CHAPTER 3

STATUS OF HOUSEHOLD BIOGAS SYSTEMS: COMPREHENSIVE ANALYSIS OF USERS' RESPONSES

Chapter 3

Status of Household Biogas Systems: Comprehensive analysis of users' responses

3.1 Introduction

A small-scale biogas system for clean cooking and crop nutrients has been promoted by the government of India. However, the expectation of household biogas systems (HBS) as a source of reliable cooking fuel and crop nutrients has not been realized as evidenced by its growth trend.

As detailed in **Chapter 1** and **Chapter 2**, there have been several studies analyzing the current state of affairs of biogas use in India. Cost of construction of the system, shortcomings in the design, and several other factors including operation (temperature, humidity, and water availability) and management (type and availability of feedstock for daily feeding of the HBS, supportive policies and regulations by the government for the development of biogas technology, and cultural and social attitudes towards waste management and renewable energy) have been identified as key issues responsible for the above.

3.2 Materials and Methods

3.2.1 Data source

It is attempted to bridge the above research gap through a systematic investigation among a representative sample consisting of (i) biogas users, (ii) past users of biogas, and (iii) prospective or potential biogas users. A total of 16 parameters have been identified for this study. An appropriate questionnaire is designed, tested, and used to capture data pertaining to those parameters. Overall, the parameters concerning the background information of the user, the experience of the use of the biogas system, the information concerning the operation and maintenance, and the understanding of the benefits of the biogas system, as summarised in **Table 3.1**. The detailed questionnaire is provided in **Appendix 3D**.

Table 3.1: Parameters considered for the study

S.No.	Group	Parameters
A	Information about the users/ not users of Biogas Plant	1. Personal information 2. Information on family members 3. Does the household own a biogas plant or not? (1= Yes, 2= No). If yes, proceed to question number 3a. If no, proceed to question number 3b. a. 3a. What are the reasons for not owning a biogas plant? b. 3b. What are the reasons behind for installation of biogas plants?
B	Information regarding the functionality, feedstock, collection, storage, and feeding	4. Functionality of biogas plant 5. How was the biogas plant constructed 6. Reasons for non-functioning of the biogas plant 7. Feedstock used for the current HBS 8. Awareness of feedstocks for a biogas plant and the status of the availability of these feedstocks 9. Collection, storage, and feeding methodology
C	Output from the biogas plant	10. Questions regarding biogas generated 11. Questions regarding bio-slurry 12. Impact on socio-economic condition
D	Training /servicing of the existing technology and new technology intervention	13. Provision of training to the users after installation of the plant 14. Services offered after installation 15. Awareness of technology intervention 16. Aspects of the HBS the users most interested in getting information about

3.2.2 Selection of study area

Three villages namely Napaam, Amolapam, and Amlighat located in the two districts of Assam: Sonitpur and Morigaon have been selected for the current study. The details of the three villages including the number of households selected as well as owners of HBS are shown in **Table 3.2**. The two districts selected out of the 35 districts in Assam can be considered the representation of the remaining districts based on the identical pattern of cooking fuel used by its population as demonstrated in the figure shown in **Appendix 3A**. Here the percentage of different cooking fuels used by the rural households in all the districts in Assam has been mapped as per information available in the District Census Handbook by the Government of Assam, India. About 20% of the households were recruited through random sampling. Napaam and Amolapam are neighboring villages located in the district of Sonitpur and Amlighat is another village located in the district of Morigaon. The data was collected through door-to-door surveys from February to December 2020. There were current users, previous users, and non-users of the biogas system in this population. The total number of HBS owners was 76. The qualitative responses are appropriately transformed into quantity and subsequently entered into a spreadsheet (Excel) along with collected quantitative data for analysis as required. The different aspects considered from the field study which are discussed in this Chapter encompass all the qualitative and quantitative data from the survey.

Table 3.2: Details of the villages for field investigation [1,2,3,4]

Parameters	Description		
Village	Napaam	Amolapam	Amlighat
Locational details (Development block and district)	Barchala, Sonitpur	Balipara, Sonitpur	Mayong, Morigaon
Latitude & Longitude	26.704° N & 92.822° E	26.705° N & 92.841° E	26.117° N & 92.274° E
Population of the village	4250	2468	2688
Total households in the village	904	464	326
Total households surveyed**	180 (5)	90 (11)	70 (60)

** number of household owning HBS at the time of survey is given in the bracket

The locations of the three surveyed villages are shown in **Fig 3.1**.

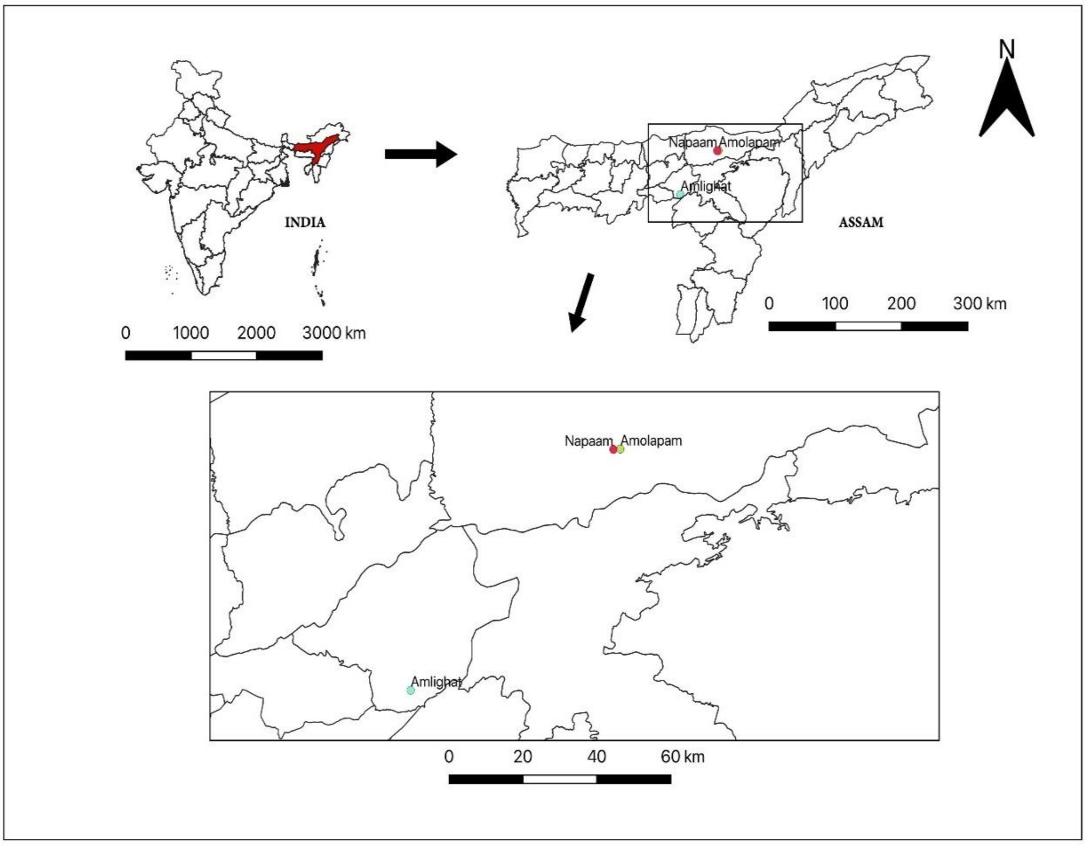

Fig 3.1: Locations of the selected survey areas: Napaam, Amolapam and Amlighat

3.2.3 System description

A typical layout of the household biogas system of two different prominent designs is presented in **Fig 3.2 a** and **Fig 3.2 b.**

In the current research, the HBS includes the biogas cookstove, the slurry tanks, and the usage of bio-slurry along with the components of a traditional biogas plant (inlet, digester, gas storage dome, and gas pipeline). The input is the feedstock (animal manure, crop residue, or other organic wastes) that is fed daily to the HBS. The anaerobic digestion takes place in the biogas digester. It can be either a fixed dome or a floating dome biogas plant. **Fig 3.2 a** shows a typical fixed dome biogas system (Deenbandhu biogas model) and **Fig 3.2 b** shows a floating dome biogas system (Janta model). The outputs are the biogas produced which is utilized in the kitchen as cooking fuel and the bio-slurry which is utilized as a substitute for chemical fertilizers.

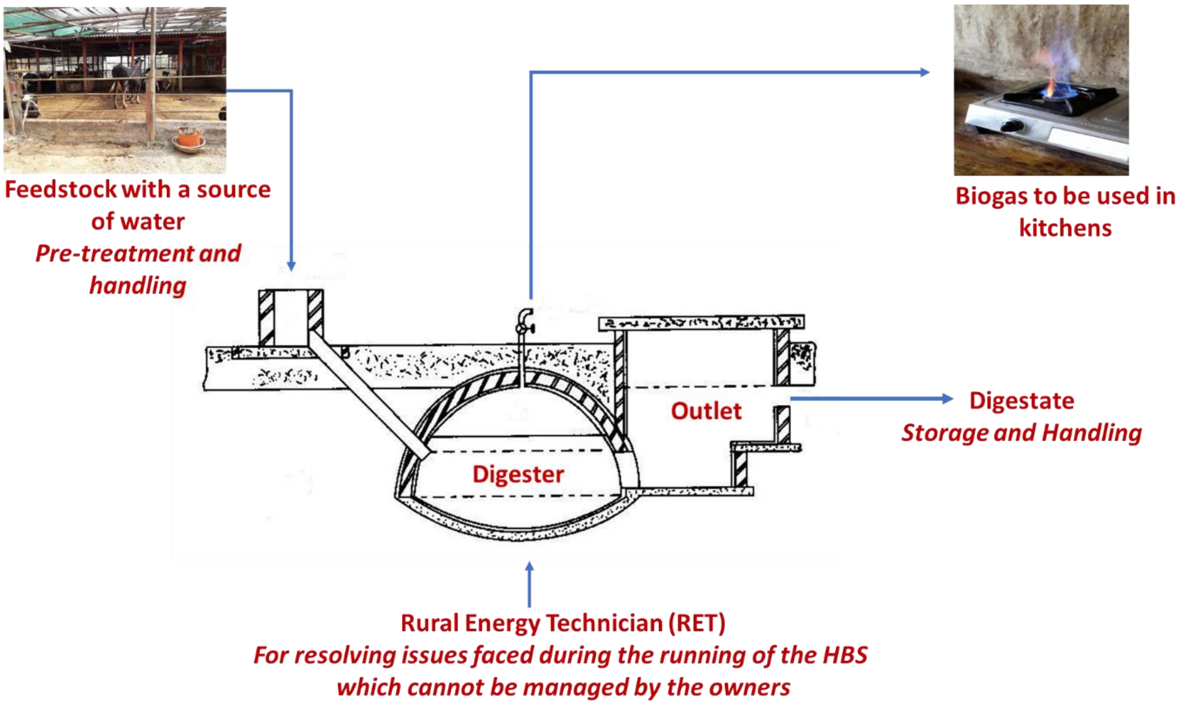

Fig 3.2 a: Layout of a typical HBS (Fixed dome type) (Deenbandhu biogas model)

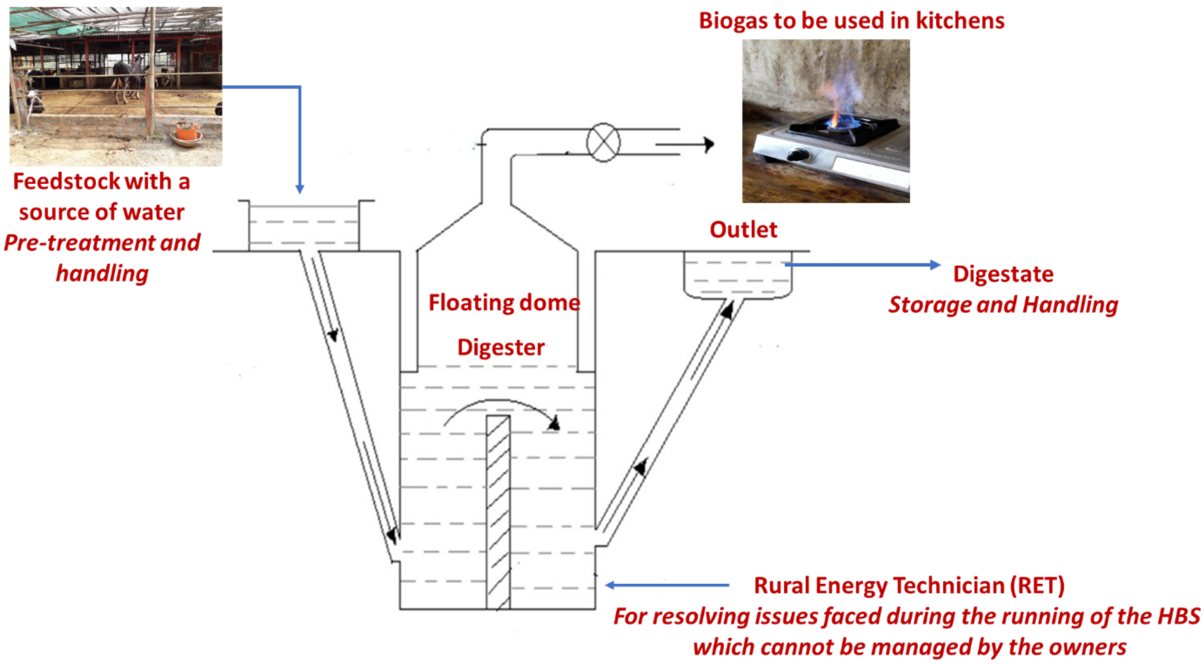

Fig 3.2 b: Layout of a typical HBS (Floating dome type) (Janta model).

The justification for using these two designs is that the questions pertain to this area. The benefits of the Deenbandhu model over other recommended models are their comparatively lower construction costs, longer life span, no corrosion problems, and loss of heat is lesser as they are constructed underground [34,35].

Based on the understanding of this system, 16 parameters are identified for the questionnaire. The questionnaire has been tested to examine the inclusion of the parameters and then tested again to check whether the intended questions have been appropriately reflected. Finally, field survey was carried out by the researcher. The collected data was analyzed systematically to understand the different aspects as below.

i. Status of installation of household biogas system (HBS)
ii. Comparative preferences for cooking fuels and status of biogas
    a. Biogas system operational experiences
    b. Technical issues during operation of the biogas system
    c. Availability of feedstock for biogas production
    d. Storage, handling, and pretreatment of feedstock for biogas production
    e. Current slurry management system and its potential impact
    f. Capacity building (training) on HBS: need assessment
iii. Economic concern while using the biogas system
iv. Technological upgradation: need assessment based on user perception

3.3 Results and Discussions

Initiatives and efforts to promote household biogas systems as a reliable option for cooking fuel have not yielded the desired results in India. Delineated objective-oriented analysis concerning user perception has remained limited though there is existing know-how available in literature. Results of the current investigation to understand the status of biogas as cooking fuel and to analyze the truthfulness of users' perception based on the field data collected from the households in the study regions which are then appropriately verified and validated using standard sources are presented in section 3.3.1.

3.3.1 Status of installation of household biogas system (HBS)

Overall, 22 % of households in the three rural clusters use biogas where Amlighat (79%) has the highest number of biogas users followed by Amolapam (14 %) and Napaam (7 %). All the installed biogas plants are under the Government of India subsidy scheme operated by different designated agencies such as Defence Research and Development Organization, India (DRDO), All India Coordinate Research Project (AICRP) on Renewable Sources of Energy (RSE) for Agriculture and Agro-based Industries by Indian Council of Agricultural

Research (ICAR), in Assam, Department of Forests and Environment, Assam, District Rural Development Agency, NABARD (National Bank for Agriculture and Rural Development) and, KVIC (Khadi and Village Industries Commission). Some of the installed plants are relatively new (13 % of biogas plants are 6 years old, 34 % of biogas plants are 9 years old) while others are older (29 % of biogas plants are 15 years old and 24 % of biogas plants are 19 years old). As of the date of the survey, 21 % of the installed plants remain non-functional with distribution for Amlighat, Napaam, and Amolapam as (0 %), (7 %) and (14 %), respectively.

Fig 3.3 a. Biogas plants in the study areas: A functioning biogas plant in Amlighat village working for 19 years

Fig 3.3 b. Biogas plants in the study areas: A 13-year-old biogas plant remains non-functional in Napaam village

Two cubic meter Deenbandhu model of a biogas plant has been the most prevalent type in the study regions. The benefits of the Deenbandhu model over other recommended models are elaborately discussed previously (**Section 3.2.3 System description**) which might be the reason for preference for this model over others. The reasons for the non-functionality of HBS were further scrutinized for the cases under study and presented citing the specific factor in subsequent Sections. The comparison of the two figures of HBS (**Fig 3.3 a** (Functional biogas plant in Amlighat) and Fig **3.3 b**(Non-functional biogas plant in Napaam) suggests that construction flaws might be the reason why the newer plants in Napaam were non-functional. Visible differences in design features are seen both in the inlet and digester for the identical model though standard design protocol is available. The convenient height of the feedstock inlet tank to feed HBS associated with the provision of water supply of the plant in Amlighat (**Fig. 3.3a**) may be considered user-friendly features which are absent with plant in Napaam (**Fig. 3.3b**). Drudgery associated with the handling of feedstock and related issues is further discussed in subsequent sections.

The better scenario of HBS prevailing in Amlighat in terms of (i) acceptability and (ii) functionality are further examined with consultation of relevant literature and stakeholders of the villages. The existence of a cooperative milk industry where villagers of Amlighat contributed milk, motivated them to keep cows and subsequently to own HBS for utilization of cow dung.

The matter of discontinuity of the installation of HBS in the study regions after 2014 (till the time of the survey) has also been attempted to investigate through consultation with relevant stakeholders. It is reported that the change of Government policy to pay the subsidy amount using Direct Benefit Transfer (DBT) to the linked bank accounts of the beneficiaries became demotivating for RET to function and hence reduced the number of new installations. The fact, however, could not be conclusively confirmed and needs further investigation.

3.3.2 Comparative preferences for cooking fuels and status of biogas

Fuel wood, LPG, and biogas have been the reported fuels used for cooking in the study region, either as a single source or a combination of these three. The result of fuel preferences reported by the households is depicted in **Fig. 3.4** estimating the respective percentages of users in each category. LPG alone has been the most preferred choice (37%) followed by LPG and fuelwood combination (31%), biogas alone (18%), and LPG-biogas combination (3%). There are households indicating a preference for fuel wood alone (10%) and its combination with biogas (1%).

The natural fuel shifting towards LPG in recent times, especially after the introduction of the Government scheme [17], has resulted in a reduction in the percentage of fuel wood users, despite the availability of fuel wood in the users' vicinity. The appropriate channelizing of LPG marketing and its penetration to rural areas, coupled with better quality of controllable flame obtained in convenient refill bottles (**Fig. 3.5**) resulted in LPG as the preferred choice over all other options. Availability of support services required for LPG usage such as connection, repair, and obtaining spare parts are also hassle-free almost in the entire study regions compared to biogas usage, which might be a learning lesson for biogas promotion.

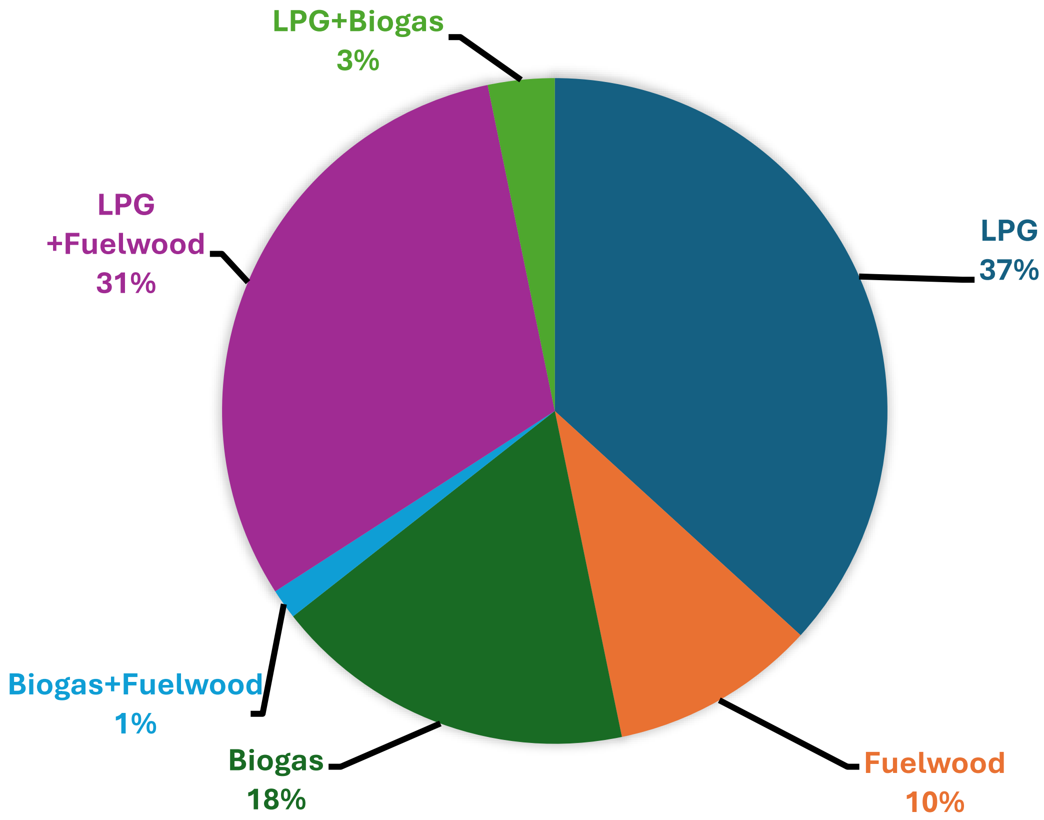

Fig 3.4: Overall cooking usage in the three villages

Fig 3.5: LPG cylinder (14.2 kg)

Fig 3.6: Wood-Fuelled Cook Stove

The further investigation of 18% of the respondents indicating a preference for biogas reveals that the easy availability of feedstock within their household and knowledge gathered from the successful biogas users resulted in interest in biogas. The concern for factors such as the environment and energy crisis has been observed very limited among the respondents.

Fig. 3.6 depicted a typical picture of a wood-fuelled cook stove in one of the study areas. The harmful impact of such technology has been elaborately discussed. The lack of awareness about the harmful effects of indoor air pollution caused by the burning of fuel wood is observed in the study. The preference for fuel wood by a major chunk of respondents has been due to the easy availability of wood. The perception of tastier cooking by fuel-wood cooking and years of attachment to this practice in addition to the additional benefits of space heating (useful during cold season) are some of the notable factors that resulted in preference for fuelwood. However, the ill effects and corresponding health hazards of solid fuel burning to be taken seriously and discouraged accordingly. Thus, the biogas from HBS should be promoted addressing the above concerns to fully substitute fuel wood and possibly also for partial substitution of LPG.

The upgradation of raw biogas (moisture and CO_2 scrubbing) to improve calorific value from its existing level of 30 MJ/kg to about 46 MJ/kg (equivalent to the calorific value of LPG) could enhance its acceptability as revealed from the study. Another concern reported during the study is the longer time requirements for cooking by biogas. The supply of biogas from the plant to the cookstove has been through a connecting pipe where pressure changes (reduces) during usage. Moreover, the pressure at which LPG is being delivered to the cookstove is 2.94 kN/m^2 with provision for regulation. But the pressure at which biogas is delivered to the cookstove is around 0.74 kN/m^2 which results in slow cooking demanding more time.

The lack of interest in biogas as a primary source of cooking fuel was further investigated and the responses are analysed and presented in **Fig 3.7**. About 41% of the respondents prefer LPG over biogas mainly due to the reasons cited in the previous paragraph. The unfavorable cost for biogas (high capital cost and frequent maintenance cost) has been cited by 36% of the respondents not having an interest in biogas. More than one-fifth of the respondents want to continue with fuel wood to avoid probable uncertainties arising while shifting from familiar practices. Interestingly, 2% of the respondents indicated ignorance about biogas which necessitates increased awareness about the ill effects of solid fuel and the benefits of biogas.

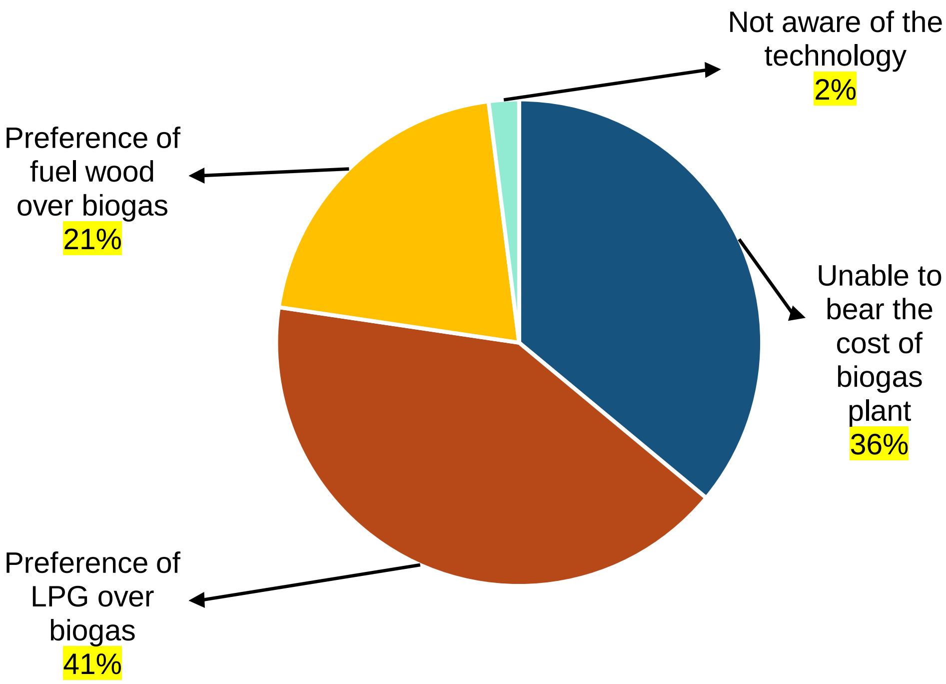

Fig 3.7: Concerns for lack of interest in biogas as a primary source of cooking fuel

3.3.3 Biogas system operational experiences

3.3.3.1 Technical issues during the operation of the biogas system

One of the major factors influencing the discontinuation of the use of HBS is the technical issues faced during the operation of the biogas system viz. during collection and handling of feedstock, digester operating parameters, and biogas transportation.

The collection of cow dung, necessary for feeding the HBS, was performed manually by family members. This process included removing small stones, sticks, and other foreign materials from the mixture. Pre-treatment of the feedstock involved manually mixing the cow dung with water to achieve the required consistency. Commonly used equipment for this task included aluminum buckets, plastic drums, and metal containers, with each bucket having a capacity of 8 liters. Typically, owners needed to carry the buckets 4 to 5 times to complete one feeding cycle for the HBS. Although some families used trolleys for transporting cow dung, the majority relied on manual carrying.

Additionally, the collection of water for mixing with cow dung to achieve the necessary feedstock consistency was another labor-intensive task. The survey revealed that 67% of the population depended on well water, 25% used handpump or underground water, and the remaining used motor-pumped water, contingent on the availability of electricity in rural areas.

The effective operation of the biogas digester requires maintaining specific operating parameters. The digester should ideally be maintained at a mesophilic range (25-40) °C to optimize microbial activity. The pH within the digester should be kept neutral, between 6.5 and 7.5, to ensure optimal biogas production. The amount of feedstock introduced into the digester should be consistent with its capacity, typically around (0.2-0.3) kg of volatile solids per cubic meter per day. The HRT, or the average time the feedstock remains in the digester, should be around 20-30 days to ensure complete digestion. Maintaining these parameters is crucial for efficient biogas production and minimizing operational issues. However, it was observed that most of the users were unaware of these aspects.

The biogas produced was delivered to kitchens through plastic pipes provided by the schemes applied for by the beneficiaries. The average distance from the HBS to the kitchen ranged from 7 to 20 meters. Users themselves managed any issues regarding leakage or replacement of pipes. Notably, users were unaware of the need to remove moisture from the pipes, and there were no provisions for moisture removal or checking gas pressure inside the pipes.

The manual and labor-intensive nature of these tasks introduces a level of drudgery that contributes to disinterest in operating the HBS and may deter prospective owners. Simple tools used in the mixing and collection processes further highlight the time-consuming and labor-intensive nature of HBS maintenance.

It was observed (**Fig 3.8**) that the cause of the malfunctioning of the HBS was not known to 38% of the users. Again, another 29% of households experience non-uniform gas production in certain seasons resulting in inadequate supply against the requirements, while 13% experience problems due to blockage of gas due to moisture traps. Overall, performance-related issues of the anaerobic digestion process appear to be the major concern of the respondents. The issues concerning the operational hassles of the typical biogas system have been extensively reported in **Chapter 2**. From the ground survey of the 76 users, it was found that the aspects the users were most interested in getting information about was the detection of the problem (69%) followed by the general monitoring of the parameters inside the HBS (15%). The remaining wanted information or guidance on how to implement a solution as they claimed to know the problems due to continuous use of the HBS. Regarding the training provided to the users for the running of the HBS, 55% of the users received one/two/three-day training by the service providers, 24 % of the users received just on-the-spot instructions, 3% received some instruction manuals by the organizing authorities and the remaining 18% received no training. Regarding the provision of follow-up services from the implementing authorities, 61% of the total users received follow-up services and the remaining did not receive any. One probable solution is the use of a robust biogas system with the proper intervention of technology so that issues concerning climate, feedstock, and microorganisms can be precisely detected for remedial actions. Real-time monitoring of the internal operating conditions of the biogas digester may be useful for diagnosing the issue and following corrective measures. The prospect of application of IoT (Internet of Things) in the diagnostic of erratic biogas systems appears potential as implementations of IoT in the biogas reactor have been already demonstrated in **Chapter 2**.

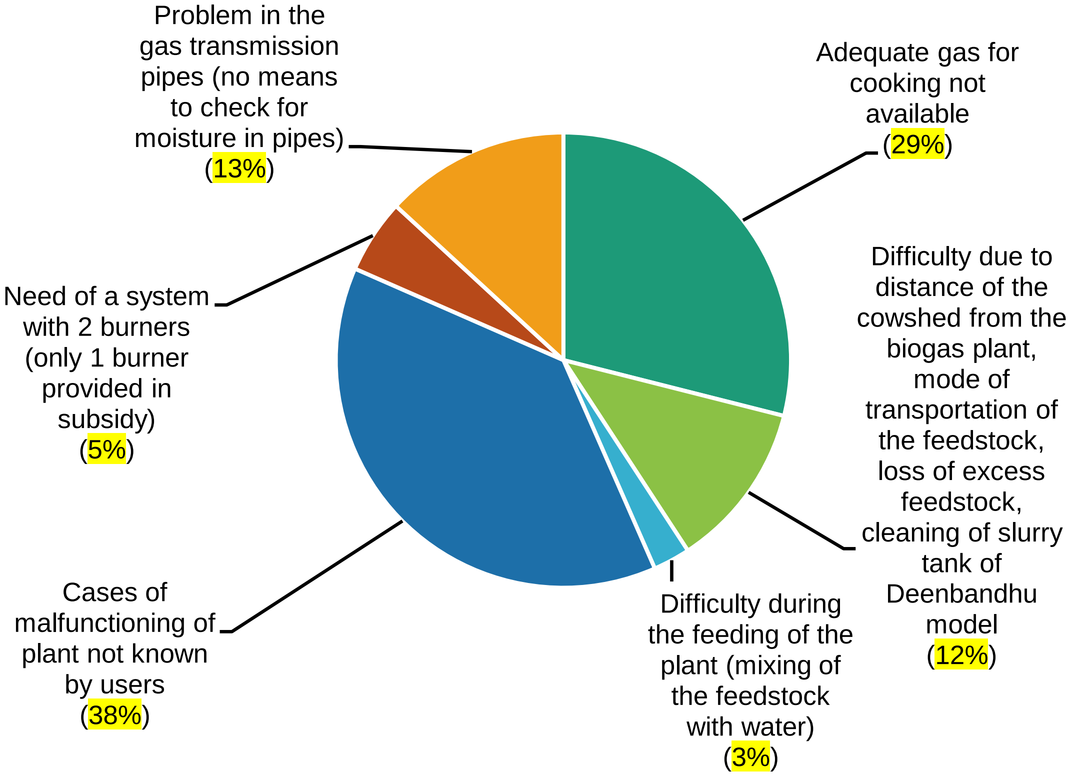

Fig 3.8: Hassles faced during the running of the HBS

3.3.3.2 Availability of feedstock for biogas production

From the perspective of **feedstock availability**, cow dung was the dominant feedstock being used in the HBS. From the survey around 58 % of the total respondents were aware of the proper storing methodology of cow dung as feedstock. They had the idea that methane would be lost, and the quality of cow dung would reduce as a feedstock for HBS if cow dung was stored in the open for a long time. As the HBS owners, as well as the prospective users of biogas encountered during the survey, were familiar with using cow dung as the primary feedstock, they were questioned about their awareness of the other feedstocks that could also act as primary feedstock for a typical HBS. The options given were agricultural waste, food waste, sewage sludge, a combination of food waste and cow dung, and a combination of food waste and agricultural waste. 38 % of the respondents were mostly aware of agricultural waste to be used as an alternative feedstock to cow dung. 20 % of the respondents were aware that food waste could be used as potential feedstock for an HBS, 19 % of the respondents were aware that a combination of food waste and agricultural waste could be used as feedstock, 18 % of the respondents were aware that a combination of food waste and cow dung could be used as feedstock and the remaining 5% knew about sewage sludge being used as a feedstock too for an HBS.

The availability of suitable alternative feedstocks apart from cow dung in the selected areas was also investigated. There has been adequate literature listing suitable items as feedstock for biogas. There is also evidence of region-specific studies providing an accounting of the available feedstock for biogas production. Varieties of distributed feedstocks including kitchen wastes (0.49), animal droppings (cow dung: 4.9, goat dropping: 0.77; and poultry droppings: 1.74) are available in the study regions (unit is in kg of dry matter per household per day). In addition to the above, crop residues (surplus rice straw and maize stalk) available in the study region are also proven feedstock for biogas production [5,6]. Considering the above, it appears that the paucity of feedstock may not be a convincing reason against the preference for household biogas plants in Napaam and Amolapam. However, the obstruction to the use of these alternative feedstocks especially agricultural wastes is that there is a lack of appropriate pretreatment techniques for converting the raw waste organic feedstock into appropriate feedstock for HBS in rural areas. This poses a serious obstacle to the widespread use of substitute feedstocks in the production of biogas. The conversion of agricultural waste into usable feedstock for HBS remains inefficient and economically unfeasible in the absence of labor and cost-efficient pretreatment technologies.

3.3.3.3 Storage, handling, and pretreatment of feedstock for biogas production

Another aspect influencing the use of HBS as a source of clean cooking fuel option was the storage, handling, and pretreatment of the feedstock for the HBS.

As the HBS is to be operated throughout the year, the proper storage of feedstock is mandatory to ensure the success of the HBS. For the part of appropriate storage of feedstock particularly cow dung, around 86% of the users were aware that storing cow dung in the open air without ensiling would lead to loss of the biomethane potential of the cow dung which would make it inefficient for use in a biogas plant. Open-air storage would also lead to nutrient leaching to the ground and the emission of an unfavorable odor. However, the remaining users were noted to be unaware of this. The distance of the cowshed from the biogas plant is also another aspect studied in the topic of the storage of feedstock. The physical location of the cowshed is a critical factor in contributing to the success of the HBS. It should be taken into account during the planning and construction of the HBS. The closer the feedstock supply, the higher the success rate of the HBS because it reduces the drudgery aspect of carrying the cow dung to the HBS. In the villages surveyed, the average distance of the cow shed from the HBS was around 6 to 7 meters. However, the distance of the cowshed should be determined considering that hygiene and sanitation are maintained even with the reduced distance. The proximity of the kitchen to the biogas plant also plays a significant role in determining the success of the HBS with the average distance between the HBS and the cowshed being around 5.5 meters as seen during the survey.

From the perspective of handling and processing feedstock, the users were aware that removing foreign materials (sticks, small stones, straw) from the cow dung to ensure an almost homogenous mixture to be fed to the biogas digester was extremely important. The users were also aware of the fact that the presence of soil in the feedstock can disrupt the anaerobic system inside the biogas digester. The anaerobic digestion process is very sensitive and is dependent partly on the physical properties of the feedstock. The users were aware that the presence of soil in the feedstock may lead to clogging of the pipes, cause sedimentation inside the slurry tanks, inhibit microbial activity inside the digester, and reduce the overall efficiency of the HBS.

However, this study has been limited to the use of cow dung only as a feedstock. The lack of availability of cow dung sometimes led to the abandonment of the HBS by the owners in the villages of Napaam and Amolapam. This is because although the users knew about the use of alternative feedstocks, they were unaware of the pretreatment techniques involved in converting these into potential feedstocks to be used in the HBS as discussed in **Section 3.3.3.2**. The conception of a ready-to-use feedstock which is already available for some other rural-based enterprises like piggery, poultry, fishery, and dairy may be explored in the biogas sector also.

3.3.3.4 Current slurry management system and its potential impact

From the perspective of slurry management technology intervention: nutrient recovery**,** the households of the villages were asked about how the bio-slurry was utilized. Responses of the households concerning the usage of bio-slurry among all three clusters (villages) are summarized below. While converting bio-waste (e.g., manure) into biofuel, a substantial portion of the mass is generated as bio-slurry i.e., a by-product of a household biogas system. Ideally, as a sustainable management practice, bio-slurry is expected to be utilized as crop nutrients to avoid environmental pollution and reduction of the consumption of chemical fertilizer. There are differences as far as utilization vis-à-vis management of bio-slurry is considered among the villages. Most of the users (75%) of the village Amlighat which has the highest number of household biogas systems which is 60, release bio-slurry to the nearby fields without targeting crop fields. The abundance of cow manure for field applications and the remoteness of crop farms are the known reasons for the low level of proper applications in Amlighat. For 2 cubic meters of biogas fed with cow dung, the amount of digestate produced was 50 kg [7]. The slurry tank constructed per the MNRE standards had the dimensions (2.7 × 1.4 × 1.2) cubic meters. Accordingly, the slurry tank was filled up in two weeks and was later discharged by the users of the villages of Amlighat into the fields automatically without the separation of the solid and the liquid digestate. This was in contrast to the users of Amolapam and Napam where bio-slurry is appropriately used as organic fertilizer (87.5%) for crop fields as well as inputs for mushroom production. In the villages of Napaam and Amolapam, a solid and liquid separation tank was constructed of dimensions (2.1 × 1.2 × 1.5) cubic meters. Here the separation of the solid and the liquid parts of the digestate was supposed to be carried out. According to this, the beneficiary had to collect the solid portion of the digestate, and the liquid part of the digestate was automatically discharged into the fields. In 2023, MNRE recommended the biogas slurry filtration unit which consists of three units: mesh filter, fine mesh filter, and filter tank, and has a filtration capacity of 80-100 liters of digestate per day. The liquid slurry is collected in the filter tank, and the solid part of the slurry is collected in the mesh and fine mesh filters. In the case of the Deenbandhu Biogas Plant, the digested slurry from the slurry tank has to be manually collected and then fed to the slurry filter and the separation takes around 48 hours after which the solid part can be removed from the filtration unit [8]. Significant nitrate contamination of groundwater has been observed in India where intensive livestock farming takes place [9,10].

3.3.3.5 Capacity building (training) on HBS: need assessment

Regarding the training provided to the users for the running of the HBS, 55% of the users received one/two/three-day training by the service providers, 24 % of the users received just on-the-spot instructions, 3 % received some instruction manuals by the organizing authorities and the remaining 18 % received no training. Regarding the provision of follow-up services from the implementing authorities, 61 % of the total users received follow-up services and the remaining did not receive any. In the villages of Napaam and Amolapam, there are no service centers nearby. In Amlighat, a full-time rural energy technician was available for the whole village. He was responsible for the installation and maintenance of the biogas plants. The amount of money spent per year by the owners of HBS for the operation and maintenance of the plant is around US$ (12-20) as recorded during the survey.

The designated local agencies and especially the rural energy technicians (RET) appointed by the Government are found to have an influencing role in all the affairs of HBS. Awareness and motivation, logistic support during installation, technical support for hassle-free operation and maintenance, and capacity building are some of the expected roles of the RETs. The actions related to the above roles and their impact on the HBS operational scenario could not be substantiated especially by the current study in Napaam and Amolapam.

One probable solution is the use of a robust biogas system with the proper intervention of technology so that issues concerning climate, feedstock, and microorganisms can be precisely detected for remedial actions. Real-time monitoring of the internal operating conditions of the biogas digester may be useful for diagnosing the issue and following corrective measures. The prospect of application of IoT (Internet of Things) in the diagnostic of erratic biogas systems appears potential as implementations of IoT in the biogas reactor have been already demonstrated in **Chapter 2**.

3.3.4 Economic concern while using the biogas system

The percentage of people living below the poverty line in the three villages Amlighat, Napaam, and Amolapam is 41.4%, 58.4%, and 26.8% respectively [20]. If biogas is adopted as a major cooking fuel by the villages especially in Napaam and Amolapam along with access to clean cooking fuel, Sustainable Development Goal 7 can also be realized through several benefits such as the utilization of bio-slurry as an agricultural fertilizer to increase crop productivity and income level of the beneficiaries [21] and local job creation [22-24].

The households of the villages were asked about their preference for cooking fuel. Responses of the households concerning their preferred cooking fuel are analyzed and summarized in **Fig 3.4**.

LPG is the most preferred fuel (37% preferred only LPG, while another 31% preferred LPG + Fuelwood) followed by biogas (18%) among the households. A transition from solid fuel (fuelwood) to gaseous fuel (LPG) has been seen in the rural areas of the study region as reflected by the trend of preferences of households. Hassles with LPG are lesser compared to fuelwood at the user end. Other reasons for higher preference for LPG over biogas have been higher capital cost and unaffordable maintenance cost of the latter.

Table 3.3 and **Table 3.4** present a comparative analysis of the cost of using cooking fuels through three options viz. biogas, LPG, and fuel wood for short-term (first year) and long-term (20^{th} year) basis, respectively. Different scenarios corresponding to these three options are considered to examine daily expenditure on fuels to support the cooking services for a typical rural family having 5 members. The provisions of subsidy for biogas plants as well as LPG are considered for short-duration analysis. The feedstock is a critical input therefore, the effect of expenses on feedstock on the daily cost of fuel is also investigated for separate scenarios *viz*., (i) cost of feedstock as per prevailing in price in the study region and (ii) ignoring cost considering the feedstock is available with the user and has no competitive use.

Table 3.3: Comparative cost analysis of three options of cooking fuels (for a small family of 5 members): short-term analysis for one year

S.No.		2 m^3 *Deenbandhu* Biogas plant			LPG cylinder domestic connection		Fuel wood through traditional clay cook stove
	Amount in USD *(1 US$ = 71.85 INR As on 21.2.2020)*	Without subsidy	With subsidy	With subsidy and without considering the cost of feedstock	Without subsidy	With subsidy (as per the PMUY scheme)	
		BS1	*BS2*	*BS3*	*LS1*	*LS2*	
1	Capital cost	306.19[a]	153.10[a]	153.10[a]	21.50[b]	13.92[c]	0.7[d]
2	Cost of feedstock/ Refilling of LPG/ Firewood	45.72[e]	45.72[e]	nil	161.25[b]	150.23[c]	282.73[f]
3	Maintenance cost	13.92 [g]	13.92[g]	13.92[g]	7.1[b]	6.68[c]	0.02[h]
	Total cost (First year)	365.83	212.73	167.01	189.85	170.83	283.44
	Cost per day	1	0.58	0.46	0.52	0.47	0.78

Superscripts (a, b, c, d, e, f, g, h) described in Appendix 3B

Contrary to the general belief (based on findings of survey data), the use of biogas as cooking fuel is estimated as the cheapest option among all the options considered for analysis, provided subsidy on capital cost is available and the user can get feedstock without paying for it. Thus, for families having adequate cow dung and/or suitable crop residues, the use of biogas as cooking fuel has direct financial benefit compared to other options. However, biogas appears costly without subsidy and if payment is to be made for feedstock on a short-term basis. Even for the short-term estimation, the use of biogas under a subsidy scheme and with purchased feedstock appears cheaper by about 41% than fuel wood. Thus, considering the additional shortcomings such as indoor air pollution primarily by soot-emitting cookstoves, an extensive collection of firewood leading to deforestation, and drudgery associated with firewood collection, especially during rainy seasons [25], the immediate replacement of firewood by biogas is recommended. The reduction of indoor air pollution and deforestation with the help of domestic biogas technology also works towards the fulfillment of Sustainable Development Goal (SDG) 7, i.e., affordable, sustainable, and modern energy for all.

The long-term costs are estimated for 20 years, based on the realistic values of the individual cost parameters calculated using historical trends. Despite ignoring the relief for subsidy and cost of feedstock for long-term analysis, the cost of biogas is estimated at more than two times cheaper than LPG and about four times cheaper than fuel wood.

Table 3.4: Comparative cost analysis of three options of cooking fuels viz., biogas, LPG, and fuel wood (for a small family of 5 members): long-term analysis for 20 years

S.No.	Type of cost	Costs to be incurred by the beneficiary in 20 years (USD) *(1 US$ = 71.85 INR as of 21.2.2020)*		
		2 m^3 *Deenbandhu* Biogas plant	LPG domestic connection	Fuelwood
1	Capital cost	306.19[a]	21.50[b]	13.92[c]
2	Cost of feedstock/fuel	1062.15[b]	4012.77[b]	8502.86[b]
3	Maintenance cost	435.71[b]	8.93 [b]	13.07[b]
4	Miscellaneous cost	nil	227.10[b]	nil
	Total	1804.05	4270.30	8529.83
	Daily cost of cooking fuel	0.25	0.58	1.17

[a] Reference: [26], [b] **Appendix 3C**

[c] Cost of traditional clay cook stove from the areas surveyed

The bio-slurry from the biogas plant provides the potential benefit of nutrient recycling and nitrate management [11-13] thus preventing the leaching of nitrate into groundwater. There has been a report indicating the amount of achievable major nutrients (*e.g.*, N, P, and K) from the used slurry (by-product) of a typical household biogas plant [7] and the unit prices of nutrients are also known from standard source [14]. The potential annual revenue from digested slurry produced from a household-level biogas plant is estimated at 12.50 USD or INR 898 based on the prevailing prices and achievable quantities of major nutrients (**Table 3.5**). The preparation of organic fertilizer from digested slurry and its marketing has already begun in India [15-17]. However, such practices remain limited to large-capacity biogas plants. The intervention of technology is required for household biogas plants to support the proper utilization of digested slurry to prevent losses of nutrients. This has been observed during the field visit. These aspects also leads to the loss of business acumen among the owners regarding their HBS.

Table 3.5: Potential revenue from biogas slurry as a source of N, P, and K

(Amount in USD (1 US$ = 71.85 INR as on 21.2.2020))

Nutrient	Price [a] (USD/kg)	Amount of nutrient obtained from a 2 m^3 digester in a year [b] (kg/year)	Revenue obtained from nutrients (USD/year)
Nitrogen	0.26	35.41	9.26
Phosphorous	0.21	5.11	1.06
Potassium	0.14	15.51	2.18
Total			**12.50**

a Reference: [18]

b Reference: [19]

The overall performance of the biogas system determines the cost of the use of biogas as a cooking fuel. The cost of production will increase if there is a failure to achieve the biomethane potential of the used feedstock. Moreover, the commercial application of the digestate (bio-slurry) as an organic fertilizer will also lead to a reduction of fuel costs through the generation of revenue from the by-product.

3.3.5 Technological upgradation: need assessment based on user perception

The technological upgradation of biogas was discussed with the owners from the point of view that the biogas is not updated like other technologies in rural areas as discussed in **Chapter 1**

(**Section 1.6 Soundness of the technology and prospect of upgradation**). This perspective is studied from the point of view of the users. The users were asked if they were aware of any new technology intervention in other sectors of energy in rural areas such as sensors on an individual solar panel that can monitor specific parameters like energy output, temperature, etc which ultimately helps solar farm managers get insight into problems faced for a specific panel. On asking if the users wanted a similar technology in the biogas plant, only 4 % of the users were aware of this and the remaining were unaware. 8% of the users seemed interested in implementing a similar kind of technology in a biogas plant. The users were asked if they wanted to implement this technology in their existing biogas plants if the HBS went non-functional and the responses were almost fifty-fifty. From the ground survey of the 76 users, it was found that the aspects the users were most interested in getting information about was the detection of the problem (69%) followed by the general monitoring of the parameters inside the HBS (15%). The remaining users wanted information or guidance on how to implement a solution as they claimed to know the problems due to continuous use of the HBS(12%) and 4% wanted some kind of feedback from the system. The users were asked about their main objective of adopting this improved technology. The majority of the users (38%) said that they wanted to depend less on technically qualified people. Some of the users expressed a desire for a reduction in the drudgery of the operation (17% wanted an easier operating protocol and 20% wanted an easier technique for daily input of feedstock inside the biogas digester). The remaining users wanted to get knowledge about the inner workings of the biogas system (15% about adequate gas available for cooking, 3% on predicting the performance of the burners, and 7% on detecting problems in the gas burner).

The prospect of using information and technology tools to carry out predictive maintenance of a typical HBS in a rural area is expected to increase the overall system efficiency and reduce the need for technically qualified people to be present to diagnose the health of a non-functioning biogas digester.

3.4 Summary

In the face of climate change and rising fuel prices, the household biogas system appears as the most appropriate option for meeting the needs of domestic cooking fuel in rural India. Interest in biogas for heat and electricity is also seen in several regions of the world. However, despite the initiatives and incentives of the Government to promote household biogas, users' motivation has not been encouraging in India in the recent past leading to a visible decrease in the growth. The diminishing interest in biogas systems is visible from the recent trends of biogas usage despite regular revision of the policy guidelines and even the name of the schemes. The existing reports on the assessment of such status have limited usefulness in identifying the grassroots issues. Contrary to the general perception of users about the higher cost of biogas as cooking fuel, the study revealed that biogas is the cheapest option among all the available options. The requirement of relief under subsidy appears justified considering the higher capital (initial) cost and lack of affordability of the majority of the rural people. The fertilizer value of digestate is generally ignored and accounting for the recycled nutrients has a favorable economic impact on household biogas systems. Traditionally cow dung is used as feedstock and its availability appears as a major motivating factor for the adoption of household biogas systems. Increased awareness about the uses of alternative feedstock in co-digestion mode is realized in areas where the availability of cow dung is an issue. Chronic poor performance is attributed to one or more factors related to feedstock, microbial activities, and climatic parameters which remain unknown to the users and lead to their diminishing interest. Technology-integrated management support is expected to revive the interest in household biogas systems in rural India.

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