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# Techno-Economic Comparison of an Off-Grid PV System and Biogas System for Dairy Farming

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***Abstract***

*This paper compares off-grid solar photovoltaic (SPV) system and biogas system for a dairy farm containing 100 cows in India and gives technical and economical assessment for the same. These technologies can sufficiently provide energy for dairy farms which cannot be connected to grid due to financial reason or geographical concern. The comparative analysis for the two different renewable energy systems is based on efficiency, reliability, space requirements, gas emissions and economic viability for both the systems. Based on the findings and estimations of economic cost, efficiencies and other factors of the two systems, recommendation is to use the biogas system as it is more reliable and cost effective method for electrifying a standalone 100-cow dairy farm, based in India.*

***Keywords:*** *Dairy farming, solar photovoltaic system, biogas system, anaerobic digestion, off-grid*

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## INTRODUCTION

India is world's largest milk producing country, which is evident from the fact that it has got highest number of dairy farms in the world as well, with over 75 million dairy farms spread across the country. India has the largest cattle and buffalo population in the world [1]. Dairy development in India has been acknowledged world over as one of modern India's most successful developmental programme [2]. The country's milk production increased from around 55.6 million tonnes in 1990s to 155.5 million tonnes in 2016 [3]. A dairy farm with 150 cows required 20000 to 25000 $ft^2$ for housing and for fodder, 17 acres of land with assured irrigation [4].

Grid extension to rural areas is untenable mainly because of the high costs required to extend it to the sparse populations who live in the rugged terrain areas [5]. Most of the dairy farms are setup in rural and remote areas where electrification by grid extension is a difficult task. The installation and distribution costs are considerably higher for remote areas [6]. So, for this purpose, use of renewable energy resources for setting up off-grid dairy farms is mostly suitable for meeting the power demand. The electricity need of the dairy farm can be met directly by natural resources available, that is, through small systems of energy generation from renewable resources [7].

Electricity generation from renewable energies can be put in service faster than by following the procedure of grid extension. Renewable energy is an energy source that is currently considered because of its high potential [8]. Renewable technologies like wind turbines, solar photovoltaics and biogas plants can be used, as enough land and manure are present in a dairy farm. However, in India, wind with sufficient speed and continuous availability is limited to coastal areas, which make its incorporation feasible in those locations only. Whereas, SPV and biogas systems can be used in any dairy farm in India in general, since about 4–5 $kWh/m^2$ average solar energy is incident over India on daily basis, suitable for SPV system, and biomass is available in enough quantity to be used for biogas plants.

Electricity production from PV systems, which is the most common renewable energy technology, shows a great potential for farms and particularly for dairy farms [9]. Solar photovoltaic systems, through their flexibility

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in use, offer unique chances for the energy sector to provide "packages" of energy services to remote rural areas [10]. Solar resources are obvious choices for dairy farm electricity generation, since they are universally available to a certain degree and the technology is well understood and available [11]. Biogas, another renewable energy resource potentially universally available at dairy farms could help to bridge variation in renewable electricity generation and on-farm demand [11].

Anaerobic digestion can be an effective solution for treating the farm waste, not only to reduce impact on the environment, but also to produce biogas energy, which is renewable [12]. The potential advantages of operating a biogas plant in a medium to large sized farm are manifold [13]. The major advantage of biogas as an energy resource over other renewable is that it can be stored for short to medium periods of time at little cost, and is available on-demand [11].

Many studies have been done explaining advantages and disadvantages of various renewable energy sources in numerous applications but none has compared the SPV system and biogas system for use in dairy farm application.

This paper makes the technical and economic comparison between an off-grid SPV and biogas system for a dairy farm containing 100 cows to determine better alternative for the purpose of off-grid electrification of the same. The arrangement of this paper is such that the next part gives the load analysis of a dairy farm, then the system modeling of SPV and biogas system, the results and conclusion; the comparison between the two models and finally, it highlights the overall conclusion.

## LOAD ANALYSIS OF A DAIRY FARM

The load requirement of a dairy farm to be set up in Haryana, India, having 100 dairy cows is given in Table 1. The daily energy consumption of the farm is around 571 kWh/day. It is observed that ventilation, milk pumping and refrigeration facilities consume the bulk power. It is estimated that the daily water requirement for an adult cow is around 100 l/day and thereby the daily water consumption in the dairy farm will be more than 10 $m^3$/day. A submersible water pump of 95 m depth and 7.5 kW capacity will be sufficient to fulfill the daily requirement of the dairy farm. Table 2 shows the space requirement of the various sheds used in the dairy farm.

Due to rising cost of energy and environmental factors, it has become necessary to use alternative energy saving system for electrification of dairy farm. Better energy management technology will help in increasing productivity, quality of environment, cost saving and profitability.

The approximate energy requirement of a 100-cow dairy farm essentially needs energy for milking system (52%), ventilation (26%), water heating (15%), lighting (4%) and other (3%) is approximately 594.7 kWh/day. The total load for this dairy farm is found to be around 117 kW.

***Table 1:*** *Load Table for a Dairy Farm.*

| Component | Power (W) | Number | Total Load (W) | Daily Running Time (h) | Total Energy (kWh) |
|---|---|---|---|---|---|
| Lighting | 18 | 40 | 720 | 16 | 11.5 |
| Ventilation | 350 | 20 | 7000 | 16 | 112 |
| Water heating | 3000 | 1 | 3000 | 9 | 27 |
| Feeder mixer | 3700 | 1 | 3700 | 1 | 3.7 |
| Packing machine | 4000 | 1 | 4000 | 1 | 4 |
| Water Pumping | 7500 | 1 | 7500 | 1 | 7.5 |
| Vacuum pump | 5000 | 3 | 15000 | 3 | 15 |
| Milk pump | 3000 | 20 | 60,000 | 4 | 240 |
| Cleaning/washing | 746 | 4 | 2984 | 2 | 6 |
| Refrigeration | 14000 | 1 unit | 14000 | 12 | 168 |

***Table 2:*** *Space Requirement of Sheds in Dairy Farm.*

| Roofing area of shed | **Area ($ft^2$)** |
|---|---|
| Main Cow Shed | 15750 |
| Calf Shed | 2760 |
| Sick animal shed | 2760 |
| Wheat straw shed | 2880 |
| Total roofing area | 24150 |

## SYSTEM MODELLING

The load requirement discussed in the above section can be met by either a SPV system or a biogas system.

### Off-grid Solar PV System

Figure 1 showing a stand-alone photovoltaic system can operate in an autonomous manner, very often, far away from the grid [4]. Solar PV technology converts solar energy in to electricity. Installation of PV modules in a dairy farm can save a lot of space as the PV modules can be installed on the roof tops of the cattle sheds.

#### *System Components*

An off-grid PV system consists of PV panels, charge controller, battery bank, inverter/charger and backup generator. PV panels generate power from sunlight. Charge controller optimizes charging by tuning voltage or current to batteries and protects them from overcharging. Battery bank stores extra energy generated to meet load demands during night or bad weather conditions. Inverter/charger converts DC to AC for dairy farm appliances and converts AC to DC for charging of batteries. Backup generator is optional. Its function is to provide energy during high demand or during cloudy weather.

#### *Sizing Calculations*

The solar PV system can be designed using the following five steps:

- In the first step, the total power and energy consumption of all loads needs to be calculated.

Total watt-hours for all the appliances needed per day =594.7 kWh
Total watt-hours needed per day from PV modules:
=594.7 kWh×1.3 (factor showing energy lost in the system)
=773.11 kWh.

- In the second step, the size of the PV modules is calculated using Eq. (1):

$$\frac{\text{Total Watt-hours per day from PV-modules}}{\text{Panel generation factor}} \quad (1)$$

=220 $kW_{peak.}$

- The third step is to calculate the number of panels needed which is calculated by dividing the result obtained in step-2 by the wattage of a single panel to be used in the installation. In the present study, 330 W panels are used.

$220kW_{peak}/330W_{peak}$ =666.66.
This shows that around 667 such panels will be needed for meeting the required dairy farm load.

- In the fourth step, the inverter sizing to convert AC to DC is done. For this, the total wattage of all the appliances needs to be calculated. For safety reasons, the size of the inverter should be 25 to 30% more than the total load wattage. In this case, it is around 220 kW.
- The last step is to calculate the size of the battery bank. It is calculated using Eq. (2).

$$\frac{\text{Total Units of Elecricity required per day}}{(\text{Inverter loss} \times \text{Battery DOD} \times \text{System Voltage})} \quad (2)$$

$$= \frac{594.7}{0.85 \times 0.6 \times 240} = 4858 \text{ Ah.}$$

The battery size will be 180 cells of 2 V each rated at 1200 Ah. There has to be different power conditioning units as per the load division and this same battery bank can be combined with them. It is advisable to take six inverters of 40 kVA and give 30 kW load on each inverter and 35 kW PV on each inverter. As per standard calculations, 100 $ft^2$ is required for setting up of 1 kW PV panels. So, a total roofing area of 24150 $ft^2$ can accommodate 241.5 kW panels and the present requirement is 220 kW.

#### *Cost Calculations*

It is estimated that an off grid PV system with battery backup costs around Rs. 80/W. Table 3 shows the breakup cost for all the components used in the solar PV system design. So, for a 220 kW system, the total cost of the PV plant will be around Rs. 1.5 crore after getting a subsidy of 30–35% from Ministry of New and Renewable Energy (MNRE).

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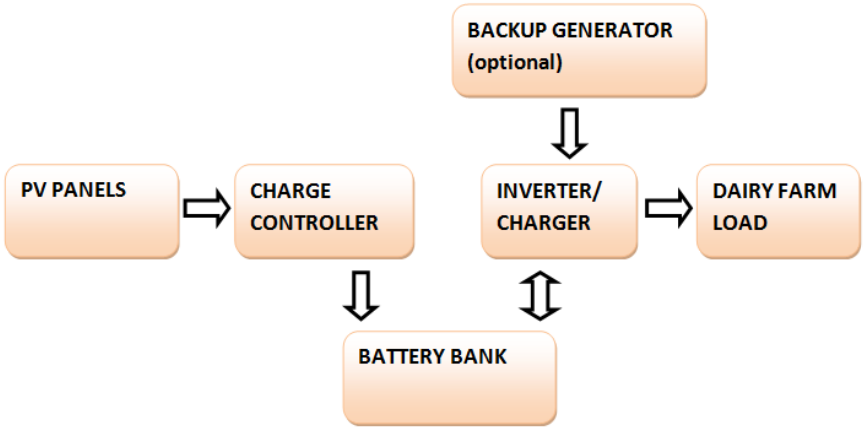


***Fig. 1:*** *Standalone PV System for Dairy Farm.*

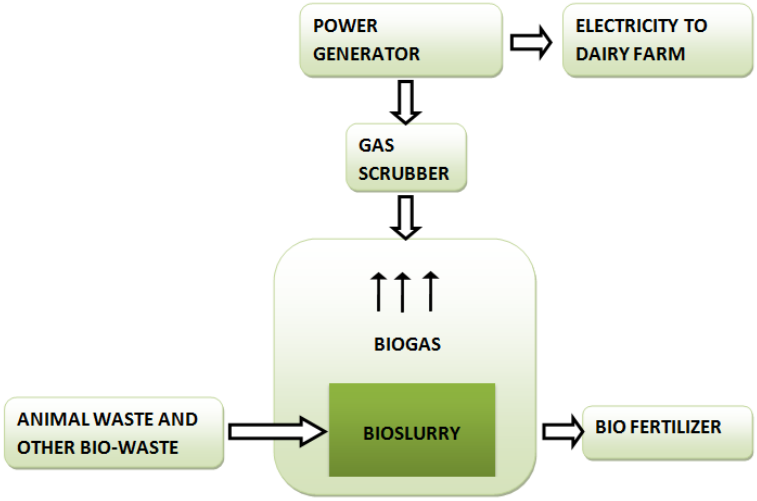


***Fig. 2:*** *Standalone Biogas System for Dairy Farm.*

**Biogas System**

Figure 2 shows a standalone biogas system. Dairy farm biogas plant uses animal dung from animals staying there and extra dung and bio-waste is used in case of fulfilling entire electricity requirement of the dairy farm. The dung is mixed with water to form slurry and transported to fermentation pits for certain retention period (30 days are taken here), where anaerobic fermentation takes place and as a result, biogas is produced and in comparison to fixed dome arrangement should be used for a heavy load requirement.

***System Components***

The biogas system consists of an anaerobic digester, filter/gas scrubber and power generator. Anaerobic digester is that part of this system in which an aerobic decay of waste takes place. Filter/gas scrubber is used to remove undesirable moisture, gases. Power generator's function is to produce power from biogas. The ready biogas which is a mixture of methane and carbon dioxide is produced by the anaerobic digestion of biomass.

***Table 3:*** *Solar PV System Component Cost.*

| S. No. | Particulars | Rate |
|---|---|---|
| 1. | Solar Panels:<br>Supply and Installation of solar PV Crystalline Modules<br>Make: Renesola/Vikram Solar 250/330 W Panels | INR 37/W |
| 2. | Hybrid Solar Inverter: Supply and Installation of Hybrid Connected MPPT Base Make: EAPRO\|30 kW at 360 V with Inbuilt Transformer | INR 16/W |
| 3. | Battery backup Requirement: HBL Southern Batteries | INR 53/W |
| 4. | (Engineering, Procurement & Commissioning) | INR 18/W |

### *Sizing Calculations*

There are around 100 adult cattle and 50 calves in the dairy farm. It is estimated that an adult cow produces around 20 to 25 kg dung every day. Therefore 100 cows along with calves will produce around 4200 to 4500 kg of dung every day. As per standard calculations for 100 kg dung available, a 10 $m^3$ plant is sufficient to produce biogas which generates approximately 1.25 kWh energy running for 10 h. So for producing around 600 units of electricity, a 500 $m^3$ floating dome type biogas plant will be required. In order to assess the biogas potential, the assessment of biogas is done on the basis of dung yield. The collection efficiency is assumed to be 70%, gas yield per kg of wet dung 0.036 m3/kg, calorific value of biogas 4700 kcal/m3, conversion factor 860 [14], generator efficiency 95% and diesel engine efficiency as 28%.

The total gas yield and energy yield can be calculated using Eqs. (3) and (4) [15]:

$$\text{Total gas yield} = 0.036 \times \text{total dung availabil} \quad (3)$$

$$\text{Energy yield}\left(\frac{\text{kWh}}{\text{day}}\right) = \frac{\text{Total gas yield(m3)} \times 4700 \times 0}{860} \quad (4)$$

### *Cost Calculations*

It is always recommended to use the best quality materials like bricks, clean gravel, cement etc. to make the dome. Usage of good quality materials will ensure a longer life and better plant efficiency. In addition, the plant should be located at least 10 m away from drinking water sources, as a precaution to avoid the risk of water pollution. The setting up of a biogas plant involves the construction of dome, finding a suitable generator and the civil work. Table 4 shows the breakup cost calculations involved in the construction of a biogas plant. The total cost of a 500 $m^3$ plant is around INR 80 lacs after subsidy of 30–35% from MNRE.

***Table 4:*** *500 $m^3$ Biogas Plant Capital Cost Calculations.*

| S. No. | Item | Unit Cost (INR in lacs) |
|---|---|---|
| 1. | Floating dome arrangement | 65 |
| 2. | Installation | 1.5 |
| 3. | Civil work | 1 |
| 4. | Biogas generator | 12 |

## RESULTS AND DISCUSSION

It is seen that two different systems, solar PV and biogas plant can be used for electrifying a dairy farm where there is no access to grid electricity. The systems can be compared on the basis of cost, lifetime, efficiency, space requirement, emissions, reliability and storage.

### Cost Comparison

The cost comparison for the two systems, solar PV and biogas can be done on the basis of capital cost and operation and maintenance cost. It is seen that the capital cost of installing a PV system to meet a load of 600 units per day is around 45% more than the initial capital cost of installing a biogas system. The biogas plant requires a regular operation and maintenance cost which includes handling the dung used for slurry formation and regular maintenance of biogas generator. The PV plant is comparatively maintenance free except for the regular cleaning of the PV panels. The initial capital cost analysis calculation is shown below in the Figure 3.

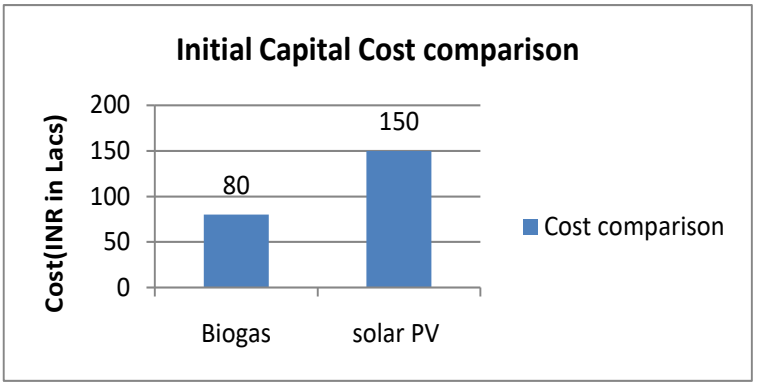


***Fig. 3:*** *Initial Capital Cost Comparison of PV System and Biogas System in Lacs.*

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**Lifetime**
Solar PV panels have average life of 25 years though the efficiency of the panels keep decreasing year after year and the inverter and batteries need to be replaced after around 10 years. The biogas system has a lifetime of 20 years, provided the dome is timely fed with the dung and cleaned regularly. The generator has a lifetime of 10 to 15 years if maintained well.

**Efficiency**
Efficiency of PV system varies between 14 and 20% which is lower as compared to 25 and 40% of biogas system.

**Space**
Solar PV can be installed on roof space of the dairy farm but the inverters and battery bank need a huge room. The floating dome arrangement and the biogas generator of the biogas system can be housed in the open space left for cattle grazing. A lot of bad odour is generated during the working of a biogas plant.

**Emissions**
The working of a solar PV does not create any emissions. Biogas plant releases carbon dioxide in the air. However, impact of $CO_2$ on environment is neutral.

**Reliability**
Solar energy will not be much efficient on a non-sunny day, whereas there is no such restriction in case of biogas system. It continues to work regardless of weather and time.

**Storage**
Biogas system generated energy need not to be stored in batteries like energy from solar PV.

## CONCLUSION AND RECOMMENDATION

With the evaluations and estimations for the off-grid solar PV and biogas system in the present study for an Indian based off-grid dairy farm, it is concluded that a biogas plant is more effective, cost saving and a more suitable option than the corresponding PV system. For producing energy for the 100-cow dairy farm, renewable standalone biogas system was found to have more favorable technical and economic parameters. After the cost analysis of both the systems, it was found that the cost of solar PV system was almost double the cost of biogas systems. It is found that a biogas plant is not dependant on the weather condition or duration of the day. The cow dung produced in a dairy farm can be effectively used for producing electricity and the byproduct that is manure can be utilized in the nearby fields.

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