CHAPTER 6

SUMMARY AND CONCLUSIONS

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The current research aims to study the slow or negative growth in the adoption of household biogas systems (HBS) in India particularly in rural areas. This has been studied considering ground-level data collected from a cross-section of people living in rural areas. A fabricated IoT-based biogas management system has been used to address management issues in household biogas plants. The prospect of HBS with the installed IoT system has been explored by comparing it to four household-based rural enterprises (piggery, fishery, dairy, and poultry), and the decarbonization potential of the surveyed villages has also been evaluated. All the set objectives were achieved, and the summary of the significant findings is provided below.

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

- For the current study, three villages have been selected: Napaam and Amolapam (in the district of Sonitpur), and Amlighat (in the district of Morigaon). Napaam and Amolapam are adjacent to each other.
- 340 households were recruited through random sampling. 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 HBS encountered was of the Deenbandhu fixed dome type.
- A total of 16 parameters have been identified for this study. A relevant questionnaire was developed, tested, and utilized to gather information encompassing the following broad areas: background of the user, experience of using the biogas system, operation and maintenance details, and knowledge of the benefits of the system.
- The better scenario of HBS prevailing in Amlighat in terms of acceptability and functionality is further examined with consultation of relevant literature and stakeholders of the villages.
- 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 most

popular fuel option was LPG alone, followed by LPG and fuelwood. This was followed by biogas alone, and then a combination of LPG and biogas.

- LPG became the favored choice over other options for cooking fuel with 41% of the population interviewed opting for it due to its effective marketing and penetration in rural areas, as well as improved flame quality of the cooking fuel and convenience of obtaining refills.
- 36% of the respondents who were not interested in biogas cited high capital expenses and frequent maintenance costs. More than one-fifth of respondents preferred using fuel wood to avoid the uncertainty of changing from familiar cooking methods. 2% of respondents expressed ignorance about biogas, highlighting the need for dissemination of knowledge about the negative consequences of solid fuels and the benefits of biogas.
- 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 lead 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.
- 38% of users had no understanding of why the digester was malfunctioning. Again, 29% of households experienced non-uniform gas production during particular times of the year, resulting in an insufficient supply of cooking fuel. 13% of the respondents suffered from gas obstruction due to moisture traps. Overall, respondents tend to be most concerned about performance concerns regarding the different parts of the anaerobic digester.
- 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 such services.

- Cow dung was the dominant feedstock being used in the HBS. The availability of suitable alternative feedstocks apart from cow dung in the selected areas was also investigated. However, the use of these alternative feedstocks, particularly agricultural wastes, is hampered by a lack of effective pretreatment procedures for transforming raw waste organic feedstock into suitable feedstock for HBS in rural regions.
- 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.
- However, the current study has been limited to the use of cow dung only as a feedstock for the HBS. The lack of availability of cow dung led to the abandonment of the HBS by the owners in the villages of Napaam and Amolapam. Although the users knew about the use of alternative feedstocks, they were unaware of the pretreatment techniques involved in converting these potential feedstocks to be used in the HBS. 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.
- In terms of slurry management and nutrient recovery, the majority of users in Amlighat discharge bio-slurry to the surrounding fields without separating the solid and liquid components of the bio-slurry and without targeting crops. In contrast to the users of Amolapam and Napam, bio-slurry is properly employed as organic fertilizer for crop fields as well as utilized for mushroom cultivation. A solid and liquid separation tank was built in the villages of Napaam and Amolapam to separate the digestate's solid and liquid components. Based on current prices and realistic quantities of main nutrients, the potential annual revenue from digested slurry produced by a household-scale biogas system is predicted to be USD 12.50.
- 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.

- 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 has been carried out. 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.
- According to results obtained from the economic analysis, using biogas as a cooking fuel is the most cost-effective choice when capital costs are subsidized and feedstock is free. Thus, for families with sufficient cow dung and/or agricultural residues, using biogas as a cooking fuel provides a direct cost benefit over other options. However, biogas appears to be costly without a subsidy and if the feedstock is paid for in the short term. Even in the short term, using biogas with a subsidy system and purchased feedstock appears to be 41% cheaper than burning wood. 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.
- The cost of using biogas as a cooking fuel depends on the overall performance of the HBS. If the biomethane potential of the feedstock is not adequate, the production cost will rise. Furthermore, the commercial application of digestate (bio-slurry) as an organic fertilizer will reduce fuel costs by generating revenue from the byproduct. One possible approach is to deploy a resilient biogas system with suitable technological intervention to precisely detect difficulties related to factors such as climate, feedstock, and microbial activity. Real-time monitoring of the biogas digester's internal operational conditions could be important for detecting the problem and implementing corrective steps.

6.2 IoT for management of household biogas system: a feasibility analysis

- To increase the overall efficacy and efficiency of a typical HBS, the viability of incorporating an Internet of Things (IoT) is explored in this Chapter. An experimental biogas reactor (Make: Shakti Surabhi 0.25 m^3) is used for implementing the IoT-based biogas management system developed in the AdaptNET laboratory of Tezpur University. The server available in the same is used for data communication.
- The system is built using an ESP32 microcontroller, BME280 sensor, DS18B20 temperature sensor, and a pH sensor. The system is powered using a power bank, which is continuously charged using a 5-volt adapter. The data acquired by the sensors is sent to the server at an interval every 15 minutes. The data can then be analyzed to identify any trends or anomalies that may be affecting the production of biogas. The system can be accessed remotely using a web interface or a mobile application.
- The functionality of the outdoor and indoor IoT components installed are periodically checked and reported to assess the performance of the IoT system during the observation period.
- 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.
- Data of the biogas system obtained from the IoT-based biogas management system pertaining to (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 have been presented and discussed.
- Several attempts were made to capture the gas composition data by installing gas sensors inside the gas holder. However, the sensors were found to be damaged and therefore composition data could not be accessed through the IoT system. This is being further investigated through a thorough inspection. The sensors were damaged probably due to exposure to humidity and acid vapor inside the digester.

Two major kinds of degradation are observed: corrosion of the solder mask layer and deposition of residue on metal bodies.

- Over a period of 6 months, the circuit components have considerably aged, structurally. The metal bodies and contacts are largely affected by these depositions. Over a satisfactory period in which an IoT system is expected to be operational, such aging may be detrimental in affecting the performance of the electronic components.
- Though the gas composition data could not be accessed in the current investigation, the functionality of the IoT system could be tested for the remaining parameters. The operational features of the test biogas system were ascertained by collecting the gas composition data using a conventional gas analyzer. Variation of the temperature and pH data of the reaction zone as recorded in the test period is indicative of the reaction condition which is found in line with the production of biogas.
- The temperature profile as recorded by the IoT system at two specific locations (a) ambient (outside of the reactor) and (b) reaction zone temperature indicates thermal management of the biogas system. The available heat of the ambiance can be transferred to the reaction zone to ensure better performance during some periods of the day as noticed from the plot. Around 72 hours period of operation, the reactor zone remained cooler than the outside whereas a higher temperature would have been better for efficient gas production.
- It was also investigated whether the IoT system might be integrated with an already existing biogas system with limited success. The current biogas infrastructure still presents significant obstacles when it comes to placing sensors for reactor data. For the biogas system, data related to a few of the parameters could be successfully retrieved using conventional devices. One visible drawback of the manual method is its inability to capture data instantaneously.
- Corrosive effects of humidity, temperature, and gases on commercially printed circuit boards are major concerns for an IoT-integrated biogas system. The different electronic modules that make up the IoT system comprise electronic components embedded in the PCBs based on the manufacturer's placement and routing strategies. Exposure of the solder-masked copper interconnect layer in a PCB to

products like H_2O and H_2S in the presence of temperature may lead to degradation of the performance of the electronic system over a long period.

- Since a smart IoT system integrated with the household biogas system is supposed to acquire data continuously throughout the day, therefore, one of the fundamental requirements in an IoT set-up is the power supply which is required to keep the system live. Direct current batteries or energy storage devices are the solutions; however, the depletion of voltage in batteries needs to be constantly monitored. Therefore, depletion of voltage at any point in time may lead to erroneous data. For a biogas system, provision and monitoring of a consistent outdoor power supply are quite important.

6.3 Potential of household biogas system as viable rural entrepreneurship and its prospect to decarbonize the rural Indian cooking sector

- 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). 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.
- There are variations of sizes, feeding habits, care and management, and outputs among the different enterprises. To overcome heterogeneity, the current investigation has been carried out with some realistic assumptions such as the entrepreneurs have fully constructed animal sheds or have land for HBS, a regular supply of essential inputs, and beneficiaries possessing previous experience of running a rural-based household enterprise. Among the different HBS models, 2 cubic meters Deenbandhu model has been selected for the current study. The thermal energy (heating) for rearing poultry is accounted whereas the electricity used for lighting is ignored due to negligible added contribution. The length of the life cycle of dairy animals (6 years), pigs (2 years), poultry (one year), and fish (one 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.

- Analysis of the relative contributions of five selected enterprises on Sustainable Development Goals (SDGs) has been done.
- The decarbonization potential of rural cooking through fuel substitution, i.e. using biogas as a primary source of clean cooking fuel instead of LPG is also analysed.
- The first-year expenditure and income profile of the five selected enterprises are calculated. 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 to up to 6 years, therefore, the inflation rate during such a short span has been ignored. The order of enterprises in terms of Levelized annual cost of fixed expenditure (LACFE) is found different than that of Fixed Cost (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. 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 of 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: robust technology and supply of proper feedstock.
- The six options of enterprises are ranked based on the Net Present Value (NPV) analysis. 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.
- 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 by using HBS.

- 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. While biogas digestate is often underutilized, its potential contributions to make a profitable rural livelihood enterprise cannot be ignored.
- 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 details of the analysis revealed that the contributions of HBS towards SDGs in India (SDG 5, 6, 7, 12, 13) are maximum compared to the remaining rural enterprises. Thus, from the profitability and sustainability point of view, HBS is a comparable option to a rural enterprise.
- It is found that per cylinder of LPG substitution for cooking by biogas 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. 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.

6.4 Conclusion and Suggestions for future work

- The current study provides insight into the retarded growth of biogas as a clean cooking fuel in India. The uninterrupted production of bio-methane and digestate can solve the problems of clean cooking in rural areas as well as generate 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.

- An online IoT system consisting of sensors is expected to be a diagnostic mechanism for the household biogas system. It is embedded with different electronic components including sensors, driver circuits, and microcontrollers. The data that is received on the server from the remote IoT system is the only source of information on which the clients or users rely for the operation of their biogas plants. However, there is a lack of an automated server-integrated error-detection mechanism that can detect if there is an error in the data acquisition by the sensors, which may arise out of events like interrupted power supply, sensor degradation, and short circuits between two components. This concern is one of the greatest challenges in IoT-integrated household biogas systems because the data size is huge and the errors may be undetectable at times owing to the complex dependence on several variables.

- In the current work, several attempts were made to capture the gas composition data by installing gas sensors inside the gas holder. However, the sensors were found damaged and therefore capture of gas composition data using IoT system was disrupted. The damage was mostly due to corrosion of the solder mask layer and the deposition of residue on metal bodies. The gas composition had to be accessed manually with a conventional gas analyzer. It may be recommended that to reduce the likelihood of corrosion affecting the solder mask layer, protective coatings, such as polymer-based or epoxy coatings be applied. These coatings act as a physical barrier, shielding the solder mask from environmental factors like humidity and temperature. In addition to extending the lifespan of the components, these coatings will help maintain accuracy by preventing interference from external conditions. They will also protect the circuit components from aging caused by the deposition of sludge or other contaminants. This would remove the need for manual intervention with a separate conventional gas analyzer and would further enhance the functionality of the IoT-based biogas monitoring system. Overall, the implementation of the automated, server-integrated error-detection mechanism that can identify issues in data acquisition caused by power supply interruptions, sensor degradation, or short circuits between components. would enhance the reliability of the biogas monitoring system by promptly detecting and addressing such errors, ensuring accurate and continuous data collection.