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The Fate of Abandoned Small-Scale Biogas Plants – Case of Vietnam

MASTER'S THESIS

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Declaration

I hereby declare that I have done this thesis entitled The Fate of Abandoned Small-Scale Biogas Plants – Case of Vietnam independently, all texts in this thesis are original, and all the sources have been quoted and acknowledged by means of complete references and according to Citation rules of the FTA.

In Prague 14.8.2020

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Kseniia Paramonova

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Abstract

Biogas production through anaerobic digestion process has been promoted in Vietnam as an appropriate technology for animal waste management and cooking activities within rural households (replacing traditionally used firewood and LPG). Despite the large quantity of small-scale biogas plants being built and promoted, there were increasingly reported cases of abandonment of biogas technology. Therefore, this study attempted to present the state of the art of small-scale biogas plants abandonment issue including reasons leading towards it. The primary data were collected in province Thua Thien Hue in Vietnam in August 2019, including semi-structured interviews with small-scale biogas plants owners who abandoned biogas technology (minimum 6 months before the survey) (n = 37) and with small-scale biogas plant owners who continually use this technology (n = 62). Using a logistic regression analysis of various cross-sectional data (with SPSS software), key forces were uncovered in order to find out the reasons behind the abandonment of biogas technology. The findings showed that households with more members working on the farm and more satisfied with the maintenance of the biogas plant are less likely to abandon it. Reported reasons for abandonment included the failure of organic waste supply (from pig keeping) as a substrate for biogas production. In majority of cases, households were not able to keep pigs due to difficulties such as reduced availability of family labour or African swine fever in the area. Furthermore, technical problems were reported as reasons too. Abandoned plants are usually not used for any other purposes but some of digesters (initially connected to the toilet) are used only for human excreta storing. In accordance with the findings of study, it can be concluded that the dis-adoption of biogas technology leads to the return of rural households to conventional energy for cooking, resulting in waste of investments to biogas technology and its possible advantages.

Key words: Vietnam; biogas; anaerobic digestion; small-scale biogas technology; biogas plant maintenance

Abstrakt

Výroba bioplynu za pomoci anaerobní digesce byla propagována ve Vietnamu jako vhodná technologie pro výrobu energie využívané na vaření ve venkovských domácnostech a současně nahrazující tradičně používané palivové dřevo a LPG. Přestože bylo postaveno velké množství malých bioplynových stanic a technologie byla propagována, byl zaznamenán vysoký počet případů odstoupení od používání této technologie. Tato práce se proto pokusila představit současný stav problematiky opouštění malých bioplynových stanic včetně důvodů, které k tomu vedly. Primární data byla shromážděna v provincii Thua Thien Hue ve Vietnamu v srpnu 2019, pomocí polostrukturovaných rozhovorů s majiteli malých bioplynových stanic, kteří odstoupili od technologie výroby bioplynu (minimálně 6 měsíců před sběrem dat) (n = 37) a s majiteli malých bioplynových stanic, kteří tuto technologii nadále používají (n = 62). Pomocí logistické regresní analýzy různých průřezových dat (pomocí softwaru SPSS) byly odhaleny klíčové důvody, které vedly k ustoupení od používání technologie výroby bioplynu. Zjištění ukázala, že u domácností s více členy pracujícími na farmě a více spokojenými s údržbou bioplynové stanice, je méně pravděpodobné, že ji přestanou používat. Uvedené důvody zanechání výroby bioplynu zahrnovaly selhání dodávky organického odpadu (z chovu prasat) jako substrátu pro výrobu bioplynu. Domácnosti nebyly schopny chovat prasata zejména kvůli obtížím jako je snížená dostupnost pracovních sil v domácnosti nebo africký mor prasat v oblasti. Dalším nejčastěji uváděným důvodem byly technické problémy. Opuštěné malé bioplynové stanice obvykle nejsou používány pro žádné jiné účely, v některých případech jsou stanice, pakliže jsou spojeny s toaletami, využívány k ukládání exkrementů. Na základě zjištění této studie lze dospět k závěru, že opuštění technologie výroby bioplynu vede k návratu venkovských domácností ke konvenčním zdrojům energie na vaření, což má za následek ztrátu investic do technologie výroby bioplynu a dalších možných benefitů.

Klíčová slova: Vietnam; bioplyn; anaerobní digesce; technologie malé bioplynové stanice, údržba malých bioplynových stanic

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List of the abbreviations used in the thesis

AD	anaerobic digestion
AFFEC	Agricultural Forestry and Fishery Extension Centre
ASF	African swine fever
BGP(s)	biogas plant(s)
BT	biogas technology
HH	household
LPG	liquefied petroleum gas
MARD	Ministry of Agriculture and Rural Development in Vietnam
UN SDG(s)	the United Nations Sustainable Development Goal(s)
USD	United State dollar
VND	Vietnamese dong

1. Introduction

There are numerous advances in discussions on sustainable development during the last 30 years. Initially the concept of sustainable development was defined through the Brundtland report (a document entitled Our Common Future (Brundtland 1987) by the World Commission on Environment and Development. According to the report, sustainable development should *“meet the necessities of the present generation without harming the future generation's capacity to meet their own”*. 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). There are three main pillars of sustainable development: social, economic and environmental. Another essential feature is dynamic and long-term nature (Moldan et al. 2012).

Various international programmes focus on the distribution and implementation of appropriate ways of energy as it is a key element to enable human development and to reduce poverty as well. Biogas technology on small-scale level is one of such technologies (Roubík et al. 2016). Several of the United Nations Sustainable Development Goals (UN SDGs) can be achieved with appropriate implementation and operation of biogas technology. For instance, UN SDG 7 - Affordable and Clean Energy - to ensure access to affordable, reliable, sustainable and modern energy for all (IRENA 2016, Sahota et al. 2018).

A lack of access to affordable and safe energy (particularly to energy sources for cooking) can be considered as a constraint on global poverty eradication and sustainable rural development. According to International Energy Agency (2019) latest data show a gradual decline in the number of people without clean cooking access across the globe. However, there is still lack of access for more than 2.6 billion people worldwide.
Marchaim (1992) stated that in both developing and industrial countries there is an increased recognition of the need for technical and economic efficiency in the allocation and exploitation of resources. Necessary goals are to achieve economic and environmental benefits through sustainable projects for resource recovery and utilization.

The use of anaerobic digestion in an integrated resource recovery system in developing countries is important to solve both ecological and economic problems.

Research into alternative energy sources was motivated by high oil prices and the spread of biogas technology gained momentum in the 1970s. The fastest growth of biogas using can be observed in many Asian, Latin American and African countries (Bond & Templeton 2011). Household biogas programmes in Vietnam have experienced rapid development. Notable results were achieved in recent years. Nevertheless, further progress may be affected. For instance, some of the promotional activities often do not ensure the key requirements for success of biogas technology such as proper maintenance and long-term operation (Roubík et al. 2020).

2. Literature review

A significant number of scientific papers have been published regarding biogas technology issues in both developed and developing countries. This chapter of the thesis aims to provide an overview of aspects related to the topic of small-scale biogas plant abandonment.

2.1. Overview of biogas technology

This chapter describes the main issues of biogas production technology - anaerobic digestion and its fundamentals.

Biogas can be defined as a flammable gas mixture containing approximately upward of 50% methane and it can be burnt to produce heat energy. The production of biogas occurs through the process of anaerobic digestion (AD). According the International Organization for Standardization (ISO 20675:2018 en) anaerobic digestion is biological conversion of biodegradable materials by micro-organisms in the absence of oxygen creating two main products: biogas and digestate (ISO 2018). Anaerobic digestion involves stages illustrated below (Figure 1).

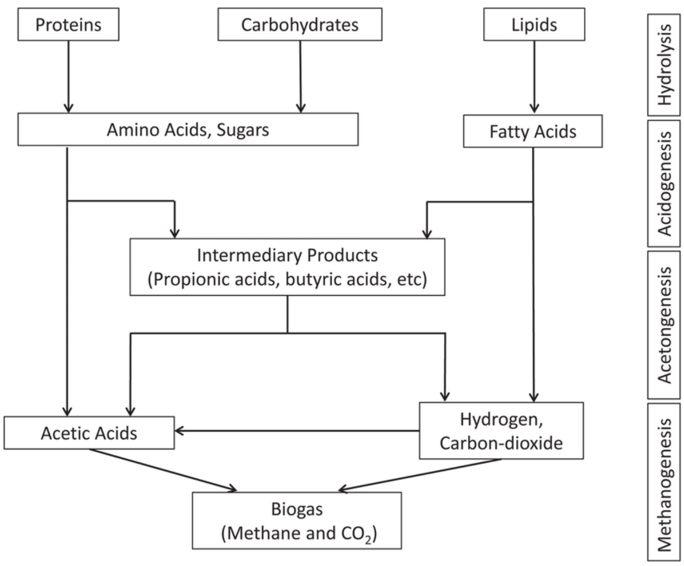

Figure 1. Stages of anaerobic digestion process and main components

Source: González & Canepa (2017)

Digestate is a slurry discharged after biogas production process. It consists of refractory organics and new cells formed during digestion. The components of digested material are similar in content to the raw material used for the digestion process. Components of slurry are soluble nutrients and trace elements, insoluble nutrients, and the organics present in the solids (humic materials) which provide soil conditioner properties (Marchaim 1992). All types of biomass containing carbohydrates, proteins, fats, cellulose and hemicellulose can be used as feedstock for biogas production. The methane yield and composition of biogas depend on the feedstock type, the digestion system and the retention time (Weiland 2010).

Different organic materials have different bio-chemical characteristics. Potential of various types of feedstock for biogas production varies. There is possibility to produce biogas from abundant organic wastes (Lam & Heegde 2011). In developing countries organic wastes with nutrient availability can be sourced primarily from agriculture (Morgan et al. 2018).

In terms of waste management for rural households usually the most problematic waste material is animal dung and human faeces. At the same time, it is the most common feedstock materials for biogas production (Roubík et. al 2018).
The productivity and stability of anaerobic digestion can be indicated using following parameters: carbon-to-nitrogen mass ratio (C:N), microbial population, pH, temperature, particle size, organic loading rate, hydraulic retention time, total solids content (mass fraction of solids), reactor configuration, oxidation – reduction potential, inhibition and toxicity. Biogas from small-scale biogas plants has typically calorific value of 21–24 MJ/m^3 (Bond & Tempelton 2011).

2.2. Biogas using

In practice, biogas is used onsite. Transportation for long distances beyond the site where it is generated is not economically feasible, because biogas is a low-value fuel. Furthermore, biogas cannot be easily shipped due to its corrosive potential (Tsydenova et al. 2019).

Generally, biogas on small-scale level is provided as energy source for cooking and lighting for a single household using plant for anaerobic digestion (Ruane et al. 2010).

2.3. Small-scale biogas plants in Vietnam

This thesis focused mainly on fixed-dome type small-scale (or household level or domestic) biogas plants (BGPs). According to Roubík et al. (2016) a piece of equipment that uses an anaerobic digestion process for biodegradable waste treatment is known as biogas plant. It is also known as bioreactor or anaerobic reactor since various chemical and microbiological reactions take place in the biodigester (Lam & Heegde 2011). The construction design (volume and form) of BGPs can vary. Variations are commonly based on the availability of feedstock and construction materials, geographical locations and climatic conditions.

In Vietnam, two varieties of the Chinese fixed dome type are prevalent: KT1 and KT2 (Figure 2). Appropriate variety should be constructed to maximize benefits and user friendliness. In order to minimize the temperature fluctuations and for space saving, both varieties are usually constructed underground from bricks. Forms of digesters vary depending on soil structure. KT1 is used for a structure of soil to be easily excavated. KT2 is used in locations where soil excavation is difficult or where high levels of ground water or floods are reported (Roubík et al. 2018).

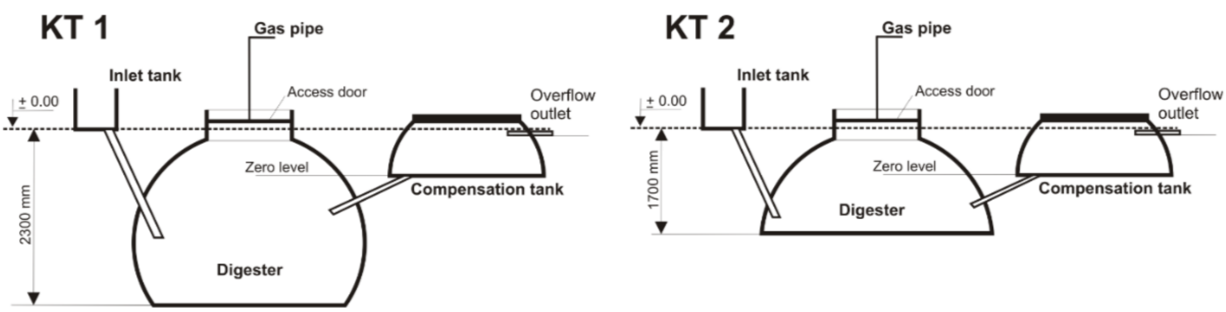

Figure 2. Small-scale biogas plant illustration - fixed dome model varieties (KT 1 and KT 2)

Source: Roubík et al. (2018)

Principle of operation as follows: the digester is filled with feedstock through the inlet tank and pipe. At the upper part of the digester the produced biogas is accumulated. The difference between the slurry inside the digester and the digestate in the compensation tank creates a gas pressure. The slurry flows back into the digester from the compensation tank after the gas is released through the gas pipe (Roubík et al. 2018).

Durability of the fixed-dome plants can be considered as very high because expected life is 20 years or more. This expectation is based mainly on the fact that the construction of plant is relatively simple. There are usually no moving parts and no rusting steel parts (Energypedia 2020). A specific feature of the household digesters is the operation at the temperature of surrounding soil in which they are buried (not heated intentionally) (FAO 2018). Seadi et al. (2008) stated for the Chinese type reactor (typically 6 m^3 to 8 m^3) a semi-continuous mode of operation. This mode means new substrate is added once a day. The physical state of a feedstock material for small-scale BGPs may be a clear liquid, a suspension of solids in a liquid, or a solid - a material with less than 70 - 80% water content (Marchaim 1992).

2.4. Advantages of biogas technology

The most obvious benefit of biogas technology is a renewable energy supply that does not pollute the environment. This is important in view of the impacts of climate change which can compound other drivers of poverty and they often act as a threat multiplier (IPCC 2018). Biogas has been officially popularized as a clean and efficient substitute for other conventional fuels in rural areas (Yu et al. 2008).

Controlled anaerobic digestion of organic material is environmentally beneficial due to the decomposition processes in a sealed environment. Potentially damaging methane is prevented from entering the atmosphere, and subsequent burning of the gas will release carbon-neutral carbon dioxide back to the carbon cycle (Ward et al. 2008).

Studies have shown the importance of using the digested slurry after the anaerobic digestion process. The use of slurry improves nutrient recycling in agriculture (Marchaim 1992). It can also help to avoid the negative impact of the production and use of chemical fertilizers on environment (Tsydenova et al. 2019). The emissions of greenhouse gasses are reduced with changing of traditional manure management practices during biogas plant exploitation (SNV 2005). However, it should be noted that the actual level of greenhouse gases reduction depends heavily on the local situation and practices of each household (with regard to domestic fuel mix and traditional manure management practices).

In comparison with other types of renewables, biogas technology via anaerobic digestion is more reliable renewable energy source. Once started and stabilized, the digester produces biogas on a continuous basis and independently of external factors such as the sun or wind (Tsydenova et al. 2019). Biogas burns with a clean flame and with little emission, therefore implementation of biogas producing systems would reduce the risk of health deficiencies related to indoor air pollution such as lung cancer, chronic obstructive pulmonary disease, child pneumonia, cataracts, high blood pressure etc. (Morgan et al. 2018).

2.5. Aspects of small-scale BGPs implementation in Vietnam

Generally, any technology is assumed to mean a new, scientifically derived, often complex input supplied to farmers by organizations with deep technical expertise (Parvan 2011). The process of the biogas technology project realization undergoes the following steps (Figure 3).

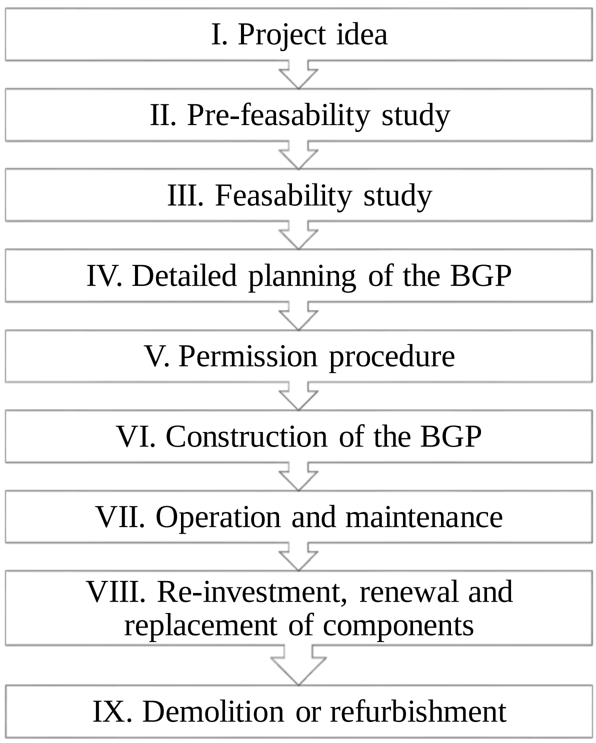

Figure 3. The process of the biogas technology project realization

Source: Seadi et al. (2008)

According to research by Jelínek (2019) from Thua Thien Hue province (the same target area) it typically takes from 1 to 2 months from decision of domestic biogas plant adoption in household to finished construction (during the projects for BGPs implementation).

Long-term and dynamic nature of sustainability is considered as its essential feature (Moldan et al. 2012). In Vietnam, one of the challenges for biogas development is lack of long-term strategies to follow up the biogas support projects. 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 name of beneficiaries, number of installed biogas plants, etc. (Nguyen 2012). Unarguably, each technology shall be supported with the management and proper maintenance especially by the local actors (Roubík & Mazancová 2019).

Different efforts for the extent 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 reach only a fraction of all farmers due to different requirements of projects promoted biogas technology in Vietnam. From the perspective of economic status of households, it is important to highlight the fact that most of the implemented biogas technology programmes in Vietnam have not targeted the “poorest of the poor” cause of their current economic status and lack of the minimal required number of livestock (Roubík & Mazancová 2016). For example, Project Renewable energy resources for rural areas in Thua-Thien Hue 2011 – 2013 with donor institution Czech Development Agency: minimal requirements for selection of beneficiaries were at least 6 pigs per household (total weight at least 200 kg) and at least 1 concrete stable for pigs divided to 2 boxes per household.

The biogas technology is well known and accepted by small farmers and households in Vietnam (Truc et al. 2016). According to FAO (2018), 43% of inhabitants are engaged in agriculture. Among all farmers in Vietnam, 89% are small family farmers. More than 65 percent are situated in rural areas. The livestock sector in Vietnam is mainly kept in small-scale household farms and there can be a high development potential for the decentralized energy generation by the use of small-scale BGPs (Roubík et al. 2017). Due to poor biosecurity on small-scale level, control of diseases can be difficult. There is increased risk of diseases transmission due to close proximity of animal-animals and animal-humans (Centennial International Group 2013). Ministry of Agriculture and Rural Development in Vietnam (MARD) has recently stated that African Swine Fever (ASF) is the most dangerous disease facing the Vietnamese livestock sector and people should not expect that country can completely get rid of it (USDA 2019). ASF can spread through direct or indirect contact and causes high mortality. The virus can persist for a long time in the environment and in a variety of swine products. Currently, there are no vaccines available (FAO 2018). There is also lack of effective treatment for sick pigs and only option for infected herd is slaughter and disposal.

2.6. Small-scale BGPs abandonment aspects

In the last decade, literature mainly investigated factors affecting biogas technology expansion and adoption on small-scale level in different countries. Limited literature examines the factors contributing to dis-adoption or abandonment different types of plants.

The continuous operation of the digesters is important for the development of rural biogas technology. For long-term utilizing of benefits, it is important to take into consideration challenges, which can occur after implementation, during the use of biogas technology. Although the biogas seems to be the potential optimal solution to a lot of problems in developing countries, there are some challenges for sustainable and long-term biogas technology using.

According to Zhou et al. (2011) and Lwiza et al. (2017) a household decides to dis-adopt biogas technology when the expected utility from continuing to use a technology is lower than the expected utility from discontinuing it. Rajendran et al. (2012) stated that in the long-run, people often stop using the household digesters for the reasons such as lack of knowledge (related to biogas technology), gas leakage, slow recovery, low gas production and inadequate supply of substrate.

Study done by He (2010) found the half of installed in China more than 7 million domestic BGPs in 1970s in China were abandoned in 1980s. Abandonment was owing to various technical barriers, such as gas and liquid leakage, insufficient feedstock from human feces and especially animal manure, blockage by crop straws, and lacking knowledge of maintenance and monitoring.

In rural Vietnam according to Roubík et al. (2017) biogas development is currently at its crossroad due to emerging problems and questions. For example, difficulties including inadequate technical services for post-installation maintenance and repair and major changes in rural settings caused by rapid economic development and urbanization across Vietnam impacting small-scale biogas production.

Abandonment of many digesters occurs within their design lifespans. Therefore, the benefit for investment is not fully realized by the government and NGOs that provide subsidies for investment, and also by the households that invest their resources to take up the technology (Lwiza et al. 2017). According to study from southern Ethiopia, abandonment of non-functioning biodigesters have contributed to the low adoption of biogas technology resulting in return to the use of traditional biomass energy systems (Shallo et al. 2020).

3. Aims of the Thesis

The main objective of the thesis is to reveal the fate of abandoned small-scale biogas plants in rural areas of central Vietnam and to present the state of the art of the issue.
The specific aims include:

- To find reasons of stopping the functionality of BGP
- To investigate possibilities of small-scale BGPs repair/why BGP owners are not able to solve occurred difficulties with BGP
- To compare different technical and non-technical challenges
- To determine main reasons behind decision of farmers for abandoning small-scale biogas technology

4. Methods

Methods of presented thesis include data analysis from primary and secondary sources. Primary data were collected via semi-structured questionnaires among households in rural areas. Collected data were converted to Microsoft Office Excel program mainly for qualitative analysis. All gathered data were also coded and processed with the help of Statistical Package for Social Sciences (SPSS 25, IBM, USA) for quantitative analysis. The study was limited by a relatively small sample size as the purposive sampling approach was used.

4.1. Data collection

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 province capital is Hue city.

Semi-structured questionnaires (Table 1 and Table 2) were used during the visits and interviews with BGP owners. The interviews were conducted in Vietnamese language and the answers were translated (at the same time during the interview) and filled to printed questionnaires in English language. The interviews took 30 minutes in average. Respondents received a financial compensation for the interview 30,000 VND (Vietnamese dong). This amount of compensation is approximately 1.29 USD.

The research team included the experts from Hue University of Agriculture and Forestry (HUAF), from Faculty of Animal Science and Veterinary Medicine and the author of thesis. The research team visited and interviewed target groups as follows: owners of small-scale BGP who abandoned biogas technology and owners of small-scale BGP who still use BGP. Village leaders and builders of BGP participated in selection of BGP owners for data collection because they know the local population in the target area. They also accompanied the research team during visits of households.

4.2. Target area

Thua Thien Hue Province (Vietnamese: Tỉnh Thừa Thiên-Huế) is located in central Vietnam (officially: the Socialist Republic of Vietnam). The province has a total area of 5,054 km^2. It is situated in a narrow strip of land with the length of 127 km and the average width of 60 km. Thua Thien Hue Province is divided into 8 districts (A Luoi, Huong Thuy, Huong Tra, Nam Dong, Phong Dien, Quang Dien, Phu Vang, and Phu Loc). The capital city is Hue (Vietnamese: Thành Phố Huế) (Figure 4). The topography is complicated and strongly partitioned lowering gradually from West to East. There are all kinds of topography such as forest and mountain, hills and mounts, coastal plain, lagoon, and sea. The target province is situated in tropical monsoon area. The average annual temperature is 25°C in the plains and in the 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).

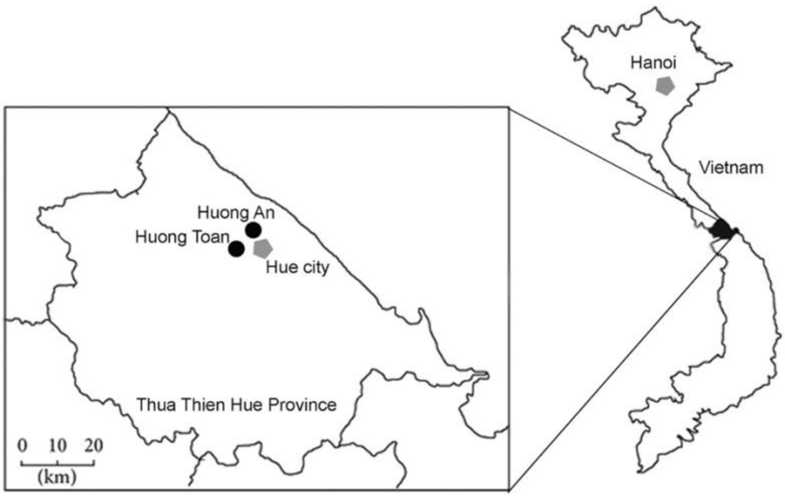

Figure 4. Map of Vietnam with highlighted target area communes

Source: Roubík et al. (2018), adjusted by author

4.3. Target groups and interviews

Selection of respondents was conditioned by ownership of small-scale biogas plants (BGPs). It is important to note that due to specific features of biogas technology, BGP owners can be defined as farmers because they depend on agricultural activities for their livelihood. However, there can be also other types of occupation of the households with BGPs and for this reason term BGP owner is more suitable for the aims of the thesis.

The first target group covered BGP owners who abandoned the biogas technology and stopped using of small-scale BGP. Interviews' structure for the first target group is presented below (Table 1). Full version of questionnaire is presented in Appendix 1. For the aims of present thesis, the small-scale BGPs were identified as abandoned, if the last time the BGPs were used was at least 6 months prior to the time of data collection (i.e. BGP was not in use after January 2020). There is an assumption that this period shows time when stopping of biogas production within households was not only affected by some possible seasonal disturbances. This period of time had been set because by the time of 6 months it is usually clear that biogas technology has been dis-adopted (abandoned). Furthermore, by that period of time from the practical point of view it is clear that BGP is not producing any sufficient amount of residual biogas from previously inserted feedstock.

Table 1. Structure of interview with respondents who abandoned small-scale BGP

Section name	Content
1. Personal information	Name, gender, age, head of HH, highest achieved education, main HH occupation, average income of HH (VND/month), share of income from on-farm activities (%), relation to the innovations, interest in new innovations, regular contact with extension agents
2. Basic information about the farm	Location, total farm area, people work on farm

3.	Basic information about BGP on the farm	BGP type, the date of the installation, BGP size (volume), connection to the toilet, source of water, who operated BGP, hours spent daily, expected lifespan of BGP, received subsidy
4.	Awareness about biogas technology	Training attendance, training provided by, satisfaction with the training
5.	Biogas plant using	Biogas using for, improvements in livelihood with BGP
6.	Biogas plant maintenance and repair	Availability of materials for repair, availability of components for repair, shop location, willingness to spend for repair
7.	The factors contributing to BGP abandonment	Reasons of abandonment, usage of BGP last time, difficulties with feedstock supply, experience with technical problems which lead to malfunctioning, experience with daily operations, condition of BGP nowadays and difficulties with repair
8.	Farmers' expectations from and satisfaction with biogas technology	Satisfaction with biogas production for cooking/for lighting, requirements on BGP operation/on BGP maintenance, economic benefits from BT, time savings thanks to BT, other sources for cooking/for lightning were used with biogas
9.	Current situation on the farm	Manure management now, energy source for cooking now, energy source for lighting now, willingness to use BGP again, needs for continuation BGP using, changes in the number of farm animals during the period of BGP using, changes in labour supply on farm during the period of BGP using, decision to stop BGP using by
10.	Other comments, information	

Source: Author (2020)

The second target group included BGP owners who used biogas technology at the moment of the data collection. Interview structure is presented in Table 2. Structure differs slightly from the structure of interview with respondents who abandoned small-scale BGP in terms of questions related to BGP abandonment issues (some questions were excluded). Full version of questionnaire is presented in Appendix 2.

Table 2. Structure of interview with respondents who use small-scale BGP

Section name	Content
1. Personal information	Name, gender, age, head of HH, highest achieved education, main HH occupation, average income of HH (VND/month), share of income from on-farm activities (%), relation to the innovation, interest in new innovations, regular contact with extension agents
2. Basic information about the farm	Location, total farm area, people work on farm
1. Basic information about biogas plant on the farm	BGP type, the date of the installation, BGP size (volume), connection to the toilet, source of water, who operated BGP, hours spent daily, expected lifespan of BGP, received subsidy
2. Awareness about biogas technology	Training attendance, training provided by, satisfaction with the training
3. Biogas plant using	Biogas using for, improvements in livelihood with BGP
4. Biogas plant maintenance and repair	Availability of materials for repair, availability of components for repair, shop location, willingness to spend for repair, experience with technical problems which lead to malfunctioning to BGP
5. Farmers' expectations from and satisfaction with biogas technology	Satisfaction with biogas production for cooking/for lighting, requirements on BGP operation/on BGP maintenance, economic benefits from BT, time savings thanks to BT, other sources for cooking/for lightning were used with biogas
6. Other comments, information	

Source: Author (2020)

4.4. Data analysis

Qualitative method was used to describe small-scale biogas plants after abandonment and main reasons leading towards it. It was hypothesized that the reasons behind dis-adoption of biogas technology influences the fate of abandoned small-scale BGPs. Reasons were stated by respondents during interviews as well as the fates of BGPs were described by them. Results are presented in the section Results and discussions.

Due to potential of biogas technology and advantages an extensive literature has developed mostly around the analysis of biogas technology adoption on small-scale level. Numerous studies assessed the factors that affect adoption of new farm technologies including biogas technology (Lwiza et al. 2017). Parvan (2011) stated that explanatory indicators for technology adoption survey varying from study to study based on their contextual applicability. Traditionally the following explanatory indicators used in surveys: farm size, risk exposure and capacity to bear risk, human capital, labour availability, credit constraints, tenure, and access to commodity markets.

According to study done by Neil & Lee (2001) abandonment of technology can be defined as one of possible outcomes of technology adoption as illustrated below (Figure 5).

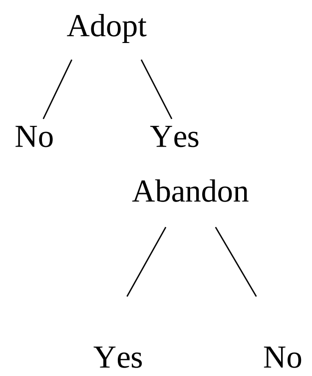

Figure 5. Decision tree for technology once adopted

Source: Neil & Lee (2001)

4.5. Logistic regression model

Logistic regression (Logit) model is commonly used for analysis of decision of biogas technology adoption for example in study by Etsay et al. (2017) and by Kabir et al. (2013). A logit model of factors influencing the decision of non-biogas users to invest in biogas was used also in the study from Vietnam by Truc et al. (2017).

According to findings by Lwiza et al. (2017) the factors that affect biogas technology adoption were socio-economic and farm specific and it was hypothesized that some of the same factors are likely to influence dis-adoption. In order to find these factors binary logistic regression model was used, where the dependent variable took on two values: household (that adopted the biogas technology before) abandoned it or is still using it.

Logistic regression model was applied to determine the underlying factors influencing the abandonment of biogas technology. Explanatory variables included to the model can be described as some household characteristics related to biogas utilization BGP owners who abandoned and use. It is similar to a linear regression model suited to models where the dependent variable has dichotomous in nature.

The analysis approach was an attempt to adopt approach from the previous study of biogas dis-adoption from Uganda (Lwiza et al. 2017) with a difference regarding to the distribution function of data (the standard normal distribution is used and leads to a probit model). Primary data obtained for present Thesis and used in model were not normally distributed.

The same approach as for adoption decision was used but there is assumption that some factors can occur during biogas using. This thesis methods attempted to include them to the model to reveal some factors related to the abandonment (which on the stage of adoption of technology was not predictable clear due to lack of experience) and how they can be associated with abandonment. There is a lack of theoretical base for some explanatory variables. Some variables were expected to be factors determining the abandonment of biogas technology.

The variables determined in this analysis were different from those reported by previous studies and studies about adoption biogas technology who followed the logit model on the willingness to adopt biogas technology.

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

4.6. Description of explanatory variables

In this subchapter, independent (or explanatory) variables expected to influence small-scale biogas plant dis-adoption are described. Some of explanatory variables for logit model were selected attempting to examine also 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.

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

Total farm area: a continuous variable measured in m_3. The findings from Uganda (Lwiza et al. 2017) showed that an increase in the land size increases the probability of dis-adoption.

Receiving subsidy for BGP adoption: it is nominal (binary) variable taking value 1 for received subsidy and 0 for cases of biogas plant construction using own respondents funding. Variable was included because receiving of subsidy can influence long-term operation. It has been widely reported, that subsidies usually can influence rapid dissemination of technology. Subsidies as the biogas technology promotional activity often do not ensure proper maintenance, which is the key requirement for success of biogas technology (Roubík et al. 2020).

Regular contact with extension agent: it is nominal (binary) variable taking 1 if household reported regular contact with extension agent and 0 if otherwise. Variable was included due to the fact that visits of extension agents positively influence respondents in improving biogas technology maintenance because it can be considered as 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 during using ordinal variable taking values as follow - 1 - very dissatisfied, 2 - dissatisfied, 3 - moderately satisfied, 4 – satisfied, 5 - very satisfied. BGP owner's attitude to the maintenance during small-scale BGP using was taken into consideration. There is assumption that BGP owners satisfied with BGP maintenance requirements during using less likely will abandon BGP.
This variable was added to the model attempting to analyse this aspect based on farmers experience of BGP maintaining.

People work on farm: a continuous variable is defined as the number of household members working on farm. This variable provides information about labour supply for biogas operation. It is hypothesized that more people working on farm and able to operate and maintain BGP less likely will abandon it.

4.7. Limitations of the Thesis

Limitations of study include lack of pilot-testing of the questionnaire. Limitations of this survey include difficulties with some questions (such as age and education level of household head) because the questionnaire design was not adopted for situations when it was not possible to ask household head directly. As a result, only part of respondents were heads of households and provided information about themselves.

5. Results and discussion

This chapter includes the primary data analysis results of semi-structured interviews with small-scale biogas plants owners.

5.1. Background of BGP owners in the study area

This chapter briefly presents demographic background of the respondents, who provided the information about current situation in their household mainly regarding to biogas plant parameters and its condition.

The first target group were BGP owners who abandoned their small-scale biogas plants (n=37; males 16, females 21). Respondents' age ranged from 16 to 84 years, with average of 54 years (±13.6 years).
The results show that all male respondents were heads of their households. Only 33.33% of female respondents reported they are heads of their households (percentage in case we consider female respondents as 100%). Female-headed households make up 8 households. According to FAO (2018) a typical family farm in Vietnam is predominantly male-headed, one-third of the farms are headed by women. An average there are 4 members per household.

According to the results of study by Jelínek (2019) covering the same communes BGPs owners reported in average 4.9 members of their households.

The average income of the interviewed households was 4,041,667 VND monthly (± 2,635,946.564 VND) (approximately 174 USD). Minimal average income monthly was 500,000 VND (approximately 22 USD) and maximal average income monthly was 10,000,000 VND (approximately 430 USD). The data here represent only farmers that have done the investment to biogas technology. It has been reported that biogas is more easily accepted by upper and middle-income farmers (Wang et al. 2016). Family sized biogas plants remain costly and unaffordable for poor households (Roubík et al. 2018).

5.2. Farms and BGPs characteristics

Total farm area varies from 150 m^2 to 2,500 m^2 with average 647 m^2 (±500 m^2). In 18.92% of interviewed households, none of household members worked on farm. Only one household member works on farm in 43.24% and two household members work on farm in 37.84%.

In interviewed households, there were two types of small-scale biogas plant 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 average 7 m^3 (±1.25 m^3). Depending on the available amount of organic waste from pigs within households the optimum volume of digesters was calculated. The minimum was set at 5 or 6 pigs (total body weight at least 200 kg).

Connection of small-scale biogas plant with the toilet can provide additional source of feedstock for biogas production in the form of human excreta. 54.1% of abandoned biogas plants 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 biogas plant operation in 100% of surveyed households. Study from Vietnam by Roubík et al. (2018) found that water used to wash pigpens can be excessive for 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 BGPs. Pigpens are commonly cleaned once a day in wintertime and twice a day in summer (water also using for cooling pigs).

The years of BGPs installation and years of BGPs abandonment were identified in order to see how different possible occasions in the study area through the years (such as biogas development projects) can possibly affect number of installations and number of abandonments as well. Overview of the results of interviews are presented below (Figure 6).

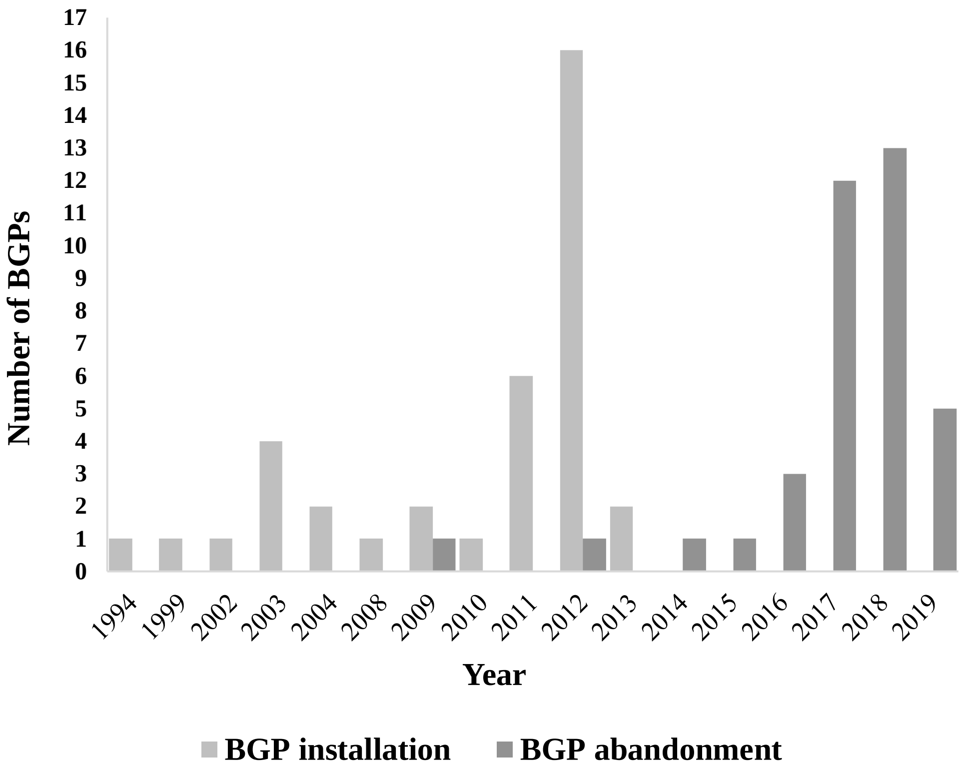

Figure 6. Overview of BGPs installation and BGPs abandonment by interviewed households through the years

It was also calculated how many years abandoned BGPs were in operation (Figure 7). The small-scale BGPs were identified as abandoned in case BGPs had not been used for at least 6 months by the time the data collection. We assumed this period shows time when stopping of biogas production within households was not only affected by some seasonal disturbances. By the time of 6 months it is clear that biogas technology has been dis-adopted / abandoned. Furthermore, by that time it is clear that also is not producing any sufficient amount of residual biogas from previously inserted feedstock.

According to Wang et al. (2016) 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 digester operation.

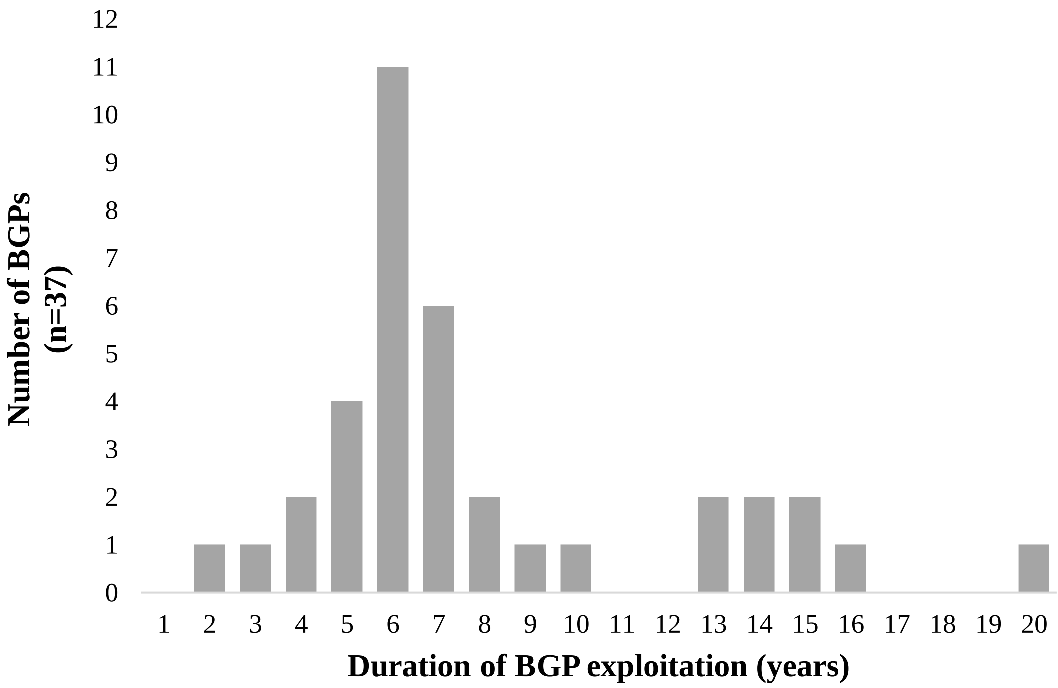

Figure 7. Duration of abandoned BGPs exploitation overview

Data provided with overview on the Figure 7 can be compared with lifespan of biogas plants. According to basic information about small-scale fixed dome biogas plants the expected lifespan of biogas plants stands at 20 years and more. Figure 7 indicates that the majority of surveyed households abandoned their digesters after 6 years of using. It may seem that this tendency can be caused by difficulties occurred with BGP cleaning. 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).

Percentage of respondents (who abandoned BGP) received subsidy for small-scale biogas plant construction from the Biogas Program was 81.08%. Amount of subsidy was 1,000,000 VND and VND 5,000,000 VND (percentage was 20% and 80% respectively).

Small-scale BGP owners' knowledge related to biogas technology was likely affected by training attendance. 72.97% of respondents have attended training regarding to the biogas technology. Respondents reported that trainings were provided for them by commune/ward staff (officers) (88.89%) and by Agricultural Forestry Fishery Extension Centre AFFEC (11.11%). The participants of trainings usually received booklets and information on the biogas technology as well instructive books for the maintenance of the biogas system. Majority of respondents were not in regular contact with extension agents and only 10.8% of respondents stated they were in regular contact. Since extension agents are usually responsible for providing the knowledge for people in rural areas, regular visits of households may prevent and solve problems timely.

Within interviewed households, biogas plants played 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, lighting for pig house and digestate as organic fertilizer. Digestate was mainly used for trees in the home garden. Nowadays electricity is widely available in Vietnam therefore use of biogas lamps is very occasional (Roubík et al. 2018).

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

5.3. Maintenance and repair of BGPs

Both communes that were selected as study areas located at a distance approximately 12 km from Hue city (provincial city of Thua Thien Hue province) there shops and markets can be easily found to acquire necessary materials and components for repair of biogas plant. There were 100% of answers related to possibility to purchase all necessary materials and components in Hue city.

In 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 the digesters). Thereby, the household members never knew where the shops were located, and they were not able to repair BGP due to inaccessibility of materials and components. In contrast, respondents from our study area were well informed about local shops and markets.

5.4. Reasons behind BGPs abandonment

The survey revealed reasons of small-scale biogas plants abandonment. Total number of interviewed households reported they stopped using of BGP was 37. Main reasons leading towards abandonment and frequency of appearance reported in interviews by respondents are summarized in table (Table 3) and detailed description presented below.

Table 3. Stated reasons associated with abandonment of small-scale BGPs in target area

Reported reason	Frequency of appearance (n=37)
BGP is full	13.51%
Unknown technical problem (leading to failure of biogas production)	16.22%
Failure to sustain livestock production (for feedstock) due to low motivation to keep pigs	18.92%
Failure to sustain livestock production (for feedstock) due to ASF	18.92%
Reduced labour supply leading to Failure to sustain livestock production (for feedstock)	16.22%
Other different reasons related to preferences of BGPs owners of energy sources	16.22%

Source: Author (2020)

The reason of BGP abandonment reported as full digester can be considered as a lack of proper maintenance due to the lack of knowledge related to biogas technology maintenance. According to Seadi et al. (2008) the fixed-dome Chinese type digester is not stirred. The sedimentation of suspended solids must be removed (2-3 times per year).

A large portion of the substrate is removed, and a small part is left as inoculum. According to some studies, much physical work is needed for the routine operation and maintenance of BGP, which is usually laborious and messy and offsets the convenience offered by biogas use (Wang et al. 2016).

It was observed, in some cases this problem occurred synchronously after certain period of BGP operation after installation. Small-scale biogas owners should be aware of importance of proper cleaning. It is responsibility of BGP owners to clean digesters and responsibility of facilitators and extension workers to instruct them how and how often to do it.

There is also lack of prompt problem solving mainly due to difficulties with technical problem recognition caused by lack of knowledge related to biogas technology.

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

According to research by Jelínek (2019) from the same target area as the target area of this thesis, technical difficulties such as insufficient biogas production can be also related to using of antibiotics for some pigs' diseases. The process of anaerobic digestion can be affected with pigs' manure (containing traces of antibiotics) using as feedstock.

The quantity of pig manure on farm (as well as the quality) played a key role in the abandonment of digester.

Another reason of abandonment was described as the lack of feedstock. This was reported in 14 cases surveyed. This happens when BGP owners are no longer able to provide sufficient amounts of organic manure for the biogas production via small-scale biogas plant. Pigs manure is a main source of organic matter for BGP in Vietnam.

This problem cannot be closely connected with the over-size of BGPs because usually number of animals is not only reduced but owners stop keep pigs within household.

Appropriate conditions for successful long-term operation of technology can depend on local circumstances such as ASF. Abandonment can occur synchronously and quite quickly in this case. In January 2019, an ASF outbreak at a family-owned backyard pig farm in Hung Yen Province, Vietnam, was reported. The farm was situated approximately 50 km from Hanoi and 250 km from the China border and housed 20 sows. 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 before. 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 movement of pigs and pork products, or by infected fomites. Therefore, it is likely that the virus originated in China (Le et al. 2019).

Currently, hog prices are soaring while it is taking a long time for the government to make indemnity payments to affected pig farmers. As a result, there are no incentives for pig farmers to report to the local government suspected cases or diseased pigs. Many farmers would rather sell off their pigs for cash or slaughter for consumption than inform the local authorities, resulting in the spread of pathogens (USDA 2019).

These findings are corresponding with study from African region by Lwiza et al. (2017). It was also revealed that in Uganda some households dis-adopted biogas technology when they lost the pigs that used to supply dung for feedstock for biogas production. The pigs died as a result of being affected by swine fever. Households could not restock pigs until the spread of the disease was under control. There is an essential need for the efficient transmission of information about biosecurity on small-scale level.

There is a variety of reported ways of changes of labour supply needed for agricultural activities including biogas plant operation and maintenance. Reasons might be that the technology is no longer supportable due to the physical inability of BGP owners to keep pigs with lack of other sources of feedstock for biogas production.

There is a number of respondents reported 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 life-style outside agriculture (Centennial International Group 2013). Abandonment occurs also than biogas technology on household level can no longer be supported and properly maintained due to the reasons such as death of husband or birth of children. Keeping pigs give them more disadvantages than advantages and one of the main benefits of biogas cannot be utilized and access to other energy sources.

Other reasons leading towards abandonment were diverse in nature. The unsatisfactory quality of biogas plant from the beginning of using and state of skills of builders according to BGP owners’ opinions were also reported. Problem can be connected with low-quality workmanship. Changes in preferences of energy sources were reported as well. Changes were associated with different accidents with biogas cookers.

5.5. Reported fates of abandoned BGPs

The revealed fates of abandoned small-scale biogas plants are presented in this subchapter. Detailed description is based on the information obtained during the interviews with respondents who abandoned biogas technology on farm.

40.5% of interviewed households reported 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 current situation on their farms where abandoned small-scale biogas plants were located at the moment of 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 farm. 37.84% of households who stopped use their digesters reported they continued keep pigs after 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 plant as a reason of dis-adoption). Respondents were also questioned about current practices of organic waste management (pig manure) on the farm. 9 interviewed households stated they used their BGPs for pig manure storing because pigpen and digester was connected with pipes for input of feedstock. Respondents clean pig house as usual and mix of water and pig manure flows directly to the biogas plant. Uncontrolled processes of decomposition of organic wastes can occur inside digester.

Some biogas plants were not in use for any other purposes on farm after abandonment. Remaining 5 households keeping pigs reported they prefer manage pig manure using other typical for rural areas practices. Pig manure management practices were reported as follows: disposal of manure directly to the garden (2 cases) or to the pond near pig house (1 case), collecting and drying of manure (2 cases). The problem is that insufficiently treated manure released into the environment polluting the air and water (including drinking water sources) and contaminating food crops with mainly 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 occurred technical problem with biogas plant.

62.16% of households reported the absence of pig manure on site because due to the different reasons they stopped keep pigs (as mentioned before). Households are no longer needed to take advantage of biogas technology which can help to solve manure management problems.

6 households highlighted the fact that they use their digesters for human excreta storing after biogas technology dis-adoption. The number of households who stopped keep pigs reported their biogas plants were initially connected to the toilet was more, but this practice was predominantly used by farmers who stopped keep pigs due to their advanced age. In case of inability to keep pigs longer and operate digester for biogas production, this practice can be considered as optimal solution for environment.

The results of interviews showed 17 biogas plants are appeared to be abandoned with no using for any other purposes within households. According to Roubík et al. (2020) relevant rehabilitation and repair activities can put the abandoned BGPs back into operation. It is noteworthy that there are no specific regulations how to dispose the biogas plant in the situations such as dis-adoption by its owner. According to the research by Jelínek (2019) from the same study area, important local actors (including masons and facilitators) provided information that BGP owners are commonly responsible for BGP when it reaches the end of its life. Local leaders are usually not aware about biogas technology dis-adoption.

5.6. Results of BGPs abandonment

The abandonment of biogas technology leads to return to the use of traditional energy sources for cooking. 54.1% of interviewed households use LPG, 40.5% use mix of LPG and firewood, 2.7% use mix LPG and electricity, 2.7% use electricity. It results in non-use of advantages of biogas technology such as money savings and reduction of smoke and emissions in the area. However, cooking activities with LPG is easy and smoke is less. Cost of energy (using LPG) for cooking increases (compared with biogas) and its use does not contribute to the local environment protection. There is no significant difference can be observed in kitchen conditions in households where biogas was replaced by LPG because stoves are used too, as opposed to use of firewood for cooking (Figure 8).

Figure 8. Photo documentation - biogas stoves types used in target area and firewood

Source: Author (2019)

51.4% of respondents agreed with the statement «I want to use BGP on my farm again», strongly agreed were 8.1% of respondents, neutral were 27%, disagreed - 11.8%, and strongly disagreed were 2.7% of respondents. Results suggest that majority of abandoned BGPs could be restarted due to the willingness of respondents to use biogas technology.

5.7. Results of the binary logistic regression model analysis

The binary logistic regression model was used to analyse the possible effects of factors influencing abandonment of small-scale biogas plants. The results are presented in Table 4 below. To check the fitness of the data obtained for binary logistic regression, Hosmer-Lemeshow test was conducted ($p>0.05$). There was no serious multicollinearity between the variables included in the model. The variance inflation factor test result shows that all independent variables have values less than 10. The data was fit for logistic regression model.

Table 4. Results of binary logit model analysis

Variable	Coefficient (B)	Standard error	Sig.	Odds ratio Exp (B)
Total area of the farm	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 the farm	**-1.253**	**0.421**	**0.003***	**0.286**
Subsidy received for BGP	-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	348.955

Number of observations 99, *$p<0.01$

Prob > Chi_2 =0.000 (Sig=0.000225) (Omnibus Test of Model Coefficients)

Pseudo R_2 (Cox&Snell R Square 0.231, Nagelkerke R Square 0.315)

Results of analysis suggested that significant predictors used in model include number of people working on the farm and the satisfaction with the maintenance of biogas plant.

Coefficients for both variables are negative, and effects of this results can be described as follow.

In respect to effect of labour supply, number of people working on farm increase with one person, increase the probability of longer use of biogas plant (28.6% probability higher). It might be due to the fact that with larger number of household members working on farm is expected their participation in biogas plant operation and proper maintenance of it. For example, usually old owners of biogas plants are not able to do it due to their physical inability and due to the absence of help from younger family members with agricultural activities too.

Study from China by Qu et al. (2013) reported that higher probability higher probability to use biogas technology with more possible labour to take care of a biogas plant were in larger families. At the same time, they are usually motivated to save on their higher energy costs for cooking. But due to limitations of presents study, number of people working on farm were taken into consideration as labour supply for biogas plant operation and maintenance.

Households more satisfied with maintenance of BGPs were found less likely abandon BGP (32.1% higher probability). BGP owners' opinion about 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).

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

6. Conclusion

The objective of the thesis was to reveal the fate of abandoned small-scale biogas plants in central Vietnam and reasons leading towards abandonment or dis-adoption of biogas technology. The results of the primary data collection and analysis present a study of small-scale biogas plants abandonment issue in rural areas of central Vietnam.

First of all, there was an attempt to present the state of the art. Especially due to the reason that scientific literature in the study field of biogas technology abandonment is still limited, it provides valuable and systematic overview.

Long-term use of small-scale biogas technology in rural areas of Vietnam can be affected by occurred difficulties leading to the dis-adoption of technology. Results of the study suggest that majority of BGPs were abandoned after 6-7 years in operation with a typical lifespan of BGP 20 years.

Difficulties were observed related to the lack of feedstock sources due to the low motivation of BGP owners to sustain keeping pigs. Which was caused by different reasons, such as decreased labour supply or households' decision to stop keeping pigs. However, there were also circumstances beyond their motivation to keep pigs. Another important lesson of the BGPs abandonment in central Vietnam was the danger posed by African swine fever outbreaks. There is a need for biosecurity of pig production on small-scale level.

The decision to stop keep pigs resulting in a lack of substrate for biogas production is not easy to prevent. In this case, biogas technology does not remain beneficial for the rural household as practice for organic waste management.

Lack of adequate maintenance, mainly cleaning of BGP, appears as a reason for stop using of BGP. Respondents also indicated some technical problems as unknown. Results suggest that the problem of knowledge related to biogas technology should be addressed. It is necessary to provide farmers with an understanding of proper BGP maintenance.

Using a logistic regression analysis of various cross-sectional data, key forces were uncovered in order to find out factors that possibly influence the abandonment of biogas technology. Results of analysis showed that households with more members working on the farm and more satisfied with the maintenance of the biogas plant are less likely to abandon it.

It was revealed that nearly half of abandoned small-scale BGPs were not in use for any other purposes which could be useful for households. Number of digesters initially connected to the toilet are currently often used only for human excreta storing. Organic waste practices after BGP abandonment can contribute to the environmental problems in the area including contamination of soil and water.

It can be concluded that the dis-adoption of biogas technology leads to the return of rural households to conventional energy sources for cooking such as firewood and LPG, resulting in a waste of investments to biogas technology and its possible advantages.

Further research to identify more different factors likely influencing the decision to abandon biogas technology is recommended. It is necessary to find ways to ensure proper maintenance of BGP and to prevent breakdowns of well-functioning biogas plants.

Biogas production through anaerobic digestion process has been promoted widely in Vietnam as an appropriate technology. In order to increase the Vietnamese rural households' reliance on a renewable source of energy it is necessary to support existing small-scale biogas plants and to keep them functional. Successful self-sustaining biogas technology can be achieved in the future with more users benefitting from biogas technology on small-scale level.

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Appendices

List of the appendices:

Appendix 1: BGP owners' interview

Biogas Research Team

Field survey 2019 - Questionnaire

Target group – farmers who disadopted the biogas technology (BT)

1) Personal information

1.1. Family name, first name: ________________

1.2. Gender: ☐ Male ☐ Female

1.3. Age: ____years

1.4. Are you head of the household? ☐ Yes ☐ No

1.5. Highest achieved education:

☐ Primary school ☐ High school ☐ University ☐ Without formal education

1.6. What is main household occupation? ________________

1.7. What is the average income of your household? _________ VND / month

1.8. What share of income (in %) comes from on-farm activities? ________%

1.9. Related to the innovations, I consider myself as:

☐ Conservative ☐ Moderately dynamic ☐ Dynamic with willingness to take a risk of failure

1.10. I am interested in new innovations.

1 (Strongly agree)	2	3	4	5 (Strongly disagree)

1.11. I am in regular contact with extension agents: ☐ Yes ☐ No

2) Basic information about the farm

2.1. Location (commune): ________________

2.2. Total farm area: ________________ m^2

2.3. How many people work on the farm? ________________

3) Basic information about biogas plant on the farm

3.1. Biogas plant type: ☐ KT 1 ☐ KT 2 ☐ Other

3.2. The date of the installation of the BGP: ________________

3.3. Biogas plant size (volume): ________________m^3

3.4. BGP connected to the toilet: ☐ Yes ☐ No

3.5. What is the source of water do you use for the BGP?

☐ Public water supply ☐ River ☐ Pond ☐ Other: ______________

3.6. Who operated the BGP? ____________________

3.7. How many hours spent the operator of BGP daily? _________________

3.8. What was the expected lifespan of the BGP? ___________ years

3.9. Did you receive any subsidy for the BGP? ☐ Yes ☐ No

If YES, how much did you receive: ______________VND

4) Awareness about biogas technology

4.1. Have you attended any trainings regarding to biogas technology?

☐ Yes ☐ No

4.2. Who provided you training regarding biogas technology? ____________

4.3. How satisfied were you with the training?

1 (Very satisfied)	2	3	4	5 (Not satisfied)

5) Biogas plant using

5.1. Did you use your biogas technology for…?

☐ Cooking
☐ Lightning
☐ Digestate

5.2. Have you noticed any improvement in your livelihood with biogas plant?

☐ Yes ☐ No

If YES, please describe____

6) Biogas plant maintenance and repair

6.1. Are there enough available possibilities in the area to acquire all necessary materials for biogas plant repair? ☐ Yes ☐ No

6.2. Are there enough available possibilities in the area to acquire all necessary components for biogas plant repair? ☐ Yes ☐ No

6.3. Where is the shop located?

☐ In your village ☐ In the neighbouring village

6.4. How much money (maximum) are you willing to spend for biogas plant repair? ____________ VND

7) The factors contributing to biogas plant abandonment

7.1. The reasons I have abandoned to use of biogas plant are:

☐ Failure of sustain livestock production (for feedstock)
☐ Non-functional biogas plant
☐ Reduced supply of family labour
☐ Preferences for alternative fuel
☐Other:____________________

7.2. When did you use biogas plant last time? ________________

7.3. Choose difficulties with feedstock supply you had:

☐ Livestock was sold to meet household needs

☐ Death of livestock

☐ Other: ____________________

7.4. Have you experienced any technical problems which lead to malfunctioning of the biogas plant?

☐ Yes ☐ No

If YES, please choose:

☐ Problems with floating layers on top of the substrate

☐ Problems that clog the gas pipeline, and/or the outlet of the digester

☐ Leakages/cracks in BGP

☐ Other: ____

7.5. Have you experienced any difficulties with daily operations?

☐ Yes ☐ No

If YES, please specify: ____

7.6. Is the BGP broken nowadays? ☐ Yes ☐ No

If YES, please, choose reasons why is it impossible for you to repair the BGP:

☐ Lack of knowledge related to biogas technology

☐ Lack of money

☐ Lack of access to shops for replacement of spoilt components

☐ Unable to access technicians and masons for repairs

☐ Other: ____

8) Farmers' expectations from and satisfaction with biogas technology

8.1. How satisfied were you with biogas production for cooking?

1 (Very satisfied)	2	3	4	5 (Not satisfied)

8.2. How satisfied were you with biogas production for lighting?

1 (Very satisfied)	2	3	4	5 (Not satisfied)

8.3. How satisfied were you with requirements on biogas plant operation?

1 (Very satisfied)	2	3	4	5 (Not satisfied)

8.4. How satisfied were you with requirements on biogas plant maintenance?

1 (Very satisfied)	2	3	4	5 (Not satisfied)

8.5. How satisfied were you with economic benefits from BT?

1 (Very satisfied)	2	3	4	5 (Not satisfied)

8.6. How satisfied were you with time savings thanks to BT?

1 (Very satisfied)	2	3	4	5 (Not satisfied)

8.7. What other energy sources for cooking did you use together with biogas? ____________

8.8. What other energy sources for lightening did you use together with biogas? ____________

9) Current situation on the farm

9.1. How do you manage manure now? ______________________

9.2. What energy source do you use for cooking? _______________

9.3. What energy source do you use for lighting? _______________

9.4. I want to use biogas plant on my farm again.

1 (Strongly agree)	2	3	4	5 (Strongly disagree)

9.5. What do you need to continue biogas plant using?

☐ Labour supply (help with daily operations)
☐ Feedstock supply
☐ Some components
☐ Consultation
☐ Cooking or lighting equipment
☐Other:___________________________________

9.6. How was changed the number of farm animals (cattle, pigs, chicken…) during the period of biogas plant using?

☐ Increased ☐ Decreased ☐ No change

9.7. Did you have any changes with labour supply on your farm during the period of biogas plant using?

____
____

9.8. Who have decided to stop using the biogas plant?

____

10) Other comments / information:

____
____

Appendix 2: BGP owners' interview

Biogas Research Team

Field survey 2019 - Questionnaire

Target group – farmers who are still using the BGP

5) Personal information

5.1. Family name, first name: ________________

5.2. Gender: ☐ Male ☐ Female

5.3. Age: ____years

5.4. Are you head of the household? ☐ Yes ☐ No

5.5. Highest achieved education:

☐ Primary school ☐ High school ☐ University ☐ Without formal education

5.6. What is main household occupation? ________________

5.7. What is the average income of your household? __________ VND / month

5.8. What share of income (in %) comes from on-farm activities? _________%

5.9. Related to the innovations, I consider myself as:

☐ Conservative ☐ Moderately dynamic ☐ Dynamic with willingness to take a risk of failure

5.10. I am interested in new innovations.

1 (strongly agree)	2	3	4	5 (strongly disagree)

5.11. I am in regular contact with extension agents: ☐ Yes ☐ No

6) Basic information about the farm

6.1. Location (district, village, GPS): _______________

6.2. Total farm area: _______________ m^2

6.3. How many people work on the farm? _______________

7) Basic information about biogas plant on the farm

7.1. Biogas plant type: ☐ KT 1 ☐ KT 2 ☐ Other

7.2. The date of the installation of the BGP: _______________

7.3. Biogas plant size (volume): _______________m^3

7.4. BGP connected to the toilet: ☐ Yes ☐ No

7.5. What is the source of water you use for the BGP?

☐ Public water supply ☐ River ☐ Pond ☐ Other: _____________

7.6. Who does operate the BGP? ___________________

7.7. How many hours spent the operator of BGP daily? ________________

7.8. What is the expected lifespan of the BGP? __________ years

7.9. Did you receive any subsidy? ☐ Yes ☐ No

If YES, how much did you receive: _____________VND

8) Awareness about biogas technology

8.1. Have you attended any trainings regarding to the biogas technology?

☐ Yes ☐ No

8.2. Who provided you training regarding biogas technology? ___________

8.3. How satisfied were you with the training?

1 (very satisfied)	2	3	4	5 (not satisfied)

11) Biogas plant using

11.1. Do you use your biogas for…

☐ Cooking
☐ Lightning
☐ Digestate

11.2. Have you noticed any improvement in your livelihood with biogas plant?

☐ Yes ☐ No

If YES, please describe____

11.3. What does motivate you to keep the BGP working?
____

11.4. What benefits do you see in the using of BT?
____

12) Biogas plant maintenance and repair

12.1. Are there enough available possibilities in the area to acquire all necessary materials for biogas plant repair? ☐ Yes ☐ No

12.2. Are there enough available possibilities in the area to acquire all necessary components for biogas plant repair? ☐ Yes ☐ No

12.3. Where is the shop located?

☐ In your village ☐ In the neighbouring village

12.4. How much money (maximum) are you willing to spend for biogas plant repair? _____________ VND

12.5. Have you experienced any technical problems which lead to malfunctioning of biogas plant?

☐ Yes ☐ No

If YES, please choose:

☐ Problems with floating layers on top of the substrate
☐ Problems that clog the gas pipeline, and/or the outlet of the digester
☐ Leakages/cracks in BGP
☐ Other: ____

12.6. Have you experienced any difficulties with daily operations?

☐ Yes ☐ No

If yes, please specify: ____

13) Farmers' expectations from and satisfaction with biogas technology

8.1. How satisfied are you with biogas production for cooking?

1 (Very satisfied)	2	3	4	5 (Not satisfied)

8.2. How satisfied are you with biogas production for lighting?

1 (Very satisfied)	2	3	4	5 (Not satisfied)

8.3. How satisfied are you with requirements on biogas plant operation?

1 (Very satisfied)	2	3	4	5 (Not satisfied)

8.4. How satisfied are you with requirements on biogas plant operation?

1 (Very satisfied)	2	3	4	5 (Not satisfied)

8.5. How satisfied are you with economic benefits from BT?

1 (Very satisfied)	2	3	4	5 (Not satisfied)

8.6. How satisfied are you with time savings thanks to BT?

1 (Very satisfied)	2	3	4	5 (Not satisfied)

8.7. What other energy sources for cooking do you use together with biogas? ____________

8.8. What other energy sources for lightening do you use together with biogas?____________

14) Other comments / information:

____

____