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TECHNO-ECONOMIC ANALYSIS FOR A HYBRID ENERGY SYSTEM OF AN AGRICULTURE FARM USING HOMER PRO SOFTWARE

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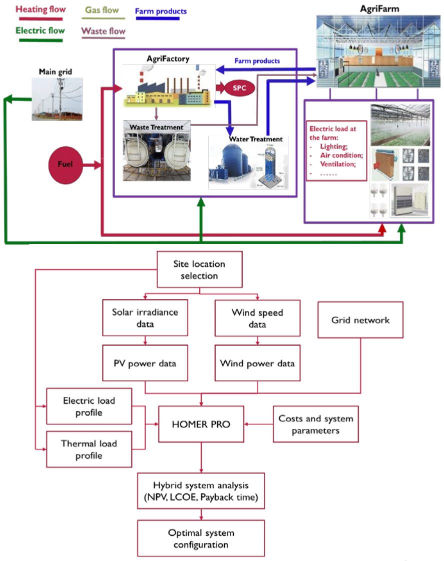
Graphical abstract



Abstract

This paper present a techno-economic analysis model to identify the most cost-effective hybrid microgrid for an agriculture farm in Daklak, Vietnam using HOMER Pro software. The consid-ered hybrid renewable energy system includes a cogeneration generator, solar photovoltaic (PV) rooftop, a small wind turbine, a battery bank, and connected to the main grid to fulfill the energy demands of the farm. The design factors include various considerations such as energy resource availability, environmental sustainability, and financial viability, where the net present cost (NPC) factor is the main objective to make the design more cost effective. From 881 possible con-figurations, a system combining PV panels with CHP generators with the lowest NPC was se-lected as the most optimal solution for the agriculture farm by saving 48% net present cost compared to the system solely connected to the main grid. The findings not only highlight the cost-effectiveness of the selected design but also provide a replicable methodology that can guide future microgrid planning for farms and rural communities in similar contexts.

Keywords: CHP microgrid, renewable energy, PV system, agriculture farm, net present cost

1.0 INTRODUCTION

A hybrid energy system combines multiple forms of energy generation, typically integrating renewable sources like solar and wind with conventional energy sources such as diesel generators or biomass boilers [1-3]. This combination leverages the strengths of each energy source to provide a more reliable, and efficient. Hybrid systems are particularly beneficial in remote or isolated areas where access to a stable energy grid is limited. By diversifying energy sources, these systems enhance energy security, reduce dependency on fossil fuels, and minimize environmental impact through lower greenhouse gas emissions [4-7]. Additionally, hybrid systems can optimize energy costs by taking advantage of the lower operational costs of renewables while maintaining consistent power availability through traditional sources. This adaptability makes hybrid energy systems a key solution for ensuring resilient and sustainable energy supply in various applications, from residential communities to industrial parks and beyond.

Most of the research has focused on residential communities [8-10], remote areas [11-14], and industrial parks [15-17]. In [18], the paper mentioned about developing a CHP grid model using biogas, renew-able energy, and storage for an off-grid livestock farm. However, the paper only focus on the conceptual design, no detailed financial analysis or cost comparison is provided. Paper [19] introduces two solar-based multigeneration systems capable of producing electricity, cooling, hot water, and hydrogen, analyzed through energy/exergy assess-ment and advanced storage integration. While the paper demonstrates innovative system performance and multiple useful energy outputs, the models are characterized by high system complexity, reliance on advanced technologies, and assumptions on solar availability, which may limit feasibility for most farms. There is a noticeable gap in the application of these studies to the agricultural field as well as the little attention given to the specific application of small Combined Heat and Power (CHP) generators within agricultural farms. This gap suggests a need for further investigation into how small-scale CHP systems can be optimized for agricultural settings, where both elec-tricity and thermal energy are crucial for operations.

In Vietnam, the agricultural sector plays a crucial role in the economy, contributing up to 15.32% of GDP in 2023. This sector also consumes a large amount of energy, relying on fossil fuels such as gasoline, diesel, and liquefied petroleum gas (LPG), as well as electricity for activities like operating machinery, irrigation systems, lighting, and preserving agricultural products. Energy demand for agricultural production in Vietnam is expected to grow by about 4-5% annually between 2021 and 2030. With this growth rate, statistics indicate that greenhouse gas emissions from the energy sector in Vietnam accounted for 65.8% of total emissions in 2020 and are projected to increase to 73.1% by 2030 [20]. Consequently, agriculture has become a sector with significant potential for applying renewable energy, while also contributing to greenhouse gas emission reduction targets in the traditional electricity sector.

This paper presents a comprehensive study on the design and feasibility of a Combined Heat and Power (CHP) microgrid system incorporating renewable energy sources and storage solutions for an agricultural farm in southern Vietnam using HOMER Pro software. The proposed energy system model includes PV panels, wind turbines, a battery bank, and a CHP generator. The PV system features generic flat plate panels with a maximum capacity of 300 kWp and a lifespan of 20 years. Wind turbines, with a maximum capacity of 200 kWp and a lifespan of 20 years, complement the PV system by harnessing wind energy. The battery bank, with a rated capacity of 1 kWh per unit and a 10-year lifespan, ensures energy storage and balance between supply and demand. The CHP Heliex142-132kW is used in this research with a nominal electric power of 132kW and a nominal heat power of 6MWth to support an animal feed manufacturing line and an agricultural drying system. The design process involves analyzing electrical load, PV, and wind module lifespan, efficiency, and cost considerations, battery longevity, energy prices from the national grid. Additionally, the study incorporates the net present cost (NPC) factor to ensure the design's cost-effectiveness. This study lies in its comprehensive approach to integrating various energy resources and advanced technologies to create a hybrid renewable energy system that is not only efficient but also environmentally sustainable and financially optimal.

The paper is structured as follows: Beginning with the methodology outlined in Section 2, where the foundational approaches and techniques used in the study are described in detail. In Section 3, the location of the study is introduced, relevance to the chosen site. Section 4 presents the model of the system design. The results and discussion, which form the core analysis and interpretation of the study's findings, are thoroughly examined in Section 5. Finally, the paper concludes with Section 6, where the key takeaways, implications, and potential future research directions are summarized.

2.0 METHODOLOGY

In this section, the process flow for designing an optimal hybrid energy system using HOMER Pro software is presented in Figure 1. The main objective of this paper is to proposed optimized system which is suitable for Agriculture farm in Daklak, Vietnam. The process begins with site location selection, which is critical for determining the available resources and energy demands. Once the site is selected, data inputs such as solar irradiance and wind speed data are gathered from global databases, such as NASA's Surface Solar Energy (SSE) and the National Renewable Energy Laboratory (NREL) Wind Prospector [21]. These datasets help estimate the PV and wind power data, reflecting the potential renewable energy resources at the location. Additionally, electric load profiles and thermal load profiles are considered to understand the energy demand patterns, while the grid network provides information on the existing energy infrastructure. All these data inputs, along with costs and system parameters, are fed into HOMER Pro, which serves as the central tool for system analysis. HOMER Pro processes this information to perform a hybrid system analysis that includes calculating the net present value (NPV), levelized cost of energy (LCOE), and payback time of the proposed system. Finally, the software evaluates different configurations and outputs the optimal system configuration, which is the most cost-effective and efficient design for the specific location and energy demands. The complete process of the optimization with HOMER will presented in the following sections.

The primary objective of this research is to investigate the potential of integrating PV rooftop systems, wind turbines, and energy storage systems for local electricity production. This investigation aims to evaluate the feasibility and cost-effectiveness of such systems in providing reliable and sustainable energy. The main objective function of this study is the investment and operating costs of the system, which are calculated according to the following equation [22-24]:

$$C_{NPC} = \frac{C_{Annual,Total}}{CRF(J, R_{project})} \tag{1}$$

where:
C_{NPC} represents the net present cost of the system;
$C_{Annual,\ Total}$ refers to the system's total annual cost;
CRF denotes the capital recovery factor
$R_{project}$ indicates the life cycle of the project;
J stands for the annual interest.

The net present cost (NPC) is a crucial metric for evaluating the long-term financial viability of the system, representing the total cost over the project's lifecycle. The total annual cost encompasses all expenses incurred in maintaining and operating the system annually. The capital recovery factor is used to convert the total annual cost into the present value, accounting for the time value of money over the project's life cycle.

Levelized Cost of Energy (LCOE) is a metric used to assess the average cost of generating electricity from a particular energy source over its entire lifecycle. It is calculated by dividing the total costs associated with constructing and operating a power plant by the total electricity it is expected to produce over its lifetime [25-27]. The formula for LCOE is:

$$LCOE=(C_{Annual,Total} - c_{boiler}*H_{served})/E_{served} \tag{2}$$

Where: E_{served} represents the total amount of electricity supplied annually (kWh/yr)

c_{boiler} denotes the marginal cost of operating the boiler ($/kWh)

H_{served} signifies the total amount of thermal energy supplied annually (kWh/yr)

The numerator reflects the present value of total costs, while the denominator accounts for the present value of the electricity generated. By considering these factors, the LCOE provides a standardized way to compare the economic efficiency of different energy generation technologies, taking into account both upfront costs and ongoing operational expenses.

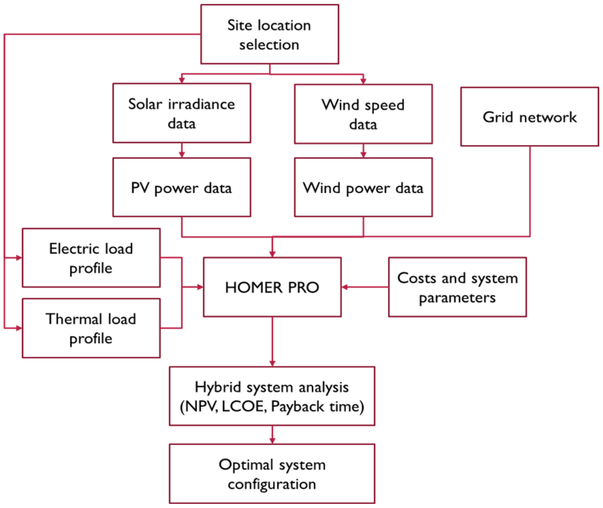


Figure 1 Method's flowchart

By analyzing these financial parameters, the study aims to provide a comprehensive assessment of the economic feasibility of implementing PV rooftop and wind turbine systems with energy storage. This assessment will help determine the potential benefits and challenges associated with local electricity production using renewable energy sources and inform decision-makers about the most cost-effective strategies for sustainable energy development.

For the proposed research project, an agricultural farm located in Ninh Giang village, Ea Puk commune, Krong Nang district, DakLak province has been selected as the primary study site. This farm has been strategically equipped with advanced systems to support a wide range of agricultural activities. Key installations include an agricultural drying system, which is crucial for efficiently dehydrating crops, and an animal feed production line that ensures the consistent and high-quality production of feed for livestock.

The farm also features comprehensive infrastructure for auxiliary needs, such as lighting loads that provide essential illumination for various farm operations, water pumps that manage irrigation and other water-related requirements, and fans that contribute to maintaining a stable and comfortable environment. Additionally, the facility is equipped with air conditioning units, which play a vital role in temperature regulation, and sun protection systems that help shield sensitive areas from excessive sunlight. Ventilation systems are also in place to ensure adequate airflow, promoting a healthy and stable atmosphere within the farm's buildings.

These integrated systems serve multiple functions, supporting the entire lifecycle of agricultural production. They facilitate the growth and cultivation of crops, the rearing and management of livestock, and the subsequent stages of harvesting, packaging, and preserving the products. The infrastructure is designed to optimize operational efficiency and productivity, ensuring that all processes are carried out with maximum effectiveness. By incorporating a combination of modern technologies and best practices, the farm aims to enhance its overall output while maintaining a focus on sustainability and resource efficiency. This comprehensive setup not only supports the farm's day-to-day operations but also serves as a model for innovative agricultural practices in the region. The current system is described in the Figure 2.

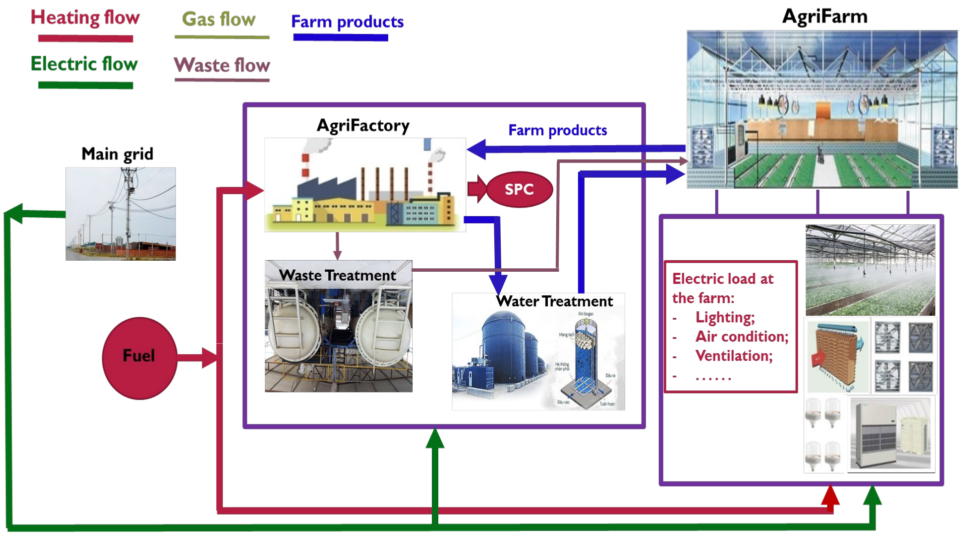


Figure 2 System diagram

Based on the clearness index and daily radiation data is shown in the Figure 3. The location indicate substantial solar energy potential. February has the highest clearness index at 0.647, while March exhibits the highest daily radiation at 6.23 kW/m²/day. These values suggest that a PV rooftop system could generate significant energy during these periods. Although the summer months show lower clearness index and daily radiation values, the system would still produce a considerable amount of energy, albeit less than in the peak months. Given the overall annual distribution of solar radiation, with winter and early spring providing the most favorable conditions, a PV rooftop system would likely be a viable and efficient investment for this location, offering substantial energy production and potential cost savings throughout the year.

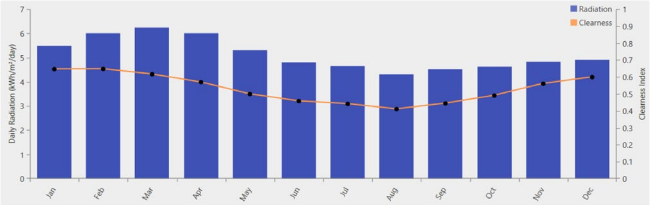


Figure 3 The clearness index and daily radiation data of the considered location in each month

Based on the average wind speed data with the highest average wind speed observed in August at 4.79 m/s, and the lowest in October at 3.08 m/s as shown in the Figure 4. Generally, wind turbines are more efficient at higher wind speeds, typically above 5 m/s. It can be seen that installing a wind turbine system could be viable but may not be optimal for high energy yield. However, the research will still consider wind turbine as a potential input for the optimal configuration.

Figure 4 The average wind speed in each month

The total electrical demand of the system requires 2636 kWh/day and has a peak of 348.14 kW. This demand is broken down into several categories:

- General electrical needs inclusion of lighting, ventilation, cooling, sun protection, water pumping, and heating highlights the essential services required for the general operation of the facility.
- Animal Feed Production Lines: There are three production lines, each requiring 97 kWe, making a total of 291 kWe for all lines combined. These components are crucial for the continuous processing and production of animal feed, emphasizing the importance of a reliable and efficient power supply.
- Drying Systems: There are two drying systems, each with a power requirement of 14.07 kW, totaling 28.14 kW. Similarly, the drying systems' power requirements, which include compressors and multiple fans, reflect the need for precise control and consistent operation to ensure the quality and efficiency of the drying process.

The details of the electric demands are provided in Table 1.

Table 1 Breakdowns of the electric load demand

Components	Unit	P(kW)	Total
Total			**348.14**
General Electrical Needs		29	29
Lighting	-	3	
Ventilation	-	3	
Cooling	-	8	
Heating	-	8	
Sun protection	-	2	
Water pump	-	5	
Animal feed production lines	3	97	291
Chopper	-	22	
Mixer	-	5.5	
Centrifuge	-	5.5	
Screw conveyor	-	3	
Press pellet mill	-	22	
Pellet dryer	-	17	
Crusher	-	22	
Drying systems	2	14.07	28.14
HP Compressor	12	0.735	
Fans	7	0.75	

Each component's average daily electric load demand and hours operating schedule per day of each month were entered into HOMER Pro. The daily electric load profile in each month are presented in Figure 5. The software then calculates the daily energy consumption for each component in each month and aggregates them to obtain the Total average daily energy demand (kWh). Mathematically, the daily energy demand is expressed as:

Total daily energy demand =

$$\sum_{n=1}^{12\ months} \sum_{m=1}^{number\ \ of\ \ components} \sum_{i=1}^{24\ hours} P_{m,n}(i) * \Delta t$$

Where:

$P_{m,n}(i)$ is the electric load demand of the component m at month n and hour i (kW)

Δt is the time step and equal 1 hour in this case (h).

Figure 5 Daily thermal load profile in each month

The same calculation method also is applied for thermal load. The thermal load involves two primary components: an agricultural dryer system and an animal feed processing line. The agricultural dryer system is seasonally driven, with a peak demand for drying activities occurring from May to the end of October, corresponding to the harvest season of various agricultural products. This seasonal operation results in a fluctuating thermal load during these months. On the other hand, the animal feed processing line operates consistently throughout the year, providing a steady thermal load that balances the seasonal variation of the agricultural dryer system. The system requires 70 kWh(th)/day and has a peak of 5.819 kW. The daily thermal load profiles in each month are presented in Figure 6.

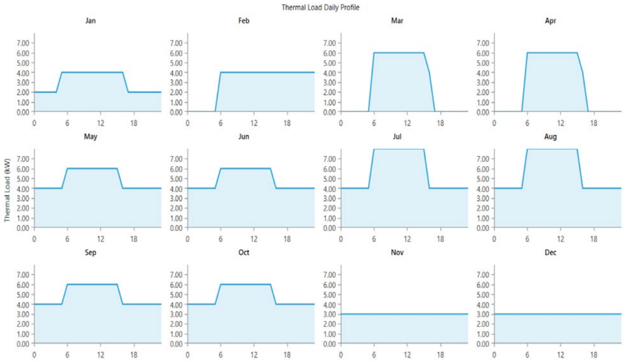


Figure 6. Daily thermal load profile in each month

This system model design focuses on combining renewable energy sources with efficient storage solutions to create a sustainable and cost-effective local electricity production system. By integrating PV systems, wind turbines, and battery banks, the model aims to maximize the utilization of renewable resources while maintaining a reliable power supply. The proposed energy system model integrates several renewable energy resources and storage solutions to optimize local electricity production. The following components are included in the system:

- PV System: The PV system comprises generic flat plate panels with a maximum capacity of 300 kWp. The capital cost for installing these panels is $700 per kWp, with a replacement cost of $350 per kWp. The operation and maintenance cost is relatively low at $10 per year, and the system is expected to have a lifespan of 20 years. The solar irradiance plot will help determine the expected energy output based on local solar conditions. Utilizes solar irradiance to generate electricity. A detailed solar irradiance plot is essential to understand the potential energy generation throughout the year.
- Wind Turbines: The wind turbines have a maximum capacity of 200 kWp. The capital and replacement costs are both $1600 per kWp, with an annual operation and maintenance cost of $50. These turbines also have an expected lifespan of 20 years. The wind speed plot will be used to analyze the energy production potential and optimize the placement of the turbines. Converts wind energy into electrical power. The wind speed plot is crucial for assessing the feasibility and performance of the wind turbines in the specified location.
- Battery Bank: The battery bank has a rated capacity of 1 kWh per unit, with both capital and replacement costs set at $200 per kWh. There are no additional operation and maintenance costs associated with the battery bank. The expected lifetime of the batteries is 10 years. Battery specifications are crucial for ensuring sufficient storage capacity to balance supply and demand. Stores excess energy generated by the PV system and wind turbines. Battery specifications are vital to ensure adequate storage capacity and efficiency.
- CHP Generator: The Combined Heat and Power (CHP) generator is a critical component of the system, designed to provide both electricity and heat, thereby significantly enhancing overall efficiency. This dual-output capability is particularly advantageous for industrial and agricultural applications that require both forms of energy. The CHP Heliex142-132kW generator has a rated electrical power output of 132 kWe and is integrated with systems such as an agricultural drying system and a cattle feed production line, which have a total thermal power requirement of 6 MWth. The system's design ensures high availability and low maintenance costs, contributing to its economical operation. With fuel prices around $3 per MWh, the production of electricity remains relatively low-cost, making the system a financially viable solution. The investment costs for the CHP generator range from $800 to $1,800 per kW, depending on the machine's size [28].

Table 2 below summarizes the parameters for each component included in the energy system model. The idea proposed system is shown in the Figure 7.

Table 2 System parameters

Components	Parameter	Value	Unit
Main grid	Purchase price		
	Normal hour (4:00-9:30), (11:30-17:00), (20:00-22:00)	*0.073*	*$/kWh*
	Idle (22:00-4:00)	*0.048*	*$/kWh*
	Peak (9:30-11:30), (17:00-20:00)	*0.134*	*$/kWh*
	Sell back price	0	$/kWh
PV system	Panel type	Generic flat plate	
	Maximum capacity	300	kWp
	Capital cost	700	$/kWp
	Replacement cost	350	$/kWp
	O&M cost	10	$/year
	Lifetime	20	year
Wind turbine	Maximum capacity	200	kWp
	Capital cost	1600	$/kWp
	Replacement cost	1600	$/kWp
	O&M cost	50	$/year
	Lifetime	20	year
Battery	Rated capacity	1	kWh
	Capital cost	200	$/kWp
	Replacement cost	200	$/kWp
	O&M cost	0	$/year
	Lifetime	10	year
CHP generator	Rated capacity	132	kWh
	Capital cost	1500	$/kW
	Replacement cost	800	$/kW
	O&M cost	0	$/year
	Lifetime	10	year

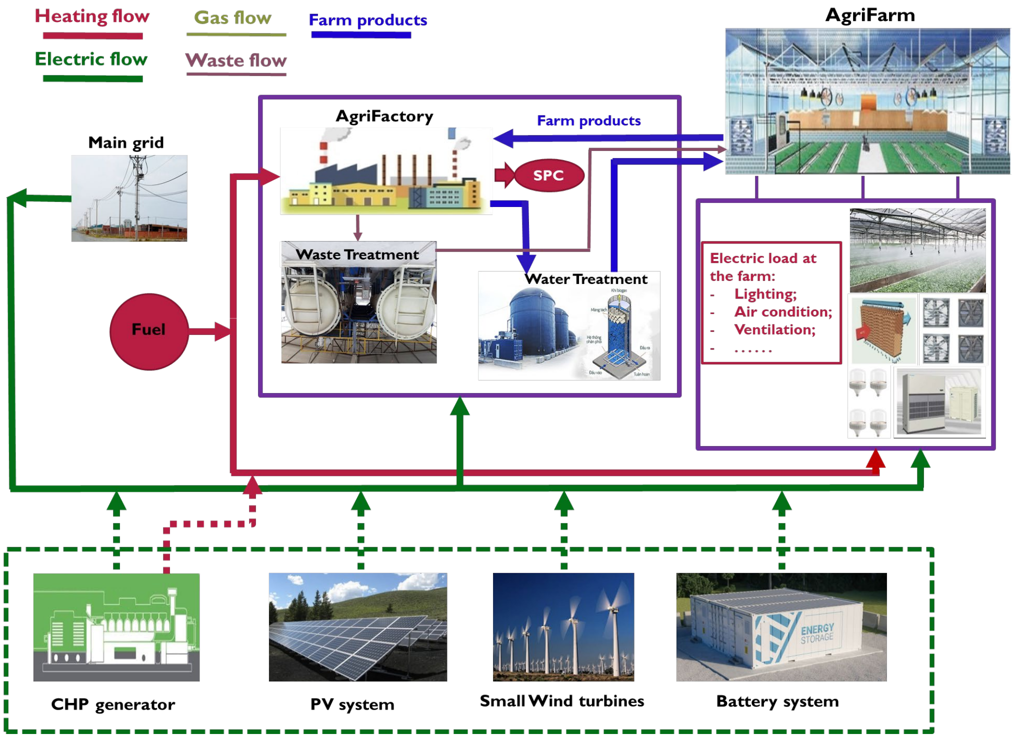


Figure 7 The idea proposed system

3.0 RESULTS AND DISCUSSION

In HOMER pro software, the technical and economic analysis of the simulated system is performed to optimize the configuration of the proposed system. 881 solutions were analyzed. In Table 3 is the top 8 best configurations which were ranked based on the minimum net present cost. The table presents a comprehensive comparison of various proposed energy systems for an agricultural farm, each integrating different components such as PV panels, wind turbines, CHP generators, battery storage. The evaluation metrics include Net Present Cost (NPC), Levelized Cost of Energy (LCOE), operating costs, and capital expenditures (CAPEX).

The PV/CHP/Grid system (System 1) with 256 kW PV, 132 CHP sets, and no wind or battery storage, emerges as a highly economical option with a Net Present Cost (NPC) of $744,379.9, the lowest Levelized Cost of Energy (LCOE) at $0.057378/kWh, and operating costs of $28,051.57 per year, supported by a capital expenditure (CAPEX) of $377,375.

Adding a 1 kW wind component to system 1 configuration (System 2) results in a slightly increased NPC of $746,234.5, an LCOE of $0.057539/kWh, and operating costs of $28,154.63 per year, with a CAPEX of $377,881.3.

Introducing battery storage, as in the PV/CHP/Bat/Grid system (System 3) with 7 kWh of battery, maintains a low LCOE of $0.057568/kWh and slightly reduces the operating cost to $28,007.02 per year, although it raises the CAPEX to $380,876.9.

Further combining wind, battery storage, and CHP (System 4) with 21 kWh of battery, the PV/Wind/CHP/Bat/Grid system results in a higher LCOE of $0.0583899/kWh, increased operating costs of $28,459.17 per year, and a CAPEX of $385,384.4.

Systems that exclude CHP but rely solely on PV and grid support, such as PV/Grid (System 5), present significantly higher costs. This system shows an NPC of $841,142.2, an LCOE of $0.06438725/kWh, and operating costs of $48,240.58 per year, with a CAPEX of $210,000.

Adding wind components without CHP, as in PV/Wind/Grid (System 6) with 2 kW of wind, increases the NPC to $843,514, an LCOE of $0.06461008/kWh, and operating costs to $48,383.18 per year, with a CAPEX of $210,506.3.

Incorporating battery storage but excluding CHP, as in PV/Bat/Grid (System 7) with 7 kWh of battery, results in an NPC of $845,335.4, an LCOE of $0.06473272/kWh, and operating costs of $48,466.35 per year, with a CAPEX of $211,239.5.

Finally, combining PV, wind, and battery without CHP (System 8) with 1 kW of wind and 21 kWh of battery, the PV/Wind/Bat/Grid system reaches the highest NPC of $855,021.8, an LCOE of $0.06549957/kWh, and operating costs of $48,856.47 per year, with a CAPEX of $215,821.9.

Table 3 The top 8 optimal configurations

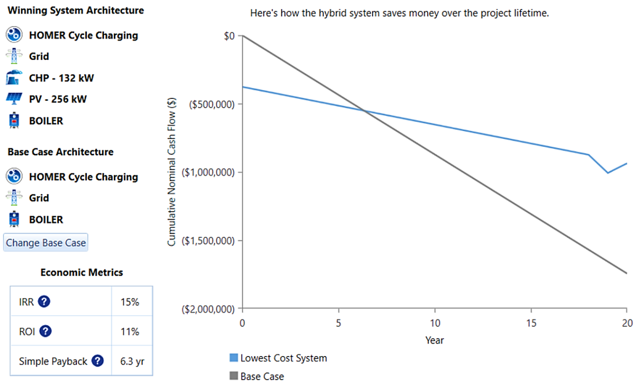
	Proposed systems	PV (kW)	Wind (kW)	CHP (set)	Bat (kWh)	NPC ($)	LCOE ($/kWh)	Operating cost ($/yr)	CAPEX ($)
1	PV/CHP/Grid	256		132		744,379.9	0.057	28,051.57	377,375
2	PV/Wind/CHP/Grid	298	1	132		746,234.5	0.057	28,154.63	377,881
3	PV/CHP/Bat/Grid	299		132	7	747,298.9	0.057	28,007.02	380,877
4	PV/Wind/CHP/Bat/Grid	298	1	132	21	757,721.9	0.058	28,459.17	385,384
5	PV/Grid	300				841,142.2	0.0643	48,240.58	210,000
6	PV/Wind/Grid	300	2			843,514.0	0.0646	48,383.18	210,506
7	PV/Bat/Grid	299			7	845,335.4	0.0647	48,466.35	211,239
8	PV/Wind/Bat/Grid	298	1		21	855,021.8	0.0654	48,856.47	215,822
9	Grid (Base case)	-	-	-	-	1,559,741.0	0.090	119,094.60	1,600

Considering the balance between costs and efficiency, the PV/CHP/Grid system (System 1) emerges as the optimal choice. It offers the lowest net present cost, providing a cost-effective and efficient solution without the additional complexities and expenses associated with wind turbines or battery storage. This system maximizes economic efficiency while maintaining a robust energy supply, making it the most suitable option based on the provided data.

Compare to the base case, System 1 (PV/CHP/Grid) presents a more cost-effective and efficient alternative to the base case (only Grid). Despite a higher initial capital investment, System 1's significantly lower NPC, LCOE, and operating costs make it a more economically viable option in the long run. By incorporating PV and CHP, System 1 not only reduces reliance on grid energy but also ensures a more sustainable and financially advantageous energy production strategy. The winning system obtained by HOMER pro software is presented in Figure 8. The comparison cost between base case and the optimal configuration is presented in Table 4.

Table 4 Cost comparison between Base system and the Lowest cost system

	Base system	Lowest cost system
NPC	$1.14M	$744,380
Initial Capital	$0.00	$377,375
O&M	$87,197/yr	$28,052/yr
LCOE	$0.0900/kWh	$0.0574/kWh


Winning System Architecture
HOMER Cycle Charging
Grid
CHP - 132 kW
PV - 256 kW
BOILER

Base Case Architecture
HOMER Cycle Charging
Grid
BOILER

Economic Metrics

IRR	15%
ROI	11%
Simple Payback	6.3 yr

Figure 8 HOMER’s winning system

The Winning System**,** represented by the blue line, shows a much more favorable financial trajectory compared to the Base Case (gray line). The slower decline in cash flow for the hybrid system suggests that the combination of CHP and PV reduces energy costs, likely through increased efficiency and reduced dependency on grid-supplied electricity. This results in a cumulative nominal cash flow of around -$800,000 after 20 years, which is significantly better than the base case, which ends at around -$1,800,000. The simple payback period of 6.3 years indicates that the initial costs for the hybrid system are recovered relatively quickly, which is crucial for long-term financial planning and investment decisions.

To evaluate the system operation throughout the year, the energy production and consumption of the system 1 is summarized in Table 5.

Table 5 Energy production and consumption of the optimal system

	Components	kWh/year	Percentage (%)
Electrical Production	PV	395,818	40.3
	CHP	411,023	41.9
	Grid Purchases	174,609	17.8
	Total	981,450	100
Electrical consumption	AC Primary Load	962,396	98.1
	Grid Sales	19,054	1.94
Thermal production	CHP	26,693	74.8
	Generic Boiler	8,995	25.2
	Total	35,688	100
Thermal consumption	Thermal Load	25,550	100
	Excess thermal	10,138	39.7

The optimal system achieves a total electrical production of 981,450 kWh/year, with PV and CHP contributing 40.3% and 41.9%, respectively, reducing grid purchases to 17.8%. This system demonstrates high efficiency, with 98.1% of the produced electricity consumed by the AC primary load and the remaining 1.94% sold back to the grid. The electric output throughout the year of the PV system and CHP are presented in Figures 9 and 10. The CHP also meets 74.8% of the thermal production needs, supplemented by a generic boiler at 25.2%, fully covering the thermal load and producing some excess thermal energy. The electric output throughout the year of the PV system and CHP are presented in Figure 11. The monthly energy purchase with utility is shown in the Table 6.

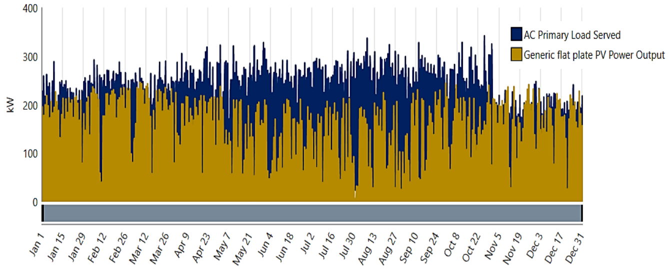


Figure 9 Electric production from PV system throughout the year

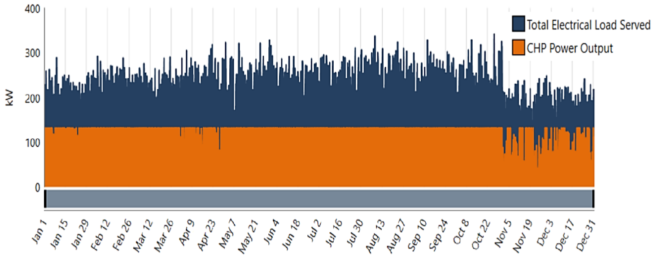


Figure 10 Electric production from CHP system throughout the year

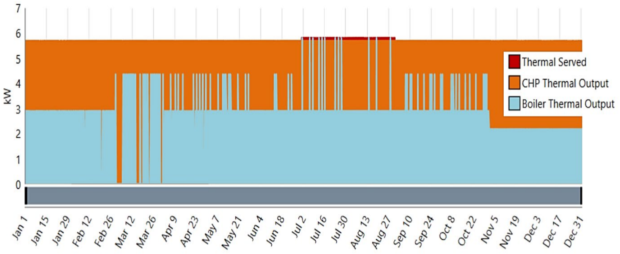


Figure 11 Thermal production from CHP system throughout the year

Table 6 Monthly energy purchase with utility

Month	Energy purchased (kWh)	Energy sold (kWh)	Net Energy purchased (kWh)	Peak Load (kW)	Energy Charge ($)
January	8,340	1,897	6,443	91	$596.56
February	10,737	1,089	9,648	126	$703.88
March	11,353	1,698	9,655	111	$745.41
April	9,958	1,812	8,146	114	$662.12
May	18,051	1,421	16,630	172	$1,283.59
June	18,286	1,163	17,123	126	$1,339.43
July	20,492	1,263	19,229	160	$1,480.67
August	24,441	976	23,465	164	$1,841.45
September	19,688	1,267	18,421	180	$1,415.88
October	19,486	1,035	18,451	150	$1,378.80
November	6,688	2,789	3,899	103	$550.53
December	7,088	2,644	4,445	65	$588.08
Annual	174,609	19,054	155,555	180	$12,586.40

In order to ensure a continuous supply of electricity, especially during periods of high demand or limited on-site generation, the system still need to supplement its power supply by purchasing electricity from the utility. Table 6 gives an overview of energy consumption, energy sales, net energy purchased, peak load, and energy charges for each month over a year.

The total energy purchased over the year was 174,609 kWh. The highest monthly energy purchase occurred in August (24,441 kWh), while the lowest was in November (6,688 kWh). Over the same period, 19,054 kWh of energy was sold back to the grid. The highest amount of energy sold was in November (2,789 kWh), while the lowest was in August (976 kWh). After accounting for the energy sold, the net energy purchased for the year was 155,555 kWh. August had the highest net energy purchased (23,465 kWh), indicating high consumption. Conversely, November had the lowest net energy purchased (3,899 kWh), likely due to higher energy sales. To assess whether the system has sufficient capacity to meet the load demand, the load analysis is implemented throughout the year as presented in Figure 12. The Figure clearly shows that both the electric and thermal load demands are successfully met, indicating the system's ability to handle the required loads consistently. The findings demonstrate that a hybrid energy system, combining CHP with solar power, can significantly reduce significantly energy cost. By fully utilizing the available renewable energy sources, the proposed hybrid system shows high applicability for agricultural farms, emphasizing its potential for broader implementation in similar contexts.

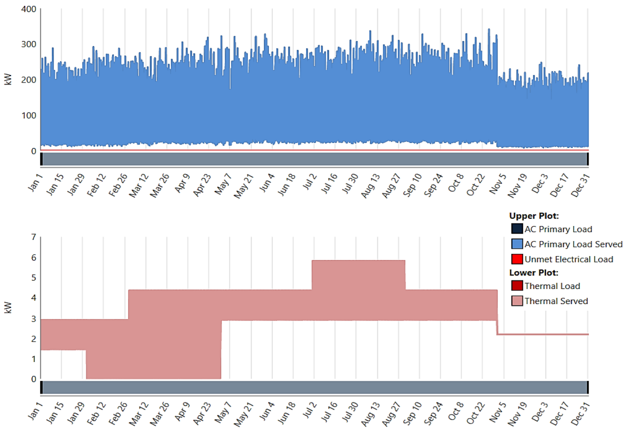


Figure 12. Electric and thermal load analysis throughout the year

4.0 CONCLUSION

This study comprehensively evaluated the feasibility and performance of hybrid system for an agriculture farm in Daklak, Vietnam. The analysis included comparisons of Net Present Cost (NPC), Levelized Cost of Energy (LCOE), operating costs, and capital expenditures (CAPEX) to determine the most cost-effective and efficient configurations. Simulations in HOMER Pro software generated 881 system configurations, with the proposed hybrid microgrid emerging as the most viable solution, achieving an NPC of $0.744 million and 40.3% renewable energy utilization. The results showed that systems combining PV panels with CHP generators demonstrate the lowest NPC and LCOE, making them highly cost-effective, presents a promising solution for sustainable and cost-effective energy management in agricultural settings. This study underscores the necessity of a holistic approach in designing energy systems that balance economic, operational, and environmental considerations. Future research should explore real-world implementation of these configurations and the potential impacts of emerging technologies and market dynamics on their feasibility and performance.

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Conflicts of Interest

The author(s) declare(s) that there is no conflict of interest regarding the publication of this paper

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