ABSTRACT

The status of the installation of a decentralized household biogas system (HBS) under Government schemes varies among the regions due to regionally varying factors. Assam which is one of the states of India apparently with favourable ambiance for HBS, fulfilled the set target of installation till the year 2016. However, there have been increasing gaps between the Government's set target and actual installation. There is a need to carry out a study that shows the ground information regarding the declining growth of HBS in Assam especially in rural areas. The management of HBS mostly relies on traditional methods, however, technological up-gradation, and inclusive growth otherwise the focal development points in rural India have been found to be absent in HBS.

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 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. 340 households (20% of the total population) 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. A total of 16 parameters have been identified for this study. An appropriate questionnaire is designed, tested, and used to capture data about those parameters which covered the areas of 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.

The survey revealed that 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 appropriate channelizing of LPG marketing and its penetration to rural areas, coupled with better quality of controllable flame obtained in convenient refill bottles and easy availability of support services resulted in LPG as the preferred choice over all other options. Further investigation of 18% of the respondents indicating a preference for biogas reveals that the easy availability of

feedstock within their household. 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.

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 particularly during the collection and handling of feedstock which were labor-intensive tasks. This also led to disinterest in operating the HBS and discouraged prospective owners. The efficient functioning of a biogas digester demands the maintenance of specified parameters for optimal biogas production. Yet the survey revealed that most of the users were unaware of such technical knowledge. 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. From the ground survey of the 76 users, it was found that the aspects the users were most interested in getting information about were the detection of the problem (69%) followed by the general monitoring of the parameters inside the HBS (15%) and the remaining wanted information or guidance on how to implement a solution.

From the point of view of the availability of feedstocks, cow dung was the dominant feedstock being used in the HBS. There has been adequate literature listing suitable items as feedstock for biogas. 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. The storage, processing, and pretreatment of HBS feedstock is a factor that influences its use as a clean cooking fuel. Because the HBS will be operational throughout the year, effective feedstock storage is essential to its performance. The physical location of the cowshed is also a contributing factor to the performance of the HBS. The households of the villages were asked about how the bio-slurry was utilized. Some users released the slurry into the surrounding field whereas others used it appropriately used as organic fertilizer. There were also differences in the training received by the owners of the HBS in the three villages surveyed. A comparative analysis of the cost of using cooking fuels through three options viz. biogas, LPG, and fuel wood for a short-term (5 years) and long-

term (20 years) basis, respectively for a typical rural family having 5 members. 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 other available choices of cooking considered for analysis, provided subsidy on capital cost is available and the user can get feedstock without paying for it. 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 as seen in the long-term costs. The potential annual revenue from digested slurry produced from a household-level biogas plant is also estimated. 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 followed by the general monitoring of the parameters inside the HBS. Some of the users expressed a desire for a reduction in the drudgery of the operation. The use of information and technology tools to perform predictive maintenance on a typical HBS in a rural area is expected to increase overall system efficiency and reduce the need for technically qualified people.

Based on the findings of the survey the next part of the research was focused on measuring the reaction parameters of an anaerobic digestion process to carry out predictive maintenance of the biogas system. An IoT-based biogas monitoring system developed in the Department of Energy, Tezpur University was implemented in a 0.25 cubic meters biogas digester. The parameters considered for monitoring were ambient temperature, ambient pressure, ambient humidity, temperature inside the digester, and pH of the reaction media inside the digester. An application software was developed for remote access of the sensor data as well as for its storage and display through a computer or smartphone. The wireless network and server available in the Tezpur University campus are used for the above purpose. In addition to understanding the technical feasibility the approximate cost of the system is also assessed from the prevailing market rate of the required components with realistic assumptions. Based on these costs, the economic analysis of the IoT-based biogas management system with some selected rural enterprises has been carried out later**.**

Application software is used to acquire the data of the biogas system about (i) reaction zone (temperature, pH), (ii) ambient conditions (temperature, RH) (iii) output gas composition (CH_4, CO_2, H_2S) using the relevant sensors, microcontroller and communication network. The stability of the electronic components used for the IoT

system installed in an outdoor ambiance has remained a major challenge. Similarly, concerns regarding software, reliable power supply, and consistent performance of sensors with expected data accuracy were also encountered.

In the final part of the research, HBS is compared with four household-based enterprises: dairy, piggery, poultry, and fishery to explore the potential of the HBS with the installed IoT-based biogas monitoring system as a viable rural entrepreneurship and its prospect to decarbonize the rural India cooking sector.

First, the comparison of HBS with the selected enterprises was carried out by assessing the income and expenditure of the enterprises required. Field data representation was taken from the three villages (Napaam, Amolapam, and Amlighat). Information available in some Government documents and collected from standard sources were also utilized for the analysis. The profitability of the enterprises was also ranked by calculating their Net Present Value (NPV) over ten years. From this economic analysis it was discovered that HBS has the potential option to be a viable rural enterprise provided it is a robust system where the gas production remains stable as per its rated capacity and there is an already existing feedstock supply chain available to the owners.

Secondly, the sustainability of the enterprises was also determined by comparing the contributions of the enterprises to the SDGs in India based on some indicators from the National Indicator Framework (NIF) developed by the Ministry of Statistics and Programme Implementation (MoSPI). The details of this analysis revealed that the contributions of HBS towards SDGs in India are maximum compared to the remaining rural enterprises.

Thirdly, the decarbonization potential of biogas was explored by comparing the Greenhouse gas emissions of the cooking fuels utilized in the three villages. The study revealed that replacing one cylinder of LPG could reduce GHG emissions by 17.63 kg of CO_2 equivalent. This value was critical in determining the decarbonization potential of using biogas as a clean cooking fuel in three villages. It was estimated that integrating biogas into daily cooking fuel usage would result in a significant reduction in carbon emissions.

In conclusion, it can be said that despite the brighter picture painted by HBS from the profitability and sustainability points of view, the acceptability of HBS among rural people is not encouraging. The uninterrupted production of bio-methane (which is a decarbonized

cooking fuel alternative to LPG) and digestate (which is an alternative to chemical fertilizers) are counted for solving the problems of clean cooking in rural areas as well as generating some income for the owners. However, both the quantity and quality of products and by-products are uncertain and dependent on factors including two major considerations: robust technology and supply of proper feedstock. Technical issues with HBS, particularly those faced with the prospect of regularly producing an adequate amount of cooking fuel must be overcome to reap the complete benefits of biogas as a clean cooking fuel. At the same time, the proper utilization of the digestate (as per the protocols set) and not discarding it wastefully in the fields will the owners will also help enhance the profitability of the rural livelihoods.