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Shortening the Payback Period of Greenhouse Gas Reduction Benefits from Photovoltaic Rooftop Systems

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Abstract: This paper presents an analysis of shortening the payback period of greenhouse gas reduction benefits from photovoltaic rooftop systems. The objective was to evaluate the amount of carbon credits generated and their returns. The study includes an economic analysis and a comparison of the economic outcomes with and without the consideration of carbon credits from 149.80 kWp and 25.68 kWp photovoltaic rooftop systems. The study evaluated the amount of electrical energy produced by the photovoltaic rooftop systems, estimated using the PVsyst program version 7.3.1, at a factory in Pathum Thani Province, Thailand. The economic indices analyzed in this study include the payback period, net present value (NPV), benefit–cost ratio (B/C ratio), and internal rate of return (IRR). The analysis is divided into four case studies: Case 1 is the base case, and Cases 2, 3, and 4 consider carbon credits for 7, 14, and 25 years, respectively. The economic indices analyzed in Case 1 include the financial internal rate of return (FIRR), payback period, financial net present value (FNPV), and B/C ratio. In Cases 2, 3, and 4, the economic indices analyzed are the economic internal rate of return (EIRR), the economic net present value (ENPV), the B/C ratio, and the payback period. This paper outlines a new economic calculation approach that incorporates carbon credits produced by photovoltaic rooftop systems, which helps achieve break-even points more quickly. It also discusses the application of carbon credits in conjunction with renewable energy.

Keywords: payback period; greenhouse gas; benefit; carbon credit; photovoltaic rooftop system

Citation: Rugthaicharoencheep, N.; Ruangsap, N.; Nedphokaew, S. Shortening the Payback Period of Greenhouse Gas Reduction Benefits from Photovoltaic Rooftop Systems. *Energies* **2024**, *17*, 6159. https://doi.org/10.3390/en17236159

Academic Editors: Dionysis Bochtis, Dimitrios Aidonis and Charisios Achillas

Received: 23 October 2024
Revised: 28 November 2024
Accepted: 2 December 2024
Published: 6 December 2024

1. Introduction

Greenhouse gasses (GHGs) are primarily composed of carbon dioxide (CO_2), which is produced by industrial processes and fuel combustion [1]. The atmosphere contains several GHGs, including water vapor, ozone, methane, carbon dioxide, and nitrous oxide. However, nitrous oxide, carbon dioxide, and methane have a particularly significant effect on global warming [2]. Climate change and global warming result from the emission of GHGs. The greenhouse effect occurs when certain gasses trap heat in the atmosphere [3]. The Third Session of the Conference of the Parties (COPs) to the Kyoto Protocol was established in 1997. This protocol sets targets for reducing greenhouse gas emissions, involving approximately 40 developed countries. Under the Kyoto Protocol, greenhouse gasses include six types: nitrous oxide, methane, carbon dioxide, perfluorocarbons (PFCs), sulfur hexafluoride (SF_6), and hydrofluorocarbons (HFCs) [4,5]. Developing countries are not obligated to directly reduce greenhouse gas emissions but can voluntarily set their own emission reduction targets. Additionally, flexible mechanisms were established that allow developed countries to purchase carbon credit.

The process of reducing greenhouse gas emissions and finding replacements for them is called "Carbon Credit". Carbon credits are certificates that show the reduction in GHGs in the atmosphere from projects designed to reduce or prevent GHG emissions. Countries that can reduce greenhouse gas emissions are entitled to sell carbon credits to countries whose emissions exceed the established standards [6]. Carbon dioxide emission intensity is a measure of the quantity of the carbon dioxide equivalent (CO_2eq) emitted per unit of energy generated. This includes GHGs other than CO_2, specifically methane and nitrous oxide. The fossil fuel technologies used to produce electricity have high carbon intensity due to the burning of high-carbon fuels [7,8].

Photovoltaic systems are used to generate electricity through green technology. The electrical energy produced is derived from natural energy sources. Solar power can help reduce carbon dioxide emissions by replacing energy sources that are intensive in carbon output. The amount of greenhouse gas emissions reduced depends on the quantity of the energy replaced and the carbon intensity of the energy source being replaced. The type of energy used, as well as the energy required to manufacture, install, and operate solar energy systems, also plays a role [7]. Solar energy technology has great potential to reduce reliance on electricity generation from fossil fuels. Solar systems can be integrated with energy storage systems, which allow stored energy to be released at night, thereby enhancing the reliability of the system [9]. The electricity distribution system is shown in Figure 1 (a) without a solar power system and (b) with a solar power system installed at Bus 3.

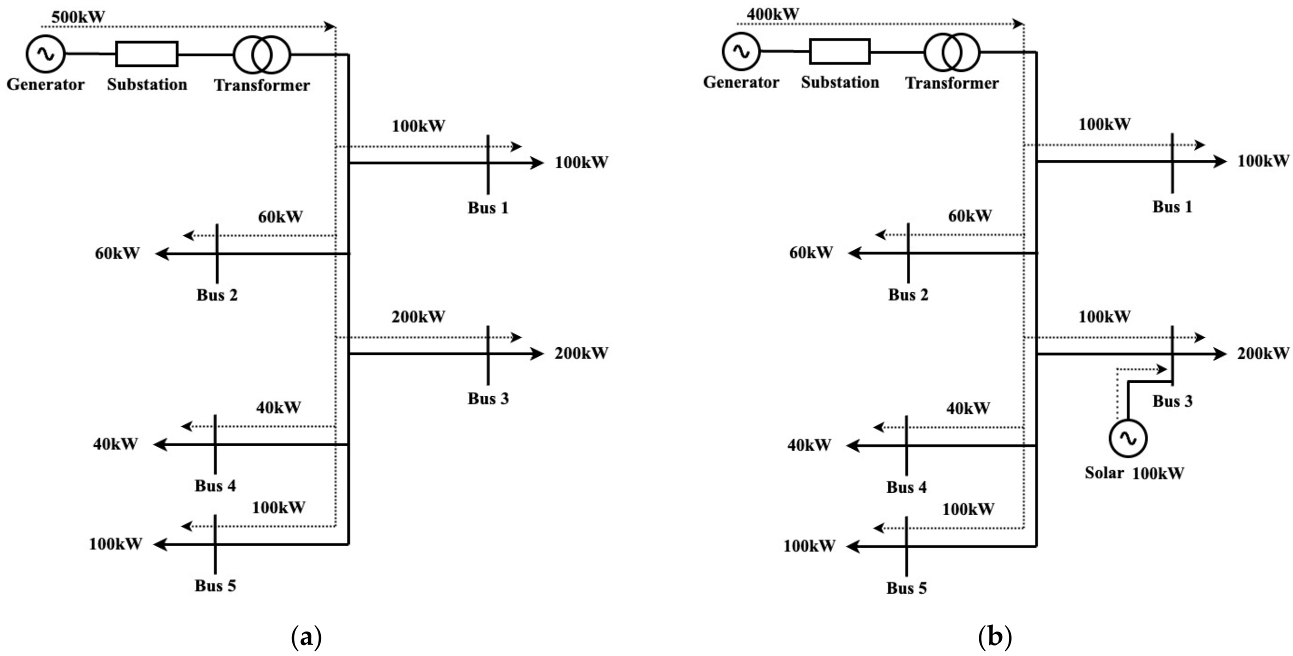


Figure 1. The electricity distribution system is shown in (**a**) without a solar power system and (**b**) with a solar power system installed at Bus 3.

Figure 1a shows that when there are no photovoltaics in the system, the total energy produced by the generator is 500 kW. The energy received from the grid is generated from fossil fuels. Figure 1b shows that when a 100 kW photovoltaic system is installed at Bus 3, the total power produced by the generator decreases to 400 kW because the distribution system compensates for the energy produced by the photovoltaic system. Therefore, the reduction in fuel usage for electricity production from the generator due to the installation of photovoltaics in the distribution system helps reduce carbon dioxide and greenhouse gas emissions.

Previous studies have assessed carbon credit and conducted economic analyses in various contexts. Prabhakant et al. (2008) analyzed the carbon credit from Solar Energy Park, New Delhi, India. The results found that the CO_2 credits received were USD 407.20 (12 sunshine hour) and USD 230 (6 sunshine hour). The energy cost of stand alone photovoltaic was USD 0.14/kWh for 30 years, USD 0.125/kWh for 40 years and USD 0.116/kWh for 50 years [10]. Susmita Mukherjee et al. (2014) evaluated carbon credit from the cells of photovoltaics in West Bengal, India. Tested for 10 h per day at an average light intensity of

4.5 kWh, the results showed that the carbon credit received was 0.33 tons/MWh/year [11]. Naskar R. et al. (2017) estimated and analyzed a 5 kWp photovoltaic system at the JIS College of Engineering in Kalyani. The purpose was to assess the cost analysis of the photovoltaic system with a capacity of 5 kWp, as well as the assessment of carbon credit over 25 years. A comparison of the payback period with and without carbon credits was also made. The payback period was 10 years, 9 1/2 months, when carbon credits were not traded. The payback period was reduced to nearly 4 years when carbon credits were traded. The price of carbon credits was 215,714.519 Indian rupee [12]. Kale (2019) analyzed the economics of a 6 kW off-grid photovoltaic system from February 2017 to January 2018. The payback period was 9 years, and the system reduced approximately 5.6 tons of carbon dioxide per year or 112 tons over its lifetime (20 Years). The price of carbon credit was INR 196,430.00. When carbon credits were considered, the payback period dropped to four to five years [13]. Bhadke et al. (2022) designed and evaluated solar PV power plants and carbon credits at the Government College of Engineering, Amravati. The PV system used 1477 modules, each with a capacity of 440 Wp, and each array contained 17 modules. The payback period was 8.24 years. The carbon credits received from the facility amounted to 20,574.07 tCO_2eq [14]. Natchapol Ruangsap et al. (2023) estimated the quantity and return of carbon credits from a hybrid solar rooftop system with a capacity of 25.68 kW. The carbon credit estimation was made over a 25-year period. The total quantity and return of carbon credits over 25 years were 368.29 tCO_2eq and THB 11,162.74, respectively [15]. In another study, Natchapol Ruangsap et al. (2023) analyzed the economics of a hybrid solar rooftop system with a capacity of 149.80 kW. The carbon credit estimation was also made for a 25-year period. The total quantity and return of carbon credits over 25 years were 2059.15 tCO_2eq and THB 62,412.88, respectively. With carbon credits considered, the payback period was 8 years and 6 months, which is 11 days faster than without considering carbon credits [16]. Esteban A. Soto et al. (2024) conducted an analysis of electrical systems in New England, California, the Southwest, and New York. They evaluated the impact of integrating solar power into the U.S.-specific electrical grid on carbon emissions reductions. The results showed that when solar power plants were integrated into the system, carbon dioxide emissions were reduced [17]. Iniobong Edifon Abasi-obot et al. (2024) designed a photovoltaic system for streetlights at the University of Uyo Main Campus, Akwa Ibom State. The daily energy demand was 144.96 kWh. The CO2 emission reduction was 48.0912 tons per year, equivalent to USD 1322.51 in carbon credits [18].

Therefore, this paper presents an analysis of the economics of photovoltaic systems installed on rooftops combined with carbon credits. This study discusses how to calculate the amount and price of carbon credits in Thailand. The major contributions of this study are as follows:

- The amount and price of carbon credits from photovoltaic systems in Thailand were calculated. Carbon credits were assessed based on the amount of electrical energy produced by the photovoltaic rooftop system using the PVsyst program.
- Economic analysis indices include the payback period, NPV, B/C ratio, and IRR. The financial economic analysis variables include project costs, O&M costs, and project returns, while the economic analysis variables include project costs, O&M costs, returns from the project, and income from selling carbon credits.

2. Background

The factory used electricity from the Provincial Electricity Authority (PEA) through transformers with capacities of 100 kVA and 800 kVA. Before the PV installation, the load was measured. The load for the 800 kVA transformer was 145.54 kW, and the load for the 100 kVA transformer was 46.22 kW. Therefore, the sizes of the PV systems—149.80 kWp and 25.68 kWp—were designed based on the average load of the plant. The PV system is configured with zero-export functionality to prevent the energy produced by the PV system from feeding into the grid, as required by the electricity authority's regulations. A diagram of the power supply to the factory is shown in Figure 2.

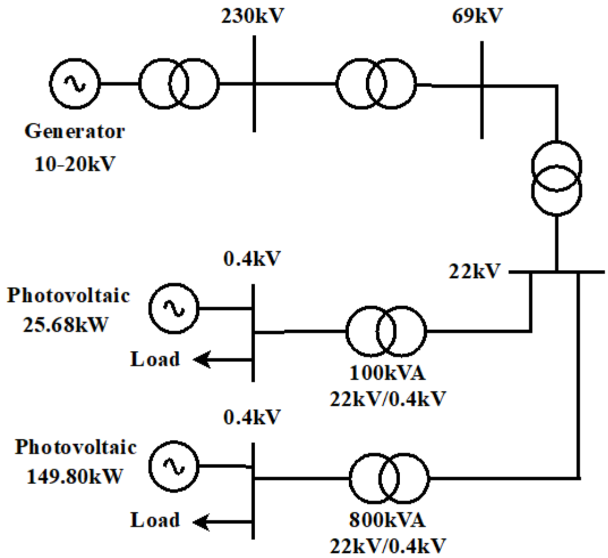


Figure 2. A diagram of the power supply to the factory.

The roof of the factory with the 100 kVA transformers is divided into two orientations. The first orientation has a tilt of 5° and an azimuth of −70°. The second orientation has a tilt of 5° and an azimuth of 110°. The schematic diagram of the 25.68 kW photovoltaic rooftop system is shown in Figure 3.

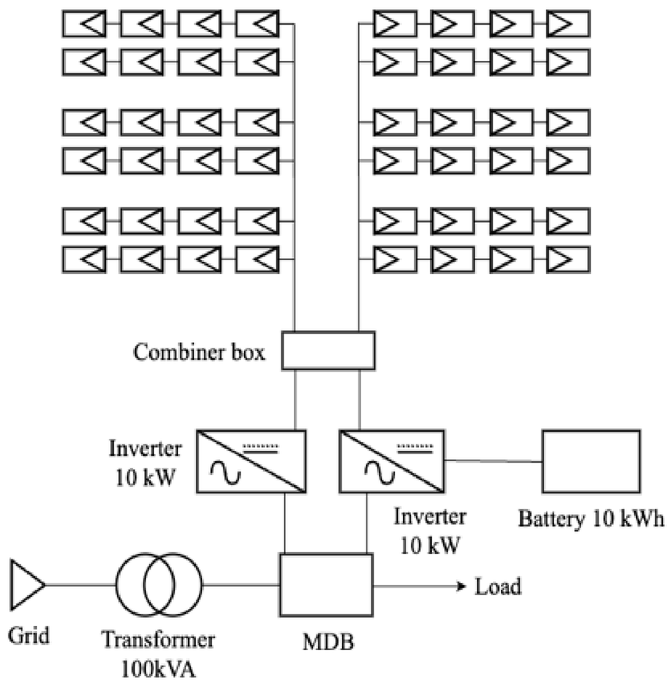


Figure 3. The schematic diagram of the 25.68 kW photovoltaic rooftop system.

Figure 3 shows that the factory roof has 48 modules, each with a capacity of 535 W. The system uses two inverters, each with a capacity of 10 kW. The plant load on the factory roof (800 kVA) was measured by the Provincial Electricity Authority of Thailand before the installation of the photovoltaic rooftop system. The results show that the average plant load was 145.54 kW, and the RMS currents for phases A, B, and C were 90.67 A, 82.16 A, and 84.85 A, respectively. A diagram of the 149.80 kW photovoltaic rooftop system is presented in Figure 4.

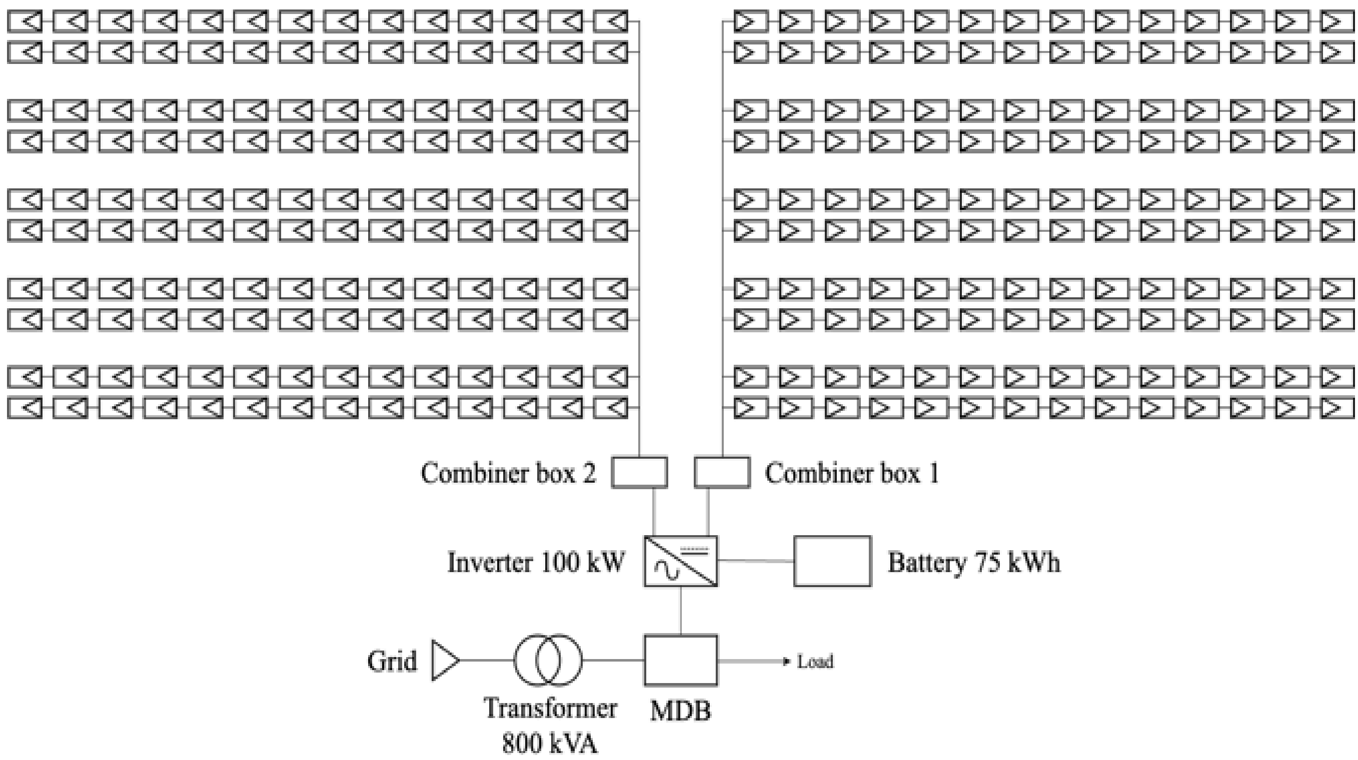


Figure 4. A diagram of the 149.80 kW photovoltaic rooftop system.

Figure 4 shows that the system consists of 20 strings, with each string having 14 modules. A total of 280 modules are used. The capacity of each module is 535 W, and the system uses one inverter with a capacity of 100 kW.

3. Evaluation of Greenhouse Gas Reduction

The amount of greenhouse gasses that can be reduced and expressed in terms of their carbon dioxide equivalent (CO_2eq) can be calculated using Equation (1).

$$ER_y = BE_y - PE_y \quad (1)$$

From Equation (1),

ER_y is the amount of greenhouse gas emissions reduction from project implementation in year y (tCO_2eq per year).
BE_y is the baseline emission in year y (tCO_2eq per year).
PE_y is the total emissions of the project in year y (tCO_2eq per year).

Electricity production from solar energy in this study falls within the scope of the methodology for producing renewable energy to replace electricity from the transmission or distribution system [19,20] and can be calculated using Equation (2).

$$BE_y = BE_{EG,y} = \left(EG_{PJ,y} \times 10^{-3}\right) \times EF_{grid} \quad (2)$$

From Equation (2),

$BE_{EG,y}$ is the amount of greenhouse gas emissions from the electricity generation of the grid in year y (tCO_2eq per year).
$EG_{PJ,y}$ is the amount of electricity produced from the photovoltaic system in year y (kWh per year).
EF_{grid} represents the greenhouse gas emissions from the electricity generation of the grid (tCO_2eq per MWh).

The EF_{grid} in Equation (2) for solar power projects is 0.4857 tCO_2 per MWh from the emissions factor from electricity generation/consumption for greenhouse gas mitigation projects and activities (27 September 2023). It is assumed to be constant throughout the study period. PE is equal to zero because no fossil fuels or electricity are used in the greenhouse gas reduction project.

4. Thailand Policy

4.1. Thailand National Economic and Social Development Plan

In Milestone 10 of the National Economic and Social Development Plan (2023–2027), it is stated that "Thailand will be a circular economy and a low-carbon society" [21]. Target 1 is the efficient use of resources and the addition of value through a circular economy. Target 2 focuses on the conservation, restoration, and sustainable use of natural resources. Target 3 aims to establish a sustainable low-carbon society. By 2027, the proportion of renewable energy in final energy consumption will increase by no less than 24 percent. By 2027, waste recycling will reach at least 40 percent.

4.2. Thailand Integrated Energy Blueprint

Thailand integrated energy blueprint viz the following:

- The Alternative Energy Development Plan (AEDP).
- The Energy Efficiency Development Plan (EEDP).
- The Power Development Plan (PDP).
- The Gas Plan.
- The Oil Plan.

The objective of the Thailand integrated energy blueprint [22] is shown in Table 1.

Table 1. Objective of Thailand's integrated energy blueprint.

Energy Plan	Objective
AEDP	In 2036, renewable energy usage increased to 20%.
EEDP	In 2036, energy intensity was reduced by 30% compared to 2010.
PDP	Enhances the capacity of electricity generation to meet future consumption needs.
Gas Plan	Manage and provide natural gas usage to adequately meet future demand.
Oil Plan	Manage petroleum consumption and reserves at an optimal level.

4.3. Net Zero Emission and Carbon Neutrality

Carbon neutrality refers to the condition where the amount of CO_2 released into the atmosphere is equal to the amount of CO_2 that is reduced, absorbed, or replaced by other methods. In 2050, Thailand aims for carbon neutrality. Net-zero emissions refer to the condition where the emissions of seven greenhouse gasses are equal to the amount of greenhouse gasses absorbed from the atmosphere. Thailand aims for net-zero emissions by 2065 [23]. Thailand has revised its Nationally Determined Contribution (NDC) by increasing its greenhouse gas reduction target from 25% to 40% compared to its original goal by 2030 [24].

5. Economic Analysis Index

Economic analysis encompasses two distinct types. Financial analysis pertains to evaluating the financial viability of individual projects and assessing their private benefits. On the other hand, economic analysis delves into the broader implications of projects for society as a whole. While financial analysis concentrates on personal financial ramifications, economic analysis is concerned with forecasting macroeconomic trends and their societal repercussions.

5.1. Net Present Value

NPV represents the difference between the present value of cash inflows and the outflow of cash. This analysis yields the project's return at a discounted rate. NPV can be calculated using Equation (3).

$$\text{NPV} = \sum_{t=0}^{n} \frac{B_t}{(1+i)^t} - \left[\sum_{t=0}^{n} \frac{C_t}{(1+i)^t} + C_0 \right] \quad (3)$$

where

B_t is the annual return.
C_t is the cost per year.
C_0 is the first year's cost.
i is the rate of discount.

From Equation (3), the project is rejected if NPV < 0. The project is accepted if NPV > 0. If NPV = 0, further considerations are needed to determine whether to accept or reject the project [25–27].

5.2. Internal Rate of Return

The discount rate that reduces the NPV of a project to zero is the IRR. IRR is a tool used to assess the feasibility of a project.

$$IRR = \sum_{t=0}^{n} \frac{B_t}{(1+i)^t} - \left[\sum_{t=0}^{n} \frac{C_t}{(1+i)^t} + C_0 \right] = 0 \quad (4)$$

where

r is IRR.

5.3. Benefit–Cost Ratio

A comparative ratio between the present value of costs and returns over the life of the project is given:

$$B/C\ Ratio = \frac{\sum_{t=1}^{n} \frac{B_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{C_t}{(1+r)^t} + C_0} \quad (5)$$

From Equation (5), the project is accepted if the B/C ratio > 1. The project is rejected if the B/C ratio < 1.

5.4. Payback Period

Payback period is the length of time required for a project's cumulative profits to equal the initial investment amount.

$$Payback\ Period\ \frac{Initial\ investment}{Cash\ inflow\ per\ period} \quad (6)$$

6. Methodology

A flowchart for analyzing greenhouse gas reduction benefits from a photovoltaic rooftop system is shown in Figure 5.

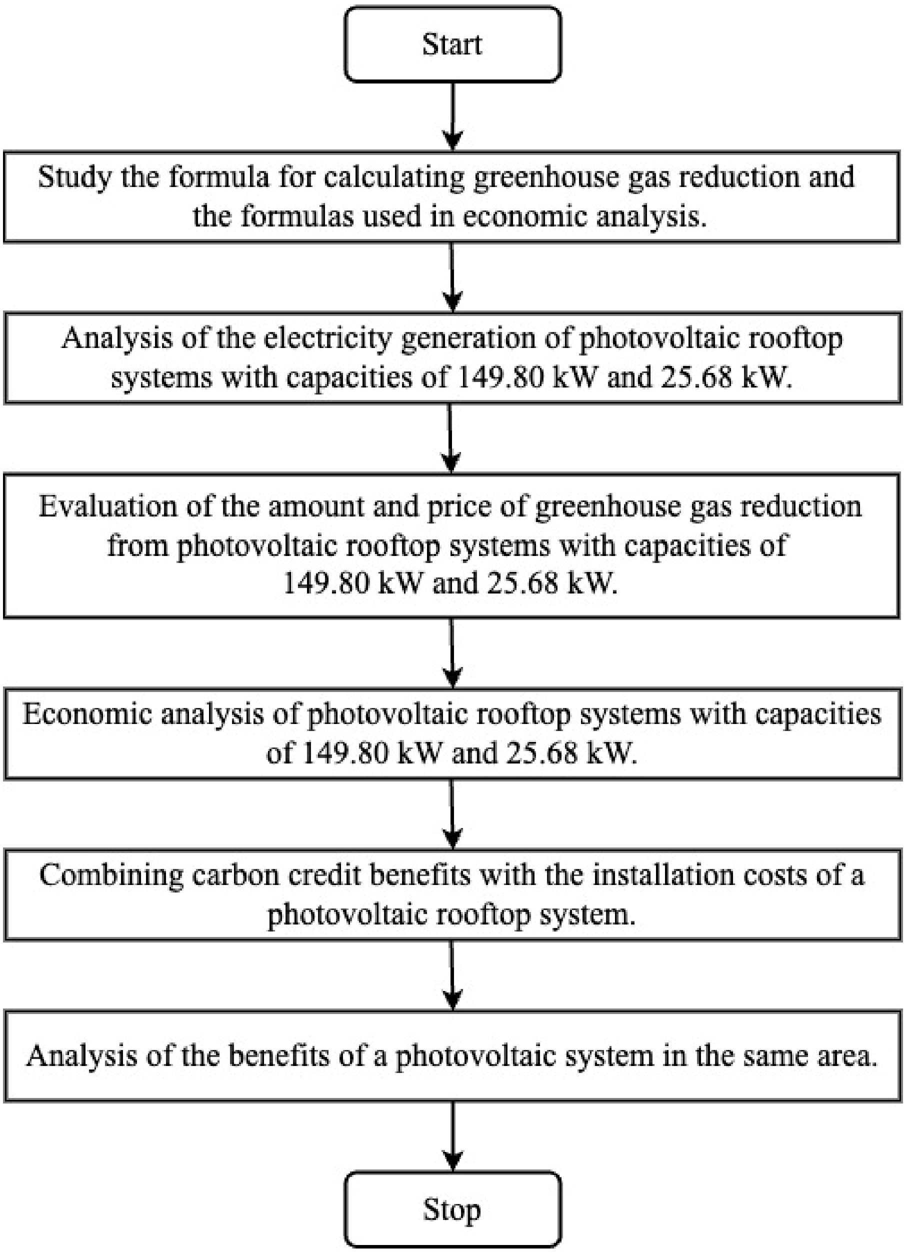


Figure 5. A flowchart for analyzing greenhouse gas reduction benefits from a photovoltaic rooftop system.

7. Case Study

The results and discussion are presented in this section. The first step was to evaluate the quantity and value of the carbon credits. The economic analysis results for the 149.80 kWp and 25.68 kWp hybrid solar power generation systems are presented. Additionally, the benefit analysis results for the hybrid solar power generation systems in the same area are presented.

7.1. Evaluation of Quantity and Value of Carbon Credits

In this section, two capacities, namely 149.80 kWp and 25.68 kWp photovoltaic rooftop systems, are considered. The evaluation of the quantity and value of carbon credits from the 149.80 kWp photovoltaic rooftop system is shown in Table 2.

Table 2. Evaluation of the quantity and value of carbon credits from the 149.80 kWp photovoltaic rooftop system.

Year	Electrical Energy Produced (kW)	Quantity of Carbon Credits (tCO_2eq)	Value of Carbon Credits (THB)
1	200,378.00	97.32	4557.66
2	199,275.92	96.79	4532.60
3	198,173.84	96.25	4507.53
4	197,071.76	95.72	4482.46
5	195,969.68	95.18	4457.40
6	194,867.61	94.65	4432.33
7	193,765.53	94.11	4407.26
8	192,663.45	93.58	4382.19
9	191,561.37	93.04	4357.13
10	190,459.29	92.51	4332.06
11	189,357.21	91.97	4306.99
12	188,255.13	91.44	4281.93
13	187,153.05	90.90	4256.86
14	186,050.97	90.36	4231.79
15	184,948.89	89.83	4206.72
16	183,846.82	89.29	4181.66
17	182,744.74	88.76	4156.59
18	181,642.66	88.22	4131.52
19	180,540.58	87.69	4106.46
20	179,438.50	87.15	4081.39
21	178,336.42	86.62	4056.32
22	177,234.34	86.08	4031.25
23	176,132.26	85.55	4006.19
24	175,030.18	85.01	3981.12
25	173,928.10	84.48	3956.05
Total	4,678,826.30	2175.18	106,421.45

The carbon credits are calculated as 97.32 tCO_2eq, 94.11 tCO_2eq, 90.36 tCO_2eq, and 84.48 tCO_2eq, equivalent to THB 4557.66, THB 4407.26, THB 4231.79, and THB 3956.05, respectively. The evaluation of the quantity and value of carbon credits from the 25.68 kWp photovoltaic rooftop system is shown in Table 3.

Table 3. Evaluation of the quantity and value of carbon credits from the 25.68 kWp photovoltaic rooftop system.

Year	Electrical Energy Produced (kW)	Quantity of Carbon Credits (tCO_2eq)	Value of Carbon Credits (THB)
1	35,047.00	17.02	797.16
2	34,854.24	16.93	792.77
3	34,661.48	16.84	788.39
4	34,468.72	16.74	784.00
5	34,275.97	16.65	779.62
6	34,083.21	16.55	775.23
7	33,890.45	16.46	770.85
8	33,697.69	16.37	766.47
9	33,504.93	16.27	762.08
10	33,312.17	16.18	757.70
11	33,119.42	16.09	753.31
12	32,926.66	15.99	748.93
13	32,733.90	15.90	744.54
14	32,541.14	15.81	740.16
15	32,348.38	15.71	735.77
16	32,155.62	15.62	731.39
17	31,962.86	15.52	727.01
18	31,770.11	15.43	722.62
19	31,577.35	15.34	718.24
20	31,384.59	15.24	713.85
21	31,191.83	15.15	709.47
22	30,999.07	15.06	705.08
23	30,806.31	14.96	700.70
24	30,613.55	14.87	696.32
25	30,420.80	14.78	691.93
Total	818,347.45	397.47	18,613.58

Table 3 shows the electricity production results estimated from the PVsyst program for years 1, 7, 14, and 25, which were 35,047.00 kWh, 33,890.45 kWh, 32,541.14 kWh, and 30,420.80 kWh, respectively. Carbon credits can be calculated as 17.02 tCO_2eq, 16.46 tCO_2eq, 15.81 tCO_2eq, and 14.78 tCO_2eq, equivalent to THB 797.16, THB 770.85, THB 740.16, and THB 691.93, respectively.

7.2. The Economic Analysis

The cost of the project and benefits from the 149.80 kWp photovoltaic rooftop system is shown in Table 4.

Table 4. The cost of the project and benefits from the 149.80 kWp photovoltaic rooftop system.

Year	Cost		Benefit	
	Investment (THB)	O&M (THB)	Benefit (THB)	Cost of Carbon Credit (THB)
0	5,827,220	0.00	0.00	0.00
1	0.00	0.00	735,693.31	4557.66
2	0.00	0.00	731,646.99	4532.60
3	0.00	44,940.00	727,600.68	4507.53
4	0.00	44,940.00	723,554.37	4482.46
5	0.00	44,940.00	719,508.05	4457.40
6	0.00	44,940.00	715,461.74	4432.33
7	0.00	44,940.00	711,415.43	4407.26
8	0.00	44,940.00	707,369.11	4382.19
9	0.00	44,940.00	703,322.80	4357.13
10	0.00	44,940.00	699,276.49	4332.06
11	0.00	44,940.00	695,230.17	4306.99
12	0.00	44,940.00	691,183.86	4281.93
13	0.00	44,940.00	687,137.55	4256.86
14	0.00	44,940.00	683,091.24	4231.79
15	0.00	44,940.00	679,044.92	4206.72
16	0.00	44,940.00	674,998.61	4181.66
17	0.00	44,940.00	670,952.30	4156.59
18	0.00	44,940.00	666,905.98	4131.52
19	0.00	44,940.00	662,859.67	4106.46
20	0.00	44,940.00	658,813.36	4081.39
21	0.00	44,940.00	654,767.04	4056.32
22	0.00	44,940.00	650,720.73	4031.25
23	0.00	44,940.00	646,674.42	4006.19
24	0.00	44,940.00	642,628.10	3981.12
25	0.00	44,940.00	638,581.79	3956.05
Total	5,827,220	1,033,620	17,178,438.71	106,421.45

From Table 4, the total investment is THB 5,827,220, the total O&M cost is THB 1,033,620, and the total benefit is THB 17,178,438.71. The total cost of the carbon credit is THB 106,421.45. The results of the economic indices for the 149.80 kWp photovoltaic rooftop system is shown in Table 5.

Table 5. The results of the economic indices for the 149.80 kWp photovoltaic rooftop system.

Case	NPV (THB)	IRR (%)	B/C Ratio	Payback Period (Year)
1	246,849.61 (FNPV)	10.57 (FIRR)	2.771	8.493
2	268,718.29 (ENPV)	10.62 (EIRR)	2.776	8.445
3	279,502.01 (ENPV)	10.65 (EIRR)	2.781	8.436
4	286,522.75 (ENPV)	10.66 (EIRR)	2.789	8.436

From Table 5, the NPV is calculated at a discount rate of 10%. Case 1 is the base case, without including carbon credits as part of the economic benefit. Therefore, it uses FNPV and FIRR. Cases 2, 3, and 4 consider carbon credits, and therefore, they use the ENPV and EIRR variables. The project costs and benefits of the 25.68 kWp photovoltaic rooftop system is shown in Table 6.

Table 6. The project costs and benefits of the 25.68 kWp photovoltaic rooftop system.

Year	Cost		Benefit	
	Investment (THB)	O&M (THB)	Benefit (THB)	Cost of Carbon Credit (THB)
0	1,766,336	0.00	0.00	0.00
1	0.00	0.00	128,676.02	797.16
2	0.00	0.00	127,968.30	792.77
3	0.00	11,280.00	127,260.58	788.39
4	0.00	11,280.00	126,552.86	784.00
5	0.00	11,280.00	125,845.15	779.62
6	0.00	11,280.00	125,137.43	775.23
7	0.00	11,280.00	124,429.71	770.85
8	0.00	11,280.00	123,721.99	766.47
9	0.00	11,280.00	123,014.27	762.08
10	0.00	11,280.00	122,306.56	757.70
11	0.00	11,280.00	121,598.84	753.31
12	0.00	11,280.00	120,891.12	748.93
13	0.00	11,280.00	120,183.40	744.54
14	0.00	11,280.00	119,475.68	740.16
15	0.00	11,280.00	118,767.97	735.77
16	0.00	11,280.00	118,060.25	731.39
17	0.00	11,280.00	117,352.53	727.01
18	0.00	11,280.00	116,644.81	722.62
19	0.00	11,280.00	115,937.09	718.24
20	0.00	11,280.00	115,229.37	713.85
21	0.00	11,280.00	114,521.66	709.47
22	0.00	11,280.00	113,813.94	705.08
23	0.00	11,280.00	113,106.22	700.70
24	0.00	11,280.00	112,398.50	696.32
25	0.00	11,280.00	111,690.78	691.93
Total	1,766,336	259,440.00	3,004,585.04	18,613.58

From Table 6, the total investment is THB 1,766,336, the total O&M cost is THB 259,440.00, and the total benefit is THB 3,004,585.04. The total cost of the carbon credit is THB 18,613.58. The economic index results for the 25.68 kWp photovoltaic rooftop system are presented in Table 7.

Table 7. The economic index results of the 25.68 kWp photovoltaic rooftop system.

Case	NPV (THB)	IRR (%)	B/C Ratio	Payback Period (Year)
1	−729,060.75 (FNPV)	3.88 (FIRR)	1.554	15.535
2	−725,235.82 (ENPV)	3.91 (EIRR)	1.557	15.484
3	−723,349.70 (ENPV)	3.92 (EIRR)	1.560	15.434
4	−722,121.74 (ENPV)	3.95 (EIRR)	1.565	15.425

From Table 7, the NPV is calculated at a discount rate of 10%. Case 1 is the base case, without including carbon credits as part of the economic benefit. Therefore, it uses FNPV and FIRR. Cases 2, 3, and 4 include carbon credits, so they use the ENPV and EIRR variables. The NPV results were negative. The factory is located at the end of the transmission line, where power outages frequently occur. Therefore, it was necessary to install a solar cell system.

7.3. The Benefit Analysis of the Same Area

The photovoltaic rooftop system with a capacity of 25.68 kWp, at a discount rate of 10%, has an FNPV of THB −729,060.75, an FIRR of 3.88%, and a payback period of 15.535 years. These figures indicate that the project is not suitable for investment. However, the factory needs to address the issue of temporary voltage drops and power outages during the rainy season. Backup loads include the server and office lighting systems. The 149.80 kWp and 25.68 kWp photovoltaic rooftop systems are installed in the same area, and the 149.80 kWp system has a payback period of 8.493 years.

Therefore, the profit from the 149.80 kWp photovoltaic rooftop system, after its payback period, was combined with the profit from the 25.68 kWp system, resulting in a faster payback. The benefit analysis of the 25.68 kWp photovoltaic rooftop system, combined with the profit from the 149.80 kWp system after payback, is shown in Table 8.

Table 8. Benefit analysis of the 25.68 kWp photovoltaic rooftop system, combined with the profit from the 149.80 kWp photovoltaic rooftop system after payback.

Case	Payback Period of the 25.68 kWp System (Year)	Payback Period of 25.68 kWp System When Combined with the Profit of the 149.80 kWp System (Year)	Comparison of the Payback Period of 25.68 kWp System When Combined with the Profit of the 149.80 kWp System (Year)
1	15.535	10.495	5.040
2	15.484	10.447	5.037
3	15.434	10.431	5.003
4	15.425	10.431	4.994

From Table 8, the payback period of the 25.68 kWp photovoltaic rooftop system, when combined with the profit from the 149.80 kWp photovoltaic rooftop system, is as follows: for cases 1, 2, 3, and 4, the mean payback period was 10.495 years, 10.447 years, 10.431 years, and 10.431 years, respectively.

8. Discussion

This study aimed to reduce the payback period of solar systems by utilizing the benefit of carbon credits. Our preliminary results indicated the following:

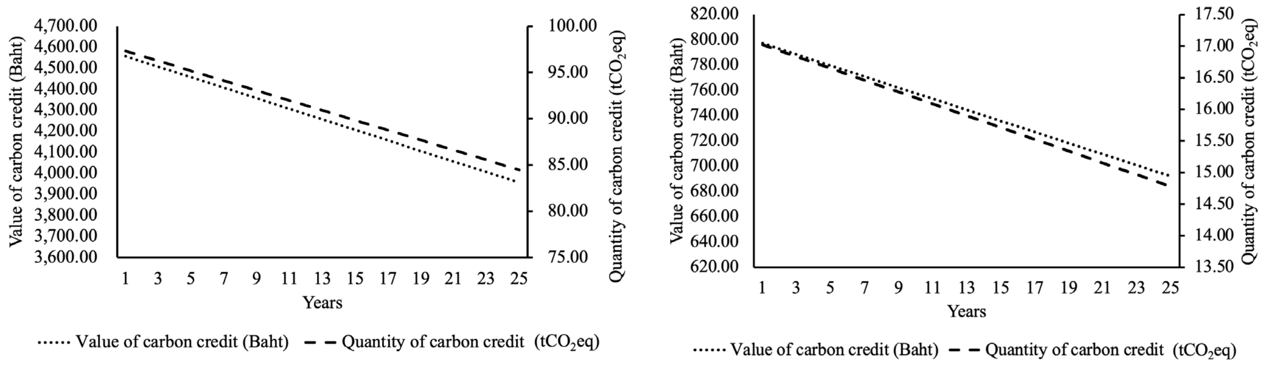
1. The Quantity and Value of Carbon Credits from the Photovoltaic System

A comparison of the quantity and value of carbon credits from the photovoltaic system: (a) in the case of 149.80 kWp and (b) in the case of 25.68 kWp is shown in Figure 6.

From Figure 6, the amount and benefits of carbon credits over a 25-year period are assessed, with production capacity decreasing by 2% in year 1 and 0.55% in the following years. The price used in this calculation is an average of THB 46.83 per ton (with the price as of 19 October 2024). In Figure 6a, the total amount of carbon credits over the 25-year period is 2175.18 tCO_2eq, with a value of THB 106,421.45. In Figure 6b, the total amount of carbon credits over the 25-year period is 397.47 tCO_2eq, with a value of THB 18,613.58.

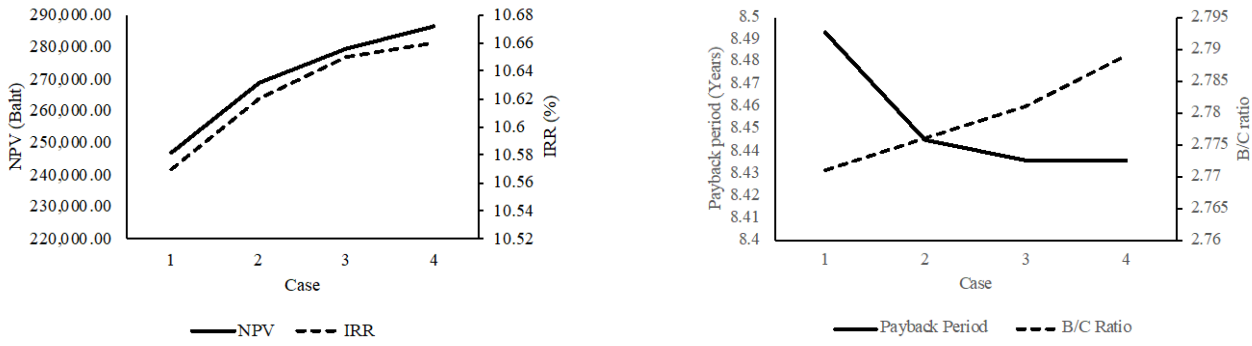
2. The Results of the Economic Analysis of the Photovoltaic System

- The results of the economic analysis of the 149.80 kWp photovoltaic system. A comparison of the economic analysis of the 149.80 kWp photovoltaic system (a) in terms of NPV and IRR and (b) in terms of the payback period and B/C ratio is shown in Figure 7.



(**a**) (**b**)

Figure 6. Comparison of the quantity and value of carbon credits from the photovoltaic system: (**a**) in the case of 149.80 kWp; (**b**) in the case of 25.68 kWp.

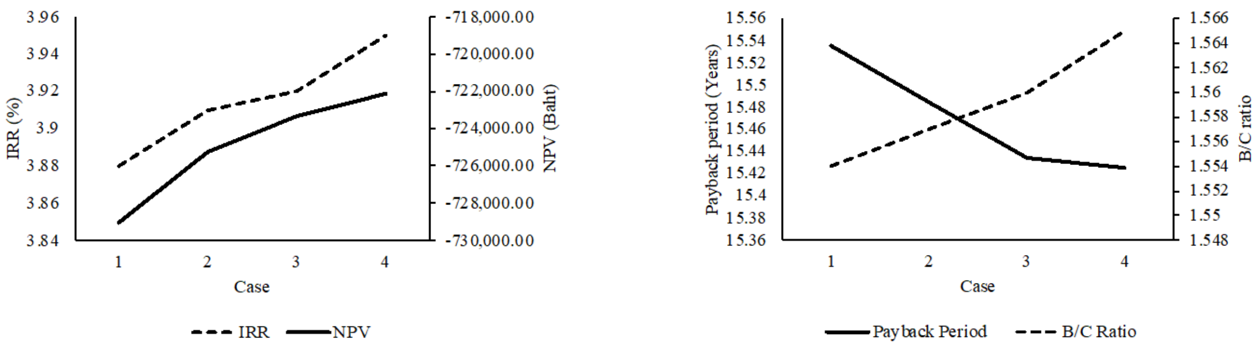


(**a**) (**b**)

Figure 7. Comparison of the economic analysis of the 149.80 kWp photovoltaic system (**a**) in terms of NPV and IRR and (**b**) in terms of payback period and B/C ratio.

From Figure 7a, the NPV is calculated at a discount rate of 10%. In Figure 7b, the payback period in Case 1, as the base case, is 8.493 years. In Cases 2, 3, and 4, when the benefits of carbon credits are included, the payback period is shorter.

- The results of the economic analysis of the photovoltaic system with a capacity of 25.68 kWp are presented. The comparison of the economic analysis of the photovoltaic system with a capacity of 25.68 kWp (a) in terms of NPV and IRR and (b) in terms of the payback period and B/C ratio is shown in Figure 8.



(**a**) (**b**)

Figure 8. Comparison of the economic analysis of the photovoltaic system with a capacity of 25.68 kWp (**a**) in terms of NPV and IRR and (**b**) in terms of payback period and B/C ratio.

From Figure 8a, the NPV is calculated at a discount rate of 10%. The NPV is negative, but the project owner wants to back up the office server system. In Figure 8b, the payback period in Case 1 (the base case) is 15.535 years. In Cases 2, 3, and 4, when the benefits of carbon credits are included, the payback period is shorter.

3. Results of the Payback Period for Photovoltaic Systems in the Same Area

Since the owner of the two solar installation sites is the same, the benefits are combined. Therefore, the benefits from the electricity cost reduction in the 149.80 kWp photovoltaic system, when the investment is worthwhile, are combined with those of the 25.68 kWp system to reduce the payback period. When combined, the benefits reduce the payback period by 5.040, 5.037, 5.003, and 4.994 years in cases 1, 2, 3, and 4, respectively.

4. Discussing Results from Previous Studies

A comparison of the study results is shown in Table 9.

Table 9. Comparison of study results.

Reference	This Paper		[12]	[13]
Year	2024	2024	2017	2019
Country	Thailand	Thailand	India	India
Capacity (kW)	149.80	25.68	5.00	6.00
Payback period (Year)	8.436	15.425	6 years 10 months	4–5
Price of carbon credit per tons	THB 46.83 (19 October 2024)	THB 46.83 (19 October 2024)	EUR 21 (20 June 2014)	EUR 21 (29 October 2018)
Price of carbon credit	THB 106,421.45	THB 18,613.58	INR 215,714.519	INR 196,430.00
Greenhouse gas reduction (tCO_2eq)	2175.18 (25 Years)	397.47 (25 Years)	125.53 (25 Years)	112.00 (20 Years)

As Table 9 shows, the difference in the payback period depends on several variables. The main variable is the price of the carbon credit used in the calculation. In this study, the price of THB 46.83 was used. In [12], the price of carbon credit is EUR 21. Here, EUR 1 is INR 81.83 (20 June 2014). In [13], THE price of carbon credit is EUR 21. Here, EUR 1 is INR 83.56 (29 October 2018).

9. Conclusions

This paper evaluates the electricity generation of a hybrid solar power system using the PVsyst program. It proposes a method for calculating the amount and value of carbon credits generated by the system, following the calculation framework of the Voluntary Emission Reduction Methodology for Renewable Electricity Generation (T-VER-S-METH-01-01). The value of the carbon credits is determined based on the T-VER purchase price for solar power projects as of 8 August 2024.

The study is divided into two parts. Part 1 presents an economic analysis of photovoltaic rooftop systems with capacities of 149.80 kWp and 25.68 kWp, assessed through four case studies: Case 1 (the base case), Case 2 (carbon credits considered over 7 years), Case 3 (carbon credits considered over 14 years), and Case 4 (carbon credits considered over 25 years). The economic indexes analyzed in Case 1 include the FNPV, FIRR, B/C ratio, and payback period, while Cases 2, 3, and 4 analyze the ENPV, EIRR, B/C ratio, and payback period. This study found that the payback period for the hybrid solar power generation system is faster when carbon credits are considered compared to when they are not.

Part 2 examines the combination of profits from a 149.80 kWp photovoltaic rooftop system, after investment payback, with a 25.68 kWp rooftop system to accelerate the payback period. This combination aims to offset the losses incurred by the 25.68 kWp system. This study shows that the combined payback period for the 25.68 kWp system, when factoring in the profit from the 149.80 kWp system, is reduced to five years.

This paper provides additional consideration for installers, offering an opportunity to reduce greenhouse gasses and generate income. Applying this method to larger systems could yield significant results, paving the way for advancements in energy and carbon credit trading by analyzing two photovoltaic rooftop systems in the same area.

Author Contributions: Conceptualization, N.R. (Nattachote Rugthaicharoencheep), S.N. and N.R. (Natchapol Ruangsap); Methodology, N.R. (Nattachote Rugthaicharoencheep), S.N. and N.R. (Natchapol Ruangsap); Validation, N.R. (Natchapol Ruangsap); Investigation, N.R. (Nattachote Rugthaicharoencheep), S.N. and N.R. (Nattachote Rugthaicharoencheep); Writing—original draft, N.R. (Natchapol Ruangsap); Writing—review and editing, N.R. (Nattachote Rugthaicharoencheep) and S.N. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: The study's original contributions are included within the article, and any further inquiries can be directed to the corresponding authors.

Acknowledgments: The authors would like to express their sincere thanks to Rajamangala University of Technology Phra Nakhon (RMUTP), Thailand, and Thai Carton (Rangsit) Service Co., Ltd. Pathum Thani, Thailand for their support.

Conflicts of Interest: The authors declare no conflicts of interest.

References

1. Chilukuri, Y.; Usman, A.; Rajpurohit, B.S. Assessing the Impact of Renewable Energy Sources to Achieve Net Zero Emissions. In Proceedings of the 2023 IEEE Conference on Technologies for Sustainability (SusTech), Portland, OR, USA, 19–22 April 2023.
2. Tavassoli, M.; Pirzaman, A.K. Comparison of effective greenhouse gases and global warming. In Proceedings of the 2023 8th International Conference on Technology and Energy Management (ICTEM), Babol, Iran, 8–9 February 2023.
3. Albuquerque, F.D.B.; Maraqa, M.A.; Chowdhury, R.; Mauga, T.; Alzard, M. Greenhouse gas emissions associated with road transport projects: Current status, benchmarking, and assessment tools. *Transp. Res. Procedia* **2020**, *48*, 2018–2030. [CrossRef]
4. Iwata, H.; Okada, K. Greenhouse gas emissions and the role of the Kyoto Protocol. *Environ. Econ. Policy Stud.* **2012**, *16*, 325–342. [CrossRef]
5. Moiceanu, G.; Dinca, M.N. Climate Change-Greenhouse Gas Emissions Analysis and Forecast in Romania. *Sustainability* **2021**, *13*, 12186. [CrossRef]
6. Sanglimsuwan, K. Carbon Markets: The Simple Fact. *Panyapiwat J.* **2011**, *3*, 123–133.
7. Nelson, J.; Gambhir, A.; Daukes, N.E. *Solar Power for CO_2 Mitigation*; Grantham Institute for Climate Change Imperial College: London, UK, 2014; Briefing Paper No. 11; pp. 1–15.
8. Naskar, R.; Ghosh, S.; Mandal, R. Analysis on Carbon Credit of a 5KWP Solar Photovoltaic Power Plant at JIS College of Engineering, Kalyani. *Imp. J. Interdiscip. Res. (IJIR)* **2016**, *2*, 1506–1511.
9. Drennen, T.E.; Erickson, J.D.; Chapman, D. Solar power and climate change policy in developing countries. *Energy Policy* **1996**, *24*, 9–16. [CrossRef]
10. Prabhakant, Y.N.; Tiwari, G.N. Evaluation of Carbon Credits Earned by a Solar Energy Park in Indian Conditions. *Open Fuels Energy Sci. J.* **2008**, *1*, 57–66. [CrossRef]
11. Mukherjee, S.; Ghosh, P.B. Estimation of carbon credit and direct carbon footprint by solar photovoltaic cells in West Bengal, India. *Int. J. Low-Carbon Technol.* **2014**, *9*, 52–55. [CrossRef]
12. Naskar, R.; Ghosh, S.; Mandal, R. Estimation & Analysis of a 5KWP Solar Photovoltaic Power Plant at JIS College of Engineering, Kalyani. *Int. Res. J. Eng. Technol. (IRJET)* **2017**, *4*, 223–230.
13. Kale, D.; Kokil, P. A Study of the Performance and Carbon Credit Analysis of a 6 KWP Rooftop Solar Photovoltaic Power Plant at Sanjay Group Aurangabad, India. *Innov. Energy Res.* **2019**, *8*, 1000226.
14. Bhadke, H.M.; Prajapati, A.B.; Gulhane, M.L. A case study of Government College of Engineering Amravati for its design and assessment of solar PV plant and Carbon credit earned. *J. Emerg. Technol. Innov. Res.* **2022**, *9*, 1–9.
15. Charlangsut, N.; Ruangsap, N.; Rugthaicharoencheep, N. An Assessment of a Return from Carbon Credit of a Hybrid Solar Rooftop System. In Proceedings of the 2023 International Conference on Power, Energy and Innovations (ICPEI), Phrachuap Khirikhan, Thailand, 18–20 October 2023.
16. Boonthienthong, M.; Ruangsap, N.; Charlangsut, N.; Rugthaicharoencheep, N. The Economic Analysis Consider Carbon Credit from Hybrid Solar Rooftop System. In Proceedings of the 2023 IEEE PES 15th Asia-Pacific Power and Energy Engineering Conference (APPEEC), Chiang Mai, Thailand, 6–9 December 2023.
17. Soto, E.A.; Wollega, E.; Ortega, A.V.; Guzman, A.H.; Bosman, L. Reduction in Emissions by Massive Solar Plant Integration in the US Power Grid. *Energies* **2024**, *17*, 1611. [CrossRef]

18. Abasi-obot, I.E.; Dan, E.E.; Umoren, M. Design and Carbon Credit Evaluation of a Grid-Connected Solar Photovoltaic Power System for Campus Streetlight: Case Study of the University of Uyo Main Campus, Akwa Ibom State. In *The Second International Adaptive and Sustainable Science, Engineering and Technology Conference*; Springer Nature: Cham, Switzerland, 2024.
19. Tantisattayakul, T.; Rassameethammachote, P.; Auisakul, M. Energy, Environmental and Economic Assessment of Solar Rooftop Systems on Buildings of Thammasat University, Rangsit Centre. *Thai Sci. Technol. J.* **2017**, *25*, 1083–1099.
20. United Nations Framework Convention on Climate Change. ACM0002: Grid-Connected Electricity Generation from Renewable Sources—Version 22.0. Available online: https://cdm.unfccc.int/methodologies/DB/XB1TX7TAZ6SLWM9B7BC67THHVD16JV (accessed on 20 October 2024).
21. Office of the National Economic and Social Development Council Office of the Prime Minister Bangkok, Thailand. The Thirteenth National Economic and Social Development Plan (2023–2027). Available online: https://www.nesdc.go.th/nesdb_en/main.php?filename=develop_issue (accessed on 20 October 2024).
22. Traivivatana, S.; Wangjiraniran, W.; Junlakarn, S.; Wansophark, N. Thailand Energy Outlook for the Thailand Integrated Energy Blueprint (TIEB). *Energy Procedia* **2017**, *138*, 399–404. [CrossRef]
23. Office of Natural Resources and Environmental Policy and Planning Ministry of Natural Resources and Environment, Thailand. Long-Term Low Greenhouse Gas Emission Development Strategy (Revised Version). Available online: https://unfccc.int/documents/622276?gad_source=1&gclid=CjwKCAjw1NK4BhAwEiwAVUHPUHS-FvBRfsFg2tq6c-V_OMdi6-FW3l0OHTlLEd7hom-OEKXeAY9b4xoC-TYQAvD_BwE (accessed on 20 October 2024).
24. Rajbhandari, S.; Winyuchakrit, P.; Pradhan, B.B.; Chaichaloempreecha, A.; Pita, P.; Limmeechokchai, B. Thailand's net-zero emissions by 2050: Analysis of economy-wide impacts. *Sustain. Sci.* **2023**, *19*, 189–202. [CrossRef] [PubMed]
25. Prechaveerakul, J.; Inwai, C.C. Engineering economic analysis between high power LED and hydrargyrum medium-arc iodide luminaries in studio lighting application. In Proceedings of the 2015 18th International Conference on Electrical Machines and Systems (ICEMS), Pattaya, Thailand, 25–28 October 2016.
26. Acharya, P.; Regmi, P.P.; Gauchan, D.; Dilli, K.C.B.; Gopa, K.C.B. Benefit Cost Analysis of Adoption of Small Farm Machineries for Rice Cultivation in Nepal. *Int. J. Appl. Sci. Biotechnol. (IJASBT)* **2020**, *8*, 448–453. [CrossRef]
27. Santoso, N.B.; Bahaweres, R.B.; Alaydrus, M. Cost-benefits, NPV, IRR and QoS analysis of the dynamic telecytology system in Indonesia. In Proceedings of the 2016 1st International Conference on Biomedical Engineering (IBIOMED), Yogyakarta, Indonesia, 5–6 October 2016.