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Techno-Economic Analysis of PV-Biomass Based Microgrid for University Campus

Journal of Electrical Systems

Abstract: - The cost effective, green and technically consistent energy to fulfil the 511.61 kWh per day load demand of a hostel of the university has been evaluated in this paper. The techno-economic analyses of a Solar (PV) and biomass generators based stand alone and grid connected microgrids are performed to ensure uninterrupted power supply. The utilization of agriculture waste to tackle the stubble burning of crop residues in nearby area has been considered for electricity generation through biomass and to reduce the environment pollution and various global warming factors. A 27.6 kW solar array, 62 kW biomass generator, 27.2 kW converter and 38 lithium-ion batteries for standalone grid and 62 kW biogas generator, 26.3 kW PV array and 18.8 kW system converter for grid-connected system has been considered to carry out the load demand of 60.34 kW as peak load and 511.61 kWh/d as average consumption of energy throughout the year. The analyses shows that 79.1% electricity generated through biomass and 20.1% by PV for 100% renewable based standalone microgrid system, while 91.9% energy generated from renewable sources in grid connected system. The energy cost for standalone and connected grid, microgrid systems were $0.187/kWh and $0.148/kWh, each. The standalone microgrid system have lesser CO2 emission compared to the grid connected system, whereas grid connected system provides cheap and reliable supply by selling excess energy to the grid.

Keywords: Biomass, Solar, Microgrid, Battery, HOMER, Optimization

1. Introduction

Most of the developed countries are converging for generating electricity from non-conventional energy sources instead by using fossil fuels. The impacts of generating power from fossil fuels on environment is major concern for any country. Solar and biomass grid connected, and standalone hybrid renewable energy systems ensures uninterrupted power supply and reduce greenhouse gases. On the basis of land mass area in the world, India is the seventh largest country. In India 1043.24 million tonne crop residue has been produced on annual basis [1]. But the major concern is the utilization of this crop residue. Majority of the farmers will burn this residue which creates huge pollution. Punjab and Haryana creates about 30% pollution in Delhi NCR in the months of October-December by burning of crop residues. 7.93 million metric tonnes and 20.17 million metric tonnes crop residue has been generated from rice, paddy straw in Haryana and Punjab respectively[2]. The govt. authorities are in search to avoid this burning of residues by providing subsidies to the farmers on several equipment to manage crop residues. Mitigation approach has been proposed by the researchers to reduce the pollution[3]. Paddy straw is most common source to generate electricity through biomass power plants in Punjab. There are several crops having high calorific values can be used to generate electricity throughout the year such as popular leave, pulse, maize and bagasse etc.[4]. In the present research/scenarios the electrification of rural areas has been done through hybrid renewable systems based on biomass for off grid and on grid systems. The PV and biomass-based hybrid energy system is found more economical and feasible after comparing with other hybrid systems in Punjab[5]. The cost of energy for biomass-solar assisted power plant is lower than only biomass-based plant. The economic feasibility is also higher in solar assisted based biomass plant[6]. The sensitive investigation shows that the PV, biomass and battery based system is more sensitive towards deviations in price of biomass, solar radiation, annual rate of interest, annual capacity storage and lifetime of biomass gasifier[7]. A hybrid system consisting of biomass, PV, wind and battery storage can be used to electrification of rural areas where electricity is not accessed or the areas which are connected to an unbalanced distribution grid. The probability of loss of power is zero in the proposed microgrid system[8]. Many areas in the world having worst condition of power infrastructure with poor reliability. The utility face high losses in the transmission and distribution in order to supply electricity in those areas. But these sites are having very good resources for renewable energy systems like solar radiation for solar plant, agriculture waste for biomass-based plant etc. So it is easy to implement such hybrid renewable system in

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that areas to minimize the losses and improve the reliability[9]. In the developing countries the extension of grid to the remote rural areas is very expensive, but biomass based decentralised mini grid system is an alternative and reliable solution in such areas. The availability of biomass material is often easy and high because agriculture is the major living activity in these areas. Many key features like socio economic, financial, technical and organizational had been assessed and found favourable to the system[10]. The hybrid renewable energy system (HRES) based on biomass can attain sustainability in rural areas where untapped agriculture waste is effective to meet the demand of clean and stable energy[11].

As per the above discussed merits of electricity generation through biomass-based plants, it is clear that the performance of grid can be improved in rural areas and pollution creates while burning of crop residues can be minimized.

1.1 Literature review:

The biomass-based HRES can build a cost-effective approach to fulfil the load demand. Due to the advantages of HRES, various hybrid energy techniques have been implemented through artificial bee colony (ABC) algorithm, Hybrid Optimization Model for Energy Resources (HOMER), mixed integer linear programming (MILP) model in the literature section [12-31]. A meticulous review of numerous configurations of renewable energy systems, types of batteries, cost of energy (COE), status of grid connection, software used and site selection, which were executed by different researchers for generation of power, have been shown in Table 1. These studies comprise of off grid and grid connected hybrid electricity generating plants across various countries. A detailed analysis has been performed based on the different parameters such as cost per unit, environmental aspects etc. Different combinations of power plants have been evaluated with energy storage batteries to fulfil the demand of various types of loads.

Table 1 Summary report of different RES Configurations, grid/off grid status, storage types, location of project, software used and the cost of energy.

Ref	**Author Name/Year**	**Cost of Energy**	**Grid/ Off grid**	**Storage**	**Load type**	**Location**	**Software**	**System type**
[12]	Qudratullah Tayyab et al., 2024	0.190 $/kWh	Off grid	Battery Energy Storage System (BESS)	Rural Area	Kandahar, Afghanistan	HOMER	PV, Diesel
[13]	Sheikh Suhail Mohammad et al, 2024	0.0171 $/kWh	Grid connected	BESS	Urban Apartment building	India	Optimization using HOMER Software	PV
[14]	Badis Bacha et al., 2024	0.09138 $/kWh	Off grid	Battery Bank	Rural Area	Biskra, Algeria	Stochastic fractal search algorithm	PV, Wind, Diesel
[15]	Md. Mustafa Kamal et al., 2023	0.14 $/kWh	Off grid	Battery Bank	Village	Uttrakhand, India	Differential Evolution	PV, Wind, Biogas, Hydro
[16]	Arashdeep Singh et al., 2022	0.0737 $/kWh	Grid connected	Lead Acid Battery	Village (225 Houses)	India	Artificial BEE Colony (ABC) Algorithm	PV, Biogas, Gasifier

[17]	Loiy Al-Ghussain et al., 2021	0.1626 $/kWh	Off grid	Pumped Hydro Storage System	University Campus Building	USA	Generalized Reduced Gradient Algorithm	PV, Wind, Biomass
[18]	Arashdeep Singh et al., 2021	0.089 $/kWh	Grid connected	Battery Bank	Village	Punjab	Artificial BEE Colony (ABC) Algorithm	Biomass, PV
[19]	Shereefdeen Oladapo Sanni et al., 2021	0.164 $/kWh	Grid connected	Trojan IND17-6V Industrial Line Flooded Battery	Domestic	Ekiti, South-West Nigeria	HOMER	PV, Biogas
Ref	**Author Name/Year**	**Cost of Energy**	**Grid/ Off grid**	**Storage**	**Load type**	**Location**	**Software**	**System type**
[20]	Arun Kumar et al., 2021	0.108 $/kWh to 0.154 $/kWh	Grid connected	BESS	School, Hospital, Hostel	India	Mixed Integer Linear Programming (MILP) Model	Solar, Biomass, DG
[21]	Ling Ji et al., 2021	0.275 $/kWh	Off grid	Battery	Village	China	Mixed Integrated Linear Programming (MILP) Model	PV, Biomass, DG, Gas boiler
[22]	Fahad Ali et al., 2021	0.072 $/kWh and 0.145 $/kWh	Grid Connected and Off Grid	Lead acid batteries	Village	Pakistan	Homer Pro	Solar, Wind, Biomass, DG
[23]	David Ribo-Perez et al., 2021	0.06 $/kWh	Off Grid	Battery Pack	Rural	Honduras and Zambia	HOMER	Biomass Gasifier
[24]	Arun Kumar et al., 2020	0.127 $/kWh	Grid connected	BESS	Educational, Industrial, Hospital	India	Mixed Integer linear Programming (MILP) Model	Solar, Biomass, DG
[25]	Jitendra Kumar et al., 2019	8.48 Rs/kWh	Grid connected	BESS	Village	UP, India	HOMER	Solar PV

[26]	Jameel Ahmad et al., 2018	0.05744 $/kWh	Grid connected	Battery Bank	Village	Pakistan	HOMER Pro	Wind, PV, Biomass1
[27]	Yingying Zheng et al., 2018	0.04 $/kWh	Grid connected	Battery Bank	Domestic	USA	Load Shifting Algorithm, Monte Carlo Simulation	PV, Biomass

1.2 Novelty and contributions:

The techno economic survey has been done in the literature section to find the suitable optimal match of various renewable based energy systems to meet the demand without any interruption with energy storage devices for both grid connected as well as for standalone grids. Ample studies have been conducted to determine the optimal configurations of various HRES regarding economic viability and reliability. However, no authors have focused to perform techno-economic analyses considering PV and biomass based microgrid system utilizing the crop residue of the agriculture waste in nearby area to fulfil the load demand a hostel. The primary contributions of this work are summarized as follows:

- To develop an optimal model for both standalone and grid connected microgrid systems utilizing PV and biogas energy resources alongside a battery bank for urban and rural areas.
- To evaluate the performance of proposed microgrid system using realistic load profiles, credible resource data, and actual component pricing.
- To determine the optimal sizes of the components in the proposed system while minimizing the cost of energy and total net present cost.
- To assess the potential impact and effectiveness of the proposed microgrid systems in leveraging biomass to reduce environmental pollution.
- To conduct a technoeconomic analysis comparing the performance of grid connected and standalone microgrid systems.

The structure of this article is as follows: section 2 discusses the resources data and energy scenario at selected location, section 3 presents the modelling of microgrid components, section 4 present estimated load profile. Section 5 and 6 contain simulation results, discussions and conclusions respectively.

2. Energy scenario and assessment of resources:

Haryana, a northern state of India, covers 1.34% (44212 km^2) of total land area of the country. The population of Haryana was 25.3 million which was 2.09% of total Indian population[28]. The selected site in this study is Boys Hostel-1, K. R. Krishnan block of Deen Bandhu Chottu Ram University of Science and Technology which is located in the Sonipat district of state Haryana. It lies between 29°1′38″ N latitude and 77°3′44″ E longitude. The installed capacity of electricity in Haryana is 3.53% of the total installed capacity of India and the consumption of electricity in Haryana is much higher (189%) than the national average in terms of per capita. The land has been thriving with solar and biomass energy. Majority of the population (65.12%) of Haryana living in rural areas, which totally depends on agriculture and cattle stock to fulfil their daily needs. The selected site is surrounded by the rural area where majority of people depend on agriculture and milk dairies. Wheat, rice, mustard and vegetables are the leading crops cultivated in that area. As a detailed survey was conducted, the surrounded area comprises of 3000 buffaloes and cows, 300 pigs, 200 poultry and 500 pet animals approximately according to the data collected.

The total dung collected from these animals is around 13750 kg and approximately 0.6–0.8 m^3 of biogas can be produced by one kg of animal dung. Hence the total energy produced by 0.6–0.8 m^3 of biogas is 1.5 kWh. Peoples are also using the cow dung in their yields as a fertilizer and dunk cakes for cooking purposes in homes, about 5000 kg of animal manure has been wasted. This can be used to produce biogas and 5000 kg can produce about 7500 kWh of electricity. Other than animal manure it has been studied that 2 kWh of energy can be generated by 1 m^3 of biogas and 240 m^3 of biogas can be generated by one ton of crop residue by anaerobic digestion. Hence, the average biomass of crop residues and animal manure available is approximately 320 kg/month throughout the year. The availability of biomass during the year is shown in figure 1. The data of solar irradiation for the selected site, which is located at 29.1° latitude and 77.53° longitude, has been gathered from the NASA (National Aeronautics and Space Administration). The site area is having around 320 sunny days in the year, which produce strong solar energy potential. The global horizontal irradiance (GHI) of solar is 250.64 W/m^2 which is maximum in the month of June with ambient temperature of 40.06°C. The solar radiation around 0.8 kW/m^2 is available throughout the year as shown in figure 2.

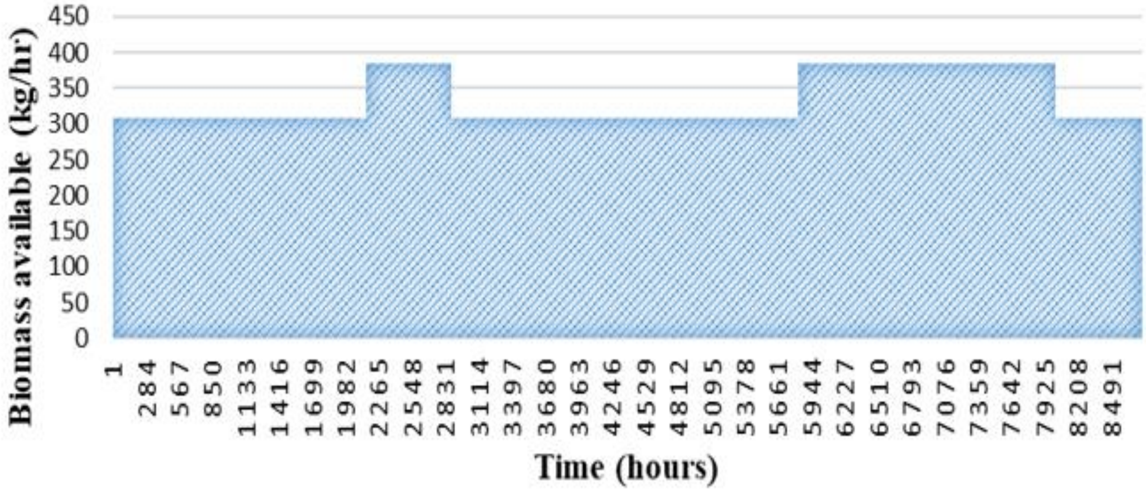


Figure.1 Biomass available during the year

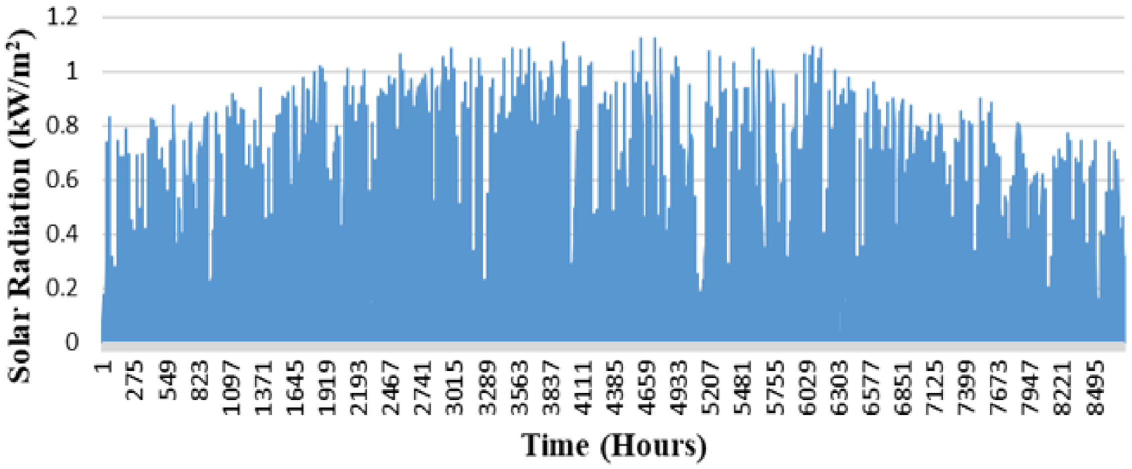


Figure. 2 Solar GHI (Global Horizontal Irradiance) available in a year

3. Modelling of microgrid components:

A microgrid is a bunch of distributed energy resources (DERs) such as microturbines, diesel/biogas generators, photovoltaic systems, bi-directional inverters with energy storage devices and load demands, which are situated closer to the customer, and perform as a single well-regulated unit with reverence to the grid. A microgrid system having various components and energy sources is shown in fig. 3.

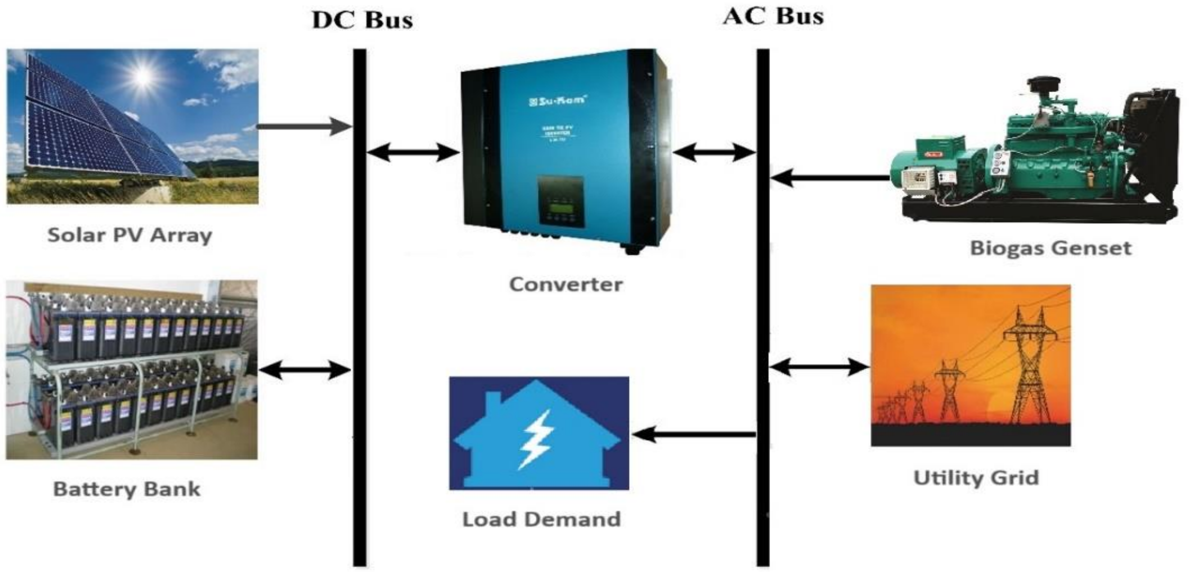


Figure. 3 Schematic of a microgrid system with hybrid supply of PV/Bio/Battery

3.1. Solar photovoltaic electricity generation model

In solar-photovoltaic (PV) system with the help of solar cells solar energy is converted into electrical energy. The generation output mostly depends on geographical location and weather condition of the location. The power output of PV array (P_{SPV}), will calculate as:

$$P_{SPV} = G_{PV} f_{PV} \left(\frac{I_T}{I_{T,STC}} \right) \left[1+\alpha_P \left(T_C - T_{C,STC} \right) \right] \quad (1)$$

where, I_T represents solar radiations in kW/m^2, G_{PV} and f_{PV} are rated capacity and derating factor of PV resp., $I_{T,STC}$ denotes the solar radiations in (1 kW/m^2)at STC (standard test conditions), PV temperature is denoted by T_C in °C, α_P represents temperature coefficient of power in (%/°C), the cell temperature is denoted by $T_{C,STC}$ under STC (25 °C). In addition, the generated power output of the PV is also dependent on the cell temperature and wind speed surroundings the panel.

In this study, a PV panel with flat plates and multi-crystalline solar modules is used. The derating factor, STC efficiency (%), and lifespan of the PV panels are assumed to be 80%, 14.5%, and 20 years, individually[29]. The variables that affect the output power of the PV cluster from its estimated capacity, such as ice cover, shade, dust particles, age, high temperatures, and losses in wires, are clubbed together to create a derating factor. The PV's capital cost, cost of replacement, and maintenance and operating cost are assumed to be 840, 800, and 10 cents per kilowatt-hour per year, respectively[30]. The costs for shipping, installation, wiring and mounting hardware are included in the capital cost.

3.2. Biogas Generator

Biogas is used to drive a biogas generator which is produced by anoxic of waste organic matter.

The maximum rating of a biomass gasifier system can be calculated by using above equation based on the availability of biomass is:

$P_M = B_T * 1000*CV*\eta_{BG}$

The total biomass is BT in tons/year, calorific value of mass is CV in MJ/kg and conversion efficiency of a biomass gasifier system is represented by $\eta_{BG.}$ In this study, the minimum load ratio is taken as 0.5 for biogas genset and the optimization rating is considered in the range of 0-100KW. The lifespan is considered as 20,000 hrs for biogas genset[31],[32].

3.3. Power converter

The converter's capital and replacement costs have each been included in at 127 \$/kW. The converter's O&M expense is taken as \$1/kW/year. In this analysis, the converter's lifespan is assumed to be 15 years (in instances 2, 3, and 4) and 20 years (in case 1), with a 90% round-trip efficiency[30].

3.4. Battery modelling

In the microgrid system's storage medium are the battery. It stores extra energy when there is minimal need for it. The calculation for the battery's energy is provided below:

$$B_{bat} = B_{bat.0} + \int_0^t V_{bat} I_{bat} dt \qquad (2)$$

where V_{bat} and I_{bat} signify the battery's voltage and current, individually, and $B_{bat.0}$ indicate for the battery's starting charge.

3.5. Economic modelling

The p.u cost of energy, and the total net present cost (TNPC) of the entire system has been used to assess the economic viability of the proposed microgrid systems under consideration. Below is a short explanation of these parameters:

3.5.1 Energy costs

The per-unit COE for an integrated hybrid energy system is utilised for the economic analysis. The COE is determined by dividing the annual cost of the system components by the total amount of energy produced. When extra energy is not given, the energy created equals the actual demand, as shown by (3):

$$COE = \frac{C_A}{E_S} \qquad (3)$$

where ‘ C_A ’ represents the total annual cost and ‘ E_S ’ represents the annual energy supply. The annual cost is made up of three components: annual replacement costs (C_{A_rep}), annual operation and maintenance costs ($C_{A\_O\&M}$), and annual capital costs (C_{A_CC}). This cost may be determined by using the formula in (4):

$$C_A = C_{A\_CC} + C_{A\_rep} + C_{A\_O\&M} \qquad (4)$$

3.5.2 Net Present Cost

The current value of all the initial capital expenditures, replacement expenses, O & M costs, and fuel costs less the current value of all the revenues is the system's TNPC. For the duration of the project, salvage values for system components are included in the revenues. When expressed, the TNPC is:

$$NPC = \frac{C_A}{CRF(i,n)} \qquad (5)$$

where ‘i’ represents the real annual interest rate, ‘N’ represent the number of years, and $CRF(i,n)$ stands for the capital recovery factor. Further,

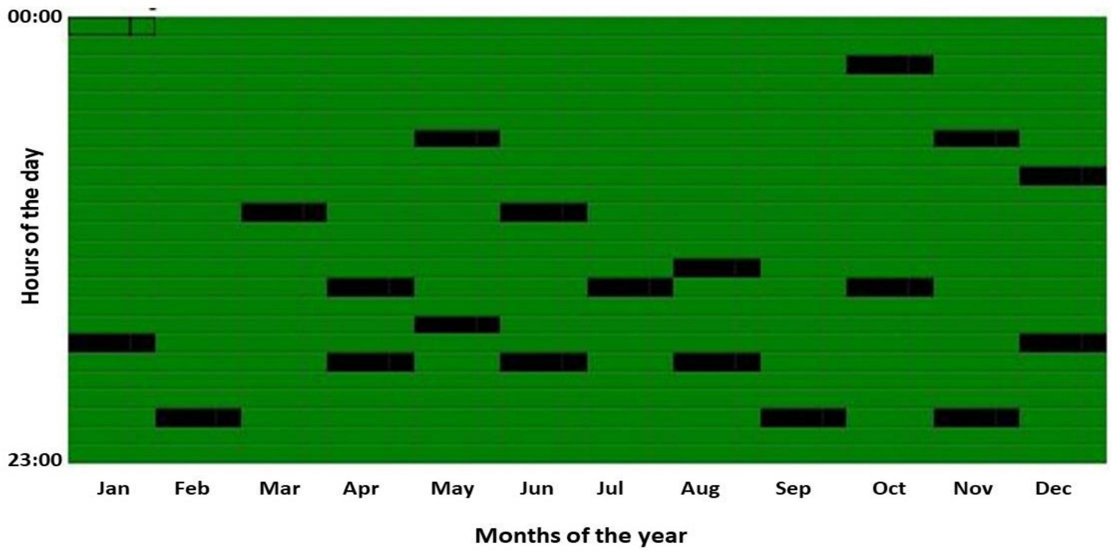
$$CRF(i,n) = \frac{i(1+i)^N}{1-i(1+i)^N} \qquad (6)$$

where, $i = \frac{i-f}{1+f}$

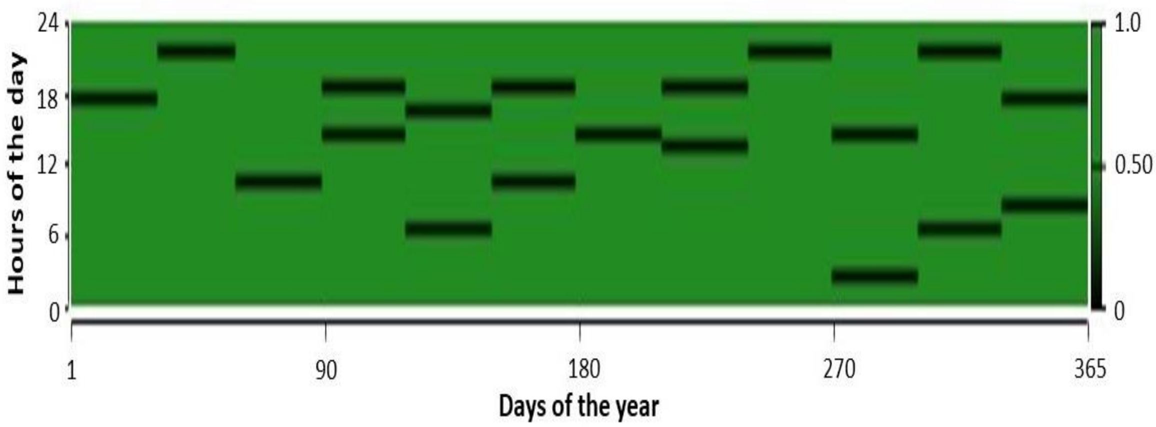
where ‘f’ stands for the yearly inflation rate and ‘i’ stands for the nominal interest rate.

3.6 Grid availability

This study focuses on DCRUST, situated just 6 km away from the main secretariat of Sonipat district in Haryana, India. The university relies on the grid to meet the energy needs of its various blocks. However, the grid often delivers unreliable and insufficient electricity. Regular power cuts occur, especially during peak hours and scheduled maintenance periods, depicted in figure 4 by black shading. To address this issue, a grid-connected microgrid system was proposed. The continuity of power supply to the hostel load. Additionally, surplus power generated from sources like PV and Biomass can be auction back to the grid using a gross metering system



(a)



(b)

Figure. 4 Grid outages with an unreliable grid (a) Hours of the day vs months of a year (b) Hours of the day vs days of a year

3.7. Microgrid

K.S. Krishnan Hall, boys hostel-1, Deenbandhu Chottu Ram University of Science and Technology, Murthal, Sonipat in Haryana state of India has been selected in this study. This hostel is connected with the distribution substation of 33kV installed in the university. But the quality of electricity supply to boy’s hostel-1 is unreliable because the distance from the substation is long, so many joints and overloaded conductor and regular power cuts during high load demand. The capital cost, equipment's installation cost, capital cost, maintenance cost, land and labour cost will be considered in the economics of microgrid. The cost of biomass is taken as 18 $/ton. A cost detail of every component in the microgrid has been described in Table 2.

Table 2 Cost summary of different components of microgrid system

Component	**Rating/Capacity**	**Capital Cost ($)**	**Replacement Cost ($)**	**Operation & Maintenance Cost**	**References**
Biogas Genset	62 kW	1162	872	0.010 $/hour	[4],[14].
Photovoltaic (Flat Plate)	27.6 kW	840	800	10 $/year	[29], [30]
Battery (Li-Ion)	38	630	600	0.50 $/year	[29], [30]
Converter	27.2 kW	127	127	1 $/year	[29], [30]

4. Estimated load profile

The projected renewable hybrid system has been designed for optimal and reliable electrification of K.S. Krishnan hall, boys hostel-1. This hostel consists of two blocks A and B, which includes 276 rooms, 12 toilets, one common room, one hostel mess and office area etc. There are two open courts for badminton and volleyball in the center of both the blocks.

4.1. Assessment of hostel load:

In this study the load data of the hostel has been collected through an inspection. The load of the hostel mainly comprises of CFL, tube light, ceiling fan, gyser and washing machine. Other load like television, insect killing machine, RO, mobile/laptop charging point are considered in miscellaneous load. The deviation in load demand because of the two dominant seasons in the selected area, summer (March-Sept) and winter (Oct.-Feb), are calculated separately because of the use of various appliances such as heaters in the winter days and ceiling fans during summer days.

Table 3 Hostel load data

Load type	**Load points in hostel**	**Power (W)**	**Load (kW)**	**Summer (March-Sept.)**		**Winter (October-Feb.)**	
				Average Load Duration (h)	**Energy Demand/day (kWh)**	**Average Load Duration (h)**	**Energy Demand/day (kWh)**
Block A and B							
Tube light	332	28	9.296	5	46.45	7	65.072
CFL	68	09	0.612	5	3.06	7	4.284
Ceiling Fan	276	80	22.08	12	264.96	-	-

Gyser	12	3000	36	-	-	4	144
Exhaust Fan	24	50	1.2	4	4.8	4	4.8
Roof Lights	16	320	5.12	8	40.96	10	51.2
Miscellaneous	278	100	27.8	4	111.2	4	111.2
Hostel Office/							
Common Area							
Tube Light	38	28	1.064	5	5.32	7	7.448
Ceiling Fan	50	80	4	8	32	-	-
CFL	48	08	0.384	5	1.92	7	2.688
Washing Machine	4	2000	8	4	32	4	32
Submersible Pump	1	1100	1.1	2	2.2	2	2.2
Miscellaneous	73	100	7.3	4	29.2	4	29.2
Badminton/							
Volleyball courts Area							
Mercury Light	4	400	1.6	4	6.4	5	8
Total Load					580.5 kWh		462.092 kWh

It has been evaluated from table 3 that the energy demand during summer is 580.5 kWh and during winter it is reduced to 462.092 kWh. The peak load demand is 60.34 kW in the month of february. It has been observed from the collected data that the students have their summer vacations in the months of june, july and winter vacations in the month of december. Therefore, the energy consumption in these months were minimum as shown in figure 5. There is no air conditioners allowed in the hostel, hence the consumption of energy in the months of summer season is less as compare to winter season months where gysers were operated. The demand between 9:00am to 5:00pm is less in the hostel as classes are conducted in the campus irrespective of the lunch time between 1:00pm to 2:00pm.

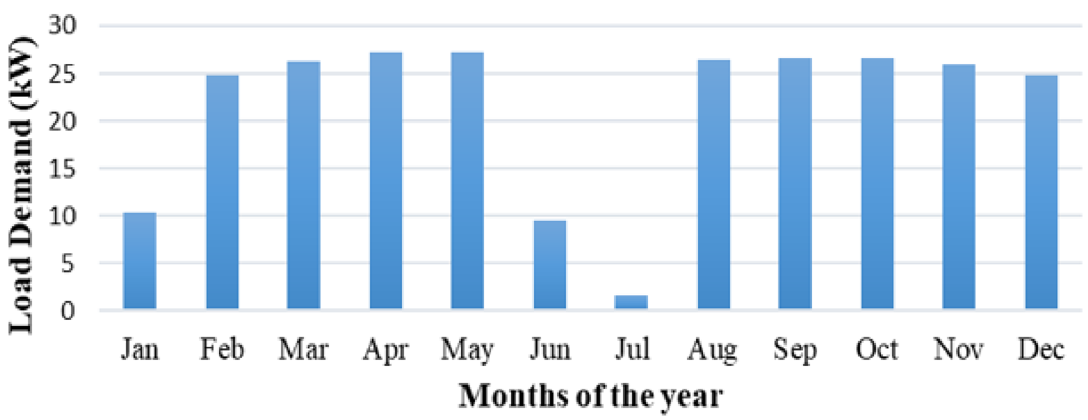


Figure. 5 Load demand of the hostel in every month of a year

5. Simulation results and discussion

This section examines the performance analysis of proposed microgrid systems designed to meet the energy demands of a hostel. The microgrid systems are categorized into two types: MG-A, which comprises photovoltaic (PV) and biomass-based generation units with battery storage but operates independently of the grid, and MG-B, which includes PV and biomass generation units connected to the grid. The analysis encompasses simulation results showcasing the generation reciprocation of different components, cost evaluations, emissions assessments, and an exploration of the impact of different vulnerability variables on Total Net Present Cost (TNPC) and Cost of Energy (COE). The investigation was accomplished using HOMER Pro version 3.14 software. The load-following (LF) dispatch strategy for the studied microgrid systems during the simulations. Multiple records were conducted to thoroughly assess the performance of both MG-A and MG-B microgrid systems.

MG-A: PV/biomass/battery

The optimal configuration for the MG-A system, which combines photovoltaic (PV) and biomass generation units with battery storage, includes a 62 kW generic biogas generator, a 27.6 kW generic flat-plate PV system, a 27.2 kW system converter, and 38 generic lithium-ion batteries, each with a rated capacity of 1 kWh. This configuration operates under a load-following (LF) dispatch strategy. The analysis yielded a Total Net Present Cost (TNPC) of $424,366, a Cost of Energy (COE) of $0.187 per kWh, and an operating cost of $24,823 per year for the MG-A system, with renewable energy sources (RESs) contributing 100% to the energy generation. The generating units successfully meet the load demand of the hostel throughout the year, with excess energy from RESs used to charge the battery unit, ensuring a continuous power supply to the load when needed as shown in figure 6. On a monthly basis, the biogas and PV generators contribute approximately 79.1% and 20.9% of the total generated power, respectively, adapting their output according to resource availability and weather conditions. Notably, the biomass generator exhibits peak performance during March-May and August- October as shown in figure 7, due to the optimal mesophilic temperature range (36°C to 44°C) for biogas production. The PV generator complements this by fulfilling the remaining power demand, as depicted in figure 10. Furthermore, Figure 8 and 9 illustrate the fuel consumption pattern of the biomass generator throughout the year and its power generation response across the days of a year, respectively. The analysis indicates sufficient fuel availability in the selected locality to sustain operation of the biogas genset year-round. Specifically, a total of 647 tons of feedstock is consumed, averaging 1.77 tons per day to operate the biomass-generating unit within the MG-A system. The biogas generator operates predominantly during evening hours, compensating for the unavailability of solar energy and thereby enhancing the microgrid system's reliability. The battery unit helps manage the variability of renewable energy resources (RER) by storing generated energy and supplying it as needed. The battery state of charge (SOC) for every day in a year is shown in figure 11.

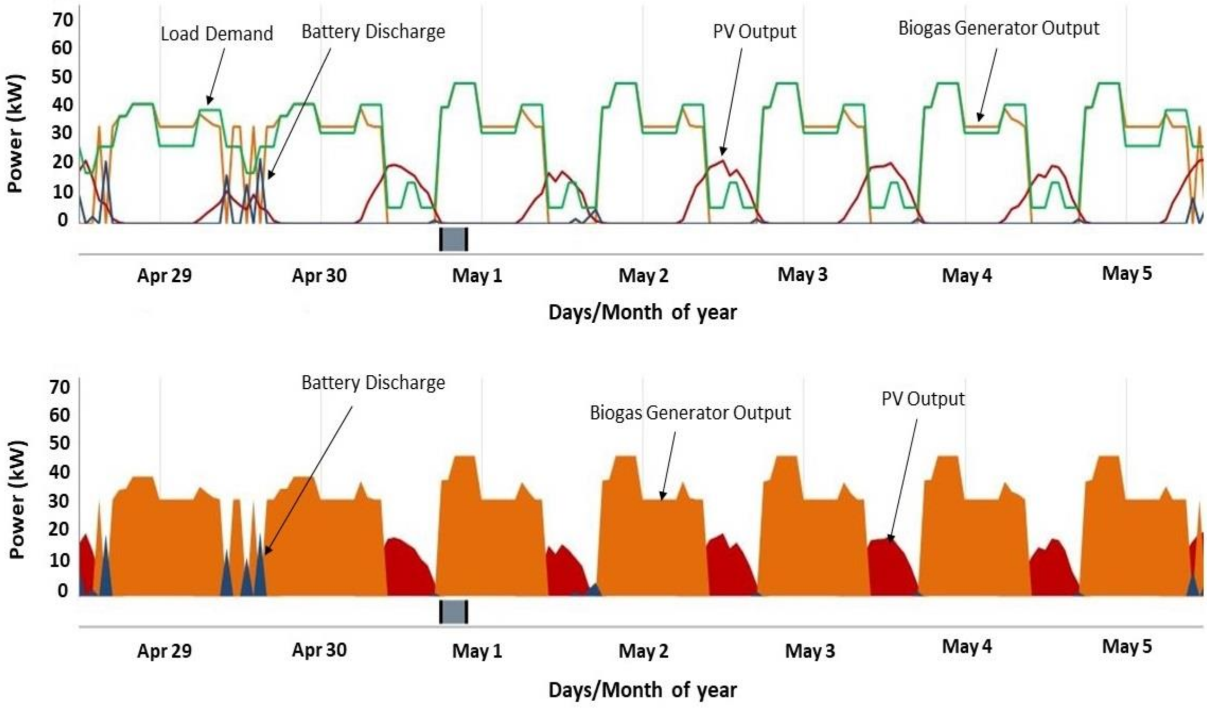


Figure. 6 Power output from different sources of microgrid system (MG-A) in peak load demand days.

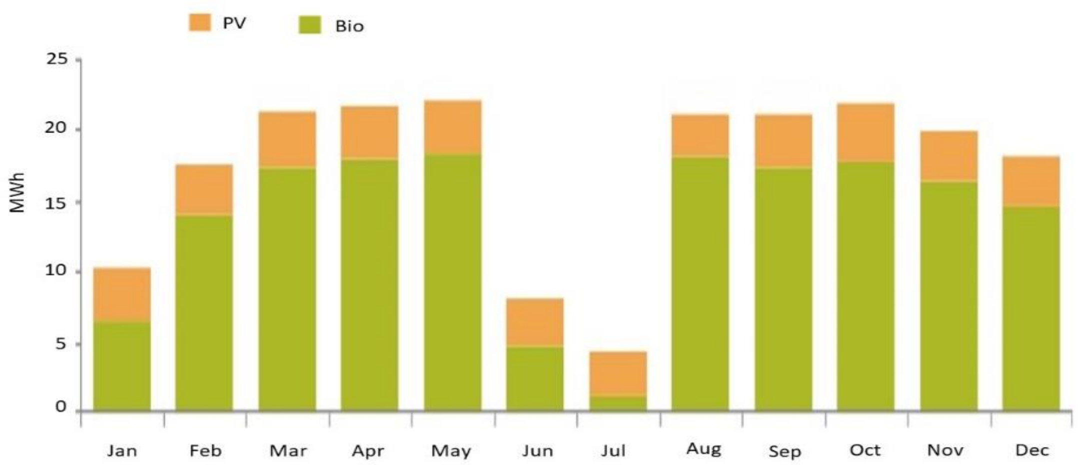


Figure. 7 Energy produced through PV and Bio in MG-A throughout the year

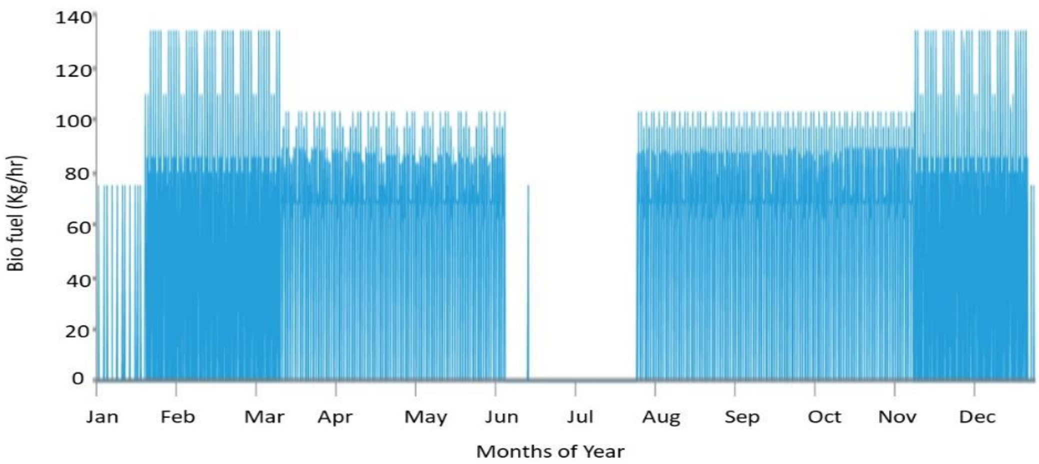


Figure. 8 Bio fuel consumed during the year

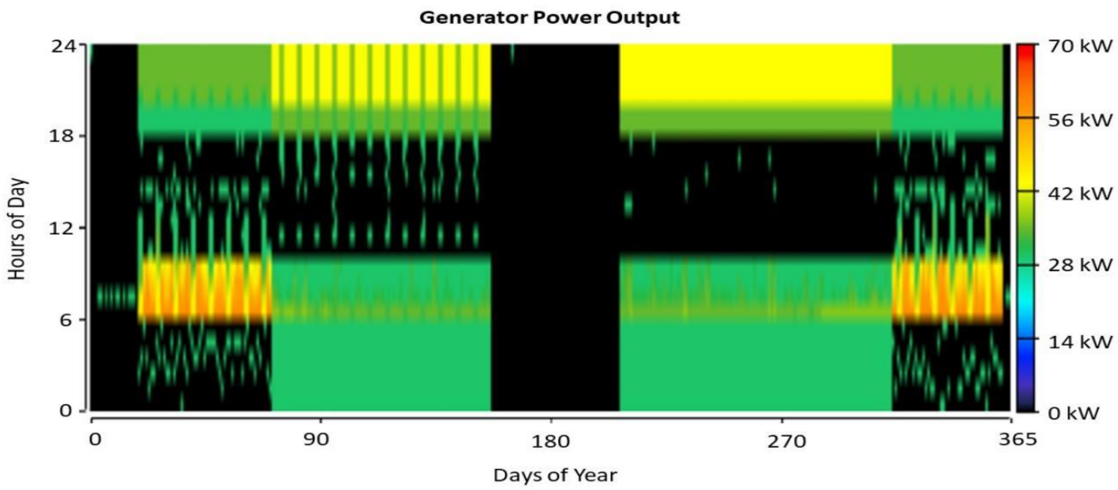


Figure. 9 Biomass generator power output vs days of the year

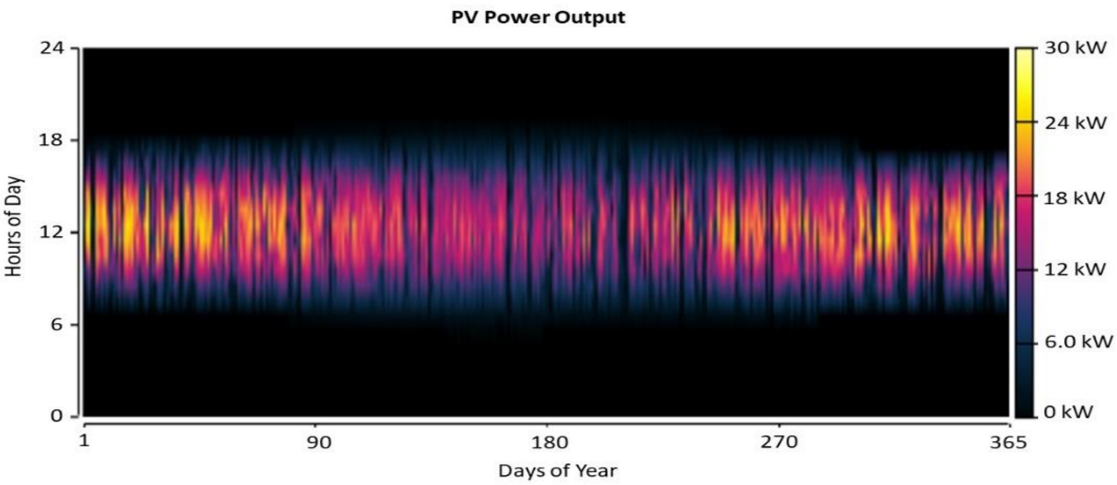


Figure. 10 PV power output vs days of the year

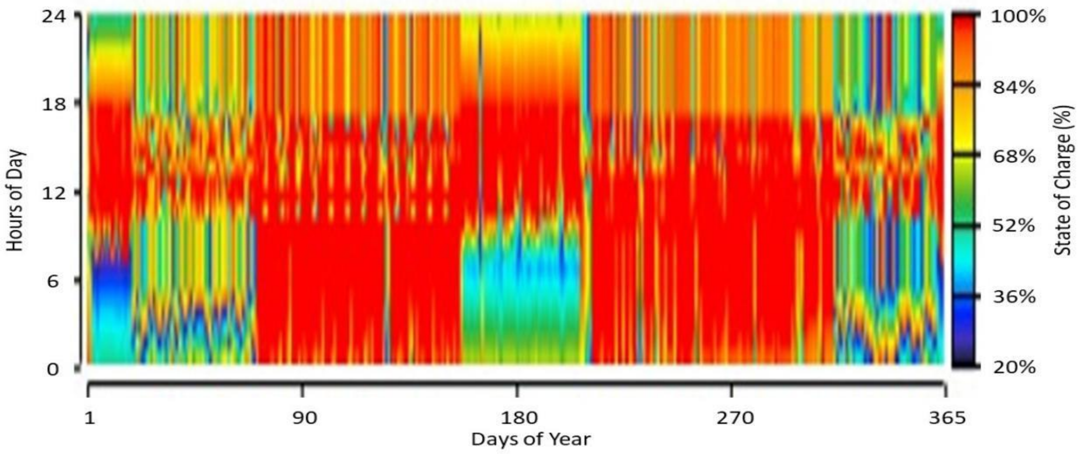


Figure. 11 Battery state of charge in hours of day vs days of year

MG-B: PV/biomass/grid

The ideal hybrid setup for a grid-connected microgrid system, referred to as MG-B, involves a blend of a 62 kW generic biogas generator, 26.3 kW PV array, and 18.8 kW system converter, all managed by a load-following (LF) dispatch strategy. This configuration yields a Total Net Present Cost (TNPC) of $366,408, a Cost of Energy (COE) of $0.148 per kWh, and an operating cost of $24,802 for the MG-B system, with 91.9% of the energy generated from renewable sources. The proposed MG-B system reliably meets the hostel load demand with 100% reliability, and surplus power generated from renewable sources (PV and biomass) can be fed back to the grid through a net metering system. Figure 12 illustrates the response of different system components over a week during the peak load month of April and May, showcasing the system's capability to generate excess power beyond meeting the hostel load demand. Additionally, figure 13 delineates the power contribution of various generating units (PV/Biogas Genset and grid). Biogas production, a temperature-sensitive process, operates optimally at mesophilic temperatures ranging from 36°C to 45°C. The study area's temperature during peak months (April to October) falls within this range (36°C to 46°C), facilitating favourable conditions for biogas production through anaerobic digestion. This leads to a significant contribution to power production from the biogas generator, particularly during grid outages when solar PV contribution is minimal during night hours. Throughout the year, MG-B consumes a total of 582 tons of fuel, averaging 1.59 tons per day. Notably, fuel consumption by the biogas generator is relatively low during June, July and January due to decreased load demand during the winter season. Excess generated power has been sold to the grid, and power can be purchased from the grid as needed. Figure 14 presents a comprehensive monthly report detailing the sale and purchase of energy to/from the grid.

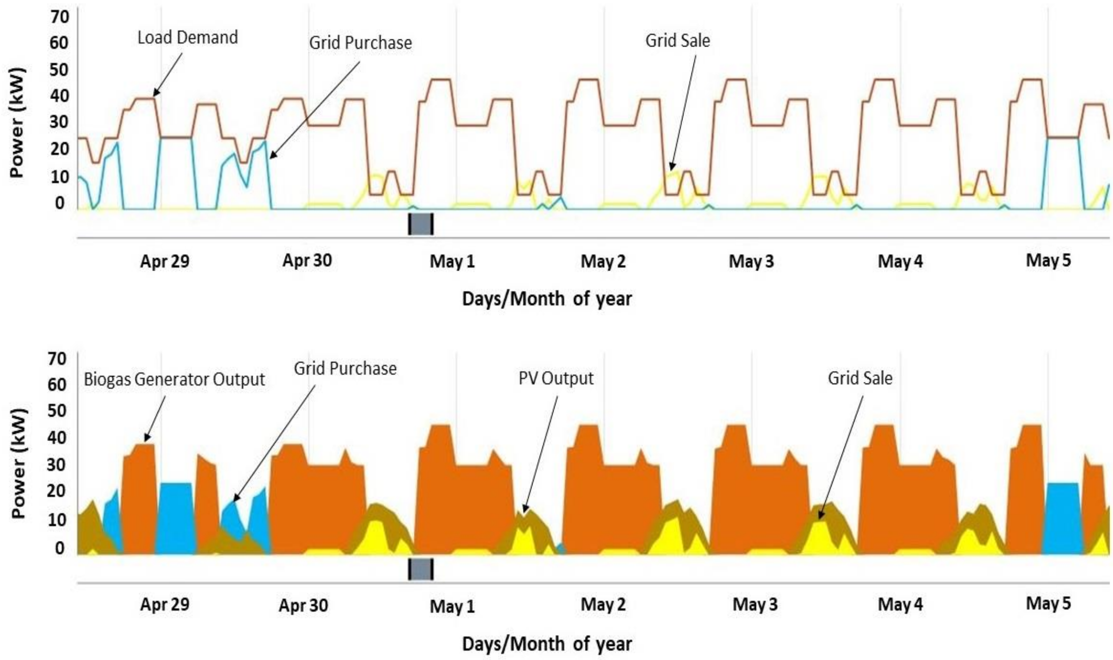


Figure. 12 Power output of MG-B with grid sale and purchase during peak load demand days

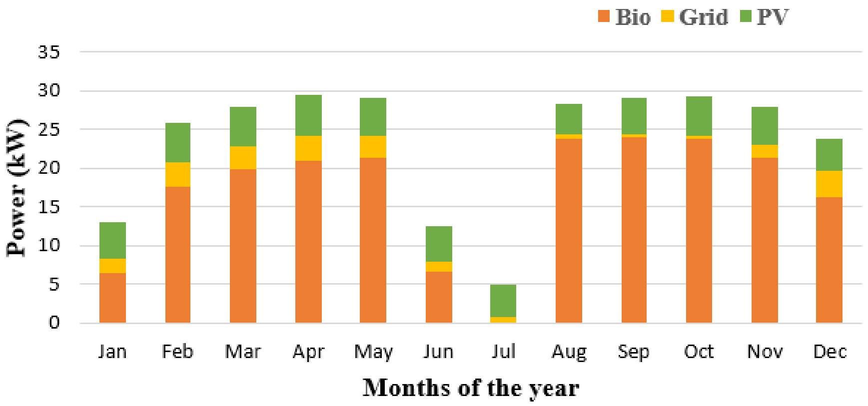


Figure. 13 Power output of Bio/Grid/PV in microgrid system MG-B

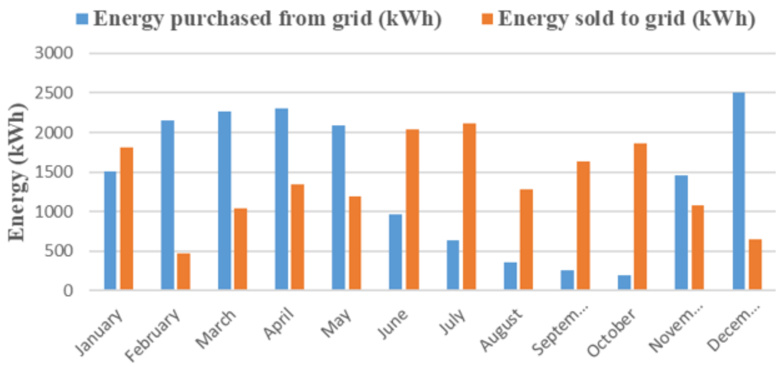


Figure. 14 Energy purchased from grid and sale to grid during the year

Pollutant emission analysis

Considering greenhouse gas (GHG) emissions as a critical global concern, from an environmental standpoint, Microgrid A (MG-A) emerges as a more attractive option. It efficiently meets the connected load demand of the hostel while emitting significantly lower levels of pollutants compared to Microgrid B (MG-B), as indicated in Table 4. However, it's crucial to also factor in the Total Net Present Cost (TNPC) and Cost of Energy (COE), which are higher for MG-A. Additionally, since the hostel is linked with the main grid, MG-B appears to be a more feasible choice due to its lower TNPC and COE. In the case of MG-B, a sustainable utilization of 582 tons of biomass annually is employed to generate electricity, a practice that prevents the release of greenhouse gases into the atmosphere. This approach leads to a substantial reduction in emissions compared to open-air biomass burning. Moreover, MG-B integrates renewable energy sources to contribute 91.9% to the energy system. Based on the techno-economic analysis, MG-B emerges as the preferred option for supplying reliable and high-quality power to hostel. It offers electricity at a lower COE of $0.148 /kWh, which is around the average tariff rate of purchasing electricity from the grid. Despite MG-A showcasing nearly negligible pollutant emissions with its 100% renewable energy setup, its TNPC and COE are slightly higher, as compared to MG-B.

Table 4 Emissions from several combinations of microgrids

Emissions	**Only Grid**	**Crop Residue Burning**	**Standalone Microgrid (MG-A)**	**Grid Connected (MG-B)**
CO_2 (kg/year)	89,770	124,112	70.1	31,125
CO (kg/year)	-	67732.4	0.756	0.472
SO_2 (kg/year)	398	138.6	0	129
NO (kg/year)	187	279.812	0.476	66.4

6. Conclusion

The study demonstrates that a photovoltaic (PV)/biomass-based microgrid presents an effective solution for harnessing biomass to provide reliable electricity to the hostel. The proposed microgrid configuration (MG-B) is capable of delivering electricity to the hostel at a cost of $0.148 per kilowatt-hour, which is lower than the $0.187 per kilowatt-hour associated with a grid-only system. Furthermore, the MG-A system substantially reduces greenhouse gas emissions by over 75%, primarily through the sustainable utilization of biomass via anaerobic digestion. This contributes to the development of a clean and environmentally friendly campus. The implications of this study extend beyond the specific case of the hostel. The research suggests that the successful implementation of the PV/biomass-based microgrid could serve as a model for other educational institutions, particularly within Haryana state. By adopting similar systems, these institutions can achieve a reliable and secure power supply while also contributing to broader sustainability goals. The study's findings provide critical recommendations for policymakers and implementing agencies, advocating for the adoption of solar-biomass microgrid systems as a strategic approach to meeting energy needs in a cost-effective and environmentally responsible manner.

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