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Feasibility Analysis of PV-Biogas System with Different PV Tracking Mechanisms

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Abstract: Energy is the sole criteria for the development of any country. There are so many remote rural areas in India where the scope of conventional energy source is not a practical aspect. Hence it becomes the responsibility of researchers in this area to provide a feasible solution of renewable energy source in the particular region. The present paper is framed to meet this aspect by providing a hybrid photovoltaic (PV)-biogas (BG)-battery (BT) system for remote rural areas of Madhya Pradesh (M.P.) under dense forest cover. The modelling and simulation is done using HOMER software. The model is tested and optimized using fixed PV mounting structure, single axis tracking mechanism and dual axis tracking mechanism. A techno-economic analysis of the hybrid system for the above three cases is done. It is clearly found that in the hybrid configuration using dual axis PV tracking arrangement, the PV system rating requirement decreases by up to 20% and battery rating requirement decreases by up to 10% in comparison to the hybrid configuration using fixed mounting structure or single axis tracker arrangement. This reduces the total net present cost (NPC), levelized cost of energy (LCOE) and capacity shortage of the system.

Key words: Net present cost, hybrid, biogas, photovoltaic, optimization.

Introduction

Power sector plays a vital role in the growth of Indian economy and it is growing at rapid pace. The maximum scope of commissioning renewable energy systems lies in rural areas with large open spaces and where grid connectivity sometimes becomes difficult due to geographical boundaries like forests and hill cover. Selection of appropriate renewable energy resource depends on the ease of availability and its potential at the site. Since renewable energy sources like PV and wind are intermittent in nature, a hybrid system with more than one renewable resource proves more suitable than considering a single source. For example, a PV system is unfit during night hours and cloudy weather. Use of wind energy system is suitable and recommended mostly in hilly and coastal areas where there is enough wind potential to rotate the wind turbines. Similarly, biogas system proves inefficient without enough availability of animal waste, forest waste or crop residues. Most of the rural mass all over India is involved in agriculture, dairy farming or forestry. These activities generate a huge amount of biomass that can be used for generation of biogas.

The use of hybrid renewable energy and most preferably PV-Biogas system is discussed and recommended by many researchers (Bhatt et al., 2016; Sharma et al., 2016; Mishra et al., 2016; Singh et al., 2016; Lai et al., 2017) for remote rural areas. The system can serve the domestic load as well as the agricultural irrigation

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water pumping load (Purohit et al., 2005, 2007). The performance of the system can be further enhanced by using trackers with the PV panels. Use of single axis trackers has been shown (Deepthi et al., 2013; Sallaberry et al., 2015; Kumar et al., 2016; Elsherbiny et al., 2017) using different techniques like PLC's and microcontrollers. The performance of PV panels tends to increase by 10-15% by use of single axis trackers. Dual axis trackers have been modelled and tested by lot of researchers (Kamble et al., 2015; Mane et al., 2016) and its use is recommended as it increases the PV panel power output up to about 40% in some cases.

Considering the above-mentioned literature about hybrid renewable energy systems and the different tracking mechanisms, the major objective of the paper is to model a hybrid PV-Biogas system and test it with fixed PV mounting, single axis tracker and dual axis tracker using HOMER software. A techno economic comparison among the above three arrangements is further done to select the best possible choice for the present site location.

Case Study

The rural electrification process is going on rapidly in M.P. The total number of inhabited villages as per census 2011 is around 51,929. There are still 47 un-inhabited villages in M.P and around 56 villages are yet to be electrified. One such remote village under off grid electrification scheme is identified and considered for the case study.

Demographic Details of the Site

A case study on one of the villages in Seoni Malwa which is a tehsil block in the Hoshangabad district of M.P is considered. According to census 2011, there are 186 villages in this block. Most of the unelectrified villages mentioned below are under dense forest cover with marginal population. Three villages—Bent, Banspani and Gidkhera—have less than 30 households with a population of less than 200 people. Villages Palasi and Barasel have more than 40 households with a population of more than 300 persons. Village Amar-katara with 113 hectares of land having less than 40 households with a population of around 208 people is considered for the present study. Figure 1 shows the topographic view of the village.

Solar Potential at the Site

The state of Madhya Pradesh is bestowed with immense solar radiation of around 300 days of clear sun. The state has favourable sites having a potential of more

Figure 1: Topographic view of Amar-katara village.

than 5.5 kWh/m^2/day for installation of solar PV systems. The daily radiation curve (kWh/m^2/day) over a period of 12 months has been captured from NASA surface meteorology for Hoshangabad district in M.P. as shown in Figure 2, the annual average solar radiation is calculated as 5.14 kWh/m^2/day.

Biomass Potential at the Site

After a survey of all the domestic households, it was found that each house had at least 2 to 3 cows. A cow is expected to produce 8 to 10 kg dung every day. With around 94 cattle in all, around 950 to 1000 kg dung is available daily.

Load Estimation

Table 1 shows the primary load 1 which comprises the domestic load and energy consumption for a single household in the village area. The total energy consumed per day for a single household is approximately 2.58 kWh in summer and 1.38 kWh in the winter season. The number of households in the village as per census 2011 is 32. Considering around 40 households after future extension, the total domestic consumption of the village in summer season is 103.2 kWh and 55.2 kWh in winter season.

System Model

The hybrid PV-Biogas model shown in Figure 3 consists of a biogas generator (Bio), an electric load (Electric load #1) showing a domestic load of 100 kWh/d with a peak load of 12.4 kW connected to a alternating current (AC) bus. The photovoltaic (PV) system and lithium

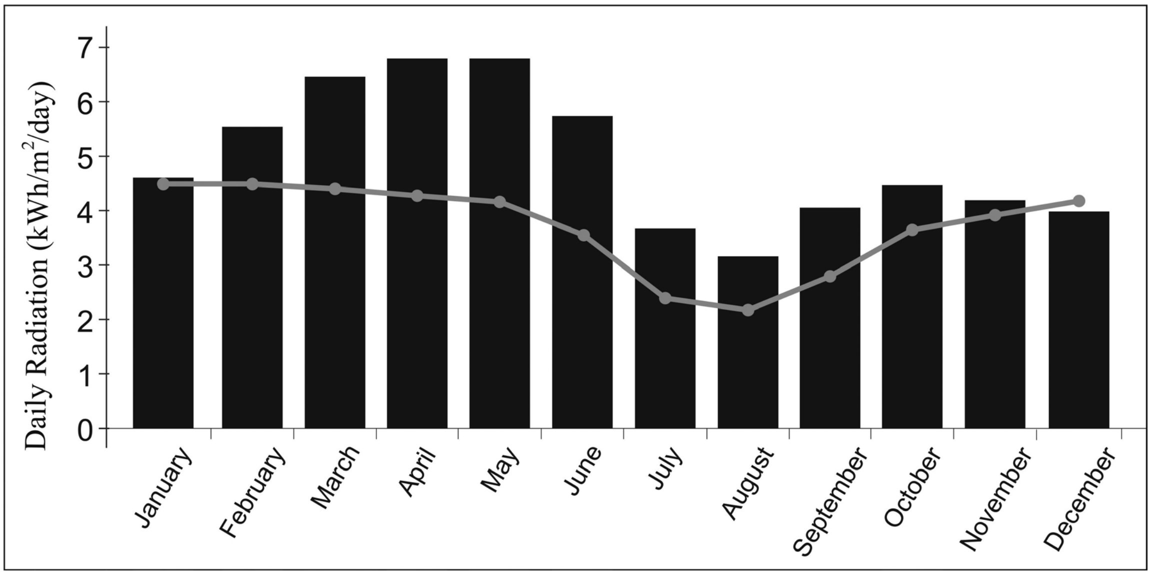

Figure 2: Daily radiation curve for the site.

Table 1: Domestic load and energy consumption per household

Domestic load	*No*	*Unit load (watts)*	*Summer (April-October)*		*Winter (Nov-March)*	
			Hours/day	*Watt-hours/day*	*Hours/day*	*Watt-hours/day*
LED tubelights	04	18	6	432	6	432
LED tubelights	01	18	16	288	16	288
Fan	02	75	8	1200	0	0
Mobile charger	02	5	6	60	6	60
Colour TV	01	100	6	600	6	600
Domestic load per household				2580		1380
Domestic load for 40 houses				103,200		55,200

ion battery (LI ASM) both are connected to the direct current (DC) bus. The converter is connected between both AC and DC buses.

According to the load estimation, the total energy requirement in a year is approximately 36,494 kWh.

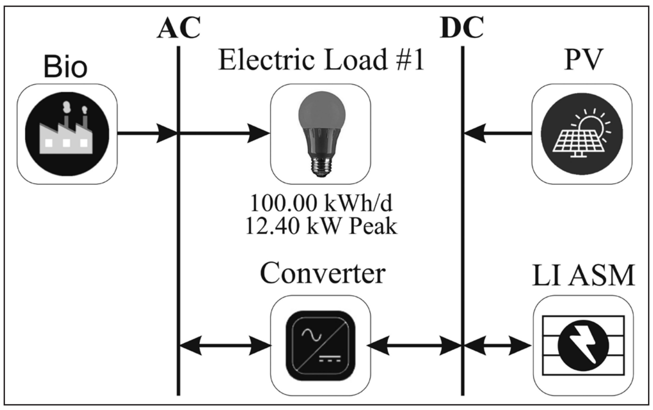

Figure 3: Schematic of the PV-BG-BT system.

PV System

A generic flat plate PV of 1 kW with a lifetime of 25 years, derating factor of 80%, a slope of 28.608 degrees and ground reflectance of 20% is considered. The panel efficiency at standard test conditions (STC) for a polycrystalline PV panel is 13%. The temperature coefficient for polycrystalline PV panels is –0.5% per °C over the scaled annual average solar irradiance of 5.14 kWh/m^2/day. Different PV system sizes (in kW) considered for study are 0 to 15 kW.

Converter

A converter can be used both as a rectifier or inverter. In the present case, an inverter is used since AC power output is required to serve the AC loads. For off grid systems the inverter must be considerable enough to handle the total amount of watts used at one time. The inverter size should be 25-30% greater than total watts of the appliances. A generic system converter having a lifetime of 15 years and efficiency of 90% is used. The inverter size can be calculated considering the total summer season load per day. For the present case an inverter of capacity ranging between 8 and 10 kW can be used. Different converter sizes (in kW) considered for study are 0 to 10 kW.

Lithium Ion Battery

A generic advanced lithium ion battery with nominal voltage 3.7 volts, nominal capacity 1 kWh and maximum capacity (Ah) as 276 with round trip efficiency of 92% and autonomy of three days is considered. The initial state of charge is 100%, the minimum state of charge is 20% and the capacity degradation limit is 30%. The battery type proposed for use in solar PV system is deep cycle battery as it has the advantage of being charged and discharged rapidly. The battery used should be large enough to store sufficient energy to operate the appliances during night hours and cloudy days.

Different battery sizes (in kWh) with string size of 65 considered for study are 0 to 10 kW.

Biogas Generator

The sizing of a biogas plant is based on three parameters—daily feed, retention time and digester volume. The biogas plant size is dependent on the average daily feed stock and expected hydraulic retention time of the material in the biogas system. The capacity of the plant indicates the quantity of gas produced in a day. A generic biogas generator of 1 kW with a lifetime of 20,000 hours and minimum load ratio of 50% is considered. The fuel biogas used has a lower heating value of 5.5 MJ/kg, density of 0.72 kg/m^3 and carbon content of 2%. The major constituent of biogas is typically carbon monoxide, hydrogen and carbon dioxide plus a significant amount of nitrogen (about 50% by weight) if thermal gasification is performed in the presence of air. Minor constituent gases include methane and water vapour. The biogas generator sizes considered for the present case are 0 to 15 kW.

Methodology

For the present study, HOMER pro tool is used to perform simulation and optimization of the proposed setups. Homer executes a time-series (hourly) simulation that can consolidate the effects of ambiguities of different input variables such as the size of the load, fuel price and availability of resources. The above tool checks for the feasibility of the system model. The system is declared feasible only if the generation meets the energy required by the connected loads. For each component, Homer combines the capital, replacement, maintenance and fuel costs along with the salvage value to find the component's annualized cost. This value is an important one because the software uses it to calculate the two major economic figures of merit for the system: NPC and the LCOE. Homer uses the equation (1) to calculate the total net present cost:

$$NPC \text{ (in Rs)} = \frac{(AC)_{tot}}{CRF} \quad (1)$$

where $(AC)_{\text{tot}}$ is the total annualized cost in rupees which is the sum of the annualized costs of each system component. The capital recovery factor (CRF) is given by equation (2):

$$CRF = i(1 + i)^n/(1 + i)^{(n-1)} \quad (2)$$

where n is the number of years and 'i' is the annual real interest rate (%).

NPC computation in Homer also takes into account salvage costs, which is the residual value of power system components at the end of the project lifetime. It estimates salvage value based on replacement cost instead of initial capital cost. Equation (3) is used to calculate salvage value (S) (Dalton et al., 2009; Aziz et al., 2017):

$$S \text{ (in Rs)} = C_{rep} \frac{R_{rem}}{R_{com}} \quad (3)$$

where S is the salvage value, C_{rep} is the replacement cost of the component, R_{rem} is the remaining life of the component and R_{comp} is the lifetime of the component. Homer uses the following equation (4) to calculate the LCOE.

$$LCOE \left(\text{in} \frac{\text{Rs}}{\text{kWh}} \right) = \frac{(AC)_{tot}}{T_{pri} + T_{def}} \quad (4)$$

where $(AC)_{tot}$ is the total annualized cost, T_{pri} and T_{def} are the total amounts of primary and deferrable load respectively that the system serves per year.

System Optimization

Using Homer software, the modelled hybrid PV-Biogas system is tested with three PV mounting arrangements—fixed structure, single axis tracker and dual axis tracker. With each mounting arrangement, the sizing of the components to meet the required load changes. Also the energy generated by the system and cost of the system varies for different arrangements. The initial cost of investment for a single axis tracker is 10%-15% more and for dual axis tracker is 25% more than the fixed mounting structure. The tracking arrangement requires regular maintenance of gears and moving parts might need to be changed from time to time. Repair and replacement may occur in the longer run with tracker arrangement. Table 2 shows the optimal unit cost of each component used in different configurations.

Table 2: Optimal unit cost of each component

Component	*Capital cost (Rs./kW)*	*Replacement cost (Rs/kW)*	*O&M cost (Rs./kW/ year)*
PV without tracker	60000	60000	60
PV with single axis tracker	70000	70000	80
PV with dual axis tracker	75000	75000	100
Biogas generator	70000	70000	Rs. 0.5/kW/ hour
Converter	16000	16000	0
Battery	39000	39000	0

Results Using Comparison of Models

A comparison based on the cost, energy produced and CO_2 emissions is done so as to decide on the best suitable configuration for the present study.

System Sizing and Cost Comparison

Cost is the prime deciding factor when it comes to choosing a particular renewable energy model. The obvious reason being that the initial cost of investment in any renewable energy resource is very high. Homer gives a detailed cash flow summary considering all the cost parameters as capital, replacement, operating and salvage costs. Table 3 shows the sizing of each component using different PV mounting arrangements. It is found that using dual axis tracker, the PV size requirement reduces by around 20% in comparison to fixed mounting and single axis tracking arrangement. Figures 4, 5 and 6 show a detailed cash flow summary for PV-BG-BT system using fixed PV mounting structure, with single axis tracking and with dual axis tracking respectively. Table 4 shows the cost summary of the different configurations taking the NPC and LCOE. It is observed that using dual axis tracking arrangement the system has least NPC of Rs. 39.4 lakhs and LCOE of Rs. 8.354, followed by fixed mounting structure. The NPC and LCOE for single axis tracker is the highest.

Table 3: Optimal size of each component

Model	*PV (in kW)*	*BG (in kW)*	*Battery (in kWh)*	*Converter (in kW)*
PV-BG-BT without tracker	12	9	7	8
PV-BG-BT with single axis tracker	12	9	6	10
PV-BG-BT with dual axis tracker	10	9	6	8

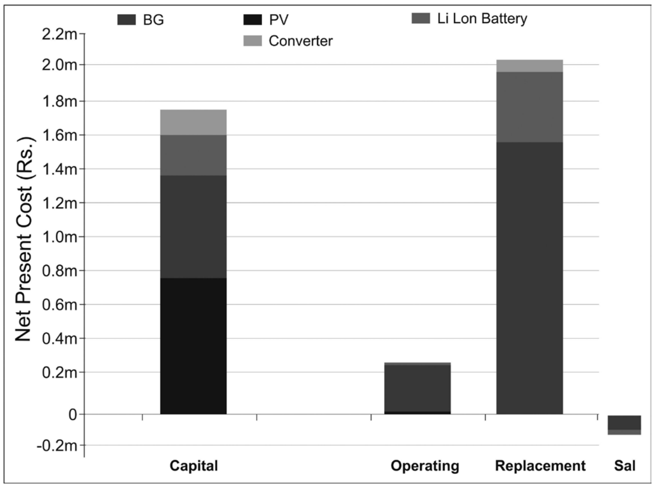

Figure 4: PV-BG-BT system without tracker arrangement.

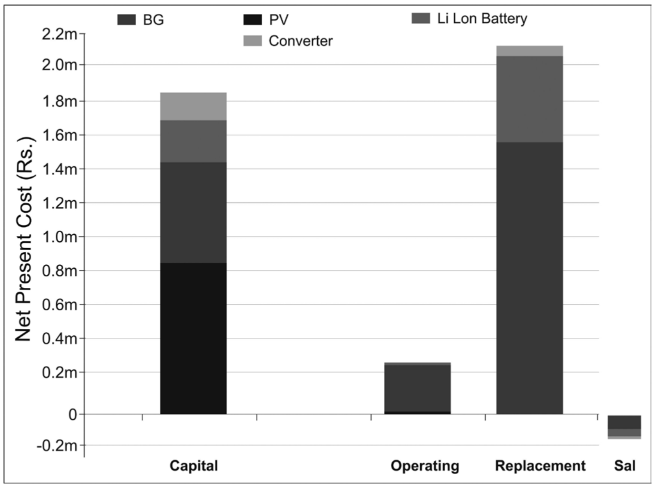

Figure 5: PV-BG-BT system with single axis tracker arrangement.

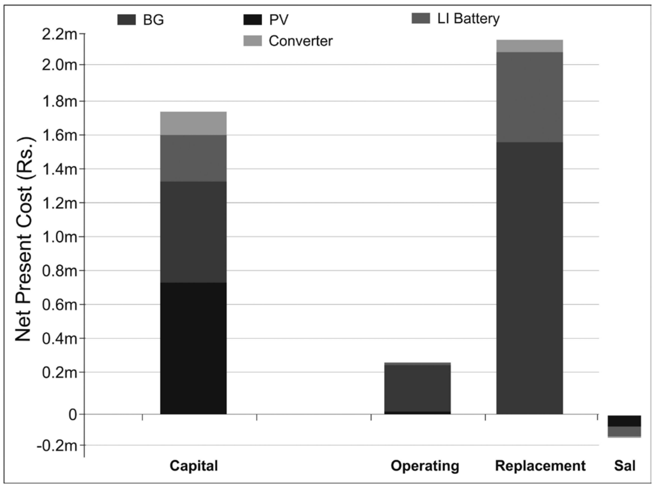

Figure 6: PV-BG-BT system with dual axis tracker arrangement.

Table 4: Cost summary of different configurations

Model	*Total NPC (Rs. in lakhs)*	*LCOE (Rs./kWh)*
PV-BG-BT without tracker	40.4	8.565
PV-BG-BT with single axis tracker	41.4	8.776
PV-BG-BT with dual axis tracker	39.4	8.354

Energy Comparison

The energy comparison is done to evaluate the production of electrical energy from the two sources PV and biogas for different configurations. It is shown in Table 5 that in the PV-BG-BT with dual axis tracker arrangement, the PV system generates the maximum energy of 23,877 kWh with a capacity shortage of 22 kWh/year. In the PV-BG-BT configuration without tracker arrangement, the PV system generates the least energy of 17,701 kWh/year with a capacity shortage of 28 kWh/year.

Table 5: Energy comparison of different configurations

Model	*Components*	*Production (kWh/year)*	*Renewable fraction*	*Capacity shortage (kWh/year)*
PV-BG-BT without tracker	PV	17701	42	28
	BG	24588	58	
PV-BG-BT with single axis tracker	PV	18,945	44	26
	BG	24,414	56	
PV-BG-BT with dual axis tracker	PV	19,023	44	22
	BG	23,877	56	

Emission Comparison

The exact composition of biogas generated is dependent on the raw material being used. In the case of cow dung, biogas is a mixture of gases composed of methane (CH_4), carbon dioxide (CO_2), hydrogen (H_2) and hydrogen sulphide (H_2S). The major chunk of emissions comprises CO_2 gas. It is seen that with tracker arrangement, the PV panels perform better and hence produce more energy and so there is less burden on biogas generation unit. As shown in Table 6, the CO_2 emissions in the PV-BG-BT with dual axis tracker arrangement are 13 kg/year in comparison to 14 kg/year for other two configurations.

Table 6: Emission comparison of different configurations

Model	*CO_2 emissions (kg/year)*
PV-BG-BT without tracker	14
PV-BG-BT with single axis tracker	14
PV-BG-BT with dual axis tracker	13

Conclusion and Recommendations

Considering the geographical limitations of the remote villages under dense forest cover, an off grid renewable energy system offers the best feasible solution to electrify such locations. Looking at the present state-of-the-art and availability of local resources such as solar energy and cow-dung, a hybrid Photovoltaic-Biogas-Battery (PV-BG-BT) system is proposed for un-electrified remote villages in Hoshangabad district in M.P. The hybrid PV-BG-BT system is tested using three different PV structure mountings—fixed structure, single axis tracking and dual axis tracking mechanism. Using Homer optimization software, a clear picture on economics, energy produced and emissions is sought for three different configurations contemplated in the study. After a comparative study of the three, it is found that PV panels with dual axis tracker arrangement perform better than fixed structure and single axis tracking arrangement. The energy produced in the PV-BG-BT with dual axis tracker arrangement is the highest and hence the total NPC along with LCOE is lowest for the above in comparison to PV-BG-BT with fixed PV structure and with single axis tracker arrangement. Moreover the level of CO_2 emissions for PV-BG-BT with dual axis tracker is lower in comparison to the other two configurations.

From the analysis of results considered, it is observed that PV-BG-BT system with dual axis tracking mechanism is a better choice in comparison to single axis and fixed structure arrangement as it is more reliable, economical and ecofriendly; therefore is recommended for the present site location. Furthermore, the system can be tested for variations in domestic and deferrable load considering a larger population. The same model can be used with any other renewable resource like wind or hydro as per the availability and tested for some other remote location. The system can also be tested with different types of batteries available in the market.

References

Aziz, A. (2017). Techno-economic analysis using different types of hybrid energy generation for desert safari camp in UAE. *Turkish Journal of Electrical Engineering & Computer Sciences*, **25:** 2122-2135.

Bhatt, A., Sharma, M.P. and R.P. Saini (2016). Feasibility and sensitivity analysis of an off-grid Micro Hydro–Photovoltaic–Biomass and Biogas–Diesel–Battery Hybrid Energy System for a remote area in Uttarakhand state, India. *Renewable & Sustainable Energy Reviews*, **61:** 53-69.

Dalton, G.J., Lockington, D.A. and T.E. Baldock (2009). Feasibility analysis of renewable energy supply options for a grid-connected large hotel. *Renewable Energy*, **34:** 955-964.

Deepthi, S., Ponni, A., Ranjitha, R. and R. Dhanabal (2013). Comparison of efficiencies of single-axis tracking system and dual-axis tracking system with fixed mount. *International Journal of Engineering Science and Innovative Technology*, **2(2):** 425-430.

Elsherbiny, M.S., Wagdy, A.R., Ismail, H.M. and A. Mikhail (2017). Design of single-axis and dual-axis solar tracking systems protected against high wind speeds. *International Journal of Scientific & Technology Research*, **6(9):** 84-89.

Kamble, S., Chavan, V., Mestry, A. and N. Patil (2015). Dual axis solar tracking system. *International Journal of Innovations in Engineering Research and Technology*, **2(4):** 1-9.

Kumar, M.A. and T.S. Arjun (2016). Design of single axis solar tracking system using PLC. *Middle-East Journal of Scientific Research*, **24(2):** 1-5.

Lai, C.S., Jia, Y., Xu, Z., Lai, L.L., Li, X., Cao, J. and M.D. Mcculloch (2017). Levelized cost of electricity for photovoltaic/biogas power plant hybrid system with electrical energy storage degradation costs. *Energy Conversion and Management*, **153:** 34-47.

Mane, P. and A. Dhumal (2016). Dual axis solar tracking system comparative study and mechanical design implementation. *International Journal of Mechanical and Production Engineering*, **4(7):** 29-32.

Mishra, S., Panigrahi, C.K. and D.P. Kothari (2016). Design and simulation of a solar–wind–biogas hybrid system architecture using Homer in India. *International Journal of Ambient Energy*, **37(2):** 184-191.

Purohit, P. and T.C. Kandpal (2005). Solar photovoltaic water pumping in India: A Financial Evaluation. *International Journal of Ambient Energy*, **26(3):** 135-146.

Purohit, P. and T.C. Kandpal (2007). Techno-economics of biogas-based water pumping in India: An attempt to internalize CO_2 emissions mitigation and other economic benefits. *Renewable & Sustainable Energy Reviews*, **11:** 1208-1226.

Sallaberry, F., Nadal, R.A., Larcher, M. and M.H.R Frank (2015). Direct tracking error characterization on a single-axis solar tracker. *Energy Conversion Management*, **105:** 1281-1290.

Sharma, R. and S. Goel (2016). Stand-alone hybrid energy system for sustainable development in rural India. *Environment, Development and Sustainability*, **18(6):** 1601-1614.

Singh, S., Singh, M. and S.C. Kaushik (2016). Feasibility study of an islanded microgrid in rural area consisting of PV, wind, biomass and battery energy storage system. *Energy Conversion Management*, **128:** 178-190.

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