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Biogas Quality across Small-Scale Biogas Plants: A Case of Central Vietnam

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Abstract: Production of bioenergy by the fermentation reaction is gaining attraction due to its easy operation and the wide feedstock selection. Anaerobic fermentation of organic waste materials is generally considered a cost-effective and proven technology, allowing simultaneous waste management and energy production. Small-scale biogas plants are widely and increasingly used to transform waste into gas through anaerobic fermentation of organic materials in the developing world. In this research, the quality of biogas produced in small-scale biogas plants was evaluated, as it has a direct effect on its use (as fuel for biogas cookers), as well as being able to influence a decision making process over purchasing such technology. Biogas composition was measured with a multifunctional portable gas analyser at 107 small-scale biogas plants. Complementary data at household level were collected via the questionnaire survey with the owners of biogas plants (n = 107). The average daily biogas production equals 0.499 m^3, not covering the demand of rural households which are using other sources of energy as well. Related to the biogas composition, the mean content of methane (CH_4) was 65.44% and carbon dioxide (CO_2) was 29.31% in the case of biogas plants younger than five years; and CH_4 was 64.57% and CO_2 was 29.93% for biogas plants older than five years. Focusing on the age of small-scale biogas plants there are no, or only minor, differences among tested values. In conclusion, the small-scale biogas plants are sustaining a stable level of biogas quality during their life-span.

Keywords: anaerobic digestion; methane; carbon dioxide; small-scale biogas plants; developing countries

1. Introduction

In developing countries, environmental pollution and access to energy sources still represent challenges, especially in relation to human and environmental health and economic development [1]. Energy influences the status and pace of development; hence, a current challenge for the developing world lies in the available supply of affordable and sustainable eco-friendly renewable energy (SDG 7) [2]. Energy poverty is exhibited by a lack of access to electricity and clean cooking facilities, which are two elements that are essential to meeting basic human needs [3]. Therefore, bioenergy production by fermentation reaction is gaining attraction due to its easy operation and a wide selection of organic wastes feedstock [4]. Anaerobic fermentation of organic materials is generally considered as a major cost-effective and matured technology [5] with its dual benefits as a waste management tool and simultaneous energy production [6]. Small-scale biogas plants are widely and increasingly used to transform waste into valuable gas in the developing world [7,8] and may represent an economically feasible technology [9,10], which is producing biogas as a main product and simultaneously producing digestate (which may be used as fertilizer) as a by-product through waste degradation [9,11].

There are many factors affecting household energy consumption (as well as CO_2 emissions), such as socio-economic factors, household characteristics and geographic factors [12].

The small-scale biogas plants also create a number of indirect environmental, economic, and societal benefits, such as a reduction in deforestation, fewer hours devoted to fuelwood collection or savings on fuelwood/fossil fuels purchasing, decreasing the need to purchase propane for cooking, the creation of jobs, the decrease of organic matter in effluent waters, the decrease of odour, the production of less indoor smoke than other fuels, the production of digestate as a fertilizer and a reduction in greenhouse gas emissions into the atmosphere, if used appropriately [6,7,13–15]. According to Zhang et al. [12] biogas households indicate having over 50% lower greenhouse gas emissions than non-biogas households. Due to above-mentioned benefits, small-scale biogas technology has been widely promoted and financially supported by governments and development aid donors in Asia, including Vietnam [13] Long-term, stable running and maintenance are key points to maximize the benefits of small-scale biogas plant [13,16]. However, if these key points are not met, the benefits of this technology may be compromised [5,13,17].

In comparison to other forms of renewable energy (solar energy, biodiesel, bioethanol, wind energy, etc.) biogas production through small-scale biogas plants is relatively simple, decentralised, and can operate under various conditions in tropical regions, such as Southeast Asia, particularly Vietnam. The most common feedstock material is animal dung or human faeces, as it is usually the most problematic waste material in terms of waste management for rural households [18]. An important advantage of small-scale biogas technology and one of the main reasons for the government support is that the technology is a cost-effective method of reducing greenhouse gas emissions and odours from animal manure, if used properly [13,19]. The biogas produced is mainly used for cooking, heating and lighting, therefore replacing energy sources such as fuelwood, dried dung, coal, or liquid petroleum gas (LPG), commonly used for these purposes in rural households [5,9,13]. It is always difficult to adopt new and unknown digester technology within households. Therefore, recommendations for various models implemented within the country are needed. The design of the biogas plants varies based on geographical locations, availability of feedstock and climatic conditions. The most common types of feedstock for chosen Asian countries can be seen in Table 1. In Asia, the fixed dome model is the most commonly used [5,16]. However, there are two exceptions—Indonesia, where various models were applied according to the regions and islands, and India with a prevailing number of the floating drum model followed by the fixed dome [20].

Table 1. Most common feedstock for small-scale biogas plants in selected Asian countries.

Country	Most Common Feedstock	Reference
Vietnam	Pig manure	[7,21]
Cambodia	Combination of pig manure and cow manure	[22]
Bangladesh	Cow and buffaloes manure	[5,23]
Laos	Cow manure	[24]
Nepal	Cow manure	[25]
India	Livestock manure	[26]
Indonesia	Cow manure	[27,28]

In Vietnam, anaerobic digestion of animal manure has already been practiced since the 1960s [7,10]. Since then its popularity has grown, mainly due to the promotion of this technology by the government and international organizations, e.g., SNV (Netherland Development Organization). The Ministry of Agriculture and Rural Development of Vietnam (MARD), together with SNV (using 10% government subsidy for support of capital costs of small-scale biogas technology), installed between 2003 and 2013 over 200,000 small-scale biogas plants [5,29]. The follow-up biogas programme by SNV and

MARD aimed to build 140,000 biogas digesters between 2006 and 2011. The current number of small-scale biogas plants in Vietnam is more than 500,000 [30]. The target was reached, and digesters serve over 600,000 people with cooking fuel with CO_2 savings of around 260,000 tons per year [31]. However, in Vietnam, the biogas technology is still far below its potential for utilizing available livestock and agricultural wastes [30].

As the small-scale biogas technology is one of the fastest growing and highly promising renewable energy sources, mainly for rural households, the main objective of this paper is to evaluate the quality of biogas produced in the small-scale biogas plants installed in central Vietnam in terms of chemical and physical parameters in relation to the age of installed biogas plants. The quality of biogas has a direct effect on its use (as fuel for biogas cookers), which may, in return, influence an individual decision of purchasing such a technology. Furthermore, biogas quality evaluation is needed to provide sufficient information for authorities to have their future policy decisions well supported.

2. Materials and Methods

The research was carried out in two districts, Huong Tra and Phong Dien, Thua Thien Hue Province, in Central Vietnam (Figure 1). Huong Tra is a rural district in the northern part of the central coast of Vietnam with a population of over 115,000 inhabitants covering an area of 521 km^2. The district is located on the northern outskirts of Hue (provincial city of Thua Thien Hue province) and can, therefore, be considered as a peri-urban area. Phong Dien has a population over 105,000 inhabitants and covers an area of 954 km^2. The district has a varied topography with mountains, plains, and coastline.

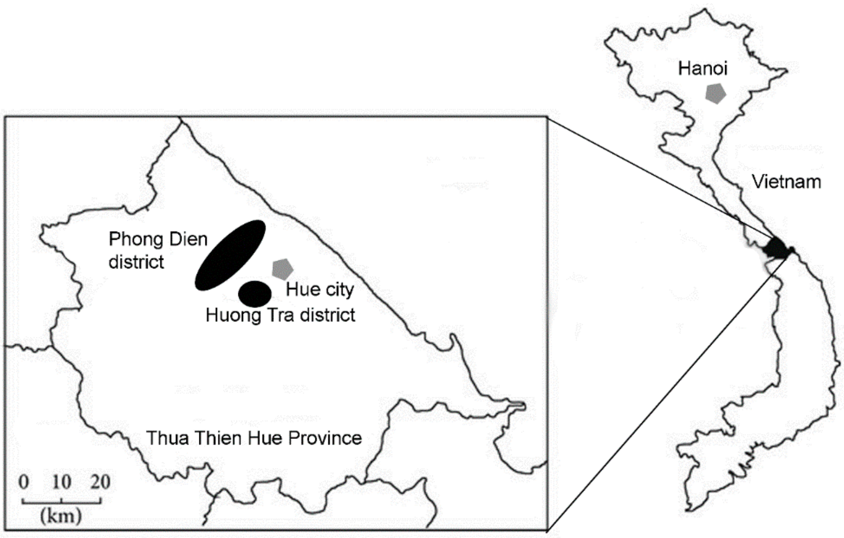
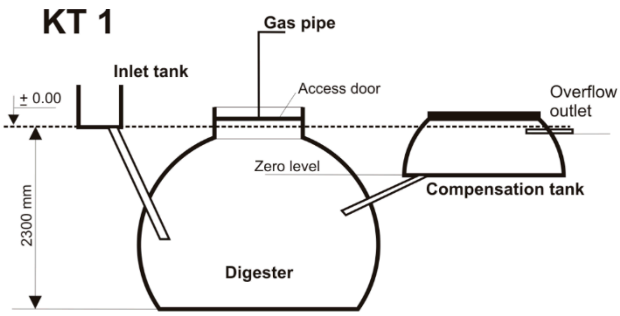


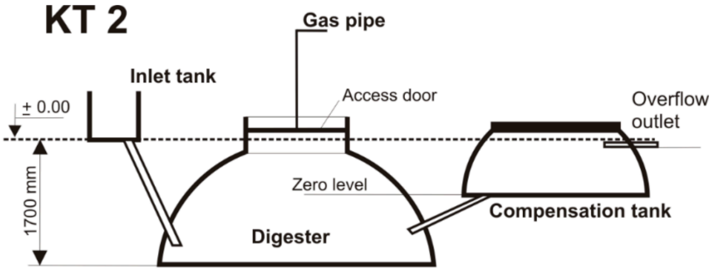
Figure 1. Thua Thien Hue province and the target area.

2.1. Description of Biogas Technology in Target Area

The study was done on two types of small-scale biogas plants, specifically KT1 (Figure 2a) and KT2 (Figure 2b). Both types are predominant in the target area. Both types are varieties of the Chinese fixed dome, where KT1 is an appropriate type for a good structure of soil to be easily excavated. KT2 is used in places where soil excavation is difficult or where high levels of groundwater or floods are reported. Both types are unheated and usually built underground, in order to minimize the temperature fluctuations and for space saving reasons. The digester is filled in through the inlet tank and the inlet pipe. The produced biogas is accumulated at the upper part of the digester and the difference between the slurry inside the digester and the digestate in the compensation tank creates a gas pressure. The slurry flows back into the digester from the compensation tank after the gas is released through the gas pipe. Both types and their potential problems are described in detail in the study by [21]. The Vietnamese small-scale biogas plants operate at the temperature of the surrounding soil as they are built underground. The time of the year significantly influences temperatures in the air, the slurry mixing tank, the soil, and the digesters. The average summer temperatures in Central Vietnam are around 34 °C (mesophilic conditions), creating a suitable environment for the bacterial fermentation; however, during winter time the temperature is in the range of 15–25 °C, which might cause lower biogas production [9,32].



(**a**)



(**b**)

Figure 2. (**a**) Small-scale biogas plant—fixed dome model (KT1). Reprinted from [21]. (**b**) Small-scale biogas plant—fixed dome model (KT2). Reprinted from [21].

2.2. Data Collection—Questionnaire Survey

The questionnaire survey was carried out with the owners of small-scale biogas plants from June to July 2013. Biogas plants were randomly selected from recipients of government subsidies (n = 107; corresponding to 20% share of total subsidy recipients in the area) listed by the local unit of the Ministry of Agriculture and Rural Development. The recipients were, at the same time, beneficiaries of one of two running projects on building small-scale biogas plants—one supported by the SNV, the other one by the Czech Development Agency (CzDA). The questionnaire included nine questions (Table 2). Furthermore, the data results were cross-checked with the local facilitators during field trips in July and August 2016 in order to increase their validity and reliability.

Table 2. Overview of variables in the questionnaire.

Variable	Type of the Question	Value	Unit
Capacity of the digester	Close-ended question	No.	m^3
Investor of the construction	Close-ended question	SNV/CzDA	-
Digester type	Close-ended question	KT1/KT2	-
Digester connection to the toilet	Open-ended question	-	-
Animal stable	Open-ended question	-	-
Feedstock materials for the BGP	Open-ended question	-	-
No. of animals	Open-ended question	No.	Heads
No. of other applications powered by biogas	Open-ended question	No.	-
Digestate practices	Open-ended question	-	-

2.3. Data Collection—Biogas Composition

There are many analytical methods for biogas quality evaluation based on its final use [33] From the technical point of view, the most important parameter is the content of the potentially corrosive components (oxygen, hydrogen, water, carbon dioxide, hydrogen sulphide, and chlorine and fluorine compounds) [34,35]. Biogas composition was measured using a GA5000 multifunctional portable gas analyser (Geotech, Leamington Spa, UK), which is adapted to measurements of CH_4, CO_2, O_2, H_2, and H_2S with the following measurement accuracy of: CH_4 (0–70 vol % $\pm$ 0.5%), CH_4 (70–100 vol % $\pm$ 1.5%), CO_2 (0–60 vol % $\pm$ 0.5%), CO_2 (60–100 vol % $\pm$ 1.5%), O_2 (0–25 vol % $\pm$ 1.0%), H_2S (0–5000 ppm $\pm$ 2.0%), and H_2S (0–10,000 ppm $\pm$ 5.0%). For measurements of media (CH_4/CO_2) a dual-wavelength infrared sensor was used, for O_2/H_2S an internal electrochemical sensor was used. The measurements were taken upstream of the H_2S filter to eliminate measurement inaccuracies. Obtained values are the mean of three measurements in the interval of one hour at each biogas plant. Calorific values were set as the quantity of heat produced by complete combustion of a unit of a combustible compound. In total, the measurements were taken in 81 KT1 small-scale biogas plants and 26 KT2 small-scale biogas plants at districts Huong Tra (n = 49) and Phong Dien (n = 58), Thua Thien Hue Province.

2.4. Data Analysis

The collected data were categorized, coded, and analysed with descriptive and inferential statistics using the SPSS version 18. Effects of variables such as type of biogas plant, age of the biogas plant, and size of the biogas plant on biogas composition were analysed by the analysis of covariance model. Dummy variables included the type of biogas plant (KT1 and KT2), the age of the biogas plant (>5 years old and <5 years old), and a continuous variable of the size of the biogas plants (m^3).

$$Y_i = \alpha + \beta x_1 + \gamma_1 D_{i1} + \gamma_2 D_{i2} + \varepsilon_i \quad (1)$$

Y_i = Biogas composition;
α = Intercept;
x_1 = Biogas plant size (m^3);
D_{i1} = Biogas plant types (D_{i1} = 1 = KT2; D_{i1} = 0 = KT1);
D_{i2} = Biogas plant age (D_{i2} = 1 5 years; D_{i1} = 0 $\geq$ 5 years);
β = Regression coefficient of biogas plant size on biogas composition;
γ_1 = The difference of biogas composition between KT2 and KT1;
γ_2 = The difference of biogas composition between <5 year and $\geq$5 year old biogas plants; and
ε_i = Error term.

3. Results and Discussion

3.1. Feedstock Used for Biogas Production

The majority of respondents (90%) are farmers producing mainly rice. However, many of them are also involved in additional off-farm activities, such as trade, rice noodle production, and rice wine production. All questioned households use pig slurry as their main feedstock for biogas plants and, in all cases, pigs were housed in concrete pigpens (with a concrete floor). Feedstock manure from other animals (65%) is also used as an additive within the surveyed households. This included chicken manure (29%) and human excreta (36%) (Figure 3). These additives are added if they are available in sufficient quantities. In every household, the pigpen is connected directly to the biogas plant, and in 37% of cases toilet outflows are connected to the biogas plant as well. Only in one case was a chicken shed was connected to the biogas plant; in the rest of cases the chicken manure is put in the digester inlet manually. Generally, the feedstock input was unified as biogas owners were recipients of one of two running projects on building small-scale biogas plants and there were criteria on the necessary number of pigs. In addition, further details regarding manure management practices of small-scale farmers in Vietnam can be seen in our previous study [6].

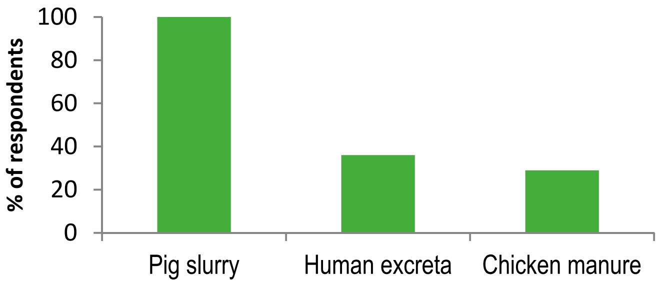


Figure 3. Feedstock used for biogas production (Multiple choices were possible) (n = 107).

3.2. Use of Products of Small-Scale Biogas Technology within the Rural Households in Central Vietnam

Small-scale biogas plants have been applied as an optimal livestock waste treatment in Vietnam since the 1960s and, although the history of this technology is rather old, the number of the constructed biogas plants is still limited. With the current number of units around 500,000 [5,23] it is still far below the real demand on livestock waste treatment [10,36] that has increased significantly in the last decade [7]. The primary use of biogas is for cooking [21]. However, it could also be used for lighting in remote areas where electrification is limited [29]. Furthermore, biogas plants produce residue from the process in the form of digestate, which can be applied as organic fertilizer to enhance agriculture production [10,17]. On a daily basis, a minimum of 20 kg of organic waste is required to operate the smallest biogas plants (4 m^3) in the area. Therefore, there is a required number (five growing pigs) of pigs (manure, respectively) to meet the feedstock needs of these plants. This quota is usually met, as the average number of animals in the area is 13–14 piglets and 2–3 sows [6,21].

3.2.1. Biogas for Cooking and Water Boiling

In developing countries, biogas produced from the household biogas plants is used mainly for cooking [29]. This is also applied to the present study, where 100% of households use biogas primarily for cooking, with an average time of 2.8 h/day. Biogas is usually used primarily for household cooking and boiling water and, afterwards, for cooking of feed for pigs. An average daily production of biogas is 0.499 m^3 ($\pm$0.086). Such an amount used for cooking purposes may represent about 8–10 m^3 and 96–120 m^3 of biogas per month and year, respectively. However, according to the study by [37], the biogas volume needed for a typical farming household of six people is 0.8 to 1 m^3 per day. This difference between average daily biogas productions could be explained by [38], as he states that the fixed dome biogas digesters can annually leak around 55% of CH_4 and the production of biogas is also dependent on the temperature of the feedstock. Therefore, the majority of respondents (60%) are still using additional energy sources in form of LPG and/or electricity (for cooking rice in rice cookers) and fuelwood (usually only for cooking of feed for animals).

3.2.2. Biogas for Lightning and Power Generation

The other major possible application of biogas may be for lighting and power generation. Biogas lamps are more efficient than kerosene-powered lamps, but their efficiency is quite low compared to electric-powered lamps [18]. In addition, electricity is now widely available in Vietnam; therefore, use of biogas lamps is very occasional. In the case of our respondents, less than 10% were using biogas lamps. Farmers usually prefer biogas for cooking instead of lighting; also, from the reason that 1 m^3 of biogas is equal to lighting of 60–100 watt bulbs for around 6 h, or cooking 2–3 meals a day for 5–6 persons. As observed during interviews with the farmers, power generation is favoured when farmers have an abundance of biogas. In that case, they purchase a combustion engine, which converts biogas into the mechanical energy in a heat engine and, consequently, the mechanical energy activates a generator to produce electrical power.

3.2.3. Digestate

The residue remaining after treatment (anaerobic digestion) in the biogas plant is called digestate. The use of digestate as a fertilizer is considered beneficial since it provides nutrients (N, P, K) which are easily accessible to plants. Digestate can be applied directly through the overflow outlet or manually. Another option is through pre-treatment (e.g., drying) before application. However, this possibility is used only sporadically. The most common practice is the usage of the digestate directly to the surrounding household home gardens and use of mainly solid parts of digestate as a crop fertilizer for rice. Another way of usage (especially of liquid manure and slurry) is partly limited by a long distance between the biogas plant location and the rice field. In 25% of cases, farmers use digestate as a fertilizer for vegetable and home-garden, which is a very popular way because of its simplicity and convenience for the farmers. Study also showed that usage of digestate for fish feeding is still not adopted in this area, as none of the respondents used digestate for such purpose even though its benefits were proven in the study by [39] focused on pig-biogas-fish systems.

3.3. Biogas Composition in Various Types of Small-Scale Biogas Plant (KT1 and KT2)

The performance of two models of biogas plants (KT1 and KT2) was observed in order to show the differences between these two types. It was revealed that the KT2 digester has demonstrated a slightly higher production of CH_4 (66.23%) and, at the same time, lower production of carbon dioxide (28.27%) (Table 3). Furthermore, slight differences might be seen among other variables, such as content of O_2, NH_3, or H_2S (Figure 4). Nitrogen, hydrogen, and water vapour were collectively marked as NHW, where slight differences were also recognized. However, factors, such as organic input, or maintenance might be the cause of these discrepancies. Furthermore, Table 4 shows a comprehensive review of biogas composition from small-scale biogas plants reported by other studies from developing countries. As is shown, CH_4 varies from 50% to 75%, and CO_2 from 25% to 50%. Other elements (N_2, CO, O_2, and H_2S) are below 2% in general and, respectively, 1% in case of H_2.

Table 3. Biogas composition according to the type of biogas plant, KT1 (n = 83) and KT2 (n = 24).

Variable	Type of Biogas Plant	Mean	95% Confidence Interval	
			Lower Bound	Upper Bound
CH_4 (vol %)	KT1	63.79	62.94	64.63
	KT2	66.23	64.70	67.76
CO_2 (vol %)	KT1	30.97	30.04	31.89
	KT2	28.27	26.59	29.94
NH_3 (vol %)	KT1	0.05	0.04	0.05
	KT2	0.04	0.03	0.05
H_2S (vol %)	KT1	0.10	0.07	0.14
	KT2	0.16	0.09	0.22
CH:CO_2 index	KT1	2.14	2.02	2.25
	KT2	2.24	2.03	2.44
Calorific value (MJ/m^3)	KT1	21.60	21.31	21.89
	KT2	22.36	21.84	22.88

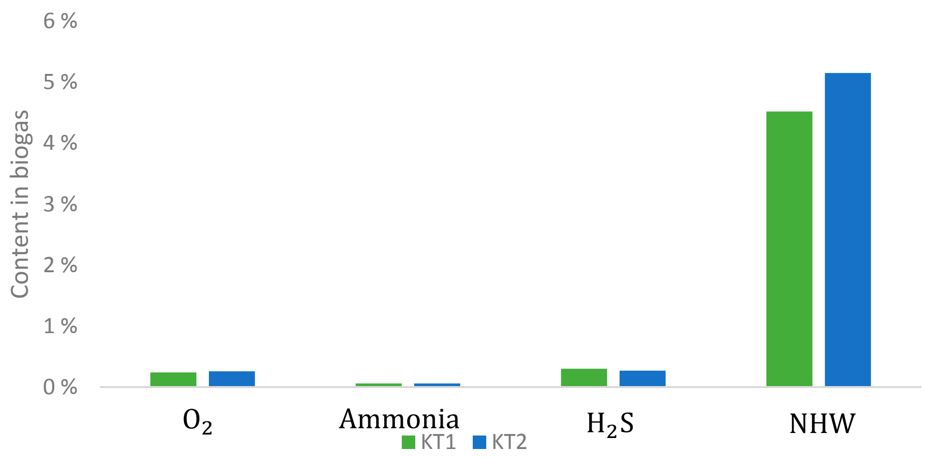


Figure 4. Performance of two models of biogas plants.

There is also the need to take into consideration the substances that can cause operation difficulties (dust, oils, and siloxanes) [33]. For the purposes of this study, another biogas quality indicator represented by methane and carbon dioxide index (CH_4:CO_2) was set up. This parameter characterises the relation between the content of CH_4 and CO_2 as two major substances influencing the final quality of biogas. From this point of view, a higher index means a higher quality of biogas.

Table 4. Biogas composition from small-scale biogas plants recognized in previous studies.

Feedstock	CH_4 (vol %)	CO_2 (vol %)	N_2 (vol %)	CO (vol %)	O_2 (vol %)	H_2 (vol %)	H_2S (vol %)	Type of BGP	Country	Reference
Animal wastewater	61–72	-	-	-	-	-	0.0043–0.0084	Tubular PVC	Costa Rica	[40]
Livestock manure	64	34	1.05	0.3	-	0.6	0.05	Floating dome	Pakistan	[8]
Livestock manure	56.2	39.51	-	1.91	-	-	1.84	Laboratory conditions	Nigeria	[41]
Livestock manure	50–75	25–45	<2	-	<2	<1	<1	Not specified	Developing countries	[42]
Livestock manure	60	35–40	-	-	-	-	-	Not specified	Malaysia	[28]
Organic waste	50–75	25–50	-	-	-	-	-	Not specified	Developing countries	[43]
Organic waste	60	-	-	-	-	-	-	Fixed dome	Sub-Saharan Africa	[44]
Generalized values	50–75	25–50	<2	<2	<2	<1	<2	-	-	-

All surveyed small-scale biogas plants (n = 107) showed in the average content of methane (CH_4) in biogas of 64.57% (±2.85) and the carbon dioxide (CO_2) of 30.20% (±3.10). The average presence of NH_3 was 0.05% (±0.02) and the presence of H_2S of 0.25% (±0.12). The average value of CH_4:CO_2 index was 2.20 (±0.35). The average calorific value of biogas produced by plants was 21.83 MJ/m^3 (±0.96), which corresponds with the typical value of 21–24 MJ/m^3 [42].

3.4. Biogas Composition According to Various Ages of Small-Scale Biogas Plants

The results presented in Table 5 is uncovering differences between small-scale biogas plants younger than five years and older than five years and its effect on various aspects of biogas quality. However, as shown in Table 5, there are no, or only minor, differences among tested values. This fact leads us to the conclusion that small-scale biogas plants using pig slurry as a main feedstock are sustaining a stable level of biogas quality during their life-span. Especially for the main indicators, which are volume of CH_4 in biogas, CH_4:CO_2 index and calorific value of biogas.

Table 5. Biogas composition from small-scale biogas plants younger than five years ($n = 82$) and older than five years ($n = 25$).

Variable	Small-Scale Biogas Plants Younger than Five Years			Small-Scale Biogas Plants Older than Five Years		
	Mean	95% Confidence Interval		Mean	95% Confidence Interval	
		Lower Bound	Upper Bound		Lower Bound	Upper Bound
CH_4 (vol %)	65.44	64.58	66.30	64.57	63.05	66.09
CO_2 (vol %)	29.31	28.37	32.25	29.93	28.27	31.58
NH_3 (vol %)	0.04	0.04	0.05	0.04	0.03	0.05
H_2S (vol %)	0.12	0.08	0.16	0.14	0.07	0.20
CH_4:CO_2 index	2.26	2.14	2.38	2.12	1.91	2.32
Calorific value (MJ/m^3)	22.08	21.79	22.39	21.87	21.36	22.39

3.5. Biogas Composition as Affected by Type, Age, and Capacity of the Biogas Plant

There was an effort to identify the factors that fundamentally influence the biogas quality (Table 6), therefore, the effects of variables of the type of biogas plant, the age of the biogas plants, and the size of the biogas plants on biogas composition were analysed. Firstly, the age of the biogas plant was tested as a relevant factor potentially influencing various aspects of the biogas quality. As demonstrated in Table 6, all biogas composition factors (including amounts of CH_4, CO_2, NH_3, H_2S, CH_4:CO_2 index, and calorific value) were not significantly affected by the age of biogas plant ($p > 0.05$). Secondly, the type of the biogas plant was tested as a relevant factor, using KT1 and KT2 models for comparison. As shown in Table 6, CH_4, CO_2, and calorific value were recognized as significantly influenced by the type of biogas plant ($p < 0.01$). The results show that KT2 model demonstrated a higher percentage of CH_4 and, consequently, a higher calorific value and a lower percentage of CO_2 of produced biogas. Another factor under the examination was the digester capacity (size). The results show different CH_4 contents, CH_4:CO_2 index values, and calorific values according to the digester capacity (size).

Table 6. Biogas composition as affected by type, age, and capacity of the biogas plant.

Dependent Variable	Parameter	Coefficient	Std. Error	*t*-Value	*p*
CH_4 (vol %)	Intercept	62.02	1.92	32.32	0.00
	Type of digester [a]	−2.44	0.82	−2.99	0.00
	Age [b]	0.87	0.81	1.08	0.28
	Digester capacity (m^3)	0.52	0.22	2.36	0.02
CO_2 (vol %)	Intercept	30.00	2.10	14.32	0.00
	Type of digester [a]	2.70	0.89	3.03	0.00
	Age [b]	−0.62	0.88	−0.70	0.49
	Digester capacity (m^3)	−0.20	0.24	−0.81	0.42
NH_3 (vol %)	Intercept	0.04	0.02	2.64	0.01
	Type of digester [a]	0.01	0.01	0.81	0.42
	Age [b]	0.00	0.01	0.67	0.51
	Digester capacity (m^3)	0.00	0.00	−0.25	0.80
H_2S (vol %)	Intercept	0.23	0.08	2.73	0.01
	Type of digester [a]	−0.05	0.04	−1.54	0.13
	Age [b]	−0.02	0.04	−0.51	0.62
	Digester capacity (m^3)	−0.01	0.01	−0.87	0.39
CH_4:CO_2 index	Intercept	1.56	0.26	5.96	0.00
	Type of digester [a]	−0.10	0.11	−0.87	0.39
	Age [b]	0.14	0.11	1.29	0.20
	Digester capacity (m^3)	0.08	0.03	2.78	0.01
Calorific value (MJ/m^3)	Intercept	20.96	0.65	32.14	0.00
	Type of digester [a]	−0.76	0.28	−2.73	0.01
	Age [b]	0.21	0.27	0.77	0.45
	Digester capacity (m^3)	0.18	0.07	2.38	0.02

[a] The base type is KT1; [b] the base age is >5 years.

4. Conclusions

Small-scale biogas plants can be a very useful tool for manure management and may help reduce global warming impacts if used appropriately. This technology offers a unique set of benefits, as it is a sustainable source of energy, it is benefiting the environment, and it provides a way to treat and reuse manure. However, if used inappropriately, its benefits may be compromised. In this study, the most common feedstock for a small-scale biogas plant was pig slurry, followed by a combination of pig slurry and human excreta. The majority of biogas plants were connected with the pig stable, or by latrine and stable. An average daily production of biogas equals to 0.499 m^3, which does not cover the demand of rural household with six members. Hence, 60% of surveyed households are still using other sources of energy as well. Biogas composition was measured with a multifunctional portable gas analyser. The mean content of methane (CH_4) was 65.44%, and for carbon dioxide (CO_2) was 29.31% in the case of biogas plants younger than five years and, respectively, CH_4 was 64.57% and CO_2 29.93% for biogas plants older than five years. The only dependent factor influencing the biogas quality was between biogas plant size and biogas composition, which was proven at CH_4, CH_4:CO_2 index, and the calorific value. Furthermore, type of the biogas plant affected CH_4, CO_2, and the calorific values of the biogas. Focusing on the influence of age of small-scale biogas plants there are no, or only minor, differences among tested qualitative biogas parameters. Concluding, that small-scale biogas plants sustaining a stable level of biogas quality during their life-span.

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