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Feasibility Analysis of Solar-Biomass Based Standalone Hybrid System for Remote Area

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Abstract: In India, around 70% of the population is living in remote areas and is not able to get proper electricity from utility grid. Around 20% of the total population has no access of electricity at all, which is not commendable for any developing country like India. Most of the electricity requirement is fulfilled by diesel generator only which is not a feasible solution because of fuel cost, greenhouse gas emission etc. Therefore, there is a need of an alternative solution for power generation in such remote areas. In view of the above, the feasibility analysis of renewable energy based hybrid system has been carried out for a remote area of district Sonipat, Haryana, India. In this study, major renewable energy sources including solar, wind, biomass and small hydro are considered to perform the feasibility analysis. A standalone hybrid model based on solar-biomass is found the feasible and viable option. The cost of power generated from proposed hybrid model is $ 0.086 per unit and is almost free from greenhouse gas emission which is at par in cost with the conventional supply and better in terms of clean production. Such hybrid systems can be very useful for electrification of other similar remote areas.

Keywords: Renewable Energy, Solar Photovoltaic, Biomass, HOMER, Greenhouse Gas Emissions

1. Introduction

India is a developing country having a population of around 1.3 billion [1] living in urban, semi-urban and remote areas. As on 31st December, 2015, most of the remote areas are electrified but around 20% [1] of the total population is not able to get the access of utility grid because of many reasons [1]. The Government of India is planning to provide "Power to all" by 2019 [1]. However, there are many challenges in achieving the target.

India has an installed capacity of 302087.84 MW as on 31.03.2016 with approximately 13% share of renewable energy sources [2]. But the share of renewable energy can be enhanced by tapping more and more available renewable energy sources. The contribution of various conventional sources and renewable energy sources (RES) in the present power system is shown in Figure 1 and Figure 2 respectively.

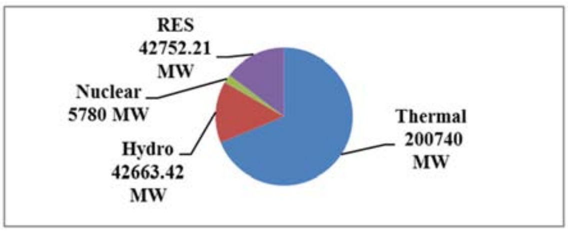

Figure 1. *Contribution of various conventional sources [2].*

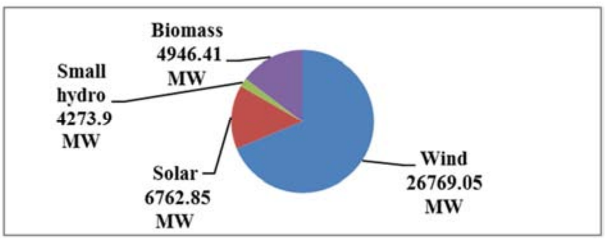

Figure 2. *Power generated from renewable energy sources in India [2].*

However, there is a lot of potential available to generate power from renewable energy sources that needs to be harnessed properly. The potential of various renewable energy sources and their status as on 31.03.2016 is also presented in Table 1.

Table 1. *Potential of different renewable energy sources and their Exploitation.*

Sources	Potential (MW) [3]	Installed capacity (MW) as on 31.03.2016 [2]	Balance (MW)
Solar energy	1500000	4878.87	1495121.13
Wind energy	300000	25088.19	274911.81
Biomass	23000	4677.63	18322.37
Small hydro	15000	4176.82	10823.18
Total	1838000	38821.51	1799178.49

From Table 1 it can be observed that there is a lot of scope of tapping renewable energy sources to generate electrical power. It can be a boon for those places where grid supply is not available or not possible. From the literature review, it is revealed that the hybrid system could be a better solution for electrification as the power generated from renewable energy is fluctuating in nature and it requires a backup for continuous power supply. In addition, hybrid system offers higher reliability and lower power generation cost as compared to a system using single source of energy [5-9].

Exploration and utilization of renewable energy sources is the need of hour for the sustainable growth of mankind. A lot of research work [10-23] has been done in this direction. Researchers have used numerous simulation techniques and devised methods, to explore various types of renewable energy sources to produce electricity, by taking case studies of different remote areas [10-23].

M AElhadidy andS MShaahid [10] have performed the feasibility analysis of hybrid energy systems for Dhahran of Saudi Arabia on the basis of hourly mean data for solar radiation and wind speed for the year 1986-1993 obtained from meteorological monitoring station. Based upon the availability of resources, the hybrid system consisting of two wind energy conversion system (WECS) of 10 kW, solar photovoltaic (SPV) panels of 120 square meter along with a battery and a diesel generator (DG) system as a back-up.

M JKhanand M TIqbal [11] used HOMER (Hybrid Optimization Model for Electric Renewable) software to perform pre-feasibility analysis of a standalone hybrid wind-DG-SPV system along with battery and fuel cell as storage system for a remote house of Newfoundland, Canada in order to meet energy requirement of 25kWh/day and a peak load demand of 4.73kW and found the hybrid wind-DG-battery system to be most suitable solution for the given area.

HOMER tool was also used by S Rehman et al. [12] to carry out the pre-feasibility analysis of adding wind energy system into an existing grid connected diesel power plant to power a village located in Saudi Arabia. G Bekele and B Palm [13] examined the possibility of providing electricity to remotely located community of 200 families in Ethiopia through hybrid solar-wind system.

An analytical study for the electrification of a remote area named Kakkavayal in Kerala, India has been done by S Kumaravel and S Ashok [14] by employing HOMER software. The result shows that the hybrid system comprising of SPV/pico-hydel/ biomass to meet the load demand is a better option than the existing pico-hydel/diesel system.

The possibility of hybrid wind/SPV/DG system to power a remotely located area in Fiji island was explored by S Lal and A Raturi [15] using HOMER software. The study reveals that the hybrid system comprising of a SPV of 200 kW; DG of 170 kW along with battery is most feasible only if there is no capacity shortage, whereas for capacity shortage of 10%, fully renewable energy-based configuration is feasible.

A HAl-Badi and HBourdoucen [16] performed feasibility analysis of adding wind energy system into an existing diesel power plant for supplying electricity to an isolated area Al Duqm in Oman and found that adding wind with the existing diesel power plant does not affect much on net present cost (NPC) and cost of energy (COE) as for the diesel only system.

M S H Lipu et al. [17] presented feasibility analysis of a hybrid wind/SPV/DG system for rural areas of Bangladesh using HOMER. The analysis shows that the electricity generated annually from wind, DG and SPV is 45%, 36% and 20% respectively. The optimized wind-SPV-DG hybrid system has less NPC and COE in contrast to wind-DG and SPV-DG system. The proposed hybrid system will also diminish the emission of carbon dioxide by 37% in the local atmosphere compared to electricity drawn from national grid.

A techno-economic analysis of SPV/wind/biogas engine hybrid system for supplying electricity to a village in Kenya has been done by S G Sigarchian et al. [18]. The results in terms of NPC, COE and capital cost indicate that the biogas engine can be a better solution as a backup system in place of a diesel engine. The contribution of power generated by SPV is 49%, biogas is 32% and wind is 19%. Moreover, the system was environment friendly as it avoids production of carbon dioxide. Rahman et al. [19] also suggested a similar hybrid energy system to provide lighting and cooking facility to households in Bangladesh on the condition that if there are at least three cattle per household.

A V Anayochukwu [20], V AAni and BAbubaka [21], S GoelandR Sharma [22] S Bhardwaj and S K Garg [23] have also carried out similar such simulation studies by using HOMER software to perform the feasibility analysis in identifying the suitable hybrid energy systems for providing electricity to different locations.

Keeping in view all of the above, major renewable energy sources like solar, wind, biomass and small hydro are considered to develop a feasible solution for a considered remote area. In the present work, a standalone hybrid model based on solar and biomass is proposed on the basis of availability of resources, cost of energy (COE) and green house gas (GHG) emissions. However, other renewable energy sources like wind energy and small hydro are also available but not sufficient to generate efficient and reliable power. In this work, a case study of a hospital located in Khanpur Kalan village of district Sonipat, Haryana, India has been considered. At present the proposed site has no access of power, even through diesel generator (DG) set. Therefore, it is of utmost importance to develop a system, which may fulfill the electricity requirement of the hospital to serve the patients in a better way.

2. Potential of Different Renewable Energy Sources at Study Area

The first step to design and develop a renewable energy based system at a particular site is to perform the feasibility analysis on the basis of availability of resources and their ability to generate efficient and reliable power. Therefore, the data regarding potential of major available renewable energy sources i.e solar energy, wind energy, biomass and small hydro at proposed site has been collected and is presented in the following sections.

2.1. Solar and Wind Energy Potential

The solar radiation and wind speed data for the different months of the year has been collected from different sources [24-25] for longitude (76^0.99' E) and latitude (29^0.00' N) and time zone (GMT+05:30) and is presented in Table 2.

Table 2. *Monthly solar data and wind speed at the proposed site [24-25].*

Month	Clearness index	Solar radiation (kWh/m^2/day)	Wind speed (m/s)
January	0.615	3.742	2.78
February	0.624	4.553	3.14
March	0.629	5.570	3.37
April	0.621	6.375	3.81
May	0.607	6.738	4.32
June	0.595	6.770	4.64
July	0.543	6.091	4.02
August	0.539	5.678	3.31
September	0.635	5.911	3.07
October	0.656	5.077	2.26
November	0.643	4.076	2.05
December	0.605	3.442	2.44
Average	0.605	5.34	3.27

From the above Table, it has been estimated that the annual average global solar radiation is 5.34kWh/m^2/day which is good enough to generate the power efficiently. It is further observed that the solar radiation is maximum in the month of June of 6.770 kWh/m^2/day while it is least in the month of December of 3.442 kWh/m^2/day. The global horizontal solar daily radiation for the proposed site is shown in Figure 3.

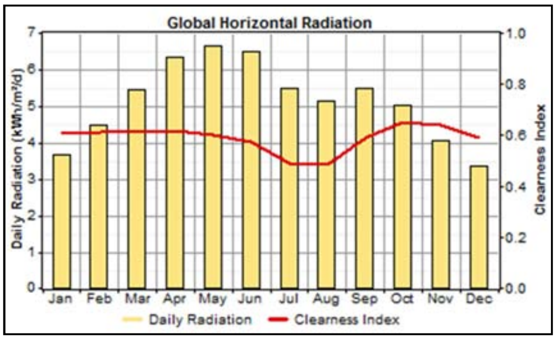

Figure 3. *Daily average global horizontal solar radiation for the proposed site.*

Further, an average annual wind speed is 3.27 m/s, which is relatively low for the power generation. Therefore, this study has not considered wind energy as a source of power generation for the identified site.

2.2. Biomass Potential

The sources of biomass are mainly crop residues, wood biomass and animal dung which are widely available in the remote areas. In this study, the woody biomass, crop residues, animal wastes from buffaloes, sheep, goats, pig and poultry etc. have been taken into consideration. The description of the various sources is presented in Table 3.

Table 3. *The number of animals at proposed site as per census 2012.*

Description	Cow	Buffaloes	Sheep	Goat	Pig	Poultry
Number of cattle	231	3347	123	17	60	10
Dung (Kg/day/cattle) [26]	10	15	1	1	2.25	0.12
Dung availability (kg/cattle/day)	2310	50205	123	17	135	1.2
Total dung (Kg/day)	52791.2					

The availability of animal dung in the study area is about 52791.2 kg/day. The biogas production evaluation is based on the animal dung obtained from different animals and it is estimated that 1 kg of animal dung can produce 0.036 m^{3}of biogas [27] and 0.8 m^{3}of biogas is necessitated to generate 1kW electricity [23]. The availability of biogas in the study area is 1900.4832 m^3/day through which we can generate about 2375 kW of electricity.

2.3. Small Hydro Potential

It has been found that the available hydro power resource is very small and is far away from the proposed site and therefore not considered in this work.

3. Electrical Load Assessment

The Government hospital building consists of three rooms having two fans 60 watt each and two fluorescent lamps of 20 watt each. The medical equipment, lightning and other devices with their power consumption ratings are given in Table 4.

Presently, the proposed site is not connected with the grid supply and even DG set or any other mode of power supply. Therefore, the hourly load assessment has been done on the basis of available connected load and as per information provided by the staff of the proposed hospital. The daily load profile for summer and winter season are shown in Figure 4 and average daily load profile for different months of the year for the proposed site is depicted in Figure 5.

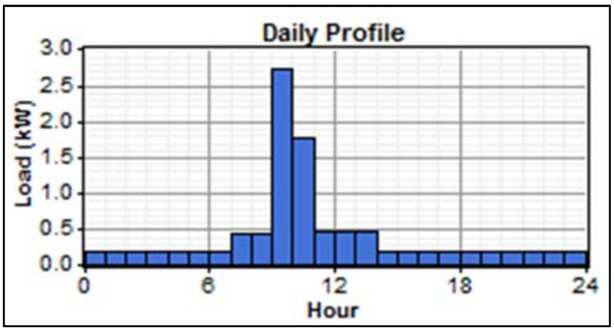

Figure 4(a). *Daily load profile for summer season.*

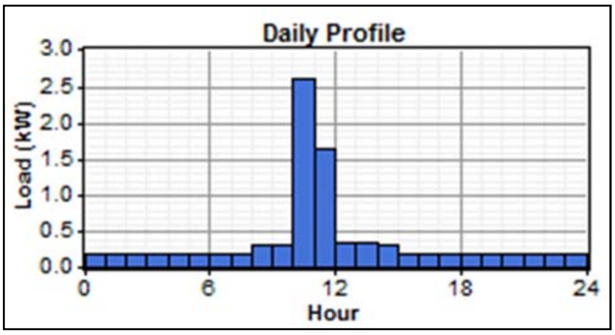

Figure 4(b). *Daily load profile for winter season.*

Table 4. *The electrical load data for the proposed site.*

Components	Power rating (watt)	Quantity	Total watt	Operating hours/day		Daily energy consumption Watt hour	
				Summer season	Winter season	Summer season	Winter season
Fan	60	02	120	07	00	840	00
CFL	20	02	40	04	04	120	120
Refrigerator	200	01	200	24	24	4800	4800
Thawing machine	100	01	100	01	01	100	100
Sterilizer	2000	01	2000	01	01	2000	2000
Centrifuge	850	01	850	01	01	850	850
Dehorner	200	01	200	01	01	200	200
Needle destroyer	60	01	60	01	01	60	60
Microscope	360	01	360	01	01	360	360
Electrical weighing machine	80	01	80	01	01	80	80

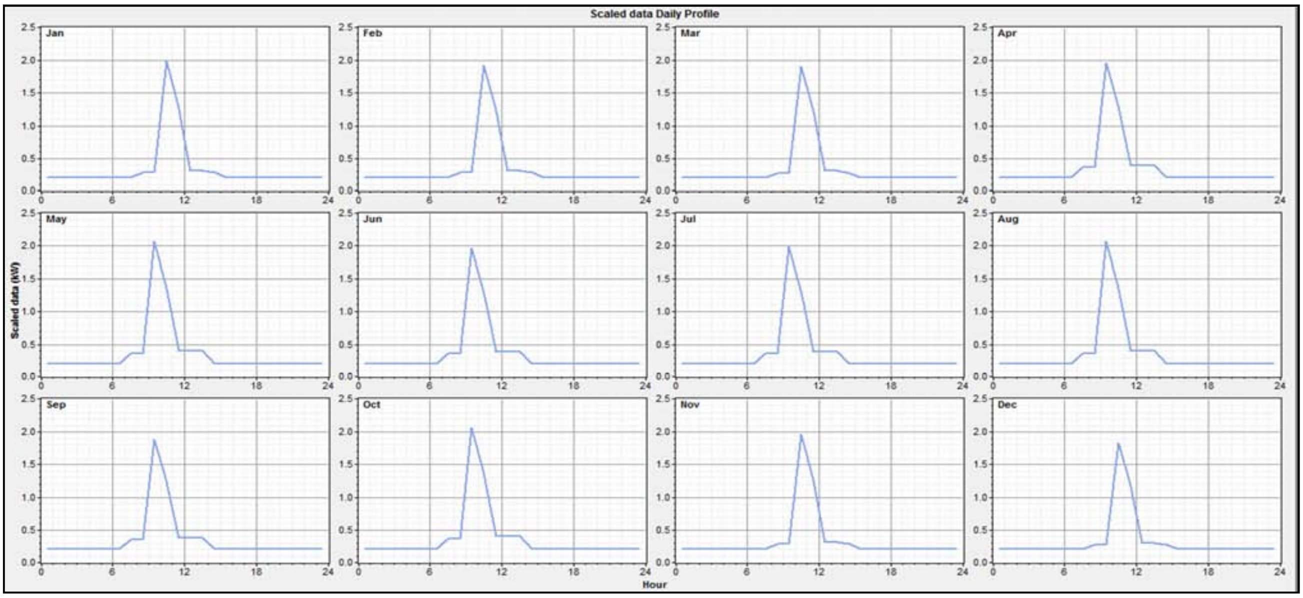

Figure 5. *Average daily load profile for different months of the year.*

4. Hybrid System Components

In order to design a feasible hybrid model various components viz. SPV system, biomass generator, battery, diesel generator and converter are selected and shown in Figure 6.

Hybrid Optimization Model for Electrical Renewable (HOMER) software [24] has been employed for the simulation and optimization purpose. The technical and economical information such as cost, size, lifetime etc. of each component required to be specified for designing hybrid model in HOMER is presented in Table 5.

Based on the availability and potential of renewable energy resources, feasibility analysis of standalone hybrid model comprising of SPV system and biomass generator along with battery is proposed for electrification of proposed site. The schematic diagram of the proposed standalone hybrid model is shown in Figure 7.

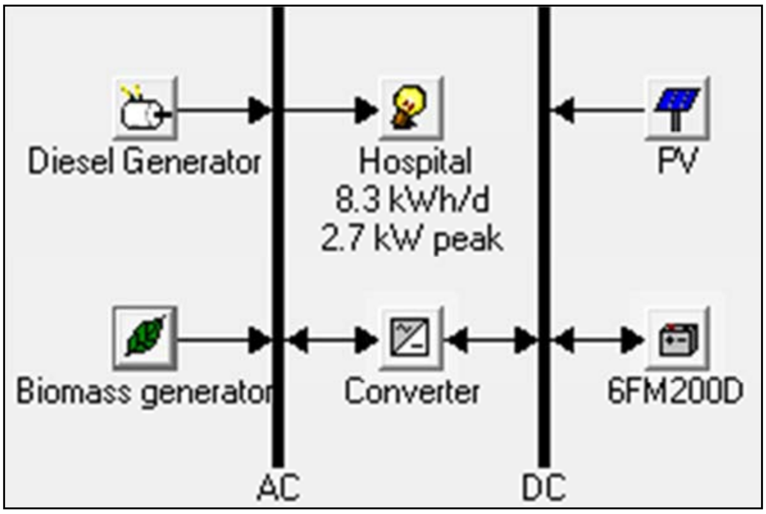

Figure 6. *Schematic diagram of the proposed hybrid model.*

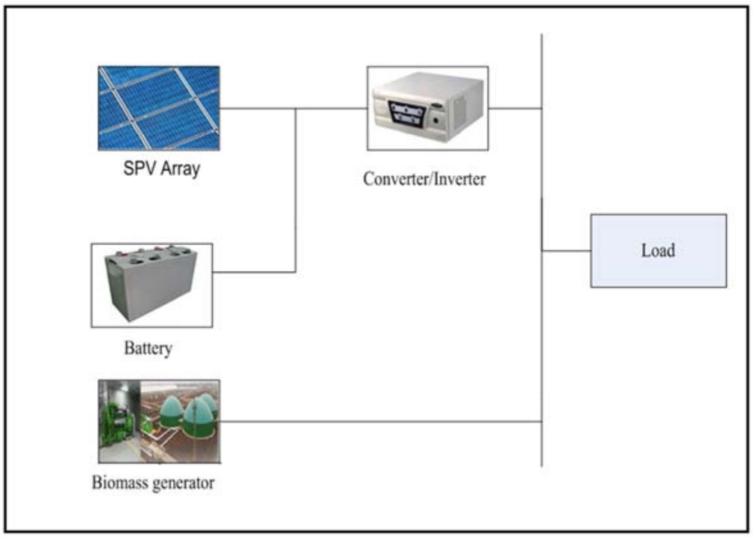

Figure 7. *Schematic diagram of proposed standalone hybrid model for study area.*

Table 2. *Technical and economical parameters required in HOMER.*

Hybrid system component	Parameter	Value
SPV	Capital cost	650 $/kW
	Replacement cost	0 $/Kw
	O&M cost	1$/kW
	Size to consider	0, 2, 3, 3.5, 4, 5, 7, 8
	Lifetime	25 years
	Derating factor (%)	80%
	Slope	0 degree
	Azimuth	0
	Ground reflectance	20 %
	Tracking system	No
Biomass generator	Capital cost	250 $/kW
	Replacement cost	150 $/kW
	O&M cost	0.08 $/kW
	Size to consider	0, 2, 2.5, 3, 3.5, 4, 4.5, 5
	Lifetime	20000 hours
	Minimum load ratio	30 %
	Biomass cost	$ 3.75/ tone

Hybrid system component	Parameter	Value
Diesel generator	Capital cost	180 $/kW
	Replacement cost	0 $/kW
	O&M cost	0.05 $/kW
	Size to consider	0, 2.7, 3, 4, 5
	Lifetime	20000 hours
	Minimum load ratio	30 %
	Diesel fuel cost	0.75 $/litre
Battery	Capital cost	150 $/kW
	Replacement cost	30 $/kW
	O&M cost	1 $/kW
	Size to consider	0-8 quantity
	Nominal voltage	12 V
	Nominal capacity	200 Ah
	Lifetime throughput	917 kWh
	Minimum state of charge	40%
	Round trip efficiency	80%
	Float life	10 years
Converter	Capital cost	190 $/kW
	Replacement cost	190 $/kW
	O&M cost	0 $/kW
	Size to consider	0, 2, 2.7, 3, 3.5, 4, 5
	Lifetime	20 years
	Inverter efficiency	95%
	Capacity relative to inverter (%)	100%
	Rectifier efficiency	85 %
Project parameter	Project lifetime	25 years
	Annual rate of interest	0%
	Operating reserve as % of hourly load	10%
	Operating reserve as % of solar power output	25%
	Dispatch strategy	Cycle charging with 70% setpoint state of charge

5. Results and Discussion

Based on the availability of energy sources at the proposed site, the optimal solution has been obtained on the basis of net present cost (NPC), cost of energy (COE) and green house gas (GHG) emissions.

The net present cost (NPC) is the present value of all costs including capital cost, replacement cost, operation and maintenance (O&M) cost, fuel costs etc. of the system acquire over its lifetime minus the present value of all revenue (salvage value) that it earn over its lifetime. The cost of energy (COE) is the average cost for each unit (kWh) of generated electricity by the system [24]. Further, all feasible system configurations with their technical and economical parameters are given in Table 6-Table 8.

Table 6. *Rating of components and economic parameters of feasible system configurations.*

Description	Parameter	SPV/biomass generator with battery	SPV with battery	SPV/DG set with battery	SPV/biomass generator	Biomass generator	SPV/DG set
System rating	SPV (kW)	2	7	3.5	5	--	8
	Biomass generator (kW)	2	--	--	2.5	3	--
	DG (kW)	--	--	2.7	--	--	2.7
	Battery	6	6	7	--	--	--
	Converter (kW)	2	3	3	2	--	3
Economic	Total capital cost ($)	3080	6020	4381	4255	750	6256
	Total NPC ($)	6537	7251	8015	34278	58356	62746
	Total annualized capital cost	123	241	175	170	30	250
	Total annual replacement cost	58	59	65	105	180	23
	Total O & M cost ($)	100	13	31	1098	2102	682
	Total fuel cost ($)	2	0	69	11	23	1572
	Total annualized cost ($)	261	290	321	1371	2334	2510
	Cost of energy ($/kWh)	0.086	0.096	0.106	0.451	0.769	0.826

From Table 6, it is observed that the hybrid SPV/biomass with battery system has lowest net present cost (NPC) of

$6537. It is followed by SPV with battery system of $7251, SPV/DG set with battery of $8015. But the configurations without battery storage system have many times (6 ~8) more costs as compared to those with battery, such as; SPV/biomass generator of $34278, biomass generator of $58356 and SPV/DG set without battery of $62746 respectively. The cost of energy (COE) of hybrid SPV/biomass with battery system is $ 0.086/kWh while it is 0.096, 0.106,

0.451, 0.769, 0.826 for SPV with battery system, SPV/DGset with battery, SPV/biomass generator, biomass generator and SPV/DG set without battery respectively. However, there are some other performance parameters such as operational hours, fuel consumption, biomassconsumption, battery autonomy and expected life of components etc. which are also important to be considered to find out a reliable system. These factors of each feasible configuration are shown in Table 7.

Table 7. *Performance parameters of biomass generator, DG set and battery of feasible system configurations.*

Component	Description	SPV/biomass generator with battery	SPV with battery	SPV/DG set with battery	SPV/biomass generator	Biomass generator	SPV/DG set
Biomass Generator	Biomass generator fuel consumption (tonne/year)	0.483	--	--	3.05	6.06	--
	Hours of operation (hour/year)	572	--	--	5466	8760	--
	Biomassgenerator start (start/year)	263	--	--	548	1	--
	Biomass generator operational life (year)	35.0	--	--	3.66	2.28	--
DG set	DG set fuel Consumption (liter/year)	--	--	91.1	--	--	2096
	Hours of operation (hour/year)	--	--	152	--	--	4994
	DG set start (start/year)	--	--	50	--	--	517
	DG set operational life (year)	--	--	132	--	--	4
Battery	Battery autonomy (hour)	24.9	24.9	29.1	--	--	--
	Battery annual throughput (kWh/year)	1338	1154	1471	--	--	--
	Energy in (kWh/year)	1493	1289	1642	--	--	--
	Energy out (kWh/year)	1197	1032	1315	--	--	--
	Storage depletion (kWh/year)	3	2	2	--	--	--
	Losses (kWh/year)	294	255	325	--	--	--
	Expected life (year)	4.11	4.77	4.37	--	--	--

Table 8. *Electrical power production of feasible system configurations.*

Parameter	SPV/biomass generator with battery	SPV with battery	SPV/DG set with battery	SPV/biomass generator	Biomass generator	SPV/DG set
SPV array (kWh/year)	3114 (76%)	10898 (100%)	5449 (96%)	7785 (65%)	--	12455 (75%)
Biomass generator (kWh/year)	988 (24%)	--	--	4158 (35%)	8554 (100%)	--
DG set (kWh/year)	--	--	236 (4%)	--	--	4068 (25%)
Total electrical power production (kWh/year)	4102 (100%)	10898 (100%)	5685 (100%)	11942 (100%)	8554 (100%)	16524 (100%)
Renewable fraction (%)	100	100	95.8	100	100	75.4
Unmet electric load (kWh/year)	0.00000748 (0%)	1.17 (0%)	0.00000705 (0%)	0.00000226 (0%)	0 (0%)	0.00000954 (0%)
Excess electricity (kWh/year)	592 (14.4 %)	7447 (68.3 %)	2144 (37.7%)	8818 (73.8%)	5518 (64.5%)	13388 (81%)
Capacity shortage (kWh/year)	0.244 (0%)	2.15 (0.1%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)

From Table 7, it is revealed that the hybrid SPV/biomass with battery system has least engine operating hours of 572 hours/years, biomass consumption of 0.483 tonne/year and battery autonomy of 24.9 hours. Therefore, the proposed solar-biomass standalone hybrid system is costeffective and reliable as compared to other possible configurations. The result also shows that the battery input of proposed system is 1493kWh/year and battery output is 1197kWh/year. The difference occurs due to losses occurred in charging, discharging (294kWh/year) and storage depletion (3kWh/year). The expected lifetime of battery is 4.11 year.

In addition, the share of electricity production of each component during one year, total electricity production, renewable fraction, excess electricity with unmet load of all different system configurations are depicted in Table 8.

In the proposed configuration, the share of SPV array and biomass in total power generation during one year operation is 3114 kWh/year (76%) and 988 kWh/year (24%) with total electricity production of 4102 kWh/year. The monthly average electricity production in SPV/biomass generator set with battery hybrid system is illustrated in Figure 8.

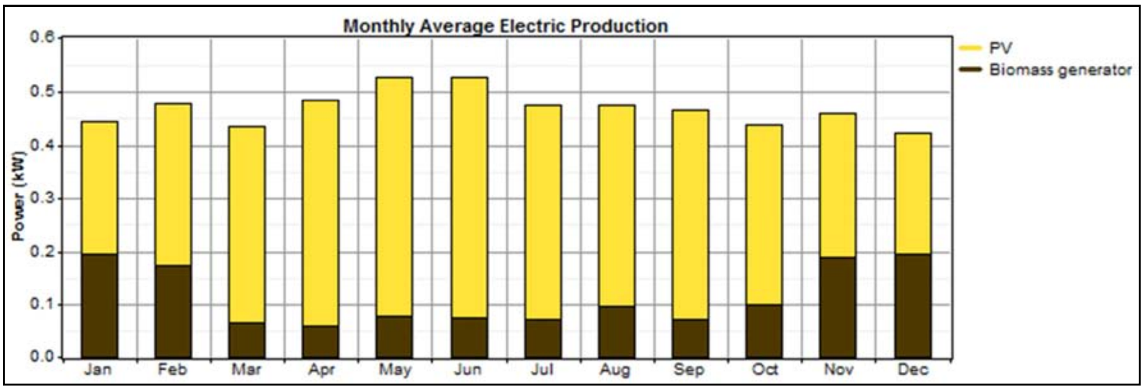

Figure 8. *Monthly average electricity production of SPV/biomass generator with battery system.*

The renewable fraction of this system is 100% which signifying share of renewable energy sources to the total electricity production. The excess electricity, unmet electrical load and capacity shortage of proposed hybrid system is 592kWh/year (14.4%), 0.00000748 kWh/year (0%) and 0.244 kWh/year (0%), respectively that indicates the proposed system can also meet the increased future demand with almost zero electrical load which is not able to serve by the system. Further, the cash flow summary by cost type of the suggested hybrid model is depicted in Figure 9.

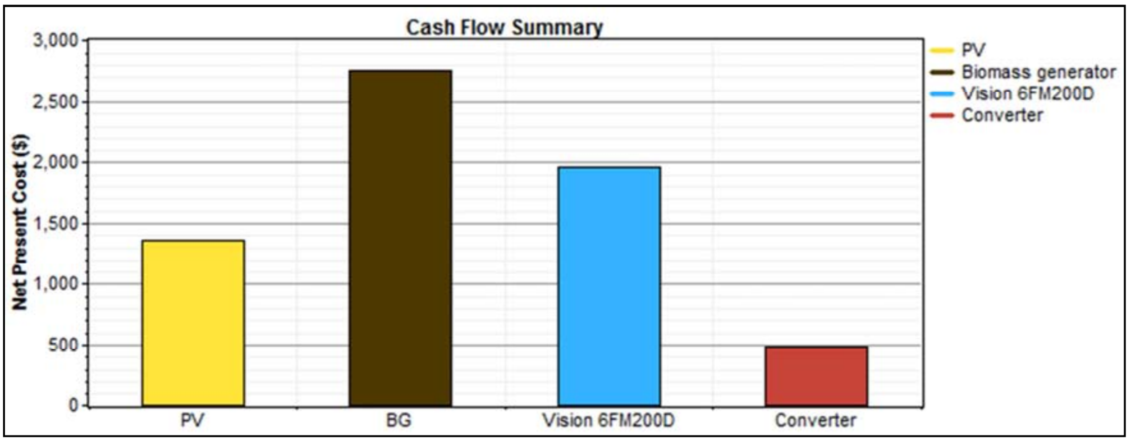

Figure 9. *Cash flow summary of hybrid SPV/biomass generator with battery model interms of cost.*

This figure reveals that most of the capital cost is due to SPV array followed by battery, biomass generator and converter respectively. The replacement cost is due to batteries and converters as they are required to be replaced throughout the project's lifetime. The majority of operating cost is because of biomass generator due to its fuel cost and remaining is due to battery and SPV. The fuel cost in the cash flow summary is due to the assumed cost of biomass. The cash flow summary of the proposed system by each component type is illustrated in Figure 10.

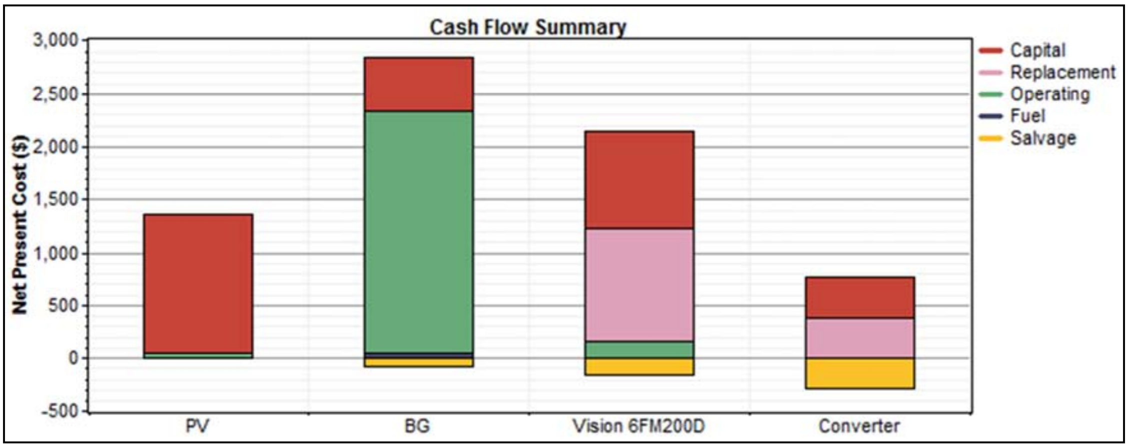

Figure 10. *Cash flow summary of hybrid SPV/biomass generator with battery system in terms of component.*

It is evident from Figure 10 that the operating cost of biomass generator is higher than its capital cost. On the other hand, the other components have higher capital cost than operating cost.

Green House Gas Emission Analysis

Now days, a large hue and cry are being raised about the increasing amount of greenhouse gases which are polluting our environment and causing various health problems. Burning of fossil fuels is one of the major reasons of production of these gases. Therefore, greenhouse gas emission analysis is also carried out and presented in Table 9 for the proposed model.

Table 9. *Green house gas emission of feasible system configurations.*

Pollutant emission	SPV with battery	SPV/biomass generator with battery	SPV/biomass generator	Biomass generator only	SPV/DG set with battery	SPV/DG set
Carbon dioxide (CO_2) emission (tonnes/year)	0	0.000615	0.00388	0.00771	0.242	5.518
Carbon monoxide (CO) emission (tonnes/year)	0	0.00000314	0.0000198	0.0000394	0.000597	0.0136
Unburned hydrocarbons (UHC) emission (tonnes/year)	0	0.000000348	0.00000219	0.00000436	0.0000662	0.00151
Particular matter (PM) (tonnes/year)	0	0.000000237	0.00000149	0.00000297	0.000045	0.00103
Sulpher oxide (SO_x) (tonnes/year)	0	0	0	0	0.000486	0.0111
Nitrogen oxide (NO_x) (tonnes/year)	0	0.000028	0.000177	0.000351	0.00533	0.122

From Table 9, it can be observed that the proposed hybrid model SPV/biomass with battery has almost negligible greenhouse gas emissions.

6. Conclusion

In the present work, feasibility analysis of a standalone solar-biomass based hybrid power system has been undertaken for a remote area of district Sonipat, Haryana, India. The purpose of this study is to devise a suitable system to provide reliable electrical power supply to a proposed hospital. At present there is no electricity supply to the hospital and even through diesel generator set. The proposed model will be able to provide a reliable power supply to the hospital at a cost of $0.086/kWh with almost zero green house gas emissions. Therefore, this study will play a significant role for the electrification of the hospital and thus will help its users in a great way for rural electrification. Similar such studies can be conducted for other remote areas fortheir electrification and would also be helpful in achieving the target of Government of India “Power to all”.

Abbreviations and Symbols

AC	Alternating current
CFL	Compact fluorescent lamp
CO	Carbon monoxide (Tonnes/year)
COE	Cost of energy ($/kWh)
CO_2	Carbon dioxide (Tonnes/year)
DC	Direct current
DG	Diesel generator
GHG	Greenhouse gas
HOMER	Hybrid optimization model for electric
NO_x	Nitrogen oxide (Tonnes/year)
NPC	Net present cost ($)
O&M	Operation and maintenance
PM	Particulate matter (Tonnes/year)
RES	Renewable energy sources
SO_x	Sulfur dioxide (Tonnes/year)
SPV	Solar photovoltaic
UHC	Unburned hydrocarbons (Tonnes/year)

Greek Symbols

$	Dollar
%	Percentage

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