Biomass Conversion and Biorefinery (2023) 13:11959–11971
https://doi.org/10.1007/s13399-021-02122-4

ORIGINAL ARTICLE

Economics and perception of small-scale biogas plant benefits installed among peri-urban and rural areas in central Vietnam

Vladimir Verner[1] · Jana Mazancová[1] · Marek Jelínek[1] · Le Dinh Phung[2] · Dinh Van Dung[2] · Jan Banout[1] · Hynek Roubík[1]

Received: 21 July 2021 / Revised: 4 November 2021 / Accepted: 22 November 2021 / Published online: 2 December 2021

Abstract

The implementation of biogas plants in Southeast Asia brings many benefits to the households through socio-economic, environmental and health improvements. This paper expands the knowledge on essential aspects of biogas implementation such as socio-economic impact, post-adaptation perception and cultural habits related to traditional fuel use, focusing on differences in household economics and livelihood diversity at the peri-urban–rural continuum. A questionnaire survey was conducted from July to September in Thua Thien Hue Province central Vietnam, among rural (n=55) and peri-urban (n=63) households owning a biogas plant of various ages. Our results show that technical problems with biogas plants were influenced by the age of the biogas plant and the owners' experience with the management of the plant. The reduction of costs on energy was the main reason for households to install a biogas plant. However, households with biogas plants in the rural area experienced lower profitability and an almost two-times longer pay-back period than those situated near cities (internal rate of return equals 20.20% and 48.16%, respectively). Furthermore, our study shows that biogas plant installation reduces firewood consumption, particularly in peri-urban areas. The saved time initially needed for dung management or firewood collection/management, households members used predominantly for leisure and household chores, less on income-generating activities. Our study concludes that rural areas face operational problems more frequently, which, together with lower economic efficiency, negatively affect the successful implementation of biogas plants in remote areas of central Vietnam.

Keywords Small-scale biogas plants · Cost-benefit analysis · Peri-urban–rural continuum

1 Introduction

Biogas technology is considered a promising strategy for supplying the increasing demand for energy at the household level [1, 2]. In less developed regions, the main benefits of biogas technology have been linked to its ability to replace currently used traditional sources of energy such as firewood or dried dung that are usually connected with environmental and/or health challenges [3, 4] as well as more advanced alternatives such as LPG, diesel or electricity that may put under pressure household expenses and rise uncertainty because of supplies fluctuations, and with the improvement of living standard of households in terms of the health situation, waste management or cash balance [5]. However, overall effectiveness varies across the worlds' regions depending on specific environmental, social, economic and cultural conditions. This could be understood particularly in the light of insufficient promotion of biogas technology, poorly managed training, or cultural behaviour and attitudes of rural

Highlights

- Peri-urban households spend more time on wood collection compared to rural.
- Households with longer experience encounter fewer operational problems.
- Operational problems are more frequent in rural than in peri-urban households.
- Use of biogas results in saving two extra hours daily per household.
- In peri-urban areas, investment into biogas results in higher profitability and shorter return rates.

✉ Hynek Roubík
roubik@ftz.czu.cz

1 Faculty of Tropical AgriSciences, Czech University of Life Sciences Prague, Prague, Czech Republic

2 University of Agriculture and Forestry, Hue University, Hue City, Vietnam

communities [6–8]. The issues mentioned above fit the situation in Vietnam, a hundred million population country in South-Eastern Asia with one of the fastest and most stable economic growth in the region [9].

Looking at the domestic biogas technology from the perspective of determinants of political economy which frames this study, the message of public policy promoting small-scale biogas plant installation was clearly formulated in the National Biogas Programme (NBP), supported with various financial schemes and measures (direct subsidies to beneficiaries, results-based financing mechanism enhancing biogas enterprises). The implementation of NBP was assured by the cooperation of SNV (Netherlands Development Organisation) and Ministry of Agriculture and Rural Development, covering the whole country [10]. It is also implemented at a regional level, in areas such as the Thua Thien Hue province, where the Czech government financed projects through Official Development Assistance (ODA) [3, 8].

Biogas technology seems to be suitable for a wide range of households not only because of its relatively straightforward operation and maintenance but also because of the large amount of input material, which is usually abundant within the rural or peri-urban areas as a result of rapid intensification through livestock production [11]. Thus, the re-use of organic waste as input material for biogas production promotes effective waste management and improves hygiene conditions of subsistence households [12]. As a result, few hundreds of thousands of biogas plants at the household level were installed throughout the country during the last two decades. Besides government support, an additional important factor supporting the rapid and smooth implementation of biogas technology in Vietnam is the significantly lower investment costs of biogas plant installation than in other countries worldwide [13]. On the other hand, there is still a lack of scientific data on biogas technology benefits and sustainability from Vietnam compared to other South-Eastern Asian countries such as Nepal [14], China [15] or Laos [16], or other developing countries around the world, such as India [17] or Ethiopia [1].

Despite the relatively good knowledge of the pros and cons of biogas technology, its maintenance and management at the household level, and increasing awareness about its impact on the environment, certain areas remain neglected, such as peri-urban–rural continuum or cultural habitats regarding the use of firewood. Therefore, our study focuses on analysing social and economic aspects of biogas technology use at the household level in rural and peri-urban areas of Central Vietnam.

2 Methods

2.1 Study site description

The household surveys were conducted in central Vietnam in two districts of Thua Thien Hue Province, specifically Phong Dien and Huong Tra. Phong Dien can be described as a rural area located about 18–35 km to the north of the provincial administrative centre Hue City (Fig. 1); the majority of households derive their livelihood from agriculture that is based on the combination of perennial crops (rubber, acacia), homegardens, and livestock production (pigs and poultry). The Huong Tra (peri-urban district) is situated at the outskirt of Hue City; the local households' livelihood has been based particularly on annual crops (rice, peanuts, vegetable) combined with livestock production (buffaloes,

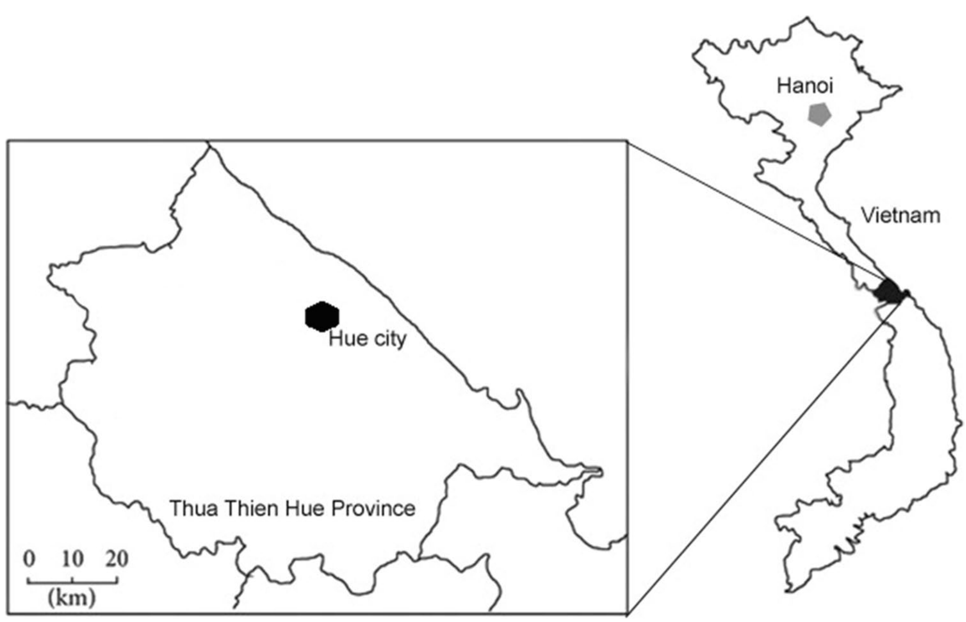

Fig. 1 Target area of Thua Thien Hue Province

cows). Due to the rapid increase of livestock production in both locations, the production of animal dung has also increased substantially. Households have partly used manure for fertilisation, but most of it has been left behind without any utilisation. The households from both study sites use residues from crop production for cooking while the failures in supplies are filled by purchased and/or collected firewood. Female household members are predominantly involved in firewood collection in both study areas.

2.2 Data collection, justification and description of the target area

Households in the central part of Vietnam, particularly those living near the Phong Dien Natural Reserve, are still running subsistence farming systems. Livestock production has been relatively underdeveloped for an extended period and is limited to poultry or small ruminants. Thus, the primary production is based on a mixture of annual and perennial crops such as rice (*Oryza sativa* L.), maise (*Zea mays* L.), peanuts (*Arachis hypogaea* L.), sugar cane (*Saccharum officinarum* L.) or rubber (*Hevea brasiliensis* L.). Off-farm activities are also very often of subsistence character and are represented by collecting forest products and firewood, running small businesses, or having irregular jobs [8, 18, 19]. Vietnam has been following a typical strategy for farming systems development in tropical areas, which is predominantly based on an extension of livestock production. As a result, between 2005 and 2015, households with large livestock tripled due to various government or international development programmes [20].

Nevertheless, more livestock brought a problem with manure management. As a result, biogas technology was decided to be implemented in the studied area to solve the problem with organic waste and to increase and diversify household incomes. Additionally, other benefits include decreased indoor smoke and firewood collection, reduced hardship of women who were mainly involved in the collection, or decreased household dependence on other sources of energies (electricity, LPG, etc.) [21]. As a result, during the last decade, up to one thousand new small-scale biogas plants were established in the area.

During growing seasons from July to September (2013), a total number of 118 farmers from rural (n=55) and peri-urban (n=63) areas participated in a household questionnaire survey. A combination of a purposive and random selection of respondents was applied. The households with installed biogas plant lists were obtained from local People's Committee Administration Offices in the Phong Dien and Huong Tra communes. All participants were familiarised with the purpose of the study and orally expressed their informed consent on participation in the survey before the interviews started. To increase the survey validity, the data and results were cross-checked with 6 local facilitators during July and September 2020 (local facilitators were from the communal, district or provincial levels).

2.3 Data analysis

The collected data were categorised, coded and analysed with descriptive and inferential statistics using the statistical software package Statistica 10, jamovi 2.0.0 and Microsoft Office Excel. Mann–Whitney's U-test p-value was done to verify the characteristics among both study areas (peri-urban and rural). In addition, effect size (a number measuring the strength of the relationship between two variables) was done to compare both study areas (peri-urban and rural) and the changes in monthly expenditures. Furthermore, the Mann–Whitney Wilcoxon test was done for differences among the amount of wood used before and after installing the biogas plant. In addition, the Shapiro–Wilk test was used to check for normality of data distribution.

2.4 Economic assessment of biogas technology

Generally, adopting new technology, innovation or farming systems is influenced by households' socio-economic characteristics [22–24]. Thus, households are more likely to accept technology or practice, which is profitable, brings more or new benefits on a short-term basis, and does not require high initial costs. Biogas is currently being adopted in various tropical regions under specific institutional, socio-economic and political conditions that influence the adoption process and behavioural changes [25].

In our study area, all biogas digesters have been built since 1997 and have a very similar design with an average size of around 6–8 m^3. We applied cost-benefit analysis (CBA) as an adequate tool to demonstrate the effect of new technology implementation [21, 26, 27]. To compute all relevant future costs and benefits in present-value terms, various discount rates of 20%, 30%, 40% and 50% were applied. Net present value (NPV), internal rate of return (IRR), and pay-back period (PBP) are the most common indicators used in CBA.

NPV (Eq. 1) and IRR (Eq. 2) were defined via the following equations [28]:

$$\mathrm{NPV} = -\mathrm{C}_0 + \sum_{t=1}^{n} \frac{B_t - C_t}{(1+i)^t} [\text{thousands VND}] \quad (1)$$

$$0 = \mathrm{NPV} = -\mathrm{C}_0 + \sum_{t=1}^{n} \frac{B_t - C_t}{(1+i)^t} [\%] \quad (2)$$

where B_t is the benefit in each year, C_t is the annual costs in each year; i is the interest (discount) rate, t is number from

1, 2, 3, …, n, where n is the number of years, i.e. life span of biogas plant which is expected to reach 15 years.

The equation for PBP calculation [29] uses the inflation and interest rates to estimate the period needed for paying back the investment into the biogas plant:

$$PBP = \frac{\ln\left(1 - \frac{C_0}{B_t - C_t}(d - f)\right)}{\ln\left(\frac{1+f}{1+d}\right)} [\text{years}] \quad (3)$$

where C_0 is the initial investment, B_t is the benefit in each year, C_t is the annual costs in each year, d is the real interest rate, and f represents the inflation rate.

Table 1 shows an overview of the initial costs of the typical biogas plant of a volume of 6–8 m^3 in the area. Therefore, the estimation was based on a model including both KT1 and KT2 types, and their averaging volumes of 6.64 and 7.62, respectively (with estimated investment costs done for 7 m^3). Out of 8.8 million VND, 4.88 mil. (55%) and 3.92 mil. (45%) are almost equally distributed into material and labour, respectively. Certified masons can only do some work; however, earth excavation (13%) is sometimes done by households themselves or subcontract cheap labour from rural areas. Nevertheless, other costs had to be paid, and there was not much chance for households to substitute the material for a cheaper one or get it in-kind. In the early stages of biogas implementation programmes, some donors offered subsidies to help and attract households to adopt biogas technology. The value of such contributions differs among donors and areas; on average, they represented 30–40% of initial costs. Table 1 presents overview of the initial costs; however, some components are likely to get replaced due to their shorter service time, i.e. H_2S filter, gasometer or gas cooker. This factor varies greatly based on proper operation and maintenance.

As already stated, Vietnam has witnessed very stable and high annual economic growth of 6.5% (±1.1%) in the last two decades [9]. As a result, households could generate more income and shift their economy from subsistence to more commercial. Annual cash household income in our study area represented 20–35

Table 1 The estimated investment costs for the construction of the household-level biogas plant in our study areas (VND)

Item	Unit of measure	Price per unit	Quantity	Costs per unit
Building material				
Bricks	number	2000	1,080	2,160,000
Cement	kg	1400	700	980,000
Sand	m^3	80,000	2	160,000
Gravel	m^3	220,000	1.50	330,000
Waterproofing additive	kg	150,000	0.20	30,000
Installation material				
Ball valve	number	25,000	1	25,000
Plastic valve	number	13,000	1	13,000
Conducting wire	m	8000	20	160,000
Binding wire	kg	15,000	0.40	6000
Steel of ø6	kg	18,000	7	126,000
PVC pipe ø140	m	115,000	3	345,000
Tube for collection of gas	m	35,000	1	35,000
Bronze cover	number	8000	1	8000
T-shape connection pipe	number	8000	2	16,000
Accessories	number	2000	12	24,000
Gasometer	number	40,000	1	40,000
Double cooker on biogas	number	350,000	1	350,000
Biogas filter	number	75,000	1	75,000
Labour				
Earth excavation	man-days	120,000	10	1,200,000
Main construction works	man-days	200,000	10	2,000,000
Supplementary construction works	man-days	120,000	6	720,000
Total investment costs				8,803,000

Notes: Despite certain fluctuations, 5,000,000 VND ≈ 250 USD. Establishment costs refer to a typical (meaning average sized) biogas plant implemented in the study area (7 m^3). Investment costs of biogas plants were converted to present prices mil. VND in rural areas, and 50–60 mil. VND in peri-urban areas, respectively. Nevertheless, together with increased income, also households' needs have been on the rise as well. Initial costs represented 14–44% of household income, and thus, it affected the decision-making process on cash security of targeted households.

Therefore, the assumption that households could finance the entire investment from their resources cannot be proven unless benefits coming from biogas installation would be converted to economic advantage. Already published studies usually classify these benefits into technical, economic, environmental and social [23, 26]. Some benefits are in the form of externalities and cannot be easily quantified financially. The development interventions on biogas technology dissemination created the synergy effect of mixing various benefits by addressing cooking and lighting household needs by energy supply, improving the household's surrounding environment, managing biowaste produced by livestock household members, and reducing demand for firewood. Leading to an improved indoor environment (less smoke) and saved time initially needed for firewood collection. The expected life span of biogas plants is 20 years. In our study, we applied 15 years as a minimum number of years of operation. The expected lifespan was derived from the used materials, simple design, which includes non-moving and non-rusting parts as well as users' experience with this type of design. Main economic benefits were linked to the value of biogas volume obtained, which differ slightly between peri-urban areas where 6 m^3 plants were predominant, compared to 7–8 m^3 in rural areas, and financial savings generated due to less consumption of alternative energy sources.

3 Results and discussion

3.1 Demographic and socio-economic characteristics of the respondents

Based on our results, a typical representative of the household owning a biogas plant in the target area is a 48-year-old man with 8 years of schooling and a member of a farmer association (76% of respondents). Furthermore, the research reveals that a typical household in the study area has five members: two represent the labour force working mainly on the farm and three are dependent members, particularly children. The average farm size is equal to 0.53 ha (±0.60), while the lion's share of land is used for subsistence rice production (39%). Table 2 shows the main characteristics of peri-urban and rural households.

Agricultural activities create 87% of annual cash income come, particularly livestock production (54%), annual crops (21%) and plantation (6%). Off-farm income includes, namely, wages, fishing or financial transfer from relatives and/or government. The average household owns an adequate number of livestock units sufficient for running the biogas plant. Distribution of livestock in tropical livestock tropical units (TLU) at household level covers buffaloes 10%, cows 3%, pigs 59%, sows 25% and poultry 3%. Furthermore, research reveals significant differences in acquiring firewood between rural and peri-urban areas. Peri-urban households diversified deliveries of firewood more equally into self-collection (50%), market (33%) and external supplier (17%). In rural areas, the breakdown of firewood acquisition was self-collection (85%), while the market or external supplier played a less significant role (6% and 9%, respectively). All households confirmed more than a half reduction in wood consumption after installing biogas plants (p-value = 0.000 for both study sites). However, peri-urban regions were able

Table 2 Overview of main biogas plant and household characteristics in both study sites

Indicator	Unit	Peri-urban households (n=63)		Rural households (n=55)		Mann–Whitney's U-test	Effect size
		Mean	S.D.	Mean	S.D.	p-value	
BGP size	m^3	6.64	±2.09	7.62	±1.48	0.000	0.368
BGP age	years	3.49	±2.87	3.53	±3.04	0.891	0.014
HH size	number	4.95	±1.69	5.98	±1.45	0.000	0.355
Farm size	ha	0.48	±0.32	0.89	±0.76	0.000	0.370
Garden size	m^2	469.37	±318.94	685.46	±807.36	0.315	0.107
Cows and buffaloes	number	0.84	±3.92	0.71	±1.65	0.292	0.078
Pigs	number	11.13	±6.18	14.95	±7.12	0.002	0.332
Annual per capita HH income	ths. VND	10,282.98	±7008.22	10,248.38	±4149.29	0.190	0.141
Subsidies	ths. VND	349.21	±1712.47	2020.91	±5440.48	0.016	0.162

Note: Shapiro–Wilk's test was used to check for normality of data distribution to reduce firewood consumption compared to rural areas significantly. As a result, the difference in firewood consumption between the studied sites became significant after biogas installation (p-value 'before' = 0.274, and p-value 'after' = 0.056, respectively). Additionally, households spent on average 3.7 h per day on firewood collection. No statistically significant difference was observed in the time needed for firewood preparation between households from peri-urban or rural areas. Although the results show a different extent of diversification of firewood delivery between rural and peri-urban areas, this could be attributed to higher amounts of this material in the rural areas and overall higher remoteness of rural households from the marketplace. As the proportion of the amount of firewood reduction was similar, with no statistically significant differences between rural and peri-urban areas, this should be in accordance with stable energy requirements in relation to the equivalent capacity of volumes of installed biogas plants (BGPs).

After the implementation, the average time that saved on firewood collection and preparation is 2.5 h per day while the time used for daily maintenance of biogas plant is in average 0.5 h per day. A similar result was found in Nepal [30], where implementation of biogas resulted in an average reduction by 2.0 h, resulting in 1.0 h needed for firewood collection per day. On the other hand, the study by Das et al. [31] concerning households mainly dependent on firewood from different target areas (Nepal, India, and Ghana) shows average times of firewood collection were 0.6, 2.3 and 0.5 h, respectively. This comparison suggests that different factors affect the time consumption of firewood gathering (i.e. local abundance of firewood, frequency of wood-collecting trips). Collection and handling of manure and water which are fed to the digester on daily basis, create time requirements, depending on distance of the animal housing and water sources. Study performed in Sub-Saharan Africa estimated this amount of time to be more than 0.5 h per day [32], suggesting that this could be generally shorter in rural areas. This needs to be kept in mind, when considering implementation of the small-scale biogas technology.

A connection between the age of a biogas plant and the familiarity of its owner with maintenance and operation instructions was found. Out of the group of farmers that have a biogas plant for six and more years, 48% understood the instructions totally and 48% partially, owners of biogas technology for 3 to 5 years understood instructions totally from 52% and partially from 44% and among the owners of the newest biogas plants 54% understood instructions totally and 42% partially. Farmers with a biogas plant older than 6 years have experienced problems principally with biogas cooker (58%), followed by biogas plant operation problems (33%). One-third of farmers from this group had expenses related to biogas production. Operation problems caused by leakages of gas pipe of gas taps and malfunctionality of gas stoves have often led to abandonment of the biogas plants, as shown in the study from Nepal [33]. Expenses related to digester performance had 23% of respondents. More than half of them have not yet removed digestate from their biogas plant; on the other hand, 4% of farmers carried out the removal of digestate five times (Fig. 2).

The newest biogas plants' owners have predominantly no costs associated with biogas production (91%) and face no problems with a biogas cooker (92%). However, 21% of them have experienced issues related to biogas plant operation or maintenance. As shown in Fig. 2, most of these respondents have not yet removed digestate from their plants.

The majority of the farmers whose biogas plants were implemented 3 to 5 years before the survey had no expenses related to biogas production (81%), but one-third of them experienced problems with biogas plant operation and 22%

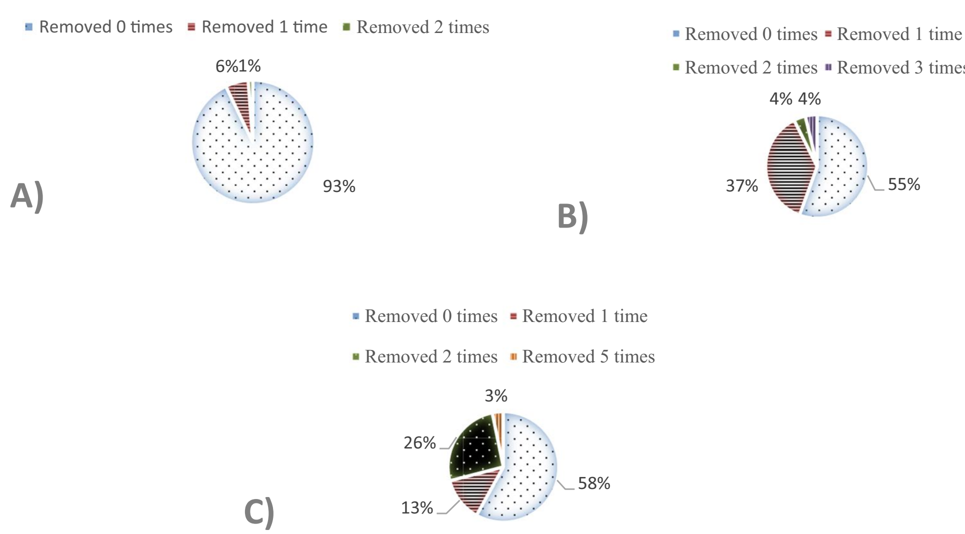

Fig. 2 **A** Frequency of digestate removal (BGP is not older than 2 years; n=84). **B** Frequency of digestate removal (BGP is 3 to 5 years old; n=37). **C** Frequency of digestate removal (BGP of older than 6 years old; n=31)

with the biogas cooker. The frequency of removal of digestate is illustrated in Fig. 2.

The relation of the lower age of BGPs and higher knowledge of technical aspects is supposedly based on higher quality and more recent training in our study's target area. In the years immediately after BGP installation, the users expected a minimum of technical difficulties; however, as indicated by our results, after 6 years onwards, most of the owners experienced problems with biogas cookers. A purchase of a new cooker (or multiple) is presumably one of the highest extra investments; therefore, further knowledge of this problem would present valuable data for considering the economics of BGP implementation.

In total, 30 (13%) respondents stated that they removed digestate from their biogas plant at least once, and 97% of these used at least some part of the digestate as fertiliser. Another way of digestate treatment was to discharge it in its liquid form directly, most often in the garden and the river (1%). This is linked with the overuse of water in the pigpens, leading to liquid digestate, which is then suitable only for some of the crops, such as Elephant grass (*Pennisetum purpureum Schumach*), used as forage. Some farmers reported that they dried it, packed it in the bags and transported to fields. In the future, respondents from both the rural and peri-urban areas planned to use digestate principally as fertiliser (82% and 93%, respectively) or discharge it in the garden (8% and 7%, respectively). Biogas plant owners from rural areas also considered giving the digestate to other farmers (5%). Therefore, it is visible, that even though digestate has nutritional value [34] and has high fertilising potential [35], this potential is still not being met. On the other hand, even though farmers are showing interest in further usage of digestate, there are several drawbacks, such as is a lack of relevant techniques to process the digestate before application to the field. According to the study of Roubík et al. [11], performed in a similar target area, the primary source of non-utilisation of digestate was also lack of knowledge. Based on literature, Vietnamese farmers see the main drawbacks to use digestate for field crops in logistic challenges [36], such as needed workload, high volume of liquid digestate, distant fields and lack of available labour, and low nutrient value of digestate [37]. This study identified the problems with digestate management as a fundamental issue and proposed further policy actions to be taken.

Expenses related to biogas production are distinctive in the rural areas where 20% of the respondents had some costs, primarily associated with emptying the biogas plant. On the other hand, 11% of farmers spent extra money on biogas production in peri-urban areas, primarily because of repairs.

In rural areas, 33% of respondents experienced specific problems with biogas plant operation or maintenance. Most of them stated that their biogas plant produces less (than needed) or no biogas. Other issues were connected to leakage of biogas. On the other hand, 18% of the peri-urban areas had problems mainly with less or no biogas and slow process. No difference between respondents from rural or peri-urban areas was discovered concerning the issues with biogas cookers.

Most of the farmers in the target area learnt about biogas technology from the extension services, either of Vietnam or non-Vietnamese origin (53%), followed by public media, such as television or newspapers (14%). Family and friends play only a minor role (4%), as is the case with companies who construct biogas plants for households (11%). Reasons for purchasing biogas (Fig. 3), the plant included cleaner environment (29%), reduction of energy costs (28%) and time devoted to firewood collection (17%). Based on answers by the 118 respondents, biogas energy is principally used for cooking for both people (49%) and animals (39%), in a smaller scope for lighting (12%).

According to our survey, 66% of farmers were trained for biogas plant maintenance, of which 52% reported that they understood instructions for the maintenance and operation, 43% understood partially and 2% did not understand at all. In addition, a very positive perception of biogas technology for cooking was observed among respondents (77%).

3.2 Social benefits and economic implications arising from biogas plant utilisation

Based on our data, there are positive social impacts of owning a biogas plant perceived by target households, as shown in Fig. 4. According to results from the questionnaire survey, 90% of the respondents claimed that there is less smoke in their house after biogas plant installation. Furthermore, 5%

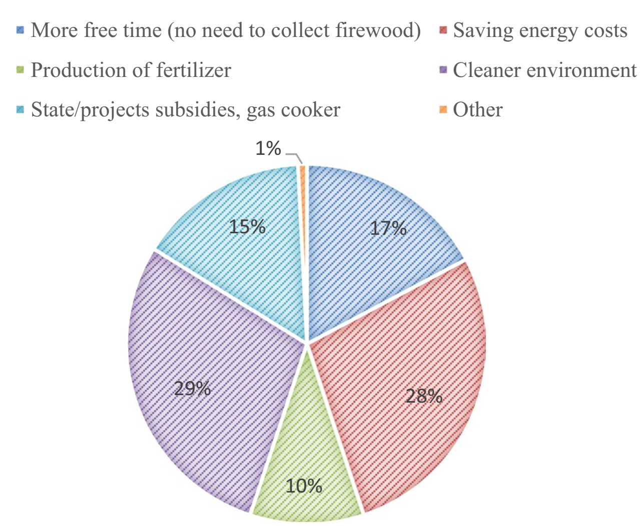

Fig. 3 Reasons for the acquisition of biogas plant (n=118)

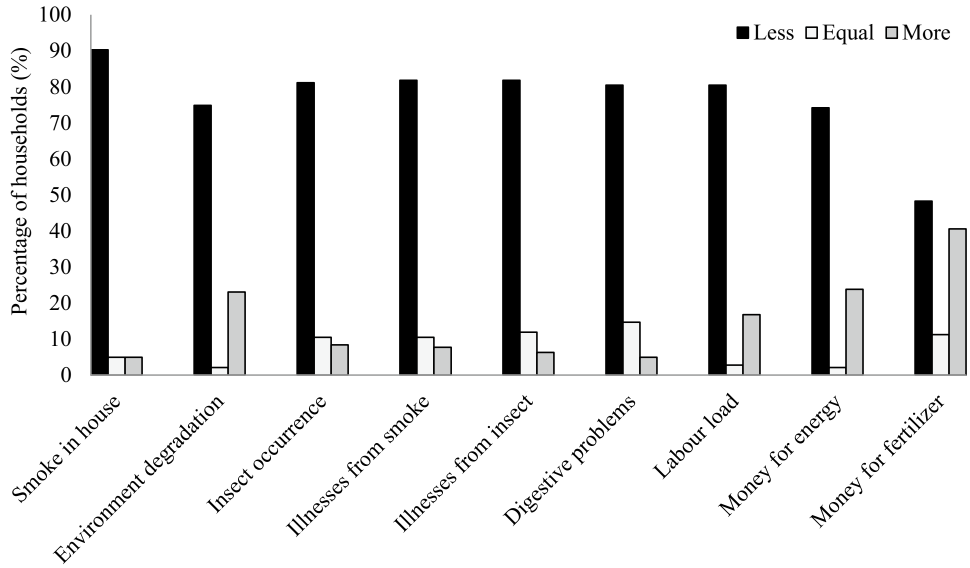

Fig. 4 Farmers' perception of social impacts of biogas plant implementation (*n*=118)

stated that the amount of smoke has not changed and 5% that there is more smoke than before (86% of respondents had the biogas plant for 2 years or less and expected that there will be less smoke in the future). Other results reveal that 75% of the farmers in the study area confirmed that the environment is cleaner after biogas plant installation. For 2%, the environment did not change, and 23% considered the environment as clean as before. Furthermore, according to 81% of the respondents, insects and mosquitoes decreased after biogas plant implementation.

The majority of the respondents claimed that their family is healthier after the biogas plant implementation. The reduction of illnesses caused by smoke was expressed by 81% of the households, 82% of the respondents stated that there is a lower occurrence of diseases caused by insects, and fewer digestive problems (linked by respondents to the better preparation of food and reduction of wastewater leaking to the environment) were noticed by 80% of the respondents. Following the majority of available literature, the results of our study support a positive impact of biogas to the reduction of smoke and to a cleaner environment, which would lead to a decrease of indoor pollution-, insect- and pathogen-caused illnesses [30, 33, 38].

Based on the survey results, 80% of farmers stated that using biogas technology gave them more free time. On average, farmers saved 2.5 h per day and household due to reduced collection and consumption of firewood energy (including also firewood preparation time). They decreased time spent in time-demanding activities such as collection and preparation of wood and soot cleaning. The average household spend 0.5 h per day on biogas plant maintenance. As a result of saving two extra hours daily per household, farmers can dedicate their time to other activities. Figure 5 describes different activities and demonstrates how many farmers dedicate additional time to each one.

Generally, the extra time farmers gain after biogas installation was mainly used for social activities or subsistence farming; very little time was related to income-generation activities. Thus, we did not consider time-saving as a financial benefit in the calculation. Our study presents data on the amount of time that farmers save due to biogas implementation (2.5 h a day) and time needed for the BGP operation (0.5 h a day), therefore resulting in an average of 2 h of extra time which was mainly used for social activities or subsistence farming. According to a study conducted in Nepal [30], the implementation of biogas resulted in a similar reduction of time needed for fuel consumption (by 2.0 h a day), while the times used for cooking and washing utensils were also decreased (by 1.5 and 0.5 h, respectively); in this study, the extra time was used mainly for the diversification of economic activities.

3.3 Environmental benefits arising from biogas plant utilisation and energy source modification/change

Firewood is the most common traditional source of energy in the surveyed communes. According to this study, the primary source of firewood in the study area is by collection (68%), followed by purchases on the market (19%) and from external suppliers (13%). Due to the biogas technology adoption, the decline in the use of firewood in terms of quantity was registered. The average amount of wood used for cooking before the biogas plant implementation was 35 monthly bundles per household; now, it is 15 monthly bundles per household. This difference is statistically

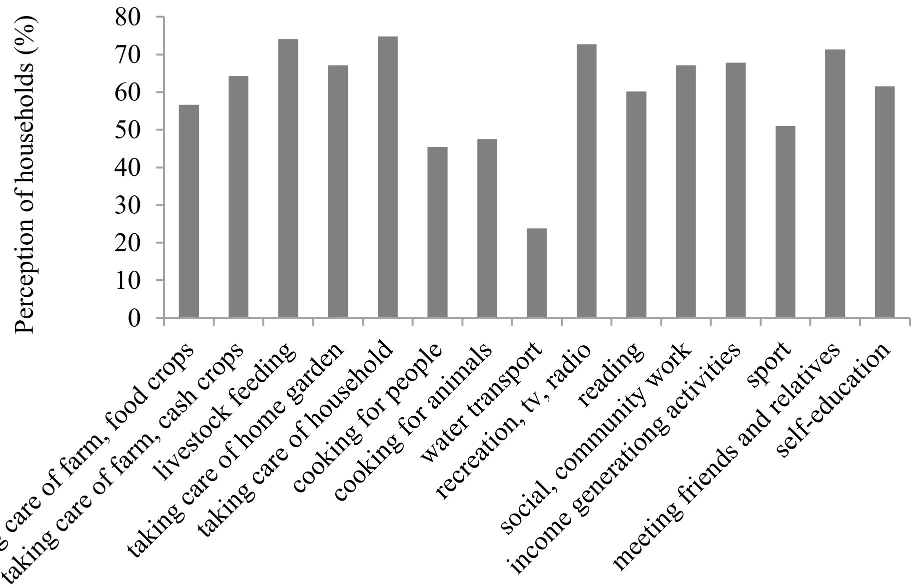

Fig. 5 Activities carried out in households within the saved time (n=118)

significant (Mann–Whitney's Wilcoxon test, p=0.000, effect size=0.977).

The primary sources of energy in the area were firewood, electricity, LPG and charcoal. Before the biogas plant implementation, peri-urban households spent money particularly on LPG (31.5%), firewood (31.3%), electricity (21.2%) and various other sources (13.9%), while rural households depended heavily on firewood (64.4%), and electricity (29.5%). However, after biogas installation, household expenditure on energy dropped to 54.7% in peri-urban and 52.9% in rural areas. A significant decrease of using of firewood, LPG and charcoal after biogas technology implementation was recognised in Ethiopia (decrease in firewood up to 60%) [39], China (decrease by 40%) [40] and India [41]. In contrast, a study in Nepal showed that domestic biogas production is insufficient to cover the cooking needs of users who still use mostly firewood [33]. In addition, direct effects of biogas technology are also to be found due to the sanitation improvements, such as use of smokeless biogas and especially sanitary toilets and sanitary waste management. This has its importance especially in the peri-urban areas where land sizes are smaller compared to rural areas (76.2% respondents for peri-urban areas reflected household surrounding and environment to improve, compared to only 63.3% of respondents from the rural areas). The structure of household expenditures on energy sources after biogas installation also changed, particularly in absolute numbers. Nevertheless, the differences between peri-urban and rural areas were documented. Rural households still relied on firewood, and despite the decrease of volume used, it still represented 52.2% of the energy budget, followed by electricity 43.8%. Energy budget among peri-urban households became more equally distributed between electricity (27.4%), various other sources (24.5%), LPG (23.8%) and firewood (22.1%). Thus, expenditures on energy sources among peri-urban households became more equally distributed and almost perfectly diversified among various sources. Rural households reduced expenses on energy sources supplied from biogas, but still, they depended on electricity and firewood. However, the only significant decrease in expenditures for energy sources was identified in the case of firewood; a very noticeable change in the use of LPG was also documented (Table 3). Both study sites reduced expenses on alternative energy sources after biogas installation. This is particularly evident in firewood contribution, which dropped from 52% in rural areas to 45% and from 36 to 29% in peri-urban areas that also witnessed a significant decrease in expenditures on LPG (Table 3).

Additionally, as shown in Fig. 5, most respondents stated that the average time they saved on firewood preparation is 2.5 h per day. In comparison, the time used for daily maintenance of the biogas plant is an average of 0.5 h. Therefore, if the time saved would be spent on income-generating activities, each household would annually earn an extra 4.08 million VND (5,000,000 VND ≈ 250 USD).

3.4 Economic assessment of biogas technology

Table 4 shows who benefits and costs of biogas plants were calculated. Benefits consist of the value of produced biogas and saved costs for other energy sources. Other benefits, such as saved costs for fertiliser, were not considered due to contradictory answers: 48% of the respondents saved money on fertiliser after adopting biogas technology; however, 41% spent less money on fertiliser before BGP implementation. Similarly, significant variations in savings were found in the

Table 3 Changes in monthly expenditures (thousands VND) for selected energy sources before and after biogas installation (n=118)

Expenditures	After		Before		Change	Mann–Whitney's Wilcoxon test	Effect size
	Mean	S.D.	Mean	S.D.		p-value	
Electricity	182.13	±208.64	249.74	±628.00	Decrease	0.152	−0.254
Firewood	180.81	±619.92	441.44	±1558.50	Decrease	0.000	−0.823
Charcoal	11.36	±43.01	17.92	±73.15	Decrease	0.209	−0.423
LPG	83.64	±395.95	211.72	±1,212.80	Decrease	0.036	−0.456
Other	85.00	±920.55	88.31	±920.98	Decrease	0.789	−0.333

Note: Shapiro–Wilk's test was used to check for normality of data distribution

Table 4 Estimation of annual operational benefits, management, and plant maintenance costs in peri-urban and rural areas of the study area (VND)

Item	Peri-urban areas (BGP of 6 m^3) (VND)	Rural areas (BGP of 8 m^3) (VND)
Biogas	435,600	501,600
Savings on firewood	2,739,048	3,572,727
Savings on LPG	2,626,667	255,927
Savings on electricity	880,571	620,830
Savings on charcoal	128,571	21,818
Savings on other sources of energy	74,286	12,347
Total annual benefits	6,884,743	4,985,250
Labour	2,025,000	2,025,000
Dung value used	222,750	256,500
Water	220,000	253,333
Maintenance (2% of installation costs)	176,060	176,060
Total annual costs	2,643,810	2,710,893
Benefit - Costs	4,240,933	2,274,357

study done in two provinces in China [40]; however, the surveyed households reported reduced expenses chemical fertilisers, pesticides, medicine, and increased net income from digestate. In our survey, costs were associated with management, maintenance and inputs value, including dung that could otherwise be used in agriculture.

The profitability of implemented biogas plants expressed by IRR differs along the peri-urban and rural continuum from 48.16 to 20.20%, respectively (Fig. 6a). Thus, biogas plant implementation was more profitable in peri-urban areas. Similarly, it is also evident from the break-even point estimation, based on cumulative NPV values, which is equal to 8–9 years in rural areas compared to 3–4 in peri-urban (Fig. 6b).

For more detailed pay-back period estimation, we combined data on benefits and costs together with inflation and real interest rates in Vietnam during the time of our study. As both inflation and interest rates fluctuate, we purposively applied two scenarios with expected minimum and maximum values: values for real interest rate 4.0% and 7.0%; for the inflation rate, 2.5% and 4.5% were applied (Table 5). Results show that similar to NPV and IRR, peri-urban households show shorter returns than those situated in rural areas. The study performed in Vietnam conducted by [8], in a target area similar to our study, focused on fixed-dome BGPs of average volumes of 7.5 (±2.2) m^3 presented a pay-back period of 2.25 (±2.04) years with a subsidy and 4.46 (±3.22) years without a subsidy from the BPAHS programme averaging on 48% of the total investment. A study conducted in Bangladesh focusing on small-scale biogas plants co-financed by 30% of total investment presented a pay-back period of 3.4 years for 2.4 m^3, 2 years for 3.2 m^3 and 2.5 years for 4.2 m^3 plants [42]. This was also confirmed by another study in Bangladesh, where NPV and IRR were used, with similar positive results [43], or similarly by the study done in Pakistan [44]. According to the estimates of the Asian Development Bank [45], a pay-back period for a small-scale BGP (10m^3) is 4 years, and the internal financial rate of return (FIRR) is estimated to be 25.3%.

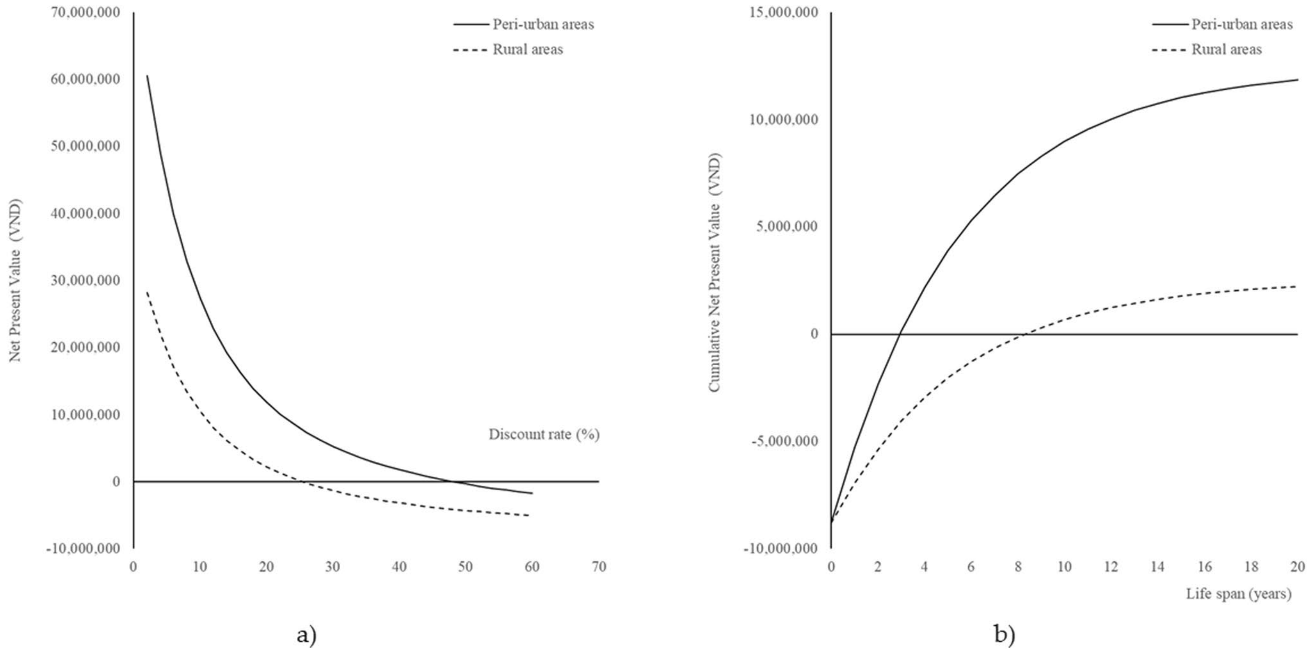

Fig. 6 Differences in the economic performance of biogas plants in peri-urban and rural areas. **a** Net present value and internal rate of return. **b** Pay-back period

Table 5 Pay-back period of biogas plants among peri-urban and rural households

	Unit of measure	Peri-urban households	Rural households
Investment costs	VND	8,803,000	
Annual operational benefits	VND	6,884,743	4,972,903
Annual operational costs	VND	2,643,810	2,710,893
Pay-back period:			
Scenario 1 (lower values for real interest and inflation rate)	years	2.18	4.14
Scenario 2 (higher values for real interest and inflation rate)	years	2.25	4.33

4 Conclusion

Our study compared small-scale biogas technology's perception and economics between rural and peri-urban households owning a biogas plant and actively using the produced biogas. Rural households show lower income, leading them to greater diversification of their livelihood strategies than peri-urban households. Both household types cover their cooking needs for human and animal food with biogas and firewood (with firewood usage decreased after implementing the biogas technology). However, there was no statistically significant difference between the household's types. Peri-urban households assure a higher amount of firewood by self-collection and thus spend more time on it. In contrast, rural households cover more than half of their firewood need from local markets, which pinpoint lower prices and higher accessibility of firewood in rural markets than in peri-urban zones. The results showed differences in feedstock used for biogas production. The semi-poor and better-off households use human excreta in addition to pig manure. In contrast, poor households use only pig manure due to the limited financial sources to build a latrine and connect it with the biogas plant. Owners of younger biogas plants self-reported higher knowledge and skills about the operation and maintenance of a biogas plant than households owning biogas plants for a longer time. The primary source of knowledge about biogas technology is extension services. The technical problems of biogas technology operation vary depending on the age of the biogas plant. Owners of older biogas plants experience frequent problems with biogas cookers, potentially leading to extra investments, but experience less operational problems than those with younger plants. Operational issues were more frequent in rural households, which have to devote higher expenses to fix them. Furthermore, our study concludes that rural areas face operational problems more frequently, which, together with lower economic efficiency, negatively affect the successful implementation of biogas plants in remote areas of central Vietnam. Both types of households use digestate as fertiliser. The primary motivation for implementing biogas technology lies in improving the environment, reducing costs for energy and saving time spent on firewood collection.

Based on the results of economic analysis, it is not possible to provide conclusive information, whether the use of digestate results in saved costs for fertiliser. However, concerning saved costs for energy resources, biogas in peri-urban households results in higher profitability and shorter return rates than those situated in rural areas.

CRediT author statement Conceptualisation: Hynek Roubík and Vladimír Verner; methodology: Hynek Roubík and Vladimír Verner; formal analysis: Vladimír Verner; validation: Jana Mazancová, Hynek Roubík; investigation: Vladimír Verner, Hynek Roubík, Marek Jelínek, Jana Mazancová, Le Dinh Phung, Dinh Vand Dung, Jan Banout; writing—original draft: Hynek Roubík and Vladimír Verner; writing—review and editing: Hynek Roubík, Vladimír Verner, Marek Jelínek, Jana Mazancová, Le Dinh Phung, Dinh Vand Dung, Jan Banout; resources and funding acquisition: Jan Banout, Vladimír Verner, Jana Mazancová and Hynek Roubík; project administration: Jana Mazancová; visualisation: Vladimír Verner; supervision: Hynek Roubík.

Funding This research was financially supported by the Internal Grant Agency of the Czech University Life Sciences Prague, Faculty of Tropical AgriSciences [20213111]. The authors also acknowledge the partial support of Hue University under the Core Research Program, Grant No. NCM.DHH.2018.04.

References

1. Gwavuya SG, Abelea S, Barfuss I, Zeller M, Müller J (2012) Household energy economics in rural Ethiopia: a cost-benefit analysis of biogas energy. Renew Energy 48:202–209. https://doi.org/10.1016/j.renene.2012.04.042
2. Roubík H, Barrera S, Dung DV, Phung LD, Mazancová J (2020a) Emission reduction potential of household biogas plants in developing countries: the case of central Vietnam. J Clean Prod 270:122257
3. Jelínek M, Mazancová J, Van Dung D, Phung LD, Banout J, Roubík H (2021) Quantification of the impact of partial replacement of traditional cooking fuels by biogas on global warming: evidence from Vietnam. J Clean Prod 292. https://doi.org/10.1016/j.jclepro.2021.126007
4. Zafar U, Ur Rashid T, Khosa AA, Khalil MS, Rahid M (2018) An overview of implemented renewable energy policy of Pakistan. Renew Sust Energ Rev 82(May 2016):654–665. https://doi.org/10.1016/j.rser.2017.09.034
5. Pizarro-Loaiza CA, Antón A, Torrellas M, Torres-Lozada P, Palatsi J, Bonmatí A (2021). Environmental, social and health benefits of alternative renewable energy sources. Case study for household biogas digesters in rural areas. J Cleaner Product 297. https://doi.org/10.1016/j.jclepro.2021.126722
6. Marie M, Yirga F, Alemu G, Azadi H (2021) Status of energy utilization and factors affecting rural households' adoption of biogas technology in north-western Ethiopia. Heliyon 7(3):e06487. https://doi.org/10.1016/j.heliyon.2021.e06487
7. Patinvoh RJ, Taherzadeh MJ (2019) Challenges of biogas implementation in developing countries. Current Opinion Environ Sci Health 12:30–37. https://doi.org/10.1016/j.coesh.2019.09.006
8. Roubik H, Mazancova J, Banout J, Verner V (2016) Addressing problems at small-scale biogas plants: a case study from central Vietnam. J Clean Prod 112(4):2784–2792. https://doi.org/10.1016/j.jclepro.2015.09.114
9. IMF (International Monetary Fund) (2020) World Economic and Financial Surveys, World Economic Outlook April 2020. Accessed online on 21 May 2020 from https://www.imf.org/en/Publications/WEO/weo-database/2020/April
10. Huong LQ, Madsen H, Anh LX, Ngoc PT, Dalsgaard A (2014) Hygienic aspects of livestock manure management and biogas systems operated by small-scale pig farmers in Vietnam. Sci Total Environ:470–471
11. Roubík H, Mazancová J, Phung LD, Banout J (2018) Current approach to manure management for small-scale Southeast Asian farmers - using Vietnamese biogas and non-biogas farms as an example. Renew Energy 115:362–370
12. Nakamya J, Tumuhairwe JB, Sabiiti EN, Strachan NJC, Avery LM, Smith J (2020) Influence of biogas digesters on faecal indicator organisms in digestate and around homesteads in Ethiopia. Biomass Bioenergy 142(August):105746. https://doi.org/10.1016/j.biombioe.2020.105746
13. Amigun R, von Blottnitz H (2010) Capacity-cost and location-cost analyses for biogas plants in Africa. Resour Conserv Recycl 55:63–73
14. Yadav MP (2017) The role of biogas for economic sustainability in Nepal: user's perspective. J Advanced Academic Res 1(2):36–46. https://doi.org/10.3126/jaar.v1i2.16587
15. Deng Y, Xu J, Liu Y, Mancl K (2014) Biogas as a sustainable energy source in China: regional development strategy application and decision making. Renew Sust Energ Rev 35:294–303. https://doi.org/10.1016/j.rser.2014.04.031
16. Vongvisith B, Wudi Z, Fang Y, Kai W, Ming L, Xiyan J, Changmei W, Xingling Z, Jing L, Hong Y (2018) Agricultural waste resources and biogas energy potential in rural areas of Lao PDR. Energy Sour, Part A: Recov Utiliz Environ Effects 40(19):2334–2341. https://doi.org/10.1080/15567036.2018.1488017
17. Minde G, Magdum S, Kalyanraman V (2013) Biogas as a sustainable alternative for current energy need of India. J Sustainable Energy Environ 4(3):121–132
18. Polesny Z, Verner V, Vlkova M, Banout J, Lojka B, Valicek P, Mazancova J (2014) Non-timber forest products utilization in Phong Dien Nature Reserve, Vietnam: who collects, who consumes, who sells? Bois et Forets des Tropiques 322(4):39–49. https://doi.org/10.19182/bft2014.322.a31233
19. Vlkova M, Polesny Z, Verner V, Banout J, Dvorak M, Havlik J, Lojka B, Ehl P, Krausova J (2011) Ethnobotanical knowledge and agrobiodiversity in subsistence farming: case study of home gardens in Phong My commune, central Vietnam. Genet Resour Crop Evol 58:629–644. https://doi.org/10.1007/s10722-010-9603-3
20. Food and Agriculture Organization of the United Nations (FAO) (2018) Transforming the livestock sector through the Sustainable Development Goals. Available online: http://www.fao.org/3/CA1201EN/ca1201en.pdf
21. Katuwal H, Bohara AK (2009) Biogas: a promising renewable technology and its impact on rural households in Nepal. Renew Sustain Energy Rev 13:2668–2674. https://doi.org/10.1016/j.rser.2009.05.002

22. Amir SM, Liu Y, Shah AA, Khayyam U, Mahmood Z (2020) Empirical study on influencing factors of biogas technology adoption in Khyber Pakhtunkhwa, Pakistan. Energy Environ 31(2):1–22. https://doi.org/10.1177/0958305X19865536
23. Bhattaraia D, Somanathan E, Nepal M (2018) Are renewable energy subsidies in Nepal reaching the poor? Energy Sustainable Development 43:114–122
24. Jan I, Akram W (2018) Willingness of rural communities to adopt biogas systems in Pakistan: critical factors and policy implications. Renew Sust Energ Rev 81(2):3178–3185. https://doi.org/10.1016/j.rser.2017.03.141
25. Roubík H, Mazancová J, Rydval J, Kvasnička R (2020b) Uncovering the dynamic complexity of the development of small–scale biogas technology through causal loops. Renew Energy 149:235–243
26. Garfí M, Ferrer-Martí L, Velo E, Ferrer I (2012) Evaluating benefits of low-cost household digesters for rural Andean communities. Renew Sust Energ Rev 16(1):575–581
27. Sarker SA, Wang SY, Adnan KMM, Sattar MN (2020) Economic feasibility and determinants of biogas technology adoption: evidence from Bangladesh. Renew Sust Energ Rev 123:109766. https://doi.org/10.1016/j.rser.2020.109766
28. Gittinger JP (1982) Economic analysis of agricultural projects. World Bank, Economic Development Institute. The Johns Hopkins University Press, Baltimore, p 445
29. Singh PP, Singh S, Dhaliwal SS (2006) Multi-shelf domestic solar dryer. Energy Conversion and Management 47(13–14):1799–1815. https://doi.org/10.1016/j.enconman.2005.10.002
30. Sigdel TP (2020) Socioeconomic Impacts of Biogas in Suklagandaki Municipality of Tanahun District. The Third Pole: Journal of Geography Education 18–19:2019. https://doi.org/10.3126/ttp.v18i0.28013
31. Das A, Mondal C, Roy S (2017) Kinetic Study of Biogas Recovery from Thermo-chemically Pre-treated Rice Husk. Indian Chemical Engineer 60(5):1–17. https://doi.org/10.1080/00194506.2017.1374218
32. Tucho GT, Moll HC, Schoot Uiterkamp AJM, Nonhebel S (2016) Problems with biogas implementation in developing countries from the perspective of labor requirements. Energies 9(9). https://doi.org/10.3390/en9090750
33. Lohani SP, Pokhrel D, Bhattarai S, Pokhrel AK (2022) Technical assessment of installed domestic biogas plnats in Kavre, Nepal. Renew Energy 181:1250–1257. https://doi.org/10.1016/j.renene.2021.09.092
34. Whangchai N, Ramaraj R, Whangchai K, Nomura K, Pimpimol T. 2020. Innovative biorefinery concept for biogas-based digestate with rice bran protein-rich feed ingredient for tilapia production. Biomass Conversion and Biorefinery:18517172. https://doi.org/10.1007/s13399-020-01098-x
35. Uludag-Demirer S, Demirer GN (2021) Post-anaerobic treatability and residual biogas potential of digestate. Biomass, Conversion Biorefinery. https://doi.org/10.1007/s13399-021-01290-7
36. Vu QD, de Neergaard A, Tran TD, Hoang QQ, Ly P, Tran MT, Jensen LS (2015) Manure, biogas digestate and crop residue management affects methane gas emissions from rice paddy fields on Vietnamese smallholder livestock farms. Nutr Cycl Agroecosyst 103:329–346. https://doi.org/10.1007/s10705-015-9746-x
37. Thu CTT, Cuong PH, Hang LT, Chao NV, Anh LX, Trach NX, Sommer SG (2012) Manure management practices on biogas and non-biogas pig farms in developing countries using livestock farms in Vietnam as an example. J Clean Prod 27:64–71. https://doi.org/10.1016/j.jclepro.2012.01.006
38. Dohoo C, Guernsey JR, Critchley K, Vanleeuwen JA. 2012. Pilot Study on the Impact of Biogas as a Fuel Source on Respiratory Health of Women on Rural Kenyan Smallholder Dairy Farms. Journal of Environmental and Public Health 2012(1):636298. https://doi.org/10.1155/2012/636298
39. Kefalew T, Tilinti B, Betemariyam M (2021) The potential of biogas technology in fuelwood saving and carbon emission reduction in Central Rift Valley, Ethiopia. Heliyon 7(9):e07971. https://doi.org/10.1016/j.heliyon.2021.e07971
40. Wang X, Di C, Hu X, Wu W, Jiang X, Jiang S (2007) The influence of using biogas digesters on family energy consumption and its economic benefit in rural areas—comparative study between Lianshui and Guichi in China. Renew Sust Energ Rev 11(5). https://doi.org/10.1016/j.rser.2005.08.001
41. Aggarwal RK, Chandel SS, Yadav P, Khosla A (2021) Perspective of new innovative biogas technology policy implementation for sustainable development in India. Energy Policy 159:112666. https://doi.org/10.1016/j.enpol.2021.112666
42. Kabir H, Palash MS, Bauer S. 2012. Appraisal of domestic biogas plants in Bangladesh. Bangladesh Journal of Agricultural Economics 35:71–89
43. Rahman A, Moller HB, Alam M (2018) Assessing the energy potential of agricultural residues and an approach to meet the rural energy demand: the Bangladesh perspective. Biomass, Conversion Biorefinery. https://doi.org/10.1007/s13399-018-0343-5
44. Abbas I, Liu J, Noor RS, Faheem M, Farhan M, Ameen M, Shaikh SA (2020) Development and performance evaluation of small size household portable biogas plant for domestic use. Biomass Convers Biorefinary. https://doi.org/10.1007/s13399-020-00956-y
45. Carbon et al. 2009 → 2009 ADB. (2012). Low carbon agricultural support project (RRP VIE 45406). Economic and Financial Analysis. Retrieved from https://www.adb.org/sites/default/files/linked-documents/45406-001-vieefa.pdf