Simulation and Optimization of an Independent Sustainable Micro Hybrid Electricity System for Rural Consumers

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Abstract. A fundamental necessity for sustainable development is to ensure reliable and cost-effective access to modern energy services, primarily for the lower income and impoverished sectors of the population. Successful rural electrification is vital to bridging the rural-urban gap, given that the vast majority of the energy-deprived population resides in rural regions of developing countries. If the existing system of energy services intervened it can influence the development process by livelihood activities, micro or small enterprises, lifestyle energy services, value-added activities, survival irrigation, and so on. Different micro hybrid systems preferably with combination of renewable energy resources will be a good option for addressing given barriers. India has a large Availability of Higher solar radiations, a society that depends on agriculture has enough biomass resources, plentiful cattle dung, forest conifers and agriculture waste. In this paper, we examine the hybrid system's techno economic feasibility and long-term viability. The system is made up of 60-kW solar photovoltaic panels (PV) and 40-kW biomass gasifier modules. Energy demand and resource availability are measured using data from comprehensive stakeholder discussions and field surveys, and they take into account daily and seasonal fluctuations in supply, end uses, and availability, as well as productive hours. The techno economic viability of electric renewable energy is evaluated using a hybrid optimization model (HOMER). Additionally, prospects for the growth of profitable uses and their extension into a long-term business model are investigated.

Keywords: Hybrid Energy, Solar Energy, Economic Model, sustainable development.

1. INTRODUCTION

We should ensure that every individual specially poor and deprived section of India is getting affordable energy services which are basic need for the sustainable development of any country. After the 73 years of independence a larger part of population is still residing in villages and electricity plays an important role in this rural urban gap.

Complete economic development of India is possible when its villages will be electrified. After the many years of efforts World Bank SE4ALL database says that still about 5% of population in India is living without electricity [1]. Grid extension alone cannot bear the burden of electrify rural and far away area because of uneconomical reasons unlike weak rural economy, terrain area, low purchasing capacity. Isolated areas like the
proposed villages face some serious problems from the government side as lack of attention, distant market availability, and cost of installation infrastructure.

As per the recently available data in 2019 around 771 million people worldwide and 155 million people in developing Asia lacking access to electrical energy. After so many efforts still around 6 million people still lack access to electricity in India by the International Energy Agency (IEA). It automatically gives an idea that India is far behind the target of universal electricity access [2]. A large scarcity of energy access in remote areas, the expansion of energy networks to mitigating a gap in urban rural divide and climate change problem on global parameters these are some problems that exists in India’s rural energy part. The best possible solution is to reach all without any lag [3]. Govt. data shows that all villages in rajasthan have been electrified by the various schemes like DDGVY, Saubhagya Yojna [4], but still a lot of households in some remote inaccessible areas still cannot afford traditionally joined electricity. Sawai Madhopur the proposed district of village has 27.7% forest cover and some partially electrified villages that are located far away. Distant villages will play an important role in the success of decentralized distributed technologies and global electrification efforts. It will be a most cost effective option for the rural areas till 2030 as the studies says [4].

This papers suggests a technically feasible and economically viable solution for rural distant households by installing a hybrid micro grid with a total 100kW capacity which consists of 60kW of solar PV and 40kW of biomass gasifier-based generation in a remote village of Bajoli in Rajasthan’s saawai Madhopur district. Load characteristics is constructed by observing the consumption cycle of different load like irrigation, community, commercial and households. A software called HOMER which generated a hybrid optimization model for maintenance cost and various data of the system [5].

2. SITE SELECTION AND RESOURCE SURVEY

The proposed village which is selected for the installation of the hybrid system is a small village in the sawai Madhopur district of rajasthan at khandar tehsil. Longitude and latitudes of this location are 76.68, 26.09. It is located at a distance of 18 km from the sub-district headquarter khaddar and 58 km from the district head quarter. According to 2009 statistics bichpuri gujran is the gram panchayat of the village. It has a total 905 hectare area. 2496 inhabitants reside in the total 350 houses in the village. If we talk about the electricity availability some households are still without electricity and rely on kerosene for illumination and biomass for cooking and heating. An extensive survey was done to estimate the electricity demand. This survey consists conversation with villagers, interviews, data collections and resource availability calculation [6].

2.1. Economy of the proposed village and demand

Village consists family size of 4 to 5 in 350 households. One secondary and one primary school is situated in village. Various scattered kirana shops are available in village for fulfilling daily requirement of the people. Agriculture is the prime source of income of the people in village with people holding 2-3 acre of land. Paddy, Pearl Millet, Green Gram, Black Gram, Sesame, Ground Nut, Soyabean in monsoon season and wheat, Mustard, Taramira are sown in winter and harvested in the spring by farmers [7]. The village is located in the vicinity of Banas River, thus making it an ideal for site for agricultural practices. So, the setup of renewable energy powered irrigation pumps can be huge benefits to the farmers in terms of costs benefits and will also increase the yield of produce.

The economy of village is completely reliant on its agricultural base such as farming activities. Due to lack of efficient power and energy sources many families in village have to depend on firewood for cooking and kerosene lamps for lighting, which are not only highly unreliable and uneconomical but also poses a great hazard to human health and environment. Children require efficient, brighter and more reliable sources of lighting in schools and homes to be able to study effectively for longer durations. Lack of lighting on the streets also raises security concerns for women and children making it difficult for them to step out of homes after sunset. It also increases crime rates after dark.

2.2. Biomass Availability

Straw Goods:
It has been observed that total straw goods yield in reported 1050 acre land is around 760 ton yearly. The amount of grain obtained from the fields is calculated from the sacks of grain available in a year, which is estimated one
hundred kilogram per sack. Straw good content from the grain is calculated from the ratio of straw to grain, which is measured to be two ratio one, means one kilogram of grain leaves two kilogram of straw. Actually it is very complex to observe availability of straw hence a non-direct method is used.

**Woody Biomass:**

The estimations were concluded after assorting through many questionnaires and weighing of some sample loads. On average, 2260 kg of wood is collected and used per year per household. [8] To estimate the potential for biomass resources, woody biomass (wastes generated from forests and plantations, straws, stems, stalks, leaves, husk, shells, peels, and whiskers) and soft biomass (agricultural, commercial, and animal waste) were surveyed for weekly consumption and extrapolated for the year. Through analysis it was found that around 570 ton of wood is collected by 250 households in a year, with a documented collection of 35 kg of wood at least two to three times a week.

**Animal Dung/Manure:**

Table 1 gives the information of survey done from village. Generally in the proposed village cows, buffaloes and goat are left freely to graze in the nearby forest or with an attendee. If a common centralized animal waste collection method is developed there can be a huge potential for biogas generation. With overall calculation and estimation it was observed a waste of seven kilogram per day per cattle, so total animal waste could be two thousand one hundred seventy tones annually.

### 3. POTENTIAL AND NEED FOR INSTALLATION WITH A BUSINESS MODEL

![Fig. 1. Screenshot designed hybrid system in HOMER.](image)

Due to its remoteness from the district headquarter; the people of Bajoli are dependent on the farming activity. People of village usually travel nearby towns for the employment and important things. At least one person from the family has gone to big cities for the employment due to lack of source of income in village. Most of the families rear Cattle for dairy only. Villagers travel to other towns and villages through privately owned buses which come two times in a day. People in villages share food, fuel, and firewood in times of requirements. Small shops also established by some of villagers to supply local needs and income. The selected village Bajoli satisfied most of the requirements for setting up a micro hybrid system like sufficient land availability, proper solar irradiance available, rich biomass and animals available for their dung. But as proper income model is not available in the village this system can help them.

### 4. HYBRID SYSTEMS AND METHODOLOGY

Here in this paper we have proposed a small independent micro hybrid system which can power a small village of a particular household capacity and can be connected or extended to grid later on which can increase the reliability of supply during outages and increase time of electricity. These technologies generally termed as distributed technologies.
4.1. Solar Photovoltaic Module
A 60kW solar photovoltaic array is used with a lifetime of 25 years and 80% derating factor. As we have sufficient waste fields available in village bajoli PV system can be installed easily. Location of village is in the dustier part of Rajasthan so proper and timely cleaning is required for the panels.

4.2. Biomass Gasifier Module
A 40kW small scale biomass system is proposed with a 15 years life time capacity and minimum load ratio of 50%. Bajoli have a lot of potential for the biomass fuel because people here have a lot of animals and cattle like goat buffalo, cows some so animal waste is available in sufficient quantity. Simultaneously wood and agriculture waste is also available as most of the villagers involved in farming activity.

4.3. Optimization of Proposed Hybrid System using HOMER
This software is developed by National Renewable Energy Labs, USA [8] and we have modeled and designed our proposed hybrid model through this package. In HOMER we can optimize, simulate, and can analyze technical and cost effectiveness by considering a particular load demand and supply every hour throughout the year. Several studies have been done [10].

4.4. System Components and Cost
As discussed earlier the combined system consists of a 60kW solar and 40kW biomass gasifier modules. The system cost comprises combined cost of biomass resources, solar resources, PV panels and biomass gasifier, batteries, converters, connection costs, O&M Costs. Fig. 1 shows the screenshot of the designed model on HOMER software for the system. Component costs (Table 2) are estimated from the market surveys from independent manufacturers and wholesale markets. Project is estimated of total 25 years life time. Discount rate and inflation rate is 10% and 5% respectively. The fixed and variable costs are site-specific and would vary with geography of operations.

4.5. Development of Load Profile
Load profiles were developed in three steps: first, to form an initial skeleton of village’s demand profile, studies of villages with similar socioeconomic, geographic, population density and electricity utilization were used for reference [9]. Second, information was collected from a range of field visits to schools, houses and local markets, and through consulting the established enterprises, and demand surveys. The demand surveys reflected on the current issues faced by the villagers in sectors and adopted plans to provide lighting in schools, street lighting, establishing paper bag making center, and provision of water heater and fridge for storing vaccines and other biomedical stuffs. Finally, with the use of conventional methods of bottom up analysis a time-dependent probabilistic distribution of loads was generated to determine the varying demand across the day to reflect the end uses. This was all done through analyzing various segments of customers with small populations typical of minigrid operations. This analysis was done by categorizing all the types of electric operations, devices and their typical loads with respect to the number of consumers and studying the probability of their usage at a given time of the day.

The loads are divided into domestic (households), commercial, community, and irrigation sectors. Similarly Commercial loads, Community loads and Irrigation loads are given in table. Monthly variation in load is shown by dividing time duration in three groups of months in summer, monsoon and winter. Loads are distributed uniformly for particular services of household, irrigation, community and commercial. In summer more cooling appliances are needed and in winter night load is decreased but water heating is used so variation in load is shown accordingly. During rainy days no water pumps are required. This variation in load can be revised according to time.
### Table 1: Cost of System Components

| Load Sector        | Appliances      | Watts | Quantity per Households | No of Households | Summer Usage Hr/Day | Winter usage Hr/Day | Monsoon Usage Hr/Day |
|--------------------|-----------------|-------|-------------------------|------------------|---------------------|---------------------|-----------------------|
| Domestic           |                 |       |                         |                  |                     |                     |                       |
| Households         | LED Bulbs       | 6     | 6                       | 200              | 8                   | 10                  | 10                    |
|                    | TV              | 70    | 1                       | 200              | 8                   | 4                   | 4                     |
|                    | Fan             | 50    | 2                       | 200              | 8                   | 0                   | 8                     |
|                    | Radio           | 15    | 1                       | 200              | 4                   | 4                   | 4                     |
|                    | Phone Charger   | 4     | 2                       | 200              | 6                   | 6                   | 6                     |
| Commercial         | LED Bulbs       | 6     | 4                       | 5                | 8                   | 8                   | 8                     |
|                    | Fan             | 50    | 2                       | 5                | 10                  | 0                   | 8                     |
| Small Cold Storage Plant | 6000 | 1 | 1 | 5 | 2 | 1 |
| Mixer              | 500             | 1     | 5                       | 5                | 5                   | 5                   | 5                     |
| Commercial Flour Mill | 15 HP Motor    | 12000 | 1 | 3 | 7 | 7 | 7 |
| Community          | LED Bulbs       | 6     | 10                      | 1                | 10                  | 8                   | 8                     |
|                    | Fan             | 50    | 6                       | 1                | 8                   | 0                   | 4                     |
| Health Center      | LED Bulbs       | 6     | 25                      | 1                | 10                  | 10                  | 10                    |
|                    | Fan             | 50    | 10                      | 1                | 8                   | 0                   | 5                     |
|                    | Fridge          | 475   | 1                       | 1                | 6                   | 6                   | 6                     |
|                    | Water Heater    | 1000  | 1                       | 1                | 6                   | 6                   | 6                     |
| Street Lights      | LED Bulbs       | 10    | 40                      | 8                | 8                   | 8                   | 8                     |
| Agriculture        | Water Pumps     | 3730  | 1                       | 8                | 7                   | 4                   | 0                     |

### Table 2: Rating and Requirements of Appliances across Sectors in Different Season

| System Component | Size     | Number | Capital Cost (US$) | Replacement Cost (US$) | O&M Cost (US$) | Life Time (Years) |
|------------------|----------|--------|--------------------|------------------------|----------------|-------------------|
| PV Array         | 1kW      | 60     | 950/kW             | 950/kW                 | 25/kW          | 25                |
| Biomass Gasifier | 40kW     | 1      | 1495/kW            | 0/kW                   | 0.20/kWh       | 25                |
| Battery          | 200 Ah, 12V | 240 | 226/Battery       | 220/Battery           | 6.0/Batt/Year  | 5                 |
| Converter        | 1 kW     | 100    | 117/kW             | 117/kW                 | 3.0/kWh/year   | 15                |
Fig. 2. (a) 30 days demand curves of Households. (b) Single day Load curves for Households Load.

Fig. 3. (a) 30 days demand curves of commercial load. (b) Single day Load curves for commercial Load.

4.6. Observation of solar irradiance
The potential of solar energy for Bajoli village with the Co-ordinates of latitude 26.09, longitude 76.68 was studied. Through the findings annual average solar radiation was 5.46 kWh/m²/day and the average clearness factor was 0.612 (Fig. 6). Around the months of February to May are best to leverage potential of solar energy because of the highest clearness resulting from low fog and low cloud cover which lessens during late summer and monsoon season caused by cloud and rain activity. It is estimated through the surveys and field visits that an approximate of 2250 ton woody biomass is available which is variable according to the seasons.

Fig. 4 Irradiation Data obtained from the NASA Database on February 21, 2021.

5. RESULTS AND DISCUSSION

5.1 Techno economic Feasibility Analysis Through HOMER
By using described software we have optimized perfectly this hybrid system with various load profiles of three types of loads. The conclusive system model comprises a 60kW solar photovoltaic array system, a 40 kW
biomass gasifier arrangement which is a size your own component in the library of homer software, a generic large 100kW capacity converter connected between AC and DC Bus with 15 years life time, 240 strings of generic 12 volt lead acid battery with 1 kwh energy storage capacity of each. A total of 0.100 % which is 164kWh/year capacity shortage was achieved in the system. Cost summary report in US$ of the above-given architecture detailed in Tables 4 and 5. The hybrid system was optimized at a levelized cost of energy of $0.3206/kW using the software.

As fuel is required for biomass gasifier modules its cost which includes after paying to villagers or collectors or providers is projected to be $30 per tonne of biomass. This would be a source of income for people of village who currently collect firewood, wood chips and straw for their home needs and can collect the agriculture residual waste, forest foliage, and fire-wood for the gasifier. In addition, more biomass resource can be easily collected from the waste fields near the villages and animal dung [9]. PV output peaks at 141 kW during the summer months as per software output, when solar irradiation is at its best, and decreases to 0 kW at night, explaining the low mean. Peak demand of electricity load is 95.58 kW, while the minimum of 0.063 kW is observed at night.

The model was able to reach zero power and energy shortages, which necessitated the use of a large battery backup numbers. The current trend of lower battery prices and higher long-term storage will help reduce battery storage costs & lower the renewable energy systems COE [10]. Notable electricity generation is useful in the case of appliance durations, day-to-day demand, and operating reserve capacity, and can be used again in the future if demand increases.

One of the three energy access goals, reducing climate change, is also a critical component of the research. Per capita greenhouse gas (GHG) emissions in rural India are estimated to be 26 kgCO2 e per year per person for homes that use kerosene and electricity for lighting purpose [11]. The entire device powering 350 houses will generate a total of 51.0 kg CO2 e per year in this case, which is a substantial reduction in emissions. Since biomass can be sourced sustainably, resulting in zero emissions, such low levels of emissions are feasible. Table 3 demonstrates the Cost of installed hybrid system whereas table 4 shown the lifetime costing of different components used.

To make the hybrid system financially viable, the capital investment must come from the government or a donor entity, and the operating costs must be recovered by the use of differential energy pricing for household and industrial end uses. It's also important to have a profit margin in the price structure to ensure the system's long-term viability. The parts that follow give an overview of some of the potential approaches to achieving these targets.

5.2 Economic Analysis of Hybrid System Feasibility

The key innovation challenge in HOMER studies is to develop the supporting business process and use the ecosystem which can facilitate the implementation of this outcome and ensure that it function successfully in future. The coming portion discusses three major types in this regard. With institutionalized partnerships, three-tiered developments in structure, funding, and final mile connectivity are proposed. Second one, a picture of business process or model is analyzed in order to perform a comparative and targeted study. Third, a business model for the Bajoli village site is suggested.

| Table 3 Cost of installed hybrid system |
|----------------------------------------|
| Total Net Present Lifecycle Cost (US$) | 631624 |
| Levelized Cost of Electricity (US$/kWh) | 0.3206 |
| Operating Cost per year (US$)           | 36122.21 |
Table 4 Component wise Breakup of Life-Time Costs

| Component             | Capital ($) | Replacement ($) | O&M ($) | Fuel ($) | Total ($) |
|-----------------------|-------------|-----------------|---------|---------|-----------|
| Biomass Gasifier      | 59800       | 0               | 650.94  | 192050  | 252500    |
| 240 kWh LA Battery    | 54240       | 52800           | 56982   | 0       | 164022    |
| Flat Plat PV          | 57000       | 0               | 70706   | 0       | 127706    |
| System Converter      | 11700       | 11700           | 4192    | 0       | 27592     |
| Distribution Connection | 51978      | 0               | 7886    | 0       | 59804     |
| System                | 234658      | 64500           | 140416  | 198050  | 631624    |

5.3 Government Policies and Regulations:

These types of startups generally face difficulties from the side of governments while they start to working in rural energy supply. These may be political, policy related and financial risks [12]. Some risks like appropriation and thefts can be controlled through better governance, law and order and village level continuous check-ups. Policy and implementation threats, such as sudden policy changes or failure of implementation plans, require greater clarity across local, global, and international guidelines. Novel billing and metering models, such as village-level funds or pay-as-you-want subscriptions, can mitigate revenue risks caused by consumer non-payment or low demand. For the selected site optimized values of selected parameters have been presented in table 5. The key policy and regulatory barriers currently plaguing the Indian rural energy market are defined as a lack of effective policies and programme, a lack of simulated private sector, a poor institutional system, insufficient governance structure, misdirected focus and priorities, ineffective distribution mechanism Due to the resource, deployment, sector, and investment complexities of decentralized renewable systems, these issues are compounded, necessitating initial capital and revenue support. Rural Energy Access Authorities have been proposed as leadership agencies at both the federal and state levels. Furthermore, they will act as a focal point for bringing energy efficiency, repair, and maintenance of micro-grid energy systems to the public through the government's various skillling and apprenticeship programmes. They will also play an important role in disseminating accurate knowledge about distributed energy systems and emphasizing the benefits in terms of health, education, and opportunities.

Table 5 Technical and economical Parameters of the system

| Configuration          | Unit       | Optimized Design |
|------------------------|------------|------------------|
| Solar PV               | kW         | 60               |
| Biomass Gasifier       | kW         | 40               |
| Battery Storage        | kW hour    | 240              |
| Converter              | kW         | 100              |
| Total Capital Cost     | US$        | 234658           |
| Total Replacement Cost | US$        | 64500            |
| Total annual Capital Cost | US$     | 9386.32          |
| Total Operating Cost   | US$        | 140416           |
| Unit Cost of Energy    | US$        | 0.3206           |
| Generation Shortage    | %          | 0.01%            |
| Unmet Load             | kW         | 83.3             |
| Excess Electricity     | kWh/year   | 78363            |
5.4 Study of different available Economic Models: With using multiple types of revenue models from the wide classifications, a diversified financing, ownership, and maintaining schemes can be seen. The following is a list of a couple of these categories.

Pay-as-you-want (Prepaid Energy Access): PAYW contracts allow consumers to use energy for which consumer have to pay in advance according to their preferred schedule or limit, similar to how cellular phone talk-time and data are sold. This is best for consumers who have a fluctuating income and are at risk of missing payments for services. Households will have more leverage over their usage, expenditures, and savings if payment chunks are smaller. Companies who choose to grow the pace of collection of revenue (7 day, 15 day, or 30 day) or adopt different payment methods may have more flexibility.

Utility-controlled development:
Partnerships between energy companies and solar and off-grid companies are a common occurrence. The companies (off grid) which are benefitted from the power companies has mighty money flows and balance sheets, while latter gain access to new markets, goods, and retail customers in new environment [7].

Operation and maintenance given on contracts and installed by community:
Community-owned and funded micro grids, which are funded at the level of village using country, regional, or local funds, may be a viable option. Specially allocated energy funds will be needed for the advance costs in high-impact countries where local funds are insufficient. These will be useful in low-income areas where skilled workers are scarce and skilled man forces and technically knowledgeable experts are in scarcity [10].

Single Company Method:
Another recent development is where a single company plans, draws, runs, have ownership, and maintain only integrated solution. A single company can showcase full financial, consulting, advance technology grid, generation resources, operations and maintenance, and a micro grid-sized technical controlling method i.e. SCADA. The strategy is restricted to companies that have a variety of electrical and software capabilities, despite the fact that it offers one-stop solutions.

5.5 Final Economic Model Proposed for the village:
We suggest the following simplified revenue and business models for the Bajoli project (Fig. 6). Its modalities operate on couple of stages: first at the last mile user level and another at the level of system. It has been divided into three groups at the last mile user level: families, industrial & irrigation, and society. Term "community" refers to all of the village's popular electricity use, such as street lights and panchayat illumination. Panchayat’s big seminar rooms, educational building etc.
The household will be responsible for the upfront installation costs. A 30 days or 15 days electricity use tariff may be utilized for industrial and irrigation end use. Cross-subsidization may be explored by high billing of industrial and agriculture use. Commercial subscribers’ payment schedules may be calculated depending on the essence of their market and payment versatility.

6. CONCLUSION

Above Research founded the technical, cost effective, & community viability of a combined biomass and solar photovoltaic system which is to be set up in a partially electrified village of Rajasthan named bajoli. This paper proceeds in three sections: first is estimation of available fuel and solar photovoltaic irradiance and capacity with load requirements, second is making of load changing table profile according to village household electricity consumption as well as community and agricultural load, this table is plotted after constant monitoring of load and taking questionnaire sessions with villagers of bajoli. Third and last section of flow of research paper is calculating the optimal operating feasibility and cost effectiveness of this proposed system using HOMER. HOMER also provides the data of emission. The output of this combined system showcases that installation is reliable, optimally designed and can meet the electricity demand of all types of loads in the village.

After considering worldwide results and existing system an economic model is also proposed which shows that it can be run as private enterprise. Study of various systems suggests that public and private partnership can be availed for installation cost sharing and for the successful operation of such systems recovery of running or operational cost plays a very important role.

We can also add some study results of impact of grid integration with present system during future high load conditions.

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