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# Calculating Solar Power Capacity and Energy Storage System for Dinsen Long An Factory: a Case Study

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**ABSTRACT**

*Installing solar rooftops benefits factories by cutting costs, supporting grid stability, and promoting sustainable energy practices which is necessary for requirements of green production. Therefore, rooftop solar has attracted and developed fast in areas with high solar radiation. This study focuses on the comprehensive assessment and determination of the solar power capacity and energy storage system implemented for the Dinsen Factory located in LongAn Province. The goal is to optimize the renewable energy integration to meet the energy demands of the factory while ensuring reliability and sustainability. Various factors including geographical location, solar resource availability, energy consumption patterns, and technological considerations are taken into account for accurate capacity calculations. Additionally, the study evaluates the integration of an energy storage system to address intermittent solar energy generation and ensure a consistent and reliable power supply to the factory. The findings and recommendations of this study aim to guide the efficient deployment of solar power and energy storage systems, promoting sustainability and reducing the reliance on non-renewable energy sources at the Dinsen Factory. The investigated results show that the optimum rooftop solar power is 2,150 kWp which generates an electricity output of approximately 2,913 MWh per year. The energy output can meet ~53.2 % electricity demand of the Factory. The solar projects contribute to environmental benefits by reducing greenhouse gas emissions of about 2,344 tons of $CO_2$ saved per year.*

## 1. INTRODUCTION

The field of renewable energy is becoming increasingly vital in meeting the world's energy demands and is gradually replacing traditional sources of energy such as fossil fuels [1]-[3]. Renewable energy is a clean, sustainable, renewable, and naturally occurring source of energy. It includes various sources of energy such as solar energy, wind energy, hydropower, geothermal energy, and biomass. These sources of renewable energy not only help reduce greenhouse gas emissions but also decrease reliance on finite fossil fuel resources [4]-[6].

Solar energy is currently being widely utilized, and this not only brings economic value but also has aesthetic and environmental benefits. Encouraging and developing solar projects, including rooftop solar, is a sensible and appropriate strategy. However, the development of solar projects needs to be carefully regulated and managed to avoid overloading the power infrastructure [7]. Therefore, it's essential to find directions and solutions for efficiently integrating solar power systems into the existing power grid infrastructure. This may include improving the power grid infrastructure, applying smart and flexible technologies in power management and distribution, and developing energy storage systems and other solutions to optimize the use of solar energy [8-10]. Implementing these solutions will increase the stability and efficiency of solar power systems and ensure the sustainable development of renewable energy.

Exploring solar energy to convert into electricity has developed quickly with some technologies such as heliostat [11], flat photovoltaic [12], concentrator photovoltaic [13]-[15], hydrogen photosynthesis [16], etc. Among these technologies, rooftop solar systems are a priority option to convert solar energy into electricity because it is simply, flexible for the size of power, widely applied from residence to industry, and available to utilize the current infrastructure of factory or house and electricity grid system [17]. All those aspects led to rooftop solar technology being used widely in the last decade in the world and Vietnam.

Rooftop solar consists of on-grid solar rooftops, off-grid solar rooftops, and hybrid solar rooftops [18]-[20]. Among the three various rooftop solar installation technologies, on-grid solar stands out as the simplest and most widely adopted. In this approach, solar panels are seamlessly integrated into the existing utility grid,

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allowing generated solar energy to offset a portion of the electricity traditionally supplied by the grid. This technology can be performed in a wide range of sizes from small ones for residence to utility-scale projects. In Vietnam, the government has deployed an encouraging mechanism called Feed-in-Tariff (FiT) to develop the rooftop solar sector allowing to sale of electricity energy generated from solar to the national grid at a high price for projects completed before the end of 2020. This mechanism helps the rooftop solar investors not worry about project size because excess energy will be purchased by the national grid while any shortage of electricity will be compensated immediately by the grid. However, after 2020 any project to be allowed for connection to the grid must ensure that no electricity is fed back to the national grid, which means self-generation/self-consumption for rooftop solar. Hence, determining the appropriate capacity for a solar power system is a matter that needs to be considered before deciding to invest in a solar power system. When installing, it's important to carefully consider how much capacity should be installed to maximize economic benefits [21]-[23]. Therefore, the conventional design of solar rooftops based on the size of the rooftop, the electricity demand of the factory, or the budget for investigation is not appropriate in this situation [24]-[26]. A novel design of solar rooftops that is a combination of the electricity demand, daily profile, price of the electricity grid, and solar radiation data is a key solution to achieving the target efficiency of the economy and utilization of solar energy systems.

Moreover, solar energy, while being a potential and clean renewable energy source, often experiences instability due to natural factors and environmental conditions. The irregularity of sunlight throughout the day, changing weather patterns, and the day-night cycle are the main factors causing fluctuations in solar energy production [27], [28]. This instability poses challenges in optimizing the use of this energy source. To address this issue, energy storage systems and flexible control technologies are being developed to consider and efficiently provide energy based on weather conditions and the availability of solar energy. Therefore, lithium-ion batteries have emerged as a promising solution for storing energy from solar sources, addressing the intermittent nature of solar power [29]-[31]. These batteries play a vital role in stabilizing the energy supply and ensuring a consistent power output despite the fluctuations in solar energy availability.

For these reasons, this study will be focused on the techno-economic analysis of rooftop solar using a specific load consumption of a factory located in South Vietnam. Through this study, the systematic methodology for designing rooftop solar with optimum power capacity with a method of combination of load demand, price of the grid system, and solar radiation data collected from the project site will be presented. The proposed storage system with suitable capacity will be introduced and answer the question of when is available for investing storage system using lithium battery system as well. The remaining sections of this paper are structured as follows: Section 2 outlines the methodology for determining the rooftop solar effective power using a combination of HomerPro and Pvsyst software. Section 3 shows the results of computes and simulates the energy output using Pvsyst, presenting a comparative analysis with HomerPro results. Section 3 also evaluates the energy storage capacity using lithium-ion batteries in HomerPro, considering various battery market scenarios. Moreover, Section 3 presents and deliberates upon the simulation outcomes and calculations for the envisaged rooftop solar system tailored to the identified factory. Lastly, Section 4 provides the concluding remarks for this paper.

## 2. METHODOLOGY

### *2.1 Information About the Rooftop Solar Project*

DinSen is a company specializing in high-quality garment manufacturing for export, a branch of the Dintsun Group headquartered in Taiwan, and a partner of major brands such as Reebok, Adidas, *etc*. The factory for rooftop solar is located in the location belonging to BenLuc District, LongAn Province. Long An province is in the South of Vietnam where the average value of solar irradiance of about 1800 - 2000 kWh/year [32]. Moreover, the Dinsen factory has a high demand for electricity energy for the operation and production process of about 3,720 MWh/year. That leads to the expense for consumption of electricity energy per year of about 5.8 billion VND approximately 250,000 USD. In addition, the factory has a large area of rooftops in which four roofs have a total area of 18,178 $m^2$, with a potential installation capacity of up to 3.2 MWp. All analyzed aspects illustrate the motivation to launch the rooftop solar project for the Dinsen factory. This project will help the company reach two goals: (i) save money for electricity energy consumption and (ii) transaction to green production which is important for export companies like Dinsen. Figure 1, Figure 2, and Table 1 provide more information about the DinSen Factory.

**Fig. 1. Overview of the DinSen Factory drawn in 3D.**

**Fig. 2. An overview of the plant captured from Google Earth.**

**Table 1. The information of DinSen factory which is important for calculation and installation rooftop solar system.**

| Parameter | Value |
|---|---|
| Position | 10°38'15.9"N 106°31'25.3"E |
| Azimuth angle | 25.6$^0$ deviation from North towards West |
| Tilt angle of the Rooftop | 5.7$^0$ |
| Average solar insolation | 1,800 to 2,000 kWh/year |

### *2.2 Technical Parameters*

Many parameters should be taken into account to reach the efficient design of rooftop solar such as temperature, solar irradiance, the geometry of the PV array, shading factor, *etc*. The operating temperature of solar panels can affect the conversion efficiency from solar energy to electricity. The decrease in conversion efficiency is about 0.35 %/$^0$C depending on the type of solar cell material [33]. In addition, the temperature can also affect the lifetime of solar cells leading to decreased benefit of the rooftop solar project. To mitigate the effect of high temperatures on rooftop solar, PV arrays are assembled to the roof by using a mounting frame system that is higher on the roof to make space for natural convection to cool the PV array. With a cooling by nature convection, the PV array employed in South Vietnam has an operation temperature of about 30 $^0$C to 60 $^0$C depending on the weather conditions. The power of a PV module is estimated as a function of PV module characteristics ($V_{OC}$, $I_{SC}$, $T_P$). Furthermore, solar irradiance affects the ISC leading to a change in the output power of the solar panel. Solar irradiance also contributes to the temperature of solar panels which is relative to air temperature correlation to natural convection. Linear regressions to the PV module temperature and other main parameters are as follows.

$$V_{OC} = 22.384 - 0.0627 \times T_P \quad (1)$$

$$I_{SC} = 0.0967 + 0.0032 \times G \quad (2)$$

$$T_P = T_A + 0.022 \times G \quad (3)$$

Where $V_{OC}$ is open circuit voltage, $I_{SC}$ is short circuit current, $T_P$ is the temperature of the operation solar panel, $T_A$ is the air temperature, and $G$ is solar irradiance coming to the solar panel. Note that the value of those equations will change depending on the type of solar cell. However, that gives an overview how the relationship between operation temperature and two important output parameters $I_{SC}$ and $V_{OC}$.

Because the position of the sun changes as a function of the time of day, days of the year, and the position for investigation, the geometry of the PV array can affect the efficiency of the rooftop solar system. The design of rooftop solar with optimum geometry parameters is not available because of depends on the azimuth angle of the roof for installation PV array. However, management of all geometry parameters of rooftop solar projects helps to calculate exactly how much solar irradiance the PV array can receive following days, months, or years. The received irradiance of the PV array is important to estimate the output electricity energy which is used to investigate and estimate the project for both technique and economic aspects

$$\mathrm{G} = \mathrm{DNI} \times \cos(\theta) + \mathrm{DHI} \times \left(\frac{1+\cos\beta}{2}\right) + \mathrm{GHI} \times \rho \times \left(\frac{1-\cos\beta}{2}\right) \quad (4)$$

Where *DNI* is direct normal irradiance, *DHI* is diffuse horizontal irradiance, *GHI* is global horizontal irradiance, $\boldsymbol{\theta}$ is the incident angle of the direct beam to the PV panels, $\boldsymbol{\beta}$ is the tilted angle of the solar panels, and $\boldsymbol{\rho}$ is the reflection factor of the environment.

The shading factor is an important parameter that should be estimated in every solar project. The shading analysis determined where and when a solar panel is affected by shadow. This analysis provides information on where we can install solar project efficiency.

Besides the above-mentioned parameters, losses in optical and electricity also need to be considered to estimate the accuracy of the output energy so that the solar project efficiency can be calculated. That initial information helps the investor to decide whether to launch the project or not. The optical losses can contain soil loss, dust loss, geometry loss, degradation of solar panel loss, etc. The electrical losses compress distribution loss, connection loss, inverter loss, temperature loss, *etc*.

Electricity consumption is estimated by using the collected data from the survey site or it is calculated by the sum of the multiplication of the load's power and time for utilization. From the energy consumption, the number of solar panels can be calculated as follows.

$$N_{PV} = \frac{E_{an}}{P_{opt.PV} \times l_{t.PV} \times l_{at.PV} \times \eta \times 365 \times h_n} \quad (5)$$

Where:

$E_{an}$: electricity consumption of the factory per year;

$P_{opt.PV}$: peak power of a solar panel (kWp);

$l_{t.PV}$: thermal coefficient of solar panel (%);

$l_{tt.PV}$: total loss coefficient of solar panel that effect by losses caused by wire distributions, connection cables, diode loss, optical loss, etc. (%);

$\eta$: total efficiency of the solar system (%);

$\boldsymbol{h_n}$: solar insolation at the site of solar project per day (kWh/day).

### *2.3 Economic Parameters*

In this study, all calculations of economic parameters have been conducted with Vietnamese currency (VND) at the exchange rate of US Dollar 1 USD = 23,500 VND. Net Present Cost (NPC) or life-cycle cost of a system is the present value of all the costs of installing and operating that system requires over the project lifetime, minus the present value of all the revenues that it earns over the project lifetime. To perform this calculation, a cash flow table for the project should be created and used. Furthermore, NPC is based on the time value of money (TVM) principle, which assumes that a unit of currency today is more valuable than a unit of currency in the future

$$NPC = \sum_{t=0}^{n} R_t (1+i)^{-t} - R_0 \quad (6)$$

Where:

*n*: lifetime of the project (years);

$R_t$: the value received on the year number t (VND);

*i*: discount rate (%/year);

$R_0$: Initial investment cost (VND);

If we know about NPC, we can estimate the ability of the qualitative benefit of the project. When NPC > 0, this shows that the project is profitable and has economic value. If NPC < 0, this shows that the project is likely to lose money and has no economic value. When NPC = 0, the project has a rate of return equal to the project's cost of capital. However, this method only shows us the project's profit or loss with a specific profit and loss level but does not show the specific profit level (more or less) of the project itself. Therefore, the internal rate of return (IRR) calculation method is used to overcome this limitation.

Internal rate of return (IRR) is the discount rate at which the base case and current system have the same net present cost. We can calculate the IRR by determining the discount rate that makes the present value of the difference between the two cash flow sequences equal to zero. We can compare the IRR with the Discount rate parameter. If IRR < Discount rate, it means the project may not be profitable and may not be worth investing in. If IRR > Discount rate, it signifies that the project is considered attractive and promising for investment. If IRR = Discount rate, it implies the project will break even. And IRR value can be calculated from NPC as follows:

$$0 = NPC = \sum_{t=1}^{T} \frac{R_t}{(1+IRR)^t} - R_0 \quad (7)$$

The payback period is the number of years at which the cumulative cash flow of the difference between the current system and base case system switches from negative to positive. The payback is an indication of how long it would take to recover the difference in investment costs between the current system and the base case system.

Weighted Average Cost of Capital (WACC) is an important financial indicator in the field of corporate finance. It measures the rate of return a business pays on all the capital it uses to operate and invest. These sources of capital include equity, debt, and any other source of capital that a business uses to finance its business operations.

$$WACC = \frac{E}{V} \times R_e + \frac{D}{V} \times R_d \times (1 - T_c \tag{8}$$

Where:
$R_e$: The cost of capital (VND);
$R_d$: Cost of using debt (VND);
$D$: Market value of total corporate debt (VND);
$E$: Market value of total equity (VND);
$V$: Total long-term capital of the enterprise (VND);
$T_c$: Corporate income tax (%).

Levelized cost of energy (LCOE) is the average cost per kWh of useful electrical energy produced by the solar system. To calculate the LCOE, we can divide the annualized cost of producing electricity by the total electric load served, using the following equation

$$LCOE = \frac{\sum_{t=1}^{n} \frac{I_t + M_t + F_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+r)^t}} \tag{9}$$

Where:
LCOE: levelized cost of energy (VND/kWh)
$I_t$: Investment cost in year number t (VND)
$Mt$: Cost of maintenance and Operation in year number t (VND)
$F_t$: Cost of fuel in year number t (VND)
$E_t$: Electric energy output from rooftop solar system in year number t (kWh)
$r$: Discount rate (%)
$n$: project lifetime (years)

### 2.4 Design Process

In the design of a solar power system, all the processes are depicted in Figure 3. Figure 3 illustrates the design flow for a rooftop solar system; this diagram requires numerous input parameters such as component costs (PV panels, inverters, operation and maintenance, replacements, etc.), weather information (temperature, irradiance, wind, etc.) from Meteonorm or NASA weather data, and the collected factory's electricity consumption. The historical electricity consumption data of the factory should span at least 365 days for running in HomerPro. The more detailed the data is, the higher the accuracy of estimating the optimal peak power for the rooftop solar system. Additionally, considering the electricity grid cost is important to determine the charging and discharging strategy for this system.

Although the input parameters have tried to insert as much as possible, some parameters have still been selected from assuming such as the trend of reducing batteries cost following years, the increase price of grid electricity is constant, *etc*. Furthermore, this study did not focus on detailed losses of electricity such as loss of distribution, loss of connection, loss of dust, *etc*. All these kinds of losses are sum in the effective coefficiency of the system in the simulation process. That makes the simulation results can be trust and valuable compared to the real system

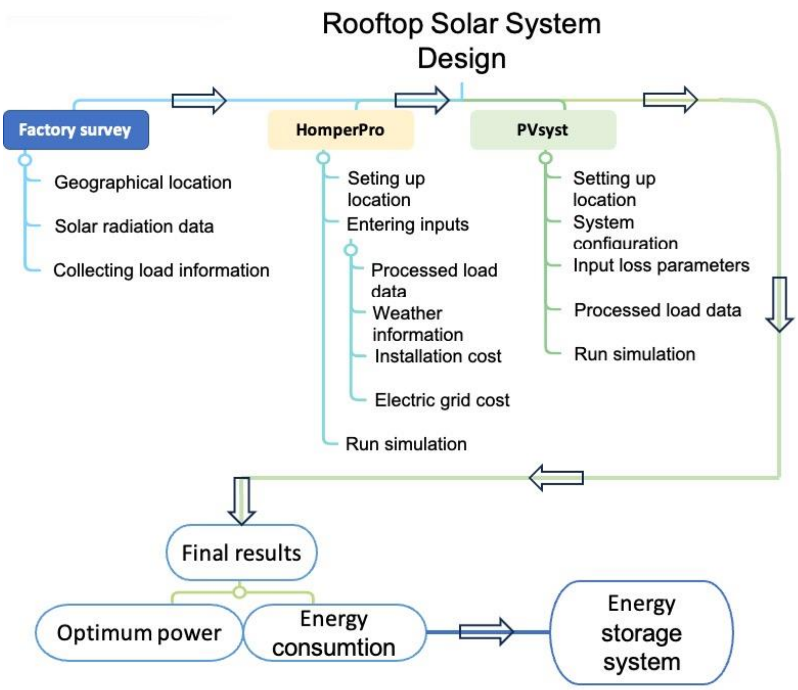


**Fig. 3. The diagram of the process to design a rooftop solar system with HomerPro.**

In general, the design process of a rooftop solar project with optimum power is carried out below steps referenced in Figure 3.

*Step 1. Factory surveys*

This first step is important for an overview of three aspects: (i) the condition of the rooftop, the geometry of the factory, and collecting historic electric consumption data. A factory that has a good rooftop will be suitable to consider for investment in rooftop solar. A good tole rooftop guarantees that it will not change during the lifetime of rooftop solar. (ii) We need to measure the geometry parameters of the rooftop such as tilt angle, area, azimuth angle, etc. The structure of the factory and the condition of the infrastructure are surveyed and estimated which helps to build the model of the factory in computer. The technical drawing will help to arrange project components with a reasonable and effective layout. Determination of building or height objectives near the site for solar installation to estimate the shadow factor. (iii) Finally, an important thing to be able to determine the optimal power of rooftop solar is to collect the plant's consumption load. Collecting load consumption history can be done quickly if the factory saves such data, otherwise, we must install equipment to measure the factory's load consumption. Load consumption must be collected over a sufficiently long period (at least 365 days) to ensure the accuracy of the plant-specific data.

**Fig. 4. Factory's infrastructure is still new that guarantee the PV can be reliable in its lifetime.**

*Step 2. Determine optimal power using HomerPro*

To determine the optimal peak power of the solar project, we need to provide three types of data to HomerPro: solar irradiance data, load consumption history, and grid electricity price list. Firstly, we must set up the project location in HomerPro. This is quite a simple thing because HomerPro is connected to Google Maps, thus, we just need to select the location or enter the latitude and longitude information of the project. After selecting a location, HomerPro software will allow us to load solar radiation data of the project's site from Meteonorm or NASA's weather database as shown in Figure 5. The consumption load is then handled, templated, and inserted into HomerPro with the requirement of at least 365 days. Figure 6 and Figure 7 show the average plant consumption load data for 12 months and representative daily load data after being imported into HomerPro, respectively. In addition, data on Vietnam's grid electricity price list at the surveyed time was also inserted into HomerPro. Necessary economic parameters can help the software determine LCOE values as a function of different installed capacities

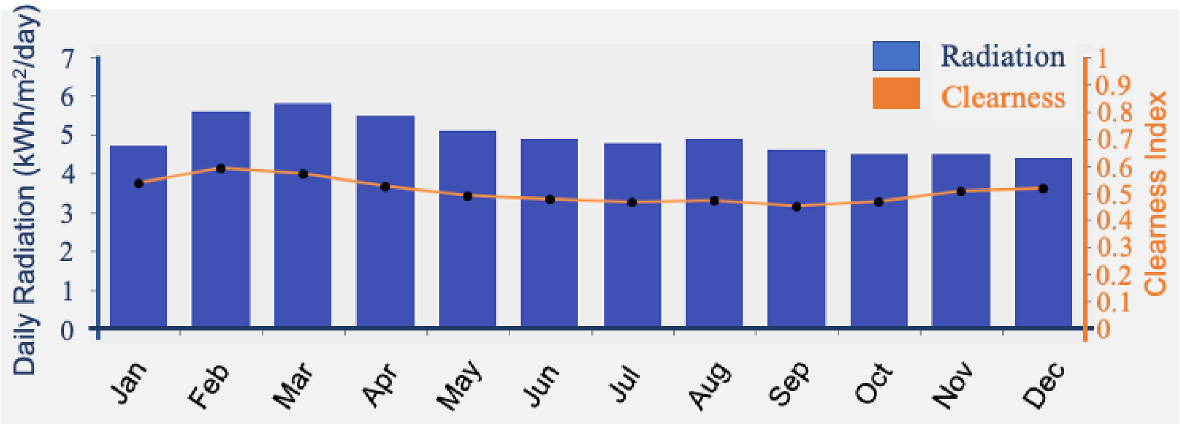


**Fig. 5. Solar irradiance data at the project site.**

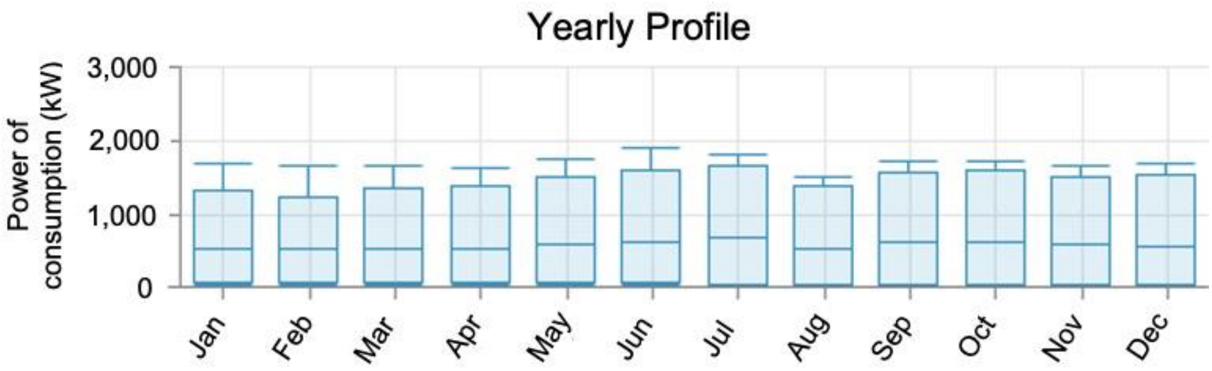


**Fig. 6. Average load's consumption for 12 months.**

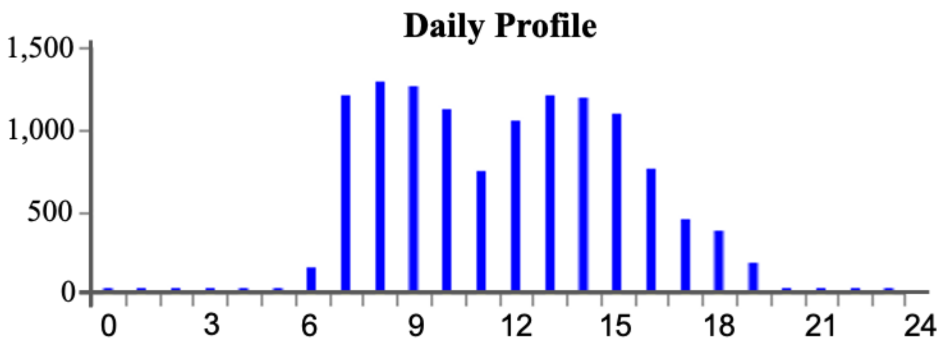


**Fig. 7. Data of load consumption for representative day after inserted into HomerPro.**

*Step 3. Running Pvsyst to estimate the output energy*

HomerPro has the advantage of helping to determine the optimal capacity of the solar project by processing a lot of information about weather, load consumption, and related economic indicators. However, HomerPro's data library is not updated with components on the market leading to it not taking into account some losses. In contrast, Pvsyst with its rich library of components available on the market should be chosen to determine the power output. Besides, another important thing is that Pvsyst can be combined with Sketchup to determine the shading coefficient, an important parameter that needs to be determined in solar power systems. Therefore, the output power results calculated by Pvsyst are more reliable than that of HomerPro. The results of Pvsyst's electricity output are information to be able to calculate economic parameters and determine the economic feasibility of the solar project. Determine the characteristics of cash flow, investment costs, and payback period based on a model specifically set up in Excel which is presented in another project.

*Step 4. Calculation of the economic parameters of the project*

All economic assessments of the project are evaluated through a model built in Excel. In this model, the load data parameters are again used in combination with the power output calculated in Pvsyst to determine the ability of the solar power system to meet the load. Because of the changeability of the weather, the output of the solar power system fluctuates and may sometimes not be able to meet the consumption load and sometimes have excess power. If excess electricity is not used, it will become waste. Therefore, storing electricity consumption is also an option of interest. Storage capacity depends on the total amount of excess electricity and project economics. To ensure that the project still has acceptable economic data, storage capacity with different price scenarios is investigated in this project.

It is a fact that if we install a storage system into a project, the optimal capacity may change because economic factors have changed. However, this difference will not be too large, so we can completely determine the capacity of the storage system and imagine that it will not affect the optimal capacity of the system. The problem of optimal capacity for the solar power system and optimal capacity for the storage system is a quite complex two-variable optimization problem and needs to be expanded and calculated in detail in another project.

*Step 5. Development of a cash flow plan for the solar project*

In this step, we focus on the investment plan that is widely used today, which is the 30% equity capital plan and 70% loan from the bank. Then the cash flow options and debt repayment plans for the project need to be accurately determined to be able to answer the question of whether the project should be invested or not. And if investing, what the cash flow throughout the life of the project will be.

In conclusion, the design process will be carried out from a site survey, simulation in HomerPro to estimate the optimum power of the rooftop solar, running in Pvsyst to determine the output electricity energy, analyzing the penetration of renewable to load demand, choosing the capacity of battery system to storage exceed electric energy and increase the fraction of penetrate of renewable energy in consumption, finally, building a suitable way for investment.

## 3. RESULTS AND DISCUSSION

### *3.1 Results and discussion for HomerPro*

To calculate the optimal capacity of the solar rooftop system at the Dinsen Factory using the technical supported software HomerPro, the parameters processed in the software need to be carefully analyzed and selected, based on technical standard requirements as well as experience in implementing projects in real conditions and surveyed time. The parameters that are input parameters for the HomperPro software are shown in Table 2.

**Table 2. Input parameters inserted for HomerPro.**

| Parameters | Value |
|---|---|
| Technique aspect parameters | |
| Irradiance data | Nasa resource (kWh) |
| Temperature | Nasa resource ($^0$C) |
| History load data | 365 days, period step 10 minutes |
| Normal hours | 4:00 AM – 9:30 AM<br>11:30 AM – 17:00 PM<br>20:00 PM – 22:00 PM |
| Off-peak hours | 22:00 PM – 4:00 AM |
| Peak hours | 9:30 AM – 11:30 AM<br>17:00 PM – 20:00 PM |
| Voltage providing for factory | 22 kV – 110 kV |
| Temperature coefficiency | 0.35 %/$^0$C |
| Norminal operating cell temperature | 45 $^0$C |
| Efficiency of PV panels | 20.2 % |
| Degradation of PV panels | 0.5 %/year |
| Project lifetime | 20 years |
| Inverter efficiency | 98.2 % |
| DC/AC ratio | 1.22 |
| Inverter lifetime | 10 years |
| Average electricity consumption | 14,094 kWh/day |
| Average power consumption | 587.26 kW |
| Peak power of consumption | 1906.1 kW |
| Economic aspect parameters | |
| Buying electric cost, normal hours | 1,555 VND/kWh |
| Buying electric cost, off-peak hours | 1,044 VND/kWh |
| Buying electric cost, peak hours | 2,871 VND/kWh |
| Cost for investment of solar system | 15,110,000 VND/kWp |
| Cost for O&M for PV system | 300,000 VND/kWp/year |
| Inverter cost | 890,000 VND/kW/year |
| Cost for O&M for inverter | 40,000 VND/kW/year |
| Grid price annual increase rate | 1.5 %/year |
| Nominal discount rate | 13 % |
| Expected inflation rate | 4 %/year |

Besides input parameters inserted into HomerPro, the collected consumption data is an important parameter that helps to reach the expected goal of estimation of optimum power. The input parameters can be the same for solar projects, but the consumption is different for every factory leading to receiving specific optimum power. Figure 6 (above-mentioned) and Figure 8 shows the handled data of consumption. The power consumption for the Dinsen Factory is quite high greater than 1000 kW for all months. The power consumption is the highest in June and the lowest value in February which consists long holiday event of the lunar new year in Vietnam. We can see the suitable between Figure 6 and Figure 8.

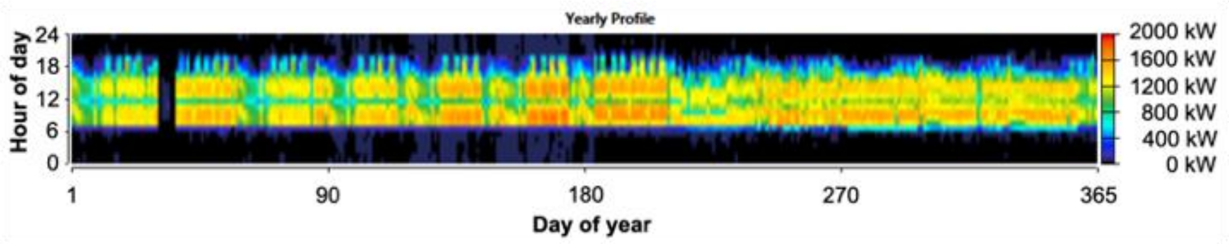


**Fig. 8. Histogram of power consumption distributing following time of day and following time of years.**

To determine the optimal power, a range of power with rough increasing steps of 100 kWp is used in HomerPro. Through this, we can determine the optimal value range. From there, the power value for each increasing step is reduced by about 5 kW to determine the optimal results. The selection of the system is based on two main criteria: minimizing the Levelized Cost Of Energy (LCOE) and the percentage of renewable energy used by the Factory. At whatever capacity the system has the lowest LCOE value, that is the optimal capacity for the system. Simulation results using HomerPro show that the solar power system with a capacity of 2,150 kWp connected to the grid has the lowest LCOE index of 1,816 VND/kWh as shown in Figure 9.

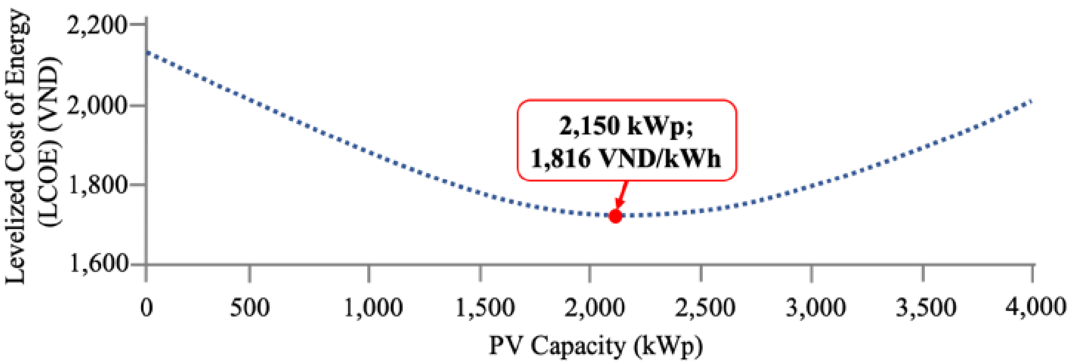


**Fig. 9. LCOE value is a function of solar rooftop power.**

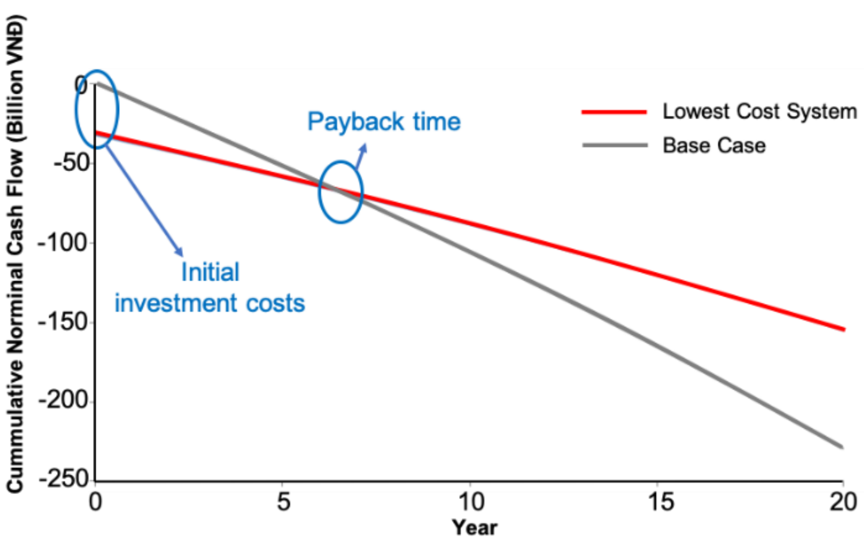


**Fig. 10. The comparison of base case (without PV system) and the case with the optimum solar power installed in 20 years.**

To see the benefits of the project, Figure 10 compares two cases: the first case is not installed PV (grey line) and the second case is installed PV with an optimal capacity of 2,150 kWp (red line). At the initial time, we need to spend money on project investment, so the red line is below year 0. After installing the solar power system, generating electricity helps reduce the amount of electricity consumed from the grid helping save some money for the factory. And the money saved from buying electricity from the national grid is accumulated until the 6th year when the savings help the factory recover its capital. Then the red line is above the gray line and the farther the distance between these two lines means the electricity savings are getting bigger and bigger compared to the base case.

### *3.2 Results and discussion for Pvsyst*

Because the factory can install and distribute PV arrays on several roofs numbered from 1 to 4, thus, in Pvsyst with input parameters as shown in Table 3, two options are chosen to calculate the electricity output and simulate shading. In option 1, all 4,784 panels are distributed on three roofs as shown in Figure 11. With this layout shading simulation is performed as shown in Figure 13 which shows that there is no issue of shadow. Besides, option 2 with the arrangement of PV arrays on roofs number 1, 2, and 4 is shown in Figure 12. In this plan, it can be seen that the azimuth angle of roof number 4 has a perpendicular direction with roof number 1 and number 2. The shading simulation results of option number 2 are shown in Figure 14.

**Table 3. Input parameters for PVsyst.**

| Parameters | Value |
|---|---|
| PV parameters | |
| Model | JA-450W |
| Power of PV | 450 W |
| Open circuit voltage ($\boldsymbol{V_{OC}}$) | 49,70 V |
| Votage at maximum power ($\boldsymbol{V_{mp}}$) | 41.52 V |
| Short circuit current ($I_{SC}$) | 11.36 A |
| Current at maximum power ($I_{mp}$) | 10.84 A |
| Hiệu suất (%) | 20.2 % |
| Inverter | |
| Model | ABB PVS100-TL |
| Maximum input voltage | 1000 V |
| Minimum input voltage | 360 V |
| Starting voltage | 420 V |
| Rated operating voltage | 620 V |
| MPP voltage range | 480-850 V |
| Number of independent MPP inputs | 6 |
| Maximum number of PVs strings on MPPT | 4 |
| AC output power | 100,000 W |
| Maximum AC output current | 145 A |
| Rated AC voltage | 400 V |
| AC voltage range | 320 – 480 V |
| Project parameters | |
| Number of PV panel in one string | 16 solar panels |
| Number of PV panel | 4784 panels |
| Number of inverter | 18 inverters |
| Number of string in one inverter | 17 string |
| Require area | 1,0668 m2 |
| Cross-section area of DC wires | 4 mm2 |
| DC wire length | 270 m |
| Cross-section area of AC wires | 70 mm2 |

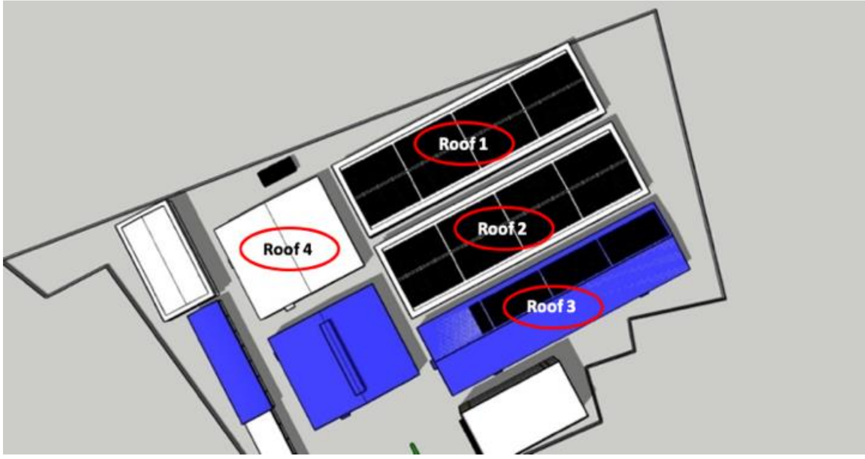


**Fig. 11. The installaion of PV panels with Option 1.**

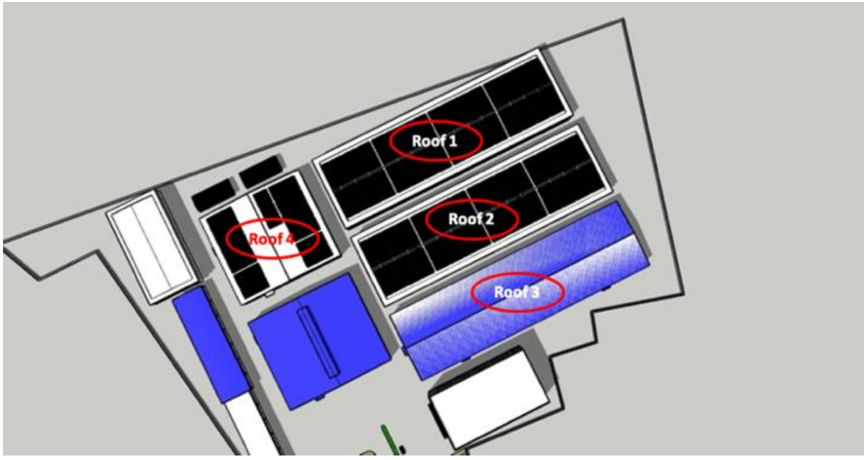


**Fig. 12. The installaion of PV panels with Option 2.**

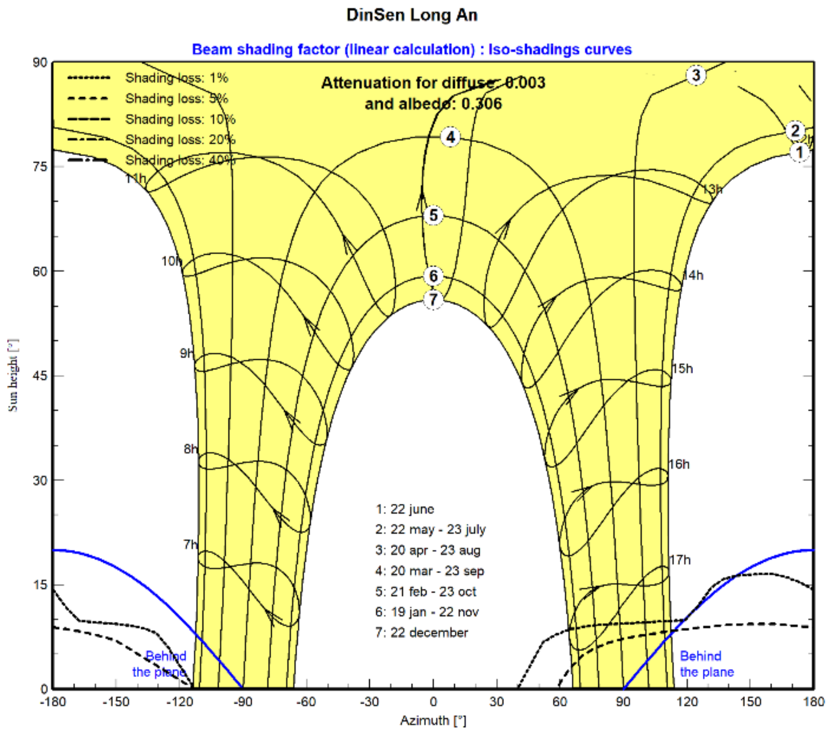


**Fig. 13. Shadow analysis in Pvsyst of Option 1.**

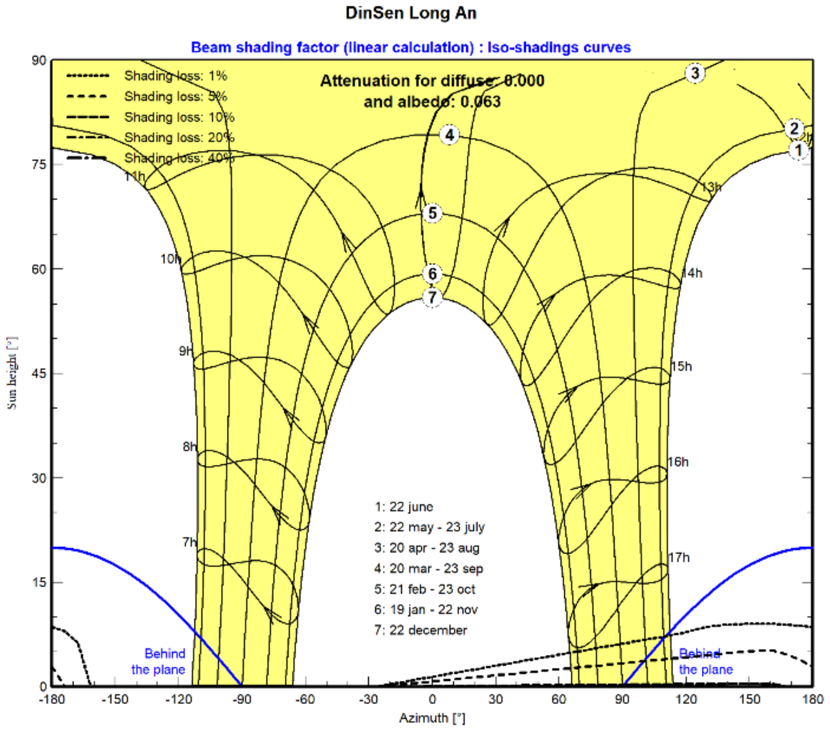


**Fig. 14. Shadow analysis in Pvsyst of Option 2.**

Through Pvsyst the energy output can be estimated. Option 1 and Option 2 have electricity energy outputs of 3,536 MWh/year and 3,542 MWh/year, respectively. The comparison between the two options illustrates the energy output value of option 1 is approximately 0.17 % lower than option 2. Although the energy output of Option 2 is higher than that of Option 1 it is not significant. Moreover, Option 2 has the aesthetics and gravity effect of the solar panels on the two roofs of building 4 quite uniform and does not affect the structure of the building leading to being reliable for a long time. Therefore, Option 2 is selected to estimate the energy output from the rooftop solar system. After that Option 2 is used to estimate the electricity energy generated from rooftop solar and the fraction of solar energy consumpted by the factory's load in HomerPro. In Option 2, the inverters are installed depending on the azimuth angles of all roofs. Based on the geometry of buildings, there are four azimuth angles for all roofs leading to the rooftop solar system being divided into four arrays named from 0 to 3 as mentioned in Figure 15.

Figure 15 presents the electricity energy output generated by rooftop solar in detail. The results show that with the installation of the solar system, the factory still needs to purchase from the grid 2,407,300 kWh/year, equivalent to 46.8% of the electricity demand of Factory loads. The remaining 53.2% of electricity demand is provided by solar systems. Furthermore, there is excessive solar energy generated, estimated at 292,780 kWh/year. Because this rooftop solar project is a grid-connected PV system with zero export, the excess electricity will be wasted energy. The addition of a battery system using Li-ion batteries to store the excess energy is a promising method.

Furthermore, to calculate the amount of $CO_2$ emissions cut due to the amount of electricity purchased from the grid being replaced by a solar power system, we use the output estimated from Pvsyst of about 2,915 MWh/year (losses taken into account) and the emission coefficient of Vietnam's power grid in 2020 which is 0.8041 $tCO_2$/MWh. Emissions cut = 2,915 MWh * 0.8041 $tCO_2$/MWh = 2,344 $tCO_2$/year if all generated energy from rooftop solar is used. The factory uses about 91 % of that amount of generated solar energy. From the calculation results, we get the amount of $CO_2$ emissions that can be reduced by using the solar power system, helping to reduce the impact of climate change and contribute to environmental protection. Moreover, If we want to use all that generated solar energy, an energy storage system is considered to integrate into the rooftop solar system.

### *3.3 Storage System*

The storage of excess energy contributes to creating a more sustainable energy system. Instead of ignoring unused energy, we can take advantage of it and reuse it when needed. This helps optimize energy use and minimize environmental impact. Table 4 shows some scenarios in which electricity generated from solar systems can be stored by using three cases of assumpted storage systems. The average excess electricity per month in Table 4 is predicted from the optimized power rooftop solar that is working with the solar radiation data for one year collected at the project site. Furthermore, rooftop solar assumes that the electricity generated reduces the following year by degradation of the system. The predicted average excess electricity is the basis parameter to estimate the capacity of the storage system. Moreover, the electricity energy stored and consumption by the Factory's load is calculated by assuming that the excess energy generated from rooftop solar is used to charge the batteries system and used to discharge to the load during peak hours time everyday.

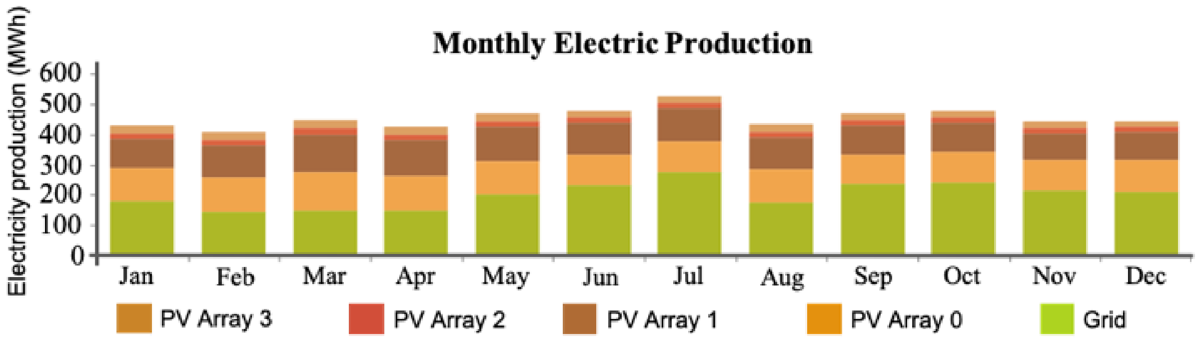


**Fig. 15. The detailed distribution of energy for load consumption of factory.**

**Table 4. Excess electricity energy (kWh) for every month of year 2022 and predicted years 2027, 2032.**

| Month | Year 2022 (kWh/year) | Predicted year 2027 (kWh/year) | Predicted year 2032 (kWh/year) |
|---|---|---|---|
| 1 | 33,705.84 | 31,832.64 | 28,328.82 |
| 2 | 31,785.68 | 29,799.94 | 27,453.91 |
| 3 | 38,671.00 | 36,215.71 | 33,345.12 |
| 4 | 39,229.31 | 36,931.86 | 35,069.03 |
| 5 | 34,195.40 | 30,923.60 | 29,033.84 |
| 6 | 25,903.61 | 23,487.17 | 21,385.03 |
| 7 | 19,529.22 | 17,419.19 | 13,979.82 |
| 8 | 27,619.60 | 25,487.91 | 21,128.74 |
| 9 | 26,908.72 | 24,730.36 | 21,999.37 |
| 10 | 19,515.19 | 18,660.58 | 17,482.52 |
| 11 | 18,074.40 | 17,511.50 | 16,839.40 |
| 12 | 18,869.87 | 17,978.18 | 16,018.65 |
| Average excess electricity/month | 28,649 | 26,636 | 24,186 |

With the current cost of the energy storage system (ESS) using Li-ion batteries, a rooftop solar power system with a capacity of 2,150 kWp and an assuming 50 kWh storage system has an LCOE energy cost of 1,829 VND/kWh. In the absence of an energy storage system, the LCOE energy cost is only 1,816 VND/kWh. Therefore, currently installing an ESS system does not bring economic benefits compared to not having an energy storage system.

Referencing the rate of decline in battery prices in the last 10 years, for example from 221 USD/kWh in 2017 to 137 USD/kWh in 2020. Therefore, it can be predicted that the cost of batteries will decrease much in the future compared to 2020 [34], [35]. Performance of simulation in HomerPro to estimate the capacity of ESS storage with different scenario cost of batteries can predict that by mid-year or late 2027, we will have the ability to install a larger rooftop solar system integrated with an ESS system with a capacity of 270 kWh with the same of LCOE value in case of 50 kWh in current time. Installing this larger-scale ESS system will help us utilize stored energy more effectively and can bring many benefits in energy supply and use. Furthermore, it is expected that by 2032, when battery prices are expected to decrease deeper compared to 2020, the LCOE energy cost is expected to be only 1,810 VND/kWh which is lower than the energy cost without an energy storage system of 1,816 VND/kWh in the current time. At that time, the installation of an ESS system with a power of 500 kW and a battery capacity of 1080 kWh is available to keep profitability positive.

### *3.4 Project Investment Plan*

When investing in solar power systems, factories, and businesses will often use loans rather than available capital due to factors related to cash flow and finance. Therefore, in this study, we will recalculate economic indicators when the investor or enterprise invests in a project with the proportion of loan capital and available capital being 70% and 30%, respectively, and with the following parameters: loan interest rates, inflation, and other factors in Vietnam.

Figure 16 shows the debt repayment plan when borrowing 70% from the bank. Green column: Represents the cash flow saved when using the PV system. According to the graph, the amount of annual savings increases over time because electricity prices increase by 1.5% each year. This shows that the PV system is actively contributing to saving electricity bills for users. Red column: Represents the amount needed to repay the loan to invest in the PV system. In the first year, the amount of money to be paid is less than in the following years because the loan policy has a "grace period". The graph also shows the dark blue line, which represents the debt service coverage ratio (DSCR) index. This index evaluates the project's ability to repay debt. If the DSCR is high, it means the project can pay off all loan interest faster and has a high profit potential. The financial parameters of the project without battery calculated are presented in Table 5. All costs of the project in detail divided following some main components listed in Table 6.

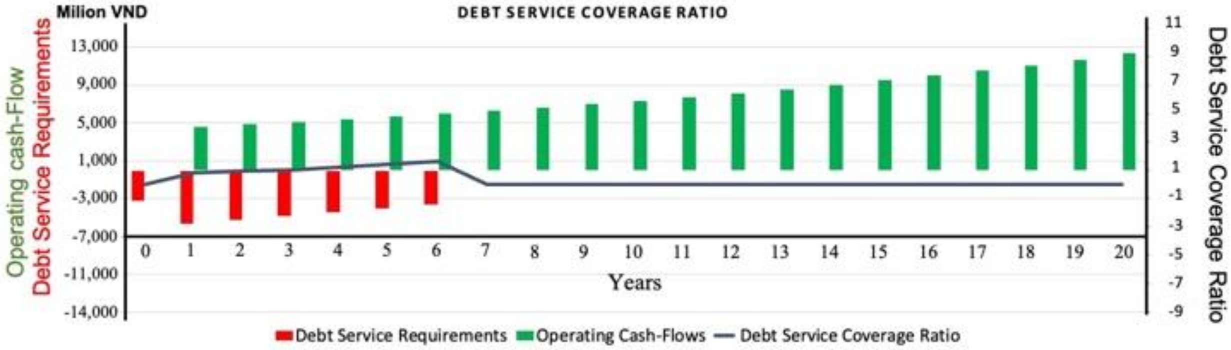


**Fig. 16. Annual debt repayment graph.**

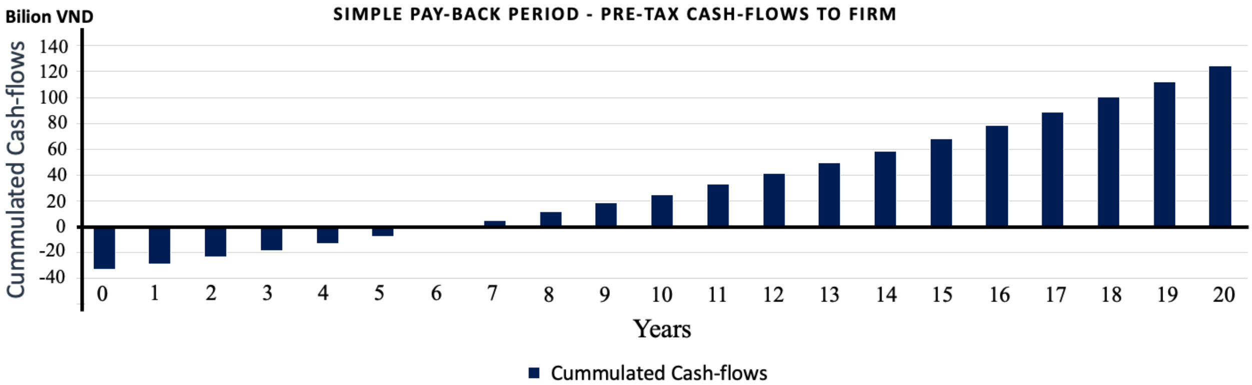


**Fig. 17. Payback period graph before tax.**

**Table 5. Financial parameters of the project without battery.**

| Parameters | Value |
|---|---|
| Total cost for the project in lifetime | 87.4 billion VND |
| Initial investment cost | 32,5 billion VND |
| IRR | 17.55 % |
| Payback time | 6.3 years |
| WACC | 15.19 % |
| NPC | 5.36 billion VND |
| Discount pay-back period | 13.91 % |
| LCOE | 2,366 VND |

**Table 6. All costs in project lifetime.**

| Name | Capital | Replacement | Operating | Total |
|---|---|---|---|---|
| Grid | 0 | 0 | 48.876 billion VND | 48.876 billion VND |
| Inverter | 4.343 million VND | 1.893 million VND | 1.826 million VND | 8.064 million VND |
| PV Module | 32.486 billion VND | 0 | 6.036 billion VND | 38.523 billion VND |
| System | 32.491 billion VND | 1.894 million VND | 54.915 billion VND | 87.408 billion VND |

By financial analysis of this project with 70 % loan capital, the results show that the total cost for the project in 20 years is 87.4 billion VND, the initial investment in year number 0 is 32.5 billion VND, the payback time is about 6.3 years, and the cumulative benefit of the project is about 120 billion VND as shown in Figure 17.

In this study, HomerPro and Pvsyst are used to estimate the output energy, therefore, the output energy from those software and real data collected from the rooftop solar installed at the site are compared to each other as shown in Figure 18. These results show that the output energy from HomerPro is quite suitable to the real data while the output energy from Pvsyst is not fit to the real data from September to December despite the total amount of energy output being closer to the real data. That result illustrates the advantage of HomerPro which can estimate the output energy following load consumption with step in one hour and following all year. Furthermore, if the parameters in HomerPro are modified reasonably, we can predict the output energy from the rooftop solar system effectively which helps to manage energy in the Factory

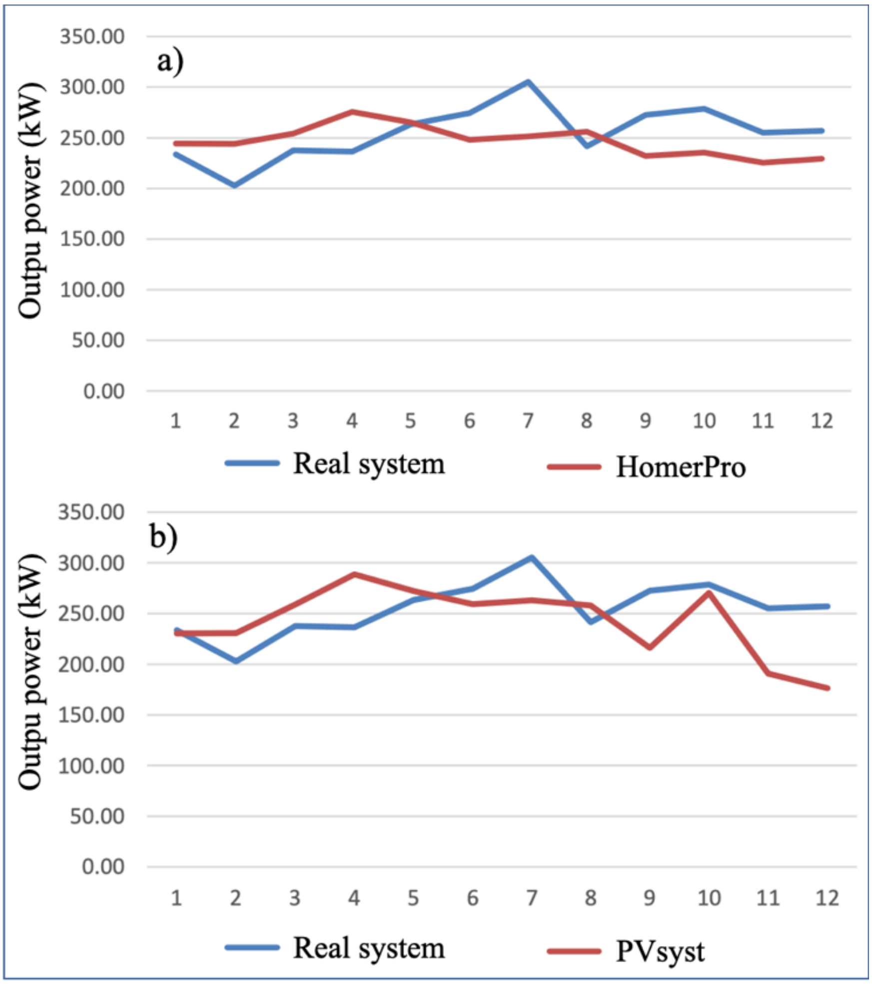


**Fig. 18. The comparison of output energy from a) HomerPro and b) Pvsyst with real data collected from installed rooftop solar system.**

## 4. CONCLUSION

In this study, the project has been analyzed and evaluated based on two factors: technical factors and economic factors.

On the technical aspect, the load data of the factory was collected and processed as a basis for determining the optimal capacity for the plant at 2,150 kWp. With the proposed capacity, the evaluation of the project's electricity output was performed using Pvsyst software. The simulation results in Pvsyst indicate that the system can generate an output of approximately 2,913 MWh per year. With this electricity output, the system can meet about 53.2% of the factory's load demand, leaving a considerable amount of excess electricity. This surplus can be stored in a battery system with a capacity of 270 kWh after 5 years and can be expanded in a 1,080 kWh battery system after 10 years still keeping profitability for the project. Moreover, thorough technical calculations were conducted to assess the feasibility of the project.

On the economic side, the project was built based on an investor scenario utilizing 30% self-funding and 70% bank loans. With a bank interest rate of approximately 12% per year based on Vietnamese conditions at the time of the survey, the project has the potential to break even within 6.3 years with an initial investment of around 32.5 billion VND. The total cost for for the project with optimized power of rooftop solar system in lifetime is about 87.4 billion VND that is used to compared with the base case without PV rooftop leading to saving more than 120 billion VND in 20 years.

Furthermore, solar projects contribute to environmental benefits by reducing greenhouse gas emissions. With this proposed project, approximately 2,344 tons of $CO_2$ can be saved per year. This demonstrates another aspect encouraging the implementation and installation of the rooftop solar system.

In the future, project expansion can proceed in the following directions: (i) Increasing Energy Storage System Capacity: Monitor the cost trends and advancements in energy storage technologies, and explore ways to enhance the energy storage system capacity to harness more solar energy efficiently. (ii) Load Management Research: Conduct a study on load management to optimize energy consumption within the factory, aiming to maximize the utilization of solar energy from the solar power system. (iii) Integration of Smart Technologies: Research the integration of smart technologies such as artificial intelligence and the Internet of Things (IoT) to improve the management and operation of the system.

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*Author Contributions*: Thanh-Tuan Pham and Tien-Dzung Tran introduced of the presented idea. Vu Thi Phuong Anh and Ha Kieu Anh handled the historic consumption data under the guide Tien-Dzung Tran. Do Quoc Am supervised the project. All authors discussed the results and contributed to the final manuscript. All authors have read and agreed to the published version of the manuscript.

*Conflicts of Interest:* The authors declare no conflict of interest.

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