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Assessment of Biomass Energy Potential for Biogas Technology Adoption and Its Determinant Factors in Rural District of Limmu Kossa, Jimma, Ethiopia

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Abstract: Increasing clean energy access for the rural population of developing countries is a priority to meet the United Nation's Sustainable Development Goals-Zero hunger and affordable modern/clean energy for all. Similarly, to meet this goal, Ethiopia moved towards the development of renewable energy. However, there is a limited knowledge on the biomass energy potential for biogas technology adoption at the local/district level. Thus, this study aimed at assessing the biomass energy potential for biogas technology adoption and its determinant factors among rural households in Limmu Kossa district, Ethiopia. Data was collected from 411 households from 13–24 June 2021. The quantitative data was analyzed using Statistical software Package for Social Science (SPSS) version 23 and Microsoft Word-Excel. The qualitative data was analyzed using content analysis. The study showed that over 96% of households rely on the traditional use of biomass energy for cooking. Nevertheless, on average, about 1 m^3 of biogas energy can be potentially available from livestock dung and human excreta per household per day. However, the huge potential of biomass energy did not contribute to improved energy technologies such as biogas. The adoption of biogas is hampered by the non-functionality of the installed biogas, a lack of awareness, the availability of firewood, and the socio-economic characteristics of the households. Thus, improving the awareness of the community, arranging financial access, and training biogas technicians, especially from the local community, would increase the adoption of the technology. However, meeting the digester water demand with the water collected from the walking distances of 15–20 min can be challenging. Community-based biogas digesters or biogas involving income generation with a water supply around the digester would be a better and more sustainable option for biogas energy adoption and use.

Keywords: biomass energy potential; biogas production; energy consumption; biogas adoption; Limu Kossa district; Ethiopia

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1. Introduction

Energy plays an important role in attaining sustainable and inclusive growth both in low- and high-income countries. An increase in coverage of energy services plays a crucial role in the country's promotion of economic growth, health improvement, poverty reduction, competitiveness enhancement, and gender balance [1]. On the other hand, it is expected that global energy demand will continue to increase with an increase in population and the expansion of energy-dissipative economic activities [2]. To address the high demand for energy, there is a need for clean and renewable energy technologies to mitigate climate change by reducing greenhouse gas emissions in the long term. To meet the energy needs of rural areas in an environmentally sustainable way, harvesting renewable energy in a decentralized way is one of the options that would improve their wellbeing and economic prospects for potential global investment [3].

Around 3 billion people cook using open fires or simple stoves that burn polluting fuels such as wood, charcoal, animal dung, crop waste, coal, and kerosene [4]. About

2.5 billion people in developing countries depend on biomass for basic energy, which includes coal and animal dung cakes since they are readily available [5]. But in Africa, despite the availability of various energy sources, more than 80% of the total population in most countries still relies on traditional biomass as the main source of energy for cooking [6].

Biomass energy is a large renewable source with the potential to contribute to the world's energy needs. It contributes between 10 and 14% of the world's primary energy, including about 3% of the world's transport, but has the potential to contribute up to 30–40 +% in 2050, depending on the source [7]. Many developing countries still rely on biomass energy. In Kenya, most households rely on charcoal conversion kilns, charcoal stoves, and woodlots, where it meets about 70% of Kenyans national energy requirements [8]. Similarly, in Pakistan, traditional cooking stoves utilize 80% of the bioenergy, resulting in 64% of biomass cooking and 86% of total biomass energy in the household sector [9].

Ethiopia has one of the world's poorest accesses to modern energy supplies. With more than 80% of Ethiopia's population residing in rural areas and heavily reliant on agriculture; the primary source of energy for this rural population is biomass, accounting for approximately 87% of total energy supply [10]. However, the country has largely untapped renewable energy resources. Ethiopia has 141.8 million tons of estimated exploitable biomass potential, with a current 70.9 million tons of exploited biomass potential [11]. The current level of electricity access is quite low in Ethiopia. In urban areas, 87% of the population has access to electricity [12], while only 5% of the rural population has access to electricity [13]. The annual theoretical hydro energy potential of the country was estimated at 954 TWh, out of which its geographic potential is 286 TWh [14]. The abundance of solar energy resources is estimated to be about 5.2 kWh/m^2/day [14,15]. Estimation at a country level also shows the adequacy of exploitable biomass energy potential from different sources [11].

Relying on biomass energy sources causes problems, especially household air pollution, which increases the risk of acute lower respiratory infections in children under five years old among others [16]. Several studies have reported the effect of non-renewable energy on environmental pollution. Non-renewable energy increases environmental stress through increases in CO_2 emissions, suggesting that renewable energy is the best alternative to non-renewable energy for mitigating the level of energy-related pollution [17,18]. In addition, it is documented that biomass energy use exposes users to physical and psychological health challenges [19].

Ethiopia is gradually moving forward with reducing its reliance on non-renewable energy sources and shifting power to a clean and renewable energy supply. Currently, the country's energy demand is increasing due to its fast-growing economy and flourishing infrastructure [10]. Thus, finding an alternative energy source and understanding determinant factors of biogas technology adoption is crucial.

Biogas is the emerging bio-energy in the rural areas of Ethiopia through biogas development, Biogas in rural households could provide a more sustainable energy source than wood fuels. Understanding its importance, Ethiopia established a national biogas program since 2007 [20]. In Ethiopia, biogas is mainly used for cooking. Biogas can also be used to power internal combustion engines, refrigerators, or radiant heaters, yet their application is even less widespread than lighting or cooking. As a result of biogas adoption in Northern Ethiopia, the fuel wood and charcoal consumptions were significantly reduced [21].

Understanding the importance of biogas technology, the National Biogas Policy of Ethiopia introduced and promoted the implementation of biogas technologies in rural areas. However, there is a huge burden on women and children, who spend up to 10 h a week gathering wood in rural areas [22]. This is partly because; there is relatively low adoption of biogas technology in developing countries in general and in Ethiopia in particular. The barriers contributing to the low adoption of biogas technology as a source of energy, especially in rural areas, are not well documented [23].

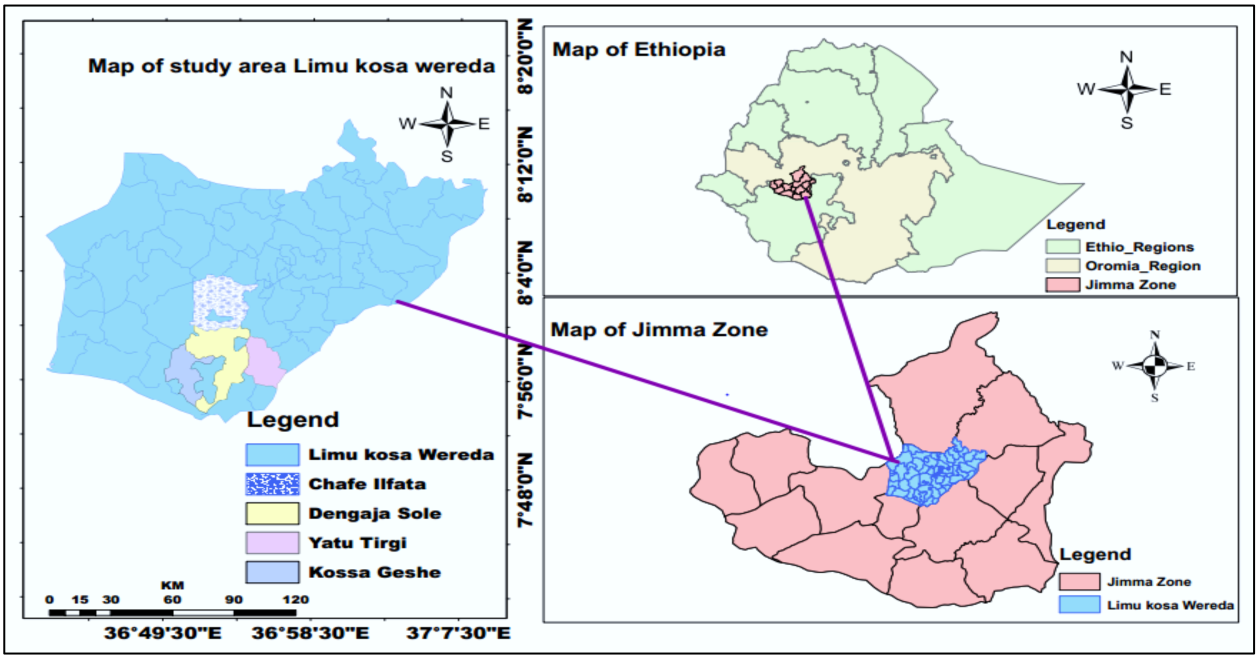
The ever-increasing demand for woody fuel and the inefficient household biomass energy utilization, which results in a huge amount of energy loss during cooking and heating, are the main causes of the subsequent degradation of woody biomass and environmental degradation in the country [24]. This is because modern fuel devices are either unavailable or unaffordable, especially for rural and poor urban people. Hence, with the increasing cost of fuel wood, households are forced to increasingly rely on lower-quality combustible materials such as dung and crop residues. Even worse, in areas experiencing a shortage of grazing lands, most of the crop residues must be devoted to animal feeds [25].

Ethiopia has a biomass energy potential of around 101,656.77 Tcal (equivalent to 118,125.17 GWh) from wood, crop residues, and cow dung, of which crop residues and cow dung account for 27% (14% dung and 13% residues) [26]. The potential of dung energy potential is around 0.55% of the global biogas energy potential from available livestock manure from cattle, buffaloes, pigs, and chickens [27]. However, the potential for biomass energy varies from place to place because of population density, household biomass sources, access to improved energy technologies, the availability of land, and common resource pools. Hence, it is imperative to study the potential of biomass energy resources, consumption patterns, and accessibility to improved energy technologies and identify the challenges and opportunities of adopting improved energy technologies, considering local contexts. Moreover, socio economic factors play a significant role in biogas adoption [28]. On the other hand, it is documented that socioeconomic and demographic factors hinder the adoption of domestic biogas energy technologies in different parts of rural areas in Ethiopia [29,30]. These are not the only factors determining the adoption of modern energy technology in general, and biogas in low-income countries with huge resource scarcity and sociocultural factors is strong. However, none of the previous studies has considered Limu Kosa district, which is a cash crop-producing area with households that have the potential to afford biogas installation. This study wishes to contribute to the existing literature by analyzing the biomass potential at the local level and the determinant factors of adopting biogas technology and, hence, suggesting the sector improve adoption of the technology. Hence, understanding the potential of an area and identifying factors that determine biogas use is crucial to devising enabling policies and taking sustainable action to enhance the adoption of improved energy technologies. Thus, this study aimed at assessing the potential of biomass energy, its consumption pattern, and the challenges of adopting improved energy technologies in rural areas of Limmu Kossa woreda, Ethiopia.

2. Materials and Methods

2.1. Survey of the Households

The study was conducted in Limmu Kossa woreda, Jimma zone, Oromia national regional state, Ethiopia. The administrative center of the woreda is Genet, which is located 75 km west of Jimma town and 426 km southwest of Addis Ababa. Limmu Kossa woreda has 44 kebeles with a total households of 47,511 and a total population of 228,054 (projected population from CSA, 2007). The woreda is among the woredas with low electric supply coverage, with a 10.4% [31].



This study considered a comparative study involving biogas adopters and non-biogas adopters of the woreda. The sample size for the non-biogas adopters was determined using a sampling technique developed by Cochran (1977) by considering a 95% confidence interval, a population proportion of 50%, a margin of error of 5%, and 10% compensation for the non-response rate, thus providing 424 households. The woreda has 32 households that have adopted biogas plants and thus has considered all of them for the comparative analysis. Accordingly, 424 non-biogas adopters and 32 adopters, for a total of 456 households living in Limmu kossa woreda were considered for the study. The study households were selected using systematic random sampling and purposive sampling techniques. First, Limmu Kossa woreda was purposefully selected considering its potential to promote improved biogas technology, and then four kebeles were selected randomly from the 44 kebeles in the woreda. A systematic random sampling technique was used to select the 424 non-biogas adopter households from the 4782 households of the four kebeles based on the list of households obtained from the woreda administration office. The first household was determined by the lottery method, and the remaining households were selected at intervals of 11 households until the sample size reached 424. All 32 biogas adopter households in the woreda were purposefully included for comparison with non-adopter. Table 1 shows the list of kebeles and the proportion of households selected from each bebele.

Table 1. Sample size distribution in each sampled kebeles.

Sampled Kebels	Total Households	The Proportion of Sampled Households
Chafe Elfata	1179	105
Dengaja Sole	1741	154
Yatu Tirgi	877	78
Kossa Geshe	985	87
Total	**4782**	**424**

This study used both quantitative and qualitative approaches to gather information. The primary data on demographic, socio-economic characteristics, institutional, and bio-physical situations of the sample households were collected through a semi-structured questionnaire, field observation, and interviews with key informants and FGD participants. The key informant interview was made with the woreda water and energy office, the woreda environmental protection, forest, and climate change authority, the woreda agriculture and rural development office, health extension workers, agricultural development agents, and the FGD involved members of biogas user household head, improved cook stoves producers, and the woreda water and energy office renewable energy team leader, considering gender and age diversities. Additional secondary data was obtained from existing literature and relevant documents from woreda/district offices. Prior to data collection, an ethical approval was obtained from the Jimma University Institute of health institutional review board, and a letter of permission was sent to the woreda and kebeles office. Confidentiality of the information from the study participants was ensured through verbal consent and the voluntary involvement of the study participants. Households were given the chance to leave the study if they were not interested or did not want to give their information. In that case, the next households were considered and kept the same sampling interval.

The quantitative data collected through the survey was analyzed using SPSS v.21 and presented using descriptive frequencies and a logistic regression model. The logistic regression model is used to determine factors affecting biogas energy technology adoption. The logistic regression model is appropriate when the outcome variable is dichotomous, and the explanatory variables are of any type and are analyzed as follows.

$$Y = \beta o + \beta 1X1 + \beta 2X2 + \beta 3X3 + \ldots + \beta nXn + \varepsilon i$$

Y is dichotomous outcome variable, Y = 1 for bigas energy technology user otherwise Y = 0, implies non-biogas users. Xi represents explanatory variables that can affect the household's decision to adopt the technology. This study adopted this empirical model as used in [32], where βo represents the constant with X1 + X2 + X3 + . . . + Xn (explanatory variables) affecting the probability of biogas energy technology adoption; $\beta o + \beta 1 + \beta 2 + \ldots + \beta n$ represent the estimated coefficients; and εi stand for the error term. Hence, the model is appropriate to analyze the relation between biogas technology adoption and socio-demographic and economic variables as follows: $Y = \beta o+ \beta 1X1 + \beta 2X2 + \beta 3X3 + \beta 4X4 + \beta 5X5 + \beta 6X6+ \beta 7X7 +\beta 8X8 + \varepsilon$. Where, Y = Adoption of biogas technology. B0 = Constant βi = Independent variable coefficients X1 = Gender of household's heads, X2 = Age of household heads X3 = Education Level of household heads, X4 = Household family size, X5 = Income, X6 = Number of livestock animals, X7 = Availability of firewood, X8 = land size and ε = error term.

2.2. Estimation of Biomass Energy Potential

The potential for biomass energy for biogas production was determined based on the specific biomass categories. The estimation of human waste production potential was made for the selected households based on their family size and average daily feces and urine production per person, as presented in the literature [33]. The quantities of wet human excreta per capital reported in the literature vary from 250 g/cap/day in low-income countries to 126 g/cap/day in high-income countries. This study considered 250 g/cap/day of feces, assuming a dry matter content of 25%, 1.5 L/person/day of urine, and a family size of 5.6 per household. Accordingly, a person produces, on average, about 0.2 m^3/kg of biogas [33]. The potential for biogas energy from livestock animals varies depending on their feed contents, size, and types. This study considered 4.5 kg/day/cattle, 1 kg/day/head of sheep and goats and 0.08 kg/day/head of chicken based on literature information, with a dry matter (DM) of 16.7%/kg, 30.7%/kg and 50%/kg for cattle, sheep/goats, and chickens, respectively [34–36]. Accordingly, this study estimated an average biogas yield of 0.24 m^3/kg DM, 0.37 m^3/kg DM for sheep/goat and 0.4 m^3/kg of DM for chicken. Hence, the daily and annual potential for biogas energy potential of the areas was calculated by considering the daily potential biomass, biogas yield per kg of biomass, and number of animals. The estimation for crop residues was made based on the cultivated land, cereal crop yield, Residues to Product Ratios (RPR) of specific crops, and the estimated collectable proportion of the residues and its biogas yields [37].

3. Results

3.1. Socio-Demographic and Economic Characteristics of the Respondents

The data was collected from 411 households with a 96.93% response rate, and of all the 32 biogas adopter households, 16 households from the non-biogas adopters were neither volunteers nor at home during the data collection time. The summary of socioeconomic and demographic characteristics of biogas technology adopter and non-adopter households is presented in Table 2.

Table 2. Socio-demographic and economic characteristics of biogas adopter and non-adopter.

Characteristics	Adopter of Biogas		Non Adopter of Biogas	
Household gender	Frequency	Percent	Frequency	Percent
Male	32	100	387	95
Female	0	0	21	5
Educational level of Households				
Never to school/illiterate	5	15.6	180	44.1
Primary school	12	37.5	92	22.6
Secondary education	15	46.9	131	32.1
Post-secondary school	0	0	5	1.2
Household family size				
1–3	5	15.6	100	24.5
4–6	24	75	186	45.6
7–9	3	9.4	97	23.8
10–12	0	0	23	5.6
>12	0	0	2	0.5
Age of household's head				
15– 24	0	0	0	0
25–34	4	12.5	70	17
35–44	22	68.8	101	24.8
45–54	5	15.6	110	27
55–64	1	3.1	69	17
>65	0	0	58	14.2
Number of cattle				
1–4	1	3	154	38
5–8	20	62.6	197	48
>8	11	34.4	57	14
Land holding size (ha)				
<0.25	0	0	26	6.4
0.25–0.5	0	0	94	23
0.6–1	0	0	120	29.4
1.1–1.5	2	6	71	17.4
1.6–2	13	41	53	13
>2	17	53	44	10.8

The study result showed that 15.6% of the biogas technology adopters never attended school, whereas 46.9% and 37.5% of adopter household heads had primary and secondary education, respectively. 9.4% of biogas adopters and 23.8% of non-adopter households had a family size ranging from 7–9 persons. Most biogas-adopter household heads (68.8%) were between the ages of 35 and 44. The study revealed that 62.6% of adopters and 48% of non-adopters' households had 5–8 cows, and the majority (62%) of biogas adopter households had more than 5 cows. None of the households with less than 1 hectare of land adopted biogas technology. 41% and 53% of biogas adopters were those with landholding sizes of 1.6–2 ha and >2 ha, respectively. In addition, 40.6% of the biogas adopters are from households with an annual income above 90,000 ETB. The majority of the non-biogas adopters are in the lower income ranges; only households with above 50,000 ETB adopted the biogas technologies (Figure 1).

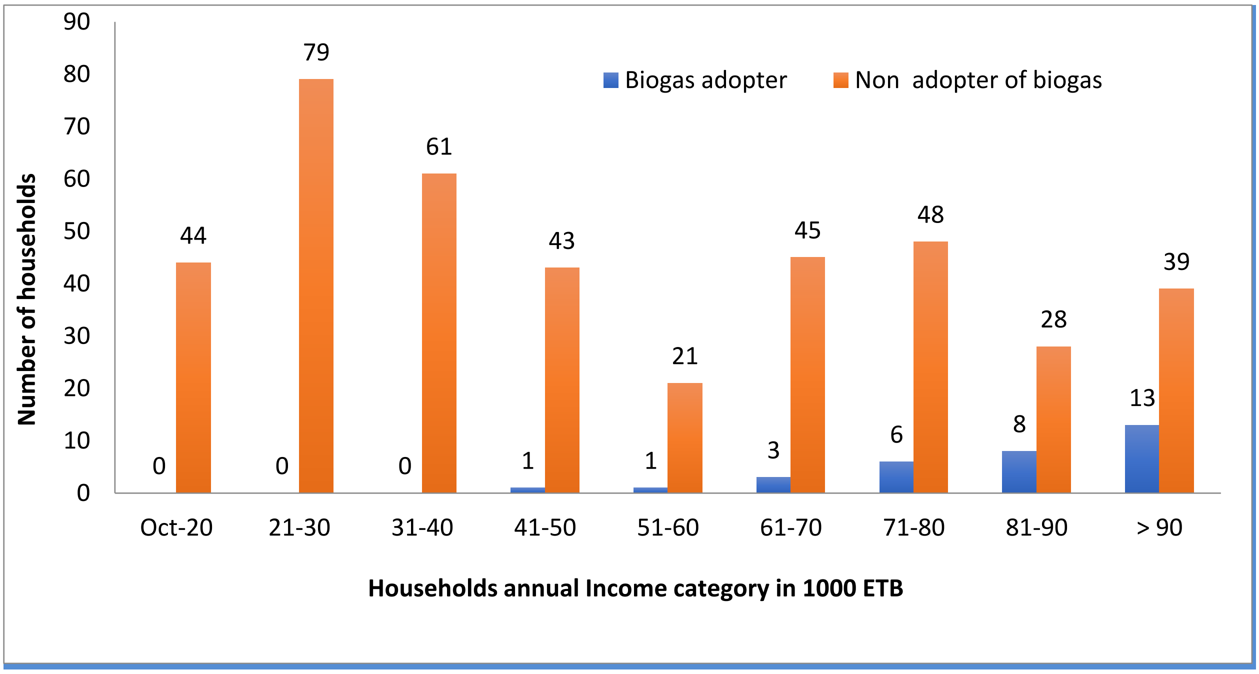


Figure 1. The annual income of biogas adopter and non-adopter households.

3.2. Types of Household Energy Usage Patterns and Cooking Appliances in the Study Area

Households were asked about the types of fuel sources for baking injera and stew and lighting. The types of fuel used for cooking and lighting are presented in Table 3. The dominant source of energy used for baking injera was firewood, which accounted for 85.4%. Only 11.2% use firewood and crop residue, and 3.4% use electric power for baking Injera. Only a few households depend solely on electricity for their cooking. The study also found that most households (87%) used firewood and crop residue for making stew and coffee. The remaining 9.8% and 2.5% of households used charcoal and electric power, respectively. Regarding types of cook stoves, the majority of the respondents 363 (88.3%) of them use three stone stoves and a few of them 48 (11.7%) used improved cook stoves. For lighting purposes, 283 (68.9%) used solar energy, 98 (23.8%) of them used kerosene, and the remaining 24 (5.84%), 3 (0.73%), and 3 (0.73%) respondents used electric power and candles, firewood, and biogas for lighting, respectively. Most respondents still rely on traditional three-stone stoves (363 (88.3%)) for cooking, and only 48 (11.7%) of them use improved biomass cook stoves and electric stoves for cooking.

3.3. Household Annual Energy Consumption Pattern

The study shows that (Table 4) households responded that, on average, they collect firewood 2.25 times per week. This implies that 2.25 loads of firewood were consumed per household per week in the study area. By considering the 25 kg weight of one load of firewood, about 56 kg of firewood were consumed per week by the household. On average household consumes about 2952 kg of biomass (firewood, crop residue, charcoal, and animal dung), 18.2 L of kerosene, and 18.2 KWh of electricity per year.

3.4. Sources of Firewood and Distance Traveled for Collection

Table 5 shows the distances traveled by the households for firewood collection in one-way trips. Accordingly, 26.5% of households traveled <2 km, the majority of them (66.6%) traveled 2–4 km, and a few of them (6.8%) have traveled greater than 4 km to collect firewood. Households were asked about the sources of biomass fuel used for domestic consumption. Accordingly, 51.1% of the households reported that they collect firewood from trees on farmland, followed by 39.0% collecting from public forests, and about 3% of the respondents responded that they purchase their firewood.

Table 3. Types of fuel used for cooking, lighting, and types of cookstoves.

Types of Energy Used for Baking Injera	Frequency	Percent
Firewood only	351	85.4
Firewood and crop residue	46	11.2
Electric power and firewood	14	3.4
Types of Energy used for cooking		
Firewood and crop residue	358	87
Biogas	3	0.73
Charcoal	40	9.77
Electric power	10	2.5
Types of energy for lighting		
Solar	283	68.9
Kerosene	98	23.8
Electric power and candle	24	5.84
Firewood	3	0.73
Biogas	3	0.73
Types of cooking stoves		
Three stone stoves	363	88.3
Improved cook stoves (mirt mitad) and electric stoves	48	11.7

Table 4. Household energy consumption pattern in the study area.

Sources of Energy	Daily Consumption/ Household	Weekly Consumption/ Household	Annual Consumption/ Household
Firewood (Kg)	8	56	2912
Crop residue (Kg)	0.08	0.56	29.12
Charcoal (Kg)	0.02	0.14	7.28
Animal dung (Kg)	0.01	0.07	3.64
Kerosene (L)	0.04	0.28	14.56
Electricity (KWh)	0.05	0.35	18.2

Table 5. Sources of firewood and distance traveled for collection (one-way trip).

Distance Traveled for Firewood Collection	Frequency	Percent
≤2 Km	109	26.5
2.1–3 Km	137	33.3
3.1–4 Km	137	33.3
>4 Km	28	6.8
Sources of firewood		
Public forest	160	39.0
Planted tree	14	3.4
Virgin land	15	3.6
Trees on farmland	210	51.1
From market	12	2.9

3.5. Households' Biogas Energy Potential

3.5.1. Biogas Potential from Animal Dung

Data on the number of cows, goats, sheep, and chickens was collected during the household survey. The average number of cows, goats, sheep, and chickens per household in the study area was 5.3, 0.24, 2.7, and 4.4, respectively (Table 6). The annual total dung collected from each animal was calculated by multiplying the total production per year by the number of heads of different animals.

Table 6. Potential of livestock manure for biogas energy production.

Livestock	Ave. Fresh Dung kg/d/Animal	Number of Livestock	Total Fresh Manure (kg/d)	Collectible Manure (kg/d)	Total DM (kg/d)	Biogas (m^3/kg) DM	Total Biogas (m^3/d)	Total Biogas (m^3/y)
Cattles	4.5	2184	9830	7860	1314	0.24	315	114,975
Sheep's	1	1123	1120	560	172	0.37	64	23,360
Goats	1	102	100	50	15	0.37	5.6	2044
Chickens	0.08	1806	140	70	21.5	0.4	8.6	3139
Total	**6.58**	**5215**	**11,190**	**8540**	**1523**	**1.38**	**393.2**	**143,518**

The expected biogas potential from animal livestock manure was 11.2 tons/day and its biogas production capacity is 549 m^3/day. This implies that the available livestock's manure potential can generate 1.3 m^3 of biogas per day at each household. By considering the collection efficiency of 80% for cattle and 50% for chicken, goat, and sheep manure, households can produce 8.54 ton/day and generate daily about 393 m^3 biogas. From this, it can be concluded that the available livestock biogas energy potential in the study area can generate 0.96 m^3/household/day.

3.5.2. Crop Residue Energy Potential in the Study Area

The average land size per household was obtained from the corresponding household survey, which gives an average farmland size of 1.63 hectares per household. The estimation of crop residue for energy sources was quantified by assuming 40% collection efficiency. Accordingly, the collectible (technical) crop residue biomass energy potential was 1146 tons. This implies that annually, 2.8 tons of technical biomass energy can be generated from crop residues at each household. The annual cereals crop residues potential is presented in Table 7.

Table 7. Annual cereals crop residues potential.

Types of Crops	Land Size (ha)	Share of Land Coverage (%)	Crop Yield (t/ha)	RPR	Theoretical Residues (t/ha)	Collectible Crop Residues (t/ha)	Collectible Crop Residue (t)
Maize	459	62	3	1.4	4.2	1.7	780
Sorghum	229	31	2.1	1.5	3.2	1.3	298
Teff	30	4	1.8	2.3	4.1	1.6	48
Wheat	7.4	1	2.1	1.3	2.7	1	7.4
Barley	7.4	1	1.8	1.3	2.3	0.9	6.7
Other	7.4	1	1.5	1.3	2	0.8	5.92
Total/Av	740	100	2	1.5	3	1.2	1146

Calculation based on (CSA, 2014); t = ton, ha = hectare, RPR = residue to product ratio.

3.5.3. Human Waste (Urine and Feces) Potential for Biogas Production

The expected biomass energy potential from the human feces of sample households was 0.58 tons/day and its biogas production capacity is 29 m^3/day. This implies that it is possible to produce 0.07 m^3/household/day biogas from human feces. However, due to the movements of people from place to place, the collection of human waste for energy would be difficult. By considering 60% of the collection efficiency of human feces and urine, it is possible to produce 0.042 m^3 of biogas per household per day. On average, 1.5 L of urine can be produced per person per day, or 5 L collectable urine per household per day which can be used for biogas production and agricultural purposes. The potential for human waste based energy is presented in Table 8.

Table 8. The potential for human waste energy from selected households.

	Sampled Kebele	Sampled Households	Average Family Size	Sampled Population	Total Fresh Feces kg/day	Total DM in kg/Days	Total Biogas m^3/day
1	Kossa Geshe	84	5.6	470	118	30	6
2	Dengaja sole	150	5.6	840	210	53	11
3	Yatu Tirgi	75	5.6	420	105	26	5
4	Chaffe Elfata	102	5.6	571	143	36	7
	Total	411		2301	576	145	29

3.6. Water Sources and Distance Traveled for Its Collection

The study found that the dominant source of water for about 89.8% of sample households was spring water, and only 9% of the households have access to public standing pipe water. Moreover, about 68% of the households have access to water sources within a walking distance of less than 1 km for a one-way trip. The sources of households' water supply and distance to water sources are presented in Table 9.

Table 9. Households' average distances to water sources (one-way trip).

Sources of Water for Domestic	Frequency	Percent
Spring	369	89.8
Pipe	37	9.0
Bore hole (birr)	3	0.7
River	2	0.5
Distance traveled to water sources		
≤0.1 km	35	8.5
0.1 km–0.5 km	112	27.3
0.6 km–1 km	135	32.8
1.1 km–1.5 km	116	28.2
1.6 km–2 km	13	3.2

3.7. Reasons for Not Adopting Biogas Technologies

Non-biogas adopters have asked why they did not adopt biogas technologies. Accordingly, 25.8% of the households responded that they had information about the importance of biogas but were not interested in adopting it. They reported that they prefer solar energy to biogas. The reasons they cited for not adopting the biogas technology include a lack of cattle, the high cost of biogas installation, and the nonfunctioning of biogas technology installed by neighbors. Furthermore, 74.2% of the surveyed households have no prior information about biogas technology and its benefits. Nevertheless, 17.4% of the households have an interest in adopting biogas technology, but they raised the issue of a lack of access roads to supply construction materials. About 43% reported that they do not have information about the procedures to construct biogas plants; 28.5% complained about the high installation cost; and 11.1% raised the problem of a lack of labor for its daily operation (Table 10).

Moreover, the local water and energy office responsible for household energy supply also supported the lack of transportation facilities for the promotion of the biogas technology, the inadequacy of the budget to provide material support for households, and the lack of after-sale service for non-functional biogas maintenance. An increase in the costs of construction materials was also raised as one of the main problems affecting the adoption of biogas technology. Moreover, 34.4% of the installed biogas was not functioning during the survey. Accordingly, 72.7% of the households reported a lack of maintenance services, and 27.3% reported a lack of accessories for their maintenance. Moreover, a field observation during the survey showed that 25 (78.1%) of biogas users do not use bio-slurry for fertilizer, and 27 (84.4%) did not get sufficient technical support from the agricultural development agent to use the bio-slurry for fertilizer. Figure 2 showing the status of installed biogas technologies in the study areas.

Table 10. Households' reasons for not adopting biogas technology.

Reason for Not Adopting Biogas Technology	Frequency (Yes)	Percent
Having information about the benefits of biogas energy	106	25.8
Reasons for not adopting biogas energy technology		
I prefer other energy like solar rather than biogas	22	20.8
Lack of sufficient cattle	12	11.3
The cost of biogas installation is high	28	26.4
Neighbors' biogas is not functional	34	32.1
Access to electric power	10	9.4
Challenges related to biogas adoption		
No accessible road to supply construction materials	53	17.4
Lack of information about the procedures	131	43
High installation cost	87	28.5
Lack of labor for daily operation/feeding	34	11.1

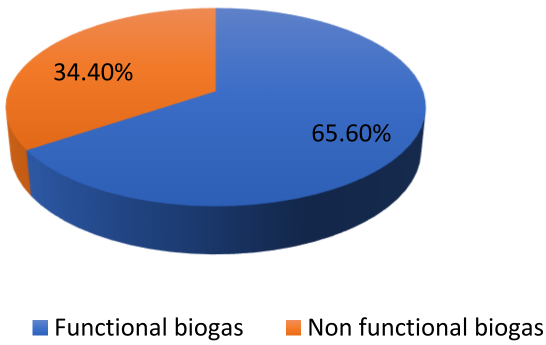


Figure 2. Status of installed biogas in the study area.

The results from the multi-regression show that household family size, gender, educational level of the household, annual income of households, distance traveled to firewood collection, the number of cattle, and age of the household were the main determinant factors for biogas adoption.

Multi linear regression results presented in Table 11 show the statistical significance of the association of biogas technology adoption with gender ($p = 0.019$), educational level ($p = 0.006$), household income ($p = 0.000$), availability of firewood in nearby places ($p = 0.007$) and age of the household ($p = 0.047$). Household family size, number of cattle, and land holding size did not show a significant statistical association with households' adoption of biogas.

Table 11. Factors determining adoption of biogas technologies.

Variables	Unstandardized Coefficients		Standardized Coefficients	T-Test	Sig.
	B Std. Error			Beta	
Households Family size	0.12	0.014	0.034	0.859	0.391
Gender	0.189	0.068	0.046	1.307	0.019
The educational level of households	0.257	0.014	0.172	1.779	0.006
Income of households	0.31	0.005	0.298	6.269	0
Availability of firewood	0.371	0.013	0.099	2.722	0.007
Number of cattle	0.08	0.16	0.176	4.707	0.214
Land Size	0.19	0.007	0.535	14.199	0.146
Age of households	0.018	0.009	0.101	1.994	0.047

4. Discussion

This study evaluated the household's energy consumption pattern, the household's biomass energy potential, and the situation for adoption of biogas energy technologies.

The study shows that over 96% of households rely on the traditional use of biomass energy for cooking, and over 65% of them collect firewood by travelling 2–4 km. These have significant implications for the socioeconomic conditions of households and the local environment. Particularly, women who shoulder household chores are at a disadvantage and deprived of several social and economic opportunities. However, the majority of households have sufficient biomass energy resources that can be used for improved biomass energy technologies such as biogas. It has been shown that households, on average, can technically produce 1 m^3 of biogas per day from different biomass energy sources. This amount is sufficient to light a 60–100-watt bulb for 6 h, can cook three meals for a family of 5–6, replace 0.7 kg of petroleum, run a one-horsepower motor for 2 h, and generate 1.25 kWh of electricity [38,39]. 1 m^3 of biogas can replace 5.56 kg of firewood per day, or 2029 kg of firewood per year. Accordingly, this amount can satisfy about 70% of the household's biomass energy demand for cooking (Table 4). Moreover, if all the available biomass energy potential of the study area can be converted to biogas energy, it can save about 9600 tons of firewood from the study area. This indicated that biogas also reduces the increasing deforestation occurring due to heavy firewood consumption. Therefore, using the existing resource for biogas energy can reduce 69% of end-user emissions and deforestation due to firewood consumption.

The adoption of biogas technology in households would directly contribute to the attainment of different SDGs in addition to SDG 7. Biogas technology can reduce the heavy dependence of households on biomass-based energy sources by providing readily available gas for cooking, lighting, and powering elementary electric appliances with minimal emissions. The use of biogas slurry for fertilizers can improve soil nutrients, increase productivity, and contribute to SDG 2. Furthermore, in addition to increasing soil productivity, it can save households expenditure for inorganic fertilizers. This will improve food production, reduce hunger and malnutrition, and enhance sustainable agricultural practices. The substitution of firewood by biogas can reduce indoor air pollutant emissions and improve health, especially for women and children who spend a lot of time in the kitchen, thus contributing to SDG 3. Anaerobic digestion can eliminate pathogens from waste and contribute to SDG 6 by reducing the burden of wastewater discharged into water bodies and ensuring water availability for other uses. The use of biodegradable waste as a biogas energy source reduces the amount of nutrients that would have caused environmental pollution in water bodies, thus contributing to SDG 15.

Ethiopia, being an energy-deficient country, has a strong interest in the development of its abundant renewable energy resources [40]. Moreover, it was suggested that the dire energy needs of the country can be addressed by decentralized bioenergy generation [41]. Apart from reducing energy poverty, biogas technology has substantial economic, environmental, health, and social importance. However, adoption of biogas technologies can be affected by several factors, as indicated in our results (Table 11). It has been shown that household gender, level of education, annual income, and distance to firewood collection were the main determinant factors for biogas adoption. Previous studies also reported family size [42,43], gender [44], level of education [45], household income [45,46], distance to firewood source [47,48], number of cattle [49], and land holding size [50] as main determinants for biogas technology adoption. This implies that access to biogas technology requires an overarching policy and strategy to alleviate these problems and enhance its adoption.

Our study did not show a statistically significant association between household family size and the adoption of biogas technology. A previous study also reported a mixed influence of family size on bio gas adoption [43]. It is believed that more family members are important for the operation and maintenance of the biogas plant. However, the insignificant effect of family size on the adoption of the biogas technology in the study area might be explained by the reliance on daily laborers rather than family members. Since the study area is a cash crop producing area, the family members might engage in different activities than biogas operations. However, one of the main challenges to biogas adoption and operation is its labor costs. In particular, a biogas operation involving dung, water, and slurry collection is labor-intensive and may not be feasible in rural areas where household members have a lot of task division and responsibilities [51].

The adoption of biogas technology can be negatively or positively affected by the gender of the head of the household. Several studies have shown that gender plays a crucial role in the adoption of biogas technology [22,44,52]. Our study revealed that all the household heads of biogas adopters are male headed. This might be because men are decision-makers in economic activities in general and energy plant adoption in an area. Similarly, a previous study conducted in Ethiopia showed that male-headed households were more likely to adopt the technology than female-headed households [22,53,54]. In contrast, one of the previous studies showed the significant influence of female-headed households decisions on biogas plant installation [28]. The decision of the household to adopt biogas technology could be linked to their ability to afford the costs of its installation. Our study showed the significant effects of a household's annual income on biogas adoption. This is supported by previous studies showing the significant association between household income and biogas technology adoption [46,54,55]. This might be due to the fact that high income facilitates the adoption of biogas technology, which requires a high initial cost for the installation of biogas digesters [56–58]. Availability and distance to fuel wood sources thus positively influence the adoption and utilization of biogas technology [58]. The result of our study shows that the availability of firewood in nearby places had a significant effect on biogas technology adoption. Similarly, a previous study showed that adoption of biogas technology was positively correlated with the availability of firewood [20,28,52]. This implies that households having access to free biomass energy collected from common sources may not be interested in paying for improved energy technologies.

5. Conclusions

The majority of the households in the study area depend on the traditional use of biomass energy for cooking. Heavily relying on the traditional use of biomass energy has huge socioeconomic and environmental implications. Nevertheless, the majority of households have sufficient biomass energy sources that could be converted to biogas and used for cooking. However, several factors are still restricting households from adopting biogas technologies. Biogas technology is more likely to be adopted by households with better socio-economic status and available resources. Households with a higher income can afford higher initial investment costs and costs of maintenance. Increasing all household income within a short period of time to afford biogas technology may not be realistic and feasible. However, connecting biogas energy technology with households' income-generation activities would likely contribute to both increasing income and the adoption of biogas technologies. Therefore, this study suggests that the government should work on improving the adoption of biogas technologies through connections to income generation activities based on the local socioeconomic context. Moreover, improving the awareness of the community, arranging financial access, and training biogas technicians, especially from the local community, would increase the adoption of the technology. In addition, future research should evaluate the cost effectiveness of such technologies to convince the community to adopt the biogas technology.

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References

1. Amigun, B.; Sigamoney, R.; von Blottnitz, H. Commercialisation of biofuel industry in Africa: A review. *Renew. Sustain. Energy Rev.* **2008**, *12*, 690–711. [CrossRef]
2. Chaturvedi, V.; Hejazi, M.; Edmonds, J.; Clarke, L.; Kyle, P.; Davies, E.; Wise, M. Climate mitigation policy implications for global irrigation water demand. *Mitig. Adapt. Strateg. Glob. Chang.* **2015**, *20*, 389–407. [CrossRef]
3. Shaaban, M.; Petinrin, J. Renewable energy potentials in Nigeria: Meeting rural energy needs. *Renew. Sustain. Energy Rev.* **2014**, *29*, 72–84. [CrossRef]
4. World Health Organization. *Increasing Access to Clean Cooking through Subsidies*; World Health Organization: Geneva, Switzerland, 2022.
5. International Energy Agency. *World Energy Outlook 2018*; International Energy Agency: Paris, France, 2018.
6. Conti, J.; Holtberg, P.; Diefenderfer, J.; LaRose, A.; Turnure, J.T.; Westfall, L. *International Energy Outlook 2016 with Projections to 2040*; USDOE Energy Information Administration (EIA): Washington, DC, USA, 2016.
7. Rosillo-Calle, F. A review of biomass energy-shortcomings and concerns. *J. Chem. Technol. Biotechnol.* **2016**, *91*, 1933–1945. [CrossRef]
8. Obure, D. Realising Sustainable Use of Biomass Energy in Kenya: Appraising the Regulatory and Institutional Framework. *J. Confl. Manag. Sustain. Dev.* **2022**, *8*, 193–217.
9. OECD; IEA. *Energy and Air Pollution: World Energy Outlook Special Report 2016*; International Energy Agency: Paris, France, 2016.
10. Berhanu, M.; Jabasingh, S.A.; Kifile, Z. Expanding sustenance in Ethiopia based on renewable energy resources–A comprehensive review. *Renew. Sustain. Energy Rev.* **2017**, *75*, 1035–1045. [CrossRef]
11. Hailu, A.D.; Kumsa, D.K. Ethiopia renewable energy potentials and current state. *AIMS Energy* **2021**, *9*, 1–14. [CrossRef]
12. Mondal, M.A.H.; Bryan, E.; Ringler, C.; Rosegrant, M. Ethiopian power sector development: Renewable based universal electricity access and export strategies. *Renew. Sustain. Energy Rev.* **2017**, *75*, 11–20. [CrossRef]
13. The World Bank. *World Development Report 2015: Mind, Society, and Behavior*; The World Bank: Washington, DC, USA, 2014.
14. Tucho, G.T.; Weesie, P.D.; Nonhebel, S. Assessment of renewable energy resources potential for large scale and standalone applications in Ethiopia. *Renew. Sustain. Energy Rev.* **2014**, *40*, 422–431. [CrossRef]
15. Mondal, M.; Alam, H.; Gebremeskel, A.G.; Gebrehiwot, K.; Ringler, C. *Ethiopian Universal Electrification Development Strategies*; The International Food Policy Research Institute: Ethiopia, Easte Africa, 2018.
16. Bruce, N.; Pope, D.; Rehfuess, E.; Balakrishnan, K.; Adair-Rohani, H.; Dora, C. WHO indoor air quality guidelines on household fuel combustion: Strategy implications of new evidence on interventions and exposure–risk functions. *Atmos. Environ.* **2015**, *106*, 451–457. [CrossRef]
17. Baloch, M.A.; Meng, F. Modeling the non-linear relationship between financial development and energy consumption: Statistical experience from OECD countries. *Environ. Sci. Pollut. Res.* **2019**, *26*, 8838–8846. [CrossRef] [PubMed]
18. Wang, Z. Does biomass energy consumption help to control environmental pollution? Evidence from BRICS countries. *Sci. Total Environ.* **2019**, *670*, 1075–1083. [CrossRef]
19. Kyayesimira, J.; Florence, M. Health concerns and use of biomass energy in households: Voices of women from rural communities in Western Uganda. *Energy Sustain. Soc.* **2021**, *11*, 1–13. [CrossRef]
20. Kamp, L.M.; Forn, E.B. Ethiopia's emerging domestic biogas sector: Current status, bottlenecks and drivers. *Renew. Sustain. Energy Rev.* **2016**, *60*, 475–488. [CrossRef]
21. Kelebe, H.E.; Olorunnisola, A. Biogas as an alternative energy source and a waste management strategy in Northern Ethiopia. *Biofuels* **2016**, *7*, 479–487. [CrossRef]
22. Mengistu, M.G.; Simane, B.; Eshete, G.; Workneh, T.S. Factors affecting households' decisions in biogas technology adoption, the case of Ofla and Mecha Districts, northern Ethiopia. *Renew. Energy* **2016**, *93*, 215–227. [CrossRef]
23. Nevzorova, T.; Kutcherov, V. Barriers to the wider implementation of biogas as a source of energy: A state-of-the-art review. *Energy Strategy Rev.* **2019**, *26*, 100414. [CrossRef]
24. Challa, T.G. Assessment of Alternative Rural Energy Sources and Technologies in South-Eastern Oromia Region, Ethiopia. *J. Energy Technol. Policy* **2019**, *5*. [CrossRef]
25. Gebreegziabher, Z. *Household Fuel Consumption and Resource use in Rural-Urban Ethiopia*; Wageningen University and Research: Wageningen, The Netherlands, 2007.
26. Benti, N.E.; Gurmesa, G.S.; Argaw, T.; Aneseyee, A.B.; Gunta, S.; Kassahun, G.B.; Aga, G.S.; Asfaw, A.A. The current status, challenges and prospects of using biomass energy in Ethiopia. *Biotechnol. Biofuels* **2021**, *14*, 209. [CrossRef]
27. Jain, S.; Newman, D.; Nizhou, A.; Dekker, H.; Le Feuvre, P.; Richter, H.; Gobe, F.; Morton, C.; Thompson, R. *Global Potential of Biogas*; World Biogas Association: London, UK, 2019.
28. Kabir, H.; Yegbemey, R.N.; Bauer, S. Factors determinant of biogas adoption in Bangladesh. *Renew. Sustain. Energy Rev.* **2013**, *28*, 881–889. [CrossRef]
29. Kelebe, H.E. Returns, setbacks, and future prospects of bio-energy promotion in northern Ethiopia: The case of family-sized biogas energy. *Energy Sustain. Soc.* **2018**, *8*, 30. [CrossRef]
30. Marie, M.; Yirga, F.; Alemu, G.; Azadi, H. Status of energy utilization and factors affecting rural households' adoption of biogas technology in north-western Ethiopia. *Heliyon* **2021**, *7*, e06487. [CrossRef] [PubMed]
31. *Limmu Kossa Woreda Electric Utility Office Report*; Ethiopian Electric Utility: Jimma, Ethiopia, 2020.

32. Ahmar, M.; Ali, F.; Jiang, Y.; Wang, Y.; Iqbal, K. Determinants of Adoption and the Type of Solar Technology Adopted in rural Pakistan. *Front. Environ. Sci.* **2022**, *10*, 895622. [CrossRef]
33. Rose, C.; Parker, A.; Jefferson, B.; Cartmell, E. The characterization of feces and urine: A review of the literature to inform advanced treatment technology. *Crit. Rev. Environ. Sci. Technol.* **2015**, *45*, 1827–1879. [CrossRef] [PubMed]
34. Batzias, F.; Sidiras, D.; Spyrou, E. Evaluating livestock manures for biogas production: A GIS based method. *Renew. Energy* **2005**, *30*, 1161–1176. [CrossRef]
35. Maithel, S. Biomass Energy: Resource Assessment Handbook. 2009. Available online: https://www.apctt.org/sites/default/files/2020-08/Biomass%20Energy%20Resource%20Assessment%20Handbook.pdf (accessed on 10 February 2023).
36. Roubík, H.; Mazancová, J.; Phung, L.; Dung, D. Quantification of biogas potential from livestock waste in Vietnam. *Agron. Res.* **2017**, *15*, 540–552.
37. Tucho, G.T.; Nonhebel, S. Bio-Wastes as an Alternative Household Cooking Energy Source in Ethiopia. *Energies* **2015**, *8*, 9565–9583. [CrossRef]
38. Andriani, D.; Wresta, A.; Saepudin, A.; Prawara, B. A review of recycling of human excreta to energy through biogas generation: Indonesia case. *Energy Procedia* **2015**, *68*, 219–225. [CrossRef]
39. Kristoferson, L.A.; Bokalders, V. *Renewable Energy Technologies: Their Applications in Developing Countries*; Elsevier: Amsterdam, The Netherlands, 2013.
40. Gabisa, E.W.; Gheewala, S.H. Potential, environmental, and socio-economic assessment of biogas production in Ethiopia: The case of Amhara regional state. *Biomass Bioenergy* **2019**, *122*, 446–456. [CrossRef]
41. Gabisa, E.W.; Gheewala, S.H. Potential of bio-energy production in Ethiopia based on available biomass residues. *Biomass Bioenergy* **2018**, *111*, 77–87. [CrossRef]
42. Lwiza, F.; Mugisha, J.; Walekhwa, P.N.; Smith, J.; Balana, B. Dis-adoption of household biogas technologies in Central Uganda. *Energy Sustain. Dev.* **2017**, *37*, 124–132. [CrossRef]
43. Sarker, S.A.; Wang, S.; Adnan, K.M.; Sattar, M.N. Economic feasibility and determinants of biogas technology adoption: Evidence from Bangladesh. *Renew. Sustain. Energy Rev.* **2020**, *123*, 109766. [CrossRef]
44. Florkowski, W.J.; Us, A.; Klepacka, A.M. Food waste in rural households support for local biogas production in Lubelskie Voivodship (Poland). *Resour. Conserv. Recycl.* **2018**, *136*, 46–52. [CrossRef]
45. Shallo, L.; Ayele, M.; Sime, G. Determinants of biogas technology adoption in southern Ethiopia. *Energy Sustain. Soc.* **2020**, *10*, 1. [CrossRef]
46. Rahman, M.S.; Majumder, M.K.; Sujan, M.H.K. Adoption determinants of biogas and its impact on poverty in Bangladesh. *Energy Rep.* **2021**, *7*, 5026–5033. [CrossRef]
47. Ahmad, M.; Wu, Y. Household-based factors affecting uptake of biogas plants in Bangladesh: Implications for sustainable development. *Renew. Energy* **2022**, *194*, 858–867. [CrossRef]
48. Meeks, R.; Sims, K.R.; Thompson, H. Waste not: Can household biogas deliver sustainable development? *Environ. Resour. Econ.* **2019**, *72*, 763–794. [CrossRef]
49. Moli, D.R.R.; Hafeez, A.G.; Majumder, S.; Mitra, S.; Hasan, M. Does biogas technology adoption improve the livelihood and income level of rural people? *Int. J. Green Energy* **2021**, *18*, 1081–1090. [CrossRef]
50. Ngcobo, L.; Obi, A.; Mamphweli, S.; Zantsi, S. Adoption and perceptions of biogas: Empirical evidence from rural households of Melani village in Raymond Mhlaba municipality. *Afr. J. Sci. Technol. Innov. Dev.* **2022**, *14*, 350–358. [CrossRef]
51. Tucho, G.T.; Moll, H.C.; Schoot Uiterkamp, A.J.M.; Nonhebel, S. Problems with Biogas Implementation in Developing Countries from the Perspective of Labor Requirements. *Energies* **2016**, *9*, 750. [CrossRef]
52. Jan, I.; Akram, W. Willingness of rural communities to adopt biogas systems in Pakistan: Critical factors and policy implications. *Renew. Sustain. Energy Rev.* **2018**, *81*, 3178–3185. [CrossRef]
53. Geddafa, T.; Melka, Y.; Sime, G. Determinants of Biogas Technology Adoption in Rural Households of Aleta Wondo District, Sidama Zone, Southern Ethiopia. *J. Energy* **2021**, *2021*, 9934942. [CrossRef]
54. Katuwal, H. Biogas adoption in Nepal: Empirical evidence from a nationwide survey. *Heliyon* **2022**, *8*, e10106. [CrossRef] [PubMed]
55. Bedana, D.; Kamruzzaman, M.; Rana, M.J.; Mustafi, B.; Talukder, R.K. Financial and functionality analysis of a biogas plant in Bangladesh. *Heliyon* **2022**, *8*, e10727. [CrossRef] [PubMed]
56. Abbas, T.; Ali, G.; Adil, S.A.; Bashir, M.K.; Kamran, M.A. Economic analysis of biogas adoption technology by rural farmers: The case of Faisalabad district in Pakistan. *Renew. Energy* **2017**, *107*, 431–439. [CrossRef]
57. Amir, S.M.; Liu, Y.; Shah, A.A.; Khayyam, U.; Mahmood, Z. Empirical study on influencing factors of biogas technology adoption in Khyber Pakhtunkhwa, Pakistan. *Energy Environ.* **2020**, *31*, 308–329. [CrossRef]
58. Uhunamure, S.; Nethengwe, N.; Tinarwo, D. Correlating the factors influencing household decisions on adoption and utilisation of biogas technology in South Africa. *Renew. Sustain. Energy Rev.* **2019**, *107*, 264–273. [CrossRef]