Optimization Assessment of Grid-tied Wind and Solar Hybrid Power System for Industrial Factory in Vietnam

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Abstract- Currently, the transition from fossil energy to renewable energy is considered an inevitable trend to reduce greenhouse gas emissions, protect the environment and minimize dependence on fossil fuels. In Vietnam, the use of renewable energy in production and business activities for sustainable development is also increasingly interested by businesses. Installation of solar power systems and wind power systems can help companies and industrial plants directly use electricity generated by clean power sources to save electricity costs and move towards friendly solutions with the environment. In this paper, optimization study results for a typical non-fired brick factory in Quang Binh province, Vietnam show that the grid-tied wind and solar hybrid power systems in scenario 1 are considered to achieve more environmental, economic, and technical efficiency than grid-tied solar power systems in scenario 2. The optimal grid-tied hybrid power system configuration includes wind power with the capacity of 300 kW and solar power with the capacity of 1,500 kW, this system has a net present cost (NPC) of US$ 5,596,978, the cost of energy (COE) of US$ 0.0847/kWh, the investment cost of US$ 1,140,000, and operating cost of US$ 384,877.

Keywords hybrid power system, wind power, solar power, net present cost, optimization.

1. Introduction

The development of renewable energy sources is considered an inevitable trend in the world today [1], [2] due to its important contribution to limiting greenhouse gas emissions, protecting the environment, as well as reducing dependence on fossil fuels [3]. In recent years, renewable electricity has seen record global growth [4], especially solar and wind power. Solar power in 2020 reached 139 GWp and increased the total installed solar power capacity to 760 GWp. On the other hand, the global wind power market expanded to 93 GW in 2020 and raised the total installed capacity of global wind power to 743 GW [5]. The investment cost of solar and wind power project has continued to decline [6], [7] due to technological innovation, efficiency change in markets, new policies, and business models.

At present, clean energy is increasingly interested in the context of the urgent need for energy transition, many companies and industrial parks around the world have improved the use of renewable energy [8] and the roadmap towards 100% clean energy with detailed actions. The RE100 [9] initiative has spread throughout Europe, the Americas, Africa, Asia-Pacific since its launch in 2014. The research results of Emanuele Taibi et al [10] have identified the potential for renewable energy application for industrial applications and proposed the development of a detailed technology roadmap to further explore this potential. The International Energy Agency (IEA) [11] assessed that the falling investment cost of wind and solar power would open up the possibility of applying and reducing greenhouse gas emissions in the industrial sector. The United Nations Industrial Development Organization (UNIDO) [12] explored the possibility of developing clean energy through the Industrial Revolution 4.0. According to the research of Meng, Y et al [13], renewable electricity was considered one of the solutions to improve energy efficiency and sustainability in smart manufacturing plants. Prathamesh Chavan and Prashant Jain [14] conducted an extensive documentary survey on the energy consumption of India's manufacturing sector and the importance of sustainable energy to the industrial sector. The results of this study also showed that renewable energy was the only option for sustainable development of the industrial production sector. On the other hand, solar air heaters are also used for purpose of heating and drying in solar thermal applications [15].

In Vietnam, solar and grid-connected wind power projects have been developed in recent years and they are considered as a useful solution to contribute to ensuring energy security and combating climate change [16], [17]. The Government of Vietnam has issued some mechanisms, and policies to develop solar power source [18], [19], [20], and wind power source [21], [22]. However, support policies of solar power including rooftop solar power and wind power were expired [23], [24] and they are waiting for new policy mechanisms from the Government next time.

Active generation of electricity in the local area of industrial zones is needed to serve the power demand of enterprises [25] because the development of manufacturing factories is very strong and fast, especially industrial parks, processing zones, so it not only put pressure on the power companies but can also directly affect the business of investors. If there is a power cut [26] in the factory due to the lack of electricity, business and production activities will be stagnant, and the damage is not only the economy but also the reputation of the enterprise [27], [28]. Therefore, businesses in Vietnam can actively create on-site power sources by using solar power, wind power systems to reduce the cost of buying electricity from the utility grid, and can even get more profit by selling excess solar power to the utility grid, so it will reduce the burden of electricity shortage, contribute to ensuring the energy security of the factory and the region, and benefiting the business of the enterprises [29], [30].

The use of non-fired building materials in Vietnam tended to increase gradually in the period from 2016 to 2020 with the national average production growth rate of 35% while the consumption growth rate of 33%. However, the cost of self-use electricity at non-fired brick factories in Vietnam typically accounts for about 2% of the plant's annual revenue. On the other hand, existing non-fired brick plants still use all electricity purchased from the national medium voltage power grid with relatively high electricity purchase prices and emit CO_2 emissions into the environment.

Therefore, the study of the application of clean power technologies such as wind power, solar power to non-fired brick factories is very necessary to save electricity costs for the factory and contribute to reducing CO_2 emissions, creating products that meet green standards and increase competitiveness in the Vietnamese market.

Many studies are selecting renewable electricity technologies [31-36] in the world. M. Hasan et al [37] has been working on optimizing renewable power systems for the industrial sector using HOMER software. Mixed-integer linear programming was used by Scheubel et al [38] to optimize the power and heat supply system to minimize annual costs and implement energy system optimization for several companies in the German industrial sector. Schulz, J et al [39] studied on-site renewable power generation stations and optimization, simulation methods of hybrid power systems at manufacturing plants to reduce their dependence on the national utility grid. The results also showed that the optimal simulation software of the hybrid power system, including TRNSYS, orbs, Balmorel, DER-CAM, HOMER Pro, MARKAL & TIMES, Energy Plan, Top Energy.

In this paper, the research results of the optimal configuration and environmental, economic, and technical efficiency at the typical non-fired brick factory in Quang Binh province, Vietnam are calculated. Using solar power system combined with wind power can save electricity costs for the plant and contribute to creating products that meet green standards, and increase competitiveness in the Vietnamese market. The study results will contribute to determining the importance of renewable power technologies for industrial plants in general and non-fired brick factories in particular in Vietnam.

2. Methodology

In this study, the grid-tied hybrid wind and solar power system in a typical non-fired brick production plant was analyzed economically and technically by using Hybrid Optimization of Multiple Energy Resources (HOMER) software [40], [41]. This simulation program of the microgrid system is created and developed by the United State National Renewable Energy Laboratory to optimize the microgrid systems and facilitate the comparison of energy sources in the hybrid mode. HOMER program simulates a variety of system configurations, eliminates unfeasible configurations, arranges viable configurations according to total net present cost (NPC) in the process of optimization, and feasible configuration with the lowest NPC is the most optimal hybrid power system configuration [42].

The main economic and technical parameters are described by the equations in HOMER Pro as below:

Solar power capacity [43]:

$$P_{PV} = Y_{PV} f_{PV} \frac{\bar{G}_T}{\bar{G}_{T,STC}} \quad (1)$$

in which: P_{PV} is the output power of solar power (kW); Y_{PV} is the rated capacity of the solar panel (PV), which means that the solar cell capacity in the standard test conditions (kW); f_{PV} is the PV power degradation factor (%); G_T is the intensity of solar radiation on the solar panel (kW/m^2); $G_{T,\ STC}$ is the intensity of solar radiation in the standard test condition (kW/m^2);

Wind power capacity [43]:

$$P_{WTG} = \left(\frac{\rho}{\rho_0}\right) P_{WTG,STP} \quad (2)$$

in which: P_{WTG} is wind turbine capacity (kW); $P_{WTG,\ STP}$ is wind turbine power in the standard temperature and pressure (kW); ρ is the actual air density (kg/m^3); ρ_0 is the air density in the standard temperature and pressure (1.225 kg/m^3);

Net Present Cost (NPC) [44]:

$$NPC = TAC^*[(1+i)^n - 1]/[i^*[(1+i)^n] \quad (3)$$

in which: TAC is the total annual cost ($); i is the annual real interest rate (%); n is the number of years.

Cost of Energy (COE) [38]:

$$COE = TAC/E_{useful} \quad (4)$$

in which: TAC is the total annual cost ($); E_{useful} is the annual production of useful electrical energy (kWh/year).

CO_2 emissions:

HOMER multiplies the purchase amount of the real power grid (in kWh) by the pollutant emission factor (g/kWh) to calculate the emissions of each pollutant associated with the purchase of grid power. The emission factor of Vietnam's power grid is currently determined as 0.804 tCO_2/MWh [45].

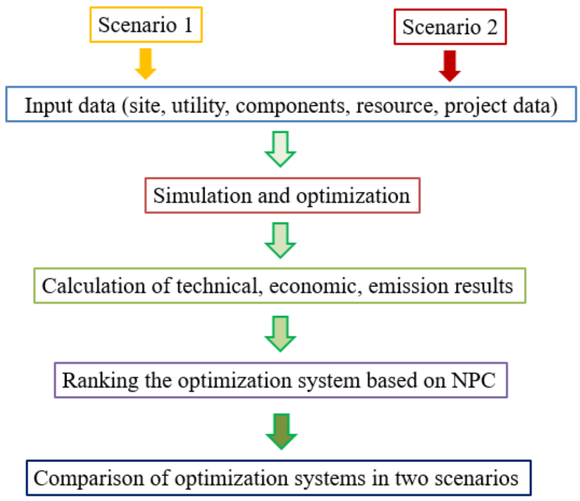

Fig 1. Optimized calculation framework for renewable power systems.

This study will simulate two scenarios using the renewable power systems at the non-fired brick factory to assess the environmental, economic, and technical efficiency of different scenarios, thereby the most feasible scenario can be evaluated. The two grid-tied renewable power scenarios are used as follows:

Scenario 1: Using the grid-tied hybrid wind and solar power system.

Scenario 2: Using only the grid-tied rooftop solar power system similar to other industrial plants applying rooftop solar power in Vietnam.

Finally, a comparison of optimization grid-tied renewable power systems between two scenarios is executed to find the best optimal scenario.

The optimization of renewable power systems at the non-fired brick factory according to two scenarios is illustrated as can be seen in Figure 1.

3. Site Selection

Fig 2. Location of the research area in Quang Binh province.

The location of the non-fired brick factory in the case study is selected in the Quang Binh province as can be seen in Figure 2. The solar energy potential and wind energy potential are determined with the help of the National Aeronautics and Space Administration (NASA) database in the HOMER Pro program. By which, the average global solar radiation in this area is about 4.55 kWh/m^2/day as shown in Figure 3, May has the highest global solar radiation value of about 5.4 kWh/m^2/day while December has the lowest global solar radiation value of about 3.4 kWh/m^2/day. The average clearness index value is about 0.45.

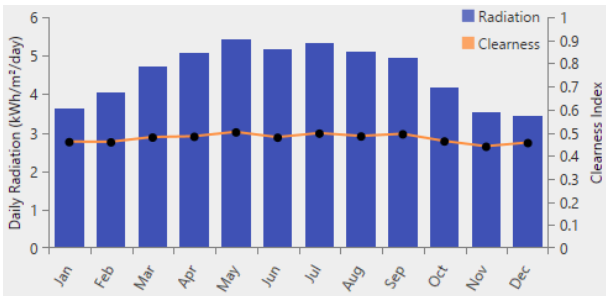

Fig 3. Global solar radiation in the project area.

On the other hand, the wind energy in this location is quite good because it is near the sea with an average annual wind speed of about 5.04 m/s as shown in Figure 4, November has the highest wind speed of 6 m/s and May has the lowest wind speed of 4 m/s.

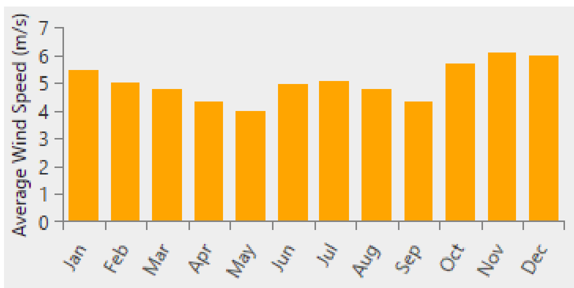

Fig 4. Wind speed at an altitude of 10m in the project area.

4. Configuration and Working Principle

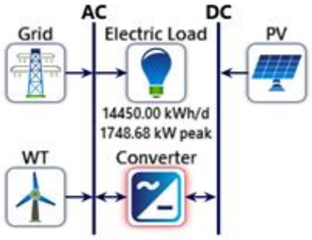

Fig 5. Proposed hybrid power system diagram.

The configuration of the grid-tied hybrid renewable energy system in the case study is described in Figure 5. The hybrid power system consists of the main components such as power grid, solar array, wind turbines, and grid-tied solar inverters. In normal operating mode, the power load will prioritize using electricity supplied from renewable power sources such as wind power and solar power. The non-fired brick factory can directly use the electricity from clean power sources, including solar and wind power to save electricity costs and contribute to environmental protection because the hybrid power system uses less electricity from fossil power sources.

The non-fired brick factory uses many large power consumption devices and works continuously all day as can be seen in Figure 6 so the daily average electricity consumption is quite high with a value of about 14,450 kWh per day. The highest load capacity is in the periods from 4:00 a.m to 10:00 a.m and from 1:00 p.m to 3:00 p.m.

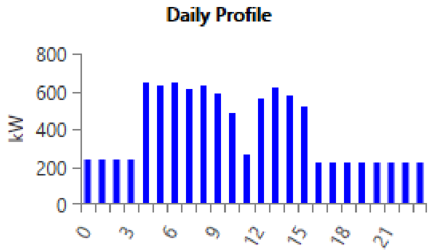

Fig 6. Daily and monthly power load profile of non-fired brick factory

Specifications of the main components in the hybrid power system are presented in Table 1, in which the capacity of solar and wind power systems will include many different values to find the optimal configuration. Solar and wind power capacity values are selected in the suitable range of the investment capability and priority to serve the main power load of the non-fired brick factory. The solar panels are installed on the roofs of the factory with a suitable slope angle.

Table 1. Input parameters for simulation

Component	Power (kW)	Life time (year)	Notes
Solar power	1000, 1100, 1200, 1300, 1400, 1500	25	Solar and wind power capacity values are selected in the suitable range of the investment capability and priority to serve the main power load of the non-fired brick factory
Wind power	100, 200, 300	10	
Utility Grid	Ensuring sufficient and continuous supply for electrical loads in the factory		Electricity purchase price: $0.077/kWh (Grid electricity price is calculated to increase by an average of 6% per year) Price of solar power: Option 1: $0.06/kWh (The price of solar power is stable throughout the project life cycle of 20 years under the power purchase contract of the power company) Option 2: $0/kWh

The purchase price of electricity from the medium-voltage power grid is calculated on average, according to the regulations of the Vietnam Electricity Corporation (EVN) [38], and this purchase price is calculated to increase by an average of 6% per year according to the annual plan of EVN. On the other hand, the FIT price of rooftop solar power is estimated by 2 options. In option 1, the FIT price is temporarily calculated of $0.06/kWh, this is a price that is expected to decrease in comparison with the old FIT price of rooftop solar power in 2020 of $0.0838/kWh [20] according to the roadmap to build the annual FIT price of renewable power of the Vietnamese Government. The FIT price of solar power is stable throughout the project life cycle of 20 years under the power purchase contract of the power company. In option 2, the Vietnamese Government does not buy the excess solar power, so the FIT price is $0/kWh.

The cost of the renewable power system in Table 2 is based on the actual cost of solar power and wind power in the market in Vietnam.

5. Study Results

5.1. Scenario 1 (Grid-Tied Hybrid Wind And Solar Power System)

Figure 7 presents the optimal configuration of hybrid renewable power system in the non-fired brick factory.

Table 2. Cost of renewable power system

Component	Investment expenses	Replacement costs	O&M expenses
Solar power	$550 $/kW	$550 $/kW	$11/kW/year
100 kW Solar Grid-tied Inverter	$5000	$5000	$100/year
100 kW wind system	$80,000	$70,000	$1,600 /year

Sellback Rate ($/kWh)	PV (kW)	WT	NPC ($)	COE ($)	Operating cost ($/yr)	Initial capital ($)
0.0600	1,500	3	$5.60M	$0.0847	$384,877	$1.14M
0	1,500	3	$5.90M	$0.0892	$410,931	$1.14M

Fig 7. The result of the most optimal configuration in scenario 1.

The simulation results in Figure 7 showed that a hybrid power system containing three wind turbines with a rated capacity of 300 kW, and the solar array capacity of 1,500 kW with the FIT price in option 1 is the most optimal configuration due to the lowest NPC cost of $5,596,978, while the COE cost of $0.0847/kWh, the investment cost of $1,140,000, and the operating cost of $384,877. Figure 8 presents the electricity production from wind turbines, solar cells, and the power grid during the year. The solar power system generates the largest electricity from April to September while the highest electricity from wind turbines from October to January next year. It is can be seen that the rate of grid power generation is 52.1%, while the rate of electricity generated from renewable power sources reaches more than 47%, of which solar power accounts for 35.4% and wind power accounts for 12.5%.

Production	kWh/yr	%
Generic flat plate PV	2,034,531	35.4
WT [100kW]	718,867	12.5
Grid Purchases	2,995,789	52.1
Total	5,749,187	100

Consumption	kWh/yr	%
AC Primary Load	5,274,250	92.4
DC Primary Load	0	0
Deferrable Load	0	0
Grid Sales	434,246	7.61
Total	5,708,496	100

Quantity	kWh/yr	%
Excess Electricity	0	0
Unmet Electric Load	0	0
Capacity Shortage	0	0

Quantity	Value	Units
Renewable Fraction	47.5	%
Max. Renew. Penetration	102	%

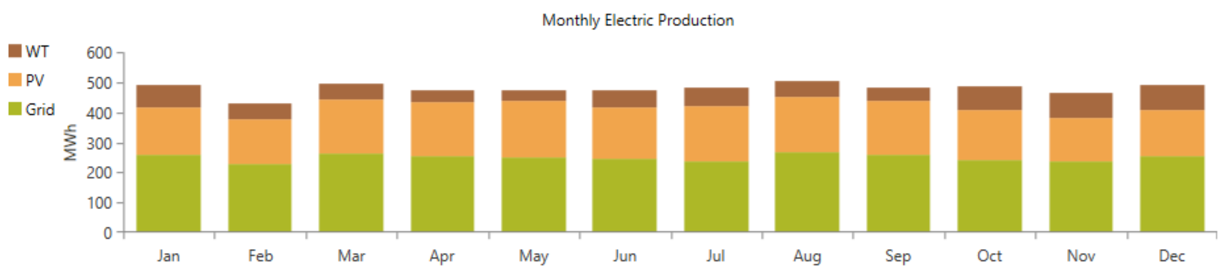

Fig 8. Electric production from the grid-tied hybrid power system.

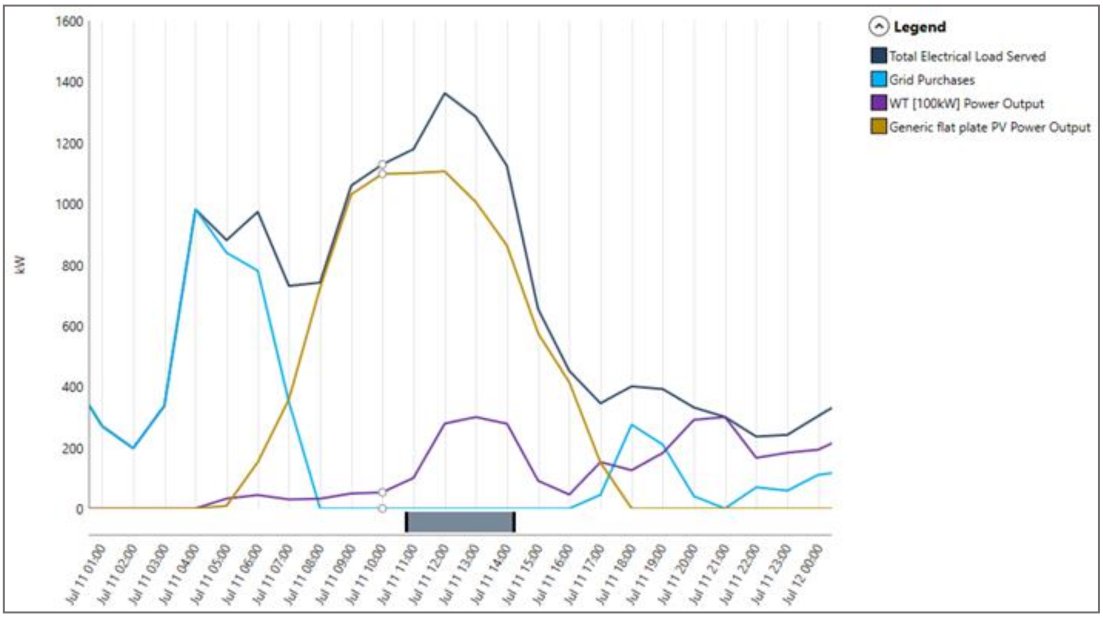

Fig 9. Typical day power generation results in scenario 1.

Figure 9 shows the results of electricity generation from power sources on the typical day of July 11. Daytime power loads mainly use electricity from solar power, and they are also added from wind power, the amount of electricity from the utility grid is quite low and only supplied at times of unfavorable weather during the day to ensure the largest rate of renewable power generation. Meanwhile, the night power load uses a lot of grid power, a small part is supplied by wind power when wind conditions are favorable. Therefore, scenario 1 shows a fairly flexible combination of wind power and solar power in the process of supplying renewable electricity to serve the electricity consumption demand for working in the factory and minimize the proportion of grid power from fossil power sources.

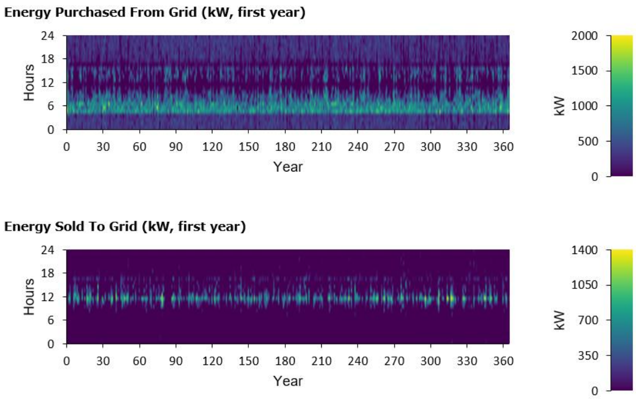

Fig 10. Electricity purchase and sale of solar power.

Figure 10 illustrates the statistical results of the frequency of buying and selling solar power to the utility grid during the year of the hybrid power system. It can be seen that the power grid provides electricity to serve the factory load mainly from 4:00 a.m to 8:00 a.m due to the highest capacity of the factory's load and there is not much sun and wind to run wind and solar power equipment during this period. On the other hand, the frequency of solar power sales to the utility grid during the year is concentrated at around noon when solar energy generation capacity is highest and the factory's load capacity is lowest during the day. At many times of the year, another part of the excess solar power can be sold to the utility grid with the help of the generation of electricity from wind turbines for load-serving in the good wind conditions during the day, so it will increase the profitability for the investor.

The results of the environmental analysis presented that the use of hybrid wind and solar power system has reduced the use of grid power and the non-fired brick factory only emits CO_2 emission of about 2.400.000 kg/year to the environment, thus contributing to reducing the environmental pollution.

5.2. Scenario 2 (Grid-Tied Rooftop Solar Power System)

In scenario 2, the calculation result in Figure 11 shows that the grid-connected solar power system capacity of 1,500 kW with the FIT price in option 1 is the most optimal configuration due to the minimum NPC cost of $6,122,231, while the COE cost is about $0.0951/kWh, the investment cost of $900,000, the operating cost of $450,959.

Sellback Rate ($/kWh)				PV (kW)	NPC ($)	COE ($)	Operating cost ($/yr)	Initial capital ($)
0.0600				1,500	$6.12M	$0.0951	$450,959	$900,000
0				1,500	$6.32M	$0.0982	$468,191	$900,000

Fig 11. The result of the most optimal configuration in scenario 2.

Production	kWh/yr	%
Generic flat plate PV	2,034,531	36.3
Grid Purchases	3,567,604	63.7
Total	5,602,135	100

Consumption	kWh/yr	%
AC Primary Load	5,274,250	94.8
DC Primary Load	0	0
Deferrable Load	0	0
Grid Sales	287,194	5.16
Total	5,561,444	100

Quantity	kWh/yr	%
Excess Electricity	0	0
Unmet Electric Load	0	0
Capacity Shortage	0	0

Quantity	Value	Units
Renewable Fraction	35.9	%
Max. Renew. Penetration	102	%

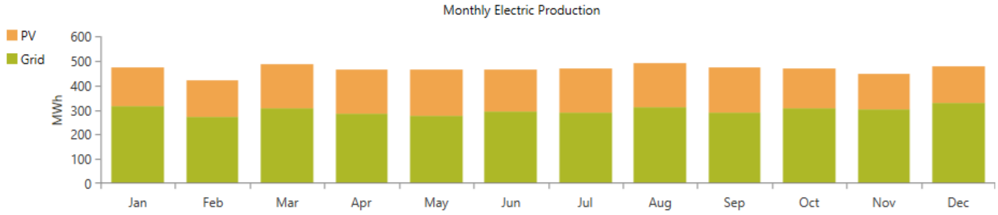

Fig 12. Electric production from the grid-tied rooftop solar power system.

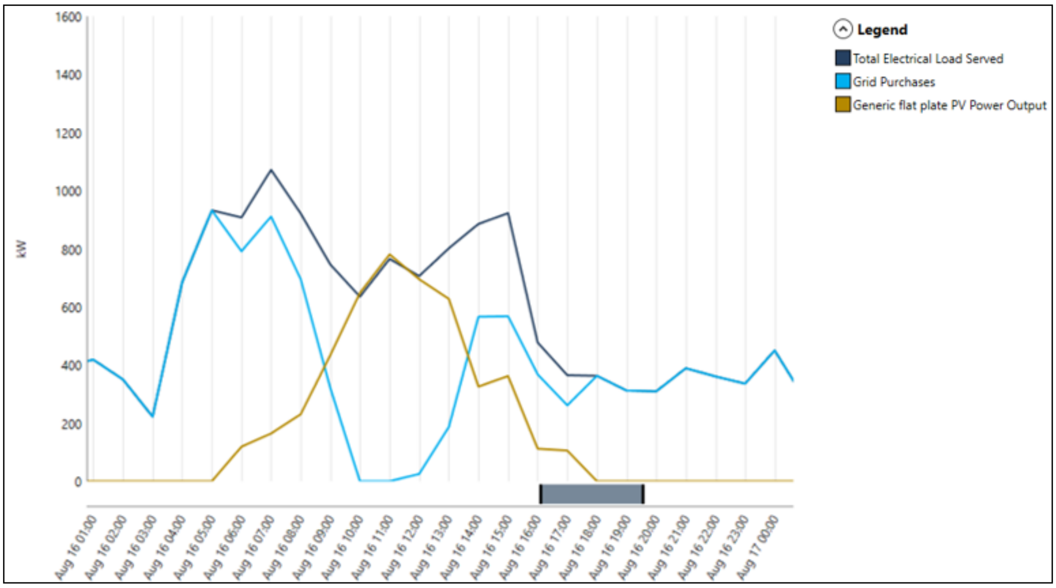

Fig 13. Typical day power generation results in scenario 2.

The amount of electricity generated from solar cells and the power grid during the year is presented in Figure 12. In which, the power generation rate of the utility grid is 63.7%, while the rate of electricity generated from solar power sources reaches 36.3%. The solar power system supplies an amount of electricity of 2,034,531 kWh to serve the power demand in the factory, while the amount of excess solar power sold to the local grid of 287,194 kWh per year. The power grid in this scenario will provide 3,567,604 kWh/year to ensure the stable operation of the factory, without power outages during the year.

Figure 13 describes the results of electricity generation from power sources on the typical day of August 16. Daytime power load prioritizes the use of electricity from solar power, the missing part is further supported from the utility grid at times with unfavorable weather during the day to ensure stable operation of the power load. Meanwhile, the night power load operation uses the entire power grid. The result of environmental analysis also presented that the factory emits CO_2 emissions of about 2,868,354 kg/year to the environment due to the use of rooftop solar power system.

6. Discussion

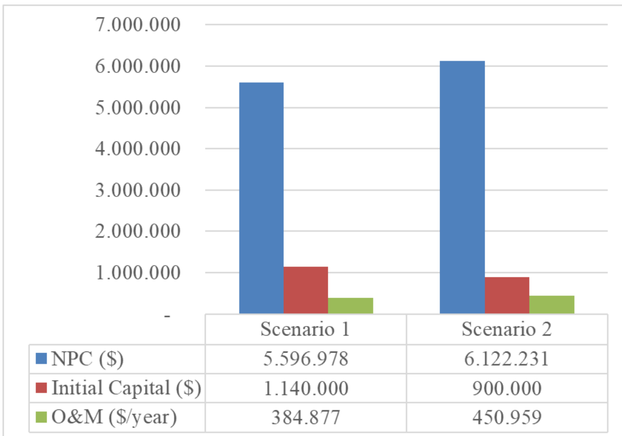

Fig 14. The comparison results of the economic factors of the two scenarios.

The comparison results of the economic factors in the two scenarios are shown in Figure 14. The grid-tied hybrid

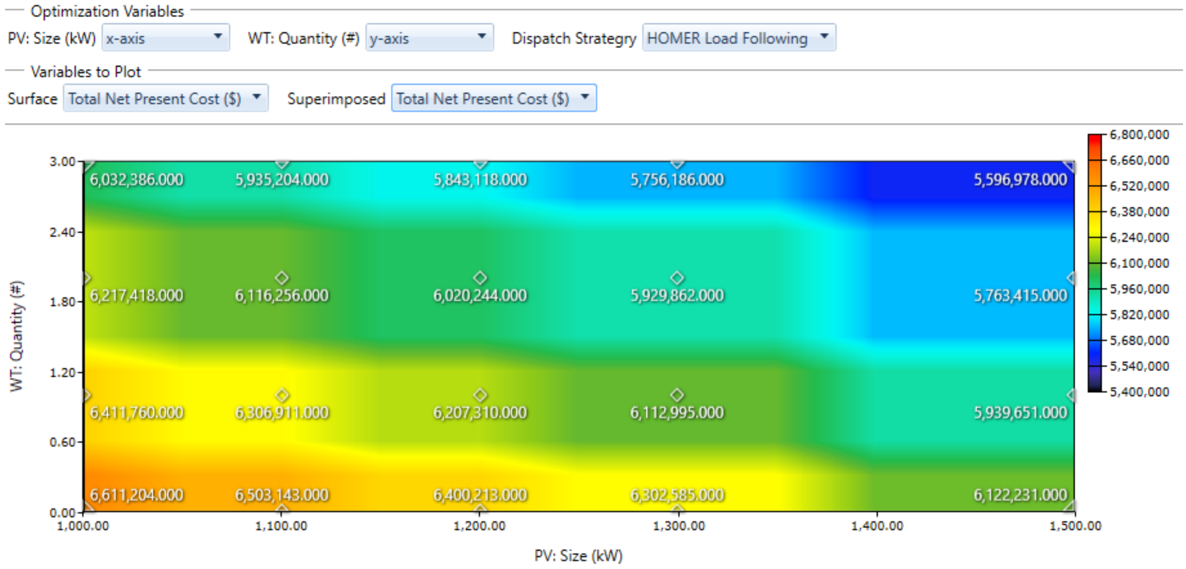

Fig 15. Analysis of optimal configuration of the renewable power system.

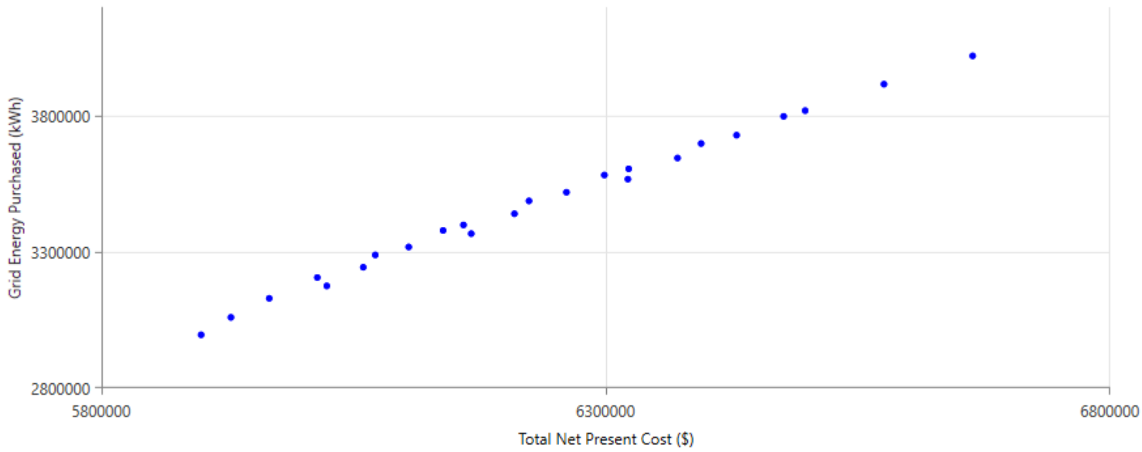

Fig 16. The relationship between the amount of electricity purchased from the grid and the total net present cost.

power system in scenario 1 has a higher initial investment cost, but a lower O&M cost and gets more benefits thanks to more solar power sold to the grid and fewer grid purchases, so scenario 1 will achieve a more optimal configuration because of the lower NPC and COE costs.

Figure 15 illustrates the results of the analysis of the optimal configuration of the renewable power system in two scenarios based on the NPC cost. The axes of the graph showing the sensitivity variables are the number of wind turbines from one to three wind turbines with the capacity of 100 kW per turbine and the solar array with the capacity from 1000 kW to 1500 kW. The HOMER program uses two-way linear interpolation to determine the optimal system. The darker blue color of the graph shows that the system has the best optimal configuration, and the configuration of the hybrid power system with three 100 kW wind turbines and the solar panel capacity of 1500 kW in scenario 1 is determined to be the most optimal because of the lowest NPC cost in comparison of the dark green configuration with the only solar power of 1,500 kW in scenario 2. Besides, the dark orange configuration with the least solar power capacity and no wind turbine will have the highest NPC cost, so it is the lowest optimal result.

The relationship between the amount of electricity purchased from the utility grid and the total net present cost is shown in Figure 16. Buying as much electricity from the utility grid will increase the total net current cost and reduce the optimal capability of the renewable power system.

Figure 17 presents the relationship between the price of solar electricity sold to the utility grid and the NPC. The study results show that the feasibility of hybrid power projects is greatly affected by the selling price of solar power to the grid. The lower the selling price of solar power, the higher the NPC, and decrease the optimal capability of the hybrid power system.

The result of the reduction in greenhouse gas emissions in Figure 18 presents that the use of renewable power systems can decrease greenhouse gas emissions, but the emissions depend on the proportion of renewable electricity for the factory’s load. The rate of renewable electricity in scenario 1 is about 11.6 % higher than scenario 2, so it can

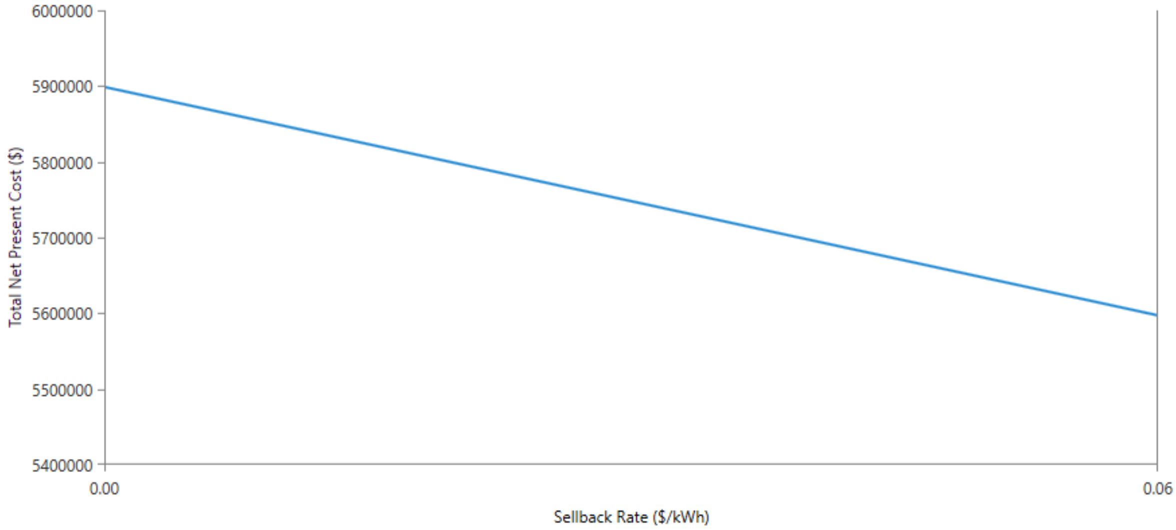

Fig 17. The relationship between the price of solar power and the total net present cost.

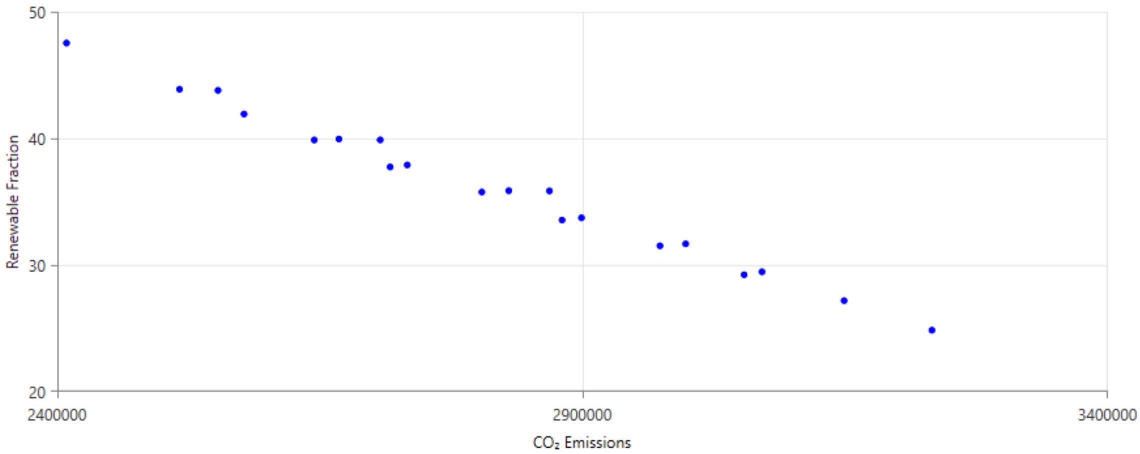

Fig 18. Results of reduction in greenhouse gas emissions.

help the non-fired brick factory emits less CO_2 emissions of about 468,354 kg per year to the environment due to reducing electricity generated from the medium voltage power grid.

7. Conclusion

In this paper, the optimization study results of the grid-tied renewable power system in the typical non-fired brick factory in Quang Binh province, Vietnam were calculated. The grid-tied wind and solar hybrid power systems in scenario 1 are considered to bring more environmental, economic, and technical efficiency than grid-tied solar power systems in scenario 2. The optimal hybrid power system configuration includes wind power with the capacity of 300 kW and solar power capacity of 1,500 kW with the FIT price in option 1, the system has the NPC of $5,596,978, the COE of about $0.0847/kWh, the investment cost of $1,140,000, and the operating cost of $384,877. Installation of too small renewable power capacity will cause the factory's investor to buy as much electricity from the utility grid and increase the increase the total net present cost, which should reduce the optimal capability of the renewable power system. On the other hand, using a renewable power system will also help the factory reduce greenhouse gas emissions, but emissions depend on the proportion of renewable electricity for the factory's load. The rate of renewable electricity from grid-tied hybrid wind and solar power system in scenario 1 is about 11.6 % higher than grid-tied solar power system in scenario 2, so it can help the factory emits less CO_2 emissions of about 468,354 kg per year to the environment due to decreasing electricity generated from the utility grid.

Thus, the use of hybrid wind and solar power systems can save electricity costs for the non-fired brick factory and contribute to creating products that meet green standards, increasing competitiveness in the Vietnamese market. The research results can contribute to determining the importance of applying renewable electricity technologies to industrial plants in general and non-fired brick factories in particular in Vietnam.

Acknowledgments

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