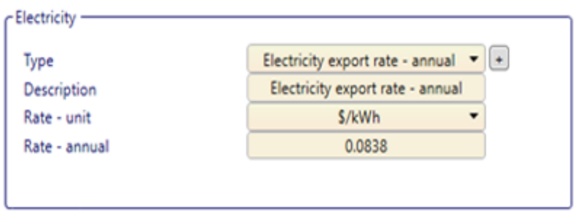


Fig. 8. The current electricity purchase price of the K'Bang PV agriculture project

The K'Bang PV agriculture project is classified in the list of rooftop solar power projects. Basing on the support policy for solar power in Vietnam [7], the electricity purchase price (excluding value-added tax) is 1,938 VND/kWh, equivalent to 8.38 US cents/kWh. This electricity purchase price is applied for 20 years from the date of operation of the plant.

Total investment for the solar power system on agricultural land in Kbang district is presented in Table 2. The loan package for the PV agriculture project in Gia Lai province with a capacity of 994 kWp will be received the support from World Bank. The bank will reduce directly the interest rate to 1.5%/year with a maximum limit of 80% in 15 years.

Table 2. Total investment for the solar power project combining agricultural production K'Bang

No	Investment portfolio	Expenses (million VND)
I	**Investment preparation**	**710**
1	Cost of buying land	660
2	Cost of establish investment project	50
II	**Preparing construction infrastructure**	**3450.845**
1	Cost for ground leveling and construction	350.045
2	Cost of acquisition and structural installation	3100.800
III	**Construction of lines and transformer stations**	**1700**
1	Cost of construction for connection lines	450
2	Cost of acquisition for construction transformer stations	1250
IV	**Solar rooftop system**	**10544.620**
1	Solar panels	7000
2	Inverter system	1500
3	Accessories for installing battery panels	50
4	Internal AC-DC distribution cabinet system	1394.620
5	Installation worker	550
6	Acceptance of energizing	50
V	**Redundancy costs**	**164.054**
VI	**VAT tax**	**1554.542**
	Total investment	18124.061

The input technical specifications of the solar power project combining agricultural production in K'Bang with a capacity of 994 kWp are shown in Figure 9. This project produced 1345 MWh per year to the utility grid.

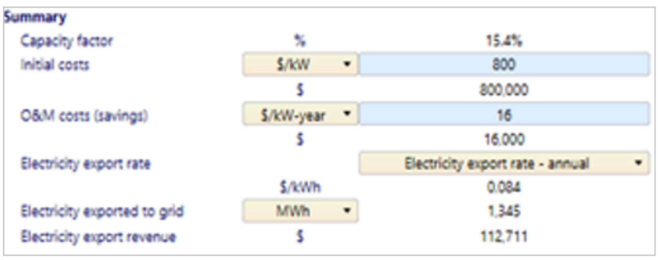


Fig. 9. The specifications in the energy model of the project

The financial feasibility of the project takes into account the escalation rate of fuel prices, the annual inflation rate, the depreciation rate, and the reinvestment rate (Figure 10).

The project is calculated over a 20-year life cycle with a concessional loan ratio accounting for 70% of the total investment, and 8.5% interest rate within 15 years.

The income tax is calculated at 10% under the Government's Decree No.218/2013/ND-CP dated December 26, 2013.

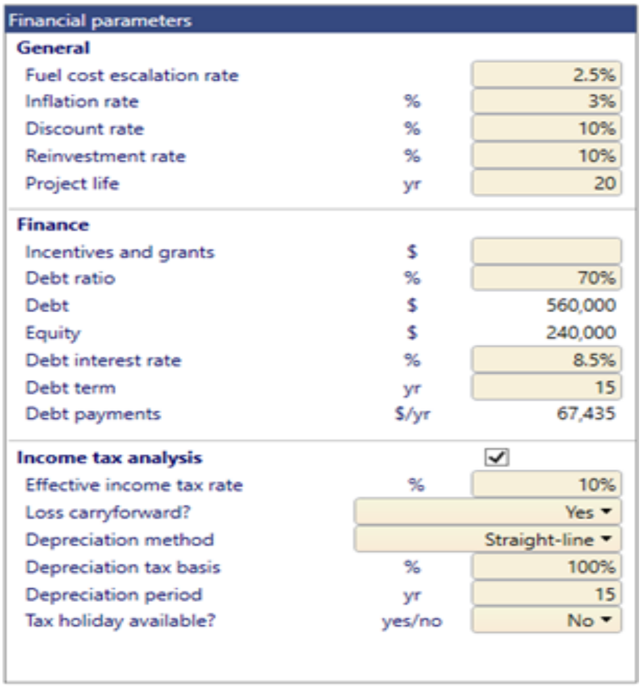


Fig. 10. The financial parameters of the project

5.1. Calculation Results

When the project is put into operation, the annual income is calculated from the following main amounts in Figure 11.

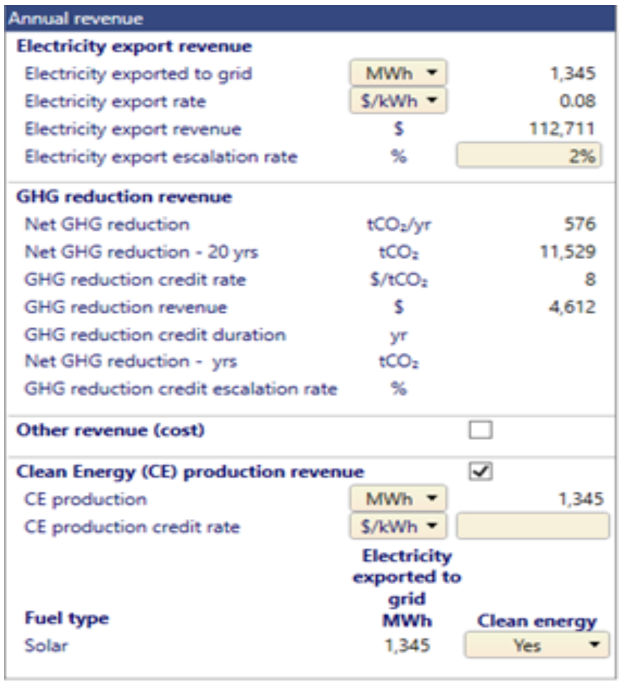


Fig. 11. The estimated annual income of the project

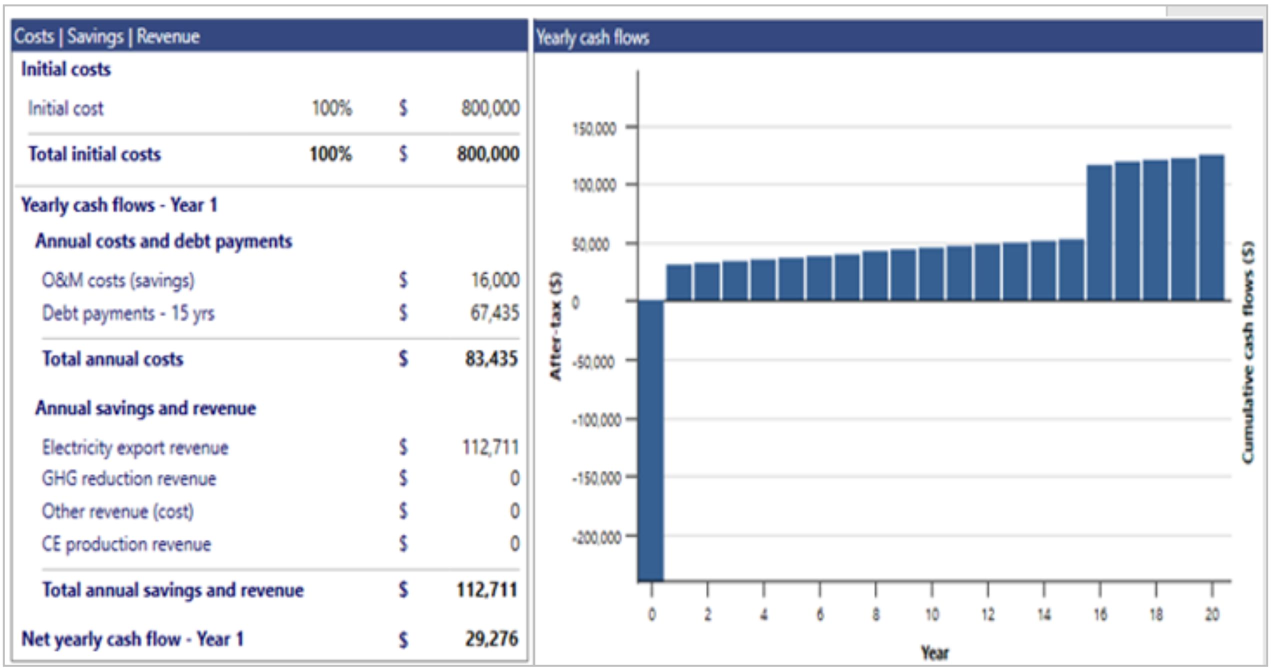


Fig. 12. The project's annual cash flow

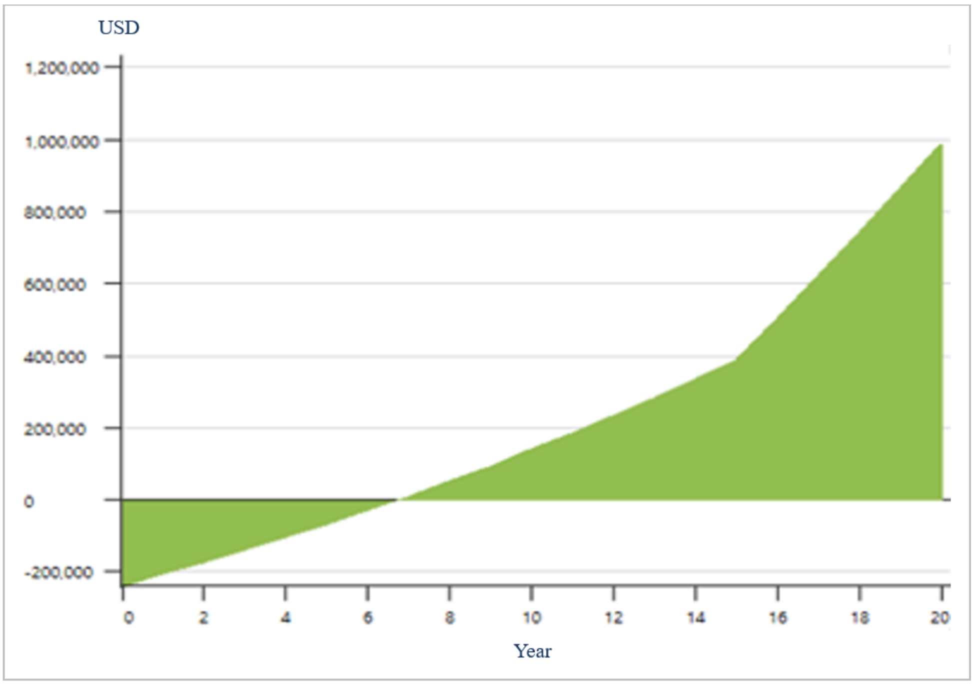


Fig. 13. Cumulative cash flows of the project lifecycle

Income from electricity export or the sale of electricity to the utility grid including account the rate of electricity price escalation every year. Income from GHG emissions reductions based on a 20-year project life-cycle reduction credit rate.

The project is built in the first year as year zero, the cash flow is now exactly equal to the total initial investment, in which, the interest payment is required and loans from year 1 to year 15. There are annual operating and maintenance costs at the same time over the entire 20-year life of the project.

The project's annual cash flow is presented in Figure 12 and the project's cumulative cash flow is shown in figure 13. There are two items of the annual income of the project: income from the sale of electricity and income from the sale of credits from greenhouse gas reduction. In addition, the financial indicators of the project such as IRR, NPV, B/C are shown in Figure 14. So, the financial efficiency of the project is acceptable. The payback period with a discount is about 8 years. The net present value (NPV) of the project is achieved at $166,983. The break-even point with energy production costs of 8.2 cents/kWh.

Financial viability		
Pre-tax IRR - equity	%	17.6%
Pre-tax MIRR - equity	%	13.3%
Pre-tax IRR - assets	%	4.1%
Pre-tax MIRR - assets	%	6.7%
After-tax IRR - equity	%	16.8%
After-tax MIRR - equity	%	12.9%
After-tax IRR - assets	%	3.4%
After-tax MIRR - assets	%	6.3%
Simple payback	yr	7.9
Equity payback	yr	5.7
Net Present Value (NPV)	$	166,983
Annual life cycle savings	$/yr	19,614
Benefit-Cost (B-C) ratio		1.7
Debt service coverage		1.5
GHG reduction cost	$/tCO₂	-3402
Energy production cost	$/kWh	0.082

Fig. 14. Financial indicators of the project

have the most influence on the outputs (NPV, B/C…) as can be seen in Figure 15. The variable input parameters are total investment, electricity selling price, O&M cost, GHG selling price.

The project considers how the financial performance indicators change when the input parameters change. The ranges of variation for these input parameters are usually taken from 0%, ± 5%, ± 10%.

An increase or decrease in the electricity price and total investment capital will affect the NPV value of the project, especially if the total investment is increased by 10% and the increase of electricity price of project with the value of 10% can not achieve a positive NPV. In this case, the PV agriculture project is not feasible.

Increasing or decreasing annual operation and maintenance costs and total investment will also affect the NPV results as shown in Figure 16. However, the variation is not much and the above sensitivity analysis shows that the project is quite feasible when changing these factors.

Sensitivity analysis

Perform analysis on: Net Present Value (NPV)
Sensitivity range: 10%
Threshold: 0 $

Electricity export rate		Initial costs ($)				
		720,000	760,000	800,000	840,000	880,000
$/MWh		-10.0%	-5.0%	0.0%	5.0%	10.0%
75.42	-10.0%	134,731	100,056	64,999	29,592	-6,122
79.61	-5.0%	185,196	150,864	116,262	81,316	46,026
83.80	0.0%	235,581	201,297	**166,983**	132,455	97,592
87.99	5.0%	285,965	251,682	217,398	183,100	148,617
92.18	10.0%	336,350	302,066	267,782	233,499	199,206

Fig. 15. The analysis of NPV's sensitivity to changes in electricity price

Sensitivity analysis

Perform analysis on: Net Present Value (NPV)
Sensitivity range: 10%
Threshold: 0 $

O&M		Initial costs ($)				
		720,000	760,000	800,000	840,000	880,000
$		-10.0%	-5.0%	0.0%	5.0%	10.0%
14,400	-10.0%	251,081	216,797	182,507	148,071	113,331
15,200	-5.0%	243,331	209,047	174,750	140,263	105,470
16,000	0.0%	235,581	201,297	**166,983**	132,455	97,592
16,800	5.0%	227,831	193,547	159,213	124,623	89,702
17,600	10.0%	220,081	185,797	151,431	116,790	81,809

Fig. 16. The analysis of NPV's sensitivity to changes in annual operating and maintenance costs

5.2. Analysis and evaluation of investment efficiency

In order to calculate the sensitivity for the K'Bang solar power plant, this project considers the input parameters that

When analyzing risk, the parameters that affect the net present value (NPV) such as the amount of electricity supplied to the grid, the electricity selling price, the initial

Risk analysis

Perform analysis on	Net Present Value (NPV)
Number of combinations	500
Random seed	No

Parameter	Unit	Value	Range (+/-)	Minimum	Maximum
Initial costs	\$	800,000	10%	720,000	880,000
O&M	\$	16,000	10%	14,400	17,600
Electricity exported to grid	MWh	1,345.00	10%	1,210.50	1,479.51
Electricity export rate	\$/MWh	83.80	10%	75.42	92.18
GHG reduction credit rate	\$/tCO$_2$	8.00	25%	6.00	10.00
Debt ratio	%	70.0%	30%	49.0%	91.0%
Debt interest rate	%	8.50%	15%	7.23%	9.78%
Debt term	yr	15	20%	12	18

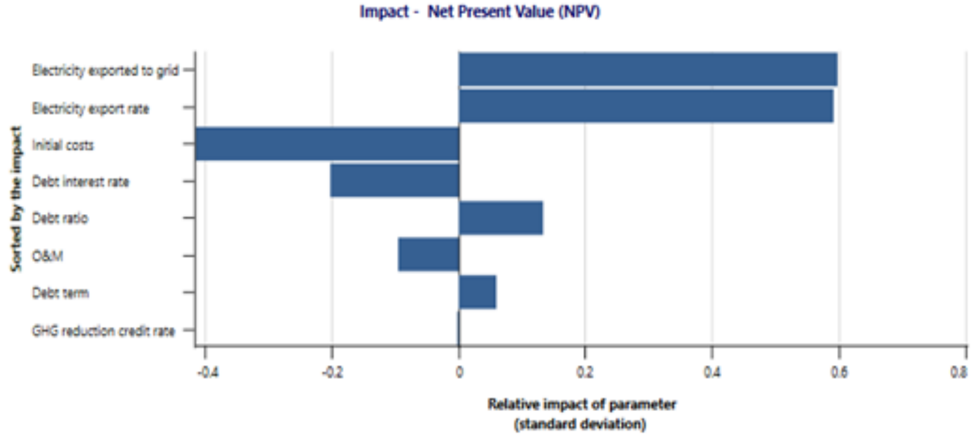


Fig. 17. The risk analysis of parameters impacting on NPV

cost, interest rate, maintenance costs, loan term, and credit of greenhouse gas reduction. When the effects of each parameter on the NPV value are marked with a "-" sign indicating the inverse effect and a "+" sign indicates the positive effect of the input parameters on the output efficiency indicators.

The different input parameters impact the output efficiency indicators at different levels (Figure 17). The total amount of electricity sold to the grid is the parameter that has the most influence on output efficiency indicators. After that, the electricity price parameter is the second biggest influence. Thirdly, the initial investment capital parameter also has a negative influence on the input parameters to the output efficiency indicators. Therefore, it is necessary to pay attention to these 3 parameters when analyzing the financial and economic of the project.

The sensitivity and risk analysis shows that fluctuations of financial performance indicators and the threshold of change of input parameters are acceptable.

6. Conclusion

The investment efficiency evaluation of the PV agriculture project in the Gia Lai province shows that the payback time is about 8 years. After that, the investor can get the profit from the rooftop solar power system until the 20th year according to the contract with EVN. The PV agriculture project can increase land-use efficiency by agricultural production on the same land area.

Moreover, the PV agriculture project can decrease about 576 tons of CO_2 per year to the environment, with an annual average generated electricity of 1345 MWh per year. Thus, it will contribute to combat the phenomenon of climate change and protect the environment.

In Vietnam, there are still many difficulties and challenges for investors in the PV agriculture project implementation process, especially the issue of legal regulations and policy mechanisms.

It is necessary to integrate the solar power development strategy in agricultural policy in the future. At the same time, it is necessary to conduct specific studies on suitable crops, animals for the weather conditions of Vietnam when combining solar power generation on agricultural land towards the national sustainable development goal of energy and agriculture production.

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