Design and Evaluation of the Economic-Environmental Benefits from Livestock Waste and Food Waste Treatment by Small-Scale Biogas Digesters in Farming Communities for Sustainable Development in Central Vietnam.

A Thesis for Acquirement of the Degree of Doctor of Philosophy

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ABSTRACT

Livestock waste and food waste are the two main sources of solid waste in Vietnam. The development of urbanization has caused the amount of municipal solid waste to increase rapidly and there is a lack of landfills for treatment. In this context, biogas digester is proposed as a useful solution for waste treatment as well as taking advantage of renewable energy sources.

This study focused on assessing the economic, environmental and social benefits of biogas digesters in central Vietnam and proposed operating models for biogas digester. It showed the results of calculations for biogas production and greenhouse gases emissions reduction due to use of small-scale biogas digesters. This analysis showed a significant reduction in GHGs emissions due to the use of biogas digesters in the context of the regional study area. This research also evaluates farmers' attitudes towards the environmental impact of biogas technology, usage satisfaction and future prospects of promoting household-scale biogas energy in central Vietnam. Then pointing out the limitations in making the decision to build a biogas digester, typically the problem of high capital.

A method to solve the economic problem to access to biogas technology is proposing two models of building the biogas digesters in cluster-scale of families, along with a combination of food waste and livestock waste as inputs for the composting digesters to utilize the maximum capacity of the digester. This study has calculated and shown the benefits of using biogas with an easier approach for farmers towards a sustainable development.

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List of Abbreviations

FAO	Food and Agriculture Organization of the United Nations
GDP	Gross Domestic Product
GHG	Greenhouse Gas
IEE	Intelligent Energy Europe
IPCC	Intergovernmental Panel on Climate Change
IRENA	International Renewable Energy Agency
JICA	Japan International Cooperation Agency
LPG	Liquefied Petroleum Gas
MONRE	Ministry of Natural Resources and Environment of Vietnam
MPI	Multidimensional Poverty Index
MSW	Municipal Solid Waste
SD	Standard Deviation
SDGs	Sustainable Development Goals
URENCO	Urban Environment Company
USD	United States Dollar
VND	Vietnamese Dong
VS	Volatile Solid

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Chapter 1 INTRODUCTION

1.1 Background

On a worldwide basis, livestock production is achieved at a substantial environmental cost with contribution of 18% of global greenhouse gas (GHG) emissions (*Steinfeld et al., 2006*). GHG emissions from animal production include CH4 directly emitted from domestic animals or livestock manures, and N_2O emitted from land applied manures and grazed lands (*Kebread et al., 2006*). Vietnam is an agricultural country with a high proportion of the population living in rural areas, so livestock production plays a very important role in the national economy. In recent years, the livestock sector in Vietnam has developed rapidly, especially pig raising, which has contributed to the rise in income and improves the living standards of local citizens of rural areas. With the current growth of the livestock industry in Vietnam, based on calculations based on animal physiological science and statistics, it can be seen that the solid waste emissions of livestock raising rate increases according to the scale growth, the average emission is estimated at about 1.5 kg of pig manure/head/day, 15 kg of buffalo, cow manure/ head/ day and 0.2 kg of poultry manure/head/day *(Quang Tri Department of Agriculture and Rural Development, 2016)*. With the total livestock population in the whole country, the average emissions are more than 85 million tons per year, several tens of billions of cubic liquid waste, several hundred million tons of gas waste. However, the management and treatment of animal waste has not been given due attention. The main reason is due to low awareness and responsibility of farm owners. Most farmers do not have proper waste treatment measures, thus environmental pollution in livestock has not been completely overcome and tends to increase. The lack of planning, especially in densely populated areas, has caused increasingly serious environmental pollution. In the uncontrolled natural environment, this is the main cause of environmental pollution of soil, water and air, adversely affecting human health.

In this circumstance, low-cost biogas digesters are a good selection for reducing environmental impacts and improving the standard of living of rural families. In recent years, biogas technology has been applied to treat livestock wastes and has brought about significant economic, environmental and social benefits. Low-cost digesters are considered to be a clean and environmentally friendly technology which can help small-scale farmers to treat livestock waste in a sustainable way, while producing a biofertiliser (digestate) and meeting their energy needs (i.e., by providing biogas) *(Kinyua et al., 2014)*. Biogas refers to the collection of gases from the decomposition and fermentation of animal, human, and plant waste resulting from the lack of oxygen and the activities of anaerobic bacteria in anaerobic digestion. This is an effective way of minimizing the negative impacts of animal waste on the environment and human health. Since the installation of the biogas digester, pollution has been reduced, households can now use the gas produced, and also families have a clean environment, which helps people get out of the air pollution caused by animal waste. Realizing the potential benefits from biogas, the Vietnamese government, local authorities as well as the farmers have decided to invest in this renewable technology. The number of household biogas digesters has considerable increased in Vietnam during the past two decades *(Nguyen, 2011; Nguyen et al., 2012). Teune (2007)* revealed that in 2007, there were more than 200,000 small-scale biogas digesters being in operation in Vietnam. This number continued to increase significantly as there were about 500,000 biogas digesters installed in the livestock farms in this country *(Mayhew, 2015; Ho et al., 2015)*.

Nowadays, global warming and climate change are issues of a great concern. Household biogas digesters are a promising solution to reduce GHGs emissions, even if environmental benefits are more significant when biogas production fully satisfies family's needs for cooking, or in large-scale projects. Biogas digesters are currently used for cooking and lighting in many developing countries and can provide an alternative energy source from traditional fuels such as firewood and liquefied petroleum gas *(Hessen, 2014; Mengistu et al., 2015; Roopnarain & Adeleke, 2017). Zhang et al. (2013)* showed that the long-term, stable running of a household biogas technology is potential in quantifying carbon emission reduction in rural China. The use of biogas technology has led to a dramatic reduction in the consumption of fossil fuels, and a reduction in fueling problems, especially in rural areas of the developing country.

According to estimates by the *Food and Agriculture Organization of the World (FAO, 2005)*, the global economic losses caused by food waste amount to one trillion USD per year. In particular, the amount of grains, vegetables, tubers, fruits, fish, oilseeds, meat and dairy products wasted in the food industry ranged from 20 to 50% per year *(FAO, 2015)*. When food is wasted, all costs associated with the production, processing, packaging, transportation, and sale of that food are also lost. Furthermore, food waste that ends up in landfills could cause serious environmental impacts *(Kawashima, 2004)*. *Salemdeeb et al. (2017)* indicated that recycling or reusing food waste as pig feed (wet or dry) could have more positive public health and environmental impacts than with other treatment methods such as composting or anaerobic composting. The world population was predicted to increase to 9.8 billion people by 2050 *(United Nations - UN, 2017)*. Along with global population growth, food waste would increase accordingly. With increasing consumer demand, the food processing industry has become one of the developed industries with increasingly strict and scientific processing processes. However, during production and after use, food waste, if not properly classified and treated, would pollute the environment and waste resources. This is a great challenge for humanity but also an opportunity for us to rethink and find new ways to treat food waste with better efficiency. In some Asian countries such as Japan and South Korea where there was a high demand for animal feed, recycling food waste for animal feed was very popular and supported by law *(Gen, 2006; Kim et al., 2011)*. Normally, feed accounts for about 70% of the total cost of livestock. In which, the majority of feed costs come from protein or amino acid-rich ingredients *(DeGroot, 2014)*. The use of food waste as animal feed in Vietnam is quite common so far.

1.2 Research site selection

Two survey sites were selected for this study: Quang Tri Province and Danang City. These are two typical areas for rural area and urban area in central Vietnam. With the rapid urbanization progress, accelerating population growth, industry accumulation, and large-scale development, the exponential expansion of the city has caused negative impacts on sustainable development of the city. Solid waste disposal management are becoming increasing concerns of both cities. Detailed characteristics of each site selection are described in Chapter 3 and Chapter 5.

The agriculture sector makes up one third of Vietnam’s continuously developing economy. In 2021, agriculture, forestry and fishing accounted for 12.56 percent of the country’s gross domestic product (GDP) *(Nguyen, 2022)*. Within the Asia Pacific region, Vietnam's growth of the agriculture sector was comparable to, for instance, Bhutan, India, and Bangladesh. The agricultural land area made up 39.28 percent of Vietnam's total land area in 2016. As of 2015, the area of land under temporary agricultural crops reached approximately seven million hectares *(Nguyen, 2022)*.

In 2018, the agriculture sector accounted for 39.8 percent of employment in Vietnam which amounted to approximately 20.47 million employed people in that year. Small-scale household based production accounts for about 70 percent of the total livestock production in Vietnam. Livestock plays an important role in generating rural income in Vietnam; an estimated 8.3 million households produce poultry and seven million households produce pigs. Increasing incomes have resulted in a higher demand for livestock products.

Main livestock products in Vietnam include buffalo, cattle, pork and poultry. In 2017, the pig production in Vietnam amounted to approximately 27 million heads. In 2018, the pork production was highest with a volume of approximately 3.8 million tons, followed by the poultry production volume amounting to around 1.1 million tons. This is a traditional profession and plays an important role in providing meat for people's daily life and for export in Vietnam today. Pig raising by traditional methods provides the majority of meat production for domestic consumption.

According to the 2018 Statistical Report of Environmental Protection in Livestock

Production by the Department of Agriculture and Rural Development of Quang Tri Province, the province has 40 farms, 92189 cattle and poultry raising households, which is mainly raising pigs. There are 28 animal husbandry farms associated with feed companies and 5 livestock cooperatives. The total number of cattle and poultry in the province as of July 2018 included: 226665 pigs, 66928 cows, 25830 buffaloes, and 2426900 poultry. The livestock industry is one of the main agricultural industries of Quang Tri Province following the model of small-scale and household livestock production. The treatment of livestock waste has not been paid much attention to by farmers, causing worrying environmental pollution. The study of appropriate livestock waste treatment solutions should be focused in this area. The livestock industry is one of the main agricultural industries of Quang Tri Province following the model of small-scale and household livestock production. The treatment of livestock waste has not been paid much attention to by farmers, causing worrying environmental pollution. The study of appropriate livestock waste treatment solutions should be focused in this area.

Besides, in the context of urbanized cities in developing countries, food waste at the consumption stage in developing economies could be even higher than in developed countries (*Liu et al., 2016; Liu et al., 2020*), which indicates that addressing food waste in urbanized cities is an urgent issue in Asia as well as Vietnam. Vietnam has experienced a remarkable shift from low to middle income over the past three decades. The rapid growth combined with industrialization and urbanization has led to significant changes in production and consumption patterns. This also brought changes in lifestyle, in line with increased consumerism and changes in eating-related habits. As a result, there has been a significant increase in the amount of municipal waste and food waste per capita, especially in large and fast-growing cities such as Da Nang. It has been reported that food waste accounts for about 50–60% (or more in some cities) of solid waste generated in urban areas, which is ultimately disposed of in burying landfills *(Ministry of Natural Resources and Environment of Vietnam (MONRE), 2017).*

Da Nang City is a port city located in central Vietnam. Da Nang is the fifth most populous city in the country, with a population of 1,080,700 as of 2018 and an area of 1285.4 km². Da Nang is subdivided into eight districts: six urban districts (Cam Le, Hai Chau, Thanh Khe, Lien Chieu, Nguyen Chieu, Ngu Hanh Son, and Son Tra) and two rural districts (Hoa Vang and Hoang Sa). It is further subdivided into one commune-level town, 14 communes, and 45 wards. Da Nang is one of the four biggest cities in Vietnam where the gross domestic product (GDP) growth rate has been higher than the country's national average. Between 2017 and 2018, Da Nang's regional GDP grew 7.9 percent annually whereas the national GDP was 7.1%, in total of 1.655 billion USD in 2018. The economy has historically been dominated by the industrial and construction sectors but is slowly changing. In 2006, the services sector became the largest economic sector in the city as measured by gross output. The tourism sector is also expected to grow, as the city strives to become a major national tourist sector After more than 20 years of development, Da Nang has gained much prosperity: tourism products are more diversified and enriched, with a high tourist growth rate of 21.93% between 2007-2016. The average revenue from tourism reached 29.6% of Da Nang GDP. The process of mining and tourism development has led to an increase in municipal solid waste, notably food waste. According to the survey data of *URENCO (Urban Environment Company)*, Da Nang City collected about 268 thousand tons of municipal solid waste in 2013, and the collection rate for 2012 was 92%. Per capita waste generation in Da Nang City is 0.675 kg per day in 2010 *(Japan International Cooperation Agency JICA, 2014).* Municipal solid waste in Da Nang composed of 68.47% food waste, 5.07% paper, 2.89% cloth, 2.79% wood, 11.36% plastic, 0.14% glass, 1.45% metal, 0.02% hazardous waste and 3.15% other waste *(Nguyen D. H., 2018)*. Currently, all municipal solid waste generated is treated with sanitary landfill technology at the Khanh Son landfill locating in Hoa Khanh Nam Ward, Lien Chieu District, Da Nang. The disadvantage of municipal solid waste disposal and treatment at this landfill is that it has become a hotspot for environmental pollution in Da Nang, and is an unfavorable use of land. Over time, costs for municipal solid waste collection and costs for treatment in this landfill have also increased, particularly to deal with odor, GHG emissions, and leachate that emerge from the landfill. The disposal of MSW, especially food waste, is one of the urgent issues of the Da Nang city agency at present, that aiming to guide Da Nang's long-term future plan in achieving environmental sustainability, and proving the view that Da Nang is a smart and "worth-living" city of Vietnam.

According to the *Food and Agriculture Organization of the United Nations (FAO)*, about 1.3 billion tons of food and food were thrown away in Vietnam in 2015. It is notable that Vietnam's rate of food waste is twice as high as that of advanced and wealthy economies in the world. A survey in 2018 by *CEL Consulting* showed that Vietnam ranked second in the Asia-Pacific region in terms of food waste with more than 8 million tons of food, causing an estimated 3.9 billion USD in damage annually. Food waste can be recycled to produce organic fertilizers or feed pigs at livestock facilities. *Kato et al. (2012)* estimated that swine breeders collected 26.3 metric tons of organic waste per day for feeding pigs, accounted for 4.1% of the domestic waste collected by the local government every day. The fact that pig farmers' recycling this waste has contributed to reducing domestic waste that ends up in the city's landfill. However, since 2019, the outbreak of the COVID-19 pandemic along with African swine fever has caused many difficulties for the farmers in collecting leftovers. Therefore, it is necessary to consider other sustainable solutions for the treatment of food waste.

1.3 Research objectives

Through a specific case study conducted in Quang Tri Province and Danang City, this study aimed to answer key questions on:

(i) The amount of biogas produced and examine if the biogas digesters are being used efficiently.

(ii) The reduction of GHGs emissions due to the use of a biogas digester using relevant factors appropriate to the study area.

(iii) Determining the factors of farmers' decision to install biogas digesters

(iv) Evaluating the impacts of household income to the configuration of biogas digesters

(v) Estimating amounts of energy cost saving

(vi) Analyzing the factors of farmers' satisfaction with a biogas digester

(vii) Proposing recommendations to enhance the adoption and development of household-scale biogas technology as a sustainable energy option in developing countries.

(viii) Estimating the capacity on the potential of biogas production from food waste combined with locally produced livestock waste. An evaluation on the economic implication of a biogas digester built from composite material for household clusters to ascertain its cost effectiveness had been done.

1.4 Chapter plan

This dissertation is divided into 6 chapters:

Chapter 1 contains a description of the background research topic and issues. The main content of this chapter: the research problems and research objectives.

Chapter 2 describes the literature review on the use of small-scale biogas digesters for livestock waste treatment along with its economic, social and environmental benefits. It also contains the state of similar research that has been done.

Chapter 3 is calculating the amount of biogas production and greenhouse gases (GHGs) emissions reduction due to use of the biogas digesters in small farms in Quang Tri Province, Vietnam. Chapter 3 aims to address the objectives (i) and (ii) referenced to the article *Biogas Production and Greenhouse Gas (GHG) Emissions Reduction due to Use of Biogas Digesters in Small Farms in Quang Tri Province, Vietnam* by Hoang and Kato (2021).

Chapter 4 is evaluating farmers' attitudes towards economic benefits, environmental impact of biogas technology, and policy recommendation in promoting household-scale biogas energy in central Vietnam. Chapter 4 aims to address the objectives (iii), (iv), (v), (vi) and (vii) and referenced to the article *Using Household-scale Biogas Digesters as a Tool for Poverty*

Alleviation in Central Vietnam by Hoang, T. H., Kato, T., and Hoang, H. (2022) and *Evaluation of Farmers' Attitudes Towards the Environmental Impact of Biogas Technology, Usage Satisfaction and Future Prospects of Promoting Household-scale Biogas Energy in Central Vietnam* by Hoang, T. H., Kato, T., and Hoang, H. (2021) which was presented in The 10th Congress of the Asian Association of Environmental and Resource Economics (AAERE) conference in 2021.

Chapter 5 is techno-economic evaluation of biogas production from livestock waste combining food waste in household clusters. Chapter 5 addresses the final objective (viii).

And Chapter 6 contains conclusion and recommendation for future studies and policy makers.

The outline diagram of the dissertation is shown in Figure 1-1.

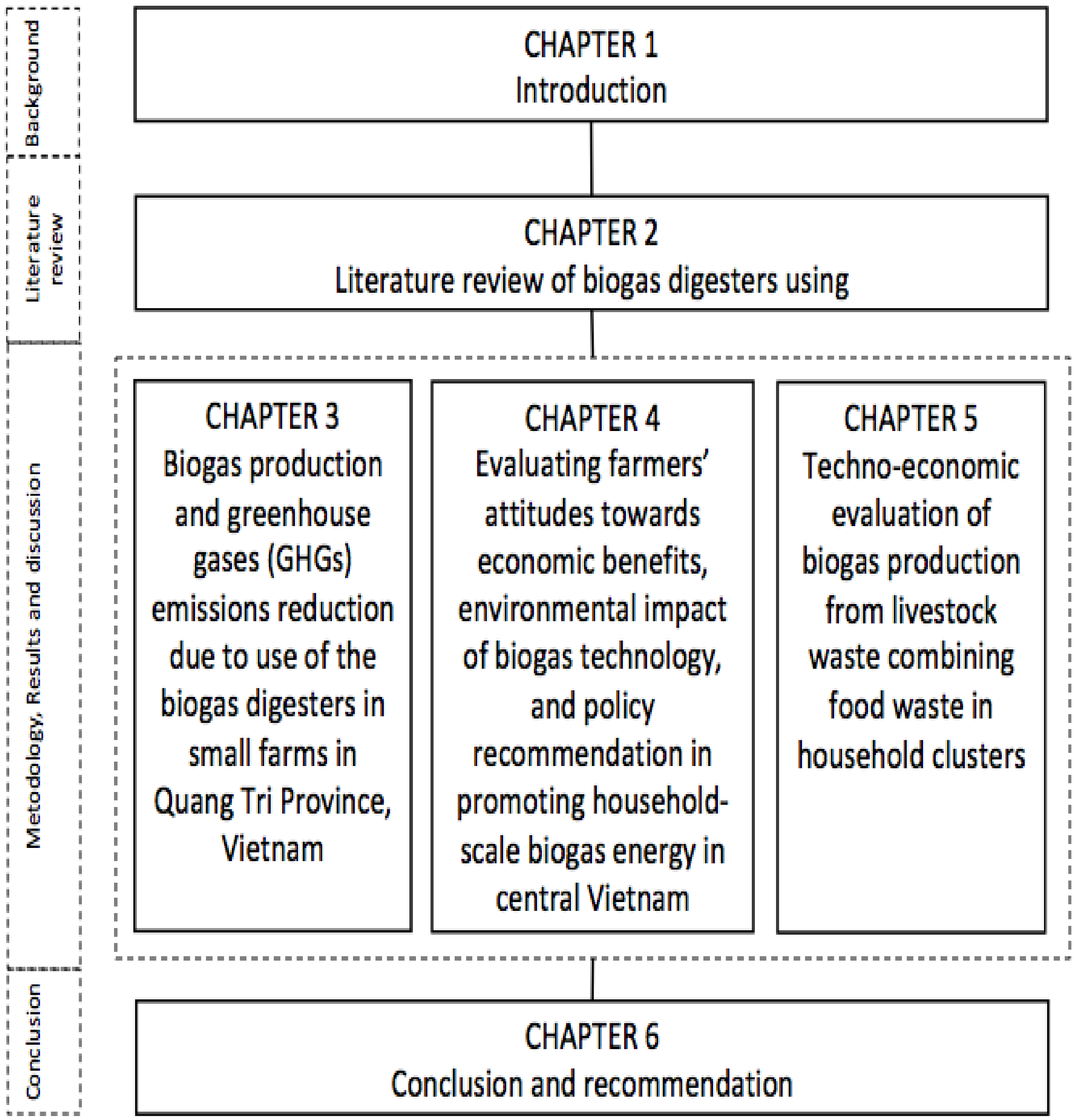


Figure 1-1 Outline of Dissertation

Chapter 2 LITERATURE REVIEW OF BIOGAS DIGESTER USE AND INOVATION OF THIS STUDY

2.1 Studies on environmental benefits from biogas digesters

For decades, many researches have been done for evaluating the effectiveness of biogas digesters in reducing greenhouse gas emissions. There are several studies showing that biogas digesters can become a means to reduce global warming impacts relatively easily if CH_4 emissions can be kept low. A study in Vietnam showed that an emission of 0.95 annual tons of CO_2 could be avoided via energy substitution from household biogas plant. It was also determined that the use of biogas led to a 20% reduction in GHG emissions compared with GHG emissions due to firewood. In addition, GHG emissions of 384.1 kg CO_2e per year per animal could be prevented *(Roubík et al., 2020).* In southern Ethiopia, each household with a biogas digester has the potential to reduce 6024 kg CO2e per year of GHG emission *(Lemma et al., 2021)*. Another research showed that the use of biogas can reduce 20% of global warming potential from India's household cooking *(Singh and Kalamdhad, 2022)*.

However, these previous studies only focused on specified GHGs emitted calculations without considering the variation of the important parameters involved for estimation. In order to calculate the exact amount of GHGs reduction by study area, this study applied sensitivity analysis for determining how different values of the independent variables (volatile solids and biogas amount) affect a particular dependent variable (the total amount of GHGs released) under a given set of assumptions.

2.2 Studies on cost savings from biogas digesters and barriers to access biogas technology

Biogas digesters are currently being used for cooking and lighting in many developing countries, and can provide an alternative source of energy from the traditional use of fuelwood (*Hessen, 2014; Mengistu et al., 2015; Roopnarain and Adeleke, 2017*). Some studies have demonstrated that biogas technology can save time and energy at the household level while providing a bio-slurry that can be used to improve agricultural production (*Gwavuya et al., 2012; Smith et al., 2014*). In southern Ethiopia, using biogas digesters help each household to reduce their fuelwood and charcoal use by about 2410 kg and 379 per year, respectively, and decreased their kerosene use (for lighting) by about 9.5 L per year (*Lemma et al., 2021)*. In Pakistan, household with biogas digester can save 18,830 PKR (equivalent to 83.94 USD) per year compared with those who do not install biogas digester *(Yasmin et al., 2019)*. *Kozlowski (2019*) economically evaluated that the generated waste from the dairy could produce approximately 14.785 MWh of electricity and 57.815 GJ of heat. This supports the construction of biogas plants that can generate electrical power of 1.72 MW. Applying biogas technology in livestock waste treatment is an effective solution not only to reduce greenhouse gas emissions but also to improve environmental quality and bring economic benefits to citizens. The produced biogas can be used as a substitute for fossil fuels such as gas, coal, firewood, and electricity... Biogas is a clean fuel that provides a gas fuel source to satisfy the needs of cooking and lighting, improving economic efficiency and living conditions for farmers, limiting the use of traditional raw materials: gas, coal and firewood. In addition, it can also be used as an alternative fuel for gasoline to run internal combustion engines to generate electricity in fuel shortage areas. *Renwick et al. (2007)* estimated that each household in Sub-Saharan Africa had a 90% reduction in coal consumption and a 75% reduction in firewood consumption after the construction of a biogas digester and on average per household saved about 30.6 USD per year in coal and firewood energy consumption costs. *Joaquin (2009)* showed that at some cattle farms in Costa Rica, electricity generated from biogas through generators is used to replace electricity for milking, providing energy for operations and the annual saving of electricity consumption is 8,030 KWh of electricity. A study in Turkey reported that the total investment cost for the 3 m^3 underground bio-digester for cattle manure was 4433 TL (Turkish Iira), which is equivalent to USD 270.52 (*Tufaner and Avsar, 2019*).

Biogas has also been reported to relieve health risks while providing environmental, agricultural, economic, and social benefits (*Katuwal and Bohara, 2009*). In Ethiopia, usage of biogas digester has brought about a reduction in illnesses caused by indoor air pollution (*Wassie et al., 2021*). Despite the benefits that biogas digesters bring, it is interesting to consider the aspects that influence farmers' decisions to use biogas digesters. With the relatively high cost of this technology, it becomes a big obstacle for farmers to decide to build a biogas digester in developing countries like Vietnam. A research in southern Ethiopia showed that 92.5% of biogas user households and 77.5% of non-users had a positive attitude towards biogas technology. It also indicated that 52.5% of the non-users lacked information about the technology while 25% of the non-users were deterred by biogas installation costs *(Lemma et al., 2021)*. The high investment costs are the most significant barrier for widespread biogas digester use in rural areas of Latin America *(Garfí et al., 2016)*. Similarly, *Roubik et al. (2018)* reached that the primary barrier to a wider dissemination of this technology was the absence of financing. The findings of study in Tigray, Ethiopia indicated that the socioeconomic, infrastructural and environmental factors that were identified as having influence on the adoption of biogas technology *(Kelebe et al., 2017)*.

However, these factors need to be clarified in further studies. Expanding the scope of research on other factors affecting the decision to build a biogas plant is considered in our study. This will help researchers as well as local authorities to gain deeper access to the wishes of the farmers in order to respond towards the dissemination of this technology in the future.

2.3 Studies on the potential amount of biogas produced

One of the concerns in the process of using biogas digesters is the amount of biogas produced. A study in Vietnam showed that the biogas potential is two times higher than current biogas generation. Increasing range of used manure and wider incorporation of connection between biogas plants and toilets are recommendation *(Roubik et al., 2018)*. Several factors should be considered for selecting biogas digester design, such as water and waste (feedstock) availability, biogas and fertilizer needs, climate conditions, local skills, material availability, transportation access, and the price point *(Garfí et al., 2016)*.

In order to provide an appropriate solution to this problem, this study approaches the models of using biogas digesters with inputs including livestock waste combining food waste in scale of household community. From there, the study draws conclusions about feasibility based on evaluations of techno-economic implication of a biogas digester built from composite material for household clusters to ascertain its cost effectiveness.

Chapter 3 BIOGAS PRODUCTION AND GREENHOUSE GASES (GHGs) EMISSIONS REDUCTION DUE TO USE OF BIOGAS DIGESTERS IN SMALL FARMS IN QUANG TRI PROVINCE, VIETNAM

3.1 Introduction

The agricultural sector plays an important role in Vietnam and currently employs nearly half of the workforce. Agriculture not only helps stabilize the lives of most of the rural population, but also serves as the foundation for socio-economic development and political stability. This creates a premise to realize the goal of industrialization and modernization of the country from a developing country like Vietnam. In 2020, although the negative impact of the Covid-19 pandemic caused many industries and services to be halted, Vietnam's agricultural production still developed, still ensuring stable food security in the country and maintain the export of agricultural products. These results are very important, considering that rural areas account for 63% of the population, 66% of households, 68% of working people; and agriculture accounts for 13.96% of GDP (General Statistics Office of Vietnam, 2019). Besides, according to *Ho et al. (2015)* and *Vu et al. (2012)*, the rapidly increasing demand for meat and growing population have caused rapid expansion of the livestock sector. According to the *Department of Livestock Production of Vietnam*, by August 2022, the total pig herd in the country is about 28.7 million heads, the country's live pork production in the first eight months of the year is estimated at 2.94 million tons. It is expected that from now to the end of 2022, the output of live pigs for slaughter is estimated at 350,000 tons/month. In Vietnam, livestock farms are mainly in the form of small-scale livestock that taking place in farmer households, below the scale of livestock production on the farm, mainly by the workers in that household perform. The current scale-up is a challenge that needs to be solved as it causes many problems related to livestock waste management, such as environmental pollution, greenhouse gas emissions and odors *(Luu et al., 2014)*. The main GHG emissions directly emitted from animals are methane (CH_4) and nitrous oxide (N_2O). CH_4 is produced during decomposition of organic matter under anaerobic conditions (enteric fermentation in ruminants and storage of manure); and N_2O is released during the microbial transformation of nitrogen in the soil or manure (nitrification and denitrification processes) as well as during nitrate fertilizer production (*De Boer et al., 2001*). Therefore, liquid waste treatment must be implemented using biogas plants or bio-buffers. Currently, however, livestock waste (urine and/or manure) is hardly treated due to lack of monitoring of implementation on small-scale farms according to national standards, due to lack of financial resources and lack of awareness and knowledge of livestock farmers who handle waste. Livestock owners treat waste by discharging it directly into the environment, creating lagoons in their backyards (*Luu et al., 2014; Ho et al., 2015; Vu et al., 2015*).

In this context, the application of biogas technology is of primary concern. This is considered a reasonable alternative considering the many benefits it can bring such as biogas production and reduction of pollutant emissions and odors. Anaerobic digestion is a biological process that has the potential to enable farmers to adopt more sustainable livestock waste management practices. Biogas digestion has the potential to reduce greenhouse gas emissions, generate commercial heating energy in a sustainable way, and produce value-added fertilizers that are better suited to crop requirements. The main end-products of biogas digestion are the conversion of organic substances to methane as fuel, and valuable fertilizer from available resources that would otherwise would be unused (*Wellinger et al., 2013*). Digestion of animal manure also reduces GHG emissions such as CH_4 and N_2O and odors (*Debruyn and Hilborn, 2007*). Currently, biogas production through anaerobic digestion is the most appropriate technology to reduce greenhouse gas emissions from manure management. In addition, biogas production can contribute to reducing greenhouse gas emissions by replacing fossil fuels.

This chapter aims to two main objectives:

- Estimating the amount of biogas produced and examine if the biogas digesters are being used efficiently.
- Calculating the reduction of GHG emissions due to the use of a biogas digester using relevant factors appropriate to the study area.

3.2 Methodology

3.2.1 Survey area selection

Figure 3-1 The map of survey area (Map data: OpenStreetMap)

The livestock industry, especially pig farming, is one of the key agricultural industries in Quang Tri Province. However, animal husbandry in this province is still mainly household farming, small-scale, livestock waste treatment has not been interested and focused by breeders. Therefore, the environmental pollution caused by livestock waste is still a matter of concern, affecting the lives of people and communities. According to the assessment of the Department of Agriculture and Rural Development of Quang Tri province, currently the number of livestock households with environmental treatment measures only accounts for about 20% of the livestock households. In the province, many scientific and technological solutions have been applied such as compost pits, probiotics (EM), biological pads, biogas digesters and HDPE tarpaulin-covered digesters for waste treatment. At present, the province has 4671 biogas plants of all kinds in raising chickens and pigs to treat livestock waste, limit environmental pollution, and make full use of CH_4 gas for cooking, generating electricity, heating...

Although the biogas digester is a popular livestock waste treatment tool in this province, the management and monitoring of its use is still lacking and needs to be improved. Studies on the process of using digesters in this area are almost nonexistent. Therefore, we have chosen Quang Tri Province as a survey site as well as a representative for central Vietnam. Two potential districts of Quang Tri province were selected to conduct the survey including Gio Linh District and Cam Lo District, where people live mainly in the livestock industry and have invested in waste treatment methods, namely biogas digesters.

Table 3-1 Information about Gio Linh District and Cam Lo District in Quang Tri Province, Vietnam

	Gio Linh District	**Cam Lo District**
1. Area	21,35Km^2 (1,66%)	9,36 Km^2 (0.73%)
2. Population (31/12/2010)	197.922 (21,17%)	179.810 (19,3%)
3. Pop. Density (2010)	9.184,92Km^2	19.064,85/Km^2

The livestock industry is one of the economic strengths of Quang Tri Province. According to the 2018 Statistical Report of Environmental Protection in Livestock Production by the Department of Agriculture and Rural Development of Quang Tri Province, the province has 40 farms, 92189 cattle and poultry raising households, which is mainly raising pigs. There are 28 animal husbandry farms associated with feed companies and 5 livestock cooperatives. The total number of cattle and poultry in the province as of July 2018 included: 226665 pigs, 66928 cows, 25830 buffaloes, and 2426900 poultry.

Table 3-2 Number of livestock statistics in Quang Tri Province in 2018

		Farm-scale livestock	**Household-scale livestock**
Buffalo	Number of farms (farms)	0	7595
	Number of animals (heads)	0	25830
Cow	Number of farms (farms)	4	13849
	Number of animals (heads)	110	66818
Pig	Number of farms (farms)	28	43100
	Number of animals (heads)	20000	206665
Poultry	Number of farms (farms)	8	27645
	Number of animals (heads)	20000	2406900
Other	Number of farms (farms)	0	1744
	Number of animals (heads)	0	20420
Total	Number of farms (farms)	40	92189
	Number of animals (heads)	40101	2706213

Breeding scale in this area is small, the main form of husbandry is farm households, the common average scale is from 1-50 pigs/ household, 1-10 buffaloes, cows/ household, 5-20 chickens/ household, 200-600 ducks/ household.

3.2.2 Research method

3.2.2.1 Data collection

Our data compilation was comprised of both primary and secondary data. The primary data of the study was gathered via the questionnaire-based survey. An in-person interview was conducted in Gio Linh District and Cam Lo District in Quang Tri Province showing in Figure 3-1 from February 26th to March 7th, 2019 by the first author of this article. The survey involved 70 households including 50 farms equipped with a biogas digester and 20 farms without it. The 25-item questionnaire was used to conduct in-person interviews of the 50 households with a biogas digester. The remaining 20 households without a biogas digester were interviewed with a questionnaire consisting of 10 questions showing in Appendix 1. The questionnaire was created to collect detailed information about household biogas use in terms of economic, environmental, and social factors such as the number of pigs that households are raising, and the consumption of fuel (i.e., gas, firewood, coal, etc) before and after the installation of the digester. For 50 households not using biogas digesters, some typical questions were asked as follows:

Q2. How much is the area for breeding?

(m^2)

Q3. What kind of animal does your family raise? Please specify the number of animals you raise.

☐ Pig ……………….

☐ Cattle (Cow, Buffalo) ……………..

☐ Poultry (Chicken, Duck) ………………...

☐ Other ( ) …………………

Q9. What kind of biogas digester do you use? (material)

☐ Cement

☐ Brick

☐ Composite

☐ Other ( )

Q10. What is the size of the biogas digester?

(m^3)

Q12. What energy do you use for cooking? Please answer the amount of money you spend monthly for that energy.

Energy	Purposes (for cooking, feeding, making products…)	Amount of money
Coal		
Wood		
Gas		
Other ( )		

Q15. How much did you pay for biogas installation?

(VND)

Q16. Did you pay more money for operation or maintenance? Please answer the times and the amount of money if you have to pay.

- ☐ Yes…………………………….
- ☐ No

Q17. What is the main use of biogas in your house?

- ☐ Cooking
- ☐ Heating
- ☐ Agriculture
- ☐ Other (   )

Q18. What kind of benefits do you avail due to biogas?

- ☐ Save energy
- ☐ Save money
- ☐ Get more income
- ☐ Health improvement
- ☐ Other (   )

For 20 households not using biogas digesters, the questionnaire was changed with some additional questions as follows:

Q7. How do you often do for treating the livestock waste of animals?

- ☐ Dumping it into the empty yard/ landfill/ lake/ river…

☐ Burying it underground

☐ Making fertilizer

☐ Using livestock waste treatment technology (ex. Biogas digester)

☐ Other (   )

Q8. Why don't you use biogas digester?

☐ Too expensive

☐ Not efficiency

☐ Don't know about biogas digester

☐ Small house area

Q9. Did you use biogas digester before?

☐ Yes

☐ No

If had, please tell the reason why you quit to use biogas digester?

The sampling method was based on the list of farm households provided by the local authorities. This interview method was combined with site visits to biogas digesters to collect reliable information. The secondary techno-economic data was gathered from the Department of Agriculture and Rural Development in Quang Tri Province.

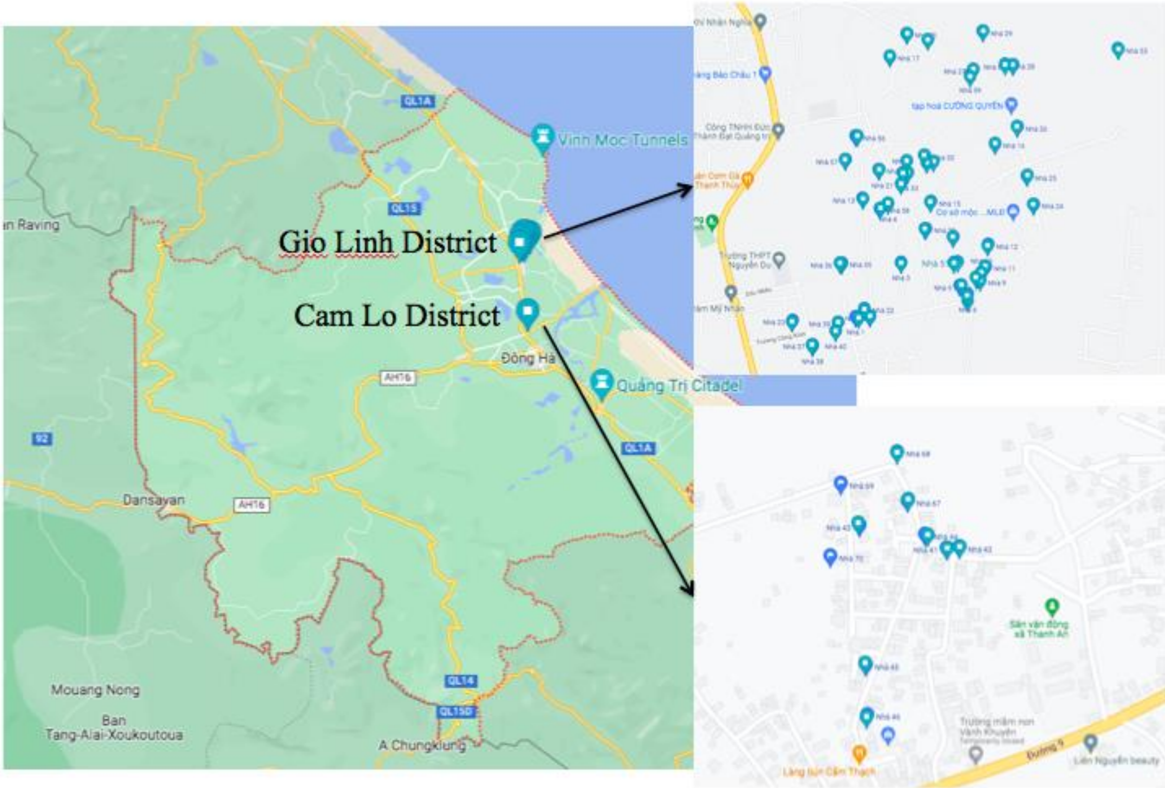


Figure 3-2 The map of surveyed households in two districts (Google map)

3.2.2.2 Method of calculating the amount of biogas produced

The statistical methods used in this study to obtain the key results are explained below:

This research uses the feedstock use method from *International Renewable Energy Agency (IRENA, 2016)* to calculate the amount of biogas production and consumption. According to *IRENA*, there are five methodologies for estimating biogas production. Estimates can be based on digester capacity, appliance use, or feedstock use or by comparing the fuel use in households with and without a biogas digester. Biogas production may also be measured directly.

Here, the feedstock use method is used to calculate the amount of biogas produced. This method calculates the biogas production on the basis of feedstock use rather than assumptions about the capacity utilization of biogas digesters. To apply this method, it is necessary to collect data on digester sizes, digester technology, and feedstock use. Biogas production is calculated for a wide range of temperatures and retention times, as follows *(IRENA, 2016, p.16)*:

$$G = \frac{Y \times V_d \times S}{1000}$$

Where:

G = the biogas production, m^3 /day

Y = a yield factor based on temperature and the feedstock retention time

V_d = the biogas digester volume, m^3

S = the initial concentration of volatile solids in the slurry, kg/m^3

The digester volume (V_d) was obtained by asking the farmers in our survey. The initial concentration of volatile solids (S) was calculated as follows. First, the total feedstock volume was estimated. In the two districts in Quang Tri Province selected for this research, the main input source of biogas digesters is pig manure. The surveyed households did not have a large population of cows, buffaloes, or poultry, and the amount of manure from these animals was small. Thus, we considered only pig manure. According to Table 5 in *IRENA (2016)*, the total animal waste feedstock per day for each pig is 5 kg, of which the volatile solids account for 1 kg. These numbers were multiplied by the number of pigs reported in our survey to estimate the total daily weight of animal waste and volatile solids. Assuming that 1 kg of animal waste is approximately equal to a volume of 1 L, we obtained the volume of the pig waste. This waste volume was multiplied by 3 to obtain the daily feedstock volume, because we learned that the local government recommended that farmers add a volume of water equal to as much as twice the volume of waste to operate the digesters. It means that the amount of additional water was 200%. The initial concentration of volatile solids (S) was calculated by dividing the daily weight of volatile solids by this daily feedstock volume. To determine the yield factor (Y) from Table 7 in *IRENA (2016)*, the temperature in the digester and the feedstock retention time (R) are necessary. The average temperature in Quang Tri Province is 25°C *(Doan et al., 2014)*, and the digester temperature is 2°C higher when the digester is located underground; thus, the temperature range is 25–27°C. The feedstock retention time was estimated by dividing the digester volume by the daily feedstock volume.

3.2.2.3 Method of calculating greenhouse gases emissions reduction

The effect of reducing greenhouse gas emissions when using biogas is realized by calculating the difference between the amount of greenhouse gas emissions before and after the use of biogas digesters by households. Figure 3-3 shows the system boundary of greenhouse gas emissions calculation before and after using the biogas digesters that was used for calculating in this study.

Without biogas digesters, GHGs emissions are calculated using the total CH_4 and N_2O from manure production and the amount of CO_2 and CH_4 from cooking fuels including LPG and firewood. After using the biogas digester, the emissions from manure production are replaced by

CH_4 from biogas production and CO_2 from biogas combustion. Then, adding the amount of CH_4 and CO2 from fuels combustion including LPG and firewood for supplement has been done to calculate the total amount of GHGs emitted.

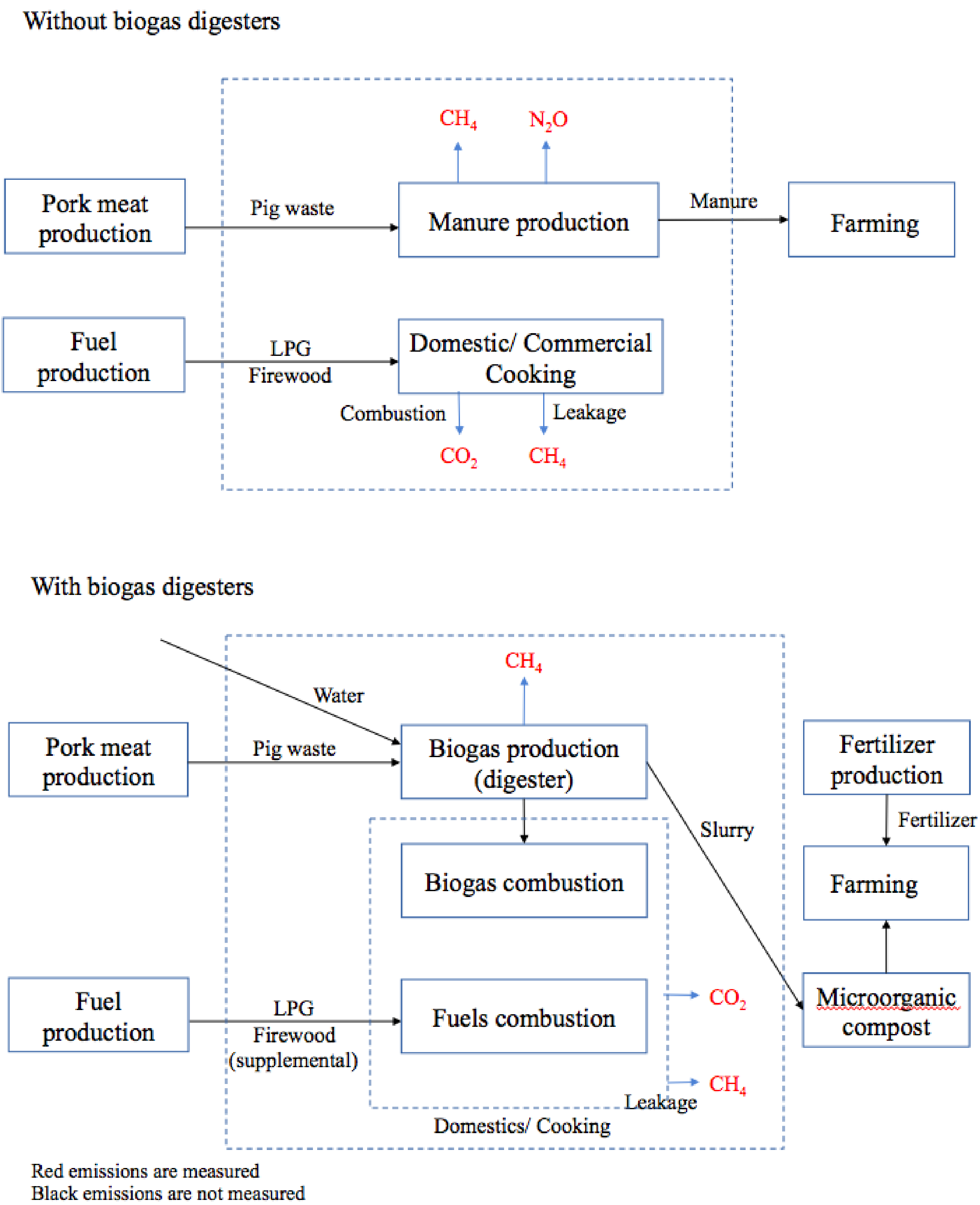
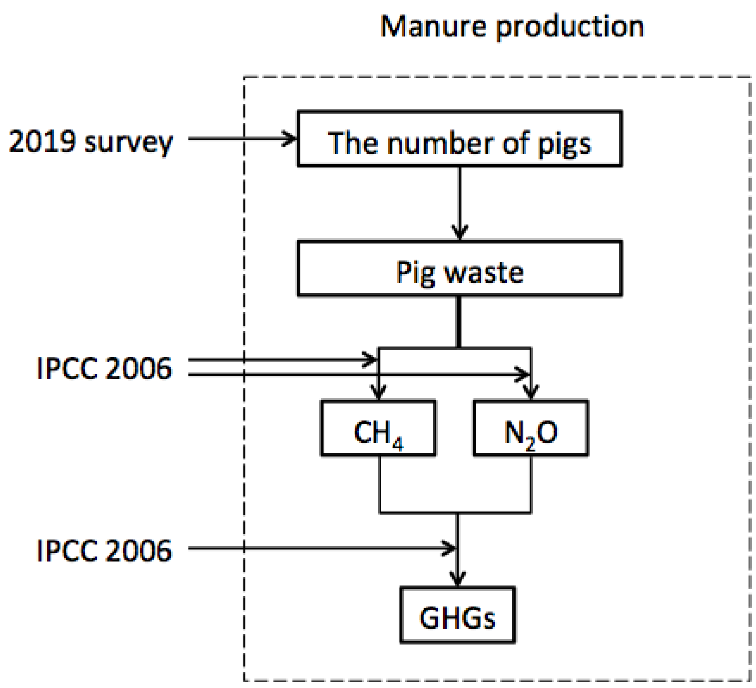
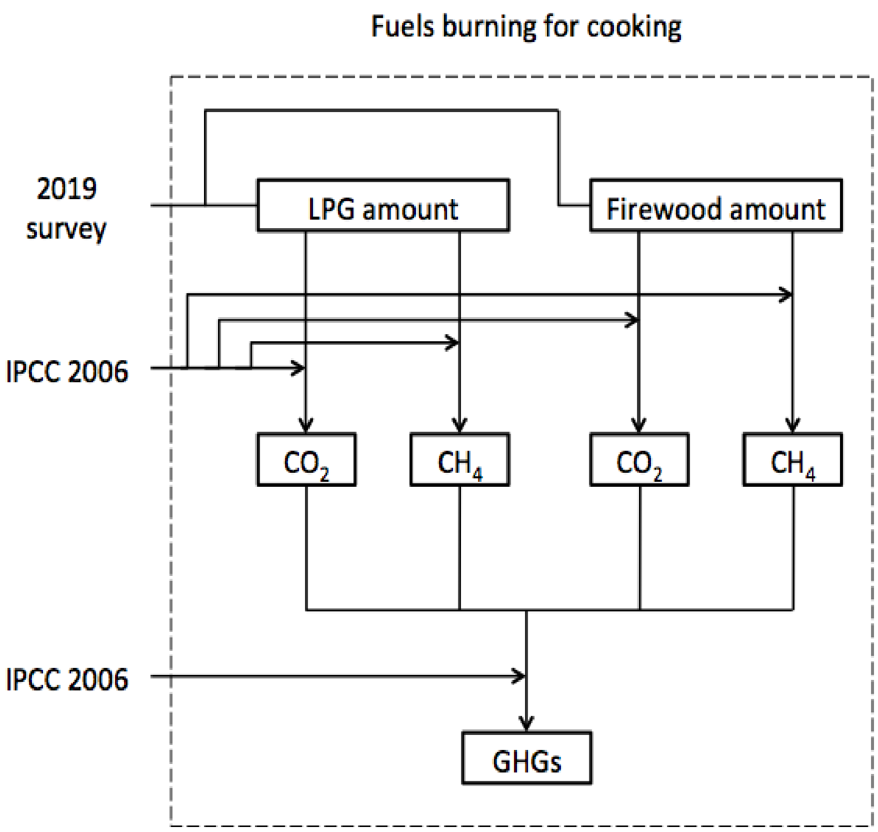


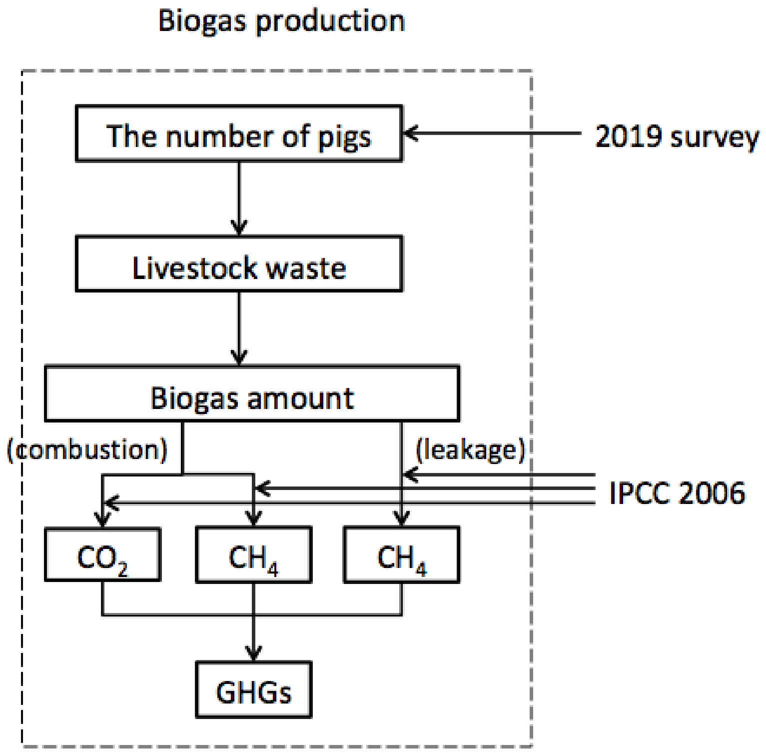
Figure 3-3 System boundary of greenhouse gas emissions calculation before and after using the biogas digesters



Emissions from manure production



Emissions from fuels burning for cooking



Emissions from biogas production and burning for cooking

Figure 3-4 Flowchart of GHGs emissions calculation

In this chapter, we set of the targets and assumptions following:

- The operational phase of biogas digesters is considered throughout the chapter. Construction and disposal phases of biogas digesters are not considered.
- The functional unit of estimation is an average farm household per year.
- Carbon neutrality is not considered in this study according to IPCC (2006).

Carbon neutrality is the balance between emitting carbon and absorbing carbon emissions from carbon sinks. Net carbon dioxide (CO_2) emissions become the amount of CO_2 emitted minus the amount of CO_2 absorbed within the food that was fed to the pigs. The feed for pigs in this area seems mainly produced from plants, but processing and transportation of the feed need fossil energy inputs. Because the amount of this fossil energy input was unclear, I chose not to apply the idea of carbon neutrality in this research.

The 2006 Intergovernmental Panel on Climate Change (IPCC)'s Guideline for National GHG inventories was chosen for estimating GHG emissions, because the complete formulation system with emission factors and parameters was suitable for the study. *IPCC (2006)* selected a number of key greenhouse gases to calculate emissions from manure pits, fuel combustion and biogas leakage. In addition, the parameters used for calculating greenhouse gas emissions are also referenced by *IPCC (2006)*. The process of calculating the amount of greenhouse gases emissions before using the biogas digesters is made according to the following formulas:

a. Calculating the average GHG emissions before the households use the biogas digesters

Step 1: Determining CH_4 emission factor from pig manure corresponding to climatic conditions of Quang Tri Province

$$EF_{(T)} = \left(VS_{(T)} \times 365\right) \times \left[B_{o(T)} \times 0.67 kg/m^3 \times \sum_{S,k} \frac{MCF_{S,k}}{100} \times MS_{(T,S,k)}\right] \quad (1)$$

(Equation 10.23)

Where:

$EF_{(T)}$ = annual CH_4 emission factor for livestock category *T*, kg CH_4/animal/year

$VS_{(T)}$ = daily volatile solid excreted for livestock category *T*, kg dry matter/animal/day

365 = basis for calculating annual VS production, days/year

$B_{o(T)}$ = maximum methane producing capacity for manure produced by livestock category *T*, m^3 CH_4/kg of VS excreted

0.67 = conversion factor of m^3 CH_4 to kilograms CH_4

$MCF_{(S,k)}$ = methane conversion factors for each manure management system *S* by climate region *k*, %

$MS_{(T,S,k)}$ = fraction of livestock category *T*'s manure handled using manure management system *S* in climate region *k*, dimensionless

According to IPCC (2006), with the annual average temperature of Quang Tri Province is 25ºC (Doan et al., 2014), the calculation coefficients are including the value of daily volatile solid (*VS*) excreted from pig is 0.30 kg per head, maximum methane producing capacity by pig B_o is 0.29 m^3/kg of *VS* excreted, methane correction factor *MCF* for manure treatment system is 65%, the handled fraction of manure management *MS* equals to 100%.

Step 2: *Calculating CH_4 emission factor from manure management:*

$$CH_{4(manure)} = GWP_{CH_4} \times N_{(T)} \times EF_{(T)} \times 10^{-3} \quad (2)$$

(Equation 10.22, IPCC, 2006)

Where:

$CH_{4(manure)}$ = CH_4 emissions from manure management, for a defined population, tCO_2e/year

GWP_{CH4} = 28: possibility of causing CH_4 greenhouse effect compared to CO_2

$EF_{(T)}$ = emission factor for the defined livestock population, kg CH_4/head/year

$N_{(T)}$ = the number of pig in the country, head

<u>Step 3:</u> *Calculating direct N_2O emissions from manure management*

$$N_2O_{(manure)} = GWP_{N_2O} \times \left[\sum_{\square}\left[\sum_T (N \times N_{ex} \times MS_{(T,S)}\right] \times EF_{3(S)}\right] \times \frac{44}{28} \times 10^{-3} \ (3)$$

(Equation 10.25, IPCC, 2006)

Where:

N_2O = direct N_2O emissions from Manure Management in the country, tCO_2e/year

GWP_{N2O} = *265:* possibility of causing greenhouse effect of N_2O compared to CO_2

$N_{(T)}$ = number of pig in the country, head

$N_{ex(T)}$ = annual average N excretion per head of pig in the country, kg N/animal/year

$MS_{(T,S)}$ = fraction of total annual nitrogen excretion for each livestock species/category *T* that is managed in manure management system *S* in the country, dimensionless

$EF_{3(S)}$ = emission factor for direct N_2O emissions from manure management system S in the country, kg N_2O-N/kg N in manure management system *S*

S = manure management system

T = species/category of livestock, in this study was pig

44/28 = conversion of $(N_2O\text{-}N)_{(mm)}$ emissions to $N_2O_{(mm)}$ emissions

<u>Step 4:</u> *Calculate the amount of CO_2 and CH_4 emissions from household fuels*

$$CO_{2(fuels)} = \sum(BG_j \times NCV_j \times EF_{CO_{2j}}) \times 10^{-6} \ (4)$$

$$CH_{4(fuels)} = \sum(BG_j \times NCV_j \times EF_{CH_{4j}}) \times 10^{-6} \ (5)$$

(Equation 2.3, IPCC, 2006)

Where:

$CO_{2(fuels)}$, $CH_{4(fuels)}$ = CO_2 and CH_4 emissions from fuel burning, tCO_2e/year

BG_j = amount of fuel *j* consumed annually by the household before the biogas digester is available, kg/year

NCV_j = Heat of fuel j, MJ/kg

EF_{CO2j} = CO_2 emission factor of fuel j, tCO_2e/TJ

EF_{CH4j} = CH_4 emission factor of fuel j, tCO_2e/TJ

Based on the IPCC guidelines (IPCC, 2006), the value of parameters of firewood and gas are shown in Table 1.

Table 3-3 Thermal parameters and emission factors of some fuels following IPCC (2006)

Type of fuel	**Heat (MJ/kg)**	**Emission factor (tCO_2e/ TJ)**	
		CO_2	CH_4
Firewood	30.5	112	0.03
LPG	47.3	63.1	0.001

Step 5: *Calculating total GHG emissions before using the biogas digester*

$$Emissions_{BEFORE} = CH_{4(manure)} + N_2O_{(manure)} + CO_{2(fuels)} + CH_{4(fuels)} \quad (6)$$

b. Calculating the amount of GHG emissions after using the biogas digester

Step 1: *Calculating the amount of CH_4 released due to leakage from the biogas digester*

$$CH_{4(biogasleakage)} = LF_{CH_4} \times \left(GWP_{CH_4} \times B_o \times D_{CH_4} \times VS \times 365 \times LN_2\right) \times 10^{-3} \quad (7)$$

Where:

$CH_{4(biogasleakage)}$ = the amount of CH_4 emissions due to leakage from the biogas digester, tCO_2e/year

LF_{CH4} = leakage coefficient CH_4 from anaerobic digester, $LF_{CH4} = 0.1$

D_{CH4} = specific gravity of CH_4, $D_{CH4} = 0.67 kg/m^3$ under normal conditions

VS = volatile solid waste in pig waste, kg dry matter/head/day

LN_2 = average number of pigs in a household with biogas digester, heads/year

Step 2: *Calculate the amount of CO_2 and CH_4 emissions from household fuels*

CO_2 and CH_4 emissions from fuels are calculated similarly to the case when there was no biogas digester.

For biogas fuel, the amount of GHG emissions is calculated by the formula:

$$CO_{2(biogas)} = H \times B_0 \times D_{CO_2} \times VS \times 365 \times LN_2 \times 10^{-3} \quad (8)$$

Where:

$CO_{2(biogas)}$ = amount of CO_2 due to biogas burning, tCO_2e/year

B_o = the maximum CH_4 volume generated from pig manure treated in biogas, m^3/kg

D_{CO2} = specific gravity of CO_2, D_{CO2} = 1.798kg/m^3 under normal conditions

H = gas producing efficiency CH_4, H = 0.9

<u>Step 3:</u> *Calculating the total amount of greenhouse gas emitted after using the biogas digester*

$$Emissions_{AFTER} = CH_{4(biogasleakage)} + CO_{2(biogas)} + CO_{2(fuels)} + CH_{4(fuels)} \quad (9)$$

3.2.2.4 Sensitivity analysis

In this research we apply sensitivity analysis for determining how different values of the independent variables affect a particular dependent variable under a given set of assumptions. In this chapter, independent variable is specified to include two parameters including volatile solids and biogas amount, and the dependent variable is the total amount of GHGs released into the environment.

3.3 Results and discussion

3.3.1 Attributes of surveyed farms

The survey results showed that of the 70 households interviewed, the main occupations were agriculture (57 households, 81.4%) and self-employment (11 households, 15.7%). In addition to the main job, households also engaged in other business activities, such as making noodles and making wine for sale. Table 1 shows the characteristics of the surveyed households. All the households had land devoted to livestock, with an average area of 75.53 m^3, the number of pigs ranged from 5 to 100. Each farm had a stable income; the monthly average was 9.97 million VND (428.71 USD). Figure 3-5 showed the difference in the income per capita among the respondents using biogas and not.

Table 3-4 Characteristics of 70 farms

	Average	Maximum	Minimum	S.D.
Area for breeding (m^2)	75.53	500	18	65.86
Number of pigs (head)	25.86	100	5	20.29
Household income (million VND/month)	9.97	20	4	4.49

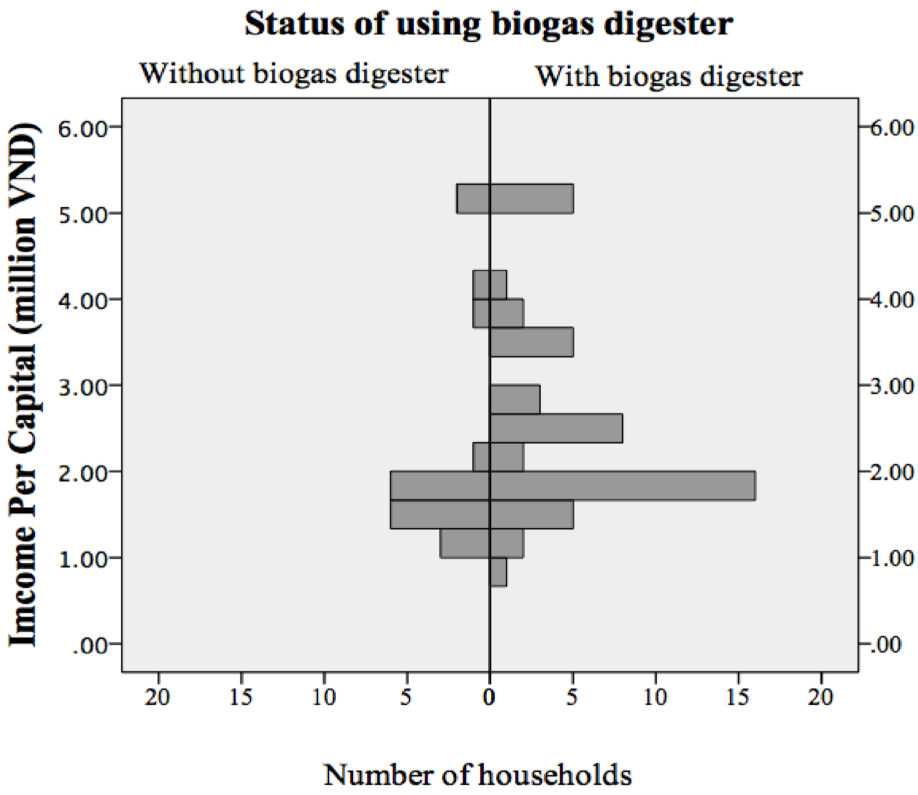


Figure 3-5 The income status of using the biogas digester

In household-scale pig raising, biogas was used mainly as a domestic fuel. Biogas was taken from the digesters through a simple filter system and then used as a fuel. The use of biogas as a fuel thus reduced the amount of money needed to purchase other fuels such as LPG and firewood. According to our survey data from the 50 households with a biogas digester, 14% of households used firewood for cooking, 24% used LPG, and the remaining 62% used both before installing a biogas digester. The amount of firewood used in the households was not available, but most of it was taken from nearby forests free of charge or purchased from retailers. The use of LPG for cooking was usually more convenient but more expensive. Among the 50 households that used biogas digesters, 20 households had cement biogas digesters and 30 households had biogas digesters built from a composite material. Table 3-4 listed the specifications of the two types of digester.

Table 3-5 Specifications of biogas digesters

		Average	Maximum	Minimum	S.D.
Volume (m^3)	Cement	13.65	20	8	4.60
	Composite	11.50	22	8	3.41
Initial investment (million VND)	Cement	15.55	30	10	5.64
	Composite	13.55	25	0	4.66
Age (years)	Cement	7.00	16	3	2.96
	Composite	4.70	10	1	2.48

3.3.2 Biogas Production

3.3.2.1 Estimated biogas production amounts

After constructing the biogas digesters, the households changed to use biogas to cook or produce products as an alternative fuel instead of liquefied petroleum gas (LPG) or firewood. The amount of biogas production was calculated by formula referenced from *IRENA (2016)* explained in section 3.2.2 Research methods. The relevant factors were calculated including: average feedstock volume is 0.39 m^3/day, average retention time is 37.95 days, initial concentration of volatile solids is 66.67 kg/m^3, and the average yield factor is 6.98. The results showed that the average amount of biogas production was 5.52 m^3 per household per day. A higher rate of gas production was recorded at the shorter retention periods (Table 3-6) than at longer retention periods. This calculation was conducted based on data collected on the number of pigs raised by each household.

Table 3-6 The average amount of biogas production corresponds to the retention time periods

(IRENA 2016 method applied)

Retention time (days)	6-10	11-20	21-35	36-50	>50
Number of household	1	10	18	9	12
Biogas production (m^3/day)	10.87	9.18	5.30	4.14	3.38

3.3.2.2 Efficiency of biogas production

According to Table 7 in *IRENA (2016)*, when the temperature is between 25 and 27°C, the yield factor reaches a maximum value of 13.59 when retention time is 6-10 days. When the yield factor has the maximum value, the amount of biogas produced from the digester reaches optimum efficiency. Figure 3-6 showed that the number of households using biogas digesters with retention time being 6-10 days only accounts for 2% of the 50 surveyed households with biogas digesters. With 80 heads of pigs, this household chose to build a biogas digester with a volume of 12 m^3 and collected 10.87 m^3 of biogas production for serving family activities each day. It is evident that the amount of biogas production they obtained was approximate to the biogas digester volume. The remaining households had longer retention time, even one family up to 133 days. Obviously, the surveyed households have not really used the most optimal amount of biogas production. In fact, there were 88% of the households having biogas digesters larger than the optimal volume and they did not use the biogas digesters efficiently.

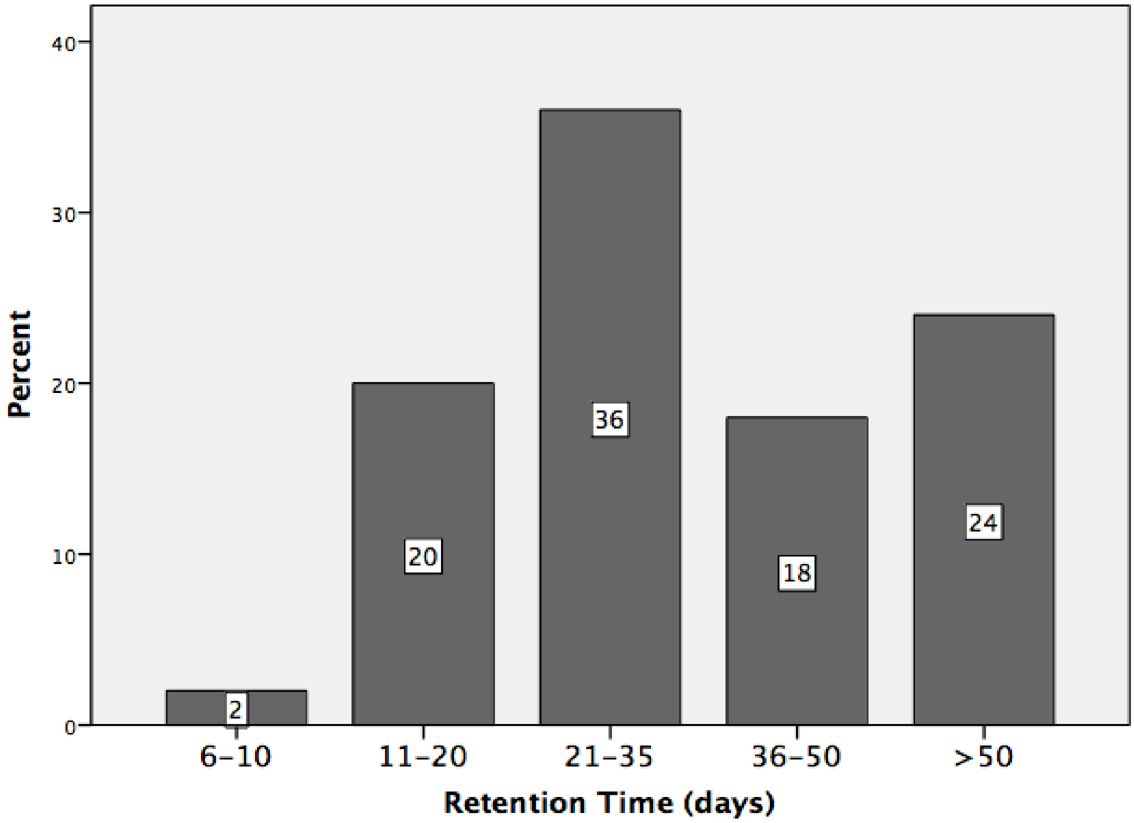


Figure 3-6 The retention time on biogas production

Decreasing the retention time will reduce the size–and thereby the costs of construction– of the biogas digesters. This study suggests an economic design of biogas digesters by reducing the size suitable for the number of livestock raised. The second solution we recommend is that farmers mix the collected pig manure with other feedstocks consisting of volatile solids such as cereals/ grains, rice straw, wheat straw, grass, corn stalks, fruit waste, vegetable waste, fat, mixed food waste, or mixed organic waste.

From the results, we provide an overview of the importance of biogas production using livestock waste in the central of Vietnam. The daily average amount of biogas production was 5.52 m^3 per household. However, this is not the maximum amount of biogas the households can obtain. Despite the good potential for biogas production in the central of Vietnam, it has not been much developed in the country. In consequence, the economic policies we propose in this study are worthy of consideration for their application.

3.3.3 Reduction of Greenhouse Gases Emissions

According to our surveyed data from the 50 households with the biogas digesters, 14% used firewood for cooking, 24% used LPG, and the remaining 62% used both before installing a biogas digester. After constructing the biogas digesters, residents could use biogas instead of other fuels such as firewood or gas. There were 41 households accounted for 58.6% of interviewed households have quitted to use firewood for cooking and 33 households accounted for 47.1 % of households have stopped using LPG.

The GHGs emissions from manure composting was calculated following the formula (2), (3) shown in Section 3.2.2. with the parameters corresponding to climatic conditions of Quang Tri Province. Additionally, number of pigs was obtained from question Q3 in the questionnaire that asks the respondents to provide information about the type and number of pigs they were raising. Based on the information on the number of pigs provided by the households, we calculated the amount of CH_4 and N_2O emissions from the manure management. From these parameters, we obtained the results that the total GHG emissions from manure composting is 12.51 tons of CO_2e/year/household before using the biogas digesters, including 11.52 tCO_2e of CH_4 and 0.99 tCO_2e of N_2O. Totally, GHGs emissions from 50 surveyed households is 625.37 tons of CO_2e/year. In particular, CH_4 accounts for 92.08% of total GHGs from composting.

In order to calculate the amount of greenhouse gases emitted by household fuels including CO_2 and CH_4, we gathered information on the annual amount of LPG and firewood used by each household through questionnaires. Question Q12 was provided to the respondents for the purpose of calculating the amount of fuels used by the households and the cost they paid before constructing the biogas digesters. In the study area, citizens use 12kg gas bottles sold by petrol retailers. To obtain information on how much LPG each household used, the question was adjusted to: "How long does it take for your farm to use one 12 kg bottle of LPG?" The annual amount of LPG and firewood used by each household was calculated based on the collected data, from which we commuted the amount of GHG emissions from the fuels use following the formula (4), (5) in Section 3.2.2. Before the installation and use of biogas digesters, households in the survey usually use LPG and firewood for cooking. According to the collected data, 14% of total respondents use wood for cooking, 24% of them use LPG and 62% left use both. Without biogas digester, on average, each household used 52.58 kg of LPG and 2292.94 kg of firewood per year for cooking needs. The GHGs emissions amount from firewood and LPG of 50 households are 401,34 tCO_2e/year (8,03 tCO_2e/household/year), in which the main contributor is CO_2 (401,23 tCO_2e/household/year), accounting for 99,97%. The total amount of GHG emissions before using the biogas digesters is equal to the total GHGs emissions from manure pits and household fuels. Table 3 showed that with 50 surveyed households before using the biogas digesters, the total amount of GHGs emissions into the environment is 1026.70 tCO_2e per year. This is a fairly large number and seriously affects the environment. If the number of households expanded further, GHGs emissions amount would increase more. It can be seen that the amount of greenhouse gases emissions from composting and burning fuels is huge. Therefore, without green development solutions, the livestock sector will be a major contributor of the climate changes causes.

Table 3-7 Total GHG emissions per year before using the biogas digesters

	From manure pits		**From using LPG**		**From using firewood**		**Total**
	CH_4 emission (tCO_2e/ year)	N_2O emission (tCO_2e/ year)	CO_2 emission (tCO_2e/ year)	CH_4 emission (tCO_2e/ year)	CO_2 emission (tCO_2e/ year)	CH_4 emission (tCO_2e/ year)	
Average household	11.52	0.99	0.19	3.04×10^{-6}	7.83	2.098×10^{-3}	20.53
Total of 50 households	575.83	49.54	9.60	0.000152	391.63	0.1049	1026.70

The emissions from the biogas digesters were calculated based on the number of pigs per household raised in combination with the parameters provided by the IPCC guidelines. Equations (7) and (8) are applied to estimate the amount of CH_4 and CO_2. The previous fuels have been almost replaced by biogas for cooking or making product. However, biogas generated from the biogas digesters was not enough to completely replace cooking fuels in some households, so they combined biogas for cooking with firewood and gas. After the installation and use of biogas digesters, the amount of LPG and firewood used for cooking has decreased. There are 17 households (accounting for 34%) continued to use LPG and 9 households (accounting for 18%) continued to use firewood for cooking. However, with the biogas digester, the amount of LPG and firewood used for daily cooking has decreased significantly to 1,356 kg and 343.1 kg per year respectively. The amount of CO_2 and CH_4 from firewood and gas was calculated similarly as before using the biogas digesters. Table 4 showed that the emission due to leakage from the biogas digesters of the surveyed households is 164.99 tCO_2e per year (3.30 tCO_2e/household/year) consisting of 88.58 tCO_2e of CO_2 and 76.41 tCO_2e of CH_4. The amount of greenhouse gas emitted from firewood and LPG is 61.05 tCO_2e/year, which is composed mainly of CO_2. The reduction of using firewood and gas has contributed to make a significant reduction in GHG emissions. The amount of CO_2 emitted from LPG decreased to a quarter compared to before and the emissions from firewood also decreased from 391.73 tCO_2e/year to 58.62 tCO_2e/year. After using the biogas digesters, the total greenhouse gas emissions reduced to 226.04 tons CO_2e/year, less than one quarter of the GHG emissions from the surveyed households before using the biogas digesters. Table 3-9 showed the difference between the GHGs emission with biogas digesters and without biogas digesters.

Table 3-8 Total GHG emissions per household per year after using the biogas digesters

	From biogas leakage	**From using biogas**	**From using LPG**		**From using firewood**		**Total**
	CO_2 emission (tCO_2e/year)	CH_4 emission (tCO_2e/year)	CO_2 emission (tCO_2e/year)	CH_4 emission (tCO_2e/year)	CO_2 emission (tCO_2e/year)	CH_4 emission (tCO_2e/year)	
Average household	1.77	1.53	0.0486	0	1.17	$3.14x10^{-4}$	4.52
Total of 50 households	88.58	76.41	2.43	0	58.60	0.0157	226.04

Table 3-9 Comparison of the total GHGs emissions from households with and without biogas digesters (Unit: tCO2e/ household/ year)

		Without biogas digester	**With biogas digester**
From manure pits	CH_4	11.52	0
	N_2O	0.99	0
From biogas digesters	CH_4	0	1.77
	CO_2	0	1.53
From LPG using	CO_2	0.19	0.0486
	CH_4	3.04×10^{-6}	0
From firewood using	CO_2	7.83	1.17
	CH_4	2.098×10^{-3}	3.14×10^{-4}
Total GHGs emissions		**20.53**	**4.52**

The annual difference in the amount of GHG emitted before and after the farmers used biogas is 16.01 tCO_2e/household. Straightforwardly, replacement of daily cooking energies with biogas helps reduce a large amount of greenhouse gases. Small-scale biogas digester is a very useful manure management tool for reducing global warming impacts. The traditional use of firewood and gas for cooking in the central of Vietnam was replaced by biogas. The findings of this study showed that the amount of GHG emissions when biogas was used like an alternative fuel instead of firewood and gas (4.52 tCO_2e/household/year) is less than one quarter of them before using the biogas digesters (20.53 tCO_2e/household/year). This is a potential approach chosen to mitigate climate change. In addition, the improvement of this technology also contributes in depreciating the firewood consumption and the deforestation.

3.3.4 Sensitivity analysis

3.3.4.1 Variability in Volatile solids

Volatile solids (VS) are the organic material in livestock manure and consist of both biodegradable and nonbiodegradable fractions. The total VS excreted by each animal species is one of needed parameters for caculating the CH_4 from pig manure showing in the equation (1) section 3.2.2. since the B_o values are based on total VS entering the systems. In the previous sections, daily VS excretion rates were adopted from *IPCC (2006),* that is one pig produces the default value of 0.30 kg VS per day. However, this parameter can be changed since the average daily VS excretion rates are estimated from feed intake levels. Feed intake for swine can be estimated using the country-specific swine production data. A study in Sub-Saharan Africa indicated that the daily discharge from pigs differed from the results indicated from *IPCC (2006)* due to variation in feed intake, specifically that the daily VS was 0.77 ± 0.5 kg per head *(Ngwabie et al., 2018).*

Another important factor worth considering here is the biogas amount parameter. This factor is calculated based on the amount of VS of the swines. Because of the variability of the number of pigs per household and the daily amount of total VS discharge, biogas amount is also a variable value. This study has referenced and included 3 typical VS values for sensitivity analysis, in order to consider the change of total greenhouse gases emissions on a case-by-case basis. These three VS values include the default value of 0.3 kg per pig per day specified by *IPCC 2006* and two values including 0.27 and 1.27 per pig per day calculated by *Ngwabie et al. (2018)*. Table 3-7 shows the changes by determining the extent to which results of GHGs emissions are affected by changes in unmeasured variables including volatile solids and biogas amount.

With each selected corresponding VS value, the amount of GHGs emitted from manure pits, biogas digesters, LPG using and firewood using per household has been calculated based on the formula system outlined in section 3.2.2. GHGs emissions were calculated and compared between two scenarios, including with biogas digesters using and without biogas digesters. Table 3-7 shows a rather large difference between the total GHGs emitted when volatile solids factor is considered. A small pig can discharge 0.27kg VS per day, while a large pig can discharge up to 1.27kg VS. Without biogas digesters using, the value of CH_4 emitted from manure pits corresponding to the two VS values mentioned above was 10.36 tCO_2e per household per year and 48.75 tCO_2e each household per year, respectively. This rather large difference led to a marked change in the total annual GHGs emissions. Other values consisted of CO_2 and CH_4 emitted from LPG and firewood using remain unchanged. With VS at 1.27 kg/head/day, the total annual GHGs amounted to 2875.01 tCO_2e per year, which was 3 times higher than the amount of GHGs when VS was at 0.27 kg/head/day.

Similarly, in the case of using biogas digesters, the amount of GHGs discharged from biogas digesters also changed when the amount of VS changed. With VS at 0.27 kg/head/day, the annual amount of CH_4 and CO_2 discharged from the biogas digester in each family is 1.59 tCO_2e/ household/ year and 1.38 tCO_2e/ household/ year respectively. The amount of CH_4 and CO_2 increased to 7.50 tCO_2e/ household/ year and 6.47 tCO_2e/ household/ year when the amount of VS was at 1.27 kg/head/day. Similar to the scenario without biogas digesters, the total GHGs emissions were significantly different between the VS values at 0.27 and 1.27 kg/head/day. However, the final results showed that when using biogas digesters, the largest average GHG emissions per household was 15.19 tCO_2e/ year, much lower than the maximum value of GHGs emissions when not using biogas digesters, 57.50 tCO_2e/ household/ year. Detailed results on GHG emissions from each household are shown in appendix.

Table 3-10 Total GHGs emissions from households with and without biogas digesters

(Unit: tCO_2e/ household/ year)

		Without biogas digester			With biogas digester		
Volatile solids (kg/head/day)		0.27	0.3	1.27	0.27	0.3	1.27
From manure pits	CH_4	10.36	11.52	48.75	0	0	0
	N_2O	0.15	0.99	0.73	0	0	0
From biogas digesters	CH_4	0	0	0	1.59	1.77	7.50
	CO_2	0	0	0	1.38	1.53	6.47
From LPG using	CO_2	0.19	0.19	0.19	0.0486	0.0486	0.0486
	CH_4	3.04×10^{-6}	3.04×10^{-6}	3.04×10^{-6}	0	0	0
From firewood using	CO_2	7.83	7.83	7.83	1.17	1.17	1.17
	CH_4	2.098×10^{-3}	2.098×10^{-3}	2.098×10^{-3}	3.14×10^{-4}	3.14×10^{-4}	3.14×10^{-4}
Total GHGs emissions	**Average household**	18.54	20.53	57.50	4.19	4.52	15.19
	SD	9.97	10.63	36.88	3.59	3.73	10.57
	Total of 50 households	927.14	1026.70	2875.01	209.50	226.04	759.50

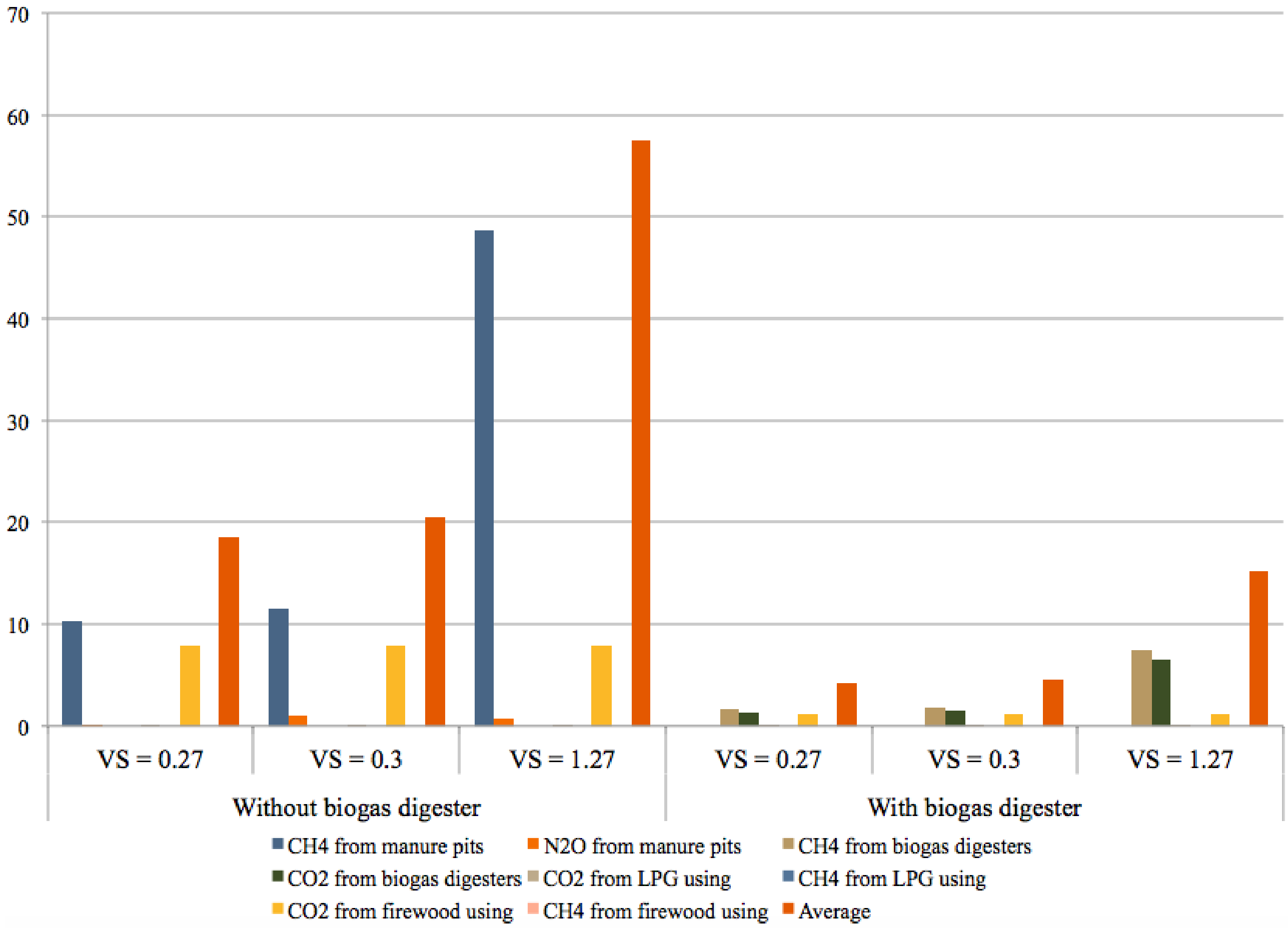


Figure 3-7 GHGs emissions from households with and without biogas digesters (tCO_2e/ household/ year)

3.3.4.2 Consideration of pig ages

Pig sizes that are correlated with pig ages affect GHGs emission estimates. This study has obtained specific results in the selected study area, central Vietnam. To calculate accurate regional results, data were collected by Kato et al. in Danang, Vietnam in 2012 was applied. The survey was conducted with 30 livestock farming households in two villages in Danang City including Hoa Tien and Hoa Khuong. Data were collected on the number of parent swines and fattening swines. Fattening swine was raised to 7 months old, reached an average weight of 75kg and then sold *(JICA, 2016)*. After that, the farm continued to buy piglets and raise them for fattening. The number of child and adult pigs is divided equally when calculating proportions. Table 3-8 showed some specific examples of the number of child and adult pigs per household used in this study. For example, the first household raised 8 pigs including 1 parent stock and 7 fattening swines. The quantity of fattening swines is divided equally, consisting of 50% child pigs and 50% adult pigs. Parent stock is calculated into the adult pigs group. As a result, the first household raised 3.5 child pigs and 4.5 adult pigs. The calculation was applied to the remaining 29 households.

Table 3-11 Ratio of child and adult pigs per household

Household	**Number of pigs (heads)**			
	Parent stock *(Kato et al. 2012)*	Fattening swine *(Kato et al. 2012)*	Child pig (estimated)	Adult pig (estimated)
1	1	7	3.5	4.5
2	3	7	3.5	6.5
...	...	...	…	…
30	1	80	40	41
Average	2	35	17	20

The obtained results showed that the average number of pigs per household was 37, of which there were 17 child pigs (accounting for 45.95%) and 20 adult pigs (accounting for 54.05%). This ratio was applied to calculate the number of child and adult pigs for 50 surveyed housedolds in Quang Tri Province. Table 3-9 showed the number of pigs by size of each household in Danang City and Quang Tri Province.

Table 3-12 The number of pigs by size of each household in Danang and Quang Tri

Location	**Average number of pigs (heads)**		
	Total	Child pig	Adult pig
Danang City	37	17	20
Quang Tri Province	30	14	16

The daily amount of VS was selected with the respective values of 0.27 kg per pig and 1.27 kg per pig for child pigs and adult pigs (Ngwabie et al., 2018). The exact GHGs emissions were calculated based on the amount of VS from the two groups of pigs and shown in Table 3-12.

Table 3-13 Total GHGs emissions in Quang Tri Province

(Unit: tCO_2e/ household/ year)

		Without biogas digester		**With biogas digester**	
		Child pig	Adult	Child pig	Adult
Quantity (heads)		14	16	14	16
Volatile solids (kg/head/day)		0.27	1.27	0.27	1.27
From manure pits	CH_4	4.76	26.35	0	0
	N_2O	0.07	0.39	0	0
From biogas digesters	CH_4	0	0	0.73	4.05
	CO_2	0	0	0.63	3.50
From LPG using	CO_2	0.19		0.0486	
	CH_4	$3.04x10^{-6}$		0	
From firewood using	CO_2	7.83		1.17	
	CH_4	$2.098\ x10^{-3}$		$3.14x10^{-4}$	
Total GHGs emission per household		39.60		10.14	

Table 3-13 showed that GHGs emissions have decreased significantly when the biogas digester has been used as a tool to treat livestock waste. On average, the amount of GHGs emitted from each livestock household in Quang Tri Province has been reduced by 29.46 tCO_2e per year when using biogas digesters.

3.3.4.3 Variability of GHG emission reduction

Table 3-14 compared the difference between GHG emissions from each household per year based on different variables. It could be seen that when calculating the exact emissions for the study area with the pig ages variable, the GHGs emissions of 29.46 tCO_2e/ household/ year were more than twice as large as the calculated emissions based on the VS original variable (16.01

tCO_2e/ household/ year).

Table 3-14 Comparison of the total GHGs emissions

(Unit: tCO_2e/ household/ year)

	Original VS = 0.3	**VS = 0.27**	**VS = 1.27**	**Pig ages**
With biogas digesters	20.53	18.54	57.50	39.60
Without biogas digesters	4.52	4.19	15.19	10.14
GHGs reduction	16.01	14.35	42.31	29.46

3.3.5 Regional estimation of GHGs emissions reduction

According to the *"Statistical report on environmental protection in livestock production in 2018"* of the Department of Agriculture and Rural Development of Quang Tri Province, there were 92189 households raising livestock and poultry all over province, of which mainly were pig farming with 43100 households. The total number of pigs in the province as of July 2018 included 226665 heads. In the province, there were 4671 small-scale biogas digesters of all kinds to treat livestock waste, reduce environmental pollution, and take advantage of CH_4 gas for cooking, electricity generation and heating. It is an assumption that if all of those 4671 households had used biogas frequently, the amount of GHGs emitted per year would have been reduced to 137607.66 tCO_2 across the province. In addition, if all of the biogas digesters were operated most efficiently, GHG emissions would be reduced more and more than reality.

3.4 Summary of findings

This chapter provided an overview of the importance of biogas production using livestock waste in central Vietnam. The daily average amount of biogas production was 5.52 m^3 per household, however, this is not the maximum amount of biogas the households can obtain. In fact, only 2% of households surveyed using biogas digester achieved biogas production approximate to the biogas digester volume they built. Despite the good potential for biogas production in central Vietnam, it has not been much developed in the country. In consequence, the economic policies need to be considered for implementation.

A small-scale biogas digester is a very useful manure management tool for reducing global warming impacts. The traditional use of firewood and gas for cooking in central Vietnam was replaced by biogas. The findings of this study showed that the amount of GHG emissions before using the biogas digesters is less than one-quarter of them when biogas was used as an alternative fuel instead of firewood and gas. The annual difference in the amount of GHG emitted before and after the farmers used biogas is 16.01 tCO_2e per household, less than one quarter without using the biogas digesters. The total GHGs emission were significantly diferente between the volatile solids values at 0.27 kg/head/day, 0.3 kg/head/day and 1.27 kg/head/day. The actual amount of VS was applied to calculate in the survey area and obtained the results that the amount of GHGs emitted from each livestock household in Quang Tri Province has been reduced by 29.46 tCO_2e per year when using biogas digesters.

Although using biogas as alternative energy helps to reduce the greenhouse gas effect, it cannot be denied that there is still a small amount of greenhouse gases emitted from the biogas digesters. When they are used inappropriately, the amount of biogas will be released into the environment. More in-depth research is needed to come up with the right policies for biogas use. We also suggested that detailed train- ing for biogas users is needed so that users can maximize the benefits they obtain from the digesters. Experimental studies that check and monitor the use of biogas digesters are also essential.

Chapter 4 EVALUATE FARMERS' ATTITUDES TOWARDS ECONOMIC BENEFITS, ENVIRONMENTAL IMPACT OF BIOGAS TECHNOLOGY, AND POLICY RECOMMENDATION IN PROMOTING HOUSEHOLD-SCALE BIOGAS ENERGY IN CENTRAL VIETNAM

4.1 Introduction

4.1.1 Background of biogas use and poverty alleviation in Vietnam

Vietnam's agriculture sector has been working toward integration into the global economy for over 20 years. Accession to the World Trade Organization in 2007 reinforced this direction and raised the stakes. Vietnam has chiefly focused on raw and primary agricultural products. However, these products bring relatively little value-added processing to farmers and producers. In order to eradicate poverty in Vietnam, the Vietnamese government needs to improve labour productivity and invest in infrastructure to create more and better jobs.

Sustainable poverty reduction has become a focal point of Vietnamese policy, which is constantly being updated and supplemented in the Vietnamese government's socio-economic development plans. The Vietnamese government's socio-economic development strategy in the 2011–2020 period aimed to promote sustainable poverty reduction suitable for each period. The strategy advocated for the diversification of resources and methods to ensure sustainable poverty reduction, especially in disadvantaged areas. One of the central goals is to support poor districts and communes through methods such as investment in production infrastructure, production support, and diversification of the livelihoods of people in poor communities.

The national multidimensional poverty index (MPI) decreased from 0.035 in 2016 to 0.016 in 2020, showing that multidimensional poverty in Vietnam has improved appreciably. However, there was still a relatively large gap in poverty between urban and rural areas. In 2020, the MPI of rural areas, 0.019, was almost twice as high as that of the urban areas, only 0.010 *(General Statistics Office of Vietnam, 2021)*, showing that poverty reduction results were not sustainable. The number of poor households decreased rapidly, but pro-poor households increased. While the infrastructure system received investment, it has yet to meet the needs of the people, and the systems of production and labour have changed slowly. If hunger eradication and poverty reduction issues are not completely resolved, this will mask the risks associated with unsustainable development, which can lead to socioeconomic instability.

Providing good access to energy resources in rural areas is important. *Son and Yoon (2020)* indicated that the inequality in energy usage was greater than the inequality of income in Vietnam, which limited the scope of benefits to microeconomic development for the poor. Monthly income per capita is one of the most direct determinants of electricity expenditure.

Addressing barriers to improving energy access and usage is a considerable issue.

Biogas is a mixture of gases produced by the bacterial decomposition of organic matter in an anaerobic environment. In Vietnam, biogas technology appeared in the 1960s and has developed extensively from 1991 to the present with support from government capital and international organizations within the framework of projects involving biogas technology. The application of biogas cellars to treat livestock waste contributes significantly to reducing environmental pollution, saving living costs, and increasing people's income. This is considered a solution with major economic benefits to replace traditional materials, such as firewood and gas, which are increasingly scarce and costly. The use of biogas digesters could help farmers raise household income and reduce poverty by increasing consumer spending in Bangladesh (*Rahman et al., 2021*). Moreover, biogas users can increase their household income by supplying gas and electricity to their customers (*Moli et al., 2021*). *Meyer et al. (2021)* demonstrated that biogas digesters are financially sound investments and economically feasible at both household and societal levels. The benefits of biogas digesters can be expressed in terms of poverty indicators. If households spend less time collecting wood and more time generating valuable income, this increases the poverty indicator of income. Switching to cleaner fuels can also reduce health risks, thereby increasing the poverty indicator of health. Over the past decade, the Vietnamese government has coordinated with local authorities to mobilize livestock farmers to build biogas digesters. Many projects have been implemented to partially support installation costs depending on the conditions and scale of husbandry. However, because of the limited budget, the project has only been implemented in a few localities and is intended for a small number of subjects. The subsidy provision inadvertently created a dependence on the part of the people. Many households are not willing to invest in digester construction without subsidies from the government. Given the tight budget constraint, finding ways to reduce initial investments to biogas digesters for farmers and utilizing the full capacity of biogas digesters to effectively reduce energy costs is necessary.

4.1.2 Biogas digesters for poverty reduction in Quang Tri Province

Agriculture is a long-standing manufacturing industry that has received increasing attention in Quang Tri Province, Vietnam. With the effective investment of agricultural extension policies, the agricultural growth rate of the province has been continuously maintained, and the lifestyles of the farmers across the province’s rural areas are constantly being improved. In 2019, although Quang Tri Province had encountered many difficulties in implementing the agricultural restructuring process, the total product reached 4121 billion VND, up 4.92% compared to 2018 *(Quang Tri Statistical Office, 2019)*. With 69% of the population living in rural areas, animal husbandry, especially pig farming, is the main source of income, which has helped increase the income and improve the livelihood of people there. Annual pig production consistently exceeds other livestock production, such as buffalo, cow, and goat, accounting for 51.32% of livestock production in this area in 2019.

In 1999, the poverty rate of Quang Tri Province placed it in the second poorest group of the country, with a poverty rate of 43.9%–52.9%. After a decade, the province's poverty level had improved to a rate of 24.1%–40%, but it was still in the second poorest group in the country. Surrounding provinces in the region have decreased their poverty level to the third poorest group, with 17.3%–24% *(Jaax, 2020)*. In 2009–2018, Quang Tri Province's local agencies effectively implemented socio-economic development programs and projects in the area. The policy focused on propaganda to mobilize people and raise awareness to allow the subject to directly overcome difficulties, thereby creating community-based movements to help each other do business. Leadership and direction, in congruence with many guidelines, programs, plans, projects, and schemes, on sustainable poverty reduction, have been strengthened and implemented with positive results. People's living standards have improved significantly, and the poverty rate has been decreasing annually.

In early 2016, according to the *Quang Tri Provincial Party Committee*, the poverty rate in this province was 15.43%, or 24,579 households. The proportion of poor households in rural areas was 18.90% or 21,498 households. By the end of 2017, the poverty rate in the province had decreased to 11.52% or 19,541 poor households. On average, poor households in rural areas decreased by 2.32% per year. In 2018, the poverty rate in rural areas was 14.25% or 17,229 households. At present, however, poverty is increasing. Economic well-being in this province is below the national average. In 2018, the gross regional domestic product per capita of Quang Tri Province was 43.6 million VND (1894 USD) *(Ministry of Planning and Investment, Vietnam, 2019)*, below the national average of 58.5 million VND, equivalent to 2,552 USD *(General Statistics Office of Vietnam, 2019)*. The perception of the people, and even some officials, has not changed and there remains a tendency to rely on the support of the government. In addition, investment is still mainly focused on infrastructure rather than product development. These are the main causes of the unsustainability of poverty reduction.

Improving economic welfare on small-scale farms is an important part of reducing poverty, the local government has implemented a project to support people who build biogas digesters, particularly in two districts, Gio Linh and Cam Lo. This project was intended to improve their economic living standard and reduce the environmental burden due to animal waste. The climate in this region is tropical and humid. The average temperature is approximately 24–25 °C, and the average annual rainfall is 2200–2600 mm *(Doan et al., 2014)*. This temperature range is suitable for biogas production throughout the year.

4.1.3 Using biogas as a tool for poverty alleviation in rural areas of Vietnam

The use of traditional energy resources such as firewood and coal in many rural areas of Vietnam has been damaging nearby forest areas *(FAO, 1995)* and increasing greenhouse gas (GHG) emissions into the atmosphere. The consumption of fossil energy in the forms of electricity, gasoline, kerosene, and liquefied petroleum gas (LPG) is increasing. However, it is still difficult for remote famers to access these energy resources. Biogas is a possible solution for farmers. The International Renewable Energy Agency showed that biogas cooking could help to address health and socio-economic issues, as well as reducing solid-fuel use *(IRENA, 2017)*. This energy source is regarded as locally available, inexpensive, and clean; it is also known to produce a residue with a high fertilizer value for crop production *(Albihn and Vinnerås, 2007, Lantz et al., 2007, Masse et al., 1997, Møller et al., 2004, Sommer et al., 2005)*. Under effective direction, the development of farm economic models including biogas use has become a driving force for local socio-economic development *(Intelligent Energy Europe, 2010)*. Because the volume of livestock waste has become larger, comprehensive research on biogas technology is needed to meet the demands of waste treatment and the reduction of waste volume and to ensure that standards for sustainable development are met.

One of the key concerns of biogas digesters for rural farms is the economic and long-term sustainable use of animal waste. Although biogas digesters have the potential to improve farmers' life in rural areas, there are technical problems associated with the economic situations of the farms. A technological review of biogas digesters at the household level in Pakistan showed that one m^3 of biogas could effectively replace approximately 0.62 L of kerosene, 0.43 kg of LPG, or 3.47 kg of wood *(Yasar et al., 2017)*. A study in Thailand showed that improved cooking stoves and small biogas digester technologies are important reducing energy consumption and the associated greenhouse gas emissions *(Limmeechokchai & Chawana, 2007)*. Researchers have investigated the achievements and failures of biogas digester projects in several countries, especially in poor countries. *Diouf and Miezan (2019)* found that biogas digesters are not attractive to private investors in rural areas because of their high risk and slow financial return. Limited financial ability prevented farmers in Senegal from constructing biogas digesters. Another study reported that the limited use of biogas plants in rural southern Ethiopia is due to poor operation, management, and gas production as well as the high rate of failure of biogas plants *(Wassie & Adaramola, 2020)*. Recently, household-scale biogas digesters have become popular in rural areas of Vietnam. *Roubík et al. (2016)* found that most of the problems that biogas digester owners experienced related to the technology, mainly the biogas production process and biogas utilization subsystems. Although many studies of anaerobic biogas processes have been conducted in Vietnam and other countries, such studies have some limitations. In particular, research on the welfare merits and unsolved biogas digester use for rural low-income farmers is still limited.

As in many other developing countries, hunger and poverty are major issues in Vietnam. This situation has significantly improved due to the government's attempts at political and economic reforms. Owing to these reforms, the economy has grown at an annual rate of more than 8% over the past decade, becoming one of the fastest growing in the world and turning Vietnam into a middle-income country from a low-income one. However, poverty reduction remains a concern in Vietnam despite these achievements, as the poverty rate has continued to decrease slower than before *(Ngo, 2019)*. At the end of 2018, 9.8% of Vietnamese people, equivalent to 9 million people, lived in poverty. Household income is among the most important elements necessary for accessing basic household social services. The use of biogas digesters in rural agricultural areas has been used as a policy tool for both environmental protection and upgrading of farmers' living conditions *(IRENA, 2017)*. This energy source is regarded as locally available, inexpensive, and clean, and it produces a residue with a high fertilizer value for crop production *(Albihn and Vinnerås, 2007; Lantz et al., 2017; Masse et al., 1996; Møller, 2004; Sommer et al., 2005)*. Developing economic models of farms that include biogas use has become a driving force for local socio-economic development *(IEE, 2010)*.

To develop sustainable plans for poverty alleviation, biogas-digester engineers need to understand the economic situation of the farmers and identify the economic impacts of this situation. Engineers can then develop appropriate designs for biogas digesters by economic conditions. Hence, interdisciplinary research in this area may be of interest to engineers, project developers, governments, and policymakers. The need to consider socio-economic conditions when developing technology exists throughout the renewable energy field *(Cantarero, 2020)*. This study aims to assist engineers in determining the extent to which farmers' income influences the decision to install biogas digesters. These engineers can then propose appropriate recommendations to enhance the adoption and development of household-scale biogas technology as a sustainable energy option in developing countries. We selected Quang Tri Province in central Vietnam as the case study site for the survey. The methods selected for this study include quantitative research, such as statistical analysis of the characteristics of biogas digester users and energy cost savings, and qualitative research, such as the impact of poverty criteria on farmers' decisions, to enable engineers to draw the information necessary to formulate plans and policies.

This chapter aimed to address the following issues. The last issue of proposing recommendations refers to the results from the previous chapters in addition to the ones obtained from this chapter.

- Determining the factors of farmers' decision to install biogas digesters

- Evaluating the impacts of household income to the configuration of biogas digesters
- Estimating amounts of energy cost saving
- Analyzing the factors of farmers' satisfaction with a biogas digester
- Proposing recommendations to enhance the adoption and development of household-scale biogas technology as a sustainable energy option in developing countries.

4.2 Methodology

4.2.1 Data collection

We used data collected in Quang Tri province as described in section 3.3.1 chapter 3.

4.2.2 Estimation of energy cost saving

To obtain information on how much fuel each household used before and after the installation of a biogas digester, the survey asked two questions: "How long did it take for your farm to use one 12 kg bottle of LPG before the installation of your biogas digester?" and "How long does it take for your farm to use one 12 kg bottle of LPG now?" of households with biogas digesters. For the households without a biogas digester, one question was asked: "How long does it take for your household to use one 12 kg bottle of LPG?". We investigated the historical gas prices in a local store within the survey area and found that the price had fluctuated between 305 thousand VND and 460 thousand VND per LPG bottle during the past 10 years. Hence, the price of LPG at the time of the study was chosen for the analysis to calculate cost savings. According to the Quang Tri Provincial Party Committee, the retail LPG price was 356 thousand VND (15.42 USD) for one 12 kg bottle as of May 2, 2018. This price was used to estimate the monthly cost of the LPG for each farm. Each LPG bottle can be used within one month, two months, or a longer period depending on household usage. If a household uses one LPG bottle within one month, they pay 356 thousand VND per month. Similarly, if they use one gas bottle in two months, they pay 183 thousand VND (7.93 USD) per month.

We defined the energy cost savings resulting from the use of a biogas digester as the difference between the LPG payments before and after the installation of the digester. Owing to the quick supply and convenience of LPG, other fuels such as coal, firewood, and kerosene are no longer popular in this area. None of the respondents reported using coal or kerosene. Some households used firewood in combination with LPG to partially reduce the cost of living. However, farmers cut the firewood themselves from the nearby forests, so its cost cannot be quantified.

4.2.3 Payback method

The payback method is the calculation used to derive the payback period. The payback period is the time required to earn back the amount invested in an asset from its net cash flows. It is a simple way to evaluate the risk associated with a proposed project. An investment with a shorter payback period is considered to be better, since the investor's initial outlay is at risk for a shorter period of time.

The simple payback period calculation is a quick assessment method used to evaluate low- or medium-cost investments without resorting to more detailed evaluation methods. The formula for the payback method is simplistic: Divide the cash outlay (which is assumed to occur entirely at the beginning of the project) by the amount of net cash inflow generated by the project per year (which is assumed to be the same in every year). The simple payback period is calculated using the following formula:

$$\text{Payback period formula} = \frac{Initial\ Investment\ Made}{Net\ Annual\ Cash\ Inflow}$$

The longer the payback period of a project, the higher the risk. Between mutually exclusive projects having similar return, the decision should be to invest in the project having the shortest payback period. The shorter the payback period, the more feasible the investment solution is considered. In this study, a simple payback period method was used to analyze and evaluate the economic efficiency of the biogas digesters to help farmers make the right choice.

4.2.4 Calculating amount of biogas production

The method described in 3.2.2.2 was used.

4.2.5 Analysis of satisfaction levels

The evaluation of satisfaction rating is based on the answers supplied by the respondents via questionnaire survey. This study uses a linear regression model and an ordinal regression model to analyze the reasons for satisfaction with the use of biogas digesters. Let y denote the dependent variable. The linear regression model assumes that the dependent variable is linearly related to k independent variables $X_1, X_2, ..., X_k$ through the parameters $\beta_1, \beta_2, ..., \beta_k$:

$$y = \alpha + X_1\beta_1 + X_2\beta_2 + ... + X_k\beta_k + \varepsilon$$

The parameters $\beta_1, \beta_2, ..., \beta_k$ are the regression coefficients associated with $X_1, X_2, ..., X_k$, respectively, and ε is the random error reflecting the difference between the observed and fitted linear relationships. The satisfaction rating is divided into 5 levels: not at all, somewhat dissatisfied, neutral, satisfied, and very satisfied. Values of 1 through 5 were assigned to each rating, respectively, and used as the dependent variable for the linear regression analysis. Because our dependent variable was ordered categorical the ordinal regression model that assumes a logistic distribution for the dependent variable was used as well to examine the robustness of estimation results.

4.3 Results and discussion

4.3.1 Operational status of biogas digesters and attributes of households

Thirty percent of the farms reported problems in using the biogas digesters, but most of them did not incur additional costs to operate or maintain their digesters. Many farmers had a positive attitude toward the use of biogas digesters. Figure 4-1 showed the attitudes and problems reported by the 50 households using biogas digesters. The questions that were used to collect information include the following:

Q11. Did you have any problems during operating process. Please describe it if you had.

☐ Yes ………………………………………………………………..

☐ No

Q16. Did you pay more money for operation or maintenance? Please answer the times and the amount of money if you have to pay.

☐ Yes………………………….

☐ No

Q19. Did you concern about the environmental issues before you decided to install biogas digester?

☐ Yes

☐ No

Q21. After installing biogas digester, did you change the way of treating the livestock waste? Please describe if you had.

☐ Yes ……………………………………………………….

☐ No

Q22. Do you think that you are getting health benefits due to use of biogas compared to previously used energy sources?

☐ Yes

☐ No

Q23. Do you get any complaints from neighbors when your family uses biogas reactors? Please describe it.

☐ Yes ……………………………………………………….

☐ No

Q24. What is the impact on the living standard of your house after the installment of the biogas plant?

☐ Increased (subsidy,…)

☐ Decreased

☐ No change

Q25. How do you rate your own satisfaction about results obtained after using the biogas reactor?

☐ Very much

☐ Much

☐ Neutral

☐ Rather not

☐ Not at all

In the question Q24. What is the impact on the living standard of your house after the installment of the biogas plant?, the respondents who selected the Increased and Decreased answers were included in the Yes box, the remainings (No change) were included in the No box. In question Q25. How do you rate your own satisfaction about results obtained after using the biogas reactor?, households who selected Very much, Much and Neutral answers were combined in the Yes box, households with Rather not and Not at all answers were entered in box No.

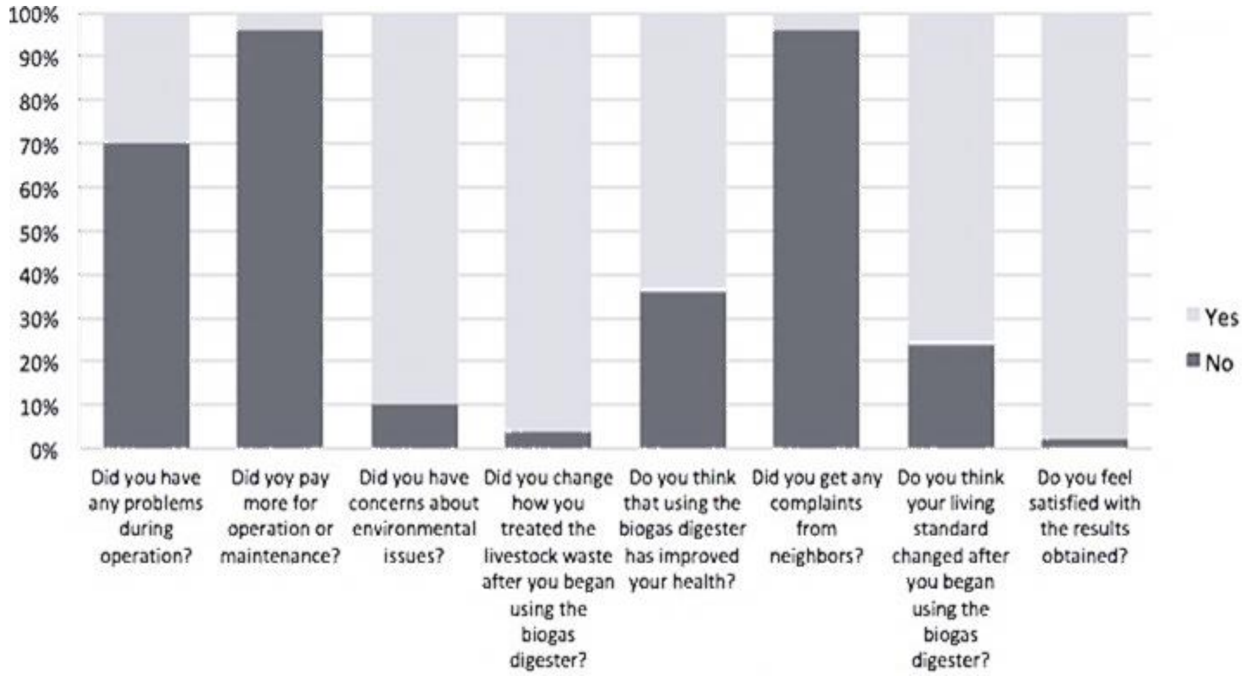


Figure 4-1 Attitudes and problems regarding biogas digesters

4.3.2 Factors influencing the decision to install a biogas digester

Among the 70 households interviewed, 20 households had not built biogas digesters. The responses from these 20 households showed that the main reason they did not install a biogas digester is the small scale of animal husbandry; in particular, the number of pigs for these households is quite small. Therefore, they feel it is not necessary to build a biogas digester. Other factors also contributed to the decision, such as the high installation cost, limited breeding area, and unpleasant smell of biogas digesters. An earlier study in Vietnam also indicated that the largest hygiene problem was odor, but the most common reason for not installing biogas digesters was lack of money *(Cu et al., 2012).*

The impact of poverty criteria on farmers' decision to install biogas digesters is examined in 70 households. Our research hypotheses are as follows: Null hypothesis H_o: Poverty criteria do not affect farmers' decision to invest in biogas digesters; alternative hypothesis H_1: Poverty criteria affect farmers' decision to invest in biogas digesters. Poverty criteria were explained in Section 4.1.1. Fisher's exact test was used to select an appropriate hypothesis. The cross-tabulation and results of the statistical tests are shown in Table 4-1. Among the poor category, 50% had a biogas digester, while this value increased to 77% among the non-poor category. The *p*-value of 0.053 was slightly larger than the significance level of 5% and we could not reject the null hypothesis. However, we need to keep in mind the possibility of low-income households facing the difficulty of purchasing a biogas digester given the small sample size of our survey.

Table 4-1 Analysis results

Poverty criteria	**Biogas digester using status**		**Total**
	With biogas digester	**Without biogas digester**	
Poor	7 (14%)	7 (35%)	14
Non-poor	43 (86%)	13 (65%)	56
Total	50 (100%)	20 (100%)	70
Fisher's Exact Test	p = 0.053		

This study then assesses the influence of the following independent variables on the dependent variable, the construction of biogas digesters, among the 70 households. The research hypotheses are as follows: (i) hypothesis H_1: The size of the breeding area affects the decision to build a biogas digester; (ii) hypothesis H_2: The main household occupation affects the decision to build a biogas digester; (iii) hypothesis H_3: The household income affects the decision to build a biogas digester; (iv) hypothesis H_4: The number of pigs affects the decision to build a biogas digester; (v) hypothesis H_5: Environmental concerns affect the decision to build a biogas digester.

A logistic regression model is used to analyze the relationship between the decision to build a biogas digester and the independent variables. The variables are defined and measured as follows: in terms of dependent variable, the respondents were asked whether they use a biogas digester. The answer was yes or no. Regarding the independent variables, we chose five factors. Area for breeding was obtained from a quantitative question, "Q2. How much is the area available for breeding?" was asked via questionnaire. Respondents provided specific figures on how much land they had for livestock production. Agricultural occupation was identified from the main household occupation selected in a multiple-choice question in the personal information section. The responses were divided into two groups, consisting of occupations related to agriculture and other jobs. The household income is the monthly income of each person living in the home, as provided by the respondent. Number of pigs was obtained from question Q3 that asked the respondents to provide information about the type and number of animals they were raising. There are three main types of livestock in the surveyed area: cattle (cows and buffaloes), pigs, and poultry (chickens and ducks). However, the amount of manure from cattle and poultry is too small for use in biogas digesters. Most of the animal manure supplied to the biogas digesters comes from pigs. Therefore, the number of pigs was selected as the independent variable for this analysis; The farmers who had concerns about environmental issues were identified from the yes/no question "Q19. Did you have concerns about environmental issues when you considered installing a biogas digester?" Among the 50 households with biogas digesters, 45 responded that they were concerned about environmental issues. Among the 20 households without biogas digesters, 13 had this concern. Thus, this variable is expected to affect their decision about building a biogas digester. Table 4-2 summarized the explanatory variables influencing the decision to install a biogas digester of the farmers.

Table 4-2 Summary table of explanatory variables influencing the decision to install a biogas digester

Variable	**Mean**	**Min**	**Max**
Area for breeding (m^2)	75.53	18	500
Primarily agricultural occupation (%)	81.4	-	-
Household income (million VND)	9.97	4	20
Number of pigs (head)	26	5	100
Concerns about environmental issues (%)	81.4	-	-

Table 4-3 presented the results of a logistic regression analysis of the relationships between the independent variables and the decision to install a biogas digester. This estimated model predicted the actual answers with an accuracy of 75.7%, indicating a good fit to the data. Two statistically significant relationships ($p < 0.05$) were found, which are shown in bold in Table 4-1. The number of pigs ($p = 0.011$) and the presence of environmental concerns ($p = 0.031$) were the two independent predictors that positively affect the farmers' decision to install biogas digesters. Other factors, such as the area available for breeding ($p = 0.064$), main household occupation ($p = 0.079$), and household income ($p = 0.178$) had little or no effect on the farmers' decisions.

Table 4-3 Analysis of the factors affecting the decision to build a biogas digester

Variable	Coefficient	*p* value	OR (95% CI)
Area for breeding	1.374	0.064	3.951 (0.923‒16.907)
Primarily agricultural occupation	1.863	0.079	6.446 (0.805‒51.602)
Household income	1.518	0.178	4.565 (0.501‒41.603)
Number of pigs	1.727	**0.011**	5.623 (1.487‒21.255)
Concerns about environmental issues	1.682	**0.031**	5.377 (1.168‒24.747)
Constant	-4.156	0.005	-
No. of cases	70		
Pseudo R^2	0.272		
Hit ratio	75.7%		

The results in Table 4-3 showed that there were two statistically significant relationships between the independent variables consisting the number of pigs ($p = 0.011$) and the presence of environmental concerns ($p = 0.031$) and the decision to install a biogas digester. In other words, farmers' decision to build a biogas digester was influenced by the number of pigs they raise and whether they care about the environment. It showed that the farmers decided to build biogas digesters when they raised a relatively large number of pigs and they cared about how to treat waste from livestock to protect the environment. Other factors have little or no effect on the farmers' decisions. The hit rate is defined as the percentage of the observations (in-sample) that is correctly predicted by the model. The table below provides an indication of how well the model is able to predict the correct category once the predictors are added into the study. Overall, the accuracy rate was very good, at 75.5%. The model exhibits good sensitivity since among those persons who will choose With biogas digester over Without biogas digester, 90% were correctly predicted to choose With biogas digester based on the model. Figure 4-1 shows the attitudes and problems reported by the 50 households using biogas digesters. Thirty percent of the farms reported problems in using the biogas digesters, but most of them did not incur additional costs to operate or maintain their digesters. Many farmers had a positive attitude toward the use of biogas digesters.

4.3.3 Comparing biogas digester conditions and farm attributes between income groups

In this sub-section, 50 households with biogas digesters were selected and divided into two groups with low and high incomes. Average per capita income was calculated based on the data supplied by the respondents. We found that the average per capita household income was 2.53 million VND per month, which is similar to the national average of 2.44 million VND per month and slightly larger than the national median of 1.98 VND per month (compiled from the World Bank's PovcalNet). We divided this group into two subgroups of households under the following criterion: Group 1 included 34 households with income below 2.53 million VND/month per capita and Group 2 included the remaining 16 households with income over 2.53 million VND/month per capita.

All low-income respondents were farmers whose main job was agriculture, of whom 58.82% earned extra income based on secondary jobs such as selling vegetables and producing wine. The number of vegetables and wine sold was small and not the main source of income that covered the household expenses. These households sold their products at a local market near their homes. The high-income households included 62.5% farmers, and the remaining 37.5% were self-employed. Their subsistence was not only based on farming, but also trading products consisting of noodles and wine. Self-employed households produced large quantities of noodles for wholesale to retailers.

We compared the attributes of the farms and biogas digester operation conditions between the low-income group and the high-income group. Table 3 shows the statistical results of comparing these two household groups. Four variables were obtained directly from the survey—the number of family members, the number of pigs, biogas digester volume, and breeding area—which were determined by the following questions: "Total number of people who are living in the same residence" in the basic information table, "Q2. How large is the area for breeding?," "Q3. What kind of animal does your family raise? Please specify the number of animals you raise," and "Q10. What is the size of your biogas digester?" Additionally, three independent quantitative variables were prepared. We calculated the biogas production and retention times from the information supplied by the respondents. The amount of biogas produced and the retention time were estimated according to the method described in Appendix A. The respondents were asked to rate their satisfaction with the biogas digesters. The satisfaction rating is divided into five levels: *not at all* (level 1), *somewhat dissatisfied* (level 2), *neutral* (level 3), *satisfied* (level 4), and *very* *satisfied* (level 5). According to our survey, of the 50 respondents, 37 were satisfied and 11 were very satisfied. One person felt neutral about the benefits gained, and one was not satisfied because of the bad smell when using biogas.

The independent-samples *t*-test was used to determine if there was a significant difference between the means of the two groups. From the *p*-values in Table 4-4, biogas digester volume ($p = 0.000$) was different between the two groups and the higher income group tended to have a larger digester.

Table 4-4 Comparison of farm/biogas digester attributes

Variable	Low income group	High income group	*p*-value
Number of household members (person)	4.35	3.88	0.249
Number of pigs (head)	29.18	31.56	0.581
Biogas digester volume (m^3)	11.29	14.63	**0.000**
Breeding area (m^2)	74.76	83.00	0.170
Biogas production (m^3)	5.34	5.90	0.820
Retention time (days)	35.85	45.13	0.058
Satisfaction level	4.11	4.25	0.924
N	34	16	

4.3.4 Energy cost saving

Before the installing of a biogas digester, 50 households that later installed a biogas digester paid an average of 599.00 thousand VND (25.94 USD) per month for purchasing LPG. By calculating the money saved following the method showing in Section 4.2.2, the amount saved by households using a biogas digester was estimated at 330.64 thousand VND per month, equivalent to 14.22 USD. The use of a biogas digester also helped households reduce other energy sources, such as firewood and electricity. Thus, our estimate of LPG reduction only shows the minimum energy cost savings. In addition, farmers can use the digestate from biogas digesters as a fertilizer for farming.

In household-scale pig raising, biogas is mainly used as a domestic fuel. Biogas is taken from the digesters through a simple filter system and then used as fuel. The use of biogas as a fuel reduces the amount of money needed to purchase other fuels, such as LPG and firewood. According to our survey data from the 50 households with a biogas digester, 14% used firewood for cooking, 24% used LPG, and the remaining 62% used both before installing a biogas digester. The amount of firewood used in the households is not available in our data, but most of it is taken from nearby forests free of charge or purchased from retailers. The use of LPG for cooking is usually more convenient, although more expensive.

The respondents had biogas digesters made of cement or composite materials. The average LPG savings for cement and composite digesters are 298.85 thousand VND (12.94 USD) and 351.83 thousand VND (15.24 USD) per month, respectively. The composite biogas digesters resulted in greater cost savings than the cement biogas digesters. In addition, a composite digester costs less to construct than a cement digester and provides greater economic benefits per month. The average lifetime of a cement biogas digester is approximately ten years, though a well-maintained cement digester can last up to 15 years. In our sample, a cement digester built-in 2003 had been operating normally until the time of the survey. A composite biogas digester has a lifespan of up to 20 years (*Quang Tri Department of Agriculture and Rural Development, Vietnam, 2015).* To analyse the economic efficiency of each type of biogas digester, we calculated the payback time and the benefits of the biogas digester throughout its life cycle. For cement biogas digesters, the initial capital investment is recovered after 4.33 years, versus 3.21 years for composite biogas digesters. *Roubík et al. (2016)* estimated that the average payback time for a biogas digester in Vietnam with a subsidy is 2.25 (± 2.04) years and without a subsidy is 4.46 (± 3.22) years. Our estimate of the payback time fell within a similar range.

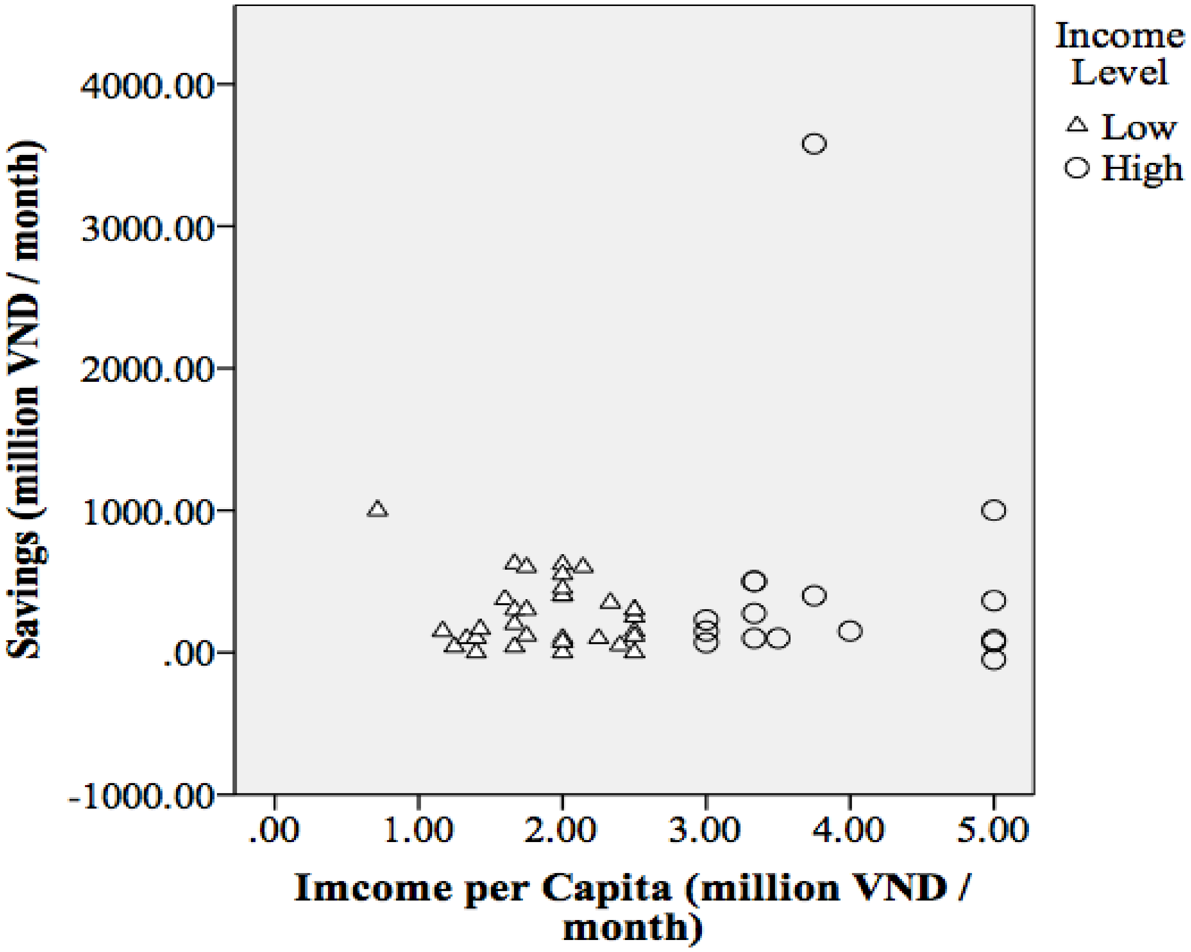


Figure 4-2 Scatter diagram of the savings per month through biogas digester use in the two income groups.

The scatter diagram in Figure 4-2 shows that there was an outlier that signified an unusually large energy cost saving in the dataset. The presence of this outlier could affect the statistical results, leading to erroneous findings. We performed a statistical analysis with the data excluding this outlier. The results showed that with 49 households using biogas digesters, the low-income households saved 264.62 thousand VND per month, while the high-income group saved 263.67 thousand VND. The *t*-test of these two groups resulted in $p = 0.894$, indicating no significant difference in the mean monthly money savings between the low-income and high-income groups.

The amount of savings per month due to replacing LPG with biogas was not significantly different between the low-and high-income groups. However, the monthly savings of 264.62 thousand VND were equivalent to 3.33% of the monthly household income of the low-income group, while on average the high-income group saved only 1.81% of their household income per month. Using biogas as an alternative energy source helped low-income families partially reduce their cost of living.

A difference was found in the volumes of the biogas digesters selected by these two groups of households as shown in Table 4-1. On average, low-income households spent 13.176 million VND to build a biogas digester with 11.29 m^3, while high-income households paid 16.844 million VND for a 14.63 m^3 biogas digester. Despite the difference in the amount of capital expenditure on installing biogas digesters, the energy savings of the two groups were almost the same. We also determined that there was no statistically significant difference in biogas production. Thus, low-income households operated biogas digesters more efficiently than high-income households.

The results showed that 80% of households with high income made money by using biogas instead of other fuels to produce wine and noodles for business. In this case, the biogas digester became a tool to help people make money.

The outlier in Fig.3 provides an important insight. While other households only used biogas to meet basic household needs such as cooking, this household used biogas as an alternative energy source for the production of rice noodles for private businesses. The estimated amount of biogas production for this household is not largely different from the others, suggesting that the other households release part of the biogas into the air. Remarkably, 6 households of the remaining 49 households were also involved in business activities such as making noodles and making wine for sale in addition to their main job, agriculture. However, they were unable to take advantage of the biogas available in their house. According to our survey, these households used electricity for operating machines for manufacturing products such as rice noodles and were not able to use their biogas resources for this purpose.

4.3.5 Satisfaction ratings of farmers regarding biogas digesters

We asked the respondents to rate their satisfaction with the biogas digesters. The satisfaction rating is divided into 5 levels: not at all (level 1), somewhat dissatisfied (level 2), neutral (level 3), satisfied (level 4), and very satisfied (level 5). According to the survey results, 48 (96%) of the 50 respondents are satisfied with the results obtained using the biogas digester; among them, 37 were satisfied, and 11 were very satisfied. One person felt neutral about the benefits gained, and one was not satisfied because of problems in using the digester (Figure 4-3).

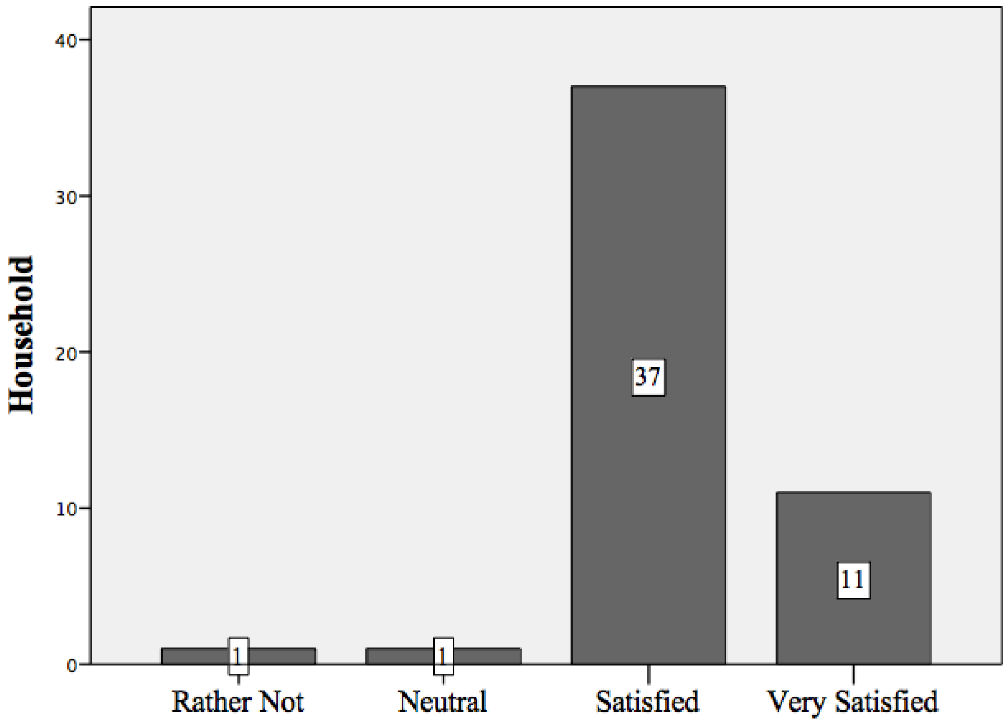


Figure 4-3 Satisfaction ratings of farmers regarding biogas digesters using

In this section, the factors affecting the satisfaction of farmers with biogas digesters are identified. A study in Thailand measured the satisfaction of the users of biogas digesters by considering three aspects: the management, use, and maintenance of the biogas system; the environmental impact; and the overall satisfaction level *(Sritrakul and Hudakorn, 2019)*. Their results showed that the respondents were very satisfied with all three of these aspects. A more in-depth study that considers a larger set of factors is needed. Our research hypotheses are as follows: (i) hypothesis H_1: Improved health after a biogas digester is installed affects user satisfaction, (ii) hypothesis H_2: Receiving complaints from neighbors after a biogas digester is installed affects user satisfaction; (iii) hypothesis H_3: Changes in living standard after a biogas digester is installed affect user satisfaction; (iv) hypothesis H_4: Energy cost savings after a biogas digester is installed affect user satisfaction; (v) hypothesis H_5: The amount of biogas produced by a biogas digester affects user satisfaction; (vi) hypothesis H_6: The payback time after a biogas digester is installed affects user satisfaction.

This study applies quantitative methods using a linear regression model and ordinal logistic regression model. As the dependent variable the order of the satisfaction ratings was considered in the ordinal logistic regression model. Values of 1 through 5 were assigned to each rating for the linear regression analysis. Three independent variables were directly obtained from our survey. Improved health, complaints from neighbors, and changes in living standard were determined by the following questions, respectively, "Q22. Do you think that you are getting health benefits due to the use of biogas compared to those of previously used energy sources?", "Q23. Do you get any complaints from neighbors when your family uses biogas digesters?", and "Q24. Did the installation of the biogas digester affect your family's living standard?" The responses to these questions were "yes" or "no," and we created a dummy variable from the answers. Additionally, three quantitative independent variables were prepared. We obtained the information and estimated the energy cost savings, the payback time and amounts of biogas produced by using biogas digesters. The explanatory variables influencing satisfaction ratings of biogas digester users were summarized in table 4-5. Energy cost savings has reached the minimum value of -50 thousand VND because there was an outlier case. After building a biogas cellar, this household turned to noodle cooking for business. The amount of biogas energy was not enough to meet the cooking needs of this family's business, so they needed to use another energy source.

Table 4-5 Summary table of explanatory variables influencing satisfaction ratings

	Mean	**Min**	**Max**
Improved health (Yes=1, No=0)	0.029	-	-
Complaints from neighbors (Yes=1, No=0)	0.457	-	-
Change in living standard (Yes=1, No=0)	0.457	-	-
Energy cost savings (thousand VND)	330.64	-50	3580
Amount of biogas produced (m^3)	5.62	2.62	16.27
Payback time (year)	7.64	0.35	28.33

Table 4-6 Analysis of satisfaction results

Variable	Linear regression		Ordinal regression	
	Coefficient	*p* value	Coefficient	*p* value
Improved health	-0.368	**0.022**	-2.015	**0.033**
Complaints from neighbors	-0.161	0.661	-1.052	0.588
Change in living standard	-0.158	0.088	-0.885	0.137
Energy cost savings	0.041	0.881	0.451	0.787
Amount of biogas produced	0.096	**0.000**	0.587	**0.003**
Payback time	0.150	0.246	0.864	0.281
Constant	3.521	0.000	–	–
Threshold 1	–	–	-0.947	0.801
Threshold 2	–	–	-0.125	0.973
Threshold 3	–	–	6.141	0.114
No. of cases	50		50	
R^2	$R^2 = 0.383$		Pseudo $R^2 = 0.325$	

Table 4-6 showed the estimated models. The ordinal regression model had three thresholds, because only four rating levels were chosen among the five satisfaction levels. The pseudo R2 value of 0.325 demonstrated that the ordinal regression model fitted the data well. From the coefficients and p values in Table 4-4, at a statistical significance of 5%, the research hypotheses H_2, H_3, H_4, and H_6 were not supported ($p \geq 0.05$), but hypotheses H_1 and H_5 were supported ($p < 0.05$). The results of the ordinal regression and linear regression models regarding these hypotheses were in good agreement. The ordinal regression analysis showed that satisfaction with the biogas digesters was positively correlated with two independent variables, health improvement (*p = 0.033*) and amount of biogas produced (*p = 0.003*), but no significant correlations with the other parameters were detected. In the rural area we surveyed, the amount of firewood used by people for cooking was collected from neighboring forests. When using biogas to cook instead of firewood, many households have saved time and energy for cutting firewood. They answered that they felt less energy needed to cut firewood and improved their health. In addition, reducing the use of firewood will help people as well as the surrounding community to reduce concerns about lung-related diseases. Saving manpower is also an alternative definition for health improvement in this case.

In this analysis, we considered various factors that can affect farmers' satisfaction with biogas digesters such as living standard changes, energy cost savings, complaints from neighbors, and payback time. The results of the satisfaction surveys clearly indicate the issues that require improvement, which should be investigated in future research.

4.4 Recommendations for biogas digester engineers and policymakers

4.4.1 Policy recommendations for local authorities of Quang Tri Province

Based on the results from this and previous chapters, following recommendations are made. The above results show a significant difference in mean digester volume between the low-income and the high-income groups. This demonstrates that farmers are willing to invest in larger volumes of biogas digesters if they have a higher income. Nevertheless, there was no difference in the number of pigs, breeding area, or the amount of biogas production between the two groups. Households have invested in biogas digesters without considering important factors such as the number of pigs or the amount of breeding area. Households with high incomes have built digesters with excessive volume, even though their actual demand for usage is not that much higher. Addressing wasteful spending on digester installation is a concern.

Our calculation showed that for the group of low-income households with an average number of pigs of 29 head, the optimal size of the digester should be 4.35 m^3. With an average number of pigs of 32 head, the high-income group should build a biogas digester with a size of 4.8 m^3. Compared with the results in Table 4-3, it is clear that the actual biogas digester size is significantly different from the optimal digester size. Among the 50 surveyed households with a biogas digester, only 6 households (12%) built biogas digesters with a volume suitable for the number of pigs they raised. The remaining 88% of the households had biogas digesters larger than the optimal volume. Surprisingly, 82% of the households had built biogas digesters with more than twice the optimal volume. This represented a waste not only in terms of land use but also in terms of the costs of constructing biogas digesters. However, small biogas digesters with the proposed optimal volume are not popular in Vietnam. The project supporting biogas technology to treat livestock waste with composite biogas digesters in Quang Tri Province has built digesters with a diameter of 2.25 m, corresponding to 8 m^3. This limitation of digester size needs to be carefully considered to better suit the needs of prospective users.

4.4.2 Policy recommendations for Vietnamese government and developing countries

In a broader context, a technical proposal can be pursued to enhance biogas production by focusing on improving feedstock supply for biogas digesters. Below are some proposed policies for Vietnamese government and several developing countries. *Taleghani and Kia (2005)* showed that various organic wastes from households and municipal authorities provide municipal solid waste as a potential feedstock for biogas digestion. Optimization of the use of biogas technology as part of a sustainable energy supply strategy revealed that co-digestion, the simultaneous digestion of a homogenous mixture of two or more substrates, can offer several ecological, technological, and economic advantages (*Jingura and Matengaifa, 2009*). To apply this method to biogas application and maximize biogas production, the optimal solution provided here is to combine livestock waste with other available waste. In the current context, an extensive study of this technological issue is necessary to move towards long-term sustainable development. In Vietnam, we aim to combine livestock waste with food waste to produce an optimal biogas on a household scale.

Biogas technology is an effective solution for reducing energy and living costs for farmers, especially in low-income households. The development of biogas technology not only solves the energy problem but also minimizes environmental pollution, contributes to the protection and enhancement of the health of the population community, and increases the efficiency of agricultural production. However, the dissemination of this model faces many difficulties due to the high cost of investment in the construction and installation of biogas digesters relative to household income.

To reduce the price of the initial investment, local authorities and government should provide reference guidelines that farmers can use to choose the optimal size of the biogas digester for their household conditions and needs. In addition, engineers should study smaller, more effective biogas digester designs to provide a more flexible selection of biogas digester volumes. It is necessary to propose a method for calculating the optimal digester size by the conditions and needs of the household, as well as external factors, such as the temperature and humidity of the given area. Inspection and supervision of biogas digester installation consulting enterprises should be strictly implemented to avoid them advising customers with misleading information for self-interested purposes. In the case of households whose livestock scale is too small for the smallest type of digester, households situated close to each other should invest in and use one biogas digester together. This will help farmers save costs as well as save land. Below is a flowchart to help farmers choose the size of the biogas digester corresponding to the number of pigs they are raising.

Table 4-7 The size of the biogas digester corresponds to the number of pigs

Your biogas digester size (m^3)	Appropriate number of pigs (heads)
4	1 - 10
7	10 - 20
9	20 - 50

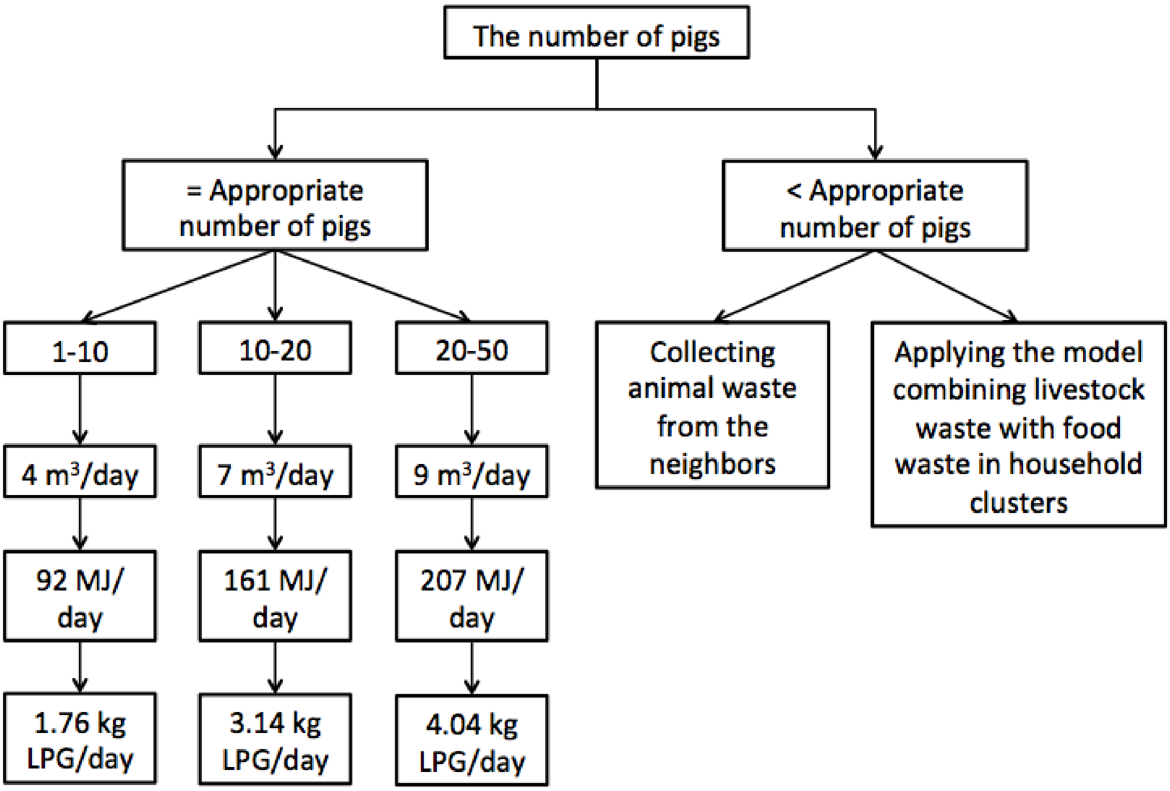


Figure 4-4 Flowchart of making decisions to effectively use biogas digesters

Many farmers in the surveyed area did not take full advantage of the benefits of biogas digesters. Local authorities should encourage people to share biogas digester among neighbours and communities. Households that have biogas digesters can collect pig waste from other farmers who do not possess ones. A problem arises because the number of pigs raised varies seasonally. Therefore, during periods in which the number of pigs is small, many farmers cannot fully utilize the biogas digesters. To solve this problem, cooperation between biogas users and non-biogas users is necessary. Farmers can mix the collected pig waste with other feedstocks consisting of volatile solids such as residual cereals, rice straw, wheat straw, grass, corn stalks, fruit waste, vegetable waste, fat, mixed food waste, or mixed organic waste.

There is a possibility that the produced biogas is not fully utilized by the owners and released to the air. The biogas emitted into the environment can causes a significant environmental problem. These households can share a digester with their surrounding neighbours. With the current technological development, biogas-to-electric converters have been manufactured and sold. Although it is not commonly used in Vietnam, encouraging investment in this new technology is essential to help people utilize biogas and save on their living costs. Developing renewable energy sources ensures energy security and addresses the growing power demand. Supporting industries play a crucial role in the development and adoption of renewable energy technologies.

Additionally, a small portion of the farmers lack the necessary scientific knowledge and are also subjective in terms of protecting the living environment of the community and their own families. In order to develop and replicate the biogas model, local authorities need to further promote propaganda and advocacy to raise people's awareness of the benefits and efficiency of this technology, as well as how to use it.

Local authorities need to disseminate the knowledge to use biogas digesters. Continuing to mobilize resources in terms of capital and labour while focusing on investment and development of self-production is necessary to promote the advantages of each locality, accelerate the restructuring of crops and livestock, and create jobs that raise people's income. In addition to the financial support for the construction of biogas digesters, detailed training and monitoring programs for biogas users are needed so that users can maximize the benefits they obtain from the digesters. Monitoring should be performed regularly to help farmers understand and overcome the problems encountered.

4.5 Summary of findings

The biogas digester is a technology that may help solve current problems with livestock waste management in rural areas of Vietnam. Its use has become popular in Vietnam, especially in households that practice small-scale livestock husbandry. An analysis of the relevant characteristics and factors shows that the number of pigs and concerns about environmental issues are the two main factors influencing farmers' decisions to build biogas digesters. In addition, the difference in household income between low-income households and high-income households influenced the decision to choose biogas digester size.

The biogas digester is a technology that may help solve current problems with livestock waste management but also with poverty alleviation in rural areas of Vietnam. We surveyed the area where the local government promoted the installation of biogas digesters to small farms. It cannot be denied that biogas technology has brought socio-economic benefits to farmers, especially poor households. Biogas technology has become common in this area as a tool for treating livestock waste and making use of alternative fuels for cooking. Replacing fossil fuels with biogas could help each household save 330.64 thousand VND (14.22 USD) per month. Because of the benefits obtained from this technology, low-income households are still willing to invest in digester construction despite the high initial investment cost. The biogas system is considered a technology that might contribute significantly to poverty alleviation in developing countries.

Biogas digesters offer environmental and economic benefits. Most of the surveyed farmers who use biogas digesters are satisfied with them. The results of this study showed that improved health and the amount of biogas produced are the most important factors affecting the farmers' reported satisfaction with biogas digesters.

Nevertheless, according to Chapter 3, some households have invested in digester installation without considering the optimal digester volume. This leads to wasteful biogas discharge into the environment. 88% of the respondents had not built biogas digesters suitable for the number of pigs they raised. This problem was partially due to the unprofessional management of the consulting team as well as the local authorities. To maximize the benefits of biogas digesters, the government and local authorities need to define clear plans and implement sound policies to support the work of people who use the technology. The policies proposed in this paper are intended to resolve the existing shortcomings in building and using biogas digesters, with the goal of helping local people use this renewable energy to alleviate poverty sustainably.

Although biogas digesters can offer many benefits, there are associated problems that have not been clarified. Biogas wastewater presents a potential danger to human and animal health when it is released into the environment and used to fertilize plants *(Luu et al., 2014)*. To date, most research has focused on the advantages of using biogas digesters and ignored disadvantages such as their effects on the health of users. We suggest that more in-depth studies be conducted on the drawbacks of using biogas digesters in order to explore and identify the most suitable solutions.

Chapter 5 TECHNO-ECONOMIC EVALUATION OF BIOGAS PRODUCTION FROM LIVESTOCK WASTE COMBINING FOOD WASTE IN HOUSEHOLD CLUSTERS

5.1 Introduction

The anaerobic digestion of waste is making a significant contribution to solving problems related to energy, environment and agriculture. This has encouraged the development of biogas technology globally as well as the need to study its economic viability. *Bhatt and Tao (2020)* mentioned that current and future research in renewable energy has contributed to the rapid increase in investment and implementation of clean energy technologies around the world. The conversion of waste to energy through anaerobic digestion is a potential option. This technology can promote sustainability and meet the world's renewable energy needs. In this regard, energy economists, industries and agencies are looking for low-cost technologies such as biogas digesters to generate energy. Many studies have examined the economic feasibility of a biogas digester and its gas yield based on various factors.

Food waste is a major component of municipal solid waste and its accumulation or disposal in landfills is worrying, causing environmental problems. *Baawain et al. (2017)* proved that food waste is usually a major portion of any municipal solid wastes, which are commonly disposed of in landfills or dumping sites, causing environmental issues. However, landfilling is expensive and requires a large amount of space. The proliferation of waste and limited space has led the Vietnamese government and local authorities to look to many other solutions instead of landfills. Furthermore, solid wastes can have a negative impact on the environment if not managed well due to the production of leachate, methane and carbon dioxide and other nuisances such as odors, flies, insects and rat. Landfill leachates were also proved as a significant source of hazardous pollutants to the environment (*Li et al., 2012*). Complex and heavy metal components in the leachates are the most dangerous substances to the groundwater and soil (*Aronsson et al., 2010*). Anaerobic processes are among the most promising technologies for food waste treatment efficiently, producing at the same time different value-added compounds (*Capson-Tojo et al., 2016*). *Zhang et al. (2014)* also showed that anaerobic digestion of food waste into biogas, is a proven and effective solution for food waste treatment and valorization. The use of food waste as a potential source for sustainable fuel production would complete the full cycle of this waste stream in a sustainable manner and thus directly support and facilitate the concept circular economy. There are several uses of biogas such as in cooking, heating, power generation, etc. In order to move towards a sustainable development in the future, natural resources and providing renewable energy sources in general that are environmentally friendly must be prioritized.

This chapter aims to approach the capacity on the potential of biogas production from food waste combined with locally produced livestock waste in Danang City, Vietnam. Besides, it seeks to evaluate the economic implication of a biogas digester built from composite material for household clusters to ascertain its cost effectiveness.

5.2 Literature review on combined food waste use and household cluster use of biogas digesters

Food waste with its high nutrient content is a promising source for producing bioenergy (*Waqas et al., 2019*). *Banks et al. (2011)* found that 615 472 m^3 of biogas was produced from the 3936 tonnes of source segregated domestic food waste over a 14-month monitoring period. *Ziauddin and Rajesh (2015)* conducted a study to compare the amount of biogas obtained from food waste and cow manure. Anaerobic digestion experiments were conducted for 8 days on two sets of samples collected, set 1 containing cow dung and set 2 containing kitchen wastes. The study revealed that food waste produced 89.37 mL of gas in eight days, more than cow manure with 23.75 mL. It can be seen that the nutrients in food waste are greater than the nutrients in cow manure, and food waste is an abundant source of input for biogas digesters. Co-digestion of food waste and livestock sludge offered major advantages in terms of resource conservation and pollution reduction when compared to concentrated anaerobic digestion of food waste or energy recovery from thermal treatment *(Banks et al., 2011).*

A key factor to be considered when choosing the volume of a biogas digester is the number of households who will benefit from the biogas when it is produced. According to *Tufaner and Avsar (2019)*, one person required approximately 0.34–0.42 m^3 of biogas to cook a daily meal. Normally, the maximum amount of biogas generated from a digester can provide to meet the cooking needs of a few households. It also leads to significant economic benefits for farmers, typically in poor and developing countries. Therefore, the aim of this chapter is to determine the economic feasibility of generating biogas in a small-scale composite biogas digester for the scale of concentrated household clusters. The study will also solve and calculate the amount of waste input required to achieve the most optimal capacity of the biogas digester.

5.3 Methodology

5.3.1 Survey area selection

We selected three districts of Da Nang city as the survey area including Hoa Phong Commune, Hoa Khuong Commune and Hoa Tien Commune. Our primary data has been collected through direct interviews with farmers. Our survey was conducted from July 1st to July 16th, 2022. A total of 30 farming households were selected for the survey, evenly distributed over the three selected communes. There were 10 households that were directly interviewed living in each commune. Target of sampling selection were based on household characteristics such as household-scale pig production.

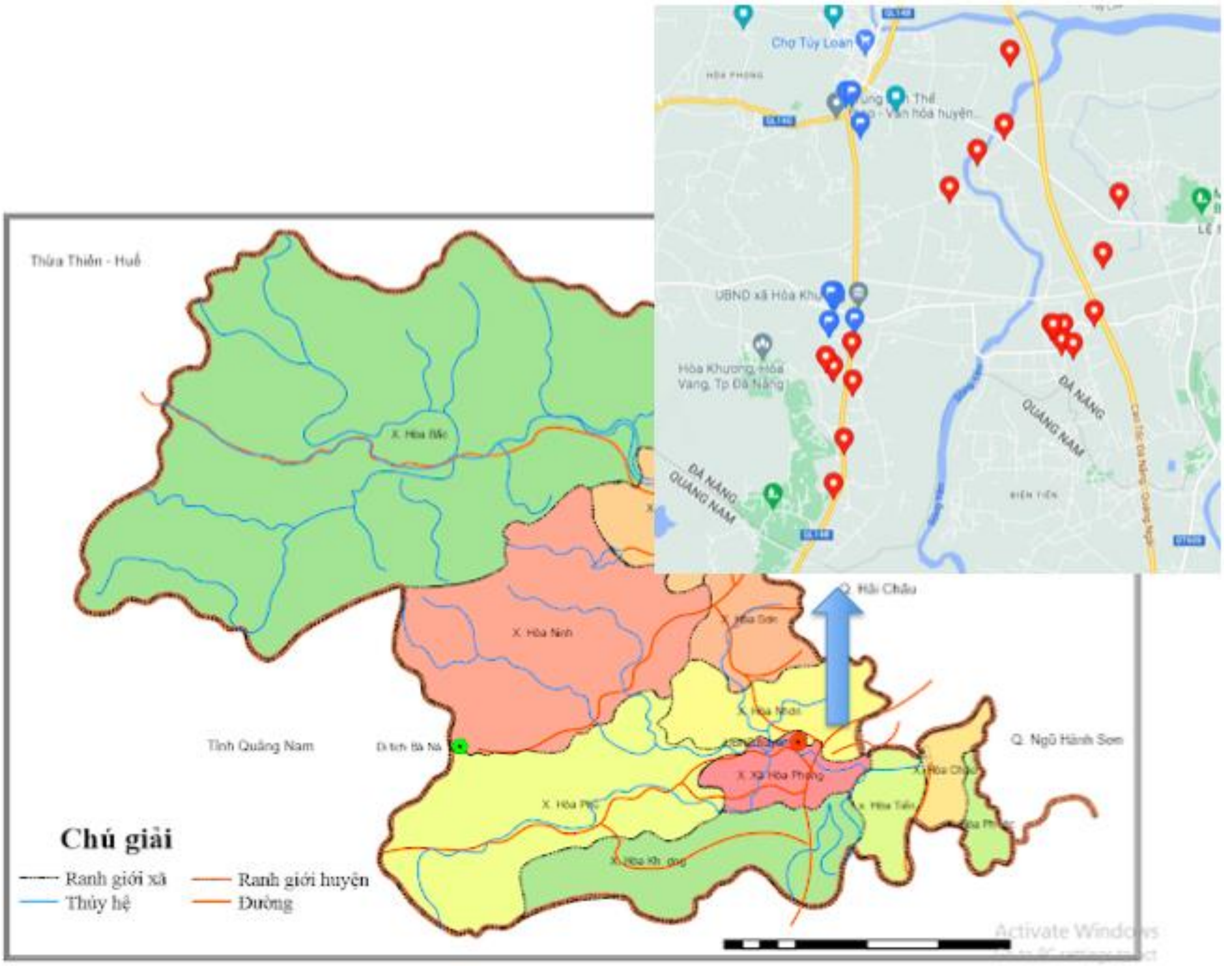


Figure 5-1 Survey area (Source: Ban-do.net, Google map photo)

Thirty selected households were directly interviewed using a 27–item questionnaire. The questionnaire was created to collect detailed information on each household's livestock waste treatment, the respondents' interest in the environment and biogas technology, as well as their willingness to do for plans to build a biogas digester in the future. Secondary information, economic and technological data on biogas digesters were obtained from the statistical yearbook of the Da Nang Statistical Office, along with information collected from residents and service providers.

5.3.2 Method of calculating biogas production and consumption

In this chapter, we used the feedstock use method referring to *IRENA (2016)* to calculate the amount of biogas produced and consumed as described in section 3.2.2 in Chapter 3. The factors considered for the calculation are similar to Chapter 3. The weight of volatile solids from food waste can be calculated using the figures shown in Table 6 (*IRENA, 2016*). For mixed food waste, volatile solid is equivalent to 0.08% of its wet weight.

5.3.3 Payback method

The method described in 4.2.3 was used.

5.4 Results and discussion

5.4.1 Household-scale farms' attributes in Danang City, Vietnam

The survey was conducted in three communes of Hoa Vang District, Da Nang City including Hoa Phong Commune, Hoa Khuong Commune and Hoa Tien Commune. Among the 30 surveyed households, 20 households (accounting for 66.67%) had agriculture as their main occupation. The remaining 11 households (accounting for 33.33%) had their main income from other jobs, mainly self-business.

As of August 15, 2019, in Da Nang city, there were 211 livestock households suffering from African swine fever, the total number of pigs infected, dead and destroyed according to regulations up to 2259 heads *(Da Nang Statistical Office, 2019)*. Therefore, the average number of pigs per household has decreased significantly compared to before. All of 30 selected respondents raised pigs in the household area, with an average of 4–5 pigs per household. The household with the maximum number of pigs is 15 heads, while the minimum is one head.

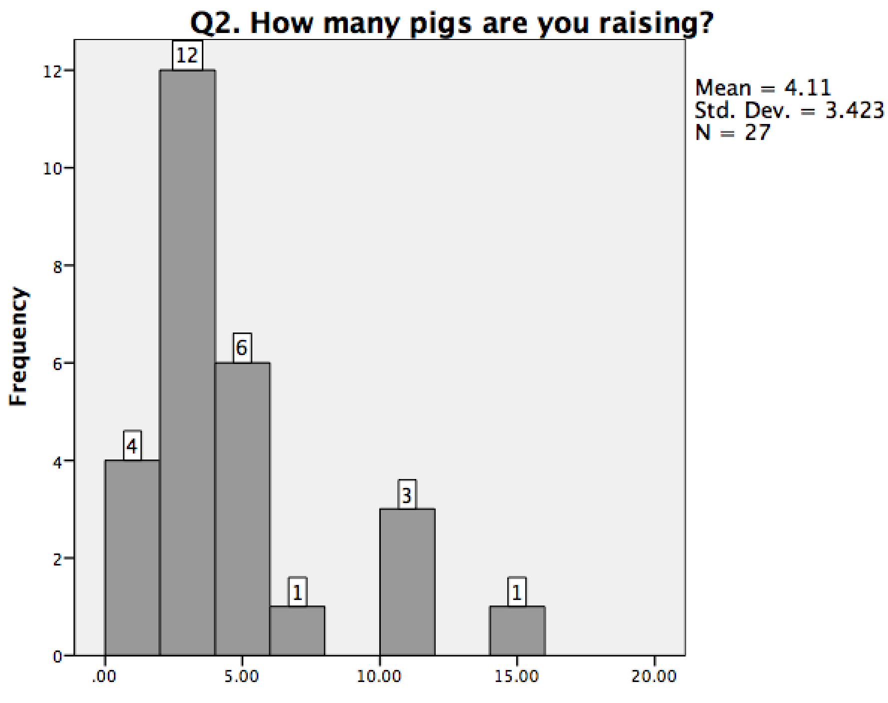


Figure 5-2 Number of pig in 30 surveyed farms

Among them, there were 27 households (accounting for 90%) that did not use biogas, instead they treated livestock waste by pouring into empty areas such as river, lake, forest, ... or making fertilizer. There were only three households having used biogas digesters in the treatment of manure waste, accounting for 10%. Households that did not use biogas digesters raised 4 pigs on average, while those using biogas digesters raised twice as many pigs, up to 8 pigs. Among 27 households that do not use biogas, 18 households (accounting for 60% of the total number of households interviewed) treated waste from raised pigs by pouring into empty areas including river, lake, and forest... The remaining 9 households combined pouring into the empty places with making fertilizer. Improper treatment of livestock waste causes many problems related to the living environment and the health of people around in this area. The smoke emissions from biomass fuels (wood, agricultural waste, and dung) are an important source of indoor air pollution, that adversely affect health - such as suspended particulate matter and polycyclic organic matter which includes a number of known carcinogens as well as gaseous pollutants (*Koning et al., 1985*).

5.4.2 Estimation of energy cost savings from using biogas digesters in combination with neighbors

5.4.2.1 Model farms

With a limited number of pigs, many households in the survey area did not decide to build biogas digesters. Out of 27 surveyed households without biogas digesters, 24 households (accounting for 88.89%) answered that they did not intend to change to using biogas to treat pig manure. To overcome the cause of the limitation in the number of livestock, we have proposed the idea of designing a biogas digester for common use by residential clusters. The family cluster size was determined based on the total number of pigs of the farms that best suited the biogas digester size. Two model farms were proposed based on the geographical situation of the survey area through satellite maps as follows:

- Model M1: Household cluster consists of 4 households with short distances between households. On average, each household raises 4 pigs. Biogas digester with size 7 cubic meters and diameter 2.25 meters is proposed for this model. Assume that the households with pig production are evenly distributed around the area where the biogas digester is built, and the average distance between each household and the biogas digester is 40 meters.

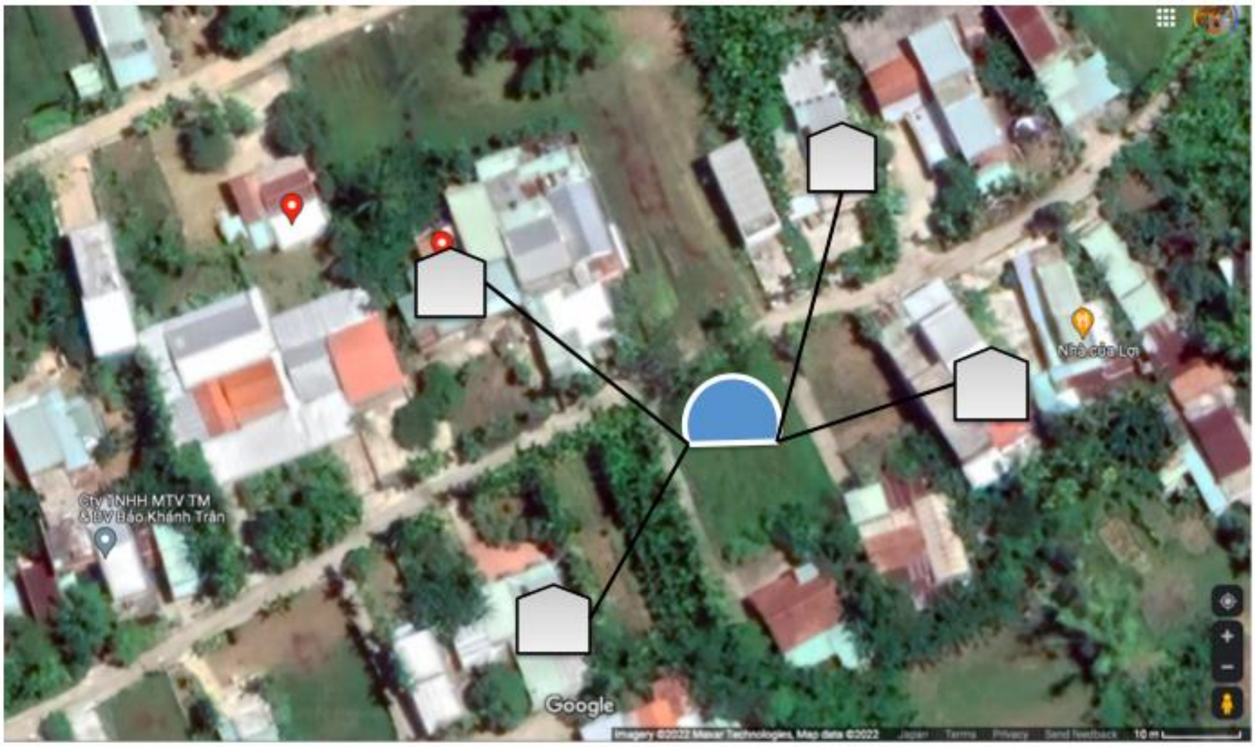


Figure 5-3 Model farm M1 (Google map photo)

Table 5-1 Criteria of model M1

Number of households	4
Total number of pigs (head)	16
Biogas digester size (m^3)	7
Total length of pipeline (m)	160

- Model M2: Household cluster consists of 8 households with long distances between households. On average, each household raises 4 pigs. Biogas digester with size 9 cubic meters and diameter 2.45 meters is proposed for this model. Assuming pig-raising households are scattered with long distances from each other, and the average distance between each household and the biogas digester is 100 meters.

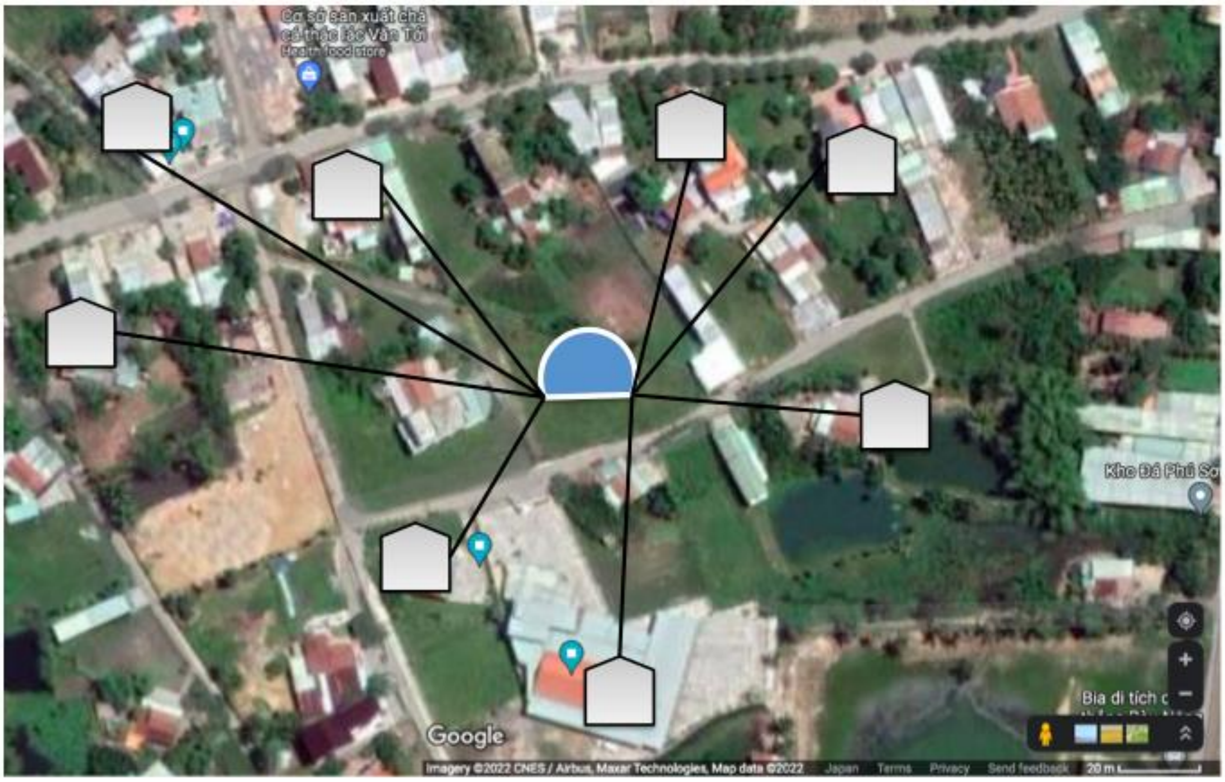


Figure 5-4 Model farm M2 (Google map photo)

Table 5-2 Criteria of model M2

Number of households	8
Total number of pigs (head)	32
Biogas digester size (m^3)	9
Total length of pipeline (m)	800

For each of the above hypothetical scenarios, we calculated the economic parameters when using biogas as an alternative energy to serve the cooking needs of households. When not using biogas, each household has to pay for cooking energy monthly including gas and coal costs. The installation of biogas digester helps households save on energy costs; instead, the cost of digester construction is calculated and divided equally among households in the cluster.

5.4.2.2 Biogas digester size and biogas pipeline

The size of the biogas digester was referenced from the biogas digester construction service provider in Vietnam. Biogas digesters built with composite materials are the most popular ones suitable for household-scale livestock farms in Vietnam. Currently in Vietnam there are three common sizes of biogas digesters including: composite biogas digester with size of 4 cubic meters (internal diameter of 1.9m), widely used in small-scale livestock households with about 1-10 heads of pig; composite biogas digester with size of 7 cubic meters (inner diameter 2.25m), suitable for the average livestock family, raising about 10-20 pigs; and composite biogas digester with size of 9 cubic meters (inner diameter 2.45m), this size composite biogas digester is mainly used for mainly farming households, however, the size of the tunnel is large, so it is difficult to move, the cost is high, and it takes a lot of underground excavation area (*Vietcomposite Building and Interior Co.,Ltd, 2019*). In this study, we have selected two sizes of biogas digester consists of medium size (7 cubic meters biogas digester) and large size (9 cubic meter biogas digester) for two clusters of households.

In addition, biogas pipeline is also a factor worth considering when installing biogas digesters. In this study, biogas pipeline installation refers to the pipe connection from the pigsty to the biogas digester and from the biogas digester to biogas consumption points. Biogas production takes place in biodegradation digester and gas storage in a gas digester. The gas must then be transported to its point of application to be used for operations such as cooking, heating or generating electricity. These connections are an important part of the construction of the biogas digester. It is necessary to pay attention to every details and quality to avoid leading to biogas problems arising from the pipeline such as low pressure, gas leaks and the presence of water in the pipeline. The PVC pipe 150 with a diameter of 15cm is used to connect from the pigsty to the biogas digester. This is a type of industrial pipe that transports liquids, chemicals, gas, discharge pipes, submersible pipes for fire fighting systems, etc. From the biogas digester to biogas consumption points, the gas pipeline used for connection is provided by the same biogas service provider. High-pressure gas line is made from high quality vulcanized natural rubber, with high flexibility and durability due to its 3-layer structure. The gas pipe does not bend, twist or crack during use in bends. The pipeline of a biogas system can run for hundreds of meters and still maintain the right pressure for cooking, however, short-distance connections are higher recommended. Selection of the shortest possible route from the biogas digester to the point of application could help limit the loss of pressure along the way (*Kenya Projects Organization, 2022*). Reducing the distance and number of bends will also significantly decrease the overall cost by using fewer resources.

5.4.2.3 Biogas production amount estimation

This study assumes that after building biogas digesters, households switch to using biogas for daily cooking as an alternative to liquefied petroleum gas (LPG) and coal. The amount of biogas produced was calculated according to the reference formula from IRENA explained in section 5.3.2 based on the two family cluster models proposed above.

The calculated related factors were shown in Table 5-3. For the model of household cluster M1, the family cluster already included 4 households, each household raising 4 pigs, so the total number of pigs was 16 heads. The relevant factors included: the feedstock volume of 0.24 m^3, retention time of 29 days, initial concentration of volatile solids of 66.67 kg/m^3, and mean yield factor of 7.15. The results showed that the average amount of biogas produced for household cluster M1 was 3.34 m^3 per day. Model of cluster M2, similarly, this cluster of families already included 8 households, each with 4 pigs, and the total number of pigs was 32 pigs. The related factors included: the feedstock volume of 0.48 m^3, retention time of 19 days, initial concentration of volatile solids of 66.67 kg/m^3, and mean yield factor of 9.37. The average amount of biogas production for cluster M2 was 5.62 m^3 per day, more than that of cluster M1.

Table 5-3 Biogas production for each model

Model	**M1**	**M2**
Number of pigs (head)	16	32
Biogas digester volume (m^3)	7	9
Total feedstock volume (m^3)	0.24	0.48
Retention time (days)	29	19
Initial concentration of volatile solids (kg/ m^3)	66.67	66.67
Yield factor	7.15	9.37
Biogas production (m^3)	**3.34**	**5.62**

Because the number of pigs raised in the survey area was quite small, the amount of biogas production obtained has not taken advantage of the maximum capacity of the biogas digester to provide alternative energy for all of households. It is proposed that the farmers could combine other wastes as inputs for the biogas digesters. Herein, food waste has been selected as the combined waste. Our survey in Da Nang city has shown that currently, households with a small number of pigs still continued to collect food waste to feed the raising pigs. Households collect leftovers from acquaintances or even their own families using paint bins. The survey results showed that on average, each family collected 1.58 paint bins of leftover food every day. The unit of paint bin has been estimated to be equivalent to 19 kg of food waste (*Kato et al., 2014*).

Assume that the household cluster M1 takes full advantage of the energy production capacity of the biogas digester with a volume of 7 cubic meters, and the retention time reaches the shortest value at 6 days. With a preset temperature between 25-27 degrees Celsius, the yield factor value is 13.59. With daily biogas production G at 7 m^3, the initial concentration of volatile solids in the slurry was calculated to reach a value of 73.58 kg/m^3. This means that the total amount of initial waste put into the biogas digester needs to reach 73.58 kg/m^3. With the existing livestock waste amount of 66.67/m^3 kg per day, the additional volatile solid of food waste required is 6.91 kg/m^3 per day, equivalent to 86.38 kg of food waste. In other words, each household will need to share 21.6 kg of food waste collected to replenish the biogas digester. The same calculation is applied for model M2, with biogas digester volume at 9 m^3 for 8 households, retention time of 6 days and yield factor of 13.59. The amount of waste required for the daily input of the biogas digester is 73.58 kg/m^3 and the additional volatile solid of food waste is 6.91 kg/m^3 per day, equivalent to 86.38 kg of food waste. However, in model M2, each farmer only needs to share 10.8 kg of leftover food to make the most of the biogas capacity.

5.4.2.4 Energy demand and biogas supply

There was a difference between the use of fossil fuels at the two survey sites. According to the survey we conducted in Quang Tri Province, when asked about the amount of fossil fuels used for daily cooking, the respondents gave the answer about the amount of LPG and firewood they used. Other fuels such as coal and other were not selected. This difference is due to the different urbanization of these two places. Danang City is one of the most growing cities in Vietnam. Therefore, the living needs of people here are higher than in rural areas in Quang Tri Province. The use of coal or firewood helps people living in Da Nang City to save time and effort. Meanwhile, firewood is a free material in Quang Tri Province. The farmers can cut firewood in the forest near the residential area to use without extra cost. Because of the lower standard of living, the cost-of-living savings are also worthy of attention by the farmers living in Quang Tri Province.

Energy demand has been converted from kg to MJ for consistency. With the average LPG demand: 5.2 kg/household/month, it has been divided equally by 30 days to become 0.17 kg per day and converted to 8.88 MJ/household/day. The average coal demand was 5 kg/household/month corresponding to 0,167 kg/day and converted to 3.98 MJ/household/day. In total, the average energy demand for cooking was 12.9 MJ/household/day. Biogas energy supply has also been converted from m3 to MJ. For model M1, each household obtained 1.75 m^3 of biogas per day equivalent to 40.25 MJ/household/day. In term of model M2, the obtained biogas energy was 1.13 m^3/household/day converting to 25.76 MJ/household/day. It could be seen that the amount of biogas could be used to replace LPG and firewood completely for the daily cooking needs of the household.

5.4.2.5 Energy cost saving estimation

a. Monthly cost to pay for fuels without using biogas digesters

According to a study by the Institute of Energy, Ministry of Industry and Trade of Vietnam 2018, gas and coal were the main fuels used by households for cooking. The study showed that the average demand for gas was about 5.2 kg/ household/ month, and the amount of coal use in urban areas was about 5 kg/ household/ month. With the gas consumption of each household reaching 5.2 kg per month, or 0.173 kg per day, this value has been converted to the equivalent of 7.89 MJ/ day. Similar to coal consumption, each household used 4.5 MJ of coal per day. Total energy consumption has been calculated to be 12.39 MJ per household per day.

As of July 2022, retail gas prices were 448800 VND/ 12kg bottle (*Gas Petrolimex Corporation, 2022*). With a monthly gas consumption of 5.2 kg (equivalent to 2.84 m^3 of LPG), the average household has to pay 194480 VND per month. Coal retail prices were collected at the coal retailers in Da Nang city. The price of coal per sack is 300000 VND for 30 kg. Therefore, each household in the survey area was estimated to have paid 50000 VND per month for the purchase of coal as fuel. In the absence of a biogas digester, the monthly cost of energy for combustion is estimated at 244480 VND per household.

If reaching the most capacity of the biogas digester, each family in cluster model M1 has 1.75 m^3 (equivalent to 36.575 MJ/ day) of biogas and each family in cluster M2 has 1.125 m^3 (equivalent to 23.408 MJ/ day) to use as a daily substitute for cooking. It can be seen that the amount of biogas collected by each household can be used to replace other fossil fuels completely. This helps households save monthly costs in purchasing LPG gas and coal for daily cooking.

b. Costs for installing biogas digesters

The installing cost of the biogas digester was collected from the service distributor. This cost includes components such as the price of the composite digester, cooking stove, biogas pipeline, some accompanying accessories (locks, gauges, screws, etc), installation and transportation costs. *Table 5-4* showed the details of the costs to be paid when building each type of digester.

Table 5-4 The price of installing the biogas digester

Type of biogas digester	Elements	Element cost (thousand VND)	Total cost (thousand VND)
7 m^3 biogas digester	*Biogas digester*	*7000*	19500
	Cooking stove	*1040*	
	Biogas pipeline	*440*	
	Accompanying accessories	170	
	Installation cost	850	
	Transportation cost	10000	
9 m^3 biogas digester	*Biogas digester*	*8000*	23300
	Cooking stove	*2080*	
	Biogas pipeline	*2200*	
	Accompanying accessories	170	
	Installation cost	850	
	Transportation cost	10000	

The price difference of the two types of biogas digesters comes from three factors: the volume of the digesters, the cooking stove and the biogas pipeline due to the difference in distance. The price of each cooking stove was 260 thousand VND. For model M1, the total price for cooking stove for 4 households was 1040 thousand VND. Similarly, it costs 2080 thousand VND for the M2 model with 8 households. With the cost of biogas pipeline is 110 thousand VND for a length of 40 meters, the total price for the pipeline for model M1 was 440 thousand VND for 4 households. For model M2, because of the longer distance up to 100 meters, the price of the pipeline was calculated at 275 thousand VND per household and 2200 thousand VND for a total of 8 households.

c. Cost saving estimation

The results showed that if choosing the household cluster model M1, each household had to pay for the installing cost of the biogas digester at 4875 thousand VND (equivalent to 200.08 USD), while if choosing the M2 model, each household had to pay 2912.5 thousand VND (equivalent to 119.54 USD) for the construction cost.

Composite biogas digester is currently a popular type of composting digester in the Vietnamese livestock market with a lifespan of up to 20 years. The payback period and benefits arising from the biogas digester during its life are calculated to consider its economic benefits. The use of biogas digesters in family clusters has helped the farmers reduce their economic burden when they had to spend a small amount of capital and shorten the payback time. For model M1, payback time and the net benefits for 20 years were calculated as follows. For simplicity, time discounting was not considered.

Payback time: $P_{M_1} = \frac{4875000}{244480 \times 12} = 1.66\ (year)$

Net benefits:

$$B_{M_1} = (20 - 1.66) \times (244480 \times 12) = 53\ 805\ 158\ (VND)$$

The model of M2 was similarly calculated:

Payback time: $P_{M_2} = \frac{2912500}{244480 \times 12} = 0.99\ (year)$

Net benefits:

$$B_{M_2} = (20 - 0.99) \times (244480 \times 12) = 55\ 770\ 777\ (VND)$$

The payback time is shorter for M2 than for M1. It takes 1.66 years from each household in cluster M1 for payback time and additional benefits they get back after that is 53 805 158 VND (equivalent to 2208.30 USD). For each household in cluster M2, with only 0.99 years, the farmers can get the additional benefits up to 55 770 777 VND (equivalent to 2288.97 USD).

5.5 Policy recommendation

The changes in waste treatment, specifically food waste and manure waste, to use as a potential source for the production of sustainable fuels would complete the full cycle of this waste stream sustainably and promote the circular economy in the form of open-loop recycling. Open-loop energy recycling represents to a thermally lead process where the energy from the thermochemical conversion process can be recovered and can be stored or used in other applications, whether it is on the recycling site or elsewhere. The circular economy concept is defined as a complementary part of sustainable development and touches on a number of the United Nations SDGs (*Farrell et al., 2020*).

The concept of a centralized anaerobic digester that receives and treats biological waste is well understood and the potential financial benefits of this approach can be enhanced by economies of scale. However, it depends on the availability of farmland for compost application and the willingness of farmers to engage in reuse. Our survey found that most farmers in this area do not intend to build biogas digesters because the number of pigs is not large. There were 88.9% of respondents answering that they would not build a biogas digester in the future, the remaining 11.1% would consider installation. When the additional question was asked about their willingness to build a biogas digester if there is a subsidy from the government, the number of respondents who would build one was up to 25.93%. Although the change was not significant, it is undeniable that government subsidies had an impact on the willingness of farmers here. It is clear that farmers are still entangled in economic barriers in making the decision to build biogas digesters. The introduction of a household cluster approach will make it easier for local authorities to encourage people to use this technology. In addition, the government can also reduce the inevitable waste in terms of the area to build the biogas digesters as well as the amount of biogas production.

In addition, building a team of professional engineers to check the operation of the biogas digester as well as assist in repairing the cellar when having problems is worth considering. This will help farmers to use the biogas digester effectively, besides they will be self-conscious in seriously using the cellar together.

5.6 Summary of findings

Co-digestion of food waste in combination with livestock waste has been shown to provide an effective method to manage both of these biological wastes. The utilisation of waste combination in the production of sustainable biogas fuel will aid in the reusing of problematic food waste by adding value and other techno-economic potential routes for application in the energy sector. This study concluded that with this combined approach, the farmers could obtain the maximum amount of biogas produced by the biogas digester in accordance with the size of the biogas digester. It could meet people's daily cooking needs, solving significant livelihood problems in poor and developing countries like Vietnam when economic factor is a big barrier. The cluster-of-household approach also eases the financial burden, making it easier for farmers to access this technology when the payback period is approximately one year. This has the potential to be more sustainable and efficient than what is currently approach.

Chapter 6 CONCLUSIONS AND FURTHER STUDIES

6.1 Conclusions

In this section, we summarized the findings presented in the previous chapters.

6.1.1 Chapter 1 and 2

An introduction to the general background and each selected research site is presented in Chapter 1. This section also briefly introduces biogas digesters, its benefits, and sets out the objectives for this study.

In Chapter 2, we briefly described the results from previous studies that were relevant to our study. Since then, we have come up with research directions to clarify the outstanding issues.

6.1.2 Chapter 3

Chapter 3 clarified the two previously set goals, including:

(i) The amount of biogas produced and examine if the biogas digesters are being used efficiently.

(ii) The reduction of GHGs emissions due to the use of a biogas digester using relevant factors appropriate to the study area.

For the objective (i), this study estimated that the actual amount of biogas production obtained was 5.52 m^3 per household per day. However, only 2% of households using biogas digesters achieved biogas production approximate to the biogas digester volume they built. Most households did not get the maximum amount of biogas. Therefore, the economic policies that we propose in this study need to be considered for implementation.

To answer the objective (ii), we proved that using the biogas digesters could help to reduce the total GHGs emissions by 16.01 tons CO_2e/year per household, less than one quarter without using the biogas digesters. We applied the actual amount of volatile solids and pig age values to calculate in the survey area and obtained the results that the amount of GHGs emitted from each livestock household in Quang Tri Province has been reduced by 29.46 tCO_2e per year when using biogas digesters.

6.1.3 Chapter 4

In Chapter 4, we set the following objectives:

(iii) Determining the factors of farmers' decision to install biogas digesters

(iv) Evaluating the impacts of household income to the configuration of biogas digesters

(v) Estimating amounts of energy cost saving

(vi) Analyzing the factors of farmers' satisfaction with a biogas digester

(vii) Proposing recommendations to enhance the adoption and development of household-scale biogas technology as a sustainable energy option in developing countries.

In term of objective (iii), we defined that the number of pigs and concerns about environmental issues are the two main factors influencing farmers' decisions to build biogas digesters in surveyed area. The government should take these two factors into account for greater scrutiny for future plans of biogas digesters construction. Besides, there were two factors influencing the farmers' decision to build a biogas digester including the number of pigs they raise and whether they care about the environment.

We estimated that biogas technology could help each household save 330.64 thousand VND (14.22 USD) per month. The composite biogas digesters resulted in greater cost savings with 298.85 thousand VND (12.94 USD) per month than the cement biogas digesters with 351.83 thousand VND (15.24 USD). In addition, a composite digester costs less to construct than a cement digester and provides greater economic benefits per month.

The analysis was done to answer the objective (vi). Most of the surveyed farmers who use biogas digesters are satisfied with them. The improved health issue and the amount of biogas produced are the most important factors affecting the farmers' reported satisfaction with biogas digesters. In addition, some plans and implement sound policies were defining to support the work of people who use the technology following objective (vii).

6.1.4 Chapter 5

In Chapter 5, we focus on researching the following objective:

(viii) Estimating the capacity on the potential of biogas production from food waste combined with locally produced livestock waste. An evaluation on the economic implication of a biogas digester built from composite material for household clusters to ascertain its cost effectiveness had been done.

From the results of this study, it could be seen that co-digestion of food waste in combination with livestock waste has been shown to provide an effective method to treat both of these biological wastes. The cluster-of-household approach also eases the financial burden, making it easier for farmers to access this technology when the payback period is approximately one year.

6.2 Further studies

The proposed biogas in community usage model needs to be put to the test to check its feasibility. The inclusion of the model in multiple household cluster sizes should also be considered. Besides, it is necessary to pay attention to other biodegradable waste sources that can be used as input sources for biogas digesters.

One of our limitations is the selection of a probability sampling method using cluster random sampling techniques to create a sample, which might not work well if the unit members are not homogeneous. In future research, we suggest considering non-probabilistic sampling methods. In principle, every respondent has an equal chance of being included in the sample. For more in-depth research on the problem of poverty reduction, it is necessary to consider the selection of a sample of low-income subjects in the study area.

Although biogas digesters offer many benefits, there are associated problems that have not been clarified. Biogas wastewater presents a potential danger to human and animal health when released into the environment and used to fertilize plants (*Luu et al., 2014*). To date, most research has focused on the advantages of using biogas digesters and ignored the disadvantages, such as their effects on the health of users. We suggest that more in-depth studies be conducted on the drawbacks of using biogas digesters to explore and identify the most suitable solutions. Finally, the scope of study should be expanded to ensure more accurate results.

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APPENDIX 1: SURVEY QUESTIONNAIRE IN QUANG TRI PROVINCE, VIETNAM

QUESTIONNAIRE FOR HOUSEHOLDS WITH BIOGAS DIGESTERS

No.

Date of survey:

Q1. Does your family have livestock?

☐ Yes

☐ No

Q2. How much is the area for breeding?

( )

Q3. What kind of animal does your family raise? Please specify the number of animals you raise.

☐ Pig ……………….

☐ Cattle (Cow, Buffalo) ……………..

☐ Poultry (Chicken, Duck) ………………...

☐ Other ( ) …………………

Q4. Does your family have other business activities (done in this location)? Please specify your other job if you have.

☐ Yes………………..….

☐ No

Q5. Do you apply biogas digester for livestock waste treatment?

☐ Yes………………..….

☐ No

If you use the biogas technology, please answer the following questions:

Q6. What reason did you choose using biogas digester?

- ☐ Save money
- ☐ Due to benefits received when using it
- ☐ Improving the kitchen
- ☐ Other (   )

Q7. Who recommend you to choose using biogas technology?

- ☐ Family members
- ☐ Relatives
- ☐ Neighbors
- ☐ The service provider
- ☐ Local government
- ☐ Media (TV, internet…)
- ☐ Newspaper
- ☐ Other (   )

Q8. How long did you use biogas digester?

(   )

I. Technology:

Q9. What kind of biogas digester do you use? (material)

- ☐ Cement
- ☐ Brick
- ☐ Composite
- ☐ Other (   )

Q10. What is the size of the biogas digester?

(m^3)

Q11. Did you have any problems during operating process. Please describe it if you had.

☐ Yes …………………………………………………………………..

☐ No

II. Economy:

Q12. What energy do you use for cooking? Please answer the amount of money you spend monthly for that energy.

Energy	Purposes (for cooking, feeding, making products…)	Amount of money
Coal		
Wood		
Gas		
Other ( )		

Q13. After using biogas digester, how much do you totally pay for using other energy?

( )

Q14. Before using biogas digester, how much do you totally pay for using other energy?

( )

Q15. How much did you pay for biogas installation?

( )

Q16. Did you pay more money for operation or maintenance? Please answer the times and the amount of money if you have to pay.

☐ Yes………………………….

☐ No

Q17. What is the main use of biogas in your house?

☐ Cooking

☐ Heating

☐ Agriculture

☐ Other (   )

Q18. What kind of benefits do you avail due to biogas?

☐ Save energy

☐ Save money

☐ Get more income

☐ Health improvement

☐ Other (   )

III. Environment:

Q19. Did you concern about the environmental issues before you decided to install biogas digester?

☐ Yes

☐ No

Q20. How do you often do for treating the livestock waste of animals?

☐ Dumping it into the empty yard/ landfill/ lake/ river…

☐ Burying it underground

☐ Making fertilizer

☐ Using livestock waste treatment technology (ex. Biogas digester)

☐ Other (   )

Q21. After installing biogas digester, did you change the way of treating the livestock waste? Please describe if you had.

☐ Yes ……………………………………………………….

☐ No

IV. Society:

Q22. Do you think that you are getting health benefits due to use of biogas compared to previously used energy sources?

☐ Yes

☐ No

Q23. Do you get any complaints from neighbors when your family uses biogas reactors? Please describe it.

☐ Yes ……………………………………………………….

☐ No

Q24. What is the impact on the living standard of your house after the installment of the biogas plant?

☐ Increased (subsidy,…)

☐ Decreased

☐ No change

Q25. How do you rate your own satisfaction about the following thing?	**5** **Very much**	**4** **Much**	**3** **Neutral**	**2** **Rather not**	**1** **Not at all**
Process using biogas digester	5	4	3	2	1
Results obtained after using the biogas reactor	5	4	3	2	1

Saving money	5	4	3	2	1
Supports from local authorities, government	5	4	3	2	1

Please tell us your basic information.	
Name	
Address	
Gender / Age	□ Male □ Female Age : ( )
Family Composition **(Please select all people who are living in this residence with you.)**	**Total number of people : ( ) people** Under 18 years old : ( ) people / Over 65 years old : ( ) people □ Grandfather □ Grandmother □ Father □ Mother □ Spouse □ Child □ Grandchild □ Brother □ Sister □ Nephew □ Niece □ Cousin
Occupation : ( )	1. Civil servant 2. Part time Job 3. Full-time Job 4. Agriculture 5. Self-employed 6. Student 7. No job 8. Other ( )
Family Income	Total ( ) VND / Year ( ) VND / Month

QUESTIONNAIRE FOR HOUSEHOLDS WITHOUT BIOGAS DIGESTERS

No.

Date of survey:

Q1. Does your family have livestock?

☐ Yes

☐ No

Q2. How much is the area for breeding?

( )

Q3. What kind of animal does your family raise? Please specify the number of animals you raise.

☐ Pig ……………….

☐ Cattle (Cow, Buffalo) ……………..

☐ Poultry (Chicken, Duck) ………………...

☐ Other ( ) …………………

Q4. Does your family have other business activities (done in this location)? Please specify your other job if you have.

☐ Yes……………….….

☐ No

Q5. Do you apply biogas digester for livestock waste treatment?

☐ Yes……………….….

☐ No

If you don't use the biogas technology, please answer the following questions:

Q6. What energy do you use for cooking? Please answer the amount of money you spend monthly for that energy.

Energy	**Purposes (for cooking, feeding, making products…)**	**Amount of money**
Coal		
Wood		
Gas		
Other ( )		

Q7. How do you often do for treating the livestock waste of animals?

☐ Dumping it into the empty yard/ landfill/ lake/ river…

☐ Burying it underground

☐ Making fertilizer

☐ Using livestock waste treatment technology (ex. Biogas digester)

☐ Other (   )

Q8. Why don't you use biogas digester?

☐ Too expensive

☐ Not efficiency

☐ Don't know about biogas digester

☐ Small house area

Q9. Did you use biogas digester before?

☐ Yes

☐ No

If had, please tell the reason why you quit to use biogas digester?

………………………………………………………………………..

Please tell us your basic information.	
Name	
Address	
Gender / Age	☐ Male ☐ Female Age : ( )
Family Composition **(Please select all people who are living in this residence with you.)**	**Total number of people : ( ) people** Under 18 years old : ( ) people / Over 65 years old : ( ) people ☐ Grandfather ☐ Grandmother ☐ Father ☐ Mother ☐ Spouse ☐ Child ☐ Grandchild ☐ Brother ☐ Sister ☐ Nephew ☐ Niece ☐ Cousin
Occupation : ( )	1. Civil servant 2. Part time Job 3. Full-time Job 4. Agriculture 5. Self-employed 6. Student 7. No job 8. Other ( )
Family Income	Total ( ) VND / Year ( ) VND / Month

APPENDIX 2: SURVEY QUESTIONNAIRE IN DANANG CITY, VIETNAM

Name:………………………………………………………………………………

Address:……………………………………………………………………………

Q1. Is the farm raising pigs?

☐ Yes

The number of pigs you raising?

When did you start pig raising in this place?

☐ No

Did you raise pigs before? If yes: When and why did you quit raising pigs?

Q2. Is the farm using food residue for feeding pigs?

☐ Yes

The total amount of food used per day?

☐ No

Did you use food residue for feeding before?

If yes: When and why did you quit using food residue? What are you feeding for pigs now?

Q3. Do you know about biogas digester?

☐ Yes

☐ No

Q4. Do you use biogas digester for livestock waste treatment?

☐ Yes

☐ No

I. If the answer is "Yes"

Q5. What reason did you choose using biogas digester?

☐ Save money

☐ Due to benefits received when using it

☐ Improving the kitchen

☐ Other (……………………)

Q6. Who recommend you to choose using biogas technology?

☐ Family members

☐ Relatives

☐ Neighbors

☐ The service provider

☐ Local government

☐ Media (TV, internet…)

☐ Newspaper

☐ Other (……………………)

Q7. How long did you use biogas digester?

(………………………………………)

1. **Technology:**

Q8. What kind of biogas digester do you use? (material)

☐ Cement

☐ Brick

☐ Composite

☐ Other (………………………………………)

Q9. What is the size of the biogas digester?

(……………………………………….m^3)

Q10. Did you have any problems during operating process. Please describe it if you had.

☐ Yes ……………………………………………………………..

☐ No

2. **Economy:**

Q11. What energy do you use for cooking? Please answer the amount of money you spend monthly for that energy.

Energy	**Purposes (for cooking, feeding, making products…)**	**Amount of money**
Coal		
Wood		
Gas		
Other (………………)		

Q12. After using biogas digester, how much do you totally pay for using other energy?

(………………………………………)

Q13. Before using biogas digester, how much do you totally pay for using other energy?

(………………………………………)

Q14. How much did you pay for biogas installation?

(………………………………………)

Q15. Did you pay more money for operation or maintenance? Please answer the times and the amount of money if you have to pay.

☐ Yes………………………….

☐ No

Q16. What is the main use of biogas in your house?

☐ Cooking

☐ Heating

☐ Agriculture

☐ Other (………………………………………)

Q17. What kind of benefits do you avail due to biogas?

☐ Save energy

☐ Save money

☐ Get more income

☐ Health improvement

☐ Other (………………………………………)

3. Environment:

Q18. Did you concern about the environmental issues before you decided to install biogas digester?

☐ Yes

☐ No

Q19. How do you often do for treating the livestock waste of animals?

☐ Dumping it into the empty yard/ landfill/ lake/ river…

☐ Burying it underground

☐ Making fertilizer

☐ Using livestock waste treatment technology (ex. Biogas digester)

☐ Other (………………………………………)

Q20. After installing biogas digester, did you change the way of treating the livestock waste? Please describe if you had.

☐ Yes ……………………………………………………….

☐ No

4. Society:

Q21. Do you think that you are getting health benefits due to use of biogas compared to previously used energy sources?

☐ Yes

☐ No

Q22. Do you get any complaints from neighbors when your family uses biogas reactors? Please describe it.

☐ Yes ……………………………………………………….

☐ No

Q23. What is the impact on the living standard of your house after the installment of the biogas plant?

☐ Increased (subsidy, …)

☐ Decreased

☐ No change

Q24. How do you rate your own satisfaction about the following thing?	5 Very much	4 Much	3 Neutral	2 Rather not	1 Not at all
Process using biogas digester	5	4	3	2	1
Results obtained after using the biogas reactor	5	4	3	2	1
Saving money	5	4	3	2	1
Supports from local authorities,	5	4	3	2	1

government					

II. If the answer is "No"

Q25. How are you currently using to treat livestock waste?

6.1 Dumping it into the empty yard/ landfill/ lake/ river…

6.1 Burying it underground

6.1 Making fertilizer

6.1 Using livestock waste treatment technology (ex. Biogas digester)

6.1 Other (………………………………………)

Q26. In the future, do you intend to change the current way of treating livestock waste?

☐ Yes …………………………………………………

☐ No

Q27. In your opinion, does the biogas digester bring benefits to the user?

A. Yes

☐ Saving energy

☐ Saving money

☐ Saving time

☐ Reducing environmental pollution

☐ Protecting your health

☐ Other (………………………………………)

B. No

In your opinion, is using a biogas digester harmful or not, specifying the disadvantages if any (health effects, worries about costs, ...)?

Q28. Do you intend to build a biogas digester in the future?

☐ Yes

☐ No

Q29. If you received a subsidy, are you willing to pay for building a biogas digester??

☐ Yes.

How many percentage of subsidy is good for you?

☐ No

APPENDIX 3: CALCULATING PROCEDURE GREENHOUSE GAS EMISSIONS

Table A3-1: Total GHGs emissions from households without biogas digesters

Household	**Number of pigs (head)**	**VS (kg/day)**	**From manure pits**		**From using gas**		**From using firewood**		**Total GHGs**
			CH_4 emission (tCO_2e/year)	N_2O emission (tCO_2e/year)	CO_2 emission (tCO_2e/year)	CH_4 emission (tCO_2e/year)	CO_2 emission (tCO_2e/year)	CH_4 emission (tCO_2e/year)	
1	50	0.27	17.42	0.26	0.13	0.000002	0	0	17.81
		0.3	19.36	0.29	0.13	0.000002	0	0	19.78
		1.27	81.96	1.22	0.13	0.000002	0	0	83.31
2	20	0.27	6.97	0.10	0.13	0.000002	7.48	0.0020	14.69
		0.3	7.74	0.12	0.13	0.000002	7.48	0.0020	15.47
		1.27	32.78	0.49	0.13	0.000002	7.48	0.0020	40.88
3	50	0.27	20.91	0.08	0.21	0.000003	0	0	21.43
		0.3	23.23	0.52	0.21	0.000003	0	0	23.79
		1.27	98.35	0.52	0.21	0.000003	0	0	100.03
4	20	0.27	6.97	0.26	0.14	0.000002	7.48	0.0020	14.70

		0.3	7.74	0.16	0.14	0.000002	7.48	0.0020	15.48
		1.27	32.78	0.17	0.14	0.000002	7.48	0.0020	40.89
5	18	0.27	6.27	0.06	0	0	24.69	0.0066	31.06
		0.3	6.97	0.07	0	0	24.69	0.0066	31.77
		1.27	29.51	0.10	0	0	24.69	0.0066	54.64
6	20	0.27	6.97	0.19	0.11	0.000002	7.48	0.0020	14.67
		0.3	7.74	0.21	0.11	0.000002	7.48	0.0020	15.45
		1.27	32.78	0.08	0.11	0.000002	7.48	0.0020	40.86
7	15	0.27	5.23	0.10	0.14	0.000002	14.96	0.0040	20.41
		0.3	5.81	0.08	0.14	0.000002	14.96	0.0040	21.00
		1.27	24.59	0.21	0.14	0.000002	14.96	0.0040	40.06
8	100	0.27	34.85	0.16	0	0	4.99	0.0013	40.36
		0.3	38.72	0.21	0	0	4.99	0.0013	44.29
		1.27	163.92	0.16	0	0	4.99	0.0013	171.35

9	100	0.27	34.85	0.10	0.43	0.000007	0	0	35.80
		0.3	38.72	0.07	0.43	0.000007	0	0	39.73
		1.27	163.92	0.36	0.43	0.000007	0	0	166.79
10	50	0.27	17.42	0.10	0.86	0.000014	7.48	0.0020	26.03
		0.3	19.36	0.00	0.86	0.000014	7.48	0.0020	27.99
		1.27	81.96	0.41	0.86	0.000014	7.48	0.0020	91.52
11	30	0.27	10.45	0.10	0.14	0.000002	7.48	0.0020	18.23
		0.3	11.62	0.31	0.14	0.000002	7.48	0.0020	19.41
		1.27	49.18	0.08	0.14	0.000002	7.48	0.0020	57.53
12	33	0.27	11.50	0.10	0.11	0.000002	12.47	0.0033	24.25
		0.3	12.78	0.10	0.11	0.000002	12.47	0.0033	25.55
		1.27	54.09	0.08	0.11	0.000002	12.47	0.0033	67.48
13	12	0.27	4.18	0.05	0.14	0.000002	7.48	0.0020	11.87
		0.3	4.65	0.05	0.14	0.000002	7.48	0.0020	12.34

		1.27	19.67	0.13	0.14	0.000002	7.48	0.0020	27.59
14	14	0.27	4.88	0.16	0.14	0.000002	7.48	0.0020	12.57
		0.3	5.42	0.21	0.14	0.000002	7.48	0.0020	13.12
		1.27	22.95	0.08	0.14	0.000002	7.48	0.0020	30.91
15	20	0.27	6.97	0.05	0.14	0.000002	0	0	7.21
		0.3	7.74	0.08	0.14	0.000002	0	0	8.00
		1.27	32.78	0.16	0.14	0.000002	0	0	33.41
16	36	0.27	12.55	0.10	0.18	0.000003	12.47	0.0033	25.39
		0.3	13.94	0.26	0.18	0.000003	12.47	0.0033	26.80
		1.27	59.01	0.10	0.18	0.000003	12.47	0.0033	72.54
17	40	0.27	13.94	0.10	0.21	0.000003	7.48	0.0020	21.84
		0.3	15.49	0.05	0.21	0.000003	7.48	0.0020	23.41
		1.27	65.57	0.26	0.21	0.000003	7.48	0.0020	74.24
18	15	0.27	5.23	0.10	0	0	7.48	0.0020	12.79

		0.3	5.81	0.31	0	0	7.48	0.0020	13.38
		1.27	24.59	0.10	0	0	7.48	0.0020	32.44
19	20	0.27	6.97	0.09	0.11	0.000002	0	0	7.18
		0.3	7.74	0.10	0.11	0.000002	0	0	7.97
		1.27	32.78	0.08	0.11	0.000002	0	0	33.38
20	15	0.27	5.23	0.52	0.21	0.000003	7.48	0.0020	13.00
		0.3	5.81	0.52	0.21	0.000003	7.48	0.0020	13.59
		1.27	24.59	0.26	0.21	0.000003	7.48	0.0020	32.65
21	40	0.27	13.94	0.16	0.21	0.000003	12.47	0.0033	26.83
		0.3	15.49	0.17	0.21	0.000003	12.47	0.0033	28.40
		1.27	65.57	0.06	0.21	0.000003	12.47	0.0033	79.23
22	30	0.27	10.45	0.07	0.21	0.000003	9.97	0.0027	20.79
		0.3	11.62	0.10	0.21	0.000003	9.97	0.0027	21.97
		1.27	49.18	0.19	0.21	0.000003	9.97	0.0027	60.09

23	40	0.27	13.94	0.21	0.14	0.000002	7.48	0.0020	21.77
		0.3	15.49	0.08	0.14	0.000002	7.48	0.0020	23.34
		1.27	65.57	0.10	0.14	0.000002	7.48	0.0020	74.17
24	30	0.27	10.45	0.08	0.14	0.000002	7.48	0.0020	18.23
		0.3	11.62	0.21	0.14	0.000002	7.48	0.0020	19.41
		1.27	49.18	0.16	0.14	0.000002	7.48	0.0020	57.53
25	20	0.27	6.97	0.21	0.21	0.000003	0	0	7.28
		0.3	7.74	0.16	0.21	0.000003	0	0	8.07
		1.27	32.78	0.10	0.21	0.000003	0	0	33.48
26	14	0.27	4.88	0.07	0.21	0.000003	7.48	0.0020	12.64
		0.3	5.42	0.36	0.21	0.000003	7.48	0.0020	13.19
		1.27	22.95	0.10	0.21	0.000003	7.48	0.0020	30.98
27	70	0.27	24.39	0.00	0.86	0.000014	0	0	25.62
		0.3	27.11	0.41	0.86	0.000014	0	0	28.37

		1.27	114.75	0.10	0.86	0.000014	0	0	117.31
28	20	0.27	6.97	0.31	0	0	18.70	0.0050	25.78
		0.3	7.74	0.08	0	0	18.70	0.0050	26.56
		1.27	32.78	0.10	0	0	18.70	0.0050	51.98
29	0	0.27	0.00	0.00	0.86	0.000014	7.48	0.0020	8.34
		0.3	0.00	0.00	0.86	0.000014	7.48	0.0020	8.34
		1.27	0.00	0.00	0.86	0.000014	7.48	0.0020	8.34
30	80	0.27	27.88	0.05	0.14	0.000002	18.70	0.0050	47.14
		0.3	30.98	0.13	0.14	0.000002	18.70	0.0050	50.28
		1.27	131.14	0.16	0.14	0.000002	18.70	0.0050	151.93
31	20	0.27	6.97	0.21	0	0	18.70	0.0050	25.78
		0.3	7.74	0.08	0	0	18.70	0.0050	26.56
		1.27	32.78	0.05	0	0	18.70	0.0050	51.98
32	60	0.27	20.91	0.08	0.14	0.000002	18.70	0.0050	40.07

		0.3	23.23	0.16	0.14	0.000002	18.70	0.0050	42.42
		1.27	98.35	0.10	0.14	0.000002	18.70	0.0050	118.66
33	15	0.27	5.23	0.26	0.14	.000002	18.70	0.0050	24.15
		0.3	5.81	0.10	0.14	.000002	18.70	0.0050	24.74
		1.27	24.59	0.10	0.14	.000002	18.70	0.0050	43.80
34	20	0.27	6.97	0.05	0.14	0.000002	7.48	0.0020	14.70
		0.3	7.74	0.26	0.14	0.000002	7.48	0.0020	15.48
		1.27	32.78	0.10	0.14	0.000002	7.48	0.0020	40.89
35	20	0.27	6.97	0.31	0.11	0.000002	7.48	0.0020	14.67
		0.3	7.74	0.10	0.11	0.000002	7.48	0.0020	15.45
		1.27	32.78	0.09	0.11	0.000002	7.48	0.0020	40.86
36	15	0.27	5.23	0.10	0.11	0.000002	7.48	0.0020	12.90
		0.3	5.81	0.08	0.11	0.000002	7.48	0.0020	13.49
		1.27	24.59	0.52	0.11	0.000002	7.48	0.0020	32.55

37	10	0.27	3.48	0.52	0.14	0.000002	7.48	0.0020	11.16
		0.3	3.87	0.26	0.14	0.000002	7.48	0.0020	11.55
		1.27	16.39	0.16	0.14	0.000002	7.48	0.0020	24.26
38	10	0.27	3.48	0.17	0.14	0.000002	0	0	3.68
		0.3	3.87	0.06	0.14	0.000002	0	0	4.07
		1.27	16.39	0.07	0.14	0.000002	0	0	16.78
39	25	0.27	8.71	0.10	0.14	0.000002	0	0	8.98
		0.3	9.68	0.19	0.14	0.000002	0	0	9.96
		1.27	40.98	0.21	0.14	0.000002	0	0	41.73
40	30	0.27	10.45	0.08	0	0	4.11	0.0011	14.72
		0.3	11.62	0.10	0	0	4.11	0.0011	15.90
		1.27	49.18	0.08	0	0	4.11	0.0011	54.02
41	40	0.27	13.94	0.21	0	0	9.97	0.0027	24.12
		0.3	15.49	0.16	0	0	9.97	0.0027	25.69

		1.27	65.57	0.21	0	0	9.97	0.0027	76.52
42	15	0.27	5.23	0.16	0.21	0.000003	0	0	5.52
		0.3	5.81	0.10	0.21	0.000003	0	0	6.10
		1.27	24.59	0.07	0.21	0.000003	0	0	25.16
43	10	0.27	3.48	0.36	0.18	0.000003	0	0	3.72
		0.3	3.87	0.10	0.18	0.000003	0	0	4.11
		1.27	16.39	0.00	0.18	0.000003	0	0	16.82
44	15	0.27	5.23	0.41	0.57	0.000009	24.94	0.0067	30.82
		0.3	5.81	0.10	0.57	0.000009	24.94	0.0067	31.41
		1.27	24.59	0.31	0.57	0.000009	24.94	0.0067	50.47
45	30	0.27	10.45	0.08	0.14	0.000002	0	0	10.75
		0.3	11.62	0.10	0.14	0.000002	0	0	11.93
		1.27	49.18	0.10	0.14	0.000002	0	0	50.05
46	20	0.27	6.97	0.08	0.14	0.000002	4.99	0.0013	12.20

		0.3	7.74	0.05	0.14	0.000002	4.99	0.0013	12.99
		1.27	32.78	0.05	0.14	0.000002	4.99	0.0013	38.40
47	50	0.27	17.42	0.13	0.21	0.000003	12.47	0.0033	30.37
		0.3	19.36	0.16	0.21	0.000003	12.47	0.0033	32.33
		1.27	81.96	0.21	0.21	0.000003	12.47	0.0033	95.86
48	20	0.27	6.97	0.08	0.21	0.000003	4.99	0.0013	12.27
		0.3	7.74	0.05	0.21	0.000003	4.99	0.0013	13.06
		1.27	32.78	0.08	0.21	0.000003	4.99	0.0013	38.47
49	20	0.27	6.97	0.16	0.14	0.000002	9.97	0.0027	17.19
		0.3	7.74	0.10	0.14	0.000002	9.97	0.0027	17.97
		1.27	32.78	0.26	0.14	0.000002	9.97	0.0027	43.38
50	10	0.27	3.48	0.10	0.14	0.000002	0	0	3.68
		0.3	3.87	0.10	0.14	0.000002	0	0	4.07
		1.27	16.39	0.05	0.14	0.000002	0	0	16.78

Table A3-2 Total GHGs emissions from households with biogas digesters

Household	Number of pigs (head)	VS (kg/day)	From biogas leakage		From using gas		From using firewood		Total GHGs
			CH_4 emission (tCO_2e/year)	CO_2 emission (tCO_2e/year)	CO_2 emission (tCO_2e/year)	CH_4 emission (tCO_2e/year)	CO_2 emission (tCO_2e/year)	CH_4 emission (tCO_2e/year)	
1	50	0.27	2.68	2.31	0	0	0	0	4.99
		0.3	2.98	2.57	0	0	0	0	5.55
		1.27	12.61	10.88	0	0	0	0	23.49
2	20	0.27	1.07	0.92	0	0	0	0	2.00
		0.3	1.19	1.03	0	0	0	0	2.22
		1.27	5.04	4.35	0	0	0	0	9.39
3	50	0.27	3.22	2.77	0	0	0	0	5.99
		0.3	3.57	3.08	0	0	0	0	6.66
		1.27	15.13	13.05	0	0	0	0	28.18
4	20	0.27	1.07	0.92	0.14	0	0	0	2.14

		0.3	1.19	1.03	0.14	0	0	0	2.36
		1.27	5.04	4.35	0.14	0	0	0	9.53
5	18	0.27	0.97	0.83	0	0	0	0	1.80
		0.3	1.07	0.92	0	0	0	0	2.00
		1.27	4.54	3.92	0	0	0	0	8.46
6	20	0.27	1.07	0.92	0	0	0	0	2.00
		0.3	1.19	1.03	0	0	0	0	2.22
		1.27	5.04	4.35	0	0	0	0	9.39
7	15	0.27	0.80	0.69	0	0	7.48	0.002	8.98
		0.3	0.89	0.77	0	0	7.48	0.002	9.15
		1.27	3.78	3.26	0	0	7.48	0.002	14.53
8	100	0.27	5.36	4.62	0	0	0	0	9.99
		0.3	5.96	5.14	0	0	0	0	11.10
		1.27	25.22	21.75	0	0	0	0	46.97

9	100	0.27	5.36	4.62	0.04	0	0	0	10.03
		0.3	5.96	5.14	0.04	0	0	0	11.14
		1.27	25.22	21.75	0.04	0	0	0	47.01
10	50	0.27	2.68	2.31	0	0	0	0	4.99
		0.3	2.98	2.57	0	0	0	0	5.55
		1.27	12.61	10.88	0	0	0	0	23.49
11	30	0.27	1.61	1.39	0	0	0	0	3.00
		0.3	1.79	1.54	0	0	0	0	3.33
		1.27	7.57	6.53	0	0	0	0	14.09
12	33	0.27	1.77	1.53	0	0	0	0	3.30
		0.3	1.97	1.70	0	0	0	0	3.66
		1.27	8.32	7.18	0	0	0	0	15.50
13	12	0.27	0.64	0.55	0	0	0	0	1.20
		0.3	0.71	0.62	0	0	0	0	1.33

		1.27	3.03	2.61	0	0	0	0	5.64
14	14	0.27	0.75	0.65	0.07	0	3.74	0.001	5.21
		0.3	0.83	0.72	0.07	0	3.74	0.001	5.36
		1.27	3.53	3.05	0.07	0	3.74	0.001	10.39
15	20	0.27	1.07	0.92	0	0	0	0	2.00
		0.3	1.19	1.03	0	0	0	0	2.22
		1.27	5.04	4.35	0	0	0	0	9.39
16	36	0.27	1.93	1.66	0	0	0	0	3.60
		0.3	2.14	1.85	0	0	0	0	3.99
		1.27	9.08	7.83	0	0	0	0	16.91
17	40	0.27	2.14	1.85	0.11	0	0	0	4.10
		0.3	2.38	2.06	0.11	0	0	0	4.55
		1.27	10.09	8.70	0.11	0	0	0	18.90
18	15	0.27	0.80	0.69	0	0	0	0	1.50

		0.3	0.89	0.77	0	0	0	0	1.66
		1.27	3.78	3.26	0	0	0	0	7.05
19	20	0.27	1.07	0.92	0	0	0	0	2.00
		0.3	1.19	1.03	0	0	0	0	2.22
		1.27	5.04	4.35	0	0	0	0	9.39
20	15	0.27	0.80	0.69	0	0	2.49	0.0007	3.99
		0.3	0.89	0.77	0	0	2.49	0.0007	4.16
		1.27	3.78	3.26	0	0	2.49	0.0007	9.54
21	40	0.27	2.14	1.85	0	0	4.99	0.0013	8.99
		0.3	2.38	2.06	0	0	4.99	0.0013	9.43
		1.27	10.09	8.70	0	0	4.99	0.0013	23.78
22	30	0.27	1.61	1.39	0	0	0	0	3.00
		0.3	1.79	1.54	0	0	0	0	3.33
		1.27	7.57	6.53	0	0	0	0	14.09

23	40	0.27	2.14	1.85	0.14	0	0	0	4.13
		0.3	2.38	2.06	0.14	0	0	0	4.58
		1.27	10.09	8.70	0.14	0	0	0	18.93
24	30	0.27	1.61	1.39	0	0	0	0	3.00
		0.3	1.79	1.54	0	0	0	0	3.33
		1.27	7.57	6.53	0	0	0	0	14.09
25	20	0.27	1.07	0.92	0	0	0	0	2.00
		0.3	1.19	1.03	0	0	0	0	2.22
		1.27	5.04	4.35	0	0	0	0	9.39
26	14	0.27	0.75	0.65	0.21	0	0	0	1.61
		0.3	0.83	0.72	0.21	0	0	0	1.76
		1.27	3.53	3.05	0.21	0	0	0	6.79
27	70	0.27	3.75	3.24	0	0	0	0	6.99
		0.3	4.17	3.60	0	0	0	0	7.77

		1.27	17.65	15.23	0	0	0	0	32.88
28	20	0.27	1.07	0.92	0	0	0	0	2.00
		0.3	1.19	1.03	0	0	0	0	2.22
		1.27	5.04	4.35	0	0	0	0	9.39
29	0	0.27	0.00	0.00	0	0	0	0	0.00
		0.3	0.00	0.00	0	0	0	0	0.00
		1.27	0.00	0.00	0	0	0	0	0.00
30	80	0.27	4.29	3.70	0.09	0	0	0	8.08
		0.3	4.77	4.11	0.09	0	0	0	8.97
		1.27	20.18	17.40	0.09	0	0	0	37.67
31	20	0.27	1.07	0.92	0.07	0	7.48	0.002	9.55
		0.3	1.19	1.03	0.07	0	7.48	0.002	9.77
		1.27	5.04	4.35	0.07	0	7.48	0.002	16.95
32	60	0.27	3.22	2.77	0	0	0	0	5.99

		0.3	3.57	3.08	0	0	0	0	6.66
		1.27	15.13	13.05	0	0	0	0	28.18
33	15	0.27	0.80	0.69	0.07	0	0	0	1.57
		0.3	0.89	0.77	0.07	0	0	0	1.73
		1.27	3.78	3.26	0.07	0	0	0	7.12
34	20	0.27	1.07	0.92	0.09	0	3.74	0.001	5.83
		0.3	1.19	1.03	0.09	0	3.74	0.001	6.05
		1.27	5.04	4.35	0.09	0	3.74	0.001	13.23
35	20	0.27	1.07	0.92	0	0	3.74	0.001	5.74
		0.3	1.19	1.03	0	0	3.74	0.001	5.96
		1.27	5.04	4.35	0	0	3.74	0.001	13.14
36	15	0.27	0.80	0.69	0	0	0	0	1.50
		0.3	0.89	0.77	0	0	0	0	1.66
		1.27	3.78	3.26	0	0	0	0	7.05

37	10	0.27	0.54	0.46	0.07	0	0	0	1.07
		0.3	0.60	0.51	0.07	0	0	0	1.18
		1.27	2.52	2.18	0.07	0	0	0	4.77
38	10	0.27	0.54	0.46	0	0	0	0	1.00
		0.3	0.60	0.51	0	0	0	0	1.11
		1.27	2.52	2.18	0	0	0	0	4.70
39	25	0.27	1.34	1.16	0	0	0	0	2.50
		0.3	1.49	1.28	0	0	0	0	2.77
		1.27	6.30	5.44	0	0	0	0	11.74
40	30	0.27	1.61	1.39	0	0	0	0	3.00
		0.3	1.79	1.54	0	0	0	0	3.33
		1.27	7.57	6.53	0	0	0	0	14.09
41	40	0.27	2.14	1.85	0	0	9.97	0.0027	13.97
		0.3	2.38	2.06	0	0	9.97	0.0027	14.41

		1.27	10.09	8.70	0	0	9.97	0.0027	28.76
42	15	0.27	0.80	0.69	0	0	0	0	1.50
		0.3	0.89	0.77	0	0	0	0	1.66
		1.27	3.78	3.26	0	0	0	0	7.05
43	10	0.27	0.54	0.46	0.07	0	0	0	1.07
		0.3	0.60	0.51	0.07	0	0	0	1.18
		1.27	2.52	2.18	0.07	0	0	0	4.77
44	15	0.27	0.80	0.69	0.57	0	0	0	2.07
		0.3	0.89	0.77	0.57	0	0	0	2.23
		1.27	3.78	3.26	0.57	0	0	0	7.62
45	30	0.27	1.61	1.39	0	0	14.96	0.004	17.96
		0.3	1.79	1.54	0	0	14.96	0.004	18.29
		1.27	7.57	6.53	0	0	14.96	0.004	29.06
46	20	0.27	1.07	0.92	0	0	0	0	2.00

		0.3	1.19	1.03	0	0	0	0	2.22
		1.27	5.04	4.35	0	0	0	0	9.39
47	50	0.27	2.68	2.31	0.21	0	0	0	5.20
		0.3	2.98	2.57	0.21	0	0	0	5.76
		1.27	12.61	10.88	0.21	0	0	0	23.70
48	20	0.27	1.07	0.92	0.18	0	0	0	2.18
		0.3	1.19	1.03	0.18	0	0	0	2.40
		1.27	5.04	4.35	0.18	0	0	0	9.57
49	20	0.27	1.07	0.92	0.14	0	0	0	2.14
		0.3	1.19	1.03	0.14	0	0	0	2.36
		1.27	5.04	4.35	0.14	0	0	0	9.53
50	10	0.27	0.54	0.46	0.14	0	0	0	1.14
		0.3	0.60	0.51	0.14	0	0	0	1.25
		1.27	2.52	2.18	0.14	0	0	0	4.84