

Optimal Simulation and Comparative Analysis of Solar and Wind Hybrid Power System: Case study of a Hostel in Da Nang City, Vietnam

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Abstract- In Vietnam, many localities have plans to combine renewable energy (RE) with tourism development. Moreover, using a hybrid wind-solar power system can help maximize efficiency in supplying power to consumer units, maintaining quality and reliability, and meeting load demand. Tourist locations such as hotels in Vietnam in general and Da Nang city in particular are also considered to be areas that consume a lot of energy. However, there is currently no detailed research on the application capability of hybrid wind-solar power systems in tourist areas in Vietnam. The article analyzed the optimal simulation results of hybrid energy systems at typical hostels in Da Nang city. Study results present that the selected hybrid power system configuration has net present cost (NPC) of 150,401 \$, cost of electricity (COE) of 0.16 \$ per kWh, operating costs are 10,142 \$, and an investment cost of 11,600 \$. The hybrid wind-solar power system in configuration 1 has the larger investment cost of 6000 \$, but it has the smaller O&M cost of 508 \$ and achieves better profits than rooftop solar power in configuration 2 thanks to higher output. Renewable electricity supplies more load and buys less grid power, so optimal configuration 1 is better than configuration 2 because it has a smaller NPC and O&M cost. The NPC cost of configuration 1 is 950 \$ higher than configuration 2. The hybrid power system generates about 2,303 kg/year (~5.48%) less CO₂ into the environment because it reduces the use of grid electricity.

Keywords solar power, wind power, hybrid power system, utility grid.

1. Introduction

Currently, RE [1] is also developed to reduce greenhouse gas emissions, combat climate change, and minimize dependence on traditional energy sources. Thus, countries on the world have pioneered the selection of clean power [2], even offering a specific roadmap towards using 100% RE. In which, wind and solar energy are increasingly used and are becoming cost-competitive alternatives to fossil energy sources [3]. However, the working performance of wind and solar power systems is not high because they are greatly affected by weather and environmental conditions [4].

Hybrid power systems [5,6] include 2 or more power sources for generating electricity such as wind power, PV power, natural gas, diesel, and biofuels to supply sustainable power to the load. Using all on-site power sources can help achieve maximum efficiency in supplying energy to consumers, maintaining quality and reliability, and powering loads [7]. Optimal configuration and the technical economic data of hybrid power systems are two very important issues that must be considered when evaluating the effectiveness of this system.

Tourism has become a large economic sector in the world [8]. Therefore, providing stable energy and using green electricity for tourist areas, hotels, and hostels is also a

topic of research and development in recent years [9]. The application of HOMER software can optimally analyze the structure and capacity of hybrid renewable energy system (HRES) for tourist areas. The study [10] investigated the feasibility of a renewable power station, including photovoltaic (PV), small wind power, and CHP, for a hotel in Amsterdam with the help of the HOMER program. The Hotel Marcel microgrid [11], modeled with HOMER Grid software, will protect the building from power outages while reducing energy costs and carbon emissions. Hotel Marcel's microgrid includes 457 kW of solar photovoltaic power mounted on the roof and in the parking lot. Suzan Abdelhady et al. [12] analyzed the calculation results of a HRES for a hotel in Egypt from technical, economic, and environmental perspectives. The study results show that the power system, including a 143 kW solar module and a 20 kW wind turbine, has the best NPC and LCOE. According to the research of Önder Güler et al. [13], the optimization of a hybrid system under 4 different scenarios for the electrical energy needs of medium-sized hotels in the Mediterranean region of Turkey was analyzed using the HOMER program.

Vietnam has large development potential for renewable power to achieve 30% of installed electricity capacity from RE by 2045, according to National Power Plan VIII, of which solar power and wind power account for 14% and 10%, respectively [14]. At present, urban areas in Vietnam are developing mainly grid-tied rooftop solar power stations [15,16]. However, the old support policy [17,18] for solar power ended while the new support policy has not yet been released, so solar power cannot be accepted to generate excess electricity to the utility grid. On the other hand, small-scale wind power projects providing electricity to city areas have not received adequate attention.

In recent years, Vietnamese tourism has been developing, and the number of international visitors as well as domestic tourists is increasing, with 12.6 million international visitors to Vietnam in 2023 [19]. Vietnamese tourism is becoming increasingly known around the world, and many domestic destinations, including Da Nang city, are voted as favorite addresses of international tourists. In the current context, developing Vietnamese tourism in association with protecting natural resources and the environment, and preserving and promoting national cultural values, is an urgent requirement to promote sustainable development [20] of the tourism industry and the socio-economy.

Tourist areas such as hotels and hostels in Vietnam in general and Da Nang in particular are also considered to consume a lot of energy [21]. Tuan et al [22] showed that the higher the hotel rating (star level) in Da Nang city, the greater the energy consumption rate, with an overall average of 87.4 kWh/m²/year or 8,628.6 kWh/bedroom/year. Besides, hybrid wind and solar power systems in Vietnam have not been fully and scientifically evaluated for tourist areas such as hotels, resorts, and hostels. There is currently no detailed research on the application capability of hybrid wind-solar electricity systems in tourist areas in Vietnam.

This paper analyzes the technical, economic, and environmental effectiveness of HRES with PV and wind power for a hostel towards low greenhouse gas emissions in Da Nang city, Vietnam. The research results can be referenced to consider applying hybrid renewable power system to other tourist areas in Vietnam.

2. Methodology

HOMER [23,24] is one of the best specialized software programs for designing microgrids. This program is used to model and optimize HRES [25]. HOMER can analyze energy production sources such as batteries, reformers, flywheels, hydrogen reservoirs, and other control and consumption systems involved in the energy supply process, including solar energy and wind energy. This study uses the HOMER program to select the optimal HRES configuration, including rooftop solar power and wind turbines, for the local load of a typical hostel based on minimum net present cost (NPC). The study method has a process as follows:

- Collecting data of solar and wind energy potential of hostel case study in Danang city, general HRES configuration (small-scale rooftop PV with or without small wind turbine), and related costs.

- HOMER software is used to optimize the HRES configurations based on the lowest NPC.

- Determining the feasible configuration for HRES investment. HOMER software automatically determines the optimal HRES configuration with or without a wind turbine.

The power from the wind turbine and solar panel is calculated by the following equations [26]:

Wind power:

$$P_w = \frac{1}{2} \rho A_w V^3 \quad (2)$$

where: ρ is the air density (kg/m³); A_w is the swept wind turbine blade area (m²); V is wind speed (m/s).

Solar power:

$$P_s = I_{ns}(t) * A_s * Eff(pv) \quad (3)$$

where: $I_{ns}(t)$ is the radiation level on time t (kW/m²); A_s is the area of the solar panel (m²); $Eff(pv)$ is the total performance of solar panel (%).

The overall performance of solar power [26]:

$$Eff(pv) = H * PR \quad (4)$$

where: PR is the performance ratio (%); H is the average global horizontal radiation on solar panel per day (kWh/m²/day).

Net present cost (NPC) [26]:

$$NPC = \sum_{t=0}^n \frac{CF_t}{(1+r)^t} = \sum_{t=0}^n \frac{B_t - C_t}{(1+r)^t} \quad (5)$$

where: CF_t is cash flow value at the end of year t (\$); B_t is benefits or income of the year t (\$); C_t is cost in year t (\$);

N is project implementation time (year); r is discount rate (%).

Levelized cost of electricity (LCOE) [26]:

$$LCOE = \frac{\sum_{t=0}^n \frac{(I_t + M_t + F_t)}{(1+r)^t}}{\sum_{t=0}^n \frac{E_t}{(1+r)^t}} \quad (6)$$

where: I_t is investment expenditure during the year t (\$); M_t is the operating and maintenance costs during the year t (\$); F_t is the fuel cost for the year t (\$); E_t is electricity supplied during the year t (kW); r is discount rate (%); n is life-time of whole system (year).

3. Site selection

3.1. Study location

A hybrid solar wind power system is used to serve the local loads in a typical hostel in Da Nang city, Vietnam. Da Nang is the central and largest coastal city of the Central region, as shown in Figure 1, and the climate in this city has a rainy season from September to December and a dry season from January to August.

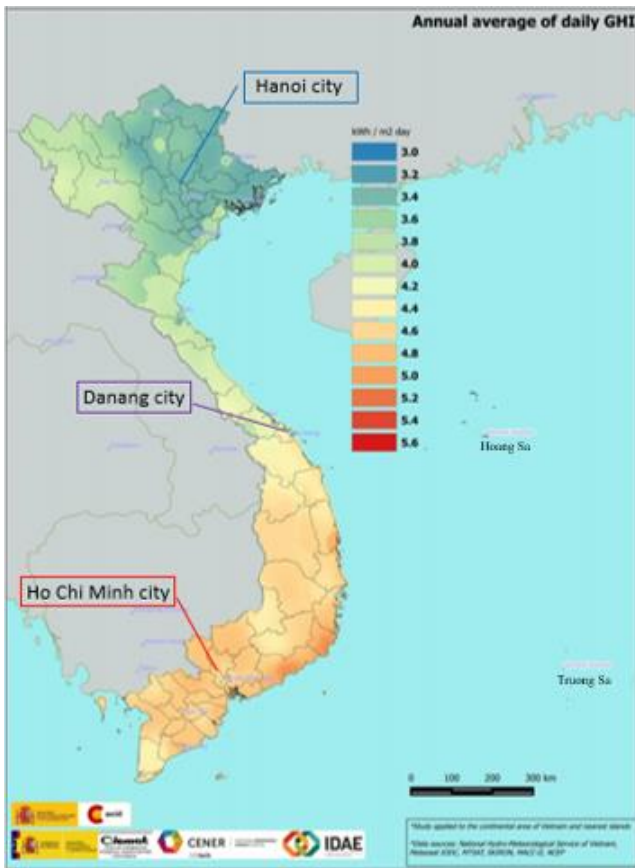
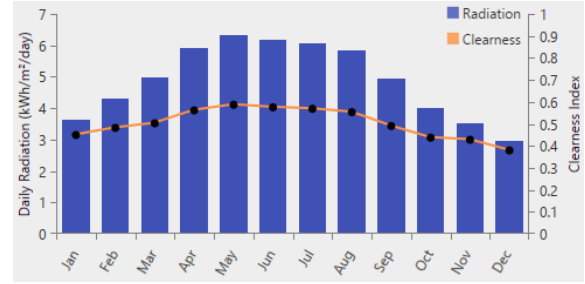
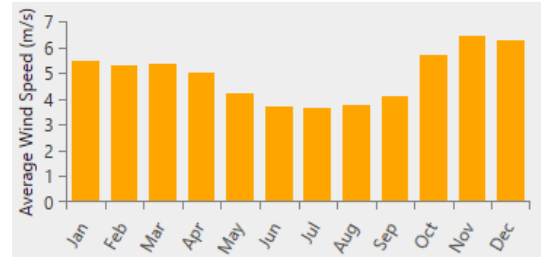


Fig 1. Solar irradiation map of Vietnam [29].



a. Solar irradiation



b. Wind speed

Fig 2. Solar irradiation (a) and wind speed data (b) of case study location.

The National Aeronautics and Space Administration (NASA) of the USA uses satellite systems to provide data to study climate processes and predict worldwide energy resources, including solar irradiation, temperature, wind speed, and direction. NASA data has been used in many countries around the world to develop RE projects [27,28].

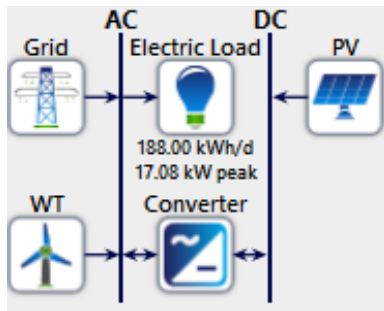
Wind speed and solar irradiation data for the case study locations shown in Figure 2 were collected from NASA data in HOMER software. The average annual solar radiation value and wind speed value of Da Nang city are 4.89 kWh/m²/day and 4.91 m/s, respectively.

3.2. Simulation data

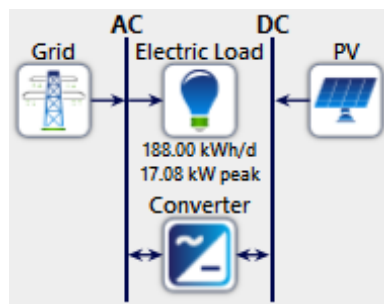
The hostel in this study serves budget guests and has 12 bedrooms. Hostel electrical loads mainly include lights, fans, air conditioners, televisions, elevators, computers, servers, water heaters, and pumps. The mean power consumption during daytime is about 188 kWh/day, while the maximum load capacity is approximately 17 kW, as presented in Figure 3. The load operates all hours of the day, with the maximum load capacity from 19:00 to 22:00, while the period from 0:00 to 3:00 is the lowest value.



Fig 3. Daily electrical load chart



a. Configuration 1 (wind-solar hybrid power system)



b. Configuration 2 (rooftop solar power system)

Fig 4. Diagram for study scenarios.

Grid-connected hybrid power system configurations of this study are depicted in Figure 4. Two configurations are simulated to supply electricity to the load of the hostel and evaluate the economic, technical, and environmental effectiveness of different scenarios:

Configuration 1: wind-solar hybrid power system.

Configuration 2: rooftop solar power system.

The wind-solar hybrid power system includes PV panels, wind turbines, power grid, and on-grid solar inverters. In good climate conditions, solar and wind energy sources supply electricity to serve the load demand. This enables facilities to use clean electricity from wind and solar power sources to reduce electricity costs and protect the environment by reducing reliance on fossil power sources. In unfavorable weather conditions, the load will use additional electricity from the utility grid to ensure stable operation. Table 1 illustrates the simulation input data of the wind and solar power system with various values to select the best configuration. The capacity values of the wind turbine and solar array are chosen within a consistent range of investment cost and installation area on the hostel's roof.

Table 1. Input data

Component	Capacity (kW)	Life time (year)	Notes
Solar power	5, 6, 7, 8	20	HOMER software will automatically determine the most optimal system configuration with or without wind turbine
Wind turbine	0, 1, 2, 3	20	
Grid-tied solar inverter	8	10	

System costs in Table 2 are selected according to the average cost of the equipment market of PV, and wind power in Vietnam and the international market. On the other hand, the average grid electricity purchase price is 0.12 \$/kWh, taking into account a 5% annual electricity price increase over 20 years. Currently, the support policy for solar and wind energy in Vietnam has ended, and there is no new policy, so PV and wind turbines cannot transmit excess electricity to the utility grid, and the selling price to the utility grid is zero.

Table 2. System costs [25]

Component	Investment expenses	Replacement costs	O&M expenses
PV	550 \$/kW	500 \$/kW	20 \$/year
Wind turbine	2000 \$/kW	1500 \$/kW	20 \$/year
Grid-tied solar inverter	150 \$/kW	110 \$/kW	10 \$/year

4. Study Results

4.1. Configuration 1 (wind-solar hybrid power system)

Figure 5 shows that the hybrid wind (3 kW) and solar (8 kW) power system is the most optimal configuration because this system has the lowest NPC of 150,401 \$, while COE is 0.16 \$/kWh, investment cost is 11,600 \$, and O&M cost is 10,142 \$.

Architecture								Cost				System
			PV (kW)	WT	Grid (kW)	Converter (kW)	Dispatch	NPC (\$)	COE (\$)	Operating cost (\$/yr)	Initial capital (\$)	CO ₂ (kg/yr)
			8.00	3	999,999	8.00	CC	\$150,401	\$0.160	\$10,142	\$11,600	39,748

Fig 5. Optimization result of configuration 1

Figure 6 presents the electricity generation results from hybrid power system of configuration 1. The ratio of electricity of the utility grid is 78.7% and the ratio of electricity generated by PV and wind turbine accounts for 16.6% and 4.68%, respectively. Generating renewable electricity at a rate of 20.6% has contributed to saving the hostel's electricity costs.

The hybrid renewable power system transmits 68,620 kWh/year of electricity to serve the hostel's electricity needs (accounting for 99.9%), while the amount of excess renewable electricity is only 100 kWh/year (accounting for

0.1%), which is suited to current policy of the Vietnamese government to develop renewable power sources for self-consumption.

Figure 7 presents the electricity supply operation result of a typical day on December 2. The electricity load in the daytime uses most of solar power from 5:00 to 17:30, and is also supplemented by grid electricity. The amount of wind power provided during the day is quite good from 7:00 to 18:00.

Production	kWh/yr	%
PV	11,489	16.6
WT	3,245	4.68
Grid Purchases	54,561	78.7
Total	69,295	100

Consumption	kWh/yr	%
AC Primary Load	68,620	99.9
DC Primary Load	0	0
Deferrable Load	0	0
Grid Sales	100	0.146
Total	68,720	100

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

Quantity	Value	Units
Renewable Fraction	20.6	%
Max. Renew. Penetration	105	%

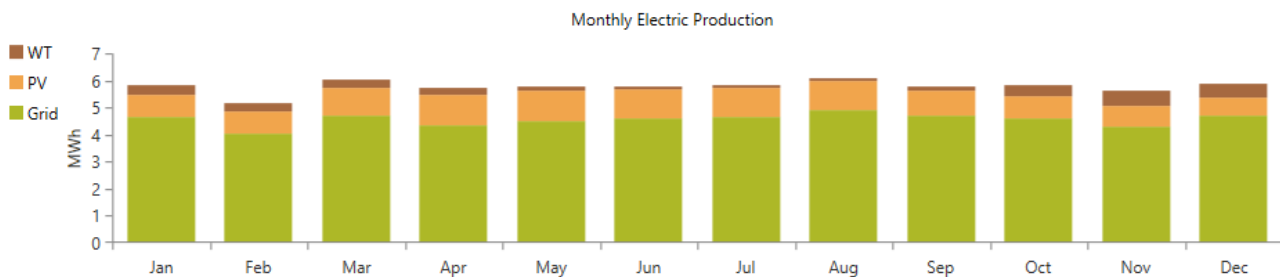


Fig 6. Simulation results from hybrid power system of configuration 1

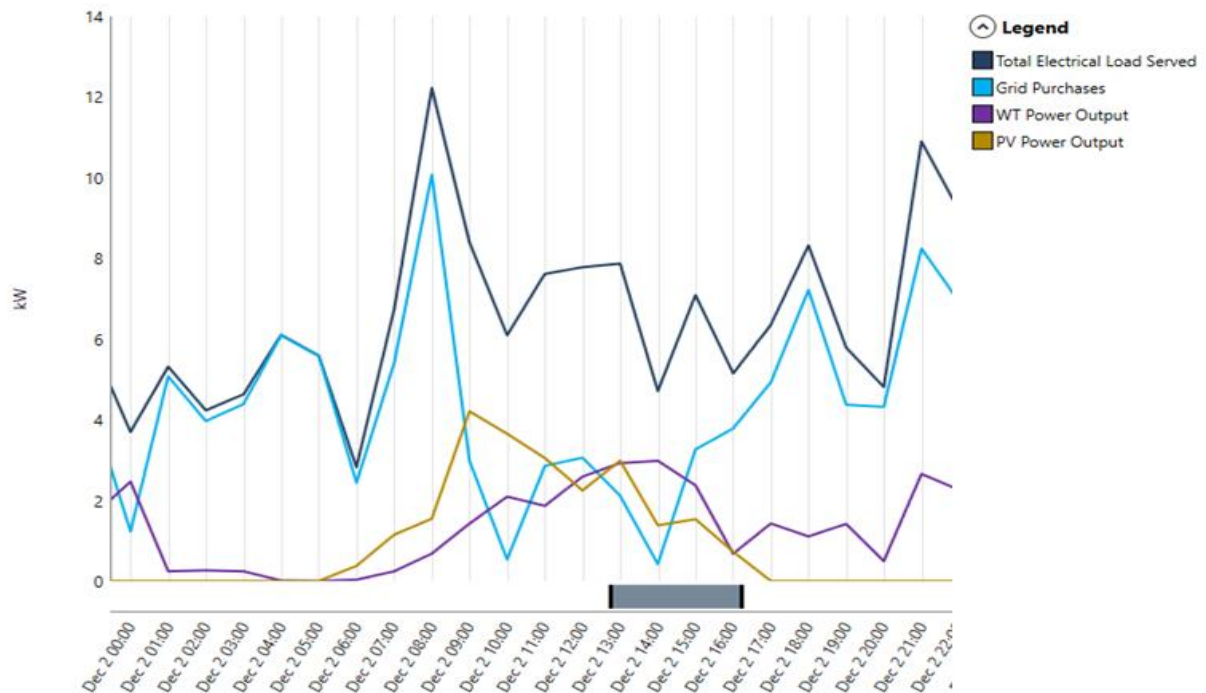


Fig 7. Power supply operation result of a typical day in configuration 1

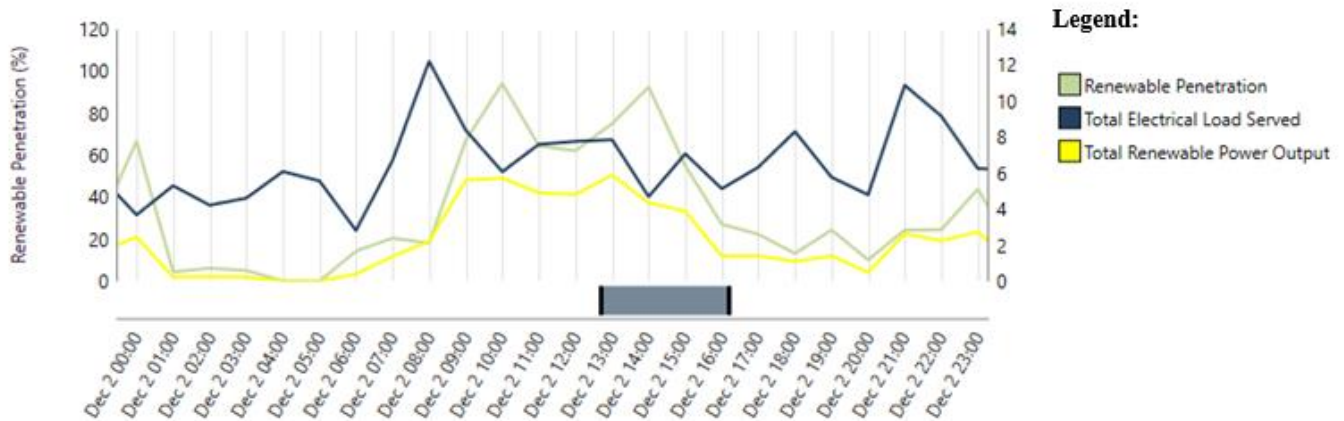


Fig 8. The largest proportion of power generation in configuration 1

Architecture							Cost				System
    	PV (kW)	WT	Grid (kW)	Converter (kW)	Dispatch		NPC (\$)	COE (\$)	Operating cost (\$/yr)	Initial capital (\$)	CO ₂ (kg/yr)
    	8.00		999,999	8.00	CC		\$151,351	\$0.161	\$10,650	\$5,600	42,051

Fig 9. Optimization result of configuration 2

The largest proportion of renewable generation serving the load in the system during the day is 94.2% at 10:00 as shown in Figure 8. Meanwhile, the load in the evening is served mainly by grid electricity, with a small portion of additional power from wind power provided from 18:00 to 23:00 under suitable weather conditions. Therefore, configuration 1 presents a suitable wind-solar hybrid power system for supplying the hostel's load needs while minimizing reliance on grid electricity from fossil fuels.

Environmental analysis results show that using a hybrid solar wind energy configuration has decreased the electricity from the power grid and has helped the hostel reduce CO₂ emissions and only emit about 39,748 kg per year to the environment, which contributes to minimizing environmental pollution.

4.2. Configuration 2 (rooftop solar power system)

In Figure 9, the simulation results show that the rooftop PV system with a solar panel capacity of 8 kW is the best configuration because it has the lowest NPC of 151,351 \$, COE is 0.161 \$/kWh, operating cost is 10,650 \$, and investment cost is 5,600 \$.

Environmental simulation results show that the hostel emits only about 42,051 kg/year of CO₂ in configuration 2 using rooftop PV power.

Figure 10 presents the electricity output per year produced from PV and utility grid. In which, ratio of electricity generated from the utility grid and PV power is 83.4% and 16.6%, respectively. The PV system generates 11,489 kWh/year of electricity to serve the hostel's electricity needs, while the excess PV power is only 36.4 kWh/year. The grid electricity source can supply 57,742 kWh/year to operate stably and continuously for the hostel, with no power shortage in a year.

Figure 11 presents the power supply operation result of a typical day on December 2. The daytime electricity load is supplied mainly by solar power. The remaining load demand part is produced by the power grid in case of unfavorable weather in day to ensure stable operation of the electricity load. Besides, the utility grid generates power to serve electrical loads in the evening. Figure 12 shows that the typical day's load-serving ratio of solar generation peaked at 60% at 10:00.

Production	kWh/yr	%
PV	11,489	16.6
Grid Purchases	57,742	83.4
Total	69,231	100

Consumption	kWh/yr	%
AC Primary Load	68,620	99.9
DC Primary Load	0	0
Deferrable Load	0	0
Grid Sales	36.4	0.0529
Total	68,656	100

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

Quantity	Value	Units
Renewable Fraction	15.9	%
Max. Renew. Penetration	105	%

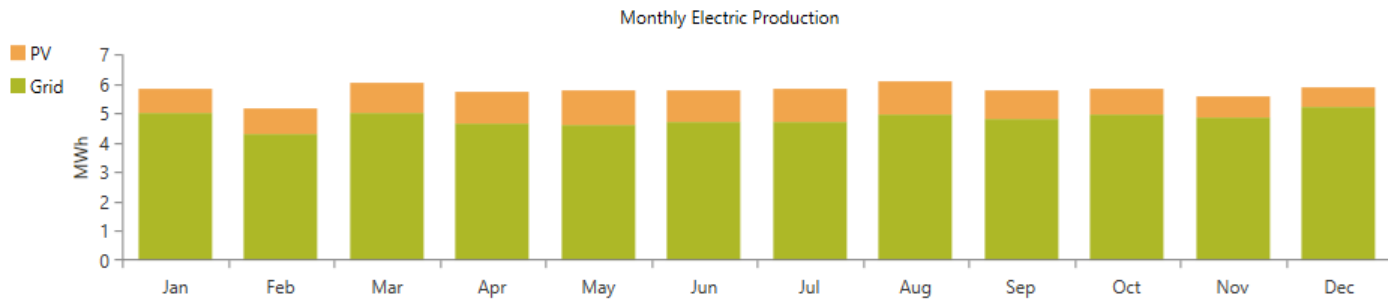


Fig 10. Simulation results of PV system in configuration 2

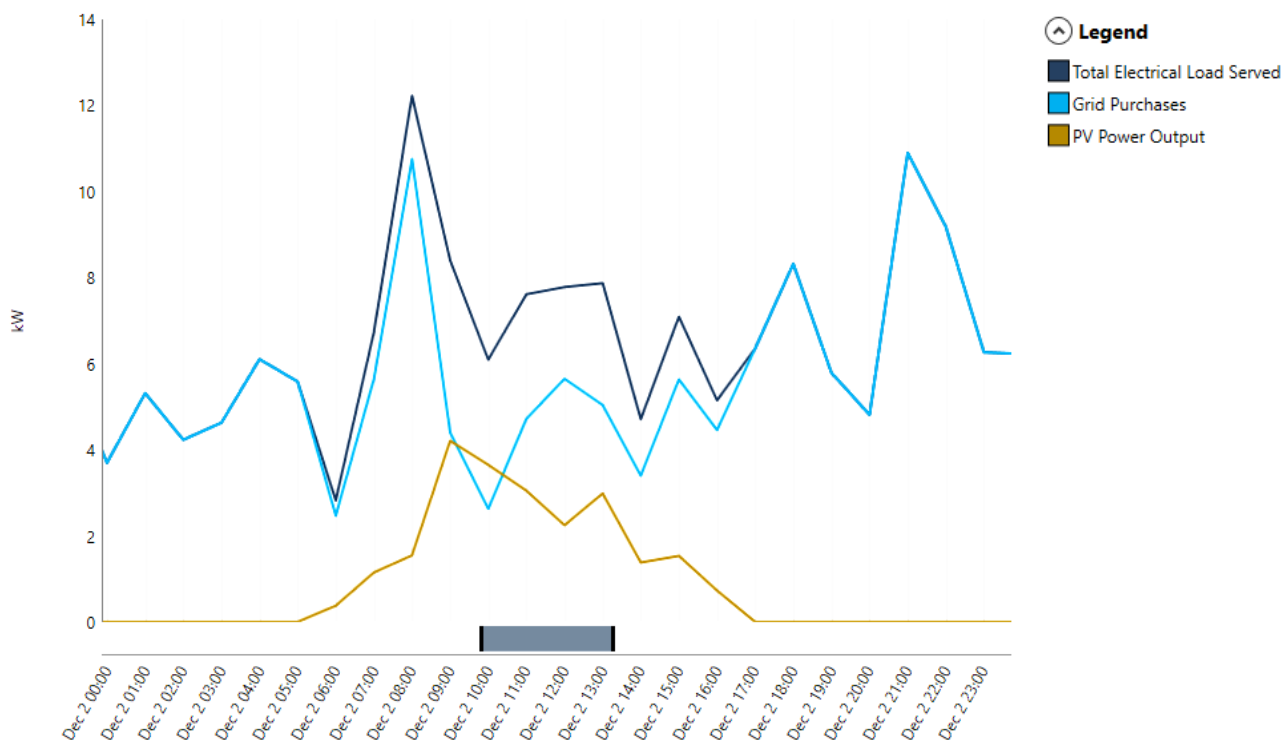


Fig 11. Power supply operation result of a typical day in configuration 2

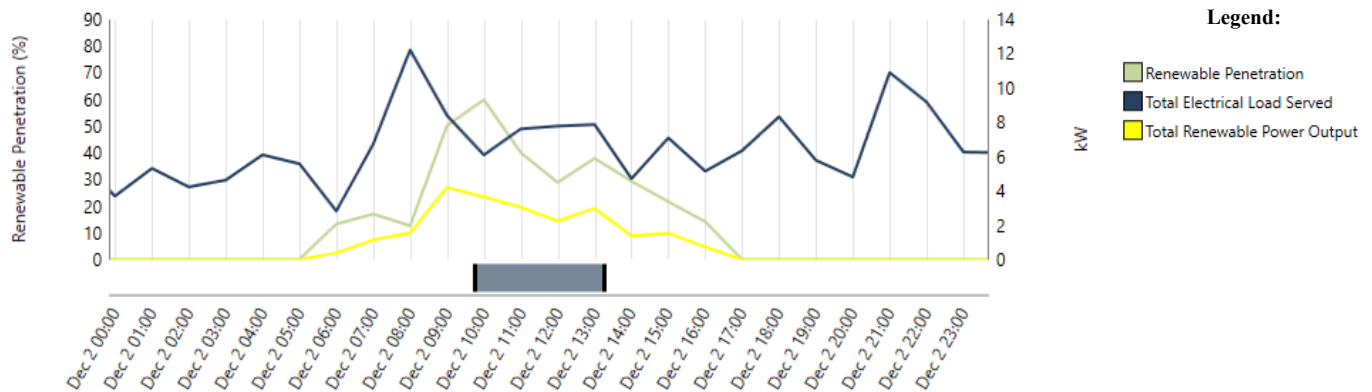


Fig 12. The largest proportion of power generation in configuration 2

5. Discussion

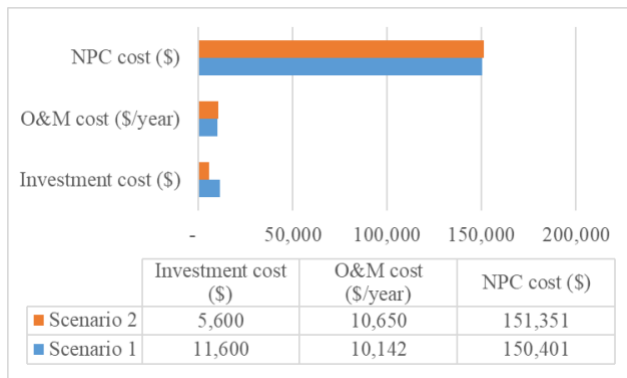


Fig 13. Economic comparison results of 2 configurations.

Figure 13 shows the economic comparison results of the 2 configurations. Although configuration 1 has the larger investment costs of 6000 \$, but it has the smaller O&M costs of 508 \$ and achieves better profits than configuration 2

thanks to higher output. Renewable electricity supplies more load and buys less grid power, so configuration 1 is better than configuration 2 because it has smaller NPC and O&M costs. The NPC cost of configuration 1 is 950 \$ higher than configuration 2.

Figure 14 shows the optimal analysis result with the sensitivity variables wind turbine power (from 1 kW to 3 kW) and solar array power (from 5 kW to 8 kW). The darker the blue color in the graph, the more optimal the configuration, and the hybrid power system using a 3 kW wind turbine and a PV array capacity of 8 kW in configuration 1 is the best option due to its lowest NPC cost. The dark orange option with the lowest PV capacity and zero wind power achieves the largest NPC cost, so this is the scenario with the smallest optimization result.

Figure 15 shows the relation between the share of renewable fraction and the total net present cost. Using a higher renewable fraction reduces the total NPC and yields a better optimization result for the hybrid renewable power system.

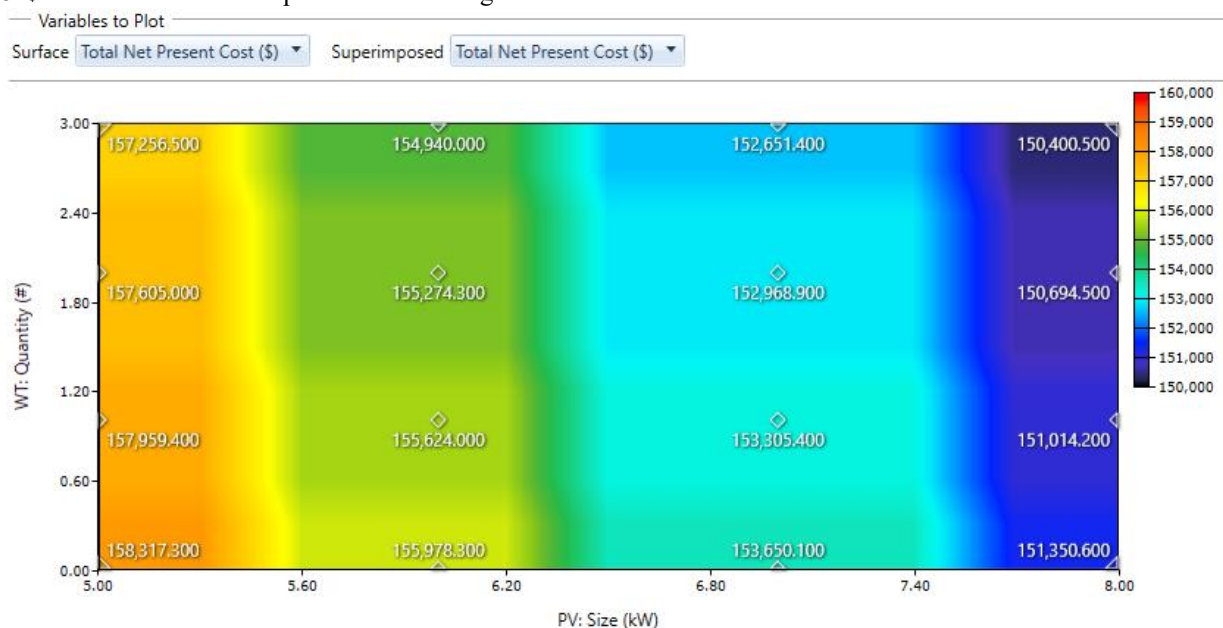


Fig 14. Optimal configuration analysis result

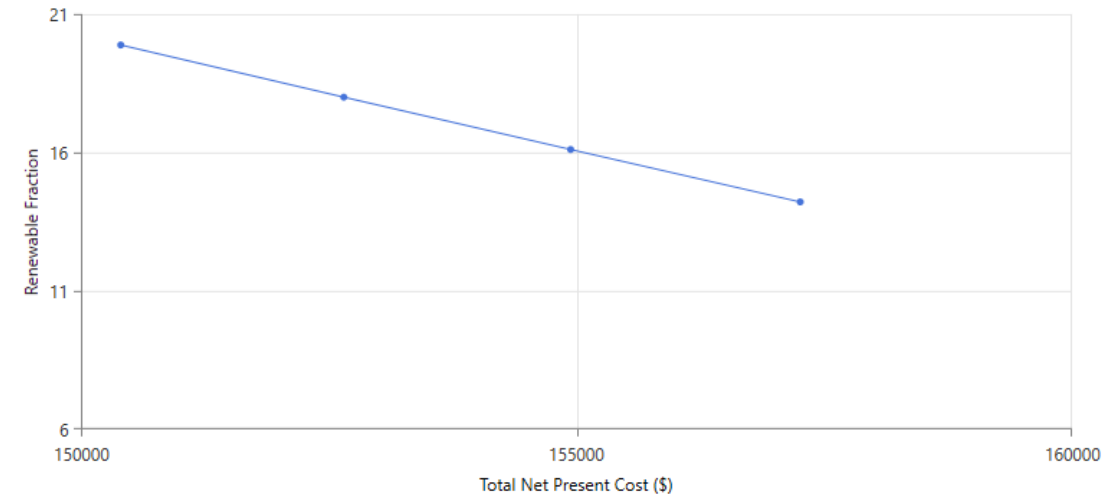


Fig 15. Renewable fraction versus the total NPC

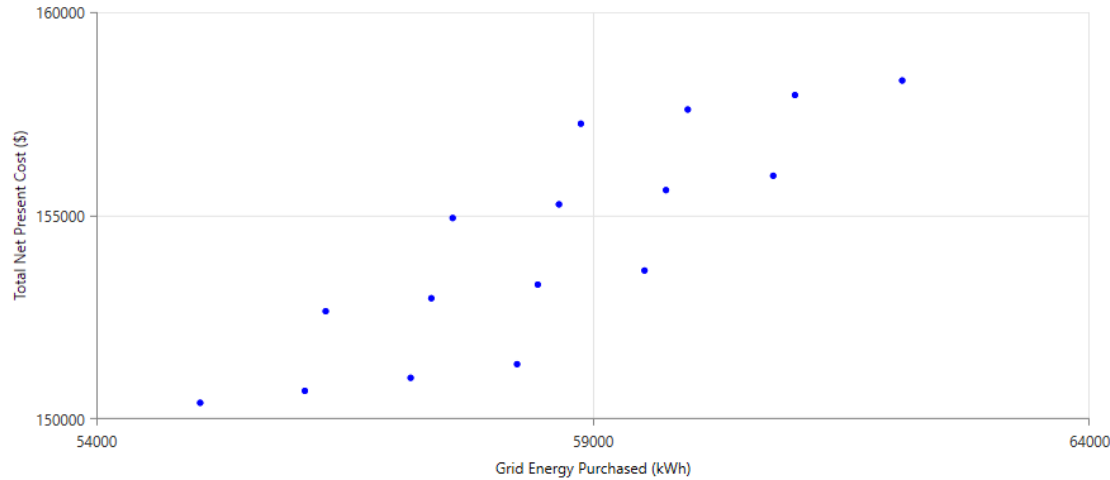


Fig 16. Grid energy purchased versus the total NPC

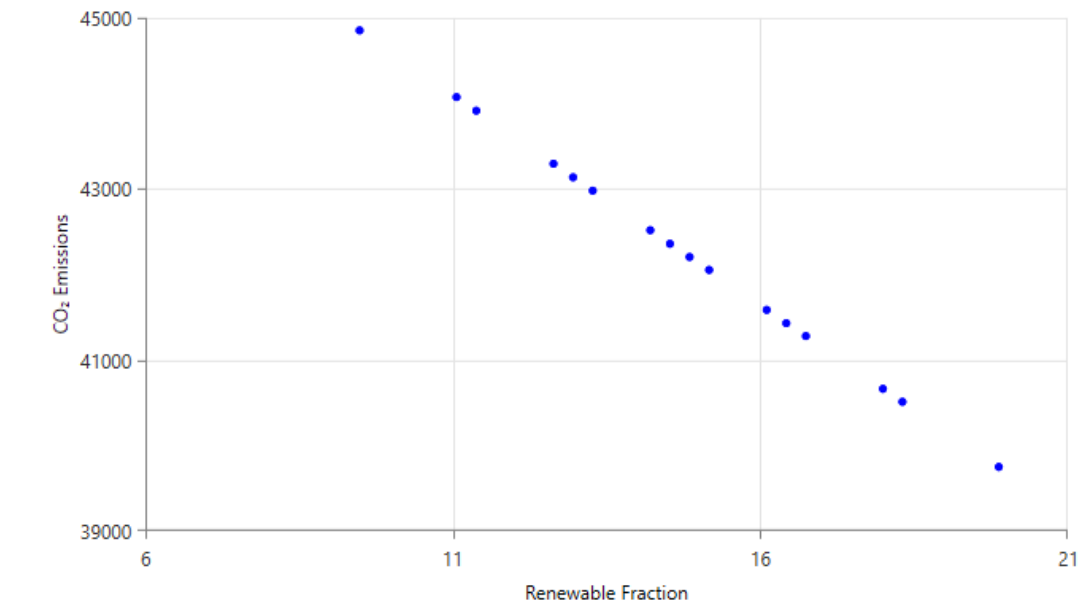


Fig 17. Results of reducing greenhouse gas emissions

Figure 16 presents grid energy purchased versus the total NPC. Purchasing more grid energy can raise the total NPC and reduce the optimal potential of the RE system.

The environmental analysis results in Figure 17 show that using less grid electricity can decrease greenhouse gas emissions, but emissions are also affected by the share of clean power serving the hostel's load demand. Configuration 1 has a higher percentage of renewable electricity than scenario 2, so the hybrid power system generates about 2,303 kg/year (~5.48%) less CO₂ because it uses less grid electricity.

The study results show that using a hybrid wind and solar power system can help save costs on purchasing electricity from the national grid, contribute to reducing greenhouse gas emissions, and increase competitiveness in the industry due to the use of clean energy. The research results can also help determine the importance of applying renewable electricity technologies to hotels in Vietnam.

Installing RE for hotels and hostels not only improves financial efficiency but also reduces greenhouse gas emissions and enhances the potential to develop green tourism products using clean energy. Therefore, it can be widely deployed and applied to many hotels and resorts in Vietnam.

However, there are some challenges to investing in RE in hotels and hostels in Vietnam, such as consumer attitudes, policies and accreditation, lack of knowledge, and human resources. In addition, another recognized barrier is a lack of funding and the long payback period to apply green regulations and technology in hotels and hostels.

6. Conclusion and Recommendation

6.1. Conclusion

The article analyzed the optimal configuration results on hybrid energy systems at a typical hostel in Da Nang city. An optimal hybrid wind-solar power system configuration, including 3 kW wind power and 3 kW solar power, has better technical, economic, and environmental performance than rooftop solar power systems. The economic parameters of the best configuration show that NPC is 150,401 \$, COE is 0.16 \$/kWh, investment cost is 1,600 \$, and operating cost is 10,142 \$. Installing less renewable energy capacity will cause investors to buy more grid electricity, increasing the NPC and reducing the efficiency of the hybrid power system. The renewable electricity system also helps the hostel reduce greenhouse gas emissions. The hybrid renewable energy system configuration achieves a higher ratio of clean electricity than the grid-connected PV power system scenario; thus, it can decrease CO₂ emissions by approximately 2,303 kg per year because less electricity is purchased from the utility grid. Thus, applying renewable electricity technologies can save energy costs and protect the environment for tourist areas in general and hostels in particular in Vietnam.

Future research can explore other hybrid configurations and investigate long-term operational challenges and solutions.

6.2. Recommendation

This paper would like to propose some recommendations to contribute to develop green tourism using RE as follows:

The Vietnamese government should introduce specific policies and regulations to encourage and support tourism businesses in converting to a green tourism model using RE, such as tax incentives and financial support.

In addition, owners of tourist areas also need to invest in infrastructure and green technology. Using renewable energy, building smart water treatment systems, and applying energy-saving technology in hotels, resorts, and transportation will reduce the impact on the environment and resources.

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Author Contributions

P. V. Duy was responsible for the methodology, software, and formal analysis. V. M. Phap was responsible for conceptualization, project administration, supervision, and funding acquisition. P. H. Hanh and N. H. Anh jointly contributed to the validation and data curation. N. T. T. Huang, D. Q. Thanh, and L. T. Tu jointly contributed to the investigation, resources, original draft preparation, review and editing, and visualization. All authors have read and agreed to the published version of the manuscript.

Conflict of Interest

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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