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Resource assessment and energy yield estimation for 160 MW solar-wind hybrid project using system advisory model

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Abstract. A techno-economic and environmental cost benefit analysis and assessment for the proposed 160 MW (Solar-120 MW and Wind-40 MW) hybrid renewable energy project with grid integration is carried out for electricity generation at Ramagiri & Muthavakuntla village locations of Anathapuram district in Andhra Pradesh state of India. Manual estimations are carried out based on recent research publications in similar line of studies and simulation studies are carried out using System Advisory Model (SAM) software under individual and hybrid operating modes with authenticated data resources to determine annual energy yield as well as sizing along with their economic and environmental concerns for solar and wind energy resources. Finally, comprehensive annual energy benefits are presented that shows techno-economic-environmental viability of this proposed project at the aforementioned location.

1. Introduction

Allocation of available, affordable and accessible power supply to different societal sectors remains as a challenging task for developing countries especially due to prevalence of high costs in addition to transmission losses and power shortages. As per the recent reports, still there is a dire need to enhance the accessibility of electrical power with emerging demands for power consumption around the world [1][2]. In this regard, renewable energy-based power plants can offer a potentially viable economic solution to meet growing energy demands [3]. Intermittent nature of wind and solar radiation over day-night and seasonal cycles impose power supply interruption leading to risk generation to rely on single renewable energy supply source. Integration of solar and wind energy under hybrid mode to grid remains as a plausible solution to overcome these issues [4-14]. Several probabilistic and deterministic approaches are available to develop hybrid system models with optimum resource combinations and assess overall system performance [15-25]. This work evaluates the technical, economic and environmental feasibility of proposed 160 MW (Solar-120 MW and Wind-40 MW) hybrid project located at Ramagiri and Muthavakuntla village, Ananthapuram district, Andhra Pradesh state of India whose geographical coordinates were N 14°20'32.76" and E 77°30'29.02" using System Advisory Model (SAM) based on ground, satellite and integrated data bases in Indian context and annual comprehensive benefit analysis based on recent similar line of research studies [25-33].

2. Site Climatology

The proposed project land encompasses 928 acres of land out of which 800 acres for Solar Park and 90 acres for wind farm. Initially, appropriate selection of location with adequate energy resources can be attained by considering parametric constraints of the requisite hybrid system. Here in this case, energy yield estimation pertaining to availability of solar radiation and wind speed at the proposed site location which in turn depends on weather and climate factors over proposed site location, energy demand, seasonal variations in load and intensity of energy resources and so on.

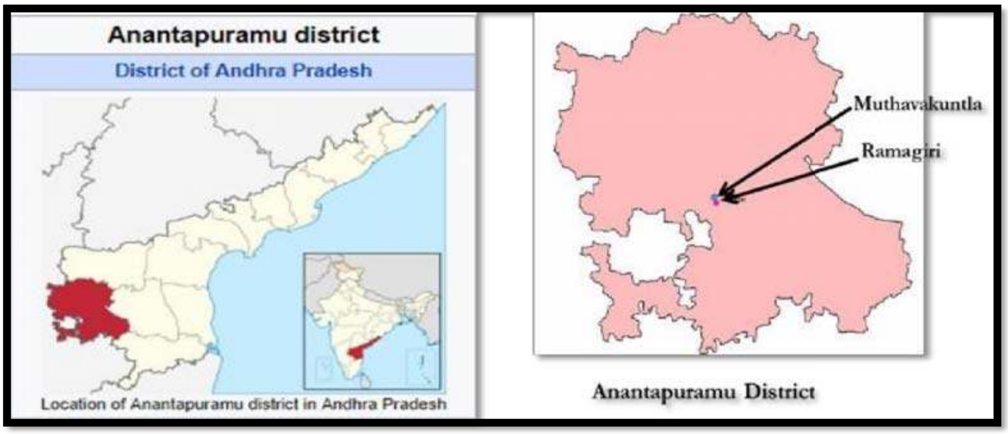

Figure 1. Proposed 160 MW Solar-Wind hybrid project location.

Figure 1 shows the proposed 160 MW Solar-Wind hybrid project location. The area that falls under this site location comes under semi-arid climatic zone of India with almost hot and dry conditions throughout a year. Summers usually start in the month of February with recorded average high temperatures at 37°C and peak temperatures in the month of May whereas monsoon starts in the month of September that lasts until November with 250 mm of observed precipitation followed by dry and mild winter in late November that lasts until early February with little humidity that exhibits temperatures averaging in between 22-23°C. Overall annual average rainfall within the district is observed to be 535 mm with mean seasonal rainfall distribution of 316 mm during southwest monsoon (June-September) while September and October months are noticed to be the wettest months of the year. The water requirement can be met through deep tube well while the maximum and minimum level of the ground water table is around 300 feet to 900 feet.

3. Technical Evaluation

The Proposed 160 MW wind-solar hybrid study was analyzed allowing for 40 MW generation facilities from wind farm and 120 MW of Solar PV capacity. Site characterization along with overall resource assessments were carried out for energy yield estimations. Wind resource assessments have been carried out by using Ramgiri wind mast, such as contour maps and wind characteristics observed at project site location and then mapping it with solar installations. The solar-wind resource assessment and overall energy yield estimation as well as photovoltaic (PV) system sizing have been carried out by using PVSyst-6.8.1 and SAM-2018 software versions. Studies pertaining to resource assessment for solar as well as wind energy generation were carried out by collecting required climatic resource data base from standard Indian Meteorological Data (IMD) and established National Solar Resource Data Base (NSRDB) data bases.

3.1 Solar output system evaluation

The solar radiation parametric data such as GHI, DNI and DHI are collected serially at periodic intervals of half-hourly and hourly along with meteorological time series data from 2004 to 2014. This data is downloaded from SAM software for Ramagiri location with temporal resolution of 1 km at geological coordinates mentioned above. Using this data, potential availability of usable solar energy for power generation can be predicted in and around proposed site at Ramagiri location. Data collected from individual sources for both solar and wind energy resources on daily, weekly, monthly and yearly basis were compared with real-time data collected by the project developer Solar Energy Corporation of India (SECI) for reference which showed GHI of 2152 kWh/m^2/year with an average GHI and DHI of 179.3 kWh/m^2 and 69.5 kWh/m^2 respectively and an average temperature of 26.3°C.

As on today, there are various solar PV and wind turbine generator technologies are available for adoption throughout the world [4]. Different available technologies were taken into consideration for the sake of analysis from both commercial and technological perceptions for the proposed site location and identified the most suitable technologies for yielding hybrid energy using Siemens Gamesa G97-2.0 MW wind turbine for wind power generation and Canadian solar CS6U-325wp solar PV module for solar power generation. PV system sizing for was carried for both DC and AC systems by considering solar PV module ratings and balance of system components with appropriate DC-AC ratios using SAM software. Table 1 shows the simulation results obtained for solar system, while figure 2 and figure 3 represents monthly energy production and monthly system power output over a year respectively. It is clearly evident that there is a deviation from desired output from table 1, figure 2 and figure 3 which can be mainly attributed to generic loss factors associated with solar PV system and environmental concerns.

Table 1. Simulation (SAM) results of the proposed 120 MW PV system.

Metric	Value
Annual energy (year 1)	241,380,112 kWh
Capacity factor (year 1)	17.7 %
Energy yield (year 1)	1,548 kWh/kW
Performance ratio (year 1)	0.77

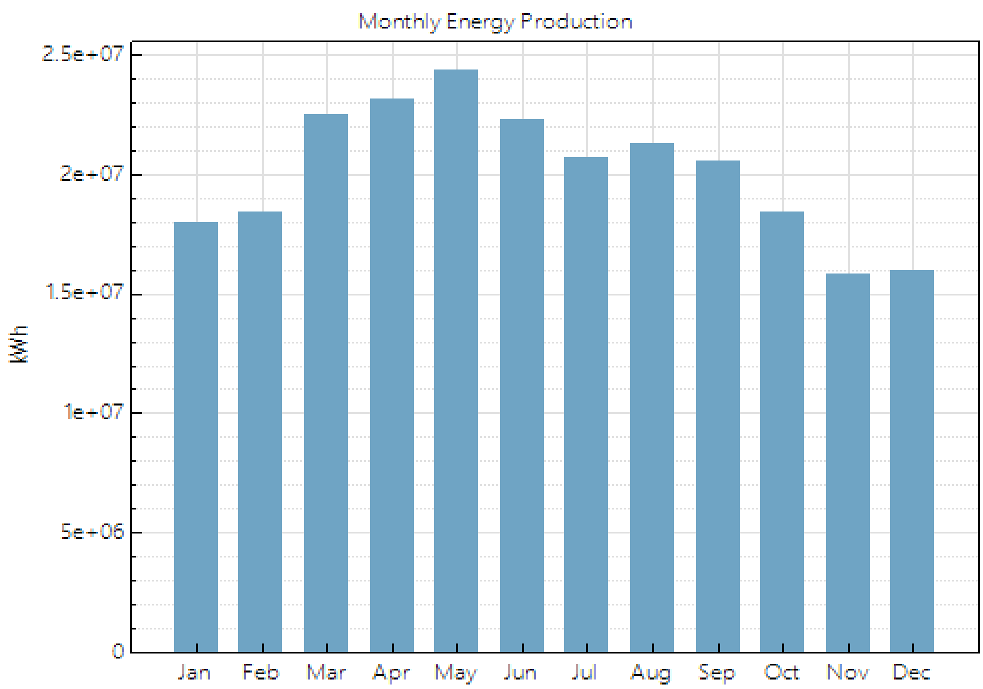

Figure 2. Simulated monthly PV energy production over a year.

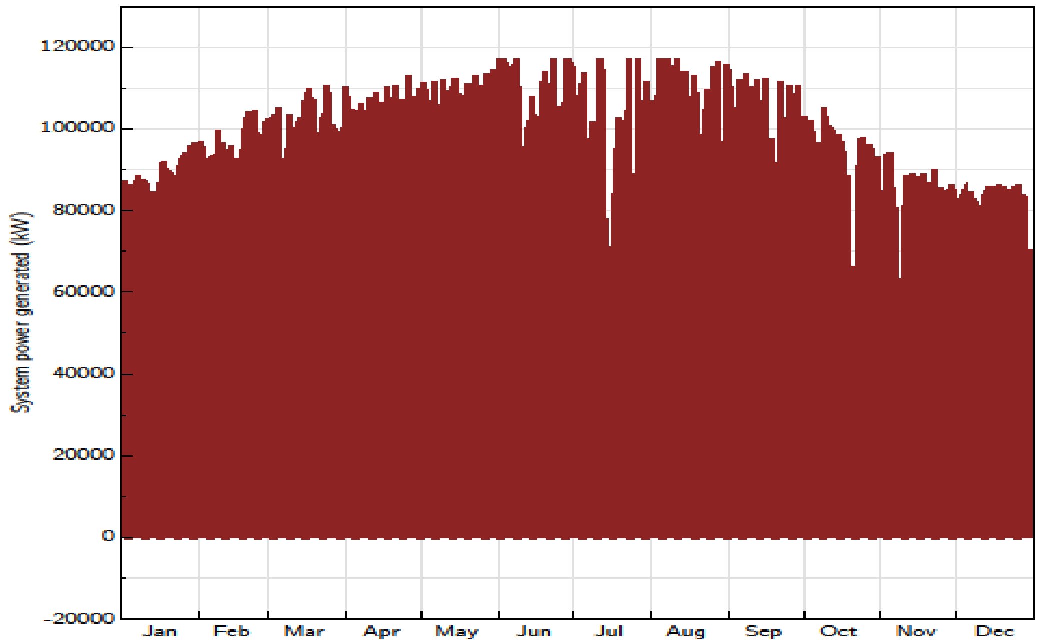

Figure 3. Simulated monthly PV system power output over a year.

3.2 Wind energy system output evaluation

Wind resource assessment was carried out by considering wind data sources from two masts of National Institute of Wind Energy (NIWE) available nearer to proposed project area, wind data from the 78 m height wind mast installed by a private developer, MERRA-2 re-analysis data from the node point nearest to the site, wind data from the 100 m height wind mast available at Ramagiri site.

Table 2. Wind data at proposed site over a year.

Month	Temperature (^{0}C)	Pressure (mbr)	Air Density (Kg/m^3)	100 m north WS (m/s)	100 m south WS (m/s)	80m WS (m/s)	50m WS (m/s)
Jan	22.1	958.9	1.12	5.1	5.1	4.9	4.5
Feb	26.24	957.5	1.11	5.5	5.5	5.2	4.8
Mar	29.98	955.4	1.09	5.4	5.4	5.2	4.8
Apr	31.43	953.5	1.08	5.1	5.1	4.9	4.5
May	28.88	950.3	1.09	5.1	5	4.9	4.5
Jun	26.65	950.1	1.10	8.5	8.5	8.2	7.8
Jul	25.73	950.4	1.10	9.7	9.7	9.5	9.1
Aug	25.06	951.3	1.10	10.7	10.7	10.5	10.1
Sep	26.01	953.6	1.10	5.9	5.9	5.7	5.4
Oct	26.15	955.9	1.11	5	5	4.8	4.4
Nov	24.41	957.2	1.11	5.1	5.1	4.9	4.5
Dec	23.25	957.5	1.12	5	5	4.8	4.4
Avg	**26.3**	**954.3**	**1.1**	**6.34**	**6.32**	**6.11**	**5.73**

Wind resource data is collected by using wind mast incorporated by SECI at proposed site and collected data regarding wind speeds at different reference hub heights such as 50 m, 80 m and 100 m in north and south direction as shown in table 2 to estimate actual energy production and the corresponding monthly mean wind speed over a year at proposed site location is shown in figure 4. From table 2 mean values of 26.3˚C temperature, 954.3 mbar pressure, 1.1 kgm^{-3}, air density can be observed with mean wind speed variability ranging from 5.73 ms^{-1} to 6.34 ms^{-1} with respect to variation in height from 50 m to 100 m indicating good wind resource for wind power generation.

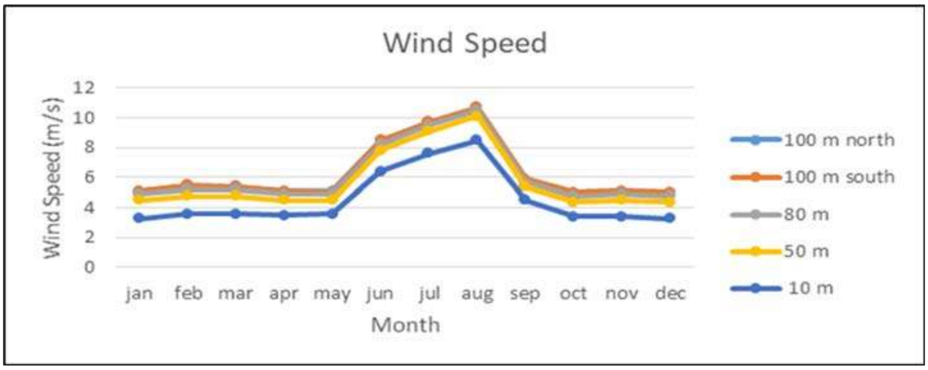

Figure 4. Monthly mean wind speed over a year at proposed site.

Annual energy Production was estimated for the 40 MW wind farm of this proposed project by considering GamesaG97 wind turbine model with each turbine rated at power generation capacity of 2 MW for 104 m hub height level and 97 m rotor diameter along with a shear coefficient of 0.14 and presumed total losses around 14% based on site characteristics represented in table 2. Using SAM software, it has been estimated that 126464.32MW of annual energy can be generated with 36.1% capacity factor. A data of the annual wind energy production is presented table 3. Further, the monthly energy production and power production from wind farm distribution were displayed in following figure 5 and figure 6 respectively. A maximum monthly generation of 1.3 x 10^{7} kWh was noticed in the month of January while almost constant system power production around 34.5 MW was noticed with partial no power production for some days in the months of June, July and August over a year.

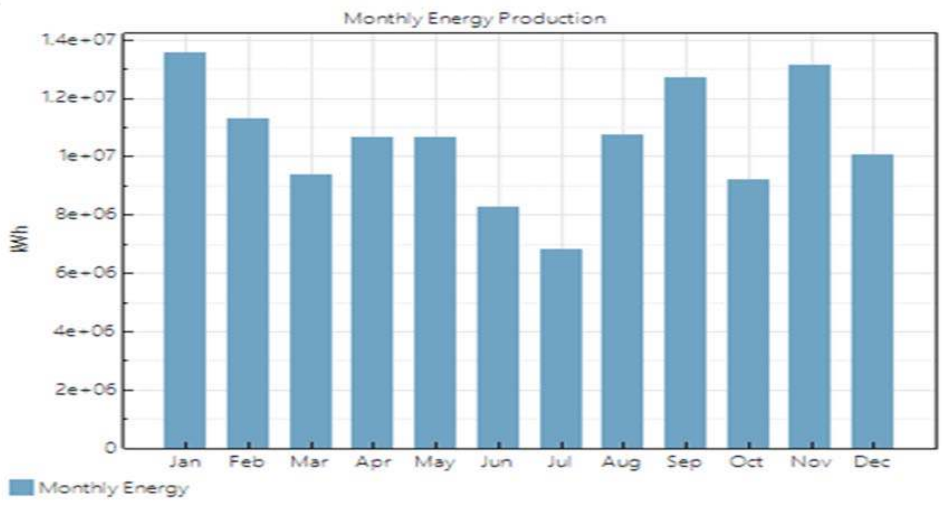

Figure 5. Monthly energy production using wind farm at the proposed site over a year.

Table 3. Annual wind energy production.

Metric	Value
Annual energy (year 1)	126,464,320 kWh
Capacity factor (year 1)	36.1%

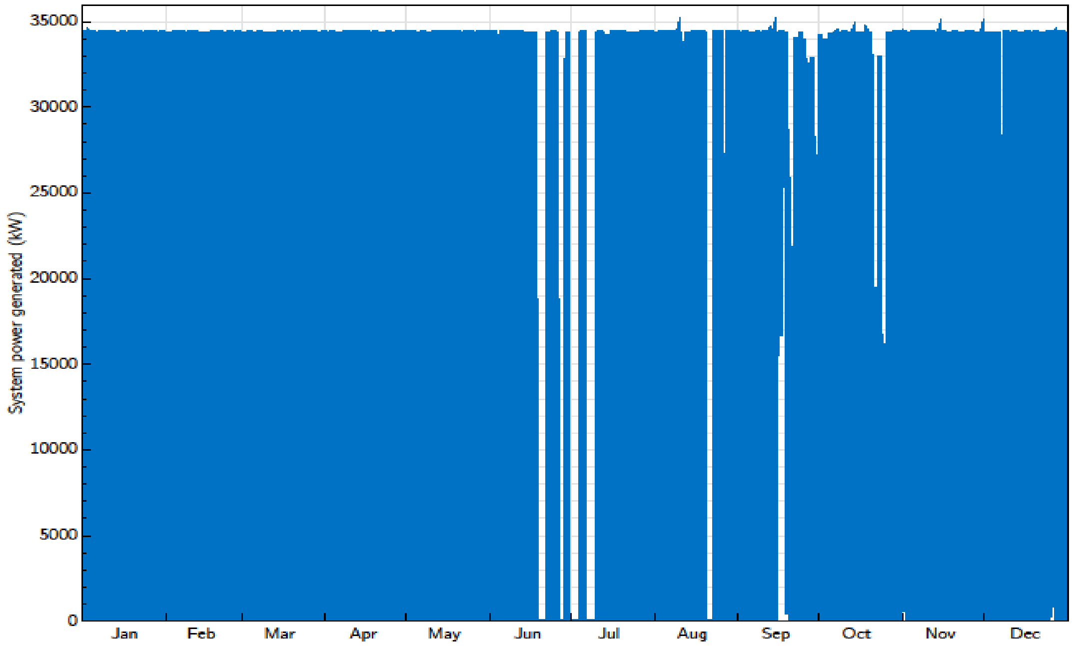

Figure 6. Power production from wind farm over a year at proposed site.

3.3 Hybrid system evaluation

By combining both solar and wind input parameters with Marco simulated parameter using generic system at the proposed project site location, it has been observed that nearly around 367844.44 MW of power can be generated with a capacity factor of 21.4%. Table 4 shows the simulation results for proposed hybrid system, while figure 7 and figure 8 shows monthly distributions of energy and power for the base case year 2018. A maximum monthly energy generation of 3.5 x 10^7 kWh in the month of May and a maximum system power production in the months of May, June and July around 150 MW can be clearly noticed.

Table 4. Simulation results of proposed 160 MW hybrid system.

Metric	Value
Annual energy (year 1)	367,844,448 kWh
Capacity factor (year 1)	21.4%

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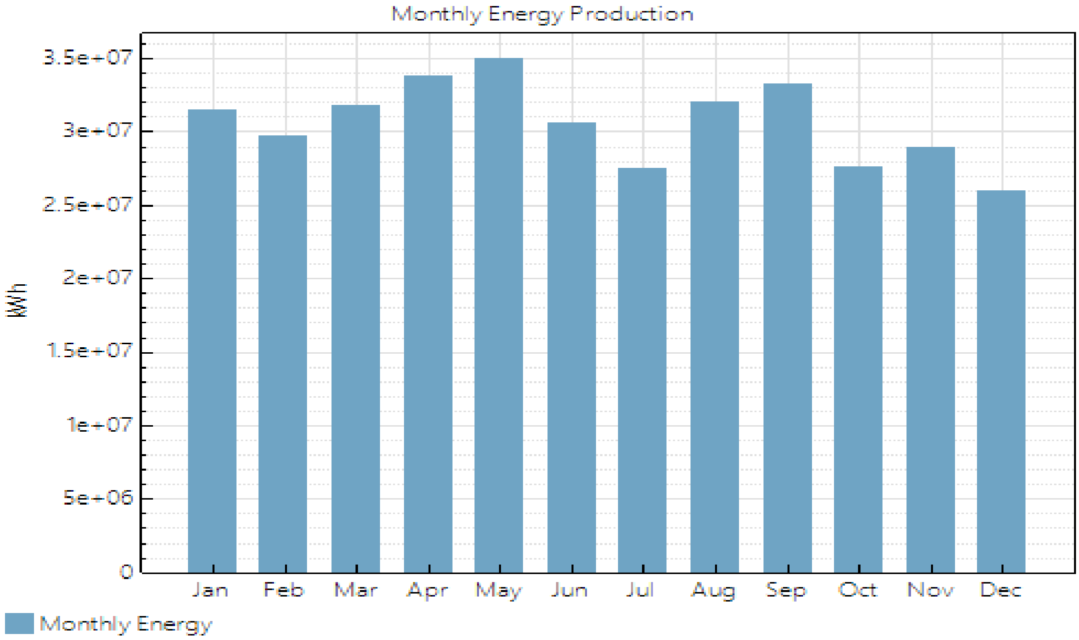

Figure 7. Simulated monthly energy generation of proposed hybrid system.

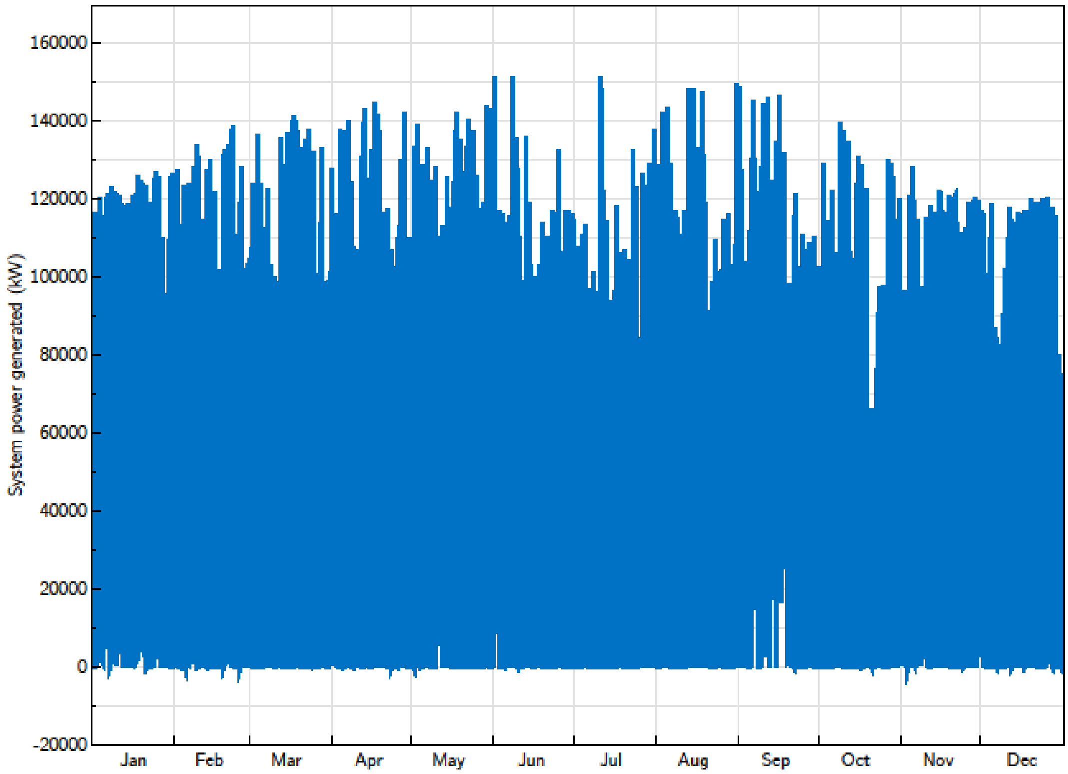

Figure 8. Simulated monthly power generation of proposed hybrid system.

4. Environment-Economic Evaluation

Hybrid power generation systems based on Solar PV and wind energy resources were recognized to be environmentally benign and sustainable with lower carbon footprint. Here environmental and economic evaluation of this hybrid system was carried out by considering technical characteristics and meteorological data of the proposed site in addition to other influencing aspects such as transportation, installation, operation and maintenance (O&M) costs using life cycle cost (LCC) assessment methods wherein costs incurred at each stage of system development, variation in O&M costs, tariff rates, discount rates and tax rates are taken into account in Indian context [7][8]. Further, this method considers all the costs involved, process flow and structure of the hybrid system by identifying energy supply, materials used, left out wastes to the environment before grid integration. The methodological analysis incorporated in this evaluation is based on the methodology outlined in [9] and the results obtained are presented in ensuing section.

5. Results and Discussion

The climatic condition at the proposed project site is favorable for the development of hybrid power generation based on solar as well as wind energy resources due to the abundance of sunshine and air flow throughout the year. The overall performance benefits and techno economic feasibility of the proposed 160 MW hybrid system are presented in the following subsections.

5.1 Energy yield estimation

In summary, the solar energy yield estimation is observed to be 241380.1 MWh per year using simulated software SAM whereas the theoretical estimation shows 2390174.5 MWh per year based on the methodology outlined [7]. Further, wind energy yield estimation is observed to be 126464.3 MWh per year using simulated software SAM whereas the theoretical estimations shows that wind energy is 128076 MWh per year. Finally, by integrating both solar and wind energy sources at the proposed location to form a hybrid energy source, estimates showed that 367844.4 MWh per year can be generated using SAM simulation software whereas theoretical estimations showed 367094.3 MWh indicating an efficiency of 15.9% and 15.8% respectively. The following table 5 shows a glimpse of energy yield estimation results that are obtained using manual and simulation approaches.

Table 5. Energy yield estimation results of the proposed hybrid system.

Source Mode	Manual energy yield outputs MWh/year	Simulated energy yield outputs MWh/year
Solar	239017.5	241380.1
Wind	128076.8	126464.3
Hybrid	367094.3	367844.4

5.2 Environmental benefits

Based on the methodological calculations outlined, and manual estimations were made and presented in table 6 which shows the resulting environmental benefits of the proposed 160 MW hybrid (solar-wind) system wherein one can clearly notice that the proposed project reduces the carbon footprint by saving 334281499 $kgCo_2$ while estimated saving based on SAM software simulations shows 334865340 $kgCo_2$. From economic point of view, the carbon benefit of the hybrid system is estimated to be nearly around 2.5 Cr/year.

Table 6. Environmental Benefit of system.

Estimation Methodology	Carbon Benefit (kgCo$_2$)	Carbon Benefit (Cr/year)
Using manual energy output data	334281499	2.5
Using simulated energy output data	334865340	2.5

5.3 Economic benefits

The Annual economic benefit of the proposed hybrid solar-wind energy system is calculated to be around 77.3 crores using methodological procedure outlined in [7] whereas it shows 77.5 crores based on SAM simulations. Further, the annual comprehensive benefit of the hybrid system is found to be around 80 crores based on the aforementioned methodological evaluation [7]. The following table 7 shows a glimpse of results that are obtained using manual and simulation approaches for assessment of economic benefit of the proposed system.

Table 7. Economic Benefit of the proposed hybrid system.

Estimation Methodology	Annual Economic Benefit of the system (Cr/year)	Annual Comprehensive Benefit of the system (Cr/year)
Using Manual energy Output	77.3	80
Using Simulated energy data	77.5	80

6. Conclusion

A well-designed hybrid power generation system based on solar and wind energy resources can be more consistent and economical which can significantly reduce not only fossil fuel consumption and associated carbon emissions but also offers fruitful economic benefits. The above results are shown by careful consideration of weather data, characteristics and losses of solar and wind energy resources over the proposed project site location using which one can predict the energy generation through hybrid system of similar kind along with procedures adopted for environmental and economic analysis. The study findings showed the techno economic and environmental feasibility of the proposed 160 MW hybrid power generation system with negative GHG emission. The present study can be extended by considering Battery Energy Storage System (BESS) and its sizing not only to meet Jawaharlal Nehru National Solar Mission (JNNSM) targets set by Indian government but also to meet prevailing demands in view of curtailment avoidance, deviation settlement avoidance, and ramp rate control towards grid stability for reliable power supply to consumers.

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