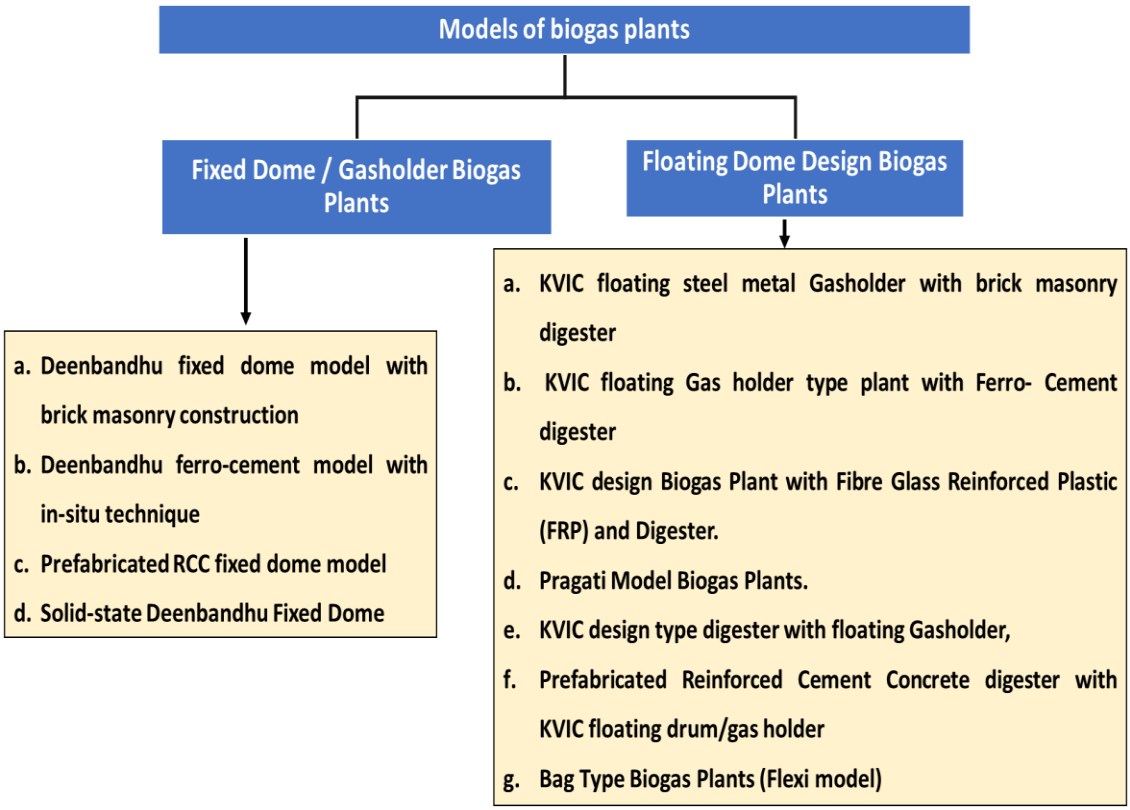
Appendices

Appendix 1 A: Different models of biogas plants in India



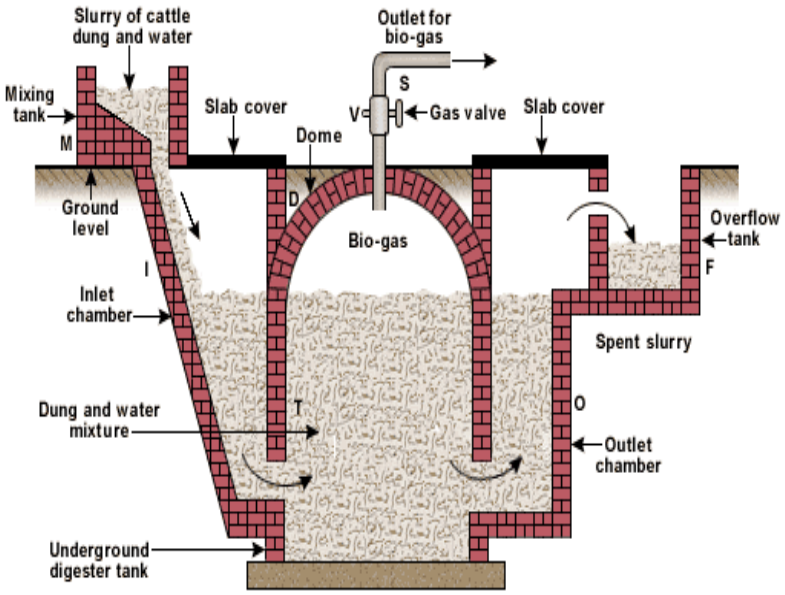


Fig 1 A: Fixed Dome / Gasholder Biogas Plants

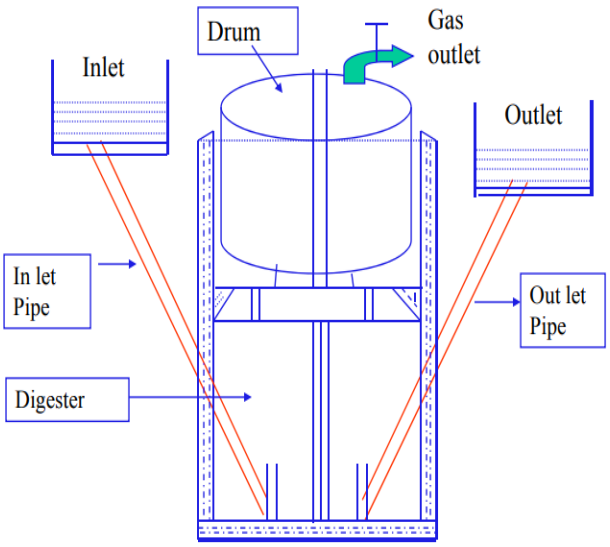
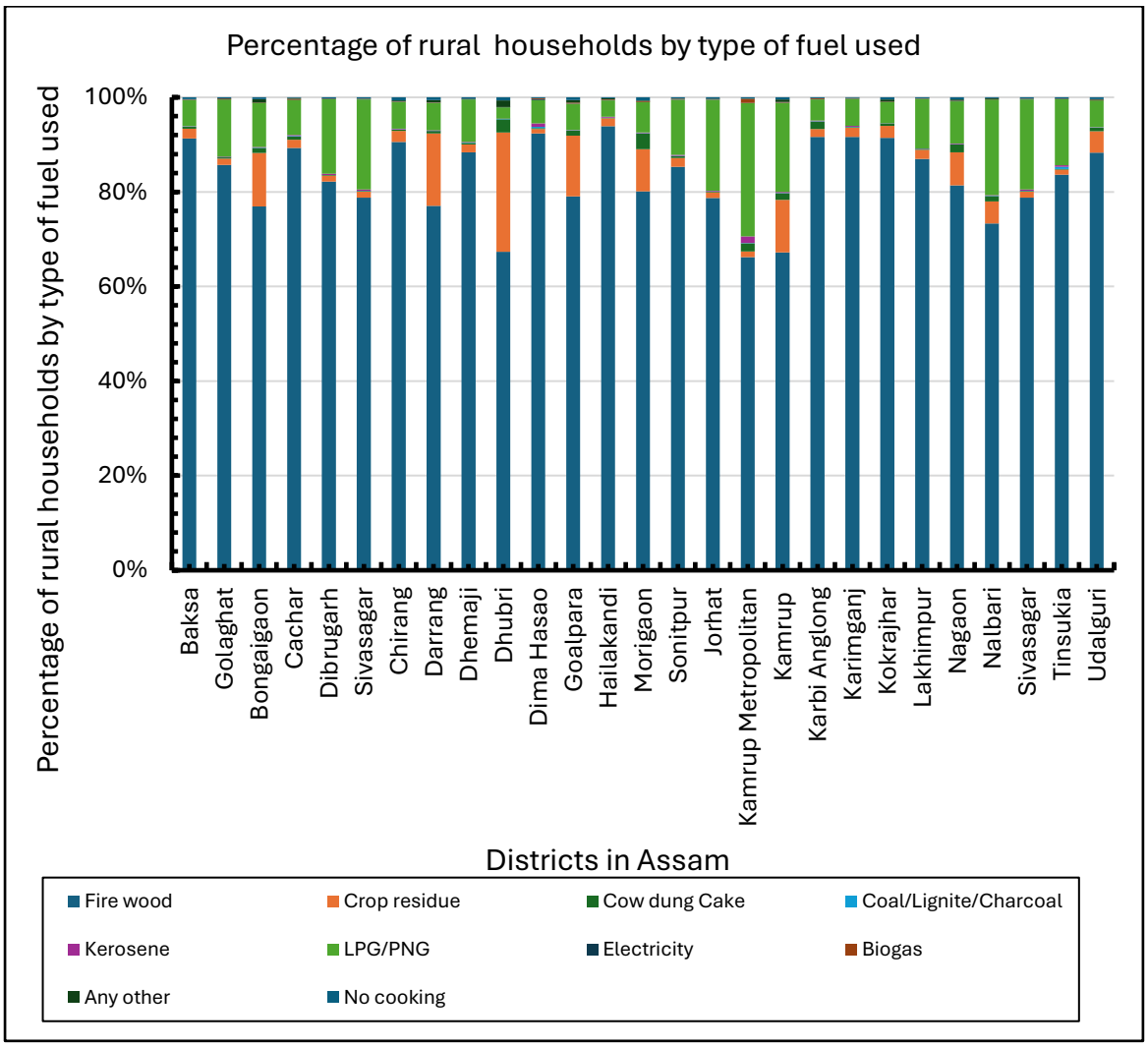


Fig 2 A: Floating Dome Design Biogas Plants

Appendix 3 A: Percentage of different cooking fuels used by the rural households in all the districts in Assam (*Data sourced from the District Census Handbook of Villages and Town Wise Primary Census Abstract (PCA), Directorate of Census Operations Assam of Census 2011 for all the districts of Assam as per 2011 Census*)



Appendix 3 B: Description of parameters for **Table 3.2**

S.No.	Parameters	Reference	Document type/source
a	Cost of a 2 cubic meters Deenbandhu biogas plant with and without subsidy	[26]	Office order Government of India
b	Total amount to be paid by a new consumer	[27]	Order by a government-owned subsidiary (Indane)
c	Total amount to be paid by a new consumer	[28]	Order by a government-owned subsidiary (Indane)
d	Cost of traditional biomass cookstove from areas surveyed	----	From field survey
e	Cost of cow dung for 365 days (30 kg for 365 days @ INR 0.3/kg)	---	From field survey
f	Cost of firewood available in the market sold at INR.7/kg and 2902 kg/year for a household of 4-5 members	[29]	Journal and verified during field survey
g	Total cost of maintenance of biogas plant for 1 year	---	Verified during field survey
h	Cost of maintenance of traditional biomass cook stove	[33]	Journal and verified during field survey

Appendix 3 C Description of parameters and assumptions used for **Table** 3.3

S.No.	Parameters	Costs (USD)	References
1	Total amount to be paid by a new consumer for a Domestic LPG cylinder connection	21.50	[30]
2	Total cost of LPG (for 1 LPG cylinder) for 20 years as required by a household as a cooking fuel from 2021to 2040	4012.8	[31]
3	Total cost of Firewood (For 1 kg of firewood) for 20 years as required by a household as a cooking fuel from 2021 to 2040	8502.86	Taken from field survey
4	Cow dung (For 1 kg of cow dung) for 20 years as required by a household as a cooking fuel from 2021 to 2040	1062.15	Taken from field survey
5	The total cost of transportation of LPG cylinder from distribution centers to households for a family of 4-5 members for 20 years considering annual average inflation rate of 4.48%	209.14	[32]
6	The total cost of servicing of the hot plate in LPG cylinder system after every 5 years for 20 years considering annual average inflation rate of 4.48%	17.96	[32]
8	Total cost of maintenance of LPG system (changing of hose pipe once every 5 years) for 20 years considering annual average inflation rate of 4.48% (USD)	8.93	[32]
7	Total cost of maintenance of biogas plant for 20 years considering annual average inflation rate of 4.48% (USD)	435.71	obtained during a survey of the selected areas
9	Total cost of maintenance of traditional clay cook stove for 20 years considering annual average inflation rate of 4.48% (USD)	13.07	[33]

Appendix 3 D: Questionnaire used to interview the participants

Part A: Information about the users/ not users of Biogas Plant

1. Personal information

Name	
Age (on the date of collection of data)(dd/mm/yyyy)	
Father's name	
Mother's name	
Address	
Mobile number	
Education (Code[a])	
Occupation(Code[b])	

Code[a] : 1- Illiterate, 2- Literate but no formal education, 3- Primary or equivalent, 4-Secondary, 5-Higher Secondary,6- Diploma holder,7- Graduation
Code[b] : 1- Farmer; 2 - Business (specify); 3 - Day laborer; 4 - Teacher; 5 - House wife; 6- Doctor,7-Others (Goldsmith, Potters, Carpenter, Tailor, Village Doctor, Mason, Barber, Rickshaw puller, Boatman etc.)

2. Information on family members

Number of family members	Male					Female				
	1	2	3	4	5	1	2	3	4	5
Name										
Age(on the date of collection of data)										
Education (Code[a])										
Occupation(Code[b])										

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.

3a. What are the reasons for not owning a biogas plant?

- Unable to bear the cost of biogas plant
- Not aware of the technology
- Alternative fuel (LPG)
- Alternative fuel (wood)
- High maintenance of biogas plants
- All of the above
- Do not know the reason

3b. What are the reasons behind for installation of biogas plants?

- Subsidy
- Non-availability of other fuel sources
- Environmental benefits
- Motivation from service provider
- Motivation from existing plant owners
- Economic benefits
- Saves time and energy
- Status symbol
- Do not know the reason

PART B: Information regarding the functionality, feedstock, collection, storage and feeding

4. Functionality of biogas plant

Size of the biogas plant (m^3)	Less than 2	2	3	4	5	6	More than 6
Date of construction of the biogas plant							
Is it in operation on the date of interview? (Yes= 1 , No=2)							
If no, how long is the is the biogas plant not in operation?(years)	Less than 1	1-2		2-3	3-4		More than 4

5. How was the biogas plant constructed?

a) Was the family involved in the construction? (Yes = 1, No = 2)
b) Was the construction carried out by contractual mason/hired mason/family member?
c) Is the biogas plant subsidized under some schemes or investment was made by the users?
d) If the biogas plant was a subsidized one, under which scheme was it given to the users?

- 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)
- KVIC (Khadi and Village Industries Commission)

e) What materials were used in the construction of the different parts of the biogas plant?
f) Were any standards followed regarding the quality of construction materials to construct the biogas plant?
g) Is the user aware of any standards that should be followed while constructing a biogas plant?

6. Reasons for non-functioning of the biogas plant

- Not interested to operate because other sources of fuel are available (firewood, LPG)
- Non uniform availability of feedstock
- Defects in digester/gas holder/pipe/inlet/outlet
- Maintenance costs not affordable
- Natural disasters
- Reasons not known

7. Feedstock used for the current HBS

Type of animals	On date of installation	Amount of feedstock generated	On date of interview	Amount of feedstock generated
• Cows				
• Buffalos				
• Ducks				
• Hens				

8. Are you aware of feed stocks for a biogas plant and the status of the availability of these feed stocks? (1=Yes, 2= No)

9. If yes, what sources are you aware of and what is the availability of these sources?

Sources	Awareness about use in biogas plant	Awareness about availability
Cow dung		
Agricultural waste		
Food waste		
Sewage sludge		
Mixture of food waste and cow dung		
Mixture of agricultural waste and cow dung		

10. Collection, storage and feeding methodology (*questions framed for cow dung used as feedstock*)

Who collects the cow dung?	Family member(Male/Female/Kid)			Paid worker engaged by the family(*mention amount being paid*)	
What is the source of cow dung?(1= own , 2 = borrowed from other local farmers, 3 = bought from other farmers,4 = others)					
How is the cow dung collected? (1= plastic bags, 2= metal container/drum, 3= plastic drum, 4= jars, 5= others)					
Is soil mixed with cow dung? (1= yes, 2= no)					
Is the user aware that excessive soil causes problems in the biogas plant? (1= yes, 2= no)					
What is the distance of the cowshed from the biogas plant?					
What is the mode of transportation of the feedstock?					
Who carries the cow dung from the point of collection to the plant?	Family member(Male/Female/Kid)			Paid worker engaged by the family *(mention amount being paid)*	
Daily loading cow dung (kg)	30-40	40-50	50-60	60-70	Above 70
Daily loading frequency of biogas plants (1= once, 2= twice, 3= thrice)					

Is the cow dung stored or used completely?					
If the cow dung is stored, for how many days is it stored?					
Is the excess cow dung stored in a line tank or in on open dumping area?					
Is the user aware that the methane is lost if the cow dung is stored for a long time?					
What is the source of water fed to the biogas plant? (1 = well, 2 = ground water, 3 = surface water bodies)					
How is the water collected?	Pumping		Manual collection		
Who collects the water?	Family member(Male/Female/Kid)		Paid worker engaged by the family (*mention amount being paid*)		
Amount of water fed to the biogas plant (litres)	30-40	40-50	50-60	60-70	Above 70
Was any difficulty faced during the dry seasons/rainy seasons?	Yes		No		
How is the cow dung and water mixed?(1= manual, 2= power machinery)					
If external power is used, what is the source of power? (1= diesel, 2= electricity, 3= others)					
Does the user have any knowledge of removal of foreign materials from feedstock?	Yes		No		

If yes, what types of foreign materials are mostly found in the feedstock?	
Is the separation of foreign materials from the feedstock done?(plastic, stone)(1= yes, 2= no)	

PART C: Output from the biogas plant

11. The following are the questions regarding the outputs obtained from the biogas plant

11 a. Questions regarding biogas generated:

How is the biogas transferred to the kitchens? (1= GI pipe, 2= Plastic pipe, 3= MS pipe)	
What is the distance of the plant from the kitchen?(meters)	• Less than 10 • 10-20 • 20-30 • 30-40 • More than 40
Is the pipe above the ground or below the ground?	
Is there any issue of leakage present? (Yes = 1, No = 2)	
If any issue of leakage is found, how is it being addressed?	
At what interval is the pipe being replaced?	
If the pipe is replaced, what is the average cost involved here?	
Is the user aware that moisture has to be removed from the pipes?	
Is there any outlet for moisture removal from the pipe?	

How frequently is the moisture being removed from the pipes?				
How many bends are there in the pipes?				
Is there any provision for checking the gas pressure?				
Is there any variation of gas pressure during the day and during the night?				
Does the user have any knowledge about the type of burners available in the market?				
How many biogas burners are used?	1	2	More than 2	
Other than biogas, what is the option of cooking?(1= firewood, 2 = LPG, 3 = kerosene, 4= cow dung cakes, 5= solar energy, 6 = others)				
How frequently is the burner cleaned?(1= daily, 2 = once a week, 3 = once in a long time, 4 = never)				
Does the user have any knowledge of the servicing of the burner? (Yes = 1, No = 2)				
Does the user know where new burners can be bought? (Yes = 1, No = 2)				
Who would bear the cost of the new burners?				
What is the quantity of gas produced from the biogas plant?	adequate	inadequate	less	more
Does it (quantity of gas) vary according to the seasons? (Yes = 1, No = 2)				
Is any difficulty faced by the households due to the lack of gas? (Yes = 1, No = 2)				
Does the household want a constant supply of biogas? (Yes = 1, No = 2)				

11 b. Questions regarding bio-slurry

Is there any arrangement for removing slurry from the slurry pit (if available)? (Yes = 1, No = 2)			
If there is no pit available, how is it removed?	• Open discharge to the soil • Unlined canal discharge to the field • Lined canal discharge to the field • others		
Is it difficult to transfer due to the consistency of the slurry? (Yes = 1, No = 2)			
Does the user feel that separation of the solid and liquid part of the slurry is useful? (Yes = 1, No = 2)			
If slurry pits are present, what is the number of slurry pits?	1	2	More than 2
If slurry pits are present, what are the dimensions of the slurry pits?			
Is slurry being used in the farms?			
How do you use bio-slurry? (1= organic fertilizer, 2 = applied directly to vegetables or fruit, 3 = to reduce weed growth, 4 = thrown away, 5= for mushroom production, 6= others)			
If slurry is being used, has the production increased in the farms in any way? (Yes = 1, No = 2)			
Is there any provision to protect the slurry from the rainfall/sunshine? (Yes = 1, No = 2)			

Does the user know that the slurry has volatile materials present in it? ?(Yes = 1, No = 2)	
Does the user know that nutrients may be drained from the slurry to the soil? (Yes = 1, No = 2)	
Does the user feel that the bio-slurry can be sold? (Yes = 1, No = 2)	
If it is saleable, what may be its value compared to cow dung?	

12. Impact on socio-economic condition

Before using biogas		After using biogas	
Time required for cooking per day (hours)		Time required for cooking per day (hours)	
Time spent in fuel wood collection(hours)		Time spent in fuel wood collection(hours)	
Time spent in preparing the fuel (hours)		Time spent in preparing the fuel (hours)	
Fuel wood utilized per month(kg)		Fuel wood utilized per month(kg)	
LPG utilized per month(kg)		LPG utilized per month(kg)	

PART D Training /servicing of the existing technology and new technology intervention

13. Was any training provided to the users after installation of the plant?

□ No training received □ Training not provided but leaflet/booklet/manual provided □ On the spot instructions □ One day/Two days/ Three days orientation training provided by service provider □ Short term training (one week) □ Long term training (one month/two months) □ Others (specify)

14. Services offered after installation

Have you received any follow up services from the agency?(Yes=1, No=2)	
Is there any service center nearby? (Yes=1, No=2) If yes, how far away is the service centre of the agency or any other agency from your place? (Within 5 km = 1, 5-10 km = 2, More than 10 km =3)	
How much money is needed per year for operation and maintenance of the plant? (1=less than Rs. 500, 2 = Rs. 500 - Rs. 2000, 3 = more than Rs. 2000)	

15. Awareness of technology intervention

Are you aware of any new technology intervention in other renewable sources of energy?(solar) *	
Do you want to implement similar type of technology in biogas plant? (Yes=1, No=2)	
If your biogas plants are not working: Will you like to adapt the technology again with some modifications? (Yes=1, No=2)	

What is your main objective of adopting this improved technology? (1= Adequate gas for cooking not available, 2 = easy operation, 3= easy feeding, 4 = less dependence on technically qualified people, 5 = easy use of burners, 6= reduce problem in the gas transmission pipes)	

* Sensors on an individual solar panel can monitor specific parameters of that panel such as energy output, temperature etc. The solar farm manager can get insight into problems faced for a specific panel. Since the energy output and efficiency of individual panels can be known, the panels that are low producers can be replaced or repaired. Do the users want a similar technology in the biogas plant?

16. What aspects are the users most interested in getting information about?

- Acquisition of data
- Detecting the problem
- Implementation of the solutions
- Feedback

Appendix 5A: Indian standards for the quality of feeds and feedstocks for different enterprises

S.No.	Enterprise	Ingredients	**Reference (** Indian Standard Specification)
1	Piggery	• Grain and Seeds (millet, barley, black gram, yam, sorghum, oats, yellow maize wild rice etc.) • Grain by-products during the processing of pulse grains • Oil Cakes • Tubers and Roots • Minerals, Vitamins and Supplements • Waste Materials and Industrial By-products (Brewers' grains, dried yeast and yeast sludge, mango seed kernel flower residue, molasses, dried silkworm pupae)	IS : 7472 - 1986
2	Dairy	• Grains and Seeds • Grain by-products • Oilcakes • Tuber and Roots • Waste materials and Industrial by-products	IS 2052 : 2009
3	Poultry	Maize, jowar, bajra, rice, wheat, barley grain, rice polish,	IS 1374:2007
4	Fishery	• Grain and Seeds • Grain By-Products • Oil Cakes • Tubers and Roots • Minerals and Vitamins • Industrial By-Products	IS 16150 (Part 1) : 2023

Appendix 5B: NPV of the five enterprises for 10 years (Amount in USD: 1 US$ = INR 82.5 as on 24.10.2022) , DF: Discount factor; PV: Present Value(*All amounts in USD)*

Year	DF @ 8%	Dairy		Piggery		Poultry		HBS_with subsidy		Fishery		HBS_without subsidy	
		Cash Flow	PV	Cash Flow	PV	Cash Flow	PV	Cash Flow	PV	Cash Flow	PV	Cash Flow	PV
0	1.00	1719.85	1719.85	361.82	361.82	1587.88	1587.88	176.79	176.79	911.52	911.52	310.12	310.12
1	0.93	1430.94	1324.94	377.58	349.61	1290.91	1195.29	473.52	438.44	543.03	502.81	473.52	438.44
2	0.86	2561.48	2196.06	480.47	411.93	1377.40	1180.90	651.39	558.46	579.41	496.75	651.39	558.46
3	0.79	2733.10	2169.62	429.87	341.24	1469.69	1166.68	695.03	551.74	618.23	490.77	695.03	551.74
4	0.74	2916.22	2143.51	547.01	402.07	1568.15	1152.64	741.60	545.10	659.66	484.87	741.60	545.10
5	0.68	3111.60	2117.70	489.40	333.08	1673.22	1138.77	791.28	538.53	703.85	479.03	791.28	538.53
6	0.63	3320.08	2092.21	622.77	392.45	1785.33	1125.06	844.30	532.05	751.01	473.26	844.30	532.05
7	0.58	2111.58	1232.09	557.17	325.11	1904.94	1111.52	900.87	525.65	801.33	467.57	900.87	525.65
8	0.54	3779.87	2042.15	709.02	383.06	2032.58	1098.14	961.23	519.32	855.02	461.94	961.23	519.32
9	0.50	4033.13	2017.57	634.34	317.33	2168.76	1084.92	1025.63	513.07	912.30	456.38	1025.63	513.07
10	0.46	4303.34	1993.28	807.21	373.89	2314.06	1071.86	1094.35	506.89	973.43	450.89	1094.35	506.89
10	0.46	600.16	277.99	119.82	55.50			68.48	31.72			135.15	62.60
NPV			**17887.27**		**3323.44**		**9737.89**		**5084.19**		**3852.75**		**4981.73**

List of Publications

These publications are the outcomes of the present research.

Journal:

1. **Sarmah, T**. and Baruah, D.C., A field-based study demonstrating the need of holistic management system for household biogas plants in rural India. *Natural Resources Forum, a United Nations Sustainable Development Journal*, 48(2):594-615, 2023, https://doi.org/10.1111/1477-8947.12335.

Journal (communicated)

1. **Sarmah, T**. and Baruah, D.C. The prospect of a household biogas system to decarbonize the rural Indian cooking sector (*Energy Research and Social Science, Elseiver*)

Conferences :

1. **Sarmah, T.,** Baruah, D.C., Biogas as a preferred choice for cooking fuel: An analysis based on some case studies in Rural Assam (India), *8th International Conference on Sustainable Solid Waste Management, THESSALONIKI 2021, National Technical University of Athens*

2. **Sarmah, T.,** Baruah, D.C., Biogas as a source of farm power: An analysis based on some contemporary issues of rural agriculture *56th Annual Convention of Indian Society of Agriculture Engineers on Agricultural Engineering Innovation for Global Food Security, 2022*

3. **Sarmah, T.,** Rasul, I., Baruah, DC., Small-Scale Biogas System: Is it a Viable Rural Entrepreneurship in Rural India. *17th TSAE International Conference*, *Thai Society of Agricultural Engineering and The Asian Association for Agricultural Engineering, 2024*.

Book Chapter:

1. Patowary, D., **Sarmah, T.**, Sarma, G.D., Terang, B., Patowary, R. and Baruah, D.C., 2020. Economic Feasibility and Environmental Sustainability of a Community Scale Multi-component Bioenergy System. In *Energy Recovery Processes from Wastes* (pp. 237-250). Springer, Singapore.

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Chapter 1

Introduction

1.1 Importance of clean cooking fuels and its status in India

Energy poverty is defined as the "absence of sufficient choice in accessing adequate, affordable, reliable, high-quality, safe, and environmentally benign energy services to support economic and human development" [1]. Access to clean cooking fuel at the household level is essential to successfully eradicate energy poverty in rural communities worldwide [2]. The provision of clean cooking fuels to households is one of the main objectives of the Sustainable Development Goals (SDG) especially SDG 7 which "ensures access to affordable, reliable, sustainable, and modern energy for all" [3,4]. Traditionally, rural Indian cooking relies on solid biomass fuel such as fuel wood, dung cake, and residues which leads to adverse consequences for health due to indoor air pollution [2]. The impact of the traditional fuels which emit particulate matter (PM) and carbon monoxide (CO) is also alarming. Because of this, the total number of deaths attributed to household air pollution in India in 2019 was 0.8 million, of which 3 % were children under 5 years [5].

Fig 1.1: Access to clean cooking fuels and technologies in India and rural India [6]

1

IoT-BASED BIOGAS MANAGEMENT : TECHNOECONOMIC ANALYSIS FOR RURAL ASSAM (INDIA)

by Trinakshee Sarmah

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