CHAPTER 5

POTENTIAL OF HOUSEHOLD BIOGAS SYSTEM AS VIABLE RURAL ENTREPRENEURSHIP AND ITS PROSPECT TO DECARBONIZE THE RURAL INDIAN COOKING SECTOR

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5.1 Introduction

The scope of improving performance and acceptability of HBS through several interventions viz. (i) feedstock blending and ready-to-use feedstock, (ii) IoT intervention for better management through prompt diagnostic and corrective action, (iii) introduction of tools and tips for reduction of drudgery while handling feedstock, (iv) upgradation of raw biogas for improving quality of fuel and (v) realization of the true values of digested slurry have been elaborately discussed in the previous Chapters. It is also observed that despite the potential of biogas technology to provide both cooking fuel and organic fertilizer at the household level in rural India, its acceptance and growth remain low. The findings of the current study also reveal the absence of business sense for the HBS among the HBS users which are detailed in **Chapter 3**. Sustainability has been another aspect of expectation besides the economic viability for all types of businesses. The contribution of Sustainable Development Goals (SDGs) set for all levels needs proper assessment.

This chapter provides a comprehensive comparison of household biogas systems with existing rural entrepreneurship models to establish their viability and examines the potential of these systems to decarbonize the rural cooking sector by generating biogas as a cooking fuel.

5.1.1 Status of entrepreneurship in rural India and the prospect of HBS

Various viable rural enterprises including dairy, poultry, piggery, and fishery contribute considerably to the Indian economy [1,2]. For example, millions of small and marginal milk producers, with two to five animals, contribute significantly to India's successful dairy sector [3]. Small-scale rural milk farmers generate 62% of the total milk production in India [4]. The poultry sector in India is broadly divided into two sub-sectors viz. (i) the organized commercial sector and (ii) the unorganized backyard poultry sector. The unorganized sector plays a key role in supplementary income generation for rural livelihoods in India and it is reported that there are around 30 million farmers engaged in backyard poultry [5]. Similarly, rural farmers reared 70% of the total pig population under the traditional system using a low-input demand-driven production system. In comparison to other livestock species, pig rearing has a higher contribution to the income of farmers [6]. India was the second largest fish-producing nation in the world after China during 2021-22. Fish production is also dominated mostly by small-scale aquaculture farmers which contributes to their income and provides some employment for a small sector of society [7]. All the above ventures are input intensive where net income from the production system is the key motivating factor. HBS can be considered as an equivalent production system as it is also input (feedstock) intensive and products (gas and digestate) have commercial importance. Therefore, a comparative study of economic performance is necessary with all the existing entrepreneurship with HBS.

5.1.2 SDG target through rural entrepreneurship

The Sustainable Development Goals (SDGs) set by the United Nations outline a global blueprint for achieving a better and more sustainable future. Rural enterprises, including those focused on biogas systems, play a critical role in this endeavour. One aspect of this study investigates the potential of household biogas systems (HBS) to contribute to several SDGs by providing clean energy, improving sanitation, promoting gender equality, and facilitating sustainable agriculture. Specifically, the current study focuses on eight indicators suggested by the Ministry of Statistics and Programme Implementation (MoSPI). These indicators provide a structured framework to evaluate the potential impact of household biogas systems on different aspects of sustainable development [9-12]. Through a detailed examination of these indicators, the study aims to offer insights into the ways household biogas systems can align with and promote the attainment of SDGs, thereby enhancing their role in sustainable rural development.

5.1.3 Decarbonizing potential of HBS

Another aspect that has been studied is the decarbonization potential of rural cooking through fuel substitution, i.e. biogas instead of LPG. Biogas is a carbon-neutral cooking fuel that creates CO_2 sequestered from the atmosphere during feedstock growth and then released during biofuel combustion as a part of the biogenic carbon cycle. This is in contrast to the burning of LPG which releases CO_2 trapped in the earth's crust for several years [8]. There have been limited studies to investigate the decarbonizing potential of HBS through fuel substitution and, therefore, considered in the present study.

The profit-making potential for HBS as a viable household-based rural enterprise is presented in this Chapter. A comparative analysis of HBS with some existing successful enterprises (piggery, fishery, dairy, and poultry) made to examine the prospect of HBS with the installed IoT system (HBS_IoT) as a viable business venture is also presented in the Chapter. Further, the potential of HBS_IoT to contribute to (i) SDGs and (ii) decarbonizing the cooking energy sector of the three villages previously selected has also been discussed in the Chapter.

5.2 Materials and Methods

As discussed above, this Chapter comprehensively addresses the various aspects of the current study. The methodologies for (i) comparative analysis of entrepreneurial potential, (ii) potential contribution of HBS towards SDGs and (iii) decarbonizing potential of HBS for rural cooking sectors have been presented below.

5.2.1 Comparative Analysis of Entrepreneurial Potential

This section details the approach used to compare the entrepreneurial potential of household biogas systems (HBS) with other rural enterprises. It involves evaluating various performance metrics, economic viability, and growth prospects within the rural entrepreneurship ecosystem.

Selection of enterprises

Ground-level data has been collected from three villages (Napaam, Amolapam, and Amlighat) located in the state of Assam, India where dairy, piggery, poultry, and fishery are common household enterprises. HBS is compared with these enterprises because of its functionality where feedstock is a major input. Moreover, all of these including HBS generate outputs of commercial importance (products and by-products). Therefore, these rural enterprises are considered for the current study as they are also a source of income generation for the population of these three villages. In general, these enterprises are run as a family business with the involvement of family members. Like other enterprises, HBS requires care and management involving manual work. The common features of the rural enterprises including HBS are graphically depicted in **Fig 5.1**. There are variations of sizes, feeding habits, care and management, and outputs not only among the different enterprises, but also variations are observed among the enterprises in the same category.

Assumptions

To overcome heterogeneity, the current investigation has been carried out with some realistic assumptions as presented below:

a) The entrepreneurs have fully constructed animal sheds (cow shed, piggery shed, fishpond, poultry shed) or have land for HBS which is a pre-condition for financial support through the Government scheme. In general, the infrastructure (viz., cow shed, piggery shed, fishpond, poultry shed, and land for construction of HBS is part of the family business that needs no additional financial burden. Therefore, capital expenditures for such infrastructure are not accounted for in the economic analysis.

b) Regular supply of essential inputs (viz., fodder for animals in a dairy farm, feed for animals in a piggery farm, fishery farm, and poultry farm, and feedstock (organic waste or animal manure) for a typical HBS) are assured, which is also a pre-condition of the Government scheme for beneficiaries.

c) The beneficiaries have previous experience of running a rural-based household enterprise as required to get benefits under Government schemes.

d) Among the several HBS models, based on their prevalence, the Deenbandhu biogas model, with a capacity of 2 cubic meters per day of gas production, is considered for the current study.

e) The thermal energy (heating) for rearing poultry is one of the major inputs unlike the other enterprises considered for this study. Therefore, electricity consumption for such heating load is accounted whereas the electricity used for lighting is ignored due to negligible added contribution.

f) The length of the life cycle of dairy animals (6 years), pigs (2 years), birds (1 year), and fish (1 year) vary. Further, the expected life of HBS is 25 years. The operation of all the enterprises is considered continuous and analysis is made for a levelized duration of 10 years covering the life cycles of lives of all the remaining enterprises.

g) The cost of the server supporting IoT is going to be distributed among all the households for a particular village for which the biogas-based monitoring system will be designed. This distribution will not put a severe financial burden on one individual household and drastically change the overall cost of the HBS with IoT-based biogas monitoring system.

Size and specification of the enterprises

The required information regarding the five enterprises has been assessed from standard literature as shown in **Table 5.1**. Sizes of the enterprises (e.g., number of animals, birds, fishes, and size of HBS) and potential produces are considered based on the prevailing scenario in the study region and subsequently confirmed through consultation with some representative owners of such enterprises (**Table 5.1**).

Fig.5.1: Representation of HBS as equivalent to some common rural enterprises

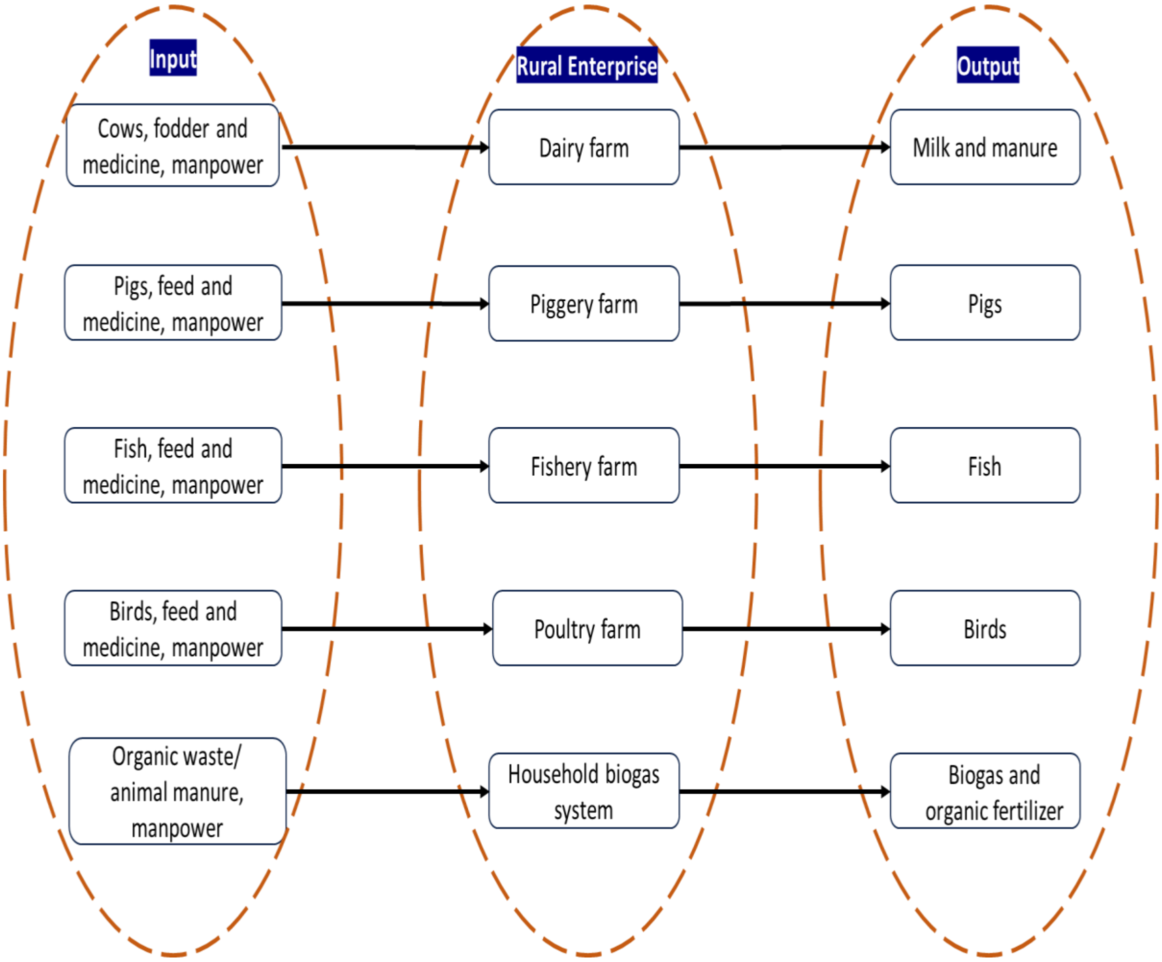

Table 5.1: Details of the enterprises including HBS

S.No.	Enterprise	Description of the enterprise (per farm)	Expenditure	Commodities for sale(annual)	References
1	Dairy	Two Jersey cows	Cost of animals, fodder, medicine	4800 liters of milk and 7.3 tonnes of manure	[13-17]
2	Piggery	3 Hampshire Cross pigs (1 male pig and 2 female pigs)	Cost of animals, feed, medicines	16 saleable piglets (3 months old pigs) + 1 male pig	[18-20]
3	Poultry	1000 birds	Cost of birds, feed, medicines, and electricity	950 birds	[21-24]
4	Fishery	1000 units of Indian major carp	Cost of fish, feed, medicines	600 units of Indian major carp	[25-29]
5	Biogas	2 cubic meters Deenbandhu biogas plant	Cost of construction of HBS	Biofertilizer	[30,31]

Income and expenditure assessment of the enterprises

The assessment of income and expenditure of the identified business enterprises required some field data representation of the rural situation. Three villages viz., Napaam, Amolapam, and Amlighat situated in the state of Assam, India were considered for the collection of the relevant data during the period from July 2022 to February 2023. Information available in some Government documents and collected from standard sources (**Table 5.1**) is also used as input required for the current analysis.

The methodology for the calculation of income of the enterprises has been shown in **Fig 5.2**. Fixed cost (FC) is the cost incurred for initiating the enterprise and is estimated for each enterprise as per the prevailing market rate in the study area. For poultry, fishery, dairy, and piggery, the total number of live units and their respective unit costs are considered to estimate the initial expenditure required to begin the enterprise. For HBS, the costs of a 2 cubic meters biogas plant along with the cost of raw materials (i.e., biomass feedstock loaded at the beginning) are considered as initial expenditures.

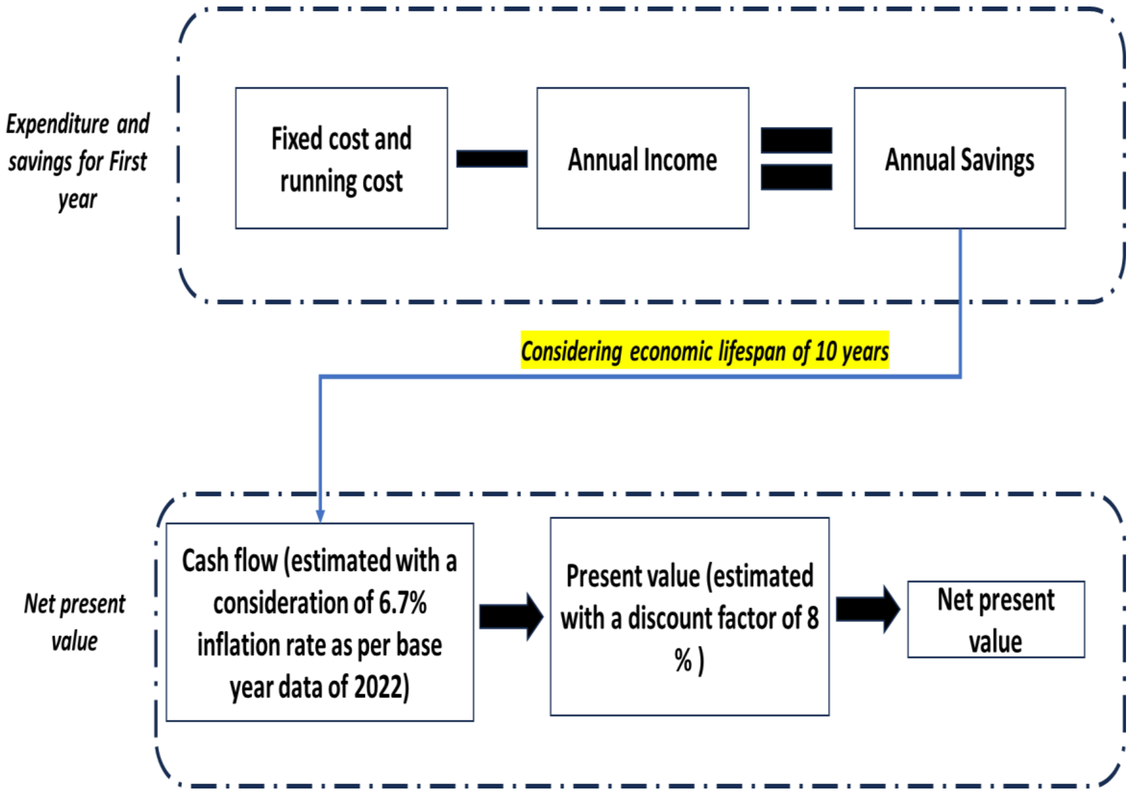

Fig. 5.2: Methodology for calculation of NPV of the enterprises

Further, to account for the varying life cycles of the enterprises, the Levelized fixed cost over life cycles is also estimated as the Levelized annual cost of fixed expenditure (LACFE). Annual running cost (RC) on feedstock and medicine refers to the total amount of money spent on purchasing feed materials and medicines. For dairy, piggery, and fishery enterprises, the total cost of feedstock/feeds, medicines, and vaccines are considered as running costs. For poultry enterprises, the cost of electricity is also added to the annual expenditure along with the costs of feeds, and medicines. In the case of HBS, the cost of cow dung as the feedstock is considered for a 2 cubic meters Deenbandhu biogas plant. Income from the sale of produce is determined using market rates prevalent in the selected survey areas for each enterprise. Periodic records of sellable outputs from all enterprises are utilized to determine the annual income. This income is then used, along with expenditure records, to calculate the annual savings for running the enterprise.

The various costs involved in the calculation of income and expenditure assessment of the enterprises obtained from the survey of the selected areas and verified with data sources have been discussed below and the results are shown in **Section 5.3.1**. The average cost of a cow is USD 484.85/ INR 40000 and a dairy farm with 2 cows is considered. The different feedstocks for the dairy farm include green fodder (10 kg/animal/day for the rate of USD 0.05/kg or INR 4/kg for 365 days), dry fodder (5 kg/animal/day for the rate of USD 0.04/kg or INR 3.3/kg for 365 days) and concentrate feed (4.5 kg/animal/day for 365 days and 0.5 kg/day in last 60 days of pregnancy for the rate of USD 0.3/kg or INR 24.7/kg). The produce obtained from a dairy farm is in the form of milk and manure. The average lactation yield per cross-breed cow is 2400 liters/year and the manure obtained from each cow is 10 kg/day for 365 days for USD 0.0036/kg or INR 0.3/kg [13].

The average cost of cross-breed pigs (1 male pig and 2 female pigs) is USD 72.73 or INR 6000. The different feedstocks for a piggery farm with 3 Hampshire Cross pigs (1 male pig and 2 female pigs) include: concentrate feed (0.5 kg/day costing USD 0.24/kg or INR 19.8/kg), and supplement feed (USD 0.06/pig/day or INR 5/pig/day) for 365 days. Considering an average of 8 piglets per sow, concentrate feed for 16 piglets (0.2 kg/piglet/day) costs USD 0.24 or INR 20 for 75 days. Medicines and vaccines cost USD 18.18 or INR 1500 in total for the enterprise for a year. The income from the sale of produce for a piggery farm is USD 36.36 or INR 3000 per piglet from the sale of 16 piglets at 3 months of age. The sale of a parent male pig of 130 kg live weight costs USD 1.21/kg or INR 100/kg[18,19].

The average cost of 1000 chickens is USD 0.3/chick or INR 25/chick and the feed for 1000 birds costs USD 0.48/ kg or INR 40/kg for a typical bird weighing 2.5 kg for 365 days. The expenditure on medicines, electricity, and water is USD 0.07/bird or INR 6/bird for 365 days. The income from the sale of 950 broilers (considering an average of 5 % mortality rate) is USD 2.42/ kg or INR 200/kg for a typical bird weighing 1.25 kg [23].

The Indian major cap is considered for the fishery enterprise and the average cost of 1000 units (seeds) of Indian major carp is USD 182 or INR 15015. For this, 2950 units of fish feed costing USD 0.22 /unit or INR 18/unit and 1000 units of medicine costing USD 0.07 /unit or INR 6/unit are required for the enterprise [25, 26]. The income obtained from the sale of produce of a fishery farm considering 600 units of fish (40 % mortality rate) is sold at USD 2.42 /unit or INR 200/unit [1].

The cost of a 2 cubic meters HBS (with and without subsidy) and the cost of cow dung have already been shown in **Chapter 3**. The costs involved in the IoT-based biogas monitoring system have been shown in **Chapter 4**. The cost savings from using HBS as a clean cooking fuel are shown in the form of savings obtained from not using LPG and utilizing the dry organic manure from the biogas plant. USD 164.86 or INR 13600 is saved, which is the cost of 12 LPG cylinders in one year [51], and the cost of dry organic manure is USD 0.24 /kg or INR 20/kg [52].

The costs involved in the first year of operation of the enterprises have been systematically studied to get a comprehensive understanding of the overall financial aspects of the enterprise. The ranking of the profitability of the enterprises is done by calculating the Net Present Value (NPV) of the enterprises. The expected future cash flows are estimated based on the inflation rate in India (6.7% in 2022) and the present value of the future cash flows are determined using the NPV method. In this analysis, the economic lifespan is taken as 10 years, and the discount rate is taken as 8% as the initial payment is covered within the first year and not in annuities [50]. The expected lifespan of an HBS is 25 years and to account for this, 50% of the cost is retained as salvage value and is added as cash flow at the end of the economic lifetime of 10 years. The salvage value of the dairy animals after the economic life of 5 or 6 lactation is taken as 25 % of the initial cost of the animals [13]. NPV is estimated using the relationship as given below in equation (5.1) [34,35]:

$$NPV = \left[\sum_{t=1}^{n} \frac{R_t}{(1+r)^t}\right] - I \qquad (5.1)$$

where,

R_t represents the annual net cash flow in year *t*,

r is the discount rate,

n is the total number of years, and

I is the initial investment cost, which is not accounted for in the cash flow calculation.

The enterprises are ranked based on their NPV, and the results are analyzed to find out the HBS ranking as compared to the other rural enterprises.

5.2.2 Potential Contribution of HBS towards SDGs

To assess the impact of household biogas systems on SDGs, this study employs a multi-faceted approach. Firstly, a comprehensive policy analysis was conducted to examine relevant government schemes, policies, and programs. Secondly, eight indicators suggested by the Ministry of Statistics and Programme Implementation (MoSPI) were utilized to evaluate the impact of biogas systems on SDGs. These indicators are aligned with UN SDG indicators and encompass metrics like access to clean cooking fuel, waste management practices, and improvements in gender equality. The details of the indicators related to the seven specific SDGs and rural enterprises are shown in **Table 5.4**.

Data collection involved gathering information from various government sources, reports, and surveys to quantify the contributions of HBS to each SDG. This included data on household usage of biogas, water quality improvements, and economic benefits from sustainable practices. Finally, a comparative analysis was performed to contrast the performance and contributions of HBS with other rural enterprises such as dairy, piggery, poultry, and fisheries. This comparison aimed to contextualize the role of HBS within the broader landscape of rural entrepreneurship.

5.2.3 Decarbonizing Potential of HBS for Rural Cooking Sector

In the three villages surveyed, the major cooking options in the three villages were a combination of the three cooking fuels viz. biogas, fuelwood, and LPG as seen in **Chapter 3**. The highest preference was given to LPG followed by a combination of LPG and fuelwood and then biogas. The section of the population who use LPG depends on the accessibility of the gas distribution centers. It is noted that if the users faced hassles with the procurement of LPG cylinders, they prefer to return to the use of firewood. There is a scope for growth of HBS in these areas as the awareness and availability of feedstock for HBS are present among the population. The cooking fuel utilized in the three villages has been determined and the potential for the reduction of GHG emissions or decarbonization of the selected population through the use of cooking fuels has been discussed.

The formula for the calculation of Greenhouse gas (GHGs) emissions (Equation 5.2) is taken from the IPCC Guidelines for National Greenhouse Gas Inventories [32].

$$Emissions_{GHG,\ Fuel} = Fuel\ Consumption_{fuel} \times Emission\ Factor_{GHG,Fuel} \quad (5.2)$$

IPCC Guidelines for National Greenhouse Gas Inventories pertaining to Stationary Combustion using LPG and biogas as fuel are considered for the assessment of GHG emissions [32]. Emissions factors of three gases viz., CO_2 (63100 kg/TJ), CH_4 (5 kg/TJ), and N_2O (0.1 kg/TJ) are attributed to LPG combustion whereas the values for biogas combustion are CO_2 (54600 kg/TJ), CH_4 (5 kg/TJ) and N_2O (0.1 kg/TJ). The total CO_2 equivalent GHG emissions for both cases using standard conversion factors are presented for a unit quantity of thermal energy (781×10^{-6} TJ) available in a typical cylinder (14.2 kg) used for the domestic supply of liquified petroleum gas (LPG) [33].

5.3 Results and Discussion

5.3.1 Cost-benefit analysis: Fixed cost, levelized fixed cost, running cost, and income-to-cost ratio

The first-year expenditure and income profile of the five selected enterprises are shown in **Table 5.2**. While the enterprises are compared based on their fixed costs (FC), the highest fixed cost (969 USD/INR 79942) is incurred by dairy followed by poultry (303 USD/INR 24997), HBS without subsidy (345 USD/INR 28462), HBS with subsidy (212 USD/INR 17490), fishery (182 USD/ INR15015) and piggery (72 USD/ INR 5940). Except for HBS, the life cycle of the enterprises is limited up to 6 years, therefore, the inflation rate during such a short span has been ignored. The order of enterprises in terms of LACFE is found different than that of FC. Poultry incurred the highest LACFE (303 USD/ INR 24997) followed by fishery (182 USD/ INR 15015), dairy (162 USD/ INR 13365), piggery (36 USD/ INR 2970), HBS without subsidy (14 USD/ 1155), and HBS with subsidy (8 USD/ INR 660). The substantially lower LACFE incurred by HBS (both with and without subsidy) is due to the longer life cycle of the enterprise and favorable considerations for business.

If the annual running cost (RC) is considered for the enterprises, poultry incurred the highest cost (1284 USD/ INR 105930) followed by dairy (750 USD/ INR 61875), fishery (729 USD/ INR 60142), and piggery (289 USD/ INR 23842). HBS (both with and without subsidy) needs the minimum running cost (39 USD/ INR 3217) among the enterprises. Relatively higher costs of operations of four enterprises compared to HBS are due to their higher expenditure on recurring inputs (viz., feed and medicines). The size of the enterprises is one of the factors affecting both FC and RC. In the present study, the enterprise sizes are considered as per the prevailing practices and recommendations of the Government schemes. The proportionately higher RC (7 to 33 times) of the four enterprises compared to the 2 cubic meter daily gas production HBS is in favor of the later business opportunity. As mentioned earlier, the HBS with a longer life cycle (25 years) compared to the other four enterprises are potential to provide continuity as a stable entrepreneurship.

Attempting to make a size-independent comparison, two ratios *viz*., (i) Income: RC and (ii) Income: (RC+ LACFE) are estimated for all the enterprises and presented in **Table 5.2**. Income: RC of HBS (both with and without subsidy) is four times higher than dairy, six times higher than piggery, and around eight times more than fishery and poultry. Similarly, the ratio of income to RC+LACFE is the highest for HBS with subsidy followed by HBS without subsidy, dairy, piggery, poultry, and fishery. Thus, HBS (both with and without subsidy) is a potential option for a viable rural enterprise.

Despite brighter economic picture of HBS in comparison to other rural enterprises, the acceptability of HBS among the rural people is not encouraging. The uninterrupted production of bio-methane (cooking fuel alternative to LPG) and digestate (by-product of HBS and alternative to chemical fertilizer) are counted for the income of HBS. However, both the quantity and quality of products and by-products are uncertain and dependent on factors including two major considerations viz., (i) robust technology and (ii) supply of proper feedstock. The traditional HBS has no provision for predicting the performance of the system and owners have to rely on experience and assumptions to ensure the smooth running of the system. The economic analysis considers an ideal system fitted with IoT-based biogas monitoring system where the gas production remains stable as per its rated capacity. Further, the absence of an established feedstock supply chain for HBS appears to be another major reason for the inconsistent performance of HBS and hence HBS's reduced popularity. The requirements of feedstock (mostly biomass origin) are a common feature for all enterprises including HBS. There are assured commercially viable feedstock supply chains for all the remaining enterprises. There are also standards available for ensuring the quality of feedstock of all the selected rural enterprises (**Appendix 5A**) except HBS. Thus, the supply chain of quality feedstock for HBS is expected to influence the prospect of HBS favourably.

Table 5.2: Expenditure and income profile of five enterprises

(*Amount in USD: 1 US$ = INR 82.5 as at 24.10.2022*)

S. No.	Particulars *(Cost in USD)*	Dairy	Piggery	Poultry	Fishery	HBS _with subsidy	HBS _without subsidy
1	Fixed cost on farm (animals/birds/fish/input feedstock),	969	72	303	182	212	345
2	Levelized annual cost of fixed expenditure (LACFE)	162	36	303	182	8	14
3	Annual running cost on feedstock and medicine	750	289	1284	729	39	39
4	Income from sale of produce	3159	739	2878	1454	650	650
5	Income / Running cost	4.2	2.6	2.2	2.0	16.7	16.7
6	Income / (Running cost + LACFE)	3.5	2.3	1.8	1.6	13.8	12.3
7	Annual savings	1440	378	1291	543	399	266

5.3.2 Net present value (NPV) analysis

The financial analysis carried out in the previous section considers the income and expenditure of the five rural enterprises without considering the value escalation of the money. While such an account is useful for comparative analysis of the selected enterprises, for understanding the net cash inflow-outflow over a relatively longer period, net present value analysis (NPV) provides a better picture. Comparative NPV analysis is carried out by accounting for the annual expenditure and income for the base year up to the 10th year of operation details of which are shown in **Appendix 5B**. The current (2022) rate of inflation reported by the Reserve Bank of India is assumed to be uniformly applicable to estimate the value of the money for each of the future years. The six options of enterprises are ranked based on the NPV analysis as shown in **Table 5.3.** Between the two HBS systems, the lower capital expenditure due to the provision of subsidy makes HBS (with subsidy) better in terms of NPV than HBS without subsidy. The better NPV of dairy and poultry are primarily due to higher revenue generated from milk and meat, respectively which are about 290% and 112.4% higher than HBS without subsidy. As discussed earlier, scaling up HBS beyond 2 cubic meters, the NPV gains of dairy and poultry could be reduced as biogas is also a commodity of commercial importance. Interestingly, NPVs of both fishery and piggery are less than the NPV of HBS without subsidy by about 15.9 % and 27.5 %, respectively. Thus, the prospect of HBS as a viable rural enterprise is established from the NPV analysis.

Table 5.3: The rankings for the enterprises based on NPV *(Amount in USD: 1 US$ = INR 82.5 as at 24.10.2022)*

Rank	Enterprise	NPV (USD)
1	Dairy	17887
2	Poultry	9738
3	HBS (with subsidy)	4810
4	HBS (without subsidy)	4584
5	Fishery	3853
6	Piggery	3323

Technical hassles of HBS, especially the prospect of generating an adequate quantity of cooking fuel (and organic fertilizer) consistently are to be addressed to avail the benefits of its potential financial merits. Along with the quantity, the quality of biogas to generate a comparable grade of thermal energy (as per LPG is also another consideration from the user's perspective. Presently, the issue of poor flame quality of biogas, due to the presence of carbon dioxide and moisture is a common reason that can be addressed through the provision of gas upgradation with HBS.

Also, although the cost of the digestate from HBS is fixed by the GoI, there exists no organized market which results in this digestate remaining underutilized. Another reason for the underutilization of digestate is the unavailability of technology to convert the biogas digestate to an easily usable form for use in agricultural purposes. Government of India is focusing on sustainable agriculture practices, organic farming, reduction of overall consumption of chemical fertilizers and improvement of soil health through schemes like Paramparagat Krishi Vikas Yojana (PKVY) (2015), Mission Organic Value Chain Development in North East Region (MOVCDNER) (2015), Sustainable Alternative Towards Affordable Transportation

(SATAT) (2018) and PM Programme for Restoration, Awareness, Nourishment and Amelioration of Mother Earth (PM-PRANAM) (2023). The standards for biofertilizer and organic fertilizer from HBS have also been fixed by the Government of India [36]. Also, the HBS has been given the "white category" by the Central Pollution Control Board (CPCB) concerning the production and disposal of organic slurry [37]. Utilizing the bio-slurry correctly can work as a substitute for chemical fertilizer to maintain soil fertility and improve productivity [38-45] as it is already proved in the literature that manures supply the required nutrients, improve soil structure, increase microbial population, improve water holding capacity of the soil and maintain the quality of crop produce [46-49]. Thus, it can be said that while biogas digestate is often underutilized, its potential contributions to make a profitable rural livelihood enterprise cannot be ignored.

5.3.3 SDG targets through rural entrepreneurship

The impact of several Government policies related to rural enterprises on Sustainable Development Goals (SDGs) is investigated based on the policy documents and relevant data. The findings (summarised in **Table 5.4)** reveal that household biogas systems significantly contribute to multiple Sustainable Development Goals. For SDG 5 (Gender Equality), HBS provide access to clean cooking fuel, reducing the need for women to collect firewood and minimizing their exposure to harmful kitchen smoke. This not only improves women's health but also enables their greater participation in economic and public life.

Regarding SDG 6 (Clean Water and Sanitation), biogas systems are classified under the "white category" by the Central Pollution Control Board (CPCB), indicating their compliance with wastewater treatment norms. This classification underscores their role in improving water quality and ensuring the safe disposal of organic slurry.

For SDG 7 (Affordable and Clean Energy), the National Biogas and Manure Management Programme has been instrumental in promoting family-type biogas plants, thereby increasing the proportion of households relying on clean cooking fuels. This transition contributes significantly to reducing reliance on traditional biomass fuels.

In terms of SDG 12 (Sustainable Consumption and Production), HBS support sustainable agricultural practices by producing organic manure and bio-fertilizers. This not only reduces waste generation but also promotes recycling and reuse of resources, aligning with the principles of sustainable consumption.

SDG 13 (Climate Action) benefits from HBS as it facilitates the transition to clean cooking fuels, helping to integrate climate change measures into national policies. This transition plays a crucial role in reducing greenhouse gas emissions and promoting sustainable energy solutions.

In comparison, other rural enterprises also contribute to various SDGs. For instance, dairy enterprises enhance food and nutrition security (SDG 2: Zero Hunger) through initiatives like the National Food Security Act and school milk programs. Piggery and poultry enterprises improve agricultural productivity and income (SDG 2) through schemes such as the Pradhan Mantri Kisan Samapda Yojana, which supports infrastructure for agro-processing units and cold chain systems. Fishery enterprises contribute to SDG 14 (Life Below Water) by promoting sustainable marine fishing practices and providing livelihood opportunities through the Integrated National Fisheries Action Plan. Taking into consideration the profitability and sustainability point of view, HBS is a comparable option to a rural enterprise.

Table 5.4: Contribution of rural livelihood enterprises with Sustainable Development Goals

Enterprise	SDG	UN Indicator	NIF Indicator/Indicator interpretation	Schemes, policies, and programs of the Government of India
Dairy	SDG 2: Zero hunger	2.1: By 2030, end hunger and ensure access by all people, in particular, the poor and people in vulnerable situations, including infants, to safe, nutritious, and sufficient food all year round	Food and Nutrition Security for population (marginalized and vulnerable)	1. National Food Security Act (NFSA), 2013 2. Mid-day meal (MDM) 3. National Nutrition Mission (Poshan Abhiyaan) 4. Milk programmes in schools
Piggery, Poultry	SDG 2: Zero hunger	2.3: By 2030, double the agricultural productivity and incomes of small-scale food producers 2.3.1: Volume of production per labor unit by classes of farming/pastoral/forestry enterprise size	Agricultural/pastoral/forestry productivity and Income	Pradhan Mantri Kisan Samapda Yojana: 1. Large-scale food parks 2. Enhancing infrastructure for Agro-processing units 3. Establishing integrated cold chain systems for livestock produce
Fishery	SDG 14: Life Below Water	14.7: By 2030, increase the economic benefits to small island developing States and least developed countries from the sustainable use of marine resources, including through sustainable	Sustainable Marine Fishing	Integrated National Fisheries Action Plan: 1. 15 million beneficiaries for livelihood opportunities through various interventions.

Enterprise	SDG	UN Indicator	NIF Indicator/Indicator interpretation	Schemes, policies, and programs of the Government of India
		management of fisheries, aquaculture, and tourism		2. Establishment of Potential Fishing Zone Advisory programme 3. Modernisation, and up-gradation of fishing centres
Biogas	SDG 5: Gender Equality	5.5: Ensure women's full and effective participation and equal opportunities for leadership at all levels of decision-making in political, economic, and public life	Access to Reproductive Health and Wellness	POSHAN Abhiyaan (National Nutrition Mission) 1. Access to clean cooking fuel so that women do not have to compromise their health in kitchens filled with smoke or must travel far to collect firewood
	SDG 6: Clean Water and Sanitation	6.3: By 2030, improve water quality by reducing pollution, eliminating dumping and minimizing the release of hazardous chemicals and materials, halving the proportion of untreated wastewater and substantially increasing recycling and safe reuse globally	Classifications of industries into 17 categories of pollution complying with wastewater treatment as per Central Pollution Control Board (CPCB) norms	1. Swachh Bharat Mission (GRAMEEN) 2. The Household Biogas System has been given the “white category” by the Central Pollution Control Board (CPCB) concerning production and disposal of organic slurry (CPCB Order, 2021)

Enterprise	SDG	UN Indicator	NIF Indicator/Indicator interpretation	Schemes, policies, and programs of the Government of India
	SDG 7: Affordable and Clean Energy	7.1.2: Proportion of population with primary reliance on clean fuels and technology	Percentage of households using clean cooking fuel	National Biogas and Manure Management Programme Setting up family-type biogas plants
	SDG 12: Sustainable Consumption and Production	12.5: By 2030, substantially reduce waste generation through prevention, reduction, recycling, and reuse	Natural Resource Management and Food Systems	1. National Mission on Sustainable Agriculture (NMSA) 2. Soil Health Management (SHM) initiative 3. Promotion of organic manures and bio-fertilizers
	SDG 13: Climate Action	13.2: Integrate climate change measures into national policies, strategies, and planning	Clean Energy	Transition to clean cooking fuels

5.3.4 Annual decarbonization potential of three villages surveyed

The estimated GHG emission from a unit quantity of fuel (one domestic cylinder/bottle contains 14.2 kg of LPG fuel which is a mixture of Propane, Butane, Propylene, Butylene, and Isobutane and thus considered as a unit quantity of fuel in the current study) and corresponding emission from equivalent quantity of biogas fuel are presented in **Table 5.5**. It is observed that CO_2 contributes to the highest share of the total emission among the three contributing gas species viz. CO_2, CH_4 and N_2O. However, the contribution of N_2O in the case of biogas is considered nil as per the procedure adopted. Compared to biogas, LPG emits higher (55%) GHG and therefore the proposed fuel substitution appears beneficial to decarbonizing the cooking sector.

Biogas is a mixture of CH_4 and CO_2. The application of biogas with a provision to capture CO_2 before combustion could make the comparison even better.

Table 5.5: CO_2 equivalent from combustion of LPG and biogas

S.No.	GHGs	LPG	Biogas
1	CO_2	49.28	31.68
2	CH_4	0.0976	0.097
3	N_2O	0.0242	---
Total kg of CO_2 equivalent		**49.40**	**31.77**

The IPCC Guidelines for National Greenhouse Gas Inventories relevant to Stationary Combustion for LPG and biogas as fuel are considered for the evaluation of GHG emissions. combustion of LPG is responsible for the emissions of CO_2, CH_4, and N_2O having emission factors of 63100 kg/TJ, 5 kg/TJ, and 0.1 kg/TJ respectively. Similarly, the combustion of biogas is responsible for the emissions of CO_2, CH_4, and N_2O having emission factors of 54600 kg/TJ, 5 kg/TJ, and 0.1 kg/TJ respectively [32]. The greenhouse gas emissions have been calculated using **Equation 5.2.** When considering the thermal energy content in a typical 14.2 kg household liquefied petroleum gas (LPG) cylinder, the total CO_2 equivalent greenhouse gas (GHG) emissions can be calculated. A similar calculation has been done for an HBS with an equivalent quantity of biogas to replace LPG.

Thus, from the above analysis, it is found that per cylinder of LPG substitution has a potential GHG reduction of 17.63 kg of CO_2 equivalent. This value is used to estimate the decarbonizing potential of the three villages considered for the study. The estimation assumes the most prospective scenario of fuel substitution i.e. 100% fuel replacement by biogas for the entire population in the three villages i.e. Amolapam, Napam, and Amlighat. Whereas, as per the Business as Usual (BAU) scenario and as per the prevailing policy of PMUY, one LPG cylinder consumption per month is considered. About 358 tonnes per annum of GHG emissions in the three villages could be reduced. (**Table 5.6**)

Table 5.6: Annual decarbonization potential of three villages surveyed

S.No.	Village	Number of households	Decarbonizing potential, tonnes of CO_2/annum
1	Amlighat	326	69
2	Napaam	904	191
3	Amolapam	464	98
Total kg of CO_2 equivalent/annum			**358**

The estimated decarbonizing potential is expected to be a motivating factor favoring the biogas system as feedstock availability and economy have already been found favorable.

5.4 Summary

The assessment of the cooking fuel usage among the three villages surveyed and factoring in the average consumption of LPG among the villagers, a significant amount of annual decarbonization potential has been seen. This demonstrates the positive impact of transitioning to biogas as a clean cooking fuel among households. The base year expenditure and income profile of the five selected enterprises have been carried out and enterprises are compared based on their fixed costs (FC), Levelized annual cost of fixed expenditure (LACFE), annual running cost (RC) and the results show the substantially lower values incurred by HBS (both with and without subsidy) which may be attributed to their longer life cycle and favorable considerations for business. The ratios (Income: RC and Income : (RC+ LACFE)) are estimated for all the enterprises and HBS (both with and without subsidy) is higher than dairy, piggery, fishery, and poultry which also demonstrates its potential option as a viable rural enterprise. However, despite favorable economic conditions of HBS, dissemination of HBS among the rural people is not encouraging because the quantity and quality of products and by-products are uncertain, absence of an established feedstock supply chain, and lack of standards available for ensuring the quality of feedstock for HBS. The NPV analysis reveals that dairy and poultry rank above

HBS and piggery and fishery rank below HBS and this can also be an indication of the prospect of HBS as a viable rural enterprise. The comparison of the enterprises based on their contribution to the SDGs reveals that HBS contributes to the highest number of SDGs. An evaluation was conducted to find out the contribution of the enterprises to SDGs and it was revealed that HBS makes the most substantial contribution to the SDGs. The expected potential for decarbonization is also anticipated to be a strong incentive for adopting the HBS. Thus, it can be established that from the perspectives of both profitability and sustainability, HBS is a comparable option to a rural enterprise. The business viability of HBS is also discussed from the lack of an organized market for the purchase and sale of digestate for agricultural purposes. The provision of the sale of digestate along with the availability of appropriate technology to utilize the digestate will further help trigger the viable business around HBS.

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