

Perceptions of livestock farmers in turning manure into wealth leading to a circular bioeconomy in Uttarakhand, India

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Contents

List of Figures	4
List of Tables	4
1. Introduction	5
1.1. Objectives:.....	6
2. Data and Methodology	6
2.1. Study area	6
2.2. Sampling	8
2.3. Methodology.....	10
3. Socio-economic and demographic aspects	12
3.1. Overview	12
3.2. Results and discussion	12
3.3. Conclusion.....	16
4. Disposal of Animal Waste	17
4.1. Overview	17
4.2. Results and discussion	17
4.3. Conclusion.....	19
5. Perceptions and people's acceptance to installation and usage of Biogas system	19
5.1. Overview	19
5.2. Results and discussion	20
5.3. Conclusion.....	22
6. Understanding preferences of business models for wither using animal waste as soil nutrient or as an energy source (Biogas)	22
6.1. Overview	22
6.2. Results and discussion	23
6.3. Conclusion.....	29
7. Assessment of Government Scheme Penetration in Animal Waste Management and Associated Risk Behaviour among Farmers	30
7.1. Overview	30
7.2. Results and discussion	30
7.3. Conclusion.....	33
7. Synthesis	34
References	35
Annexture	0

List of Figures

Figure 1: Number of small-scale biogas plants (2500 m ³) installed in all the states and UTs of India	6
Figure 2: District wise proportion of livestock population in Uttarakhand state	7
Figure 3: Proportion of livestock farmers (%) belonging to different primary occupations	13
Figure 4: Proportion of livestock farmers (%) belonging to different primary occupations	13
Figure 5: Percentage of farmers using different animal waste disposal sites in the study area	17
Figure 6: Open dumping of animal waste	18
Figure 7: Frequency of animal waste disposal (in % of farmers)	18
Figure 8: Awareness on health impacts of improper management of animal waste among farmers (in % of farmers)	19
Figure 9: Major sources of energy used for cooking (in % of farmers)	20
Figure 10: Annual LPG cylinder consumption range reported by farmers	20
Figure 11: Factors motivating farmers to install biogas system in future (in number of farmers)	21
Figure 12: Main concerns related to using a biodigester system (in percentage of farmers)	22
Figure 13: Number of livestock farmers accepting different business models for better manage the animal waste	23
Figure 14: Reasons for not choosing either soil nutrient-based application or biogas generation using animal waste (in number of farmers)	24
Figure 15: Number of farmers reporting perceived advantages of choosing (a) Individual household level production (b) Community level production and (c) Cooperative level production business models	25
Figure 16: Number of farmers reporting perceived disadvantages of choosing (a) Individual household level production (b) Community level production and (c) Cooperative level production business models.	27
Figure 17: From Awareness to Implementation: Number of Farmers Involved in Animal Waste-Based Soil Nutrient Application Schemes	30
Figure 18: From Awareness to Implementation: Number of Farmers Involved in Animal Waste-Based biogas and bio-manure production Schemes	31
Figure 19: Factors influencing farmers' willingness of to take risks in adopting new technology (in % of farmers)	32

List of Tables

Table 1: Socio economic characteristics of livestock farmers as adopters and non-adopters based on using animal waste as soil nutrient or not.	15
Table 2: Preferences of livestock farmers for business models for effective management of animal waste	23
Table 3: Multinomial Logistic Regression to identify perceived advantages significantly influencing preferences of different type business models.	27
Table 4: Association between Risk acceptance and willingness to technology adoption	32

1. Introduction

'Livestock' a major player in the Indian economy has shaped livelihoods of millions of people for centuries and it remains as an integral part of Indian culture, supporting agriculture and economic activities. Accounting for 25 percent of global output with an annual production of 239 million tonnes, livestock sector has recorded an impressive CAGR of 12.77 percent in recent years that contributes 31 percent to agricultural Gross Value Added (GVA) and 5.5 percent to the national economy (*PIB, 2025*). Along with ensuring prosperity, growing livestock population has become a cause of concern due to improper animal waste management approaches. India currently produces an estimated 3 million tonnes of livestock waste annually from a population of over 535 million livestock (*Team Pashudhan Praharee, 2022*). More than 50 percent of the animal waste generated is disposed of in the environment as a result analysis on outbreaks by India's Integrated Disease Surveillance Programme (IDSP) reveals that, 8.3 percent of the total outbreaks were zoonotic diseases (*Mogan et al, 2025; Kaviprawin et al., 2025; Priya et al, 2020*).

Conversely, piling up animal dung along with kitchen, field, and other waste is a common practice, this contains dung, urine, bedding material, and feed leftovers, and are stored without cover, contributing to greenhouse gas emissions, nutrient loss, and posing risks to both human and environmental health. Dung cakes on the other hand are culturally valued in Indian cooking, where 92 percent of surveyed households in rural parts of North India use dung cakes as a major source of fuel for cooking (*Aashish Gupta et.al, 2020*). Emissions from cooking using dung cakes, charcoal, and wood are linked to [more than 2.6 million](#) premature deaths each year and cause deadly chronic and acute health effects such as child pneumonia, cancer, cataracts, and heart disease (*UN Foundation, 2017*). In India household air pollution contributes up to 30 percent of outdoor air pollution.

In nutshell methane emissions from animal waste have risen from 0.28 teragrams per year (Tg/yr) in 2003 to 1.11 Tg/yr in 2019 (*Anuja et al, 2024*). Animal waste alone accounts for approximately 9.54 percent of the total methane emissions from livestock in the country. Improper management of it can lead to significant environmental degradation, affecting soil, water, and air quality (*Naturinda et al., 2025; Erisman et al., 2008*).

Proper incorporation of the concept of circular economy in livestock would create a more climate resilient ecosystem in the realm of exponentially growing human population, rising energy prices and climate change concerns of the country to ensure positive externalities in water, food and energy domains for self-sufficient and sustainable bionetwork. This includes generating bioenergy from livestock waste such as biogas and biofuels, which can substantially contribute to reducing fossil fuel dependence and support rural livelihoods.

India's bioenergy sector, including advanced biofuels and compressed biogas (CBG) production from agro-residues and livestock waste, is a key component of this strategy. Government initiatives like the Ethanol Blending Program, SATAT (Sustainable Alternative Towards Affordable Transportation), National Biogas and Manure Management Programme (NBMMP) and Galvanizing Organic Bio-Agro Resources Dhan (GOBAR-DHAN) schemes are central to promoting bioenergy, manure production and circular bioeconomic practices, enabling India to work toward a cleaner and self-reliant energy future by 2047. Under Animal Husbandry Infrastructure Development Fund (AHIDF) 3% interest subvention is provided to eligible entities for establishment of Animal Waste Management units like production of PROM, Bio CNG and infrastructure development for cow dung/cow urine processing units (*PIB, 2025*). The Department of Animal Husbandry and Dairying through National Dairy Development Board (NDDB) is promoting eco-friendly practices in the dairy sector by actively collaborating with the Central/ State Governments, dairy cooperatives, and various institutional stakeholders.

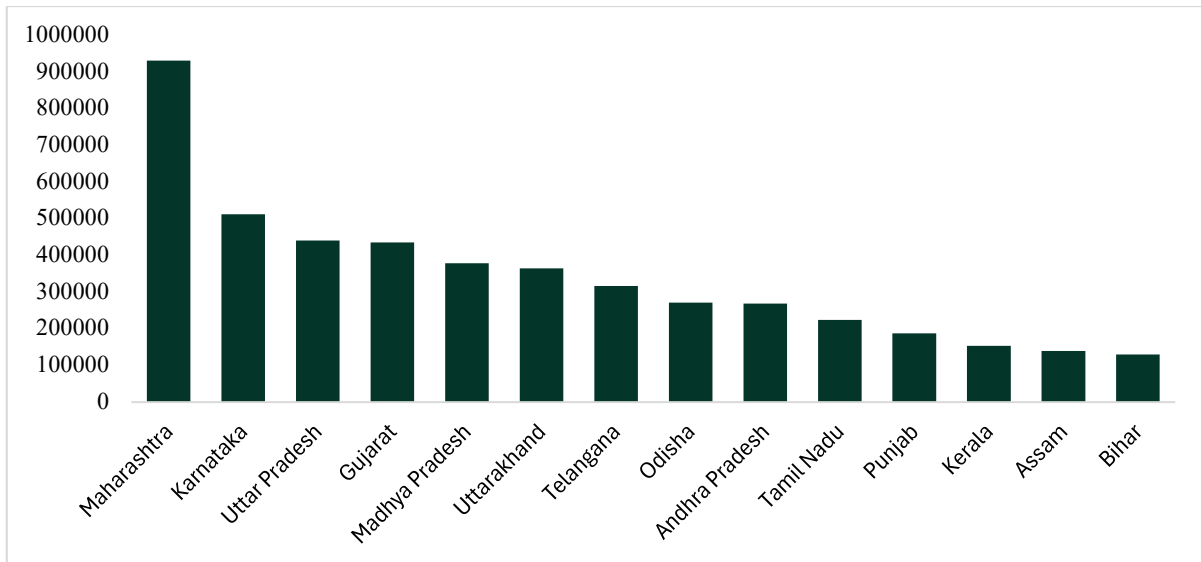


Figure 1. Number of small-scale biogas plants (2500 m³) installed in all the states and UTs of India

Source: data.govt.in, 2022 (Digital India Initiative)

Despite government initiatives to promote a circular economy with a strong emphasis on energy generation through biogas plant installations, achieving deep penetration in rural India remains a challenge due to various financial, institutional, social, market, technical, and infrastructure-related barriers (Kush Sagwadia, 2018). The accompanying graph above (Figure 1, data in the Annexure I) presents a picture on the implementation of small-scale biogas plants (1–25 m³/day) across different states and union territories, clearly illustrating significant disparities in installation rates. These small scale biogas plants were installed through New National Biogas and Organic Manure Programme (NNBOMP) and Biogas Power Generation (Off-grid) and Thermal Energy Application Programmes. In reference to large scale biogas plants (>25 m³/day) in 2018 SATAT came with ambitious target of setting up 5000 large scale biogas plants (>25 m³/day) to produce compressed biomethane gas (CBG) by 2023, but in reality, until August 2025 only 113 biogas plants have been commissioned in India (Pankaj & Sonal, 2025; Garkoti & Thengane, 2025) indicating the gaps between policy and on ground implementation highlighting the importance of addressing barriers in dissemination and installation. Therefore, understanding people's and entrepreneurs' perceptions about animal waste management either for biogas production or as soil nutrients is crucial from a policy perspective becomes precursory step in the implementation. In this context, the current study has established four objectives covering different viewpoints, including those of households, interests in various business models, and policy considerations.

1.1. Objectives:

- To assess the performance and scalability of business models for livestock waste management, with a focus on recovering (i) biodigester-based energy and biofertilizer, and (ii) soil nutrients/conditioners.
- To analyze the socio-economic and institutional factors that influence the success or failure of biodigester models across different regions, particularly in areas like the Song River basin.
- To analyze stakeholder preferences and perceptions regarding alternative livestock waste recovery models, identifying barriers and enablers to adoption at household, cooperative, and community levels.
- To identify policy and investment interventions required to support the sustainable and inclusive uptake of livestock waste recovery solutions.

2. Data and Methodology

2.1. Study area

The study conducted in the Song River Basin of Uttarakhand, which covers upstream hilly Dehradun and downstream plains Hardwar districts, also intersects with critical pollution issues that influence river health. The

Song River is a tributary of the Ganges and flows alongside the Suswa River basin, with all these rivers eventually merging into the Ganges. Pollution in these rivers is a significant concern, especially downstream. Studies show the Song and Suswa rivers suffer from contamination primarily due to anthropogenic activities such as untreated industrial effluents, municipal sewage discharge, agricultural runoff, and improper animal waste disposal (*Shruti et al., 2023 & Quamar et al., 2025*). Hence, acknowledging the river's vital position as a tributary to the Ganges, a river of considerable ecological and cultural importance, we have tried to assess need for integrating river water quality management through sustainable biogas and soil nutrient initiatives in the region.

In addition to water pollution, livestock population was a key consideration in the site selection process. Livestock census data highlights the distribution of various types of animals across districts in Uttarakhand. Focusing on major cattle species such as cows and buffaloes, the top three districts in terms of livestock population are Pauri Garhwal, Dehradun, and Haridwar (Figure 2). Since both Dehradun and Pauri Garhwal are located in the uphill region, Dehradun was chosen to represent the upstream zone, while Haridwar was selected from the downstream region for comparative analysis.

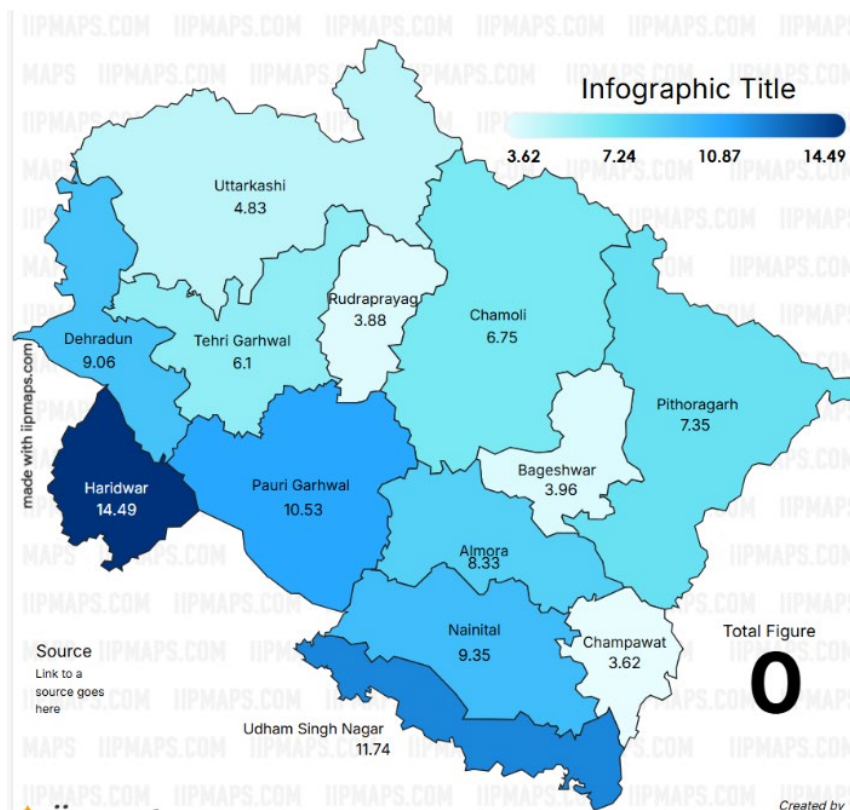


Figure 2. District wise proportion of livestock population in Uttarakhand state

Source: Livestock census data 2019

Rationale for Selection of study blocks in Dehradun and Haridwar Districts

To gain a more granular understanding of livestock waste management practices and the potential for adopting circular economy business models, the study further narrowed its focus to specific blocks within the selected districts of Dehradun and Haridwar. The block-level selection was guided primarily by the livestock population, particularly the number of cattle (both indigenous and cross-bred cows) and buffaloes as these directly influence the volume and type of livestock waste generated, and thus, the feasibility of biodigester-based and soil nutrient recovery models.

In **Dehradun district**, two blocks were selected considering the composition of different livestock population (Annexure II).

Dehradun Block: This block has one of the highest populations of cross-bred cows (33,989) and a significant number of buffaloes (14,687), making it a high-potential site for biodigester-based systems due to the consistent and high-yielding waste generated from these animals (Annexure II).

Vikasnagar Block: With 23,869 indigenous cows and 18,349 cross-bred cows, Vikasnagar stands out as a densely livestock-populated area. The diversity in animal type and sizeable waste generation makes it a suitable site for exploring both energy recovery and soil nutrient recovery models (Annexure II).

In **Haridwar district**, the following two blocks were selected:

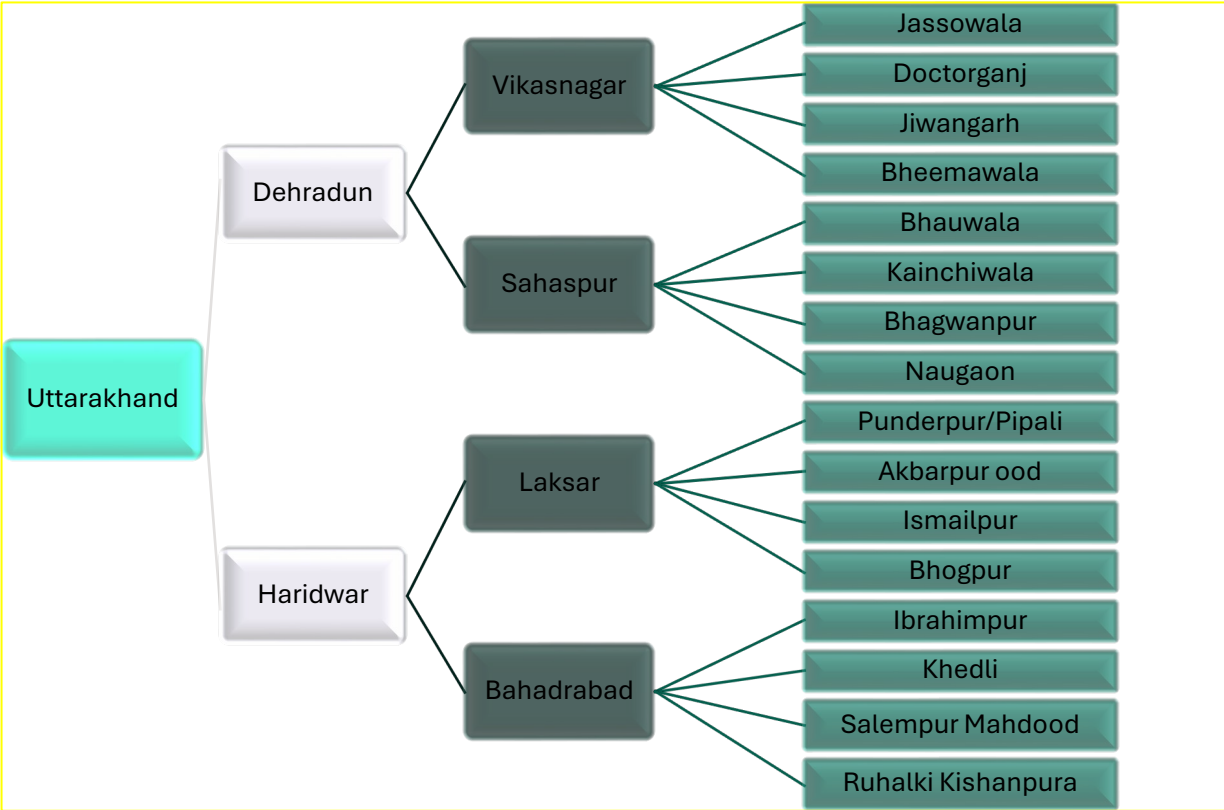
Bahadrabad Block: This block has the highest livestock count among all blocks considered, with 124,670 total livestock, including 51,758 crossbred cows and 48,117 buffaloes. This volume presents a strong case for implementing large-scale, cooperative level biodigester systems (Annexure II).

Laksar Block: Laksar also shows high livestock density, with 23,006 crossbred cows and 31,409 buffaloes. It provides a contrasting socio-economic context to Bahadrabad while still maintaining significant potential for livestock waste recovery initiatives (Annexure II).

Together, these blocks represent a strategic mix of upstream and downstream geographies, varied livestock composition, and differing implementation contexts - allowing the study to explore a wide range of operational, social, and institutional factors influencing livestock waste management in the Song River Basin.

Selection of villages

It has been decided to cover 4 villages from each block. The villages have been selected where the density of farmers with livestock is high. The information has been collected by engaging discussion with local people and PRI members of the respective blocks. Thus, the following villages have been selected in each block of the 2 districts.



2.2. Sampling

Total survey of 597 respondents were conducted. Selected samples are distributed proportionally based on the rural population share of the two selected districts. According to the latest population data, 42 percent of the sample was drawn from Dehradun district and the remaining 58 percent from Haridwar, reflecting their respective contributions to the total rural population of the study area.

District	Block	Village and percent of total sample from each village in a Block		
Dehradun – 42%	Vikasnagar – 50%	Jassowala	25%	
		Doctorganj	24%	
		Jiwangarh	27%	
		Bheemawala	24%	
			N=127	
	Sahaspur – 50%	Bhauwala	38%	
		Kainchiwala	25%	
		Bhagwanpur	20%	
		Naugaon	17%	
				N=126
Haridwar – 58%	Laksar – 47%	Punderpur/Pipali	27%	
		Akbarpur ood	27%	
		Ismailpur	19%	
		Bhogpur	27%	
				N=161
	Bahadrabad – 53%	Ibrahimpur	24%	
		Khedli	23%	
		Salempur Mahdood	30%	
		Ruhalki Kishanpura	23%	
				N=183

Questionnaire

A well-structured questionnaire including 12 sections to address the study objectives was prepared. Along with the household survey, Knowledge, attitudes, and practices (KAPs) study among farmers and cooperative to understand livestock waste management and qualitative interviews with Government agencies, NGOs, and private sector stakeholders to understand the preference of soil nutrient-based application or biogas-based models of animal waste management were conducted.

List of stakeholders of qualitative discussions are given below.

Key informant interviews with the following stakeholders

1. Companies supplying biodigester units and composting technologies
2. Renewable energy companies (biogas developers)
3. Organic fertilizer companies
4. Agri-tech startups focused on livestock waste solutions
5. Agricultural Universities
6. Livestock Research Institutes
7. Climate Change and circular bio economy Think Tanks
8. Environmental advocacy groups
9. Organizations providing carbon credit certification services
10. Platforms linking farmers to voluntary carbon markets

In addition to that, focused group discussions have been conducted with the farmers group who have experience of using biogas plant and also those who have not used biogas plant.

Recruitment and training of field survey team (Enumerators)

Data collection was carried out by a team comprising 12 interviewers and 2 supervisors. After finalization of the questionnaire, a three-day training program was conducted from July 31st to August 1st at Dehradun. This training ensured all team members were well-prepared for the fieldwork and familiar with the survey instruments.

Two-day training program commenced with a brief presentation by IWMI staff (Dr. Deepa MPM), followed by comprehensive training on administering the questionnaire using Android-based mobile devices. A pilot testing of survey was conducted in presence of IWMI staff to understand and address the difficulties faced by enumerators

and duration of the survey. After this from 3rd August to 18th August 2025. A team of 12 interviewers and 2 supervisors have been deployed to complete the work in a timely manner.

Some images of the training and pilot testing of the survey form are given below.

Day 1 training



Day 2 training



Field testing in day 2



2.3. Methodology

Descriptive statistics were used as a common method to evaluate central tendency, variability, and distribution patterns, while also improving the visualization and interpretation of the data.

Multinomial logistic regression was employed to identify perceived advantages significantly influencing preferences for various livestock waste management business models, with the individual household-level production serving

as the baseline category. The dependent variable was the preferred business model, categorized into individual household, community-level, and cooperative-level production.

The model equation is: eq (1)

$$\log \frac{P(Y = j | X)}{P(Y = J | X)} = \beta_0j + \beta_1jX_1 + \beta_2j X_2 + \dots + \beta_{pj}X_p, \quad j = 1, \dots, J - 1 \quad \dots \dots \dots \text{eq (1)}$$

X=(X1,X2,...,Xp) are the independent / predictor variables. These predictor variables included perceptions related to decision-making autonomy, trust, availability of animal waste, profit sharing, operational costs, access to locally produced energy, collective waste management, community support, resource availability, job creation potential, risk sharing, production scale, market reach, utilization of animal waste, financial assistance, and social bonding.

Statistical significance of predictors was evaluated through z-values and p-values, with results indicating which factors are positively or negatively associated with preferences in different business model categories. Significance levels were reported at 1%, 5%, and 10%, guiding the interpretation of influential factors and providing insights for policy and implementation strategies.

A non-parametric Mann-Whitney U test and Fishers Exact tests were employed to compare the means of socioeconomic and demographic variables between adopters and non-adopters.

The association between willingness to adopt new livestock waste management technologies and varying levels of self-perceived risk acceptance was examined using Pearson's chi-square test of independence. This non-parametric statistical test assesses whether a significant relationship exists between two categorical variables—in this case, risk acceptance levels classified as high, moderate, and low, and responses to statements measuring willingness to adopt technology. Chi-square values and corresponding p-values were computed for each statement to evaluate the strength and significance of the association. This analysis provides key insights into behavioural factors affecting technology uptake in rural settings.

3. Socio-economic and demographic aspects

3.1. Overview

Livestock forms an essential part of rural livelihoods, local economy and agricultural systems in Uttarakhand, with diverse indigenous breeds adapted to its unique agro-climatic conditions. With 74 percent of population residing in rural area, agriculture and animal husbandry form the core livelihood and economic activities for over 70 percent of Uttarakhand's population, reflecting the state's rich endowment of diverse livestock and their crucial role in enhancing the well-being of its people (*Department of Animal Husbandry, Uttarakhand, 2025 & Kamal Singh and H.S Singh, 2007*).

The *Livestock population census 2019* shows that cattle and goats are the most populous livestock categories across most districts, reflecting significant buffaloes' population in the plains (Annexure III). Districts like Pauri Garhwal and Dehradun have high cattle and goat populations, supporting rural livelihoods with dairy and meat production. Buffalo population is very prominent in Haridwar and Udham Singh Nagar, which are mainly plain areas suitable for buffalo rearing. Sheep and goat populations are particularly large in hilly districts such as Pithoragarh, Chamoli, and Uttarkashi, indicating small ruminants' importance in rugged terrains.

This chapter explores the socio-economic and demographic dimensions influencing livestock management practices, particularly focusing on the adoption of sustainable technologies such as biogas systems and animal waste reuse as a soil nutrient. Through detailed field studies from districts this chapter seeks to present a nuanced understanding of how demographic patterns, occupational structures, and resource availability shape livelihoods and technology adoption in Uttarakhand.

3.2. Results and discussion

Study carried out in Dehradun and Haridwar Districts of Uttarakhand with the sample size of 597 depicts various aspects of the population with respect to animal waste management, socio-economic and institutional factors that influence use of animal waste as a soil nutrient or a biogas.

Frequency analysis of their occupation depicts that Animal Husbandry dominates as a secondary occupation (63%), much higher than its representation as a primary occupation (19%) (*Figure 3 & Figure 4*). This suggests many farmers supplement their main source of income with livestock-related work. 41 percent of the farmers are engaged in farming activity as a primary occupation. The link between primary and secondary occupations illustrates a dual livelihood strategy for many livestock farmers, with animal husbandry playing a vital secondary role. 63 percent of sample farmers are directly involved in livestock rearing, which creates opportunities and motivation to adopt animal waste management technologies. Farmers primarily engaged in cultivation may adopt animal waste reuse practices differently from those whose primary or secondary occupation is animal husbandry, as their familiarity and direct use of animal waste can vary.

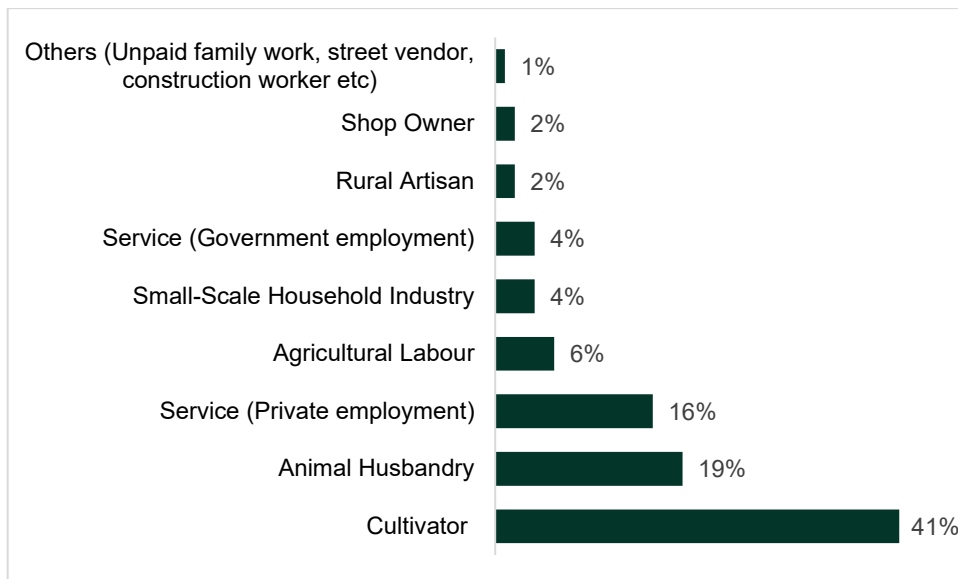


Figure 3. Proportion of livestock farmers (%) belonging to different primary occupations

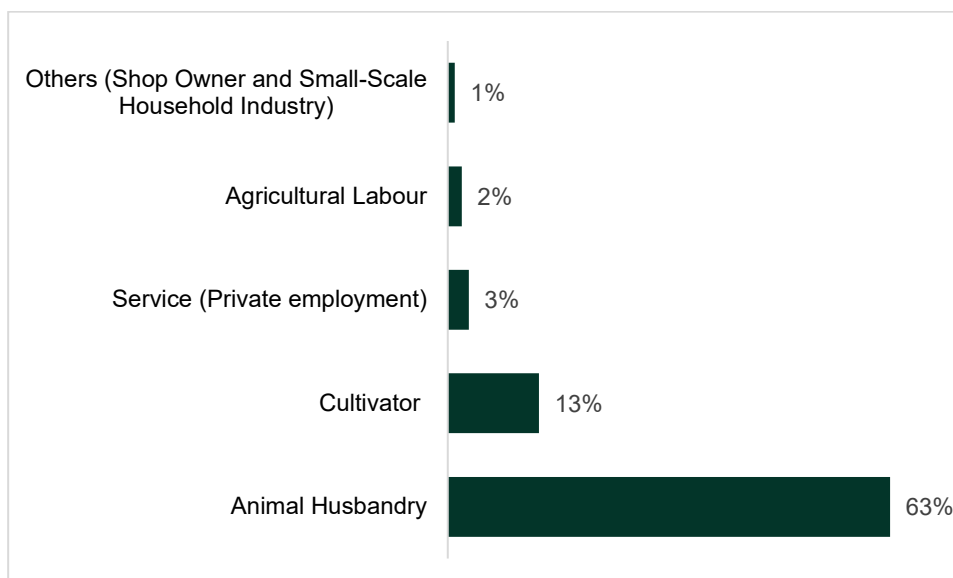


Figure 4. Proportion of livestock farmers (%) belonging to different primary occupations

The relatively lower involvement in government service (4 %) and private employment (16 %) in primary occupation and (3 % in private sector) in secondary occupations respectively suggests less reliance on formal sectors. This occupational pattern likely influences farmers' knowledge, engagement, and adoption of animal waste management technologies, with those more involved in livestock as either primary or secondary occupations are more readily adapting technologies to their livelihood needs. This occupational structure highlights the need for tailored outreach and training approaches that consider the diverse primary and secondary livelihood roles surrounding animal husbandry and crop cultivation.

Since use of animal waste as soil nutrient and/or biogas technologies were focused, collected data was observed to identify number of individuals using animal waste as soil nutrient (though composted in a very local context), individuals disposing animal waste and those neither dispose nor use as soil nutrient on farm but give it to the neighbouring households based on the demand. The data showed that 460 individuals (77%) utilized animal waste as a soil nutrient, 84 disposed of it (14%), and 53 shared it with their neighbours (9%). There were no formal or verbal agreements between livestock farmers and neighbours for selling compost; however, such informal systems are common in rural areas based on neighbourly relationships. There were seven households among the 460 samples who use animal waste as soil nutrient that had biogas unit installed in the house yard.

Through animal waste we get natural manure which we can use in our fields. Once we apply natural manure, the soil remains fertile for 3 to 4 years. But if we use chemical fertilizers like urea, they last only 1 to 2 months – Farmers FGD in Haridwar.

Since a larger number of households have adopted the technology of using animal waste as a soil nutrient, the samples were categorized into adopters and non-adopters to facilitate further technical and economic analysis. Table 1 compares the Socio-economic characteristics of the adopters and non-adopter categories using non-parametric tests.

The mean value for the gender dummy variable is significantly lower in adopters (0.15) than in non-adopters (0.37), with a p-value of 0.00, indicating a statistically significant difference. This suggests a different gender composition between adopters and non-adopters, indicating more males among adopters. Adopters have a higher average age of 50.72 years compared to non-adopters i.e. 46.29 years, with this difference being statistically significant ($p=0.01$) indicates that experienced farmers with higher age are more inclined to use animal waste as soil nutrient rather than disposing. Farming and livestock variables show that adopters have much larger agricultural land holdings (17.14 Bhiga vs 0.65 Bhiga) and more livestock (4.17 vs 3.98), both significant at $p=0.00$ and 0.01 respectively, indicating that readily available resource may influence adoption as no extra efforts have to be put to buy and apply on field incurring transportation costs as well. The availability of dung combined with the presence of large agricultural lands creates a complementary relationship, providing farmers with an incentive to apply animal waste to their fields to enhance soil quality and boost crop productivity. Nonadopters have slightly more awareness about government schemes, but availability of the land is the major constraint to focus more on using animal waste on farm, but adopters have significantly higher cooperative membership (0.16 vs 0.01, $p=0.00$), which may facilitate adoption of technologies through social networks or support. With inherent advantage of having larger land area for crop cultivation farmers in adopter category are able to undertake intensive agricultural activities with minimum of two crops per annum and are able to spend more on fertilizer and Farmacyard manure (FYM) application indicating that, adopters are economically better off and more invested in farm inputs to get good returns.

Whereas variables i.e. education years, family size, livestock waste management training, outstanding loan amount, and presence of bank account, with no significant test value indicate that, these do not differentiate adopters from non-adopters. The significant p-values (at 1% Significance) indicate that adopters and non-adopters differ substantially on many socio-economic and farm characteristic variables. Adopters tend to be older, have larger land and livestock holdings, participate more in cooperatives, and have higher economic capacities (expenditure, income). This analysis suggests that adoption of animal waste application as soil nutrients is strongly associated with better resource access, cooperative membership, and economic investment in farming, which may facilitate adoption decisions.

Table 1. Socio economic characteristics of livestock farmers as adopters and non-adopters based on using animal waste as soil nutrient or not.

Variable	Adopters		Non-adopters		Non-Parametric test ^a
	Mean	SD	Mean	SD	p value
Gender (dummy)	0.15	0.36	0.37	0.49	0.00***
Age (Years)	50.72	15.15	46.29	13.54	0.01***
Scheduled tribe (dummy)	0.05	0.22	0.04	0.19	0.78
Scheduled caste (dummy)	0.15	0.36	0.32	0.47	0.00***
Other backward classes (dummy)	0.54	0.50	0.38	0.49	0.00***
General (dummy)	0.26	0.44	0.26	0.44	1.00
Education (years of schooling)	7.40	4.84	7.12	5.73	0.67
Agriculture land (Bhiga)	17.14	16.15	0.65	3.51	0.00***
Family size (numbers)	5.13	1.77	4.99	1.75	0.46
Number of livestock (numbers)	4.17	2.68	3.98	3.36	0.01***
Awareness about government schemes (dummy)	0.59	0.49	0.69	0.47	0.08*
Membership in cooperative (dummy)	0.16	0.37	0.01	0.11	0.00***
Training on livestock waste management (dummy)	0.02	0.14	0.02	0.15	0.68
Outstanding loan amount (Rs.)	22232.61	65909.86	8738.10	37592.01	0.22
Presence of Bank account (dummy)	0.91	0.29	0.86	0.35	0.16
Scale of FYM production (Tonns/year)	3828.04	1149.98	0.00	0.00	0.00***
Expenditure on Fertilizer (Rs.)	3667.05	8333.45	14.29	130.93	0.00***
Expenditure on FYM (Rs.)	1605.56	6469.11	72.50	371.04	0.00***
Number of crops grown (numbers)	1.83	0.96	0.12	0.45	0.00***
Household monthly expenditure (Rs.)	15971.55	10870.58	14065.01	10946.11	0.00***
Outcome variable					
Household monthly income (Rs/month)	30782.61	13493.18	25630.95	11153.67	0.00***

^a Mann-Whitney test and Fisher exact test used for continuous and nominal variables, respectively

*Significant at 10% level, **Significant at 5% level, ***Significant at 1% level.

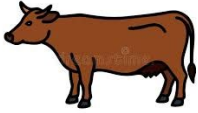
In our region, almost all we keep cow/buffalos. In our community, we don't keep any other animals as that's not considered good. We only have cows/buffalos. Since last 5 years, the number of domestic animals is reducing as the cost of animal feed has gone up significantly. However, on the other hand, earlier there were more animals, though milk production was less since we had indigenous breeds. Now, new breeds like Holstein, Friesian, Jersey, and Sahiwal have improved milk yields to 15–20 liters per cow. Overall, the milk price in villages has not grown significantly – Farmers FGD in Sahaspur.

Livestock statistics of sampled households



Cross-breed cows

About 91% of households maintain small herds of 1–5 animals, with very few exceeding 10. This reflects household-level dairy rearing rather than commercial-scale operations.



Local cows

Similarly, nearly 92% households keep 1–4 animals, showing consistency across both districts, though Haridwar households tend to have slightly larger units.



Buffaloes

The majority (98% overall) keep between 1–10 animals, but Haridwar has a small fraction (1.9%) with herds above 20, suggesting occasional larger dairy operations.



Oxen

Households typically own 1–2 oxen, with Dehradun showing slightly fewer than Haridwar.

3.3. Conclusion

The socio-economic and demographic characteristics of livestock farmers in Uttarakhand significantly influence the adoption of sustainable practices related to animal waste management and resource recovery. Larger landholdings, greater livestock numbers, and cooperative memberships emerge as key facilitators among adopters, who also tend to be older and more economically invested in their farming activities. The dual livelihood strategy, with animal husbandry often serving as a secondary occupation, highlights the intricate balance farmers maintain between crop cultivation and livestock rearing. With government schemes awareness varying but land availability being a major constraint, targeted interventions that consider these socio-economic realities can enhance the adoption of biogas technology and promote sustainable agricultural practices. Ultimately, improving access to resources, strengthening cooperative networks, and aligning technological solutions with livelihood needs are critical to fostering resilient and environmentally sustainable rural economies in Uttarakhand.

4. Disposal of Animal Waste

4.1. Overview

In India, disposal of animal waste into water bodies is a significant environmental concern, particularly in rural areas where livestock rearing is a major livelihood activity. Studies have unfolded the hazards of faecal contamination of surface and groundwater in India due to improper disposal of livestock manure (*Shakya et al. 2022*). Likewise, livestock waste and agricultural runoff are major contributors to non-point source water pollution, often exceeding WHO drinking water standards for nitrates and faecal coliforms (*Raj, 2023*). This widespread pollution exacerbates waterborne diseases, which have a higher prevalence in rural regions due to inadequate sanitation and waste management infrastructure. This chapter explains about household's awareness about disposal of animal waste, frequency of disposal and associated health risks due to it.

4.2. Results and discussion

The survey data shows that 14% of households do not utilize their animal waste and instead dispose of it directly. Among these households, the most common disposal sites are open grounds (62%), followed by dump yards outside the village (14%) and nearby water bodies (13%) (Figure 5). Disposal of animal waste on open grounds and in water bodies has a significant impact on environmental and communities. Study by *Evet et al. (2025)* in Africa region has shown that CH₄ emissions related to manure management were estimated to be 71.82 kg CH₄ per year.

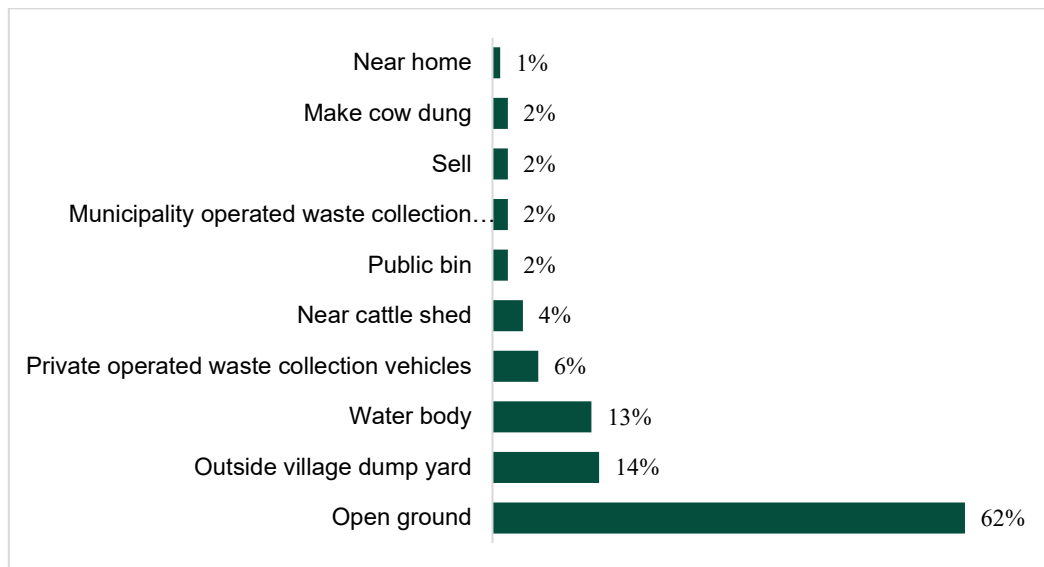


Figure 5. Percentage of farmers using different animal waste disposal sites in the study area

Open dumping (Figure 6) on ground may lead to release of nutrients such as nitrogen and phosphorus which may accumulate in the soil, raising the likelihood of leaching into groundwater and runoff into surface waters, which can potentially contaminate drinking water sources. Putting of animal waste in water bodies leads to nutrient pollution, especially nitrogen and phosphorus, causing eutrophication of surface waters which leads to oxygen-depleted "dead zones" harmful to aquatic life. It also carries pathogens and antibiotics contaminating drinking and irrigation water sources, increasing disease risks (*Inciner8 Blog, 2024*). Such improper management and disposal of animal waste may spread fecal pathogens and antimicrobial resistance, posing direct threats to humans and animals through contaminated water and food chains (*World Bank, 2024*).



Figure 6. Open dumping of animal waste

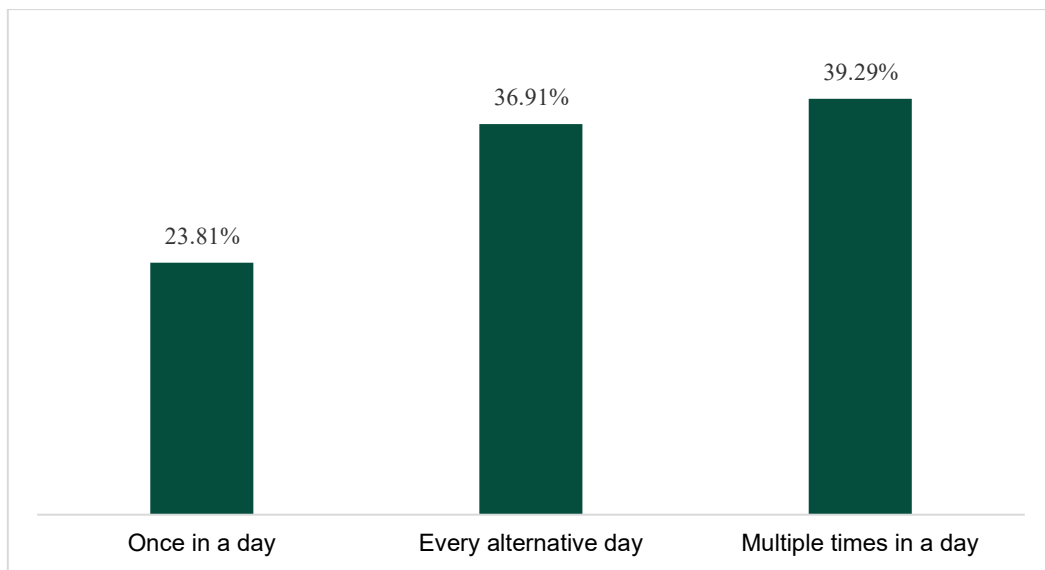


Figure 7. Frequency of animal waste disposal (in % of farmers)

Among the households that dispose of animal waste (14% of the sample), 39% reported disposing of waste multiple times per day (Figure 7). Such frequent disposal, often into open areas or water bodies, not only poses environmental risks but also results in the loss of a potentially valuable resource that could be converted into energy or used to enhance soil quality through proper composting.

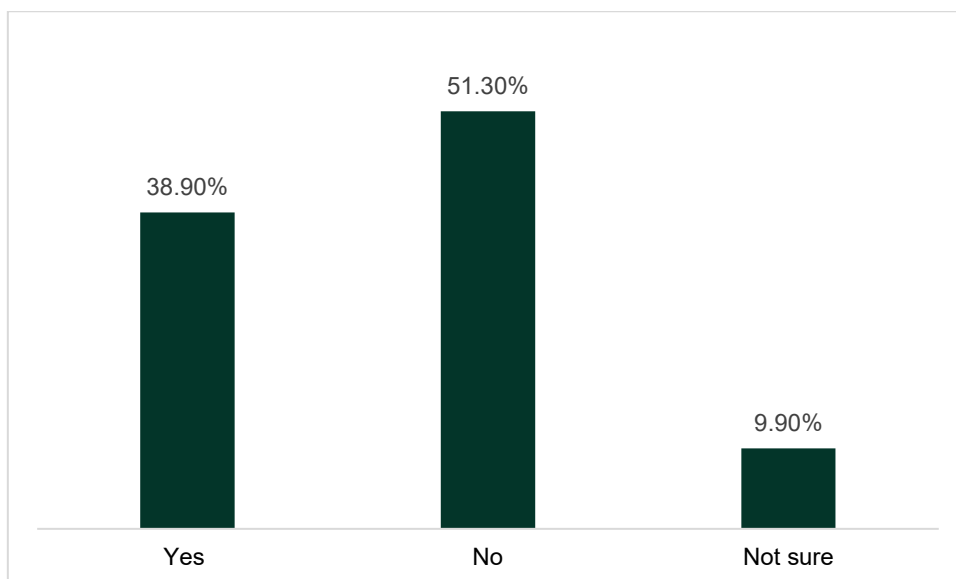


Figure 8. Awareness on health impacts of improper management of animal waste among farmers (in % of farmers)

A significant concern related to the unplanned disposal of animal waste is the widespread lack of awareness about its potential health hazards. Around 52 percent of the households surveyed were unaware that improper management and use of animal waste can lead to serious health issues (Figure 8). In contexts like India, livestock dung holds cultural significance and is traditionally respected; however, this cultural value often overshadows the risks associated with poorly managed waste.

“In and around Uttarakhand, most farmers dump animal dung directly in the fields before the crop season, without proper composting. This leads to nutrient loss, and the dung they apply is not well-decomposed. To address this, we introduced proper composting techniques — we built compost pits and provided mobile compost units made of HDPE. Now, farmers have adopted composting on a large scale. Around 130 farming families have adopted this composting technology. They are now preparing compost instead of dumping dung directly on the field”

– Soil nutrient specialist, ICAR

4.3. Conclusion

Hence, creating widespread awareness about proper handling and use of animal waste along with adoption of better animal waste management aspects through anaerobic digesters (Biogas units) and better nutrient management via composting plays key role in safeguarding animal, human and environmental health. Such grassroot level adoption and impact calls for clear and strict regulatory enforcement.

5. Perceptions and people’s acceptance to installation and usage of Biogas system

5.1. Overview

Biogas, a renewable form of green energy, holds significant potential to reduce greenhouse gas emissions and fulfil the clean energy needs of households, especially in remote areas. Recognizing its importance, both the Government of India and the Uttarakhand state government have been actively promoting biogas through policy support and on-ground installations. Uttarakhand alone has seen the installation of approximately 3.6 million small-scale biogas units. However, there is limited data on the operational efficiency of these systems and ongoing efforts to resolve field-level issues.

Simultaneously, the subsidized supply of liquefied petroleum gas (LPG) poses challenges by potentially undermining the uptake of biogas as a clean cooking fuel. This chapter explains the level of understanding of

households regarding functioning of biogas system along with exploring contradicting policy interventions competing with the clean energy interest.

5.2. Results and discussion

LPG is the most widely used cooking fuel (97%), indicating broad access or policy-driven penetration of cleaner fuels. Among these LPG-using households, 62% reported receiving LPG at subsidized prices, which helps reduce their cooking fuel expenses. Further, 36% of LPG-using households consume 10 to 12 cylinders per year, indicating effective subsidy penetration and regular usage patterns (Figure 10). More than half the households use dung cakes (56%) and half use firewood (50%) often alongside LPG, suggesting significant fuel stacking (Figure 9). Despite being a renewable and clean option, biogas adoption is extremely low.

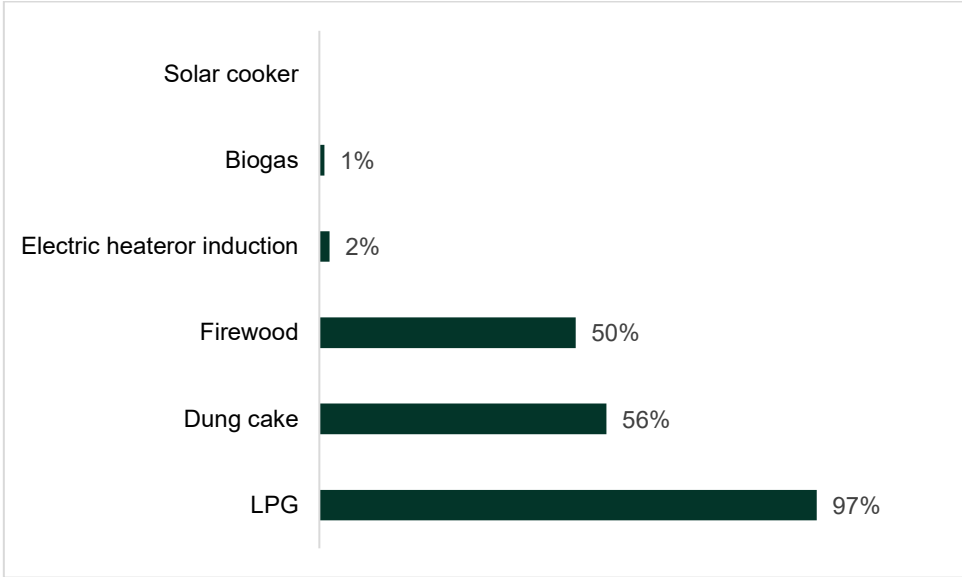


Figure 9. Major sources of energy used for cooking (in % of farmers)

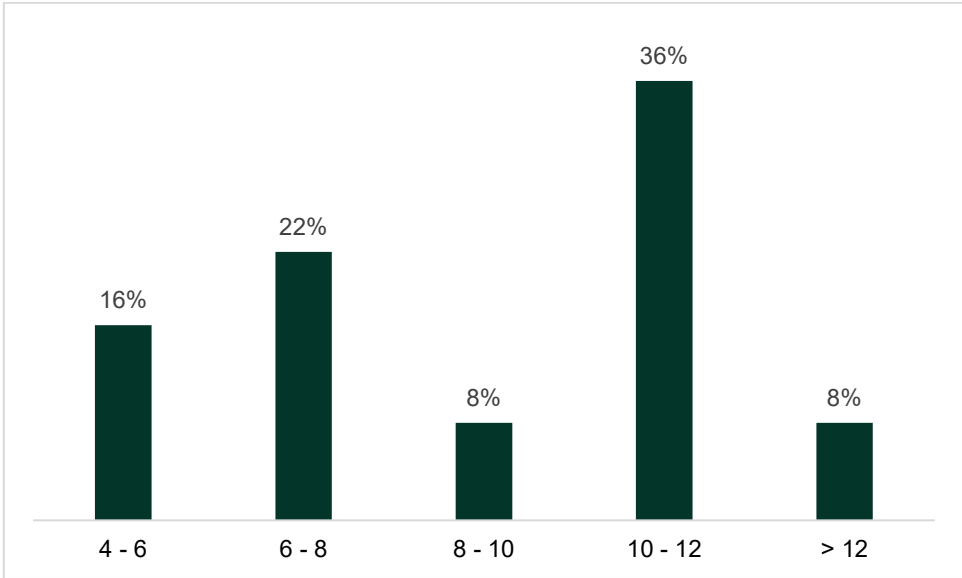


Figure 10. Annual LPG cylinder consumption range reported by farmers

However, 17% of households indicated that they would prefer to use biogas in the future as a way of managing their animal waste. Among these biogas-interested households, 27% are fully aware of how a biodigester functions, 46% are somewhat familiar, and 19% reported having no knowledge of system functioning. Even with these varying levels of awareness, over 90% expressed a willingness to install a biogas system, and Figure 11 presents the reasons behind this interest.

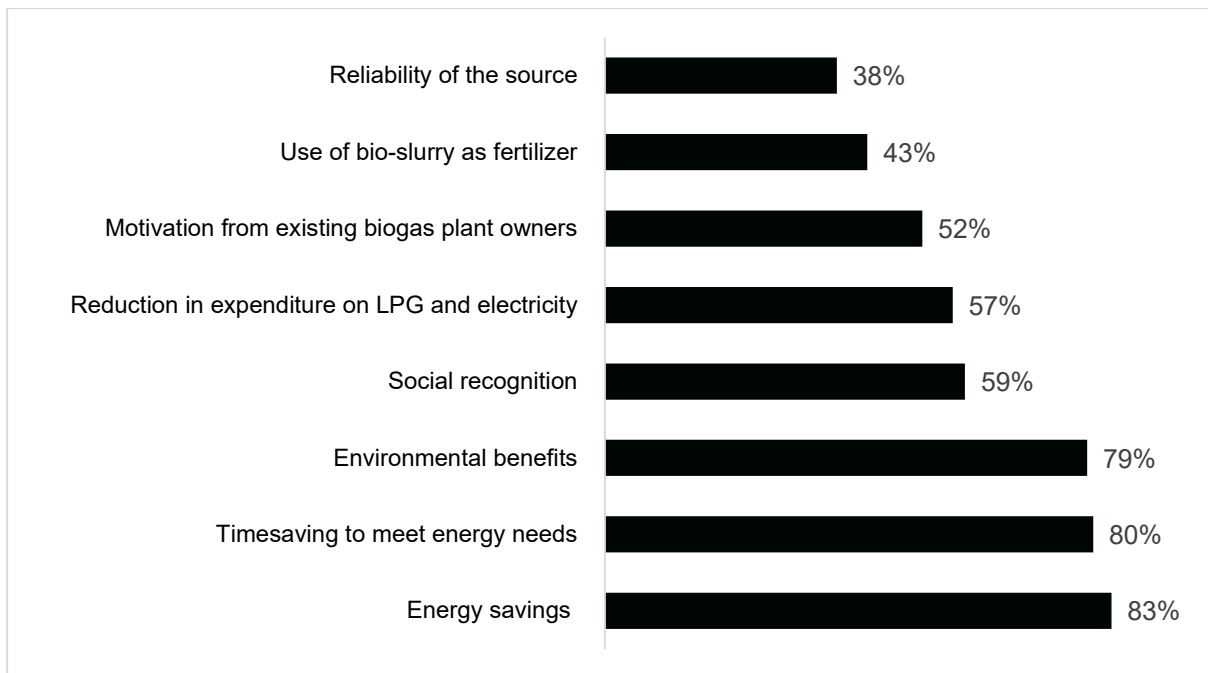


Figure 11. Factors motivating farmers to install biogas system in future (in % of farmers)

The main challenge with biogas is the initial installation cost — that’s often why people hesitate to adopt it. Once it’s set up, there’s no major expense; you just need to feed it regularly with cow dung and water to prepare the slurry, which then produces gas. However, during certain periods, gas productivity decreases slightly. To address that, one can either install a slightly larger biogas unit or add a storage tank to store excess gas produced during high-output periods. That stored gas can then be used later when production drops.

– Farmers FGD in Dehradun, Sahaspur.

Future adoption of biogas in the study area is driven by a combination of practical benefits (energy savings, time efficiency), economic savings, and social-environmental incentives. Farmers reported multiple factors encouraging interest in biogas (Figure 11). Energy-related benefits emerged as the strongest motivators: over four-fifths cited energy savings (83%) and timesaving in meeting energy needs (80%). Environmental benefits were also widely acknowledged (79% overall), showing that households recognize biogas as a clean energy option with ecological advantages. Economic incentives are another strong driver. Two-thirds (57%) mentioned reduced expenditure on LPG and electricity when used in the long run. Social factors also play a role. Social recognition (59%) and peer influence (52% reporting motivation from existing plant owners) highlight how visibility and success stories within communities encourage adoption. Interestingly, bio-slurry as a fertilizer is a moderate but significant motivator (43% overall). Policymakers and implementers should prioritize these motivations, while addressing reliability and demonstrating successful use to encourage broader adoption.

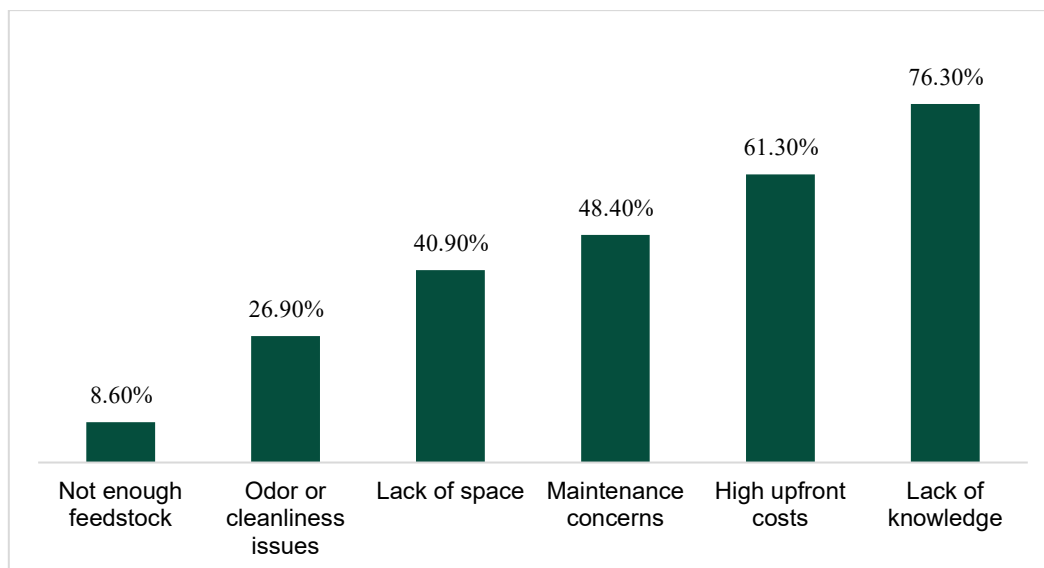


Figure 12. Main concerns related to using a biodigester system (in percentage of farmers)

Among households interested in biogas, the main concerns regarding biodigesters reported (Figure 12) were primarily lack of awareness and high upfront costs. Specifically, 76% of respondents cited lack of knowledge as a barrier, while 61% pointed to the high initial investment required. Space constraints affected 41% of respondents, and maintenance concerns were noted by 48%, particularly in Dehradun, where space limitations and costs are more pressing. Other less frequently reported issues included odor or cleanliness problems (27%) and insufficient availability of feedstock (9%). Despite the recognized value of biogas as a clean and renewable energy source, these awareness, financial, and practical challenges remain significant obstacles to wider adoption.

The government's Din Bandhu Yojana scheme also provides support for biogas units, but farmers must contribute over ₹20,000, making it less affordable. Since the scheme involves brick-and-mortar structures, adoption has been low due to concerns about maintenance, lack of post-project support, and previous project failures.

– BAIF Representative

5.3. Conclusion

These findings align with broader challenges reported in similar contexts, where the dissemination of decentralized renewable energy systems like biogas is hindered by financial barriers, lack of trained manpower, and maintenance difficulties. Improving user education, providing financial incentives, expanding training and support infrastructure, and addressing space-related constraints could enhance biogas adoption and usability in the region (Mohammad Yaqoot, 2015; Sreevidhya & Balamurugan, 2025).

6. Understanding preferences of business models for either using animal waste as soil nutrient or as an energy source (Biogas)

6.1. Overview

Understanding people's preferences for technology and discovering effective ways to sustain it through appropriate business models is essential for successful implementation. Business models play a crucial role in sustaining technological practices and incentivizing adoption by offering economic benefits for users. These models enhance

outreach, especially when technology results in marketable products such as nutrient-rich compost or biogas. Currently, India's drive for efficient green energy transition has led fuel companies to purchase biogas from large production units for use as automotive and industrial fuel, under programs like SATAT. Such arrangements not only ensure steady demand for biogas but also enable producers to tap into government incentives and assured buy-back schemes. On the compost side, digested slurry from biogas plants contributes to agricultural fertility and creates additional income streams for farmers through organic fertilizer sales. Altogether, these business models are essential to scaling biogas and compost initiatives, reducing environmental impacts, and providing reliable income for rural communities (*Global Methane Initiative, 2020*).

Hence, the study explored perceptions about three main business models for compost and /or biogas production (Table 2): (a) individual household-level systems, which allow families to produce and utilize animal waste for their own needs; (b) community-based models, where residents share resources, responsibilities, and benefits of adopted technology at a village or neighbourhood level; and (c) cooperative models, which involve formal collaboration among farmers or households to jointly produce and manage compost and /or biogas, often improving access to finance and technical support.

6.2. Results and discussion

Table 2. Preferences of livestock farmers for business models for effective management of animal waste

	Overall acceptance	Non-acceptance	Household level	Community level	Cooperative level
Samples	386	211	336	28	22

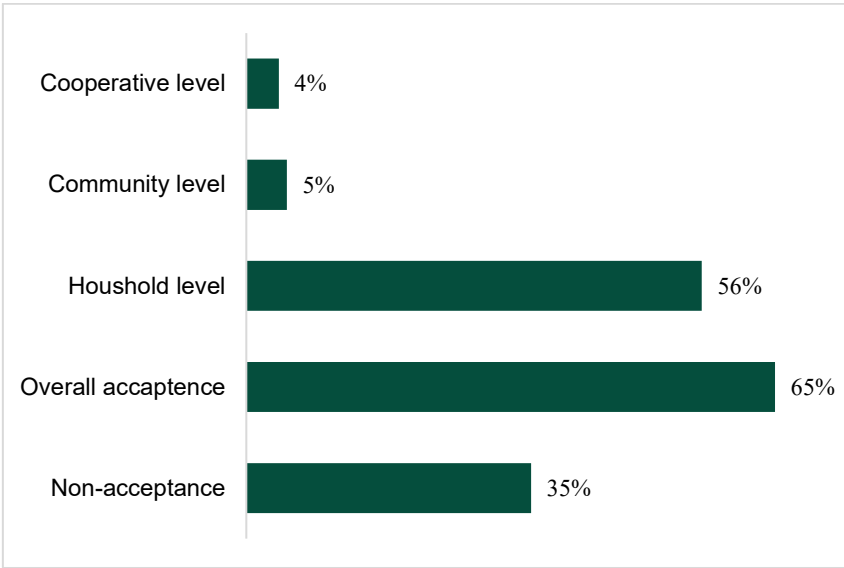


Figure 13. Percentage of livestock farmers accepting different business models for better manage the animal waste

About 65% of households expressed willingness to adopt business models, while 35% indicated that they were not interested in venturing into them (Figure 13). Among the three proposed business models, the household-level model had the highest overall acceptance, with 56% of farmers selecting it as their preferred option. The community-based and cooperative-level models received limited support, with only 5% and 4% of farmers favoring them, respectively. Efforts were made to identify the bottlenecks in adopting each business model, and the results are presented in the figures below.

The reasons for not adopting any business model were first analyzed and are presented in Figure 14, with responses displayed in descending order of frequency. The most common barrier among non-acceptors is lack of time (79% of non-acceptors), as individuals do not have sufficient time to engage in these activities. 41% cited insufficient number of animals, resulting in inadequate waste to make these operations feasible. For 26%, the main

issue is that these practices do not contribute significantly to their income, while 16% reported insufficient labor to carry out the operations. A smaller group (9%) mentioned other reasons, such as lack of confidence to start a business or limited knowledge of marketing. Overall, this pattern highlights that time constraints, limited raw material, and unclear financial incentives are the primary barriers to adopting animal waste-based soil enrichment or biogas generation.

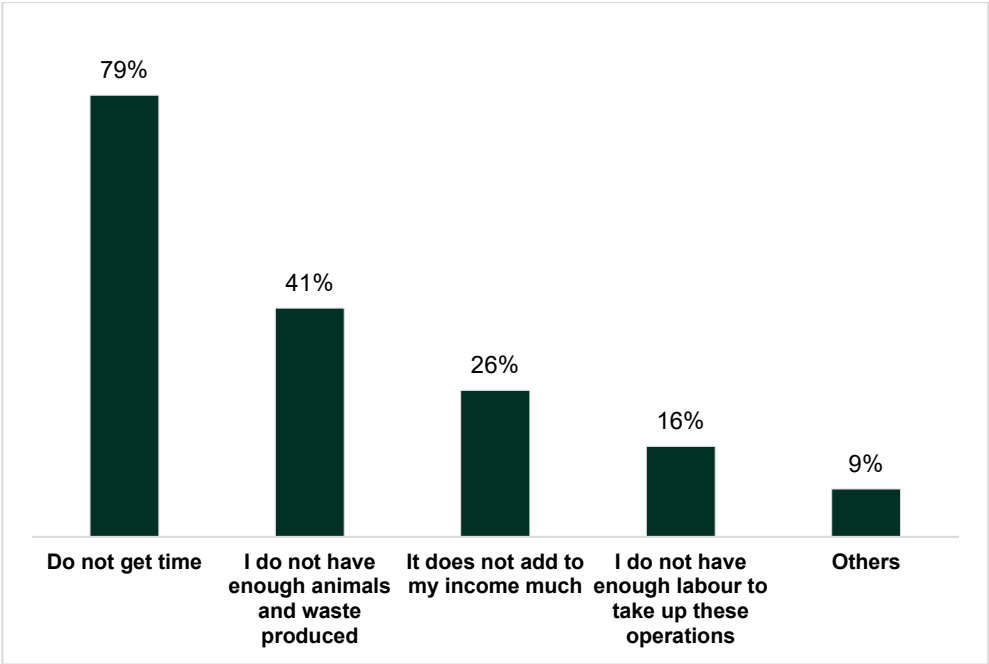
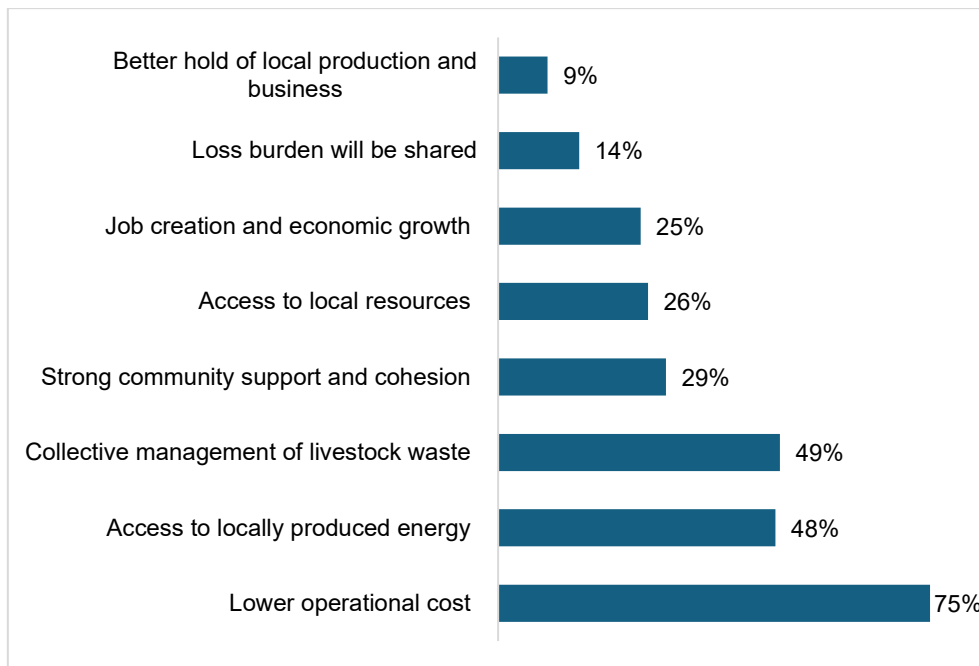


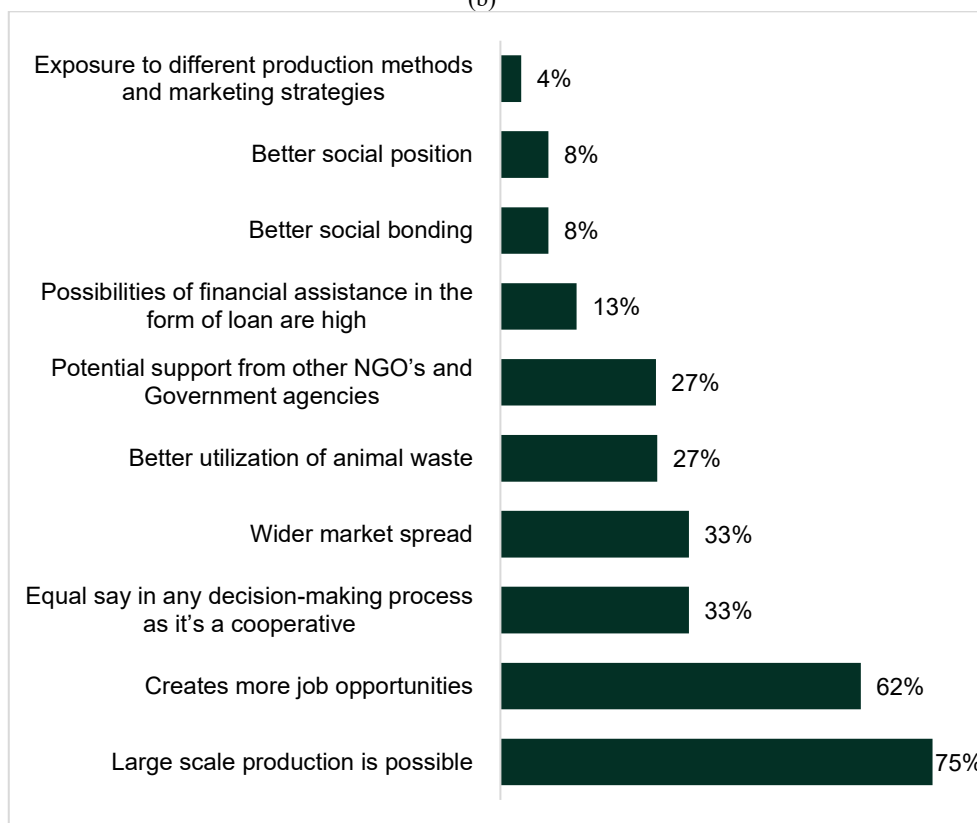
Figure 14. Reasons for not choosing either soil nutrient-based application or biogas generation using animal waste (in % of farmers)



(a)



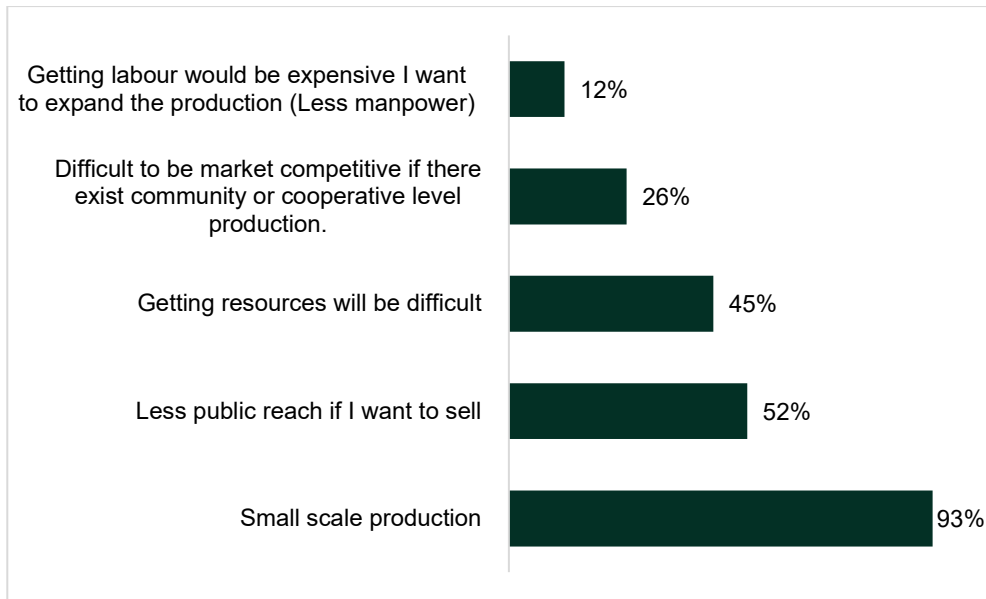
(b)



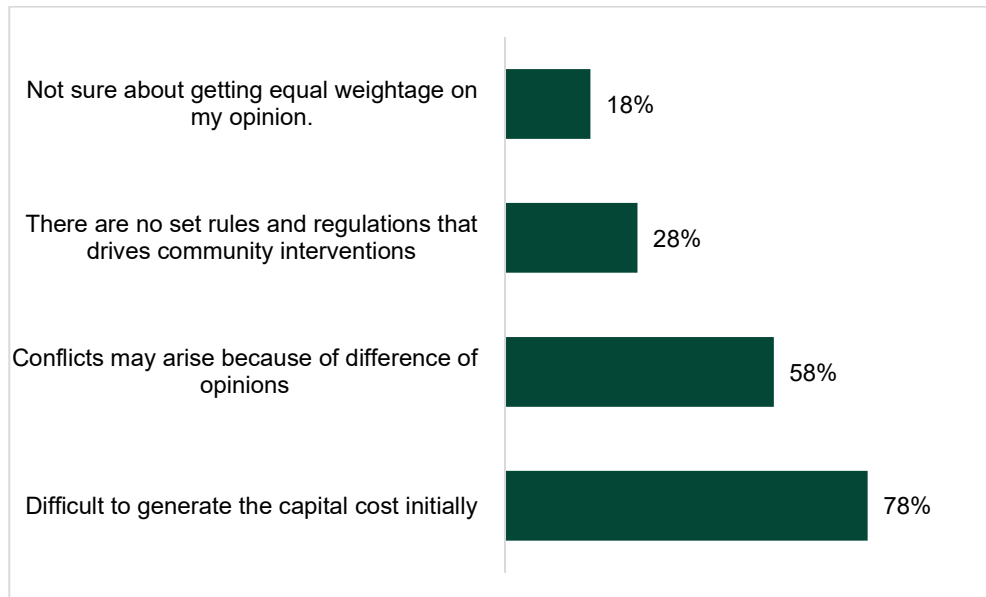
(c)

Figure 15. Percentage of farmers reporting perceived advantages of choosing (a) Individual household level production (b) Community level production and (c) Cooperative level production business models

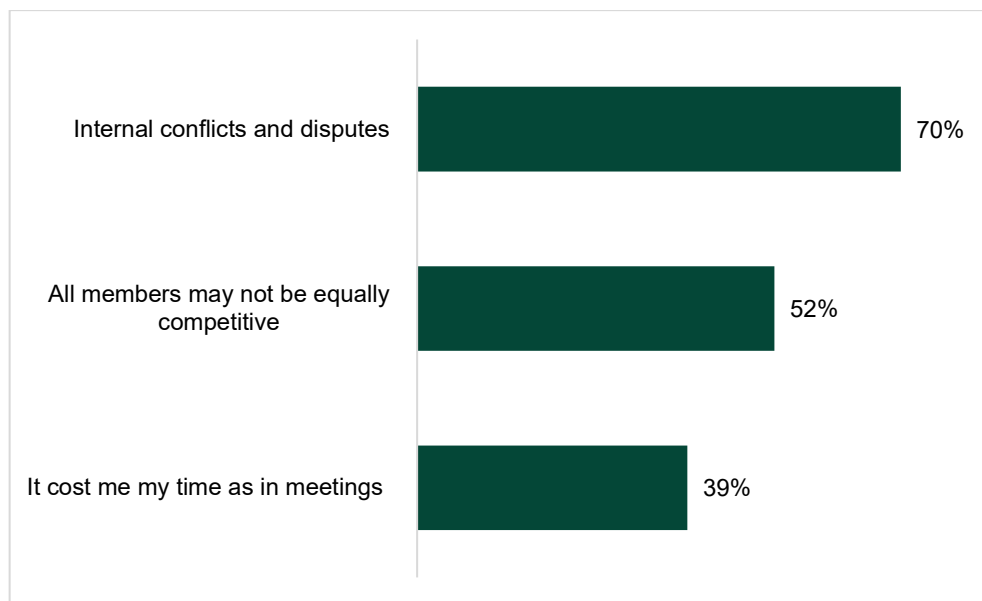
Among the 56% of farmers who preferred household production models, autonomy emerged as the key strength with 94% citing independent decision-making as a major advantage (Figure 15). This preference is further supported by distrust of others (68%) and a desire to manage their own business (39%). However, significant disadvantages were also reported in such model, including limited scale of operation (93%), restricted public reach for sales (52%), and difficulties in accessing necessary resources (45%) (Figure 16).



(a)



(b)



(c)

Figure 16. Percentage of farmers reporting perceived disadvantages of choosing (a) Individual household level production (b) Community level production and (c) Cooperative level production business models.

“Managing livestock populations is difficult due to lack of manpower. Younger generations are not continuing farming. Another major challenge is animal menace — wild animals like deer and boars damage crops, discouraging farmers from cultivation. If they stop farming, composting also loses relevance. There’s also the drudgery of handling and mixing dung. Some farmers manage it, but smaller ones are reluctant.” – Soil nutrient Specialist, ICAR

“For farmers with fewer cattle and limited dung production, setting up individual biogas units is not feasible” BAIF Representative

Table 3. Multinomial Logistic Regression to identify perceived advantages significantly influencing preferences of different type business models.

Individual Household Level Production (Base level)								
Preferred business model	Margins	Std.err	Z	P	Margins	Std.err	Z	P
	Community Level Production				Cooperative level production			
I can take independent decision	-0.46	0.96	-0.48	0.63	-3.60 ***	0.84	-4.28	0.00
I do not trust others	-0.60	0.53	-1.15	0.25	0.43	0.80	0.54	0.59
I have enough animal waste	-0.63	1.47	-0.43	0.67	-1.91	1.10	-0.92	0.99
I can take entire profit	-1.38	0.73	-1.90	0.06	-0.74	0.76	-0.98	0.33
Lower operational cost	-0.47	0.55	-0.84	0.40	-1.31	0.76	-1.72	0.09
Access to locally produced energy	0.92**	0.47	1.95	0.05	0.95	0.71	1.35	0.18

Collective management of livestock waste	0.98 ***	0.47	2.10	0.04	1.53**	0.78	1.96	0.05
Strong community support and cohesion	-0.50	0.82	-0.61	0.54	0.03	0.94	0.03	0.97
Access to local resources	-0.06	1.04	-0.06	0.96	0.95	0.83	1.14	0.25
Job creation and economic growth	-2.12	1.34	-1.58	0.11	-1.13	1.04	-1.09	0.27
Loss burden will be shared	2.54 *	1.40	1.81	0.07	3.50***	1.28	2.74	0.01
Better hold of local production	-1.73	1.87	-0.92	0.36	-1.73	2.58	-0.67	0.50
Large scale production is possible	1.52 *	0.82	1.86	0.06	1.09	0.87	1.26	0.21
Equal say in any decision making	0.34	0.64	0.53	0.60	2.11***	1.22	2.73	0.02
Potential support from other NGO's and Government agencies	-0.62	0.88	-0.70	0.48	-0.25	1.07	-0.23	0.82
Wider market spread	-2.06	1.29	-1.59	0.11	1.21	0.87	1.38	0.17
Better utilization of animal waste	-0.06	1.07	-0.06	0.96	0.04	0.90	0.04	0.97
Possibilities of financial assistance in the form of loan are high	0.53	1.64	0.33	0.74	1.22	1.17	1.05	0.30
Better social bonding	2.36***	1.13	2.08	0.04	2.08*	1.10*	1.89	0.06
Constant	-3.02	1.23	-2.45	0.01	-1.81	1.06	-1.71	0.09
Number of observations	386.00							
Log likelihood	-117.93							
LR chi2(38)	130.33							
Prob > chi2	00.00***							
Pseudo R2	0.36							

*Significant at 10% level

**Significant at 5% level

***Significant at 1% level

Among the 5% of farmers who preferred the community production model, the main advantages were reported were lower operational costs (75%), easier access to locally produced energy (64%), collective livestock waste management benefits (50%), and strong community support (14%) (Figure 15). Still, they are impeded by challenges of raising initial capital (93%) and managing potential conflicts (54%). Additional disadvantages include lack of formal governance rules within community interventions (25%) and concerns about unequal representation in decision-making (11%) (Figure 16).

Among the 4% of farmers who preferred the cooperative production model, key perceived advantages reported were large-scale production benefits (77%), job creation (77%), equal say in decisions (27%), and access to non-governmental organization and government support (23%). Wider market access and improved utilization of animal waste are particularly noted benefits at the cooperative level (Figure 15). However, internal conflicts (14%), uneven competitiveness among members (14%), and the time burden of meetings (73%) pose significant challenges (Figure 16).

Overall, livestock farmers display clear preferences that reflect trade-offs: household models garner favor for independence and control but struggle with scale and market reach; community models promote cost-sharing and collective advantage but grapple with governance and conflicts; cooperatives offer scale and job potential but require complex social management.

These insights emphasize the need for well-designed business models that balance individual autonomy with the collaborative and economic benefits of collective management. Tailoring governance structures and capacity-building initiatives to address financial, operational, and social constraints is critical for the sustainable and effective management of animal waste among livestock farmers.

Further a Multinomial Logistic Regression was performed to econometrically identify which perceived advantages (independent variables, business model advantages) significantly influence these preferences. Here since majority (56%) of the households have chosen to go with household level production, this category has been considered as a base category and then comparison of the preferences for business models at the Community Level Production and Cooperative Level Production relative to the base category were made and econometrically analysed (Table 3).

For Community Level Production, positive and significant factors increasing preference include access to locally produced energy (margin = 0.92, $p=0.05$) and collective management of livestock waste (margin = 0.98, $p=0.04$), indicating the appeal of shared resources and community cooperation. Other positively influential variables, with marginal significance, include the shared burden of loss (margin = 2.54, $p=0.07$ marginally), possibility of large-scale production (margin = 1.52, $p=0.06$), and better social bonding (margin = 2.36, $p=0.04$), highlighting social and economic benefits motivating this choice.

For Cooperative Level Production, a strong negative coefficient for independent decision-making (margin = -3.60, $p=0.00$) suggests that the need for personal autonomy reduces preference for cooperatives, where decisions are collective. However, cooperative models benefit from positive associations with collective waste management (margin = -3.60, $p=0.00$), shared loss burden (margin = 3.53, $p=0.01$), and marginal social bonding advantages (margin = 2.08, $p=0.06$), indicating economic and communal incentives also play a role.

Model statistics show robust explanatory power, with a significant likelihood ratio chi-square and a pseudo-R-squared of 0.36, indicating a good fit to the data (Table 3). In nutshell community and cooperative preferences are shaped by factors promoting shared resources, social cohesion, and risk-sharing, but cooperative models face resistance over autonomy loss. These results provide valuable insight for designing targeted interventions and business models that balance individual autonomy with social and economic benefits to optimize adoption and effective management of animal waste.

6.3. Conclusion

Results reveal that, preferences for community and cooperative models are strongly influenced by factors such as shared resource access, social cohesion, and risk-sharing. Yet, the need for individual autonomy limits some preference for cooperatives. These insights highlight the necessity of designing business models that carefully balance individual independence with collaborative economic benefits. Tailored governance structures, capacity-building, and financial support mechanisms are critical to overcoming operational and social constraints. Such an approach will optimize adoption and effective management of animal waste among livestock farmers, fostering sustainability and enhanced livelihoods.

7. Assessment of Government Scheme Penetration in Animal Waste Management and Associated Risk Behaviour among Farmers

7.1. Overview

In the interest of transforming India’s rural landscape in terms of animal waste management and agriculture development Indian Government has implemented several schemes i.e. (a) National Mission on Sustainable Agriculture, (b) Soil Health Card Scheme, (c) Rashtriya Krishi Vikas Yojana (RKVY), (d) Paramparagat Krishi Vikas Yojana (PKVY), there are also schemes thought in the lens of clean energy production via scientific management of livestock waste through anaerobic digestion, i.e. (a) National Biogas and Manure Management Programme (NBMMP), (b) BioCNG / Biogas Power & Thermal Program (BPGTP), (c) State Biogas Programme (Uttarakhand) and Galvanizing Organic Bio-Agro Resources Dhan (GOBARdhan) etc (Agrawal, 2025). Starting from improving soil condition through application of scientifically composted animal waste to producing biogas and bio-manure to promote clean energy technology these schemes are trying to enhance rural sanitation, energy access and income generation. This integrated effort strategically address environmental, economic, and social dimensions in India’s livestock waste management and agriculture. Mere existence of these schemes does not ensure on ground impacts as ground level penetration always faces challenges. Therefore, to gain an evidence-based understanding of this situation questions regarding awareness, access and actual implementation were discussed with sample households.

7.2. Results and discussion

Figure 17 indicates above mentioned four government schemes related to soil nutrient management using animal waste, measured by three parameters: awareness about the scheme, accessed schemes, and grants received.

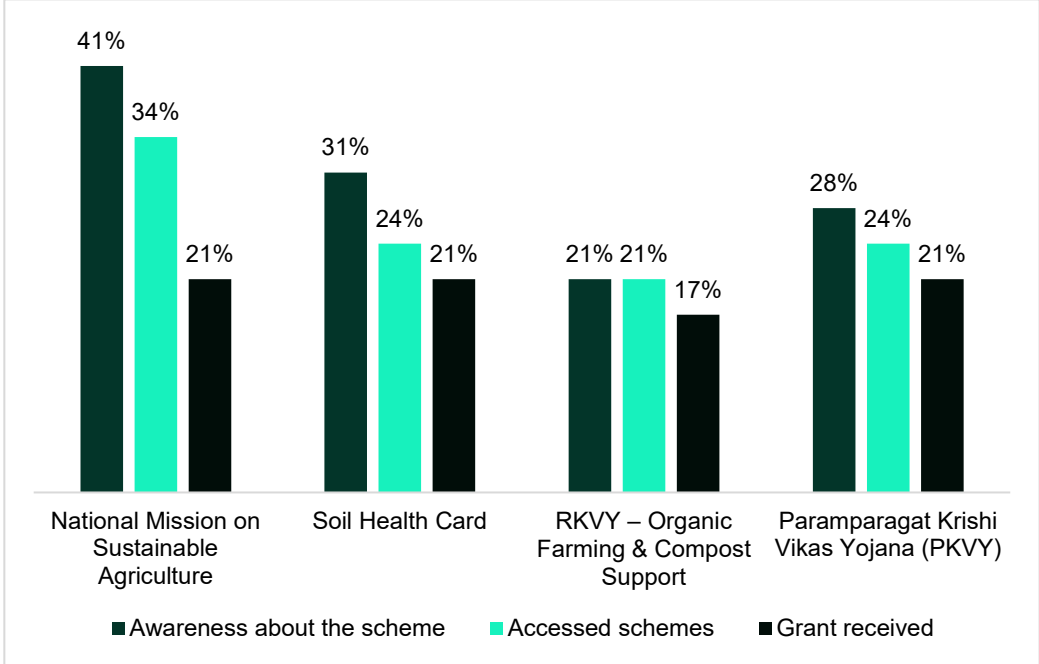


Figure 17. From Awareness to Implementation: Percentage of Farmers Involved in Animal Waste-Based Soil Nutrient Application Schemes

Out of the 597 sampled households, 48% expressed interest in using scientific composting methods for animal waste to enhance soil nutrition. However, among this interested group, only a small fraction

were aware of any government schemes that support such practices (Figure 18). The number accessing the schemes and implementing them drops even further. Similarly, Figure 18 depicts the status of four government schemes focused on biogas and bio-manure production from animal waste. The data reveal that awareness levels for these schemes are even lower than for those related to composting and soil health. This significant gap highlights that, despite India having the world’s largest livestock population and considerable biogas generation potential, the reach and impact of these clean energy initiatives remain limited on the ground. As a result, India’s progress toward its green and clean energy targets—especially in the livestock biogas sector—remains substantially below its true potential. This underscores that the main bottleneck is not resource availability or interest, but rather the limited dissemination and accessibility of information and support related to these schemes. This fact also emphasizes the urgent need for improved outreach, better implementation, and increased beneficiary participation to realize the environmental and economic benefits of livestock-based biogas production.

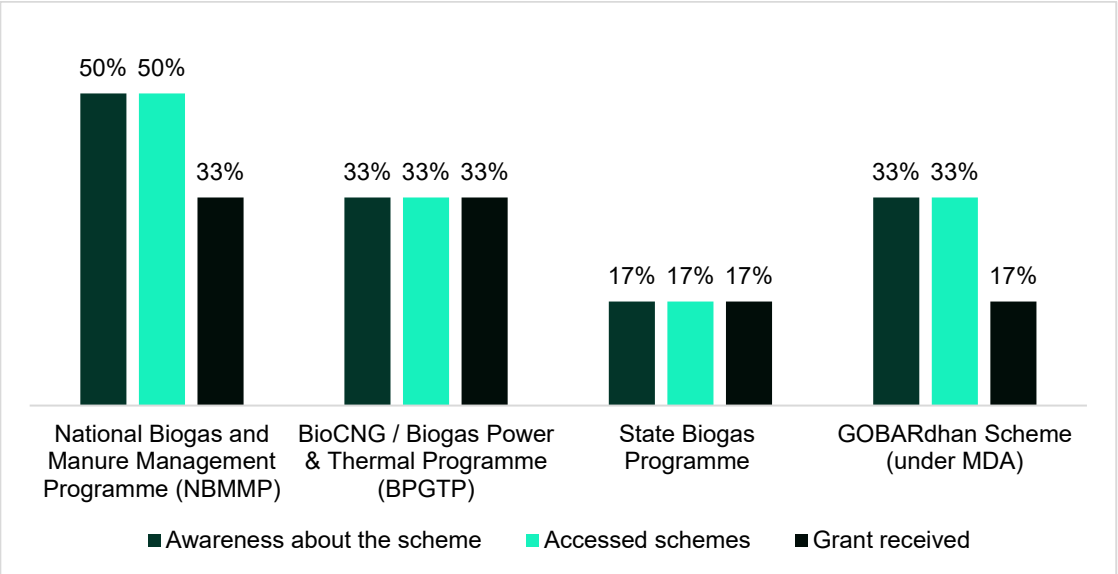


Figure 18. From Awareness to Implementation: Percentage of Farmers Involved in Animal Waste-Based biogas and bio-manure production Schemes

Training and capacity building programs increases the outreach and understanding of the schemes and implementation, but 97% of the sample households mentioned that they have not received any training on scientific composting of animal waste and only 3% have attended such training programs conducted by Government Departments on composting process. Operation and maintenance of biogas system and Government schemes and subsidies indicating a huge gap in the outreach process.

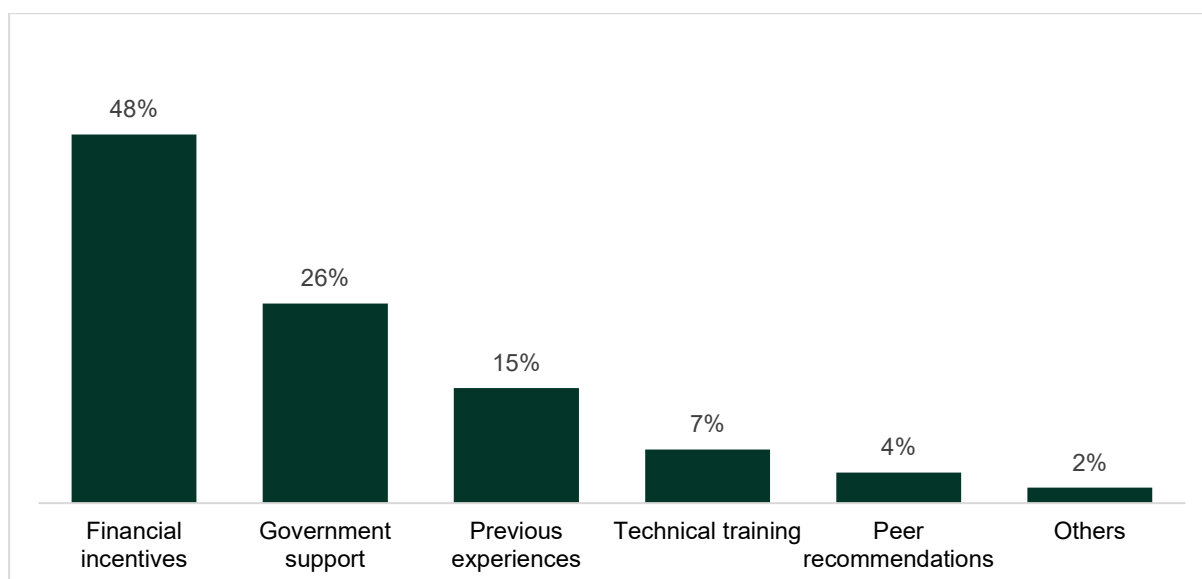


Figure 19. Factors influencing farmers' willingness of to take risks in adopting new technology (in % of farmers)

The adoption of government-supported interventions in rural India depends not only on policy efforts but also on individual motivation and financial capacity. For rural households, even modest investments carry significant implications for their livelihoods, making risk tolerance a critical factor when considering new agricultural or livestock technologies. Analysis of data from Figure 19 reveals that the most influential factors shaping willingness to adopt new technologies are financial investment requirements (48%) and the availability of government support (26%), together accounting for 70% of the decision-making process. This highlights the importance of both economic considerations and public policy incentives in driving technology adoption among rural communities.

Moving further assessment of how perceived risk acceptance behaviour of individuals direct them towards adoption of a particular technology was assessed using chi² test (Table 4). Individuals identifying as high risk-takers are much more likely to show strong willingness to adopt innovations: for the statement "I generally consider myself a person who takes risks," 43.12% reported high-risk acceptance and willingness to adopt, compared to only 20.47% among low risk-acceptance responders. Entrepreneurs who enjoy uncertainty ("I usually enjoy situations where the outcome is uncertain") overwhelmingly demonstrate high risk acceptance (83.82%) and therefore a strong lean towards technology adoption.

Table 4. Association between Risk acceptance and willingness to technology adoption

	Willingness to adopt new technology related livestock waste management			Pearsons Chi ²
	High risk acceptance (%)	Moderate risk acceptance (%)	Low risk acceptance (%)	
I generally consider myself a person who takes risks.	43.12	36.41	20.47	1200
I usually enjoy situations where the outcome is uncertain or unpredictable.	83.82	15.15	1.03	110
I tend to carefully evaluate all factors before making a decision.	2.2	14.86	82.94	1200
I don't tolerate the event of business loss due to any reason	1.87	22.41	75.75	1200
I do not venture into any business or technology adoption in future if I face loss once.	2.65	31.66	66.00	139
I do not feel confident to initiate adoption of any technology.	8.03	44.36	47.61	114

Conversely, those who carefully evaluate all factors, dislike losses, or are hesitant after previous failure, generally fall into the low risk-acceptance category and show a much lower willingness to adopt new technologies (e.g.,

82.94% for careful evaluators and 75.75% for those not tolerating business loss). When lacking confidence, the response is most mixed: 8.03% high, 44.36% moderate, and 47.61% low, showing indecision and risk aversion.

The data demonstrate that willingness for technology adoption in livestock waste management is powerfully driven by an individual's risk-taking orientation: risk-tolerant individuals are consistently more open to adopting innovations, while risk-averse individuals are much less likely to do so. These insights are critical for designing outreach and support strategies tailored to different risk profiles in rural communities.

The very high Pearson chi-square values indicate these patterns are highly statistically significant the relationship between individual perceived risk and technology adoption is robust and strongly non-random.

7.3. Conclusion

Despite the Indian government's implementation of numerous schemes targeting sustainable animal waste management and clean energy production, the actual penetration and impact of these programs on rural households remain limited. Awareness, access, and adoption rates are generally low, with financial investment requirements and limited dissemination of information identified as key barriers. The analysis emphasizes that beyond policy existence, individual risk-taking behaviour strongly influences technology adoption; risk-tolerant farmers are more likely to embrace innovations while risk-averse individuals hesitate.

8. Synthesis

Considering animal waste as one of the factors of water pollution happening in Song River and Suswa River basin which are the tributaries of Ganges the study explores ways of integrating alternative environmentally friendly technologies of compost and /or biogas through household, community and cooperative level business models. In this direction efforts are made to understand livestock farmers perceptions about animal waste management either through biogas production or using as soil nutrients from a policy perspective as a precursory step in the implementation. In this context, the study focused on covering different viewpoints, including those of households, interests in various business models, and policy considerations.

The socio-economic and demographic characteristics of livestock farmers in Uttarak

hand significantly affect their adoption of sustainable animal waste management practices. Larger landholdings, higher livestock numbers, cooperative memberships, and older age are key facilitators among adopters who integrate both crop cultivation and animal husbandry into their livelihoods. Despite varying awareness of government schemes, land availability remains a major constraint, underscoring the need for targeted, context-specific interventions to promote biodigester technology and composting for improved soil and environmental health.

The preference patterns for community and cooperative production models further highlight the balance farmers seek between autonomy and collective benefits. While shared resources and social cohesion motivate community and cooperative models, concerns about governance and decision-making autonomy shape adoption choices. This necessitates business models that cleverly navigate these trade-offs through tailored governance, capacity building, and financial support mechanisms.

Furthermore, limited penetration of government schemes is a critical bottleneck, exacerbated by low awareness, financial barriers, and inadequate dissemination of Government support. The analysis reveals that individual risk-taking behaviour strongly influences technology adoption, suggesting that differentiated outreach and incentive strategies addressing economic and psychological dimensions are crucial. Achieving sustainability and clean energy objectives in livestock waste management in Uttarakhand and similar contexts thus calls for integrated, participatory approaches bridging policy and grassroots realities.

This comprehensive understanding of socio-economic and behavioural factors provides invaluable guidance for designing effective interventions and policies to advance sustainable livelihoods and environmental stewardship in the region.

Recommendations

1. Promote decentralized waste-to-value models: Introduce small and medium-scale biodigester units adaptable to mixed animal populations.
2. Provide technical support for FYM and bio-slurry management: Establish training centres through KVKs for compost quality control and safe storage to reduce spoilage.
3. Encourage collective management: Pilot cooperative or SHG-led composting clusters to share labour, manage logistics, and market surplus FYM.
4. Implement demonstration projects: Visible success stories (as in NDDDB dairy cooperatives) can trigger community trust and adoption.
5. Integrate health and environment messaging: Highlight benefits like reduced open dumping, cleaner water sources, and lower disease risks to increase motivation.

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Annexure

Annexure I

Installation of small-scale biogas plants in different states of India

State/ UT	Biogas (upto 2500 m3) - Nos
Andaman and Nicobar	97
Andhra Pradesh	268631
Arunachal Pradesh	3621
Assam	139414
Bihar	130072
Chandigarh	169
Chhattisgarh	60252
Dadara and Nagar Haveli	681
Delhi	578
Goa	4234
Gujarat	435640
Haryana	64015
Himachal Pradesh	47718
Jammu and Kashmir	3201
Jharkhand	7890
Karnataka	512823
Kerala	153705
Madhya Pradesh	379163
Maharashtra	931358
Manipur	2128
Meghalaya	11156
Mizoram	5857
Nagaland	7953
Odisha	271753
Puducherry	17541
Punjab	187177
Rajasthan	72887
Sikkim	9044
Tamil Nadu	224075
Telangana	316732
Tripura	3744
Uttar Pradesh	441220
Uttarakhand	365198
West Bengal	1217
Total	5080944

Source: Digital India Initiative, 2022. (<https://www.data.gov.in/>)

Annexure II

Livestock population in selected blocks of Dehradun and Haridwar districts

Type of animals & their numbers	Chakrata	Kalsi	Vikas Nagar	Dehradun	Tyuni	Rishikesh	Total
Indigenous cows	22018	13052	23869	16761	20372	14184	110256
Crossbreed cows	150	749	18349	33989	1577	15837	70651
Buffaloes	2792	3005	23259	14687	697	8405	52845
Total	24960	16806	65477	65437	22646	38426	233752

Source: Livestock population census 2019

Type of animals	Bahadrabad	Bhagwanpur	Roorkee	Narsan	Laksar	Khanpur	Total
Indigenous cows	24795	9641	5910	7538	9114	2118	56998
Crossbreed cows	51758	27473	22793	28133	23006	14036	153163
Buffaloes	48117	33717	35054	38866	31409	14958	187163
Total	124670	70831	63757	74537	63529	31112	397324

Source: Livestock population census 2019

Annexure III

Livestock population of Uttarakhand from 2019 Livestock Population Census.

District	Cattle	buffalo	sheep	goat	horse	pony	mule	Donkey	camel	pig
Pauri Garhwal	256311	30076	13276	142816	588	96	1374	186	0	1092
Dehradun	194043	52185	6222	158314	444	131	1724	254	0	1692
Haridwar	179395	214480	4697	26594	456	30	18	16	0	6129
Nainital	176506	77759	828	66213	734	188	1368	2	15	779
Udham Singh Nagar	166349	152911	2068	51014	1181	19	77	23	0	6030
Pithoragarh	162869	37056	44533	226060	622	0	2798	18	0	161
Almora	149080	77444	2186	185319	239	101	1392	4	0	359
Chamoli	145625	37922	75417	96861	600	0	4064	4	0	287
Uttarkashi	105479	25945	80349	100882	900	1	5989	71	0	269
Tehri Garhwal	86362	79394	21145	126944	479	3	2667	8	0	623
Champawat	79686	18599	10	60516	44	116	547	0	0	80
Bageshwar	76181	31432	20800	102075	243	3	1714	2	0	114
Rudraprayag	74237	31115	13084	28363	217	17	2561	1	0	44

Source: Livestock population census 2019



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