Integration of SPV/Biomass resources for sustainable energy supply in Leh: a HOMER modeling approach

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Abstract:

This research explores the viability and optimization of a Photovoltaic (PV), Biomass, and Battery Hybrid Energy System to address the unique energy challenges faced by Leh, a high-altitude region characterized by harsh climatic conditions. Leveraging the Hybrid Optimization Model of Electric Renewables (HOMER) software, this study aims to analyze, design, and optimize a hybrid energy configuration tailored to Leh's specific requirements. The model is designed to enhance energy reliability by combining solar power from PV panels, continuous power from biomass resources, and energy storage capabilities provided by batteries. The integration of these elements aims to mitigate the intermittent nature of solar energy and ensure a stable power supply throughout varying weather conditions and energy demand patterns. The study employs HOMER to model the hybrid system, incorporating local meteorological data, load profiles, and biomass availability unique to Leh's environment. The optimization process seeks to minimize the levelized cost of electricity (LCOE) while maximizing energy reliability. Sensitivity analyses are conducted to assess the impact of key parameters, such as biomass availability, solar irradiance, and battery characteristics, on the system's performance and economic feasibility.

INTRODUCTION

The demand for energy on Earth is increasing dramatically as a result of industrialization and population development. It is critical to understand that the population has increased by two billion people in a single generation, with acquiring countries playing a critical role. Protecting against a major energy crisis is one of the most common challenges of the twenty-first century. As a result, the need for power is increasing rapidly in order to meet the needs of the world's growing population [1].When it comes to global power generation, traditional sources of energy such as diesel-powered winter energy plants, coal-powered thermal power plants, nuclear-powered thermal power plants, and hydroelectric power plants dominate. According to a 2014 REN21 article, renewables supplied 19% of humans' global power consumption and 22% of their electrical energy output in 2012 and 2013, respectively. This power usage is divided as follows: 9% from traditional biomass, 4.2% from high temperature power (non biomass), 3.8% from hydroelectricity, and 2% from wind, geothermal, and solar [2]. A few long-term scenarios assume an ever-increasing percentage of inexhaustible solutions (produced in lieu of solar, contemporary biomass, geothermal, wind, in addition to the traditional energy source, i.e. hydro). With the correct laws and technology development projects, inexhaustible may link up to fifty percent of total power demand by the mid-twentieth century [3].

RESs have a reputation for being limitless, efficient, dependable, environmentally friendly, and inexpensive, and are therefore attended to as the greatest possible realistic supply of energy strategies to these types of sites. Furthermore, limitless power holds the key to prospective riches as well as a suitable global globe, and it is considered as a viable method of resolving environmental friendly pollution difficulties [4-6].

Biomass is defined as a bio residual made available by moisture-dependent organic waste, forest, or vegetation, by harvest generation, agro, or maybe food industry garbage. Only in India are many types of biomass materials manufactured. They are classified as grasses, vegetables, fruits, woody plants, aquatic plants, and manures since they are only found in the natural world. Today, algae and Jatropha may both be used to produce bio fuel. Center distinctive energy sources of biomass power are often classified as farming harvest leftover, power plantation residue, as well as industrial and municipal waste product [7]. India produces a large amount of various biomass waste products. By using a biochemical and thermo-chemical transformation technique, these waste products may be converted into large energy sources known as bio fuels [8].

However, one barrier to endless energy usage is the volatility of its internal generation as well as time-dependent feature. Adaptable demand management [9-11] and intelligent power management [12,13] may help, but they are insufficient in maintaining a feeling of balance between demand and output of electrical energy. In this approach, power storage space architecture might be a significant technique for overcoming the intermittent issue of endless power generation. It stores generated power when it exceeds need and allows dispatching of stored power when production is less than demand [14].

Hybrid solar biomass plants might be an alternative option for these places where the sun learning resource is adequate but biomass materials are readily available. When sun insolation is present, hybridization can maximize a strength grow outcome by constraining biomass source usage. When there isn't enough sun throughout the winter, the biomass hone system will be used [15].

The research was carried out in the Ladakh area of Leh, India. Due of geographical constraints, the location lacks a consistent and reliable power source. The mountainous topography makes grid extension difficult, which might make electricity supply more inexpensive. However, it receives adequate insolation throughout the year. The location has the ability to provide a moderate amount of biostock fuel for the biomass generator.

Utilizing HOMER software for simulating a PV-Biomass hybrid system in Leh, Ladakh, India, is a strategic choice rooted in several compelling reasons. Leh's unique geographical and climatic conditions demand a sophisticated simulation tool that can intricately model the integration of photovoltaic and biomass energy sources. HOMER's robust optimization algorithms empower engineers and planners to design a hybrid system that precisely meets the region's energy demands, accounting for the intermittency of renewable resources and the specific energy needs of Leh. The software's ability to perform techno-economic analysis is crucial for assessing the financial feasibility of the project, considering factors like initial costs, operational expenses, and potential savings over time. Additionally, HOMER's user-friendly interface facilitates collaboration among stakeholders, ensuring effective communication and decision-making. With its customization capabilities and scenario analysis tools, HOMER allows for tailoring the simulation model to Leh's local conditions, enabling a more accurate representation of the system's performance. In essence, HOMER serves as an invaluable aid in designing an optimized, cost-effective, and resilient PV-Biomass hybrid system tailored to the unique energy requirements of Leh, Ladakh, India.

The current study intends to offer the Solar PV-biomass hybrid combination system and examine the viability of such a hybridized alternative for dependable, continuous, and cost-competitive power supply for the suggested community load

LITERATURE REVIEW

Kumar et al. (2019) forecast the performance, energy loss, and deterioration of a 200 kW roof-integrated crystalline photovoltaic (PV) system placed at IRB Complex-5 in Chandigarh, India. The PVsyst simulation program is used to anticipate energy generation and loss [16]. Kumar et al. (2020), discussed that solar energy is a rapidly growing source of energy all over the world. The total installed solar power capacity in India is 34811.78 MW as of April 30, 2020. PVsyst simulation software was also used to analyze the performance ratio and losses [17]. Makhija et al. (2021), presented that remote region electrification is a crucial for every developing nation's administration. India is also working on it, however despite ongoing attempts to electrify rural areas, many thousand Indian families remain without power. Software created by the National Renewable Energy Laboratory (NREL) in the United States was used to design and simulate floating and on ground PV systems in Narayanpur distrcict of Chhatisgarh [18]. Akikur et al. (2013) discuss solar power research in the form of a hybrid and stand-alone energy model technique utilized to electrify off-grid areas. The standalone solar PV construction designed here is intended to be used to give power to a single residence or a small community [19]. Chambon et al. (2021), presented as the cost of solar PV continues to fall and pollution law requires less burning of agricultural leftovers, decentralized renewable energy is becoming more cheap for delivering electricity to one billion people who do not have access to a power grid. This article offers a case study of biomass gasification in off-grid and grid-connected mini-grids for community-scale energy use in rural Uttar Pradesh, India [20]. Kaur et al. (2020) discovered that burning agricultural leftovers worsens pollution generated by coal-fired thermal power plants in most developing nations, including India. Crop residue is mostly composed of organic components and may be used to generate biogas in a sustainable manner via anaerobic digestion. This research offers a microgrid (MG) system for the efficient use of renewable resources and dependable rural electricity. Furthermore, by properly using the plentiful biomass resources, the suggested MG power system helps to decrease pollution emissions into the atmosphere [21]. According to Bhatia et al. (2020), India is a fast developing country, putting strain on its natural resources. Various sorts of trash are created throughout its growth and development as a result of agricultural, industrial, and human activities, as well as an increase in energy consumption to maintain its pace of expansion in order to become a developed nation. In India, waste to energy might reach a market size of 14 billion USD by 2025, with an annual rise of roughly 5%. To capture this untapped source of energy, scientific waste management, along with government policies, schemes, and incentives for waste management, renewable energy, agriculture, and so on, and their implementation, are critical cornerstones for promoting biogas technology and obtaining renewable energy on a long-term basis [22]. Krishnamoorthy et al. (2021) focuses on a renewable energy-based rural electrification system. Two strategies were employed to solve the problems. The first is the best-fit model of a hybrid configuration system, which makes use of village-owned resources such ample biomass and sun irradiation [23]. Nykamp et al. (2012), discussed the integration of inexhaustible power production creates in major challenges for division power grid operators. If the feed in of photovoltaic (PV), biomass, and wind-powered generators exceeds significantly the area demand, massive expenditures are required. . Furthermore, a technique is described that allows for the estimation of the optimal as well as the bare minimum input in induced by various combinations on the assessed solutions [24].

PV PERFORMANCE ASSESSMENT

The amount of solar radiation that reaches the earth's surface must be calculated in order to compute energy generation and other associated activities. Observing sun radiation over an extended length of time offers vital information about the place. The potential of such an energy source must be analyzed at the location. This data collection is often used in other fields of research to determine other parameters. Various governments installed numerous satellites to determine such potential, and they analyzed such data to build their energy legislation as well [25].

BIOMASS ENERGY ASSESSMENT

Organic matter is used to generate biomass energy. It includes vegetation, municipal solid trash, bio waste, sewage, food leftovers, energy crops, and many other things [26-28]. The world is looking for a fuel that will alleviate environmental concerns while also providing large amounts of power, and biomass has emerged as a possible answer to the aforementioned issues. Biomass accounts for around 35% of worldwide energy [29]. Likewise, because of the fantastic volatile matter substance (80% in biomass against 20% in non-sustainable power sources), it leads to a source with high starting consistency [30]. It has the capability of producing a large amount of electricity in either a combined or solo mode [31]. Regardless, the energy thickness of biomass is 10-40% that of most oil-based commodities [32]. Regardless, waste and biomass storage are now believed to be vast and, to some extent, insignificant sources of energy [33].

SIMULATION METHODOLOGY

The NREL lab in the United States of America developed the Hybrid optimal model for electric renewables (HOMER) [34], which is used in this review to simulate the proposed scheme. The HOMER is suitable for replicating various ecologically friendly power sources, for example, sunshine, wind, biogas, and so on. The heap may be precisely analyzed by incorporating the haphazardness of day and time step. HOMER employs both conventional and unconventional energy sources in reproduction, depending on the situation. The reproduction provides reliability information that may be studied to determine the plan's practicality and financial viability [35].

WORKING PRINCIPLE

The methods proposed in this particular study include powerful generators (PV arrays, biomass generators, and batteries) and end-user stations (controller and load). The system is assumed to operate in standalone mode. Analysis is actually Leh Ladakh designed in India.

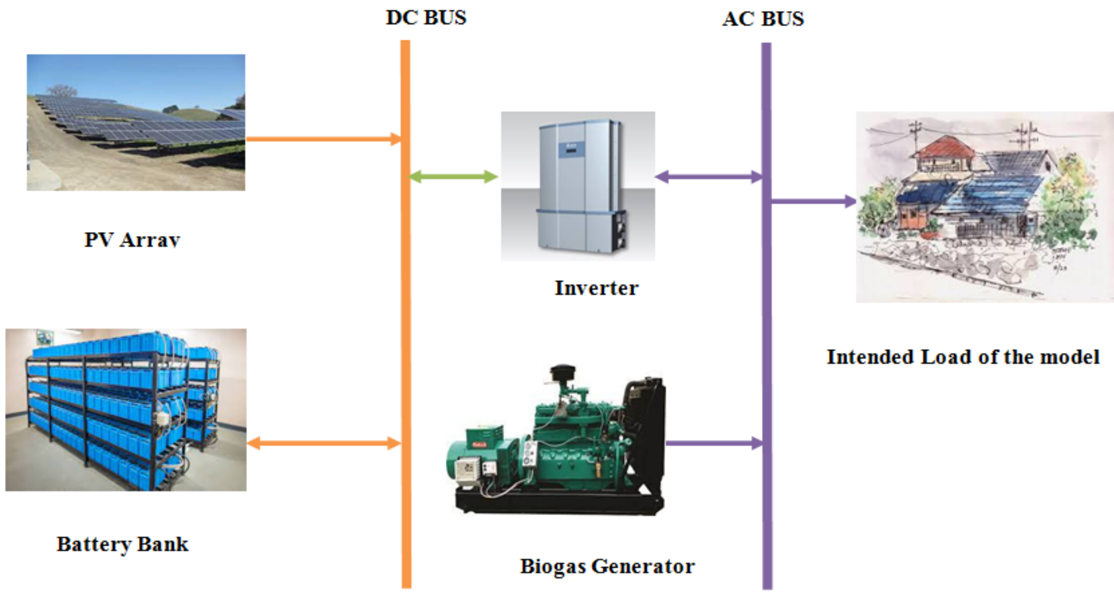

Fig. 1. PV-Biomass hybrid configuration

The model seeks to strike a balance between weather-dependent and independent sustainable energy sources to meet most of the proposed demand. Photovoltaic systems operate to provide energy during sunny hours. After meeting the load demand, if there is almost surplus power, that power will be saved in the battery account and can be used during the power shortage period. Biomass generator typically run at a fixed time in the evening when there is actual demand that succeeds the power generation strength of the SPV along with the battery bank. If continuous power from the battery is available, the biomass cannot be driven that night. The system also includes an inverter product that converts the DC power from the PV array into AC power In this way, a sustainable and reliable energy supply is guaranteed 24 hours a day, provided there are sufficient charge/discharge rates and capacity of the battery and biomass generator. The master device of the system is PV array, biomass generator, battery, inverter ,converter as well as controller.

LOAD PROFILE

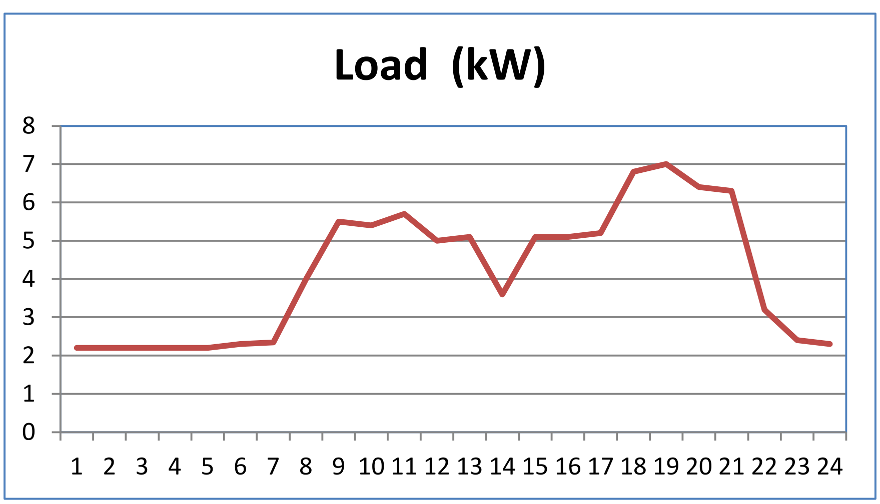

Fig. 2. Hourly average load

The recommended system is created to serve day load of 99 kWh/day which has a peak load of 12 kW. Nevertheless, this symbolizes the average load need. Also, the power demand is going to rise thanks to the growing amount of gear wearing long term that is near. The device is generally design and style to cater the domestic demand. It can easily be also observed that this excellent demand of this load is occurring in romantic evening period. So with this study the daily base load is synthesized in HOMER application with the addition of randomness of day, to generate a fairly sensible ton profile. As well as for ease of use the seasonal perturbation of load is not taken into consideration. The ton of the proposed design is considered as constant in all of the weeks for the simulated 12 months.

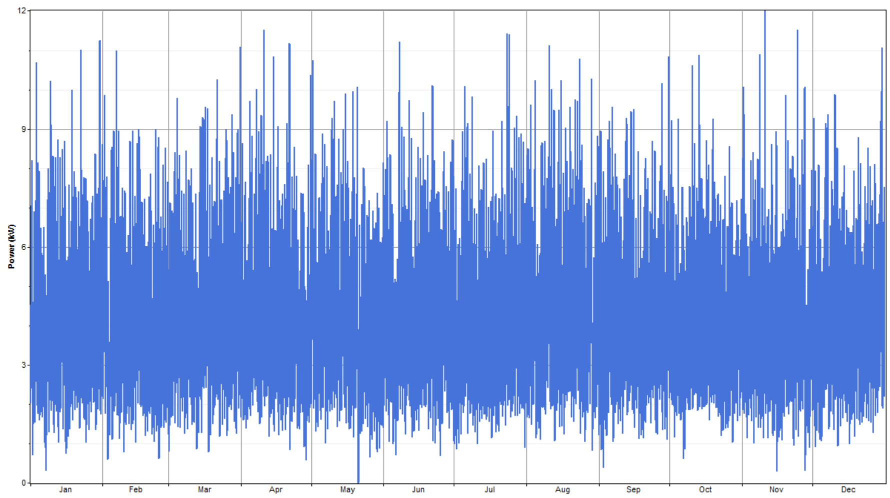

Fig. 3. Hourly load variation

SOLAR RESOURCE OF THE SITE

Solar energy will play an important role in the proposed design. In one hand technological advances are actually increasing the power generation of photovoltaic systems and on the otherhand it decreases the cost of energy produced by the utilization of SPV cells . The amount of power generated by a photovoltaic system depends on the weather at the installation site. Regular deviations in solar energy radiation in India have been found to be between 3 and 8 kWh/m2/day. The study will be conducted at 34.35 degrees latitude and 77.45 degrees longitude. Also, the typical monthly solar radiation suggested on the site is determined to be 5.48 kWh/m2/day with a clarity index of 0.656 and the installed power of the PV system is 12 kWP.

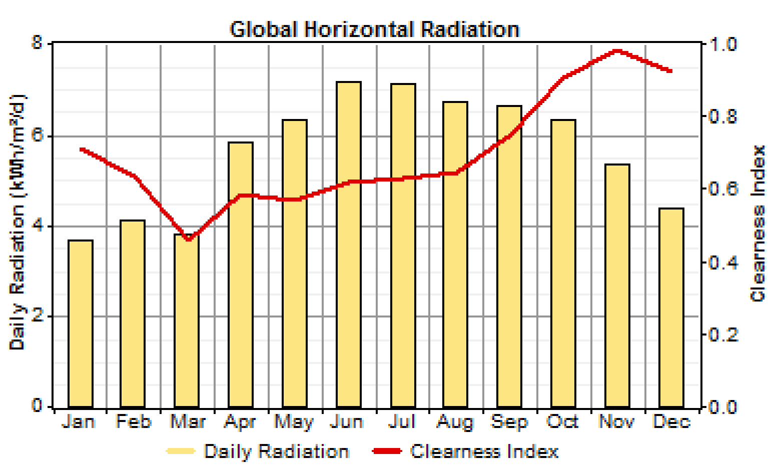

Fig. 4. Solar energy resources

ESTIMATED BIOMASS RESOURCE

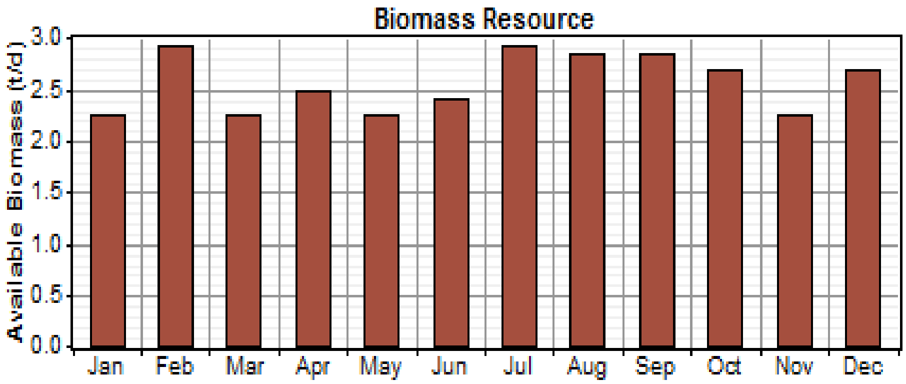

Fig. 5. Biomass resource

Biomass generators are the only system in the model integrated to enhance the reliability of the system as its operation does not upon the weather condition. There are many people who keep cattle as livestock in the planned site, and biomass resources are abundant. In addition, biodegradable waste such as leftover food and agricultural residues are also common. This system perfectly solves the problem of waste disposal and generates the power that is scarce in this place.

According to this recommended scheme, the capital cost and replacement price of a 3 kW biomass generator will be INR 2,76,000 plus an assumed O&M cost of INR 2 per hour. The biomass (as fuel) transport price for this method is amalgates along with the system price, since there are no other options to insert the same in the modeling program. .

STORAGE FACILITY

A photovoltaic array and Biomass generator are the method of energy generation in the proposed system. The amount of power generated by a solar power system depends on the weather. And operating the biomass generator both have environmental concern and the energy produced through this is bit costly. Additionally, the system is equipped by a battery bank to take care of the load of light nature.

To make the system more reliable, an appropriate rated battery bank is placed The modeling of Scheme 14 implements a Surrette 4KS25P battery device. For this recommended scheme, the capital cost of the battery subsystem is INR 79,100 and the O&M cost is INR 7,000 per year.

RESULT ANALYSIS

SOLAR RADIATION AND OUTPUT POWER

The figure above shows the change in photovoltaic power with changes in global solar irradiance. A maximum power output of 45.67 kWh is observed to be achieved with an average radiation dose of 0.333 kW/m2 throughout the day.

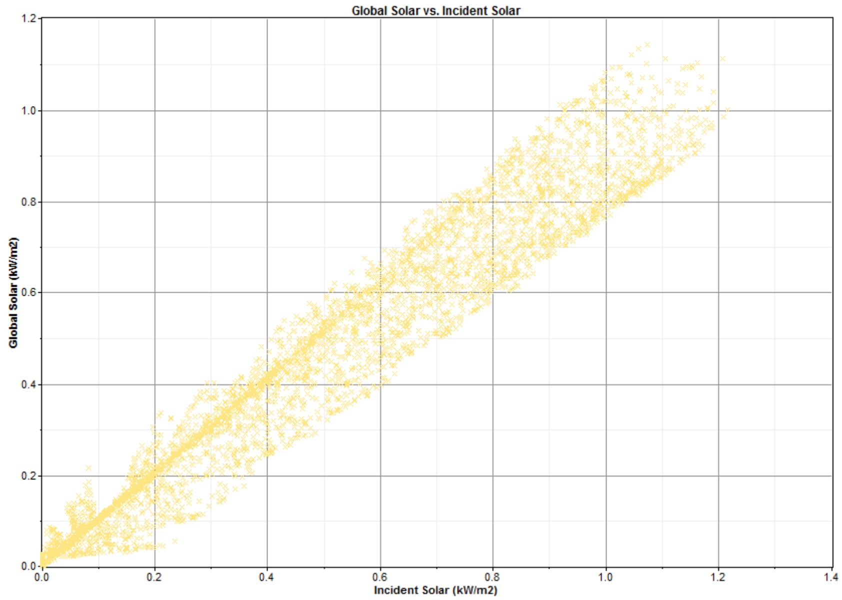

Fig. 6. Solar Radiation and PV Output Power

BIOMASS RESOURCE AND OUTPUT POWER

The below figure shows the variation of Biomass power output with the change in biomass resource available. It is observed that it has maximum production capacity of 3 kW, produces 14,913 kWh/year with fuel consumption of 160 t/ year.

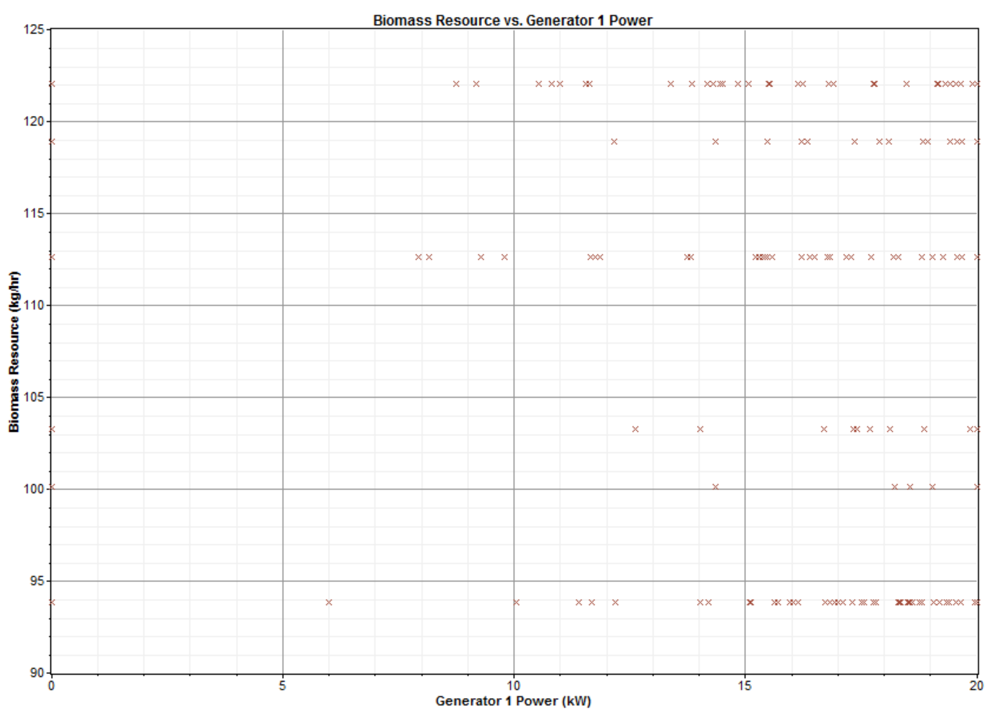

Fig. 7. Biomass resource and output power

MONTHLY POWER OUTPUT FROM PV ARRAY

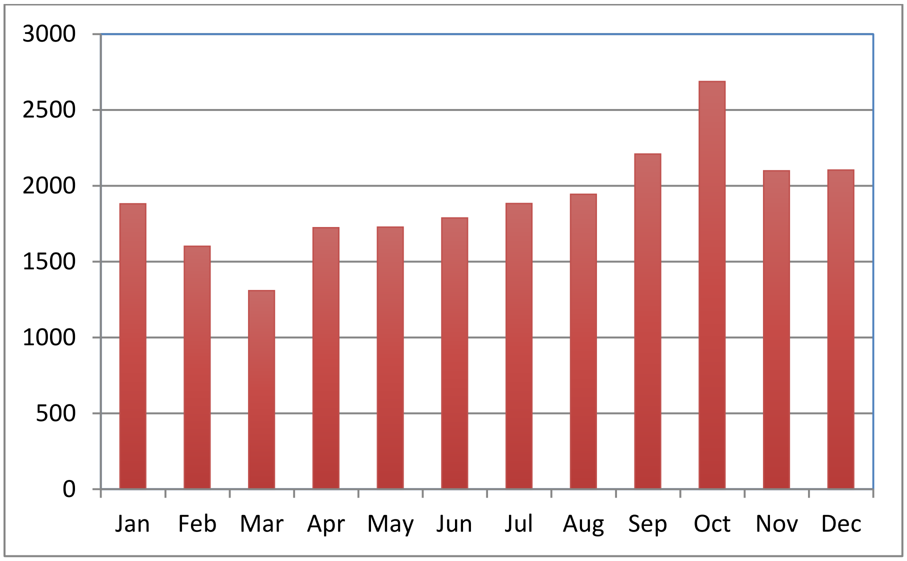

Fig. 8. Monthly variation in power output

The graph above shows the monthly fluctuations in the amount of power generated by the SPV system. This indicates that the power output of the PV system is sufficient throughout the year and is highest in the months from September to November. This allows the photovoltaic system to generate the right amount of electricity all year round. Depending on climatic conditions, the photovoltaic system is estimated to generate 22,962 kWh per year.

BIOMASS ENERGY

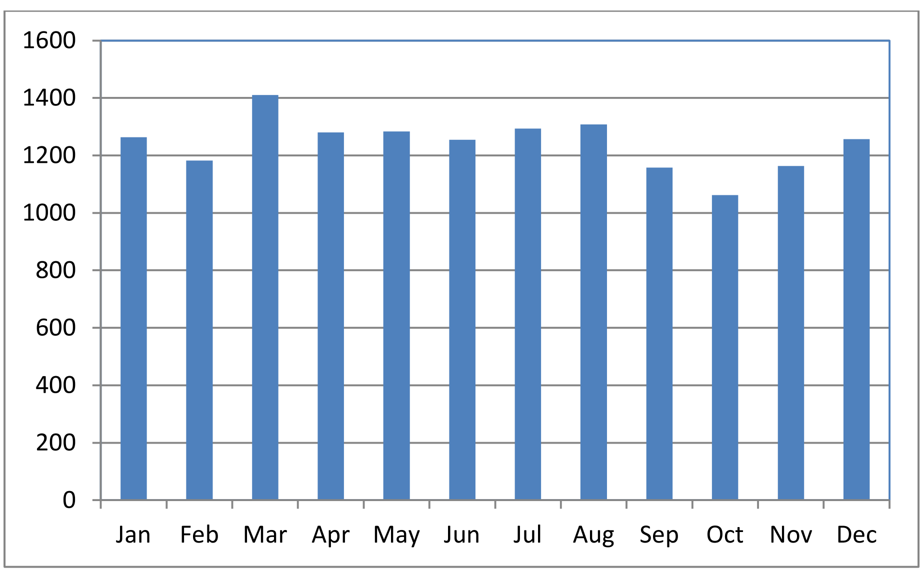

Fig. 9. Biomass generator power output

Systems intended for use with available wet waste such as household waste leftover food, feed remnants, and other wet waste such as cow dung and other livestock materials. Waste is collected, processed in a gasifier, and then passed through a generator to produce electricity. This model proves that there is sufficient wet waste available for power generation throughout the year. The annual output of the biomass generator is 14,913 kWh. This model consumes 160 tons of bio-materials per year and has 4,974 operating hours per year.

BATTERY OUTPUT

Depending on the system design, the battery can act as a secondary power source. Absorbs excess energy during solar and biomass generator operation. When the power output from the combined operation of the photovoltaic array and/or biogas generator is not sufficient to cover the load requirements, the stored energy is released to provide energy. A charge controller is used to control the battery unit. Total battery energy input/output is 7,806 kWh/year, 6,301 kWh/year, loss is 1,442 kWh/year, and battery storage depletion is estimated at 63 kWh/year. .

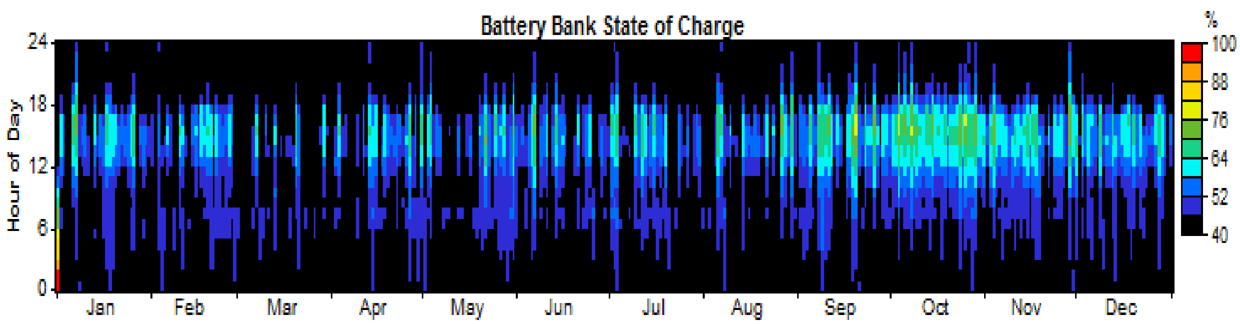

Fig. 10. Battery state of charge

BATTERY SOC VARIATION

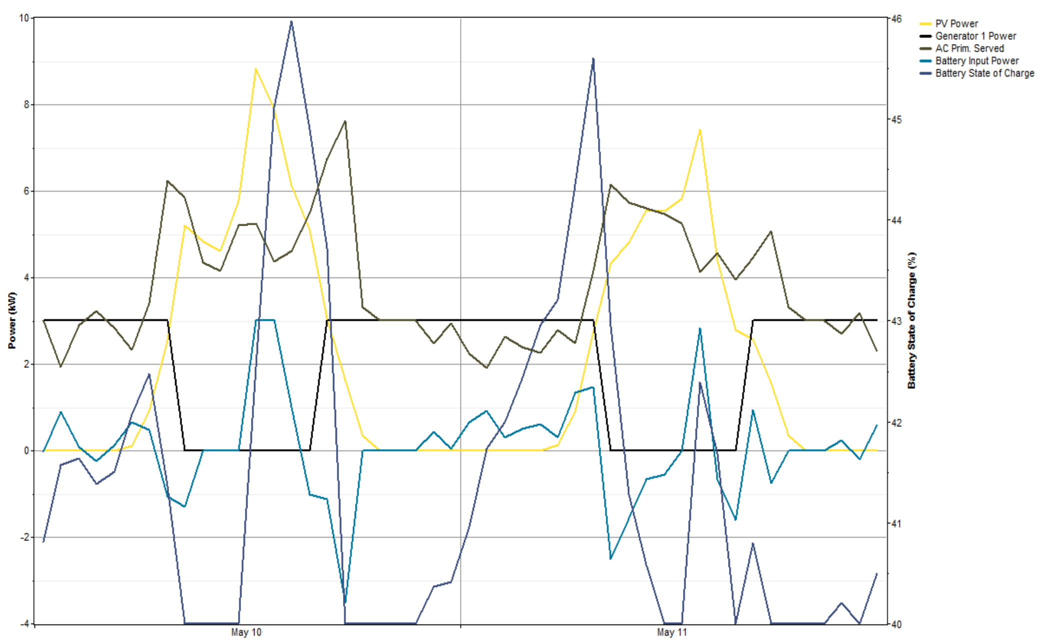

Fig. 11. Battery SoC variation

May 10th to 11th of the simulation year are chosen for observing the state of charge of the battery. The generation pattern is that the SPV will generate electricity during sunny hours and the biogas will run for fixed hours (usually at night) unless the battery can meet the load demand. If the battery cannot handle the load, biomass kicks in and handles the load, while the battery also charges. Charge and discharge commands are controlled by the charge controller. When there is excess energy production, the battery charges and when there is a shortage of energy demand, the battery discharges. A navy blue line indicates SoC of the battery.

ENERGY EQUILLIBRIUM

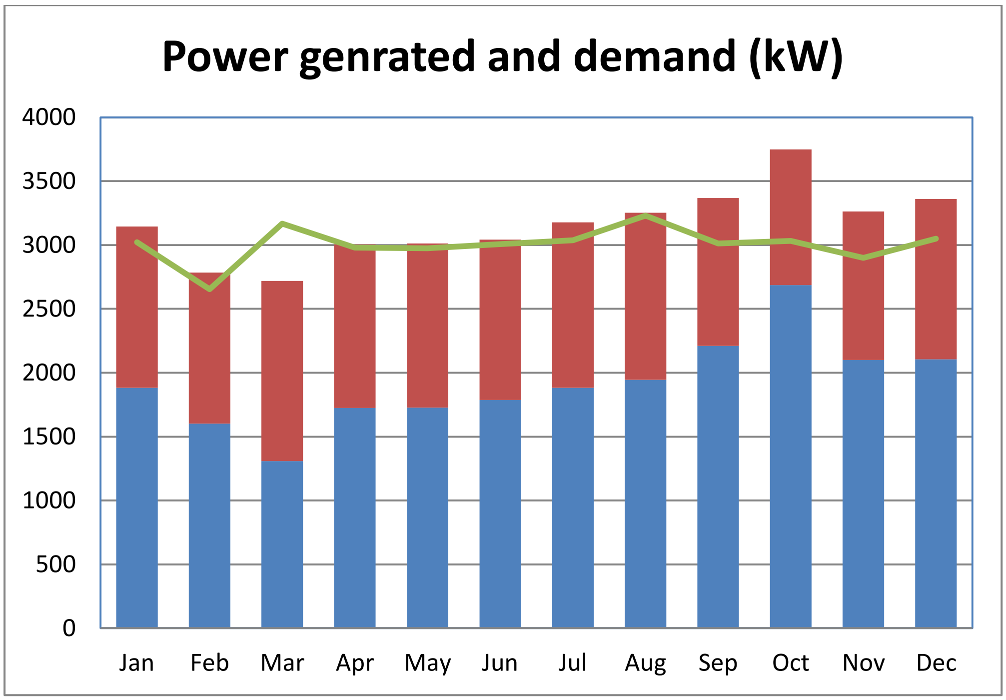

Fig. 12. Daily mean energy production and load demand

Biomass is the main source of the proposed system along with the SPV. The system includes a 12 kWP photovoltaic system and a 3 kW biomass generator. 39% of load is covered by biomass generator where as the SPV delivers 61% of the power requirements. The system observes that the power shortage is almost 1about 14% per annum. The integration of SPV with the biogas generator serves 86% of the load requirement which is quite an acceptable characteristics. The blue bar shows the power generation from the SPV while the red bar shows the power generation form the biomass generation and the green line shows the load requirement of the system.

EFFECT OF BATTERY INTERGRATION

It can be observed that the load of all power requirement of private and commercial consumers changes frequently. As the load changes, so must the power supply to keep the system running smoothly. In the proposed system, electricity is generated by a photovoltaic system and biogas, and emergency power is provided by a battery bank. The output of a photovoltaic system naturally fluctuates because it depends on the weather. To accommodate changes in load demand, battery power must change accordingly. For using pattern of the customers, it is designed to be most stressed in the evening. In the evening, the SPV power declines due to lack of sunlight. Biogas is a possible alternative for energy production. Biogas produces electricity almost constantly, but fluctuations in production take time. This event supports the use of batteries to smooth power supplies by absorbing excess energy and releasing deficit energy throughout operation.

SEASONAL LOAD VARIATION

Electricity consumption at the planned site is estimated at 99 kWh/day. The figure below shows an example load profile for four different seasons. March 10th is considered a typical day representing the spring season (red line), May 10th is considered the summer season (green line). August 10th is considered for monsoon (violet line) and January 10th represent the winter season (blue line). Since the system is designed for domestic loads, peak demand occurs in the evenings throughout the year.

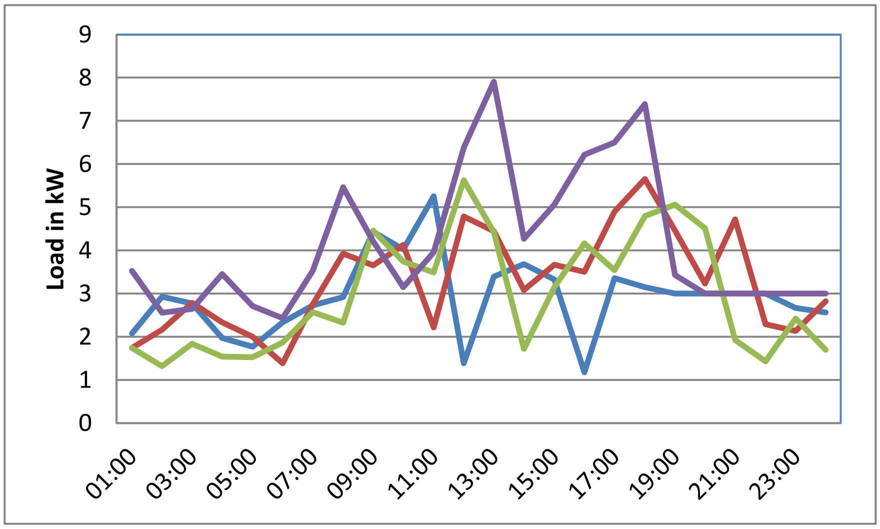

Fig. 13. Electricity consumption of four typical days in a year

RENEWABLE PENETRATION LEVEL

A feature of the proposed system is the degree of penetration of renewable energy. The proposed system uses photovoltaic panels and biomass to generate electricity, all of which are renewable in nature. The proposed system can achieve approximately 100% of its power production from renewable sources, ignoring the power consumed in the production of the system's main components and other ancillaries.

HOURLY ENERGY BALANCE OF THE PROPOSED SYSTEM

An example of hourly simulation results on august 10th is considered to analyze the energy balance of the proposed system, which is shown in the figure below. The photovoltaic power is indicated by the blue bar, the biomass generator power is indicated by the red bar, the violet bar represents the battery power exchange with the system, and the green line indicates the average load. The system is designed so that solar power is the main source of energy to meet the load demand during sunny hours, with excess energy stored in the battery unit. To mitigate the intermittent nature of SPV, continuously charging and discharging of battery banks provision is allowed in the scheme. Biomass generators only operate when there is a shortage of energy from the SPV combined with the battery to meet the load demand. It can be seen that biomass energy is mainly used in the evening when energy demand is not so high.

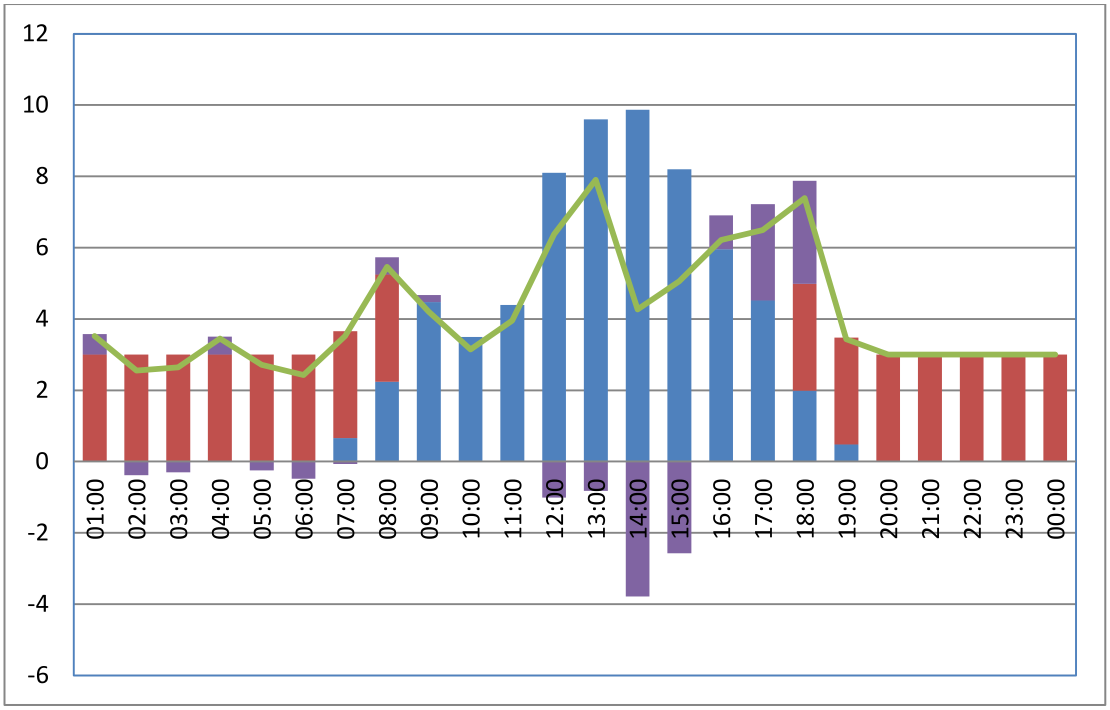

Fig. 14. Hourly energy balance

SENSITIVITY ANALYSIS

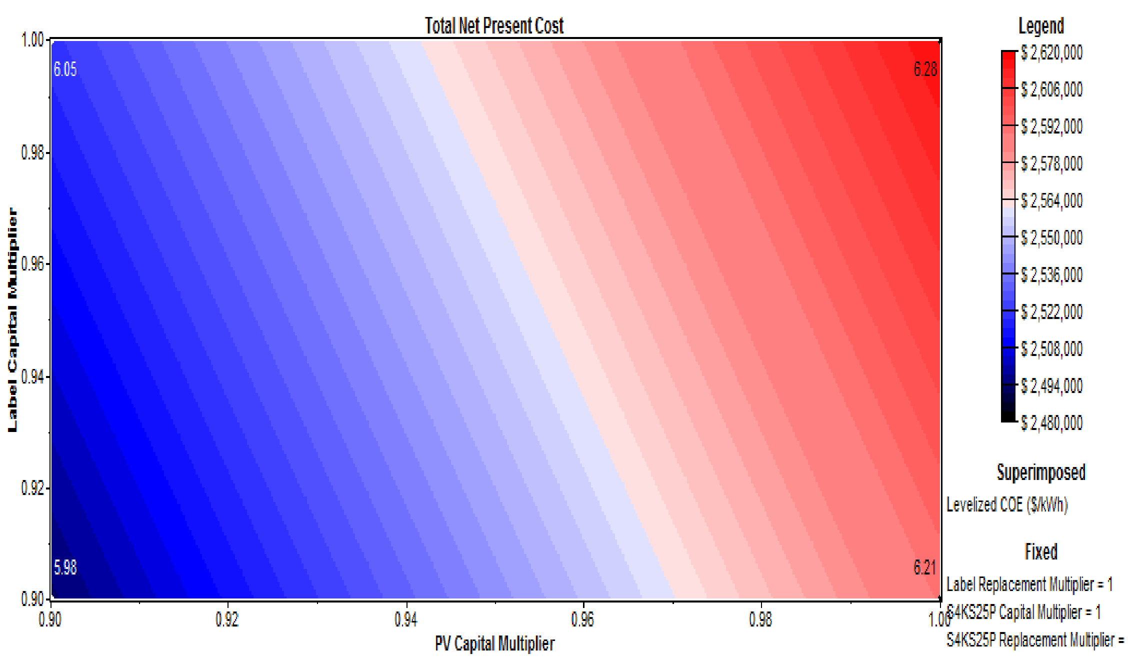

Fig. 15. Surface plot of electricity charge

India is encouraged to reduce costs and develop technology for renewable energy systems in recent years. Therefore, this study assumes that system costs are likely to decrease in the future. In order to simulate the declining cost for the long term analysis; a 10% reduction in capital cost of PV, Biomass, Battery and Converter has been incorporated in the estimation. While the replacement cost is considered about 15% from the present cost. The levelized cost of energy is super imposed over the net present cost to create the surface plot. The cost of energy varies between INR 5.98 to 6.28 depending upon the present market condition and the inflation level.

FINANCIAL ANALYSIS

The graphic depicts the total optimization outcomes for the HOMER software-generated hybrid system. Each table row illustrates a conceivable system configuration. The first four columns show the symbols, the next four show the number or size of each component, and the last eight show the key simulation results: system initial capital cost, operating cost, net present cost, CoE, renewable fraction and capacity shortage, biomass (t), and label hour. The ideal setup has the lowest NPC and includes 12 kWP PV, a 3 kW biomass generator, 14 S4KS2P battery banks, and a 9 kW converter. The initial capital cost is INR 13,71,800, the operating cost is INR 97,377 annually and the total NPC is INR 26,16,611. It has a COE of 6.276/kWh and consists of 100% renewable energy sources.

Table 1 Optimization result of SPV-Biomass integrated System

PV (kW)	Label (kW)	S4KS 25P	Converter (kW)	Initial capital	Operating cost ($/yr)	Total NPC	COE ($/kWh)	Renewable fraction	Capacity shortage	Biomass (t)	Label (hrs)
12	3	14	9	$ 1,371,800	97,377	$ 2,616,611	6.276	1	0.14	160	4,974
12	3	15	9	$ 1,377,450	97,526	$ 2,624,159	6.284	1	0.13	159	4,944
12	3	14	5	$ 1,346,600	1,00,001	$ 2,624,943	6.249	1	0.13	167	5,211
12	3	14	11	$ 1,384,400	97,658	$ 2,632,802	6.335	1	0.14	159	4,939
12	3	15	5	$ 1,352,250	1,00,356	$ 2,635,135	6.253	1	0.13	167	5,191
12	3	14	7	$ 1,359,200	99,902	$ 2,636,277	6.228	1	0.12	166	5,155
12	3	15	11	$ 1,390,050	97,745	$ 2,639,562	6.343	1	0.14	158	4,906

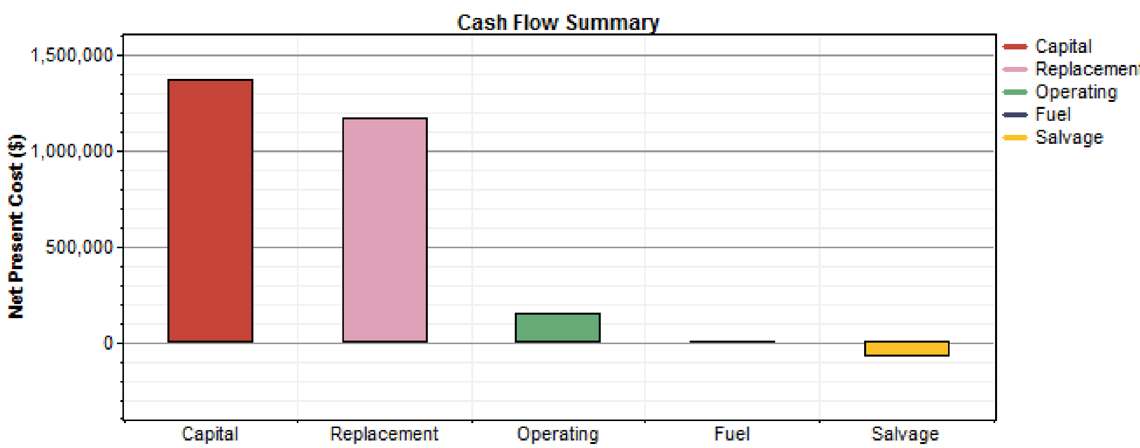

Fig. 16. Funding Flow Structure

The cash flow analysis provided in Figure 16 is used to calculate the NPC. The stydy observes that SPVs contribute to the system's maximum capital cost. By include replacement and operational expenses, biomass generators' capital share rises. Lowest capital share for batteries and converters. The table below summarizes the NPCs in the optimized model.

CONCLUSION

In this work, a Solar PV-Biogas hybrid system is investigated for a load compromising a few home and other societal necessities in Leh, Ladkh area. The system's power production will rise, the capacity shortfall is 14%, which boosts system dependability, and the levilised cost of energy is 6.276 INR/kWh, which may decrease in the near future as the costs of such systems are dropping. The outcome demonstrates that the system is viable and appropriate for the proposed site, with the potential to electrify such an area with enough supply and maximize the use of renewable sources existing on the site.

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