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SHORT RESEARCH AND DISCUSSION ARTICLE

Dis-adoption of small-scale biogas plants in Vietnam: what is their fate?

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Abstract

Biogas production at a small-scale level through anaerobic digestion has been promoted in Vietnam as an appropriate technology for cooking and animal waste management within rural households. Despite the large number of small-scale biogas plants being built, there is an increase in the reported cases of their dis-adoption. This study attempts to present the state of the art of biogas plants' abandonment issue and reveal the fate of biogas plants. The primary data were collected in Thua Thien Hue province in central Vietnam among owners of small-scale biogas plants selected with the purposive sampling technique. Methods included semi-structured interviews with respondents who abandoned their biogas technology (at least 6 months before the primary data collection) ($n=37$) and with respondents who continually use it ($n=62$). SPSS 25 IBM was used for the binary logit model with 6 independent variables. Using a logistic regression analysis of various cross-sectional data, key forces were uncovered to determine the factors that can influence the abandonment of biogas technology. Results showed that households with more members working on the farm and those more satisfied with the biogas plant maintenance are less likely to abandon it. Respondents provided the information that their biogas plants mainly were not used for any other purpose after dis-adoption (excepting biogas plants used for further storage of human excreta because they were connected to toilets).

Keywords Household anaerobic digester · African swine fever · Appropriate technology · Fixed-dome digester · Technology abandonment · Biogas plant maintenance · Manure management

Introduction

There are numerous advances in discussions on sustainable development during the last 30 years. And even though greater progress has been observed in industrialized countries, many developing countries have also realized the need to seek sustainability (Salvia et al. 2019). A prime example is the bioenergy sector from South East Asia. Households in rural areas of Vietnam contribute to sustainable development with the use of biotechnologies for decentralized energy generation. According to Truc et al. (2016), biogas technology in Vietnam is well known and accepted by households and small farmers.

Biogas can be defined as a flammable gas mixture containing approximately 50% of methane. Its generation occurs during anaerobic digestion (AD), through the process of biodegradable materials conversion in the absence of oxygen by micro-organisms. A by-product of AD is digestate (ISO 20675:2018). Feedstock for biogas and digestate production with nutrient availability can be sourced in the form of organic waste primarily from agriculture, especially in developing countries (Morgan et al. 2018). In rural households, animal manure and human excreta are the most common feedstock materials for biogas production. These types of waste materials are the most problematic in terms of organic waste management (Roubík et al. 2018). In practice, biogas is used onsite. Transportation for long distances beyond the site where it is generated is not economically feasible because

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biogas is a low-value fuel. Furthermore, biogas cannot be easily shipped due to its corrosive potential (Tsydenova et al. 2019). The corrosion can be caused by hydrogen sulfide present in biogas chemical composition (Fontenelle et al. 2017).

In Vietnam, two varieties of biogas plants (hereinafter BGPs) called the Chinese fixed-dome type are prevalent: KT1 and KT2. Appropriate variety is usually constructed to maximize the benefits of biogas technology and user-friendliness. Both varieties are constructed from bricks underground to minimize the temperature fluctuations inside and for space-saving on farms. Forms of digesters vary depending on the soil structure on farms. KT1 is used for soil structures that are easily excavated. KT2 is used in locations where soil excavation is difficult or where high levels of groundwater or floods are reported (Roubík et al. 2018). The durability of the fixed-dome plants can be considered very high because their expected life is 20 years or more. There are usually no moving parts and no rusting steel parts. So, this expectation is based on the fact that the construction of BGPs is relatively simple (Energypedia 2020). There is high development potential for decentralized energy generation by using small-scale biogas plants. The livestock sector in Vietnam is mainly kept on small-scale household farms (Roubík et al. 2017).

Nevertheless, further progress may be affected. For instance, some of the promotional activities often do not ensure the critical requirements for the success of biogas technology, such as proper maintenance and long-term operation (Roubík et al. 2020b). According to Lwiza et al. (2017), the abandonment of many biogas digesters occurs within their design lifespans. Therefore, the benefit for investors is not fully realized by the government and NGOs that provide subsidies for investment and by the households that invest their resources to take up the technology. Roubík and Mazancová (2019) claimed that unarguably, each technology shall be supported with the management and proper maintenance, especially by the local actors. For the long-term utilization of benefits, it is important to take into consideration challenges, which can occur after the implementation and during the use of biogas technology. Shallo et al. (2020) have shown that the abandonment of non-functioning biodigesters has contributed to the low adoption of biogas technology resulting in a return to the use of traditional biomass energy systems in southern Ethiopia.

Different efforts for the extent of possible long-term operation of small-scale BGPs can be observed in Vietnam. For example, regulation on the national level exists. The National Standard for small-scale biogas plants was released in 2002. The standard regulates the biogas construction works and includes 8 parts: general technical requirements, requirements for construction, requirements for distribution and utilization of gas, standard for check and acceptance, requirements for operation and maintenance, safety requirements, list of necessary parameters and technical specification, and standard designs (Nguyen 2012).

Major efforts were made to promote biogas, but these only reach a fraction of all farmers due to different requirements of projects that promoted biogas technology in Vietnam. From the perspective of the economic status of households, it is important to highlight the fact that most of the implemented biogas technology programs in Vietnam have not targeted the "poorest of the poor" because of their current economic status and lack of the minimal required number of livestock (Roubík and Mazancová 2016). The challenges for biogas development in Vietnam also include the lack of long-term strategies to follow-up the biogas support projects. In Vietnam, the local authorities are not sufficiently interacting with projects, and the implemented projects are not systematically documented. There are no centralized records about the biogas project, such as the name of beneficiaries and the number of installed biogas plants (Nguyen 2012). Thus, difficulties such as inadequate technical services for post-installation maintenance and repair and major changes in rural settings are caused by rapid economic development and urbanization across Vietnam as well impact the small-scale biogas production in rural areas. Biogas development in rural Vietnam is currently at its crossroad due to emerging problems and questions (Roubík et al. 2017).

A great deal of previous studies of biogas technology in rural areas has been developed emphasizing technology adoption and expansion due to multiple advantages of technology. To sustain and increase the Vietnamese rural households' reliance on renewable sources of energy, it is also necessary to keep them functional for as long as it is possible. In order to find potential solutions to prevent future breakdowns of biogas plants, it is important to analyze the current situation with a focus on abandoned ones.

The objective of the present study was to reveal the fate of abandoned small-scale biogas plants in rural areas of Vietnam. To check the assumption that the fate of abandoned BGPs depends on the reason for abandonment, the study also aimed to find the main reasons for stopping the use of adopted small-scale biogas plants. In addition, to shed new light on occurring difficulties while using leading to dis-adoption and possibilities to solve them.

The findings of this study can contribute to the state-of-the-art of topic and to limited literature examining the dis-adoption of biogas technology on the small-scale level. Therefore, the novelty of this study lies in developing of method and presenting a valuable and systematic overview of the small-scale biogas plant abandonment issue.

Materials and methods

Methods of the present survey included field data collection and analysis from primary and secondary sources. Primary data were collected for analysis via semi-structured

questionnaires among households in rural areas. The field data collection included households visits in rural areas of central Vietnam, namely, in two communes Huong An and Huong Toan located in Thua Thien Hue province.

The overall methodology of this study is illustrated below with a flowchart on Fig. 1.

Study area

Thua Thien Hue Province with a total area of 5,054 km^2 is located in central Vietnam (Fig. 2). The capital city is Hue. The target province is situated in a tropical monsoon area. The average annual temperature is 25 °C in the plains and hills and 21 °C in the mountains. The lowest average monthly temperature is in January at 20 °C. The annual precipitation in the province is 3,200 mm (with significant variations). The rainy season is from September to December and about 70% of the precipitation is accounted for in those months. Rainfall often occurs in short heavy bursts, which causes flooding and erosion (Tong et al. 2012).

Data collection—interviews

The primary data were collected in the study area in August 2019. Sample size for survey was calculated accordingly to Tabachnick and Fidell (2007) using following formula $N \geq 50 + 8\ m$ (where m is the number of independent variables in regression). The sampling method was purposive. The selection of respondents in the target area was conditioned by ownership of small-scale BGPs. Two target groups of respondents were interviewed to obtain data for the logistic regression model as follows: biogas plants owners who abandoned biogas technology ($n = 37$) and biogas plant owners who continually use the biogas technology ($n = 62$) at the moment of data collection in the study area. For the aims of the study, biogas technology on a small-scale level was defined as abandoned within the household if the last time biogas plants that were used were at least 6 months before the moment of data collection. There was an assumption that this period shows the time when the stopping of biogas production within households was not only affected by some possible seasonal disturbances. Furthermore, by that period

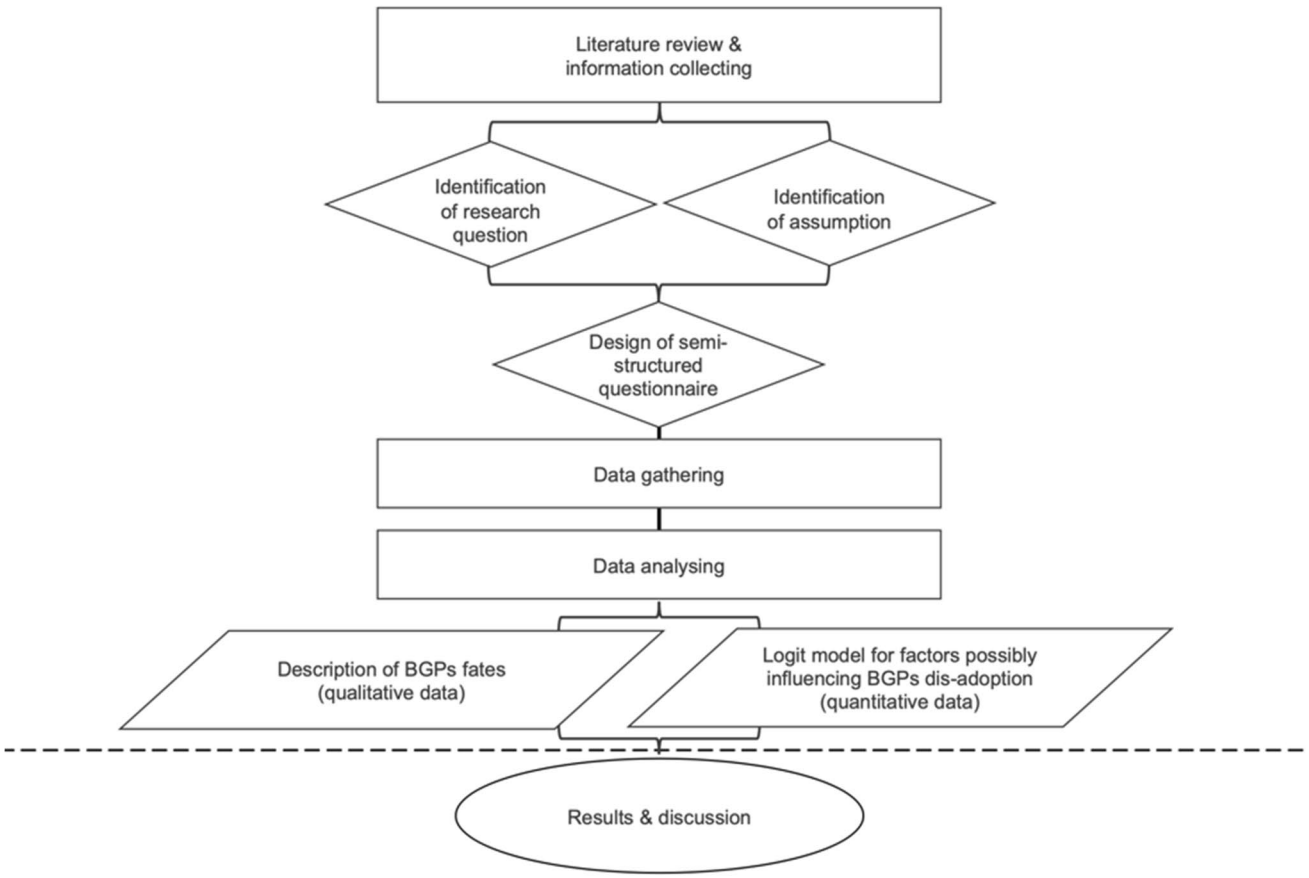

Fig. 1 Methodology framework

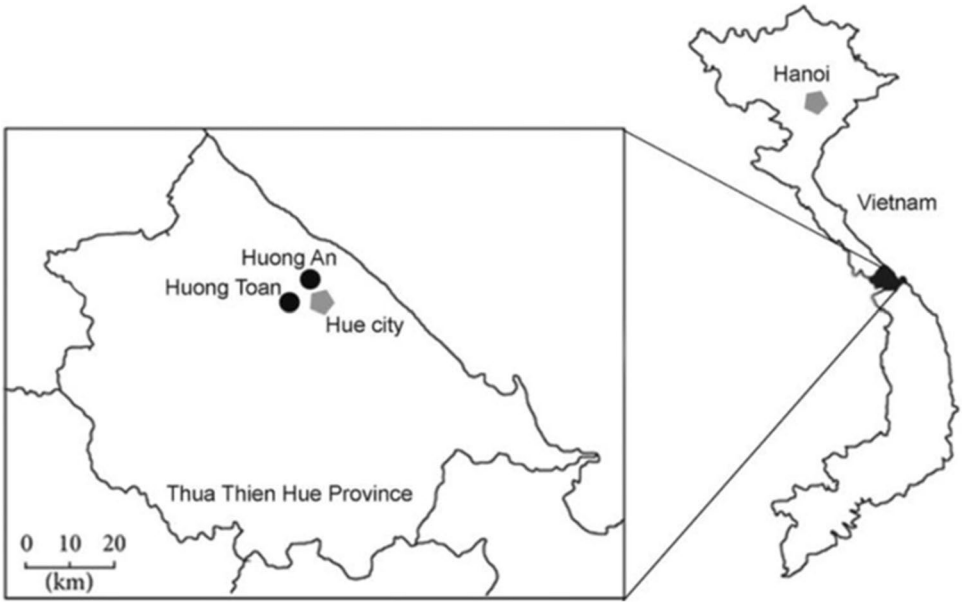

Fig. 2 Location of the province in Vietnam with highlighted study area communes (Roubík et al. (2018), adjusted by author)

of time, from the practical point of view, it is clear that the biogas plant is not producing a sufficient amount of residual biogas from the previously inserted feedstock.

Data analysis

Collected data were converted to Microsoft Office Excel program mainly for qualitative analysis. The qualitative method was used to describe small-scale biogas plants after abandonment and the main reasons leading toward it.

For quantitative research analysis, all gathered data were coded and processed with Statistical Package for Social Sciences (SPSS 25, IBM, USA). A logistic regression model was run to determine characteristics and factors influencing dis-adoption of BGPs in the study area. This analysis provides statistically significant findings on which factors are likely to increase (or decrease) the influence of the dependent variable.

Binary logistic regression model

The binary logistic regression (logit) model was applied to determine the underlying factors influencing the abandonment of biogas technology. The logit model is commonly used for the analysis of decisions, such as biogas technology adoption, for example, in the study by Etsay et al. (2017) and by Kabir et al. (2013) and the analysis of the decision of non-biogas users to invest in biogas in the study from Vietnam by Truc et al. (2017). For dis-adoption analysis, the logit model was used by Lwiza et al. (2017), where it was stated that the factors that affect biogas technology adoption were socio-economic and farm-specific. It was hypothesized that some of the same factors are likely to influence dis-adoption. To find these factors, binary logistic regression model was used, where the dependent variable took on two values: the household (that adopted the biogas technology before) abandoned it (this value was coded as 1) or is still using it (this value was coded as 0). Explanatory variables included in the model can be described as some household characteristics related to biogas utilization BGP owners who abandoned and use the technology.

The analysis approach was an attempt to adopt an approach from the previous study of biogas dis-adoption from Uganda (Lwiza et al. 2017) with a difference regarding the distribution function of primary data (the standard normal distribution is used and leads to a probit model). Primary data (obtained for the present study and used in the model) were not normally distributed. There was also an assumption that some other additional factors could affect abandonment in the case of the study area in Vietnam. There was an attempt to include them in the model to reveal some factors related to abandonment (which on the stage of adoption of technology was not predictably clear due to the lack of experience) and how they can be associated with abandonment.

The small-scale BGP dis-adoption in this study is considered the dependent variable. It was measured by asking directly the respondent to indicate their small-scale biogas plant condition. Independent variables were expected to affect the BGPs owner's decision to abandon BGP (besides the main reported reason for abandonment).

Description of factors

Some of the explanatory variables for the logit model were chosen, attempting to examine the same factors as factors usually influencing the adoption of biogas technology. It is essential for understanding the abandonment as the reversal process to the adoption (Table 1).

The average monthly income of a household (HH): a continuous variable defined as the amount of income in Vietnamese dongs (VND). This characteristic of the rural household is usually used in models as one of the basic characteristics.

Total farm area: a continuous variable measured in m^2. The findings from Uganda (Lwiza et al., 2017) showed that an increase in the land size increases the probability of dis-adoption.

Variable subsidy receiving was included because it has been widely reported that subsidies usually can influence the rapid dissemination of technology. However, subsidies as the biogas technology promotional activity often do not ensure proper maintenance, which is the key requirement for the success of biogas technology (Roubík et al. 2020a).

Variable regular contact with extension agent was included because visits of extension agents positively influence respondents in improving biogas technology maintenance. After all, it can be considered a possibility to address some issues and technical difficulties. Proper extension services contribute to poverty reduction and household income improvement in the long-term period (Roubík and Mazancová 2019).

Satisfaction with BGP maintenance requirements when using ordinal variable takes values as follows: 1—very dissatisfied, 2—dissatisfied, 3—moderately satisfied, 4—satisfied, and 5—very satisfied. BGP owner's attitude to the maintenance during small-scale BGP use was taken into consideration.

There is an assumption that BGP owners satisfied with BGP maintenance requirements during use are less likely to abandon the BGP. This variable was added to the model attempting to analyze this aspect based on farmers' experience with biogas plant maintenance.

Variable people work on the farm provides information about labor supply for BGP operation. There is an assumption that households, where more people working on the farm and able to operate biogas plant, are less likely to abandon the BGP.

Results and discussion

Background of households with abandoned biogas plants in the study area

Respondents were interviewed in order to obtain information about their households. The current situation within rural households, mainly regarding the BGP parameters and its condition, was described as well.

The average income of the interviewed households was 4,041,667 VND monthly (± 2,635,946.564 VND) (approximately 172.76 USD in 2022). Total farm area varies from 150 m^2 to 2,500 m^2 with an average of 647 m^2 (± 500 m^2). In 18.92% of interviewed households, none of the household members worked on the farm. Only one household member worked on the farm in 43.24%, and two household members worked on the farm in 37.84%.

Within interviewed households, BGP played an important role in their daily routine. 62.2% of respondents used biogas mainly for cooking, 35.1% of respondents used biogas for cooking and digestate as organic fertilizer, 2.7% of respondents used biogas for cooking, digestate as organic fertilizer and lighting for pig house. Digestate was mainly used for trees in the home garden.

The percentage of respondents (who abandoned BGP) who received a subsidy for small-scale BGP construction from the Biogas Program was 81.08%. The amount of the subsidy was either 1,000,000 VND (42.74 USD in 2022) and 5,000,000 VND (213.72 USD in 2022) (the percentage was 20% and 80% respectively).

Table 1 Definitions and description of variables types used in the model

Variables	Definition	Type of variable
The average income of a household (HH) monthly	The average amount of income in Vietnamese dongs (VND)	Continuous
Total farm area	Measured in m^2	Continuous
Receiving subsidy for BGP adoption	Value 1 for received subsidy and value 0 for cases of biogas plant construction using respondent's own funding	Nominal (binary)
Regular contact with extension agent	Taking 1 if the household reported regular contact with the extension agent and 0 if otherwise	Nominal (binary)
Satisfaction with the maintenance of BGP when using	Likert scale values: 1—very dissatisfied, 2—dissatisfied, 3—moderately satisfied, 4—satisfied, 5—very satisfied	Ordinal
People work on the farm	The number of HH members working on the small-scale farm	Continuous

In interviewed households, there were two types of small-scale BGPs constructed: KT1—31 plants (83.78%) and KT2—6 plants (16.22%). The volumes of digesters ranged from 6 m^3 to 10 m^3 with an average of 7 m^3 (depending on the available amount of organic waste from pigs within households, it was an optimum volume of digesters for every household). BGPs in interviewed households were installed in the period between 1994 and 2013 and abandoned in the period between 2009 and 2019.

The connection of small-scale BGPs with the toilet provides an additional source of feedstock for biogas production in the form of human excreta. 54.1% of abandoned BGPs were initially connected to the toilet and 45.9% were not connected. Wells were used as the main source of water for mixing with pig manure for BGP operation in 100% of surveyed households. The study from Vietnam by Roubík et al. (2018) found that water used to wash pigpens can be excessive for the biogas production process. Farmers commonly used as much water as necessary to completely spray and clean the manure from pigpens. This practice typically led to high water/manure ratios in the BGP. Pigpens are commonly cleaned once a day in wintertime and twice a day in summer (water also used for cooling pigs). The years of BGPs installation and years of BGPs abandonment were identified to see how different possible occasions in the study area through the years (such as biogas development projects) can affect the number of installations and number of abandonments. The number of years the abandoned BGPs were in operation was also calculated.

According to Wang et al. (2016), the regular operation is more difficult to achieve than its initial installation. The loss of interest by users is one of the main causes that lead to the failure of sustaining BGP operation. According to basic information about small-scale fixed dome BGP, the expected lifespan of BGPs stands at 20 years and more. The majority of surveyed households abandoned their digesters after 6 years of use (Fig. 3). It may seem that this tendency can be caused by difficulties that occurred with the cleaning of the biogas plant. Each BGP requires regular maintenance. Cleaning of BGP is required every 5–10 years when breaking of floating scum in the digester takes place (Spuhler 2014).

Small-scale BGPs owners' knowledge related to biogas technology was likely affected by training attendance. 72.97% of respondents have attended training regarding biogas technology. Respondents reported that trainings were provided by commune/ward staff (officers) (88.89%) and by Agricultural Forestry Fishery Extension Center (11.11%). The participants of the trainings usually received booklets and information about biogas technology as well as instructive books for the maintenance of the biogas system.

The majority of respondents were not in regular contact with extension agents with only 10.8% of respondents stating that they were in regular contact. Since extension agents are usually responsible for transferring knowledge to people in rural areas, their regular visits to the households may prevent and solve problems on time.

Respondents were able to answer the question about improvements in livelihood with biogas as open-ended question the results were as follows: biogas usage saves money—21.6%, biogas usage saves time—54%, biogas usage saves both time and money—8%, biogas is better for boiling drinking water—2.7%, biogas is easy for cooking—2.7%, and biogas provide a better environment and save time—2.7%. No improvements with biogas were reported in 8% of interviewed respondents.

Both communes were selected as study area located at approximately 12 km from Hue city (provincial city of Thua

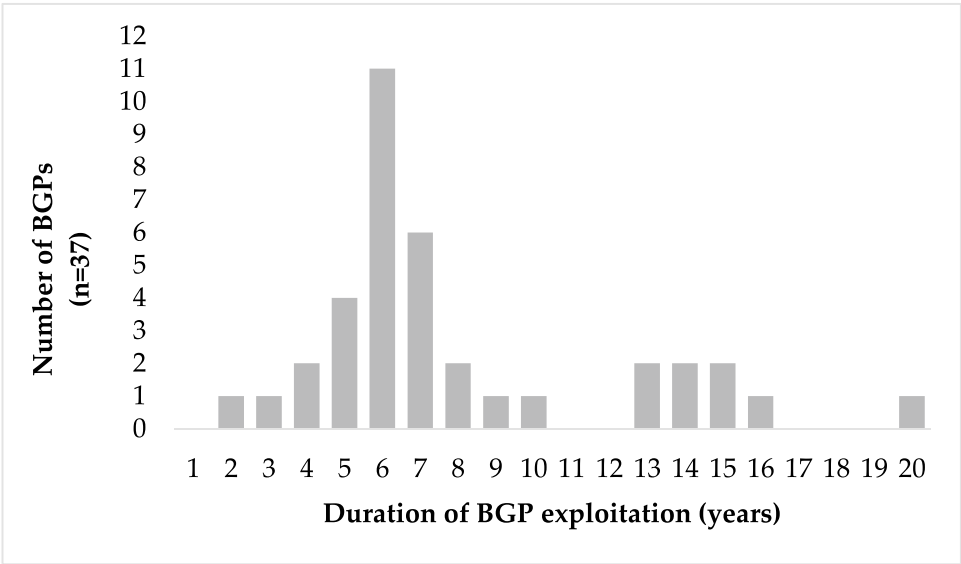

Fig. 3 Duration of abandoned BGP exploitation overview

Thien Hue province) where shops and markets can be easily found to acquire necessary materials and components for repair of the BGPs. There were 100% of answers related to the possibility to purchase all necessary materials and components in Hue city. In the study from Uganda by Lwiza et al. (2017), it was found that the construction materials and appliances were provided by the NGOs that were promoting the biogas technology (during the installation of digesters). Thereby, the household members never knew where the shops were located, and they were not able to repair the BGP due to the lack of access to materials and components. In contrast, respondents from our study area were well informed about local shops and markets where parts could be purchased.

Reasons behind the abandonment

This section presents the results of the qualitative analysis. The total number of interviewed households who reported they stopped using of a BGP was 37. The survey revealed reasons for small-scale biogas plants' dis-adoption. Table 2 provided an overview of the reasons.

The reason for biogas technology abandonment reported as a full BGP can be related to the lack of proper maintenance. It is the responsibility of the NGPs owners to clean digesters regularly. Facilitators and extension workers are commonly responsible for instructions for BGPs owners. Wang et al. (2016) pointed out that much physical work is needed for the maintenance of BGP, which is usually laborious and messy and offsets the convenience offered by biogas technology use.

Some interviewed households have their BGPs installed in the middle of the pigpen covered with concrete. The inconvenient location of the BGP and poor accessibility (resulting in difficulties in the operation and maintenance) were reported in those cases. Respondents have the opinion that there is no access to the digester, but in reality, it is possible to maintain and repair. This incorrect opinion can be linked to a lack of knowledge about biogas technology. This should be in the competence of local facilitators, and it should be discussed in detail during workshops.

According to the research conducted in the same target area by Jelínek et al. (2021), insufficient biogas production can be related to using of antibiotics to cure some pigs' diseases. Probably because some of those questioned BGPs owners were not aware of improper usage of pig manure as a feedstock containing traces of antibiotics, the process of anaerobic digestion inside their BGPs was negatively affected. There is a lack of prompt problem solving, mainly due to difficulties with technical problem recognition by BGPs owners. It can be caused by a lack of knowledge related to biogas technology.

The quantity of pig manure on-farm played a key role in BGPs dis-adoption as it is the main source of organic matter for biogas production on a small-scale level in Vietnam. Lack of sufficient amount of feedstock was reported as a problem caused dis-adoption of biogas technology in 14 households. Some of the BGPs were abandoned synchronously and quite quickly owing to local circumstances such as the outbreak of African swine fever (hereinafter ASF) in the area. In February 2019, an ASF outbreak at a family-owned backyard pig farm in Hung Yen Province in Vietnam was reported. The farm housed 20 sows and was situated approximately 50 km from Hanoi and 250 km from the China border. As the outbreak was confirmed in the northern part of the country, near China and according to studies, it is 100% identical to those from China. Many instances of illegal movement of animals and meat products across the China–Vietnam border have been reported in this region. Considering the epidemiologic features of the site where ASF has recently occurred, the virus is highly likely to have reached Vietnam via infected wild boar, by the movement of pigs and pork products, or by infected fomites. Therefore, it is likely that the virus originated in China (Le et al. 2019). ASF spread to all provinces in Vietnam in roughly five months after the first reporting of ASF in the country including areas around Hue city (Mai et al. 2021).

According to USDA (2019) usually, there are no incentives for small-scale pig farmers to report suspected cases of infected pigs to the local government because hog prices are soaring while it is taking a long time for the government to make indemnity payments to affected pig farmers. Many

Table 2 Reasons for dis-adoption of biogas technology stated by respondents

Reported reason	Frequency of appearance ($n=37$)
Technical problem—BGP is full	13.51%
Technical problem—unknown	16.22%
Failure to sustain livestock production (no intention to keep pigs)	18.92%
Failure to sustain livestock production (for feedstock) due to ASF	18.92%
Reduced labor supply leading to failure of livestock production (for feedstock)	16.22%
Other reasons related to the change of preferences of BGPs owners of energy sources	16.22%

farmers would rather sell off their pigs for cash or slaughter them for consumption than inform the local authorities. Probably it was resulting in the spread of pathogens in the area and at the same time the abandonment of household BGPs. Findings are corresponding with the study from the African region by Lwiza et al. (2017). In Uganda, some households dis-adopted biogas technology when they lost the pigs that used to supply dung for biogas production because of ASF infecting. Households could not restock pigs until the spread of the disease was under control. For minimizing the risks of biogas technology dis-adoption, there is an essential need to avoid the rapid spread of ASF. According to Normile (2019), nowadays, there are promising ASF vaccines that are under development but they are still at least 3–4 years away from the market and until then the only option is to reduce the transmission of ASF.

There was a variety of reported ways for changes in labor supply needed for agricultural activities including biogas plant operation and maintenance. The reasons might be that the technology is no longer supportable due to the physical inability of BGP owners to keep pigs with a lack of other sources of feedstock for biogas production. Several respondents reported that they are too old to keep pigs. They form a large group of "last generation" livestock farmers because their children being educated and most probably choose a lifestyle outside of agriculture (Centennial Group International 2013). Abandonment also occurs when biogas technology on the household level can no longer be supported and properly maintained due to reasons such as the death of a husband or the birth of children. Keeping pigs give them more disadvantages than advantages and one of the main benefits of biogas cannot be utilized.

The remaining reasons were diverse in nature. The unsatisfactory quality of the BGP from the beginning of its use and the skills of builders according to BGP owners' opinions were also reported. The problem can be connected to low-quality workmanship. Changes in preferences for energy sources were also reported. Changes were associated with different accidents with biogas cookers.

Reported fates of abandoned biogas plants

The detailed description is based on the information obtained during the interviews with respondents who abandoned biogas technology. 40.5% of interviewed households reported that their domestic BGPs were used for other purposes instead of biogas production after abandonment, and 59.5% reported their BGPs were not used for any other purposes after abandonment. Respondents were interviewed about various aspects of the current situation on their farms where abandoned small-scale biogas plants were located at the moment of the survey.

The fate of domestic biogas plants after abandonment varied depending on the presence or the absence of organic waste from animal production, especially pig manure, on the farm. 37.84% of households who stopped using their digesters reported that they continued to keep pigs after the dis-adoption of biogas technology. Even though the feedstock for anaerobic digestion in the form of pig manure was available on their farms, biogas plants were not used for biogas production (mainly due to the malfunctioning of the plant as a reason for dis- adoption). Respondents were also questioned about the current practices of organic waste management (pig manure) on the farm. Nine interviewed households stated they used their BGPs for pig manure storing because the pigpen and digester were connected with pipes for the input of feedstock. Respondents cleaned the pig house as usual and a mixture of water and pig manure would flow directly to the biogas plant. Uncontrolled processes of decomposition of organic wastes can occur inside the digester. Some biogas plants were not in use for any other purposes on the farm after abandonment. The remaining five households keeping pigs reported that they prefer to manage pig manure using other practices typical in rural areas, such as disposal of manure directly to the garden (2 cases) or the pond near pig house (1 case) and collecting and drying of manure (2 cases). The problem is that insufficiently treated manure is released into the environment polluting the air and water (including drinking water sources) and contaminating food crops mainly with bacterial and parasitic helminth pathogens (Huong et al. 2014). For farms still keeping pigs, it can be assumed that biogas production can be restarted again. Technical assistance of local masons is needed to help farmers to identify and solve the technical problems that may occur with the biogas plant. A 62.16% of households reported the absence of pig manure on-site as due to different reasons they stopped keep pigs (as mentioned before). The households, therefore, no longer needed to take advantage of the biogas technology as there was no further need to solve manure management problems. Six households highlighted the fact that they use their digesters for human excreta storing after biogas technology dis-adoption. This practice was predominantly used by farmers who stopped keep pigs due to their advanced age. In case of the inability

Table 3 Energy sources for cooking activities after biogas technology dis-adoption

The energy source for cooking	Percentage of interviewed households
LPG	54.1%
Mix LPG and firewood	40.5%
Mix LPG and electricity	2.7%
Electricity	2.7%

Table 4 Results of binary logit model analysis

Variable	Coefficient (B)	Standard error	Sig.	Odds ratio exp (B)
Total area of the farm (m^2)	0.000	0.000	0.744	1.000
Average income of HH (VND/month)	0.000	0.000	0.475	1.000
Number of people working on farm	-1.253*	0.421	0.003	0.286
Subsidy received for BGP (VND)	-0.018	0.659	0.979	0.982
Regular contact with extension agents	-1.294	0.774	0.094	0.274
Satisfaction with the maintenance of BGP	-1.136*	0.431	0.008	0.321
Constant	5.855	1.805	0.001	

Number of observations 99, $^{*}p < 0.01$. Pseudo R^2 (Nagelkerke R Square 0.315)

to keep pigs longer and operate digester for biogas production, this practice can be considered as an optimal solution for the environment. The results of interviews showed 17 biogas plants appeared to be abandoned with no use for any other purposes within households. Roubík et al. (2020a) stated that relevant rehabilitation and repair activities can put the abandoned biogas plants back into operation. The fact that there are no specific regulations on how to dispose of the biogas plant in the situations such as dis-adoption by its owner is noteworthy. According to the research by Jelínek et al. (2021) from the same study area, important local actors (including masons and facilitators) are provided with the information that BGP owners are commonly responsible for BGP when it reaches the end of its life. Local leaders are usually not aware of biogas technology dis-adoption.

Results of biogas plant abandonment

The abandonment of biogas technology leads to the return of households to using traditional energy sources for cooking activities such as firewood, liquified petroleum gas (LPG), and electricity (Table 3). Within households where biogas was replaced by liquified petroleum gas and electricity, stoves for cooking were used. No significant difference in kitchen conditions for cooking activities can be observed (in contrast to firewood). Depending on the reason for abandonment, biogas technology benefits such as appropriate organic waste management practicing, time-saving, money-saving, and reducing of smoke in the area are wasted.

Results of the binary logistic regression model analysis

The binary logistic regression model was used to analyze the possible effects of factors influencing the abandonment of small-scale biogas plants. There was no serious multicollinearity between the variables included in the model. The results are presented in Table 4.

Results of the analysis suggested that significant predictors used in the model include the number of people working on the farm and the satisfaction with the maintenance of the biogas plant. Coefficients for both variables are negative, and the effects of these results can be described as follows.

With respect to the effect of labor supply, if the number of people working on the farm increased by one person, the odds of longer usage of the biogas plant increased by 0.286 times. It might be due to the fact that with a larger number of household members working on the farm, it is expected that the participation in the biogas plant operation and proper maintenance is increased. For example, elderly owners of biogas plants are not able to carry out the maintenance of the plant due to their physical inability and the absence of help from younger family members in addition to agricultural activities. A study from China by Qu et al. (2013) reported that larger families had a higher probability to use biogas technology as they provide more possible labor to take care of a biogas plant. At the same time, they are usually motivated to save on their higher energy costs for cooking. But due to limitations of the present study, the number of people working on the farm was taken into consideration as labor supply for biogas plant operation and maintenance.

Households more satisfied with the maintenance of BGPs were found less likely to abandon BGP (by 0.321 times) than households less satisfied with the maintenance. BGP owners' opinion about the maintenance of BGP was taken into consideration due to the reason that satisfaction with maintenance is based on the BGP owners' experience with maintenance (both target groups).

The remaining variables including the average income of households (VND/month), the total area of the farm, subsidy received for BGP, and regular contact with extension agents had no statistically significant impact on the abandonment of small-scale biogas plant.

Conclusion

This study is aimed at revealing the fate of abandoned small-scale BGPs in rural areas of Central Vietnam. Using both qualitative and quantitative research, the fates of BGPs were revealed and presented as well as

possible factors influencing their use. Predominantly, abandoned small-scale BGPs were not used for any other purposes within rural households. With typical durability of 20 years, small-scale BGPs were abandoned after an average of only 6 years of operation for biogas production. The lack of adequate maintenance during the BGPs operation (especially the lack of regular cleaning) results in problems with functionality, which subsequently results in a reason for dis-adoption. It is necessary to provide BGP owners with an understanding of proper BGP maintenance. An important lesson of the biogas plants abandonment in Vietnam is the danger posed by African swine fever outbreaks in the area. Failure in feedstock supply for biogas production led to the dis-adoption of BGPs. Biogas technology does not remain beneficial for rural households as practice for organic waste management when difficulties related to keeping pigs occurred. There is a need for biosecurity measures for pig production on small-scale farms. Results of the binary logit model showed that households with more members working on the farm and more satisfied with the BGP maintenance are less likely to abandon the technology. Following the findings of the survey, the dis-adoption of biogas technology leads to the return of rural households to conventional energy sources for cooking such as firewood and liquified petroleum gas, resulting in a waste of investments in the biogas technology and its possible advantages including environmental benefits. To increase the Vietnamese rural households' reliance on renewable sources of energy, it is necessary to support existing small-scale biogas plants and keep them functional as long as it is possible. Finding ways to ensure proper maintenance and prevent breakdowns of well-functioning biogas plants will ensure that the plants will serve their full lifespan and will enable the households to take full advantage of the financial and environmental benefits that this technology has to offer. Due to the fact that abandoned small-scale BGPs can be found anywhere where biogas technology was adopted, future work including further studies in rural areas of other regions is recommended in order to show real state-of-the-art about biogas plant abandonment problems in other parts of the world. Both qualitative and quantitative research approaches can be applied in further studies to explore more broadly different aspects of biogas technology dis-adoption on a small-scale level.

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Availability of data and materials The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate All interviewed participants agreed with publication of anonymized data during the interview.

Consent for publication All respondents gave their informed consent for inclusion before they participated in the study. The study was conducted in accordance with the Declaration of Helsinki.

Competing interests The authors declare no competing interests.

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