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Grid-Connected Hybrid PV-Wind System Simulation in Urban Java

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ABSTRACT

This research proposes optimizing the energy harvesting system based on solar and wind energy, using the enhanced PV-Wind Turbine hybrid power grid to supply electrical energy somewhere in the city of Yogyakarta, Indonesia. The analysis was conducted by researching the possibilities of wind and solar energy and gathering data from numerous sources. To examine the available data and the economic feasibility of the proposed hybrid power system, the Hybrid Optimization Model for Electric Renewable (HOMER) program was employed. The scheme was simulated and optimized using the National Renewable Energy Laboratory's Hybrid Optimization System for Electric Renewables model (NREL). Various analyses are examined, such as Net Present Value (NPV), Energy Expenditure, Energy Output, Usage, and Excess Energy created by each component of the resultant system. The results gained via the installation of this hybrid system are fairly excellent due to monthly production optimization and minimal maintenance costs with potential investments.

1. INTRODUCTION

Compared to other Indonesian islands, Java Island has the most human activity [1]. Because of the increased activity, the average power usage is 11.26 kWh/day, with a maximum electrical load of 2.09 kW [2, 3]. As a result, Indonesia focuses on improving accessibility, particularly to electrical energy sources. Indonesia's landmass, which runs from 6°08' North Latitude to 11°15' South Latitude and from 94°45' East Longitude to 141°05' East Longitude, is strategically placed on developing potential renewable energy sources [4].

Presidential Regulation 5 of 2006 governs the development of innovative and renewable energy sources. According to Chapters 1 and 2 of the Presidential Regulation, energy is primarily derived from nature and includes oil, natural gas, coal, wind, water, biothermal, biomass, biogas, and renewable energy. The use of ocean waves to increase national renewable energy consumption [5]. As a result, it is critical to diversify power plant energy sources by emphasizing the effective utilization of new and renewable energy sources. The policy on using new and renewable energy sources as a source of electrical energy must focus on technical, economic, and environmental security concerns [6]. As a result, renewable energy may be employed as an alternative energy source to help the Indonesian archipelago overcome its electrical issue [7, 8].

Solar and wind are renewable energy resources that may provide a clean energy alternative while economically competitive with conventional power plants [9, 10]. Furthermore, this energy source is plentiful. Indonesia is an archipelagic country with two seasons, which causes it to be traversed by the west and east monsoons. Surprisingly, Indonesia is also located in the tropics, which means it has adequate light intensity and can produce up to 112,000 GWp daily [11, 12]. Solar and wind renewable energy supplies exhibit random fluctuations and are not individually trustworthy. Combining photovoltaic (PV) - wind systems to harness solar and monsoon wind resources is particularly intriguing. Solar energy is extensively available throughout the summer and winter when the sun is shining, whereas wind is substantially more available during the winter and at night [13]. Solar and wind energy blended into one utilizing a hybrid system can complement each other through daily and seasonal fluctuations [14, 15].

This latest trend can increase average electricity consumption and reduce solar photovoltaic (PV) costs in the residential solar system market. Understanding political, financial, and technical decision analysis is invaluable for informing those who support society's transition to clean energy [16]. The Hybrid Optimization Model for Electric Renewable (HOMER) modelling software is used here to simulate the local energy use of the research center [17]. Sensitivity analysis is considered one of the unique properties of HOMER, which can compare the effects of many variables. This feature makes the software ideal for reviewing the factors determining cost-effectiveness between pure grid and grid/PV/wind turbines from local power systems. This study investigates the factors that influence the economic system [18].

This research explains the possible usage of a grid-connected hybrid wind-photovoltaic energy system based on the power demand in Java. This study will use photovoltaics, wind turbines, and inverters as the primary power generating components in conjunction with grid-mounted technologies. It is envisaged that by taking into account essential factors such as load needs, renewable energy potential, and the capacity and composition of the power generating system, this research would be able to solve the challenges mentioned above. Furthermore, the techno-economic study incorporates utilization costs and payback periods to assess how long it will take to return the capital [19].

2. METHOD

2.1 Model description

As illustrated in Figure 1, this study replicates the Connected Hybrid PV-Wind System in each major city on the island of Java. The system is used to examine and decide the necessary cost model. The HOMER program was used to model the simulations. A Hybrid Renewable Energy Technology (RET) system is configured in the HOMER evaluation, followed by a techno-economic analysis. This hybrid technology utilizes wind and solar power by using PV Panels and wind turbines to produce electrical energy. The technical aspects of the system and the system life cycle cost drive the study (LCC). LCC includes initial capital costs and compares alternative equipment with varied restrictions and sensitivities to optimize system design, installation costs, and operating costs during the system's life. HOMER allows simulation by developing alternative technologies to fulfill unique demands [6].

The electricity consumption load profile estimates usage for residential areas validated by the HOMER software. The consumption load for each city on the island of Java in this study uses the same area average with the assumption that its usage is 11.26 kWh/day. The maximum power load is 2.09 kW. This electricity consumption load is calculated for each month [2, 20] with the profile details as shown in Figure 2.

The Grid-Connected Hybrid PV-Wind System necessitates several critical components to establish the best design and cost. Wind turbines, PV arrays, and power converters are the primary components of a grid-connected hybrid system. Table 1 shows the component specs. The network's input parameters include the price of electricity and the network's selling price, which the central government sets. The government-set selling price is Rp. 911, while the price of network electricity is Rp. 1,500 [21].

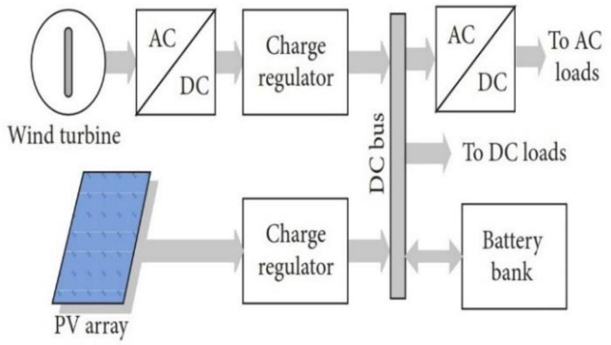

Figure 1. Case study system configuration schematic

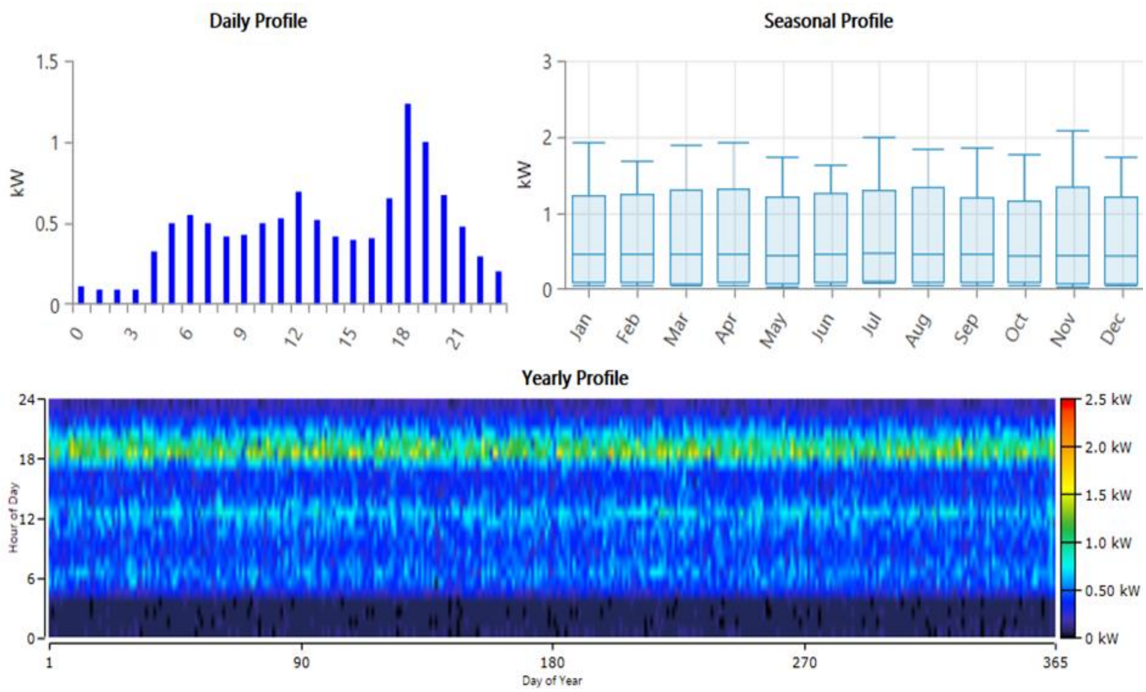

Figure 2. Electricity load for each city

Table 1. System components [21]

Parameter	Studer VarioTrack VT-65 with Generic PV	AWS HC 5.1kW Wind Turbine	Dynapower MPS - 250 800 V
Capital Cost	Rp 2,715,406.00	Rp 35,500,000.00	Rp 107,000,0000.00
Replacement Cost	Rp 1,740,424.00	Rp 28,400,0000.00	Rp 107,000,0000.00
O&M Cost	Rp 543,851.00	Rp 3,550,000.00	Rp 10,700,0000.00
Lifetime	20	20	15

2.2 Environmental parameters

Surface meteorological data and NASA solar energy were used to acquire data on ambient temperature, wind speed, and solar radiation in different cities on the island of Java. Java Island is Indonesia's most densely inhabited territory, with the most significant energy demands, and the potential for growing renewable energy is pretty significant. As a benchmark in carrying out this research, various cities are the centers of several areas on the island of Java.

The average temperature in Figure 3 varies from 23.71°C to 27.31°C. The hottest temperature was 29.22°C in Surabaya in October. Figure 4 depicts average wind speeds ranging from 3.38 to 4.29 m/s. August is the month with the most significant wind speed. Meanwhile, Figure 5 depicts monthly average solar radiation statistics. The most incredible intensity of radiation was 6.12 KWh/m^2 in September.

Based on the statistics in the preceding tables, it is clear that Surabaya has the most significant development potential, with favorable environmental factors as the starting point for developing this hybrid-PV technology. In addition, various additional variables are considered when conducting research. Weather factors are not absolutely the basis in the selection of cities, as economic factors and ease of care are also considered. HOMER also uses electrical loads and expenses as input data.

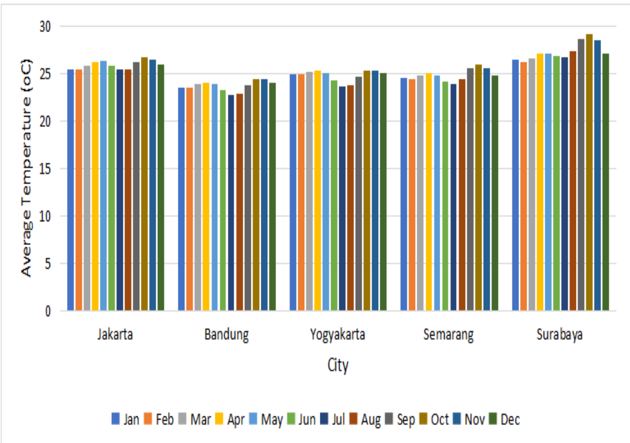

Figure 3. Environmental temperature (monthly average)

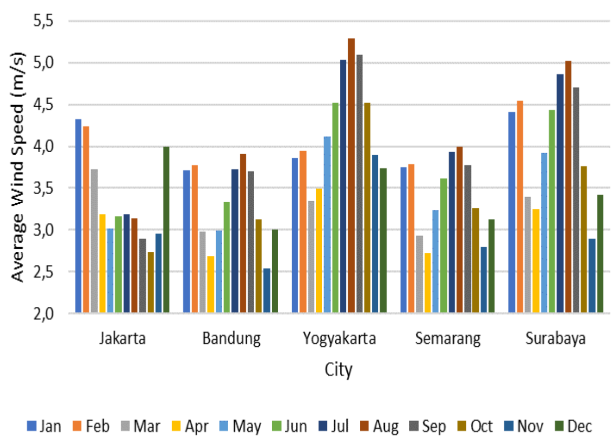

Figure 4. Wind speed (monthly average)

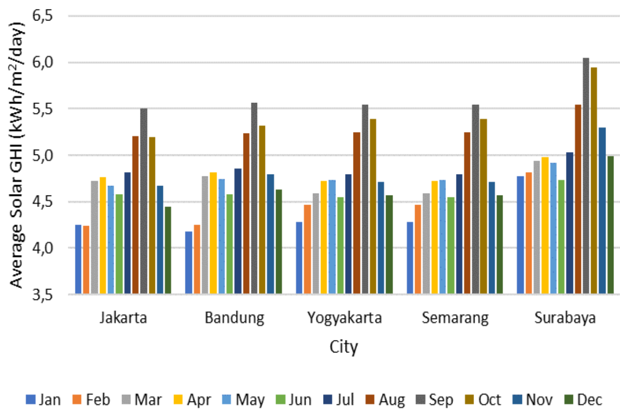

Figure 5. Radiation intensity (monthly average)

3. COST ANALYSIS

PV arrays may be modeled as DC energy-producing equipment in HOMER. The PPV (DC) power generated by the solar module may be calculated using the following equation while disregarding the Influence of Temperature on the PV module [22]:

$$PPV = fpv.\ Ypv \frac{G_T}{G_{T,STC}} \tag{1}$$

where,
Ypv: Output power under standard conditions (kW)
Fpv: PV derating factor
GT: Instantaneous radiation on the surface of the PV module (kW/m^2)
GT,STC: Instantaneous radiation under standard test conditions (1 kW/m^2)

The PV array's cost is defined by the cost of capital owned (Rp), component replacement costs (Rp), and operation and maintenance expenses (Rp/yr). Meanwhile, component replacement costs are estimated costs that can occur if there is a component malfunction such as a decrease in the working life of the panels, replacement of turbine components, maintenance of electrical components, etc. Economic value is significant in the HOMER simulation process since the operation process seeks the system configuration with the lowest Net Present Cost (NPC). NPC is calculated by HOMER using the following equation [23]:

$$\text{CNPC} = \frac{C_{ann,tot}}{CRF\ .i.Rproj} \tag{2}$$

where,
Cann, tot: total annual fee (Rp/year)
CRF: Capital recovery factor
i: interest rate
Rproj: age/life of use (years)

The cost of energy (COE) is the average cost per kWh of the system's useable electrical energy. COE is computed as follows [24]:

$$COE = \frac{C_{ann,tot}}{L_{prim,AC} + L_{prim,DC}} \tag{3}$$

Lprim, AC, and Lprim, DC are the system's AC and DC loads. The projected life of this technology is 25 years. The determination of this estimated time is based on the estimated return capital using HOMER. With optimal care, it is hoped that the age of this technology can reach this estimate. An estimated impairment show in Figure 6 below.

Figure 6. Annual inflation

4. RESULT AND DISCUSSION

This simulation procedure aims to establish the best size variable for each of the primary components placed while functioning independently. HOMER arranges the configuration results depending on the system configuration with the highest NPV (Net Present Value). As illustrated in Figure 7, the ideal system configuration outcome is defined by the highest NPV since it becomes the cost of the complete system over a given period [25].

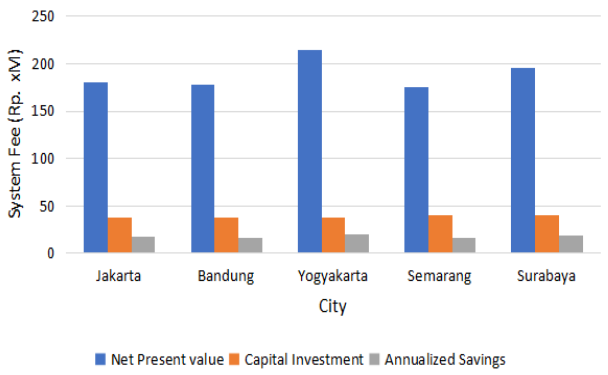

Figure 7. System fee comparison

Figure 8 shows the comparative cost recovery data that can occur every year. The high percentage of return on capital makes the profits obtained even greater. This profit percentage is the main factor in determining the most strategic location outside of environmental parameters that can change throughout the year. NPV and payback are preferred.

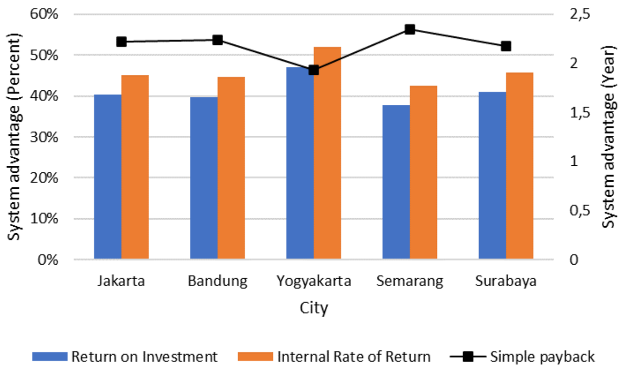

Figure 8. System advantage comparison

As shown in Figure 7 and Figure 8, which show the potential for very rapid economic development in the city of Yogyakarta compared to other cities. This tremendous economic potential makes the city of Yogyakarta a strategic place to conduct this research. Environmental conditions in this city are also very supportive, with the highest wind speed variable among other cities. Combined with sufficient monthly average solar radiation to supply the required solar energy, this is the main reason for choosing this city as the first choice for testing this hybrid PV - wind turbine system.

The installation of this hybrid system necessitates the purchase of numerous essential components. Table 2 and Figure 9 depicts the cost flow for the existing project over the next 25 years, depending on the value of capital, replacement, salvage, operational, and fuel. There is also a salvage value in the 25 - year period, which is the salvage value after the hybrid power system project for 25 years.

The estimated service life of 25 years is based on the average working life of solar panels that can work optimally. To reach the age of 25 years requires some maintenance and replacement of components which is quite costly not only from PV panels but also some wind turbine components. For 25 years, it is projected to be able to obtain benefits in the form of return of initial capital and other maintenance costs with commensurate energy production results.

The deciding considerations are the high initial investment cost and reliance on environmental variables. Scientific and technical advancements in terms of technology advancement and cost reduction can expand the potential of these systems. Furthermore, one of the benefits of this system is its minimal maintenance costs and rapid payback times. The payback period for WT/hybrid and PV/hybrid systems is 3 to 4 years and 6 to 7 years, respectively [26].

Table 2. Cost flow

Component	Capital	Replacement	O&M	Fuel	Salvage	Total
AWS HC 5.1kW Wind Turbine	Rp 35,500,000.00	Rp9,054,128.74	Rp45,892,683.75	Rp0.00	-Rp5,102,582.21	Rp85,344,230.28
Dynapower MPS - 250 800V	Rp107,000,0000.00	Rp45,397,299.77	Rp138,324,427.07	Rp0.00	-Rp8,544,229.99	Rp282,177,496.85
Grid	Rp0.00	Rp0.00	-Rp227,747,186.13	Rp0.00	Rp0.00	-Rp227,747,186.13
Studer VarioTrack VT-65 with Generic PV	Rp2,715,406.00	Rp554,859.96	Rp7,030,642.80	Rp0.00	-Rp312,699.17	Rp9,988,209.59
System	Rp145,215,406.00	Rp55.006,288.48	-Rp36,499,432.51	Rp0.00	-Rp13,959,511.37	Rp149,762,750.60

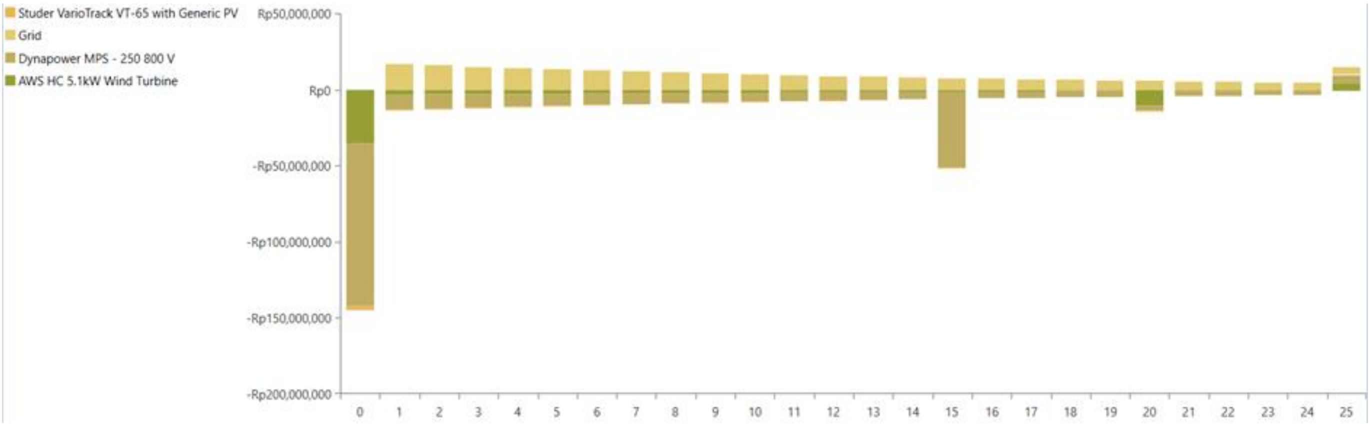

Figure 9. 25 Years of financing process

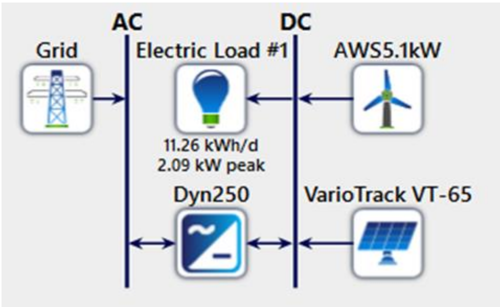

Figure 10. Hybrid system setup

HOMER replicates the above two settings on the same area and load to assess system performance in different conditions based on expenses such as expected installation costs, operation and maintenance costs, replacement costs, interest costs, and energy prices. The grid-connected hybrid system's major components are the wind turbine, PV array, Dynamo power, and Studer Vario Track, as show in Figure 10. The following values are used in economic analysis.

After analyzing with HOMER, the average monthly electricity production data from the proposed model is obtained as follows Figure 11:

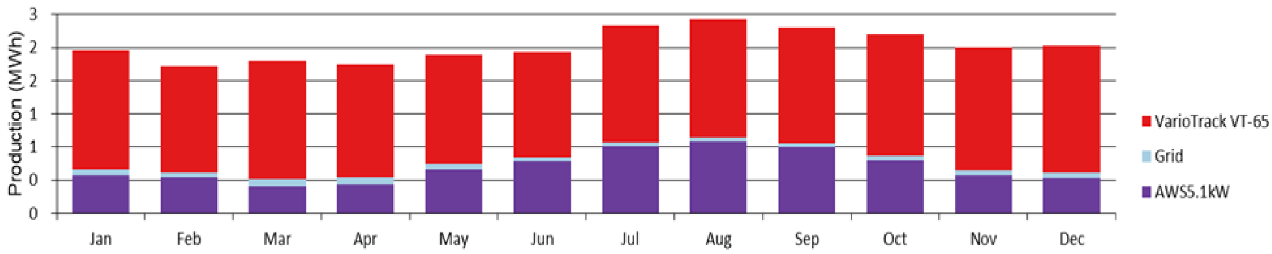

Figure 11. Average monthly electricity production using the proposed model

Based on the data on the average monthly electricity production generated in each of the proposed modes, it shows that the provision of a grid does not significantly increase electricity production. Meanwhile, the effect of wind turbines is considered the best because they can produce energy production that is relatively stable and consistent throughout the year, with a total investment cost of Rp 85,344,230.28 with an estimated usage time of 25 years. It affirmed that the hybrid PV-Wind Turbine system has potential advantages over conventional PV panels based on the results of the HOMER simulation conducted in Yogyakarta.

5. CONCLUSIONS

This research compares on-grid hybrid power systems to grid-connected hybrid power systems in Java cities. At the same load, the optimization findings reveal that the grid-connected hybrid (PV/wind) system is more efficient and cheaper than standard PV systems. According to the modeling results, the hybrid system connected to the grid does not require an extra battery bank under typical working conditions, and excess renewable energy will be added to the network.

Based on the simulation results obtained using the HOMER software, the potential for renewable energy (wind energy and solar light) found on the island of Yogyakarta is feasible to be used as a hybrid power generation system. During the 25 years the project has been running, there are only a few maintenance costs that need to be done. The other major components do not require replacement during the project because they have a lifetime and operation hours that are more than the project's duration.

Sensitivity analysis forecasts the probability of value changes in the following years. Daily load usage and fuel cost are two sensitivity variables that influence the setup of this hybrid power system. Based on the project cost flow simulation findings, it is concluded that the components of the hybrid power production system will be more valuable after the project.

With a compelling upgrade over conventional systems, one may expect a future cost reduction in the cost of Component Investment. As a result, hybrid systems will grow increasingly appealing over time. There are several advantages of using a Hybrid PV-Wind Turbine System, including: producing more effective electrical energy through wind and solar power conversion; Continuous operation of the system; Simple maintenance lower pollution levels.

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