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Global Warming Potential as a Challenge for Small-scale Biogas Plants in Vietnam

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Declaration

I hereby declare that I have done this thesis entitled Global Warming Potential as a Challenge for Small-scale Biogas Plants in Vietnam independently, all texts in this thesis are original, and all the sources have been quoted and acknowledged by means of complete references and according to Citation rules of the FTA.

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Abstract

Biogas production in small-scale plants is considered as appropriate, cost-effective method of energy supply to rural households, providing many benefits including reduction of greenhouse gas emissions, organic waste management and production of fertiliser. By four-stage reaction of anaerobic digestion, the organic material is transformed into methane-rich biogas, which is used mainly for daily cooking activities in developing countries. Replacing traditionally used fuelwood and LPG by biogas promises reduction of households' global warming potential. Problems resulting from inappropriate operation of biogas plants can result in mayor setbacks, including process inhibition and biogas loss. The amount of methane released to the atmosphere due to leakages or intentional release threats to neutralize the benefits of biogas use on the environment. The objective of this thesis was to quantify the impact of partial replacement of traditional fuels for cooking by biogas.

The data collection was performed in province Thua Thien Hue in Vietnam from April to May 2017, including interviews of biogas plant owners (n = 22), masons (n = 5) and biogas facilitators (n = 5), following the previously assembled dataset of Biogas Research Team (n = 123). The quantification used Global warming potential (GWP), accounted for reported 40% methane loss, and possible scenarios of 0% methane loss and use of biogas exclusively. After implementation of biogas, traditional fuels' use of households was reduced; fuelwood by 57.3 % and LPG by 56.3 %. Currently, households use 56.68 % of daily cooking energy from biogas. GWP was reduced by 1.05 % in comparison to the state before biogas plant (BGP) implementation. Quantification of two potential scenarios resulted in GWP reduction by 42.74 % in case of zero methane loss scenario and 74.22 % in case of using biogas exclusively. Break-even point of methane emissions was found at 41 %, close to the current reported values, indicating that the problem of methane leak is crucial and should be addressed.

Key words: small-scale biogas technology, global warming potential, biogas, greenhouse gases

Abstrakt

Výroba bioplynu v malých bioplynových stanicích je považována za vhodnou a vzhledem k nákladům efektivní metodu dodávek energie do venkovských domácností, což přináší mnoho výhod, včetně snížení emisí skleníkových plynů, nakládání s organickým odpadem a výroby hnojiv. Během čtyřfázové reakce anaerobní digesce je organický materiál přeměněn na bioplyn s vysokým obsahem metanu, používaný v rozvojových zemích především k účelu každodenního vaření. Nahrazení tradičně používaného palivového dřeva a LPG ve spotřebě domácností bioplynem může mít za následek snížení potenciálu globálního oteplování. Problémy vyplývající z nevhodného provozu bioplynových stanic mohou způsobit výrazné komplikace, včetně zastavení procesu výroby bioplynu či ztráty do ovzduší. Vysoké množství metanu uvolněného do ovzduší v důsledku úniků nebo úmyslného upouštění může v důsledku neutralizovat výhody využití bioplynu na životní prostředí. Cílem této práce bylo vyčíslit dopad částečného nahrazení tradičních paliv používaných na vaření bioplynem.

Sběr dat byl proveden v provincii Thua Thien Hue ve Vietnamu od dubna do května 2017, včetně rozhovorů s majiteli bioplynových stanic (n = 22), zedníky (n = 5) a facilitátory (n = 5), které navazovaly na datový soubor sestavený Biogas Research Teamem (n = 123). Výpočet potenciálu globálního oteplování (GWP), zahrnoval scénář s 40% ztrátou metanu, a dále teoretické scénáře 0% ztráty metanu a výhradního využití bioplynu. Po zavedení bioplynu do domácností bylo využití tradičních paliv sníženo o 57,3 % v případě palivového a o 56,3 % v případě LPG. V současné době pochází 56,68 % energie využívané v domácnostech na vaření z bioplynu. GWP byl snížen o 1,05 % ve srovnání se stavem před zavedením bioplynových stanic (BGP). Výsledky výpočtů v případě dvou potenciálních scénářů by vedly ke snížení GWP o 42,74 % v případě scénáře 0% ztráty metanu a ke snížení o 74,22 % v případě použití výhradně bioplynu. Bod zlomu emisí metanu byl zjištěn na úrovni 41%, blízko současných hodnot, což naznačuje, že problém úniku metanu je zásadní a měl by být řešen.

Klíčová slova: malé bioplynové stanice, potenciál globálního oteplování, skleníkové plyny

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AD	anaerobic digestion
BGP	biogas plant
CO_2eqv	carbon dioxide equivalent
GHG	greenhouse gas
GWP	global warming potential
LPG	liquefied petroleum gas
HUAF	Hue University of Agriculture and Forestry

1. Introduction

Small-scale biogas production is one of key solutions to meet household energy demand of rural areas in Southeast Asia, as it is a promising technology for farmers who depend on livestock farming.

Organic matter is digested in biogas plants (BGPs) and the product – biogas can be used in households for cooking in biogas stoves. In the process of biogas production, the organic residue – digestate is considered as a by-product and can be used as natural fertilizer. Use of manure as a feedstock for biogas plants is an appropriate solution, as it enables to manage waste that could potentially harm the environment.

Biogas as an energy source in rural Vietnam replaces traditionally used fuelwood and light-petroleum gas (LPG). The use of biogas results in economic benefits. Another advantage of biogas is the reduction of the health risk of women and children, caused by indoor fuelwood burning. Anaerobic digestion (AD) helps to manage organic waste, otherwise potentially harmful to the environment, which as it is generated continuously in the farm area, serves as a feedstock to the digester.

Technical difficulties such as gas leakage and process breakdown decrease the efficiency of biogas production and use. These setbacks need to be considered, as they can significantly affect the environmental impact and benefits of biogas technology.

Depletion of fossil fuel resources such as oil, natural gas or coal seems inevitable and poses one of the major global problems. On top of that, use of traditional fuels as fuelwood contributes to pressure on deforestation. Use of fossil fuels and deforestation together causes increase of greenhouse gas (GHG) emissions, as carbon is extracted from its natural storage and at the same time carbon sinks are depleted. Replacement of fossil fuels by alternative technologies including biogas is a promising trend, both in that it reduces the rate of fossil fuel consumption, and on the other hand helps to mitigate greenhouse gas emissions. For rural areas of developing countries, it is a challenge to implement efficient technologies with mitigation potential.

2. Literature Review

Small-scale biogas technology has been a subject to a great number of scientific papers. The literature deals with many aspects of biogas production. This literature review aims to provide basic information regarding topics related to the thesis.

2.1. Biogas technology extension

Biogas technology is estimated to be used already in the 10th century B.C. in Assyria and in ancient China (He, 2010). Well documented attempts of biogas production were in the 19th century. In the first half of 20th century in China began commercial expansion of small-scale biogas plants (BGPs) and popularization of technology (He, 2010). Technology of biogas production had been continuously developed and expanded. This process accelerated in the second half of the 20th century under influence of recurrent oil crises. Substantial petroleum shortages and elevated prices were among causes of increased interest in renewable sources of energy (Bond & Templeton, 2011). A significant increase in the number of BGPs occurred in 1970s and 1980s in Asia, South America and Africa (Ni & Nyns, 1996). Support of renewable technologies was encouraged, when environmental problems drew attention to anthropogenic impact on the planet (Zhou et al, 2019), resulting in environmental policies, such as Kyoto protocol designed to reduce greenhouse gas emissions (Liu et al, 2016). At present, biogas is used worldwide, in different scales and with implementation stages varying widely. Biogas expansion is based on the country's development status and available energy sources. The focus of developed countries is set primarily on large-scale BGPs, producing biogas for heat and electricity generation. In developing countries, generally small-scale digesters are used to produce biogas for cooking and lighting (Khalil et al, 2019).

2.2. Biogas in Vietnam

In Vietnam, the biogas technology was introduced in 1960s by government. BGPs constructed between 1960 – 1975 were not very successful due to improper management and technical difficulties (Nguyen, 2012). After the country's reunification in 1976, renewable energy became one of the priorities and a research program "Application of biogas technology in Vietnam" was issued. During the 1980s, more emphasis was placed into biogas research and cooperation was extended to Institute of Energy, The Ministry of Health and universities of Hanoi, Ho Chi Minh City, Da Nang University of Technology and Can Tho (Nguyen, 2012).

A breakthrough in the economic development of the Vietnam, resulting from Doi Moi policy initiated in 1986 (Nguyen & Maclaren, 2007), brought government's support of foreign investments and initiation of transformation to socialist-oriented market economy. From 1991, the biogas technology started to receive more support from the government programs with cooperation of international NGOs. In 2003, Vietnam biogas programme was launched, supported by Dutch organization SNV in cooperation the Netherlands Ministry of Foreign Affairs. There was more than 80,000 units installed by 2009 (Ghimire, 2013). Since 2013 the international project Energising Development has supported the SNV biogas implementation. Until 2015, there was already 500,000 BGPs installed in the country of size mainly smaller than 6 m^3 (Ho et al, 2015).

The technology is implemented with help of local authorities and NGO projects, but also from the farmer's initiative. A plan of the Vietnam Renewable Energy Development Project intends to increase the share of renewable energy of the total energy production and to reduce fossil fuel dependency. A support should be provided to the alternative energy sources such as hydropower, wind power, solar power, and biomass processing and biogas production. Utilization of biogas technologies is supposed to be enhanced from 4 million m^3 in 2015 to 8 million m^3 in 2020 and further to 60 million m^3 in 2030 and 100 m^3 in 2050. The GHG emissions should be decreased (from 2015) by 5 % in 2020; 25% in 2030 and 45% in 2050 (MIT, 2015). As a research of Surendra et al. (2014) suggests, the waste energy potential of the country is still underutilized.

2.3. Pros and cons of biogas technology

Biogas, the main product of the AD, can be used for cooking, lighting and generating of electricity, while it replaces other commonly used fuels such as LPG and fuelwood. Biogas content of methane is around 65 % and carbon dioxide 30 % in the small-scale BGPs in the target area of study (Roubík et al, 2018). In rural areas of developing countries, biogas is used mainly for cooking purposes (Ferrer et al, 2009). The amount of biogas used in household for this purpose can be 30 – 45 m^3 monthly (Rajendran et al, 2012). Another important component of biogas is hydrogen sulphide, although only taking up a small proportion of biogas, its presence can cause health problems such as dizziness or headache (Meier et al, 2018; Lebrun et al, 2019). Excessive proportion of this component is easily recognizable by the unpleasant smell, during combustion, which stays in the room for a few minutes.

The most of the anthropogenic GHG emissions are generated during combustion of fossil fuels (Day & Day, 2017), while the sources of the fossil fuels such as oil, natural gas or coal are likely to be depleted in upcoming century (Shafiee and Topal, 2009). Technologies using renewable resources, such as biogas have the potential to reduce GHG and in the same time approach the challenge of growing energy demand. Demand for energy in rural areas is currently not so high that it would be necessary to produce energy in larger quantities. Considering the GHG emissions, it is more appropriate to have small-scale plants as they have a greater potential of carbon savings (Mesa-Dominguez et al., 2015).

Although fuelwood is a traditional source of energy, its replacement brings many benefits. While fuelwood is burned, household members are exposed to the smoke. Smoke substances pose a potential health risk, which leads to headache, respiratory problems and higher risk of cancer (Mumford et al., 1989). This factor is particularly risky for women and children who are present at home during the cooking time. Another benefit of fuelwood replacement is reduction of time necessary for its collection. This time can be used for different purposes, i.e. for leisure time or education. On top of that, usage of traditional fuels as fuelwood contributes to pressure on deforestation. Using of fossil fuels and deforestation together causes GHG emissions, as carbon is extracted from its natural storage and at the same time carbon sinks are depleted. Decreased demand for fuelwood results in a reduction of deforestation problem. In household biogas production in developing countries, the feedstock is commonly available directly from the farm production. The size of a BGP is chosen in dependence to the amount of organic waste available onsite. Since the inputs are available in the same area and there is no need for their transport, no fuel is consumed and thus no further fuel usage. Biogas production uses different kinds of organic matter, which serve as nutriments for methanogenic bacteria. Among the materials that are suitable for the reaction, there are different kinds of organic waste and agricultural residues, such as animal manure, human excreta, municipal solid waste and residual parts of crops. In practice, the feedstock is usually mixed to generate higher biogas yields (Braun & Wellinger, 2003). Knowledge about the composition of feedstock is a key factor for understanding its connection with biogas yields. If the process is under control, it is possible to predict the amount of biogas to be produced (Cu et al, 2015). According to study of Cu et al. (2012) farmers in Vietnam tend to supply too much slurry into the digesters. Due to a different biogas potential of different organic materials, this may cause a problem of overproduction. Unused biogas is then usually released into the atmosphere, increasing methane emissions (Bruun et al, 2014).

After the organic material is used as a feedstock for AD and the biogas is generated, the remaining product is called digestate. It is a solid or liquid mixture of indigestible material and dead microorganism cells. Digestate is rich in plant valuable nutrients, which make it suitable to be used as a natural fertilizer. On the contrary to the synthetic fertilizers, digestate is produced continuously onsite, and since there is no need to buy it and transport to the farm, it brings substantial financial benefits to the farmer and helps to reduce fossil fuel consumption.

Waste management in developing countries is generally a major problem, resulting from combination of farmer's poor awareness of possible environmental consequences and a lack of pressure from the authorities. Biomass which could be used as a feedstock for AD is often just discharged or deposited without consideration of environmental impact. Besides water and soil pollution, untreated livestock manure causes problem of unpleasant odour and methane emissions. The amount of odour from manure during and after digestion is substantially lower (Kearney et al., 1993). Common practice of waste management is combustion, landfilling or discharging into the environment (Mihai and Taherzadeh, 2017). While plastic and other non-biodegradable materials are best to be separated and receive proper treatment in recycling plants, organic waste has a potential to be reused for energy generation and agriculture at the place of its origin. However, untreated bio-waste, especially manure and human excreta is potentially harmful to the environment and capable to harm plants or bring health risks to the rural population due to presence of pathogenic organisms and parasites. When the waste is discharged to the environment directly, it poses a potential threat to human health as a source of various infectious diseases including cholera, typhoid, hepatitis, polio, cryptosporidiosis, ascariasis, and schistosomiasis (WHO, 2000). In certain conditions, pathogens can survive for a long time and remain in the soil or contaminate water. In fisheries, manure is sometimes used to feed the fish directly, therefore water can be contaminated by pathogens such as *E. coli*, *Salmonella sp. and Staphylococcus sp.* (Yen-Phi et al., 2009; Vu et al., 2007). When fish is fed by animal manure, potential health risks are increased not only for rural communities of the country but also for countries importing the fish and fish products (Yajima and Kurokura, 2008).

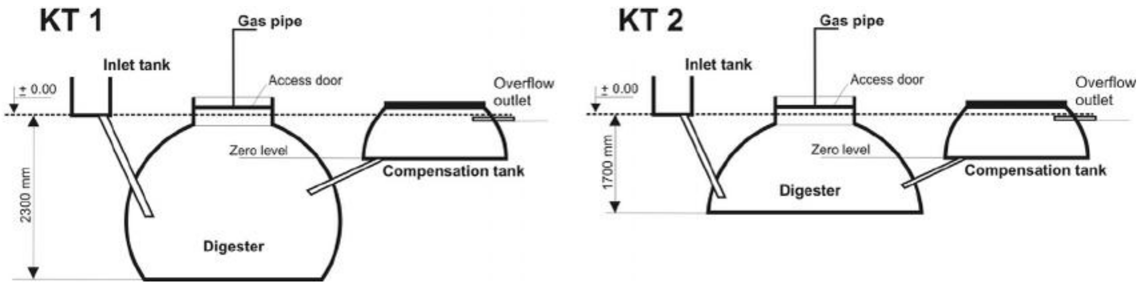
Biogas together with composting are environmentally friendly options of organic waste treatment. Biogas technology helps to deal with the problem of organic waste management as the material with a potentially high content of pathogens is treated in a digester in anaerobic conditions insulated from the environment by the construction of the plant. With this treatment, the potentially harmful material does not contaminate the water and surroundings of the farm. During the AD, pathogens are reduced due to competitive microbial reactions, temperature, pH, feedstock composition or presence of toxic materials (Avery et al., 2014). Pathogens contained in manure and human excreta are not effectively inactivated during mesophilic AD, as they are not exposed to a necessarily high temperature within too short hydraulic retention time (Watanabe et al., 1997).

Implementation of biogas technology generates job opportunities in the region. There are workers employed as facilitators and masons, who received special training with certification. This was achieved in cooperation with non-profit organizations such as CzDA or SNV with the support of national governments. A significant advantage for farmers is projects, which include co-financing of the initial costs.

2.4. Small-scale biogas plants in Vietnam

The BGP designs used in Vietnam are mostly KT1 and KT2 (Roubik et al. 2016), which are shown in Figure 1. Usually, small-scale reactors are used, as they fit to the household level of organic waste generation and energy requirements, small farms are usually run by family members.

Figure 1. *Types of BGP used in Vietnam.*



Source: (Roubík et al., 2016)

BGPs in target area are constructed from bricks. The system consists of 6 main parts: Inlet (mixing tank), inlet pipe, digester (reactor), outlet pipe, gas pipe, compensation tank.

2.5. Biogas production and use

Biogas is generated during the process of anaerobic digestion (AD). AD occurs under anaerobic conditions using biodegradable materials as feedstock. The feedstock is gradually decomposed by microorganisms into simpler forms and subsequently transformed into two products: biogas and residual organic matter (digestate).

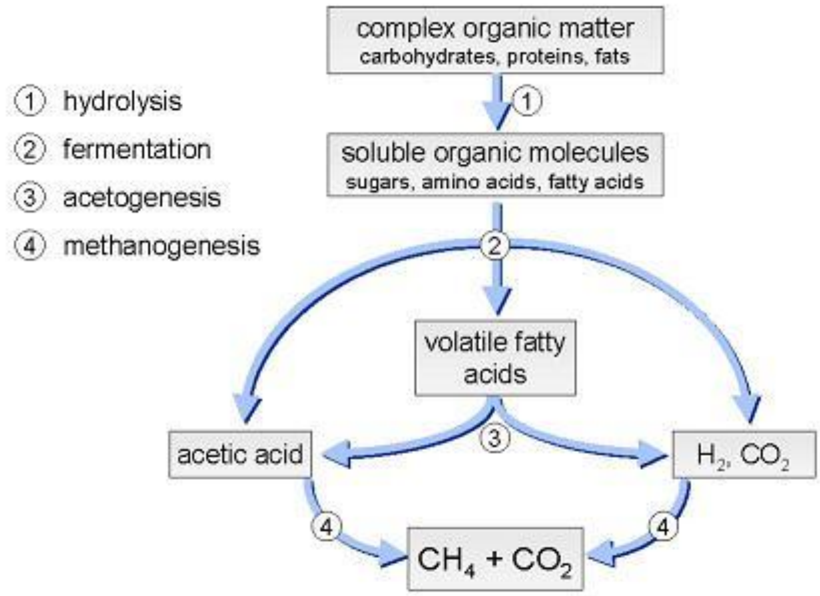
The conditions suitable for AD are natural environment like marshes, swamps, water bottoms and sediments, deep soil (Botheju & Bakke, 2011), during agricultural production (animal digestion, manure storage) or waste management (waste landfills, wastewater treatment plants, biogas plants). Though the AD has been utilized for centuries, it is still a subject of present scientific research (Zhang et al, 2016).

In small reactors, that are typical for South East Asia, the feedstock is supplied on daily basis and the reaction is continuous. The produced biogas is then used for common activities like cooking or lighting. Progress of the reaction is influenced by several conditions and factors as absence of oxygen, suitable temperature, C/N ratio and pH. Daily operation with BGP requires several principles. Careful gas pressure inside the reactor should be supervised.

2.5.1. **Phases of Anaerobic digestion**

The literature divides the process of AD into four phases, according to the different reactions occurring: hydrolysis, acidogenesis, acetogenesis and methanogenesis. As indicated in Figure 2, the organic matter is converted into simpler forms.

Figure 2. Stages of anaerobic digestion.



Source: (Mountain Empire Community College, 2013)

The process of AD starts with initial feedstock and inoculation.

In hydrolysis phase, non-soluble large organic polymers (biopolymers) are cleaved to soluble organic compounds, which is necessary for further processing by bacteria (Mes, 2003). Hydrolytic bacteria such as *Bacteriodes*, *Clostridium*, and *Acetivibrio* are present in this phase of AD (Goswami et al., 2015). The complex organic molecules such as proteins, carbohydrates and lipids are broken down into amino acids, monosaccharides, and fatty acids and glycerol (Al Seadi et al., 2008). Compounds resulted from hydrolysis are components of subsequent reactions.

In acidogenesis phase, microbia is present the highest diversity. Along with most of the bacteria from the first phase the main important agents are acidogenic (fermentative) bacteria such as *Enterobacterium*, *Acetobacterium* and *Eubacterium* (Schnurer and Jarvis, 2010). These bacteria cause fermentation reactions. Soluble organic compounds produced in hydrolysis are converted into volatile fatty acids (VFA) such as acetic acid, propionic acid, butyric acid, succinic acid or lactic acid. Amino acids are converted into ammonia. Other products of this reaction are hydrogen and carbon dioxide and alcohols (Mes, 2003; Schnurer and Jarvis, 2010). Hydrogen along with acetate are suitable for direct interaction with methanogens. Remaining products need to be degraded into simpler forms.

Majority of microbia active in the acetogenesis stage are known acetogens, as acetate is one of the main products of the phase (Drake et al 2008). Examples of these are *Syntrophomonas*, *Syntrophus, Clostridium* and *Syntrobacter.* Their activity takes place in cooperation with methanogenic microbia (McInerney et al. 2008). In acetogenesis the VFA, alcohols and aminoacids are cleaved into hydrogen, acetate and carbon dioxide (Heeg et al. 2014). These compounds can be then used directly by methanogens in the fourth phase.

In the final phase of methanogenesis, the biogas is formed. In methanogenesis acetate and carbon dioxide as two main substrates are converted to methane as a main product, the remaining are carbon dioxide, hydrogen and small amount of different gases (Mes, 2003; Slonczewski and Foster 2014).

2.5.2. **Factors affecting anaerobic digestion**

Process of AD requires an anaerobic environment. The bacteria active in AD reaction are contained in the liquid manure and the anaerobic ecosystems. It is not necessary to add bacteria to the mixture, however adding them as a sample from already functioning reactors can accelerate the initial phase of the process. It is necessary to continually sustain conditions for the further development of bacteria. Methanogenic bacteria are strictly anaerobic and survive in oxygen free or oxygen low environment. In case of reactor damage and subsequent range of oxygen access, an inhibition of the process can be caused. (Botheju and Bakke, 2011)

AD is a process sensitive and dependent on the temperature. It is important to sustain a constant temperature to keep the process stabilized and avoid a decrease of the process effectivity. There are two ranges where the microorganisms responsible for AD are active. Mesophilic microorganisms are the primary microorganism active in temperature from 30 to 40 °C. Thermophilic microorganisms are active in a range of 50 to 60 °C. For mesophilic digestion, there is no need to supply heat and the reaction is more stable and reliable, however it takes place at a slower rate and is not capable to process as high loadings. In practice, majority of the BGPs in developing countries are designed to operate at mesophilic conditions. Optimum temperature for AD is around 35 °C. In countries with tropical climate, it is not common to control the temperature in the digester. The temperatures may be ambient in relation to weather and daytime conditions, which may differ in 5 - 10 °C (Zhang et al., 2006). To avoid the impact of the temperature fluctuations the plants are built underground. This creates insulation, which is important in areas with colder temperatures in winter. Reactor temperature is primarily affected by outdoor air temperature, degree of heat exchange, soil and input temperature (Pham et al, 2014).

For the reaction, it is essential to sustain a reasonably high ratio of C/N ratio. The ratio can be influenced by composition of organic input. Nitrogen is used for synthetic reaction of amino acids, proteins and nucleic acids. When nitrogen is converted to ammonia, it helps to keep a neutral pH of environment. If the proportion of nitrogen is too high, it leads to rapid nitrogen consumption. In such case, there is not enough nutrients for an effective reaction with carbon. At too low proportion of nitrogen a toxic amount of ammonia can occur. Both of the cases lead to lower production of biogas. According to many studies the optimal C/N ratio for methane production is between 25-30:1 (Kayhanian, 1992; Marchaim, 1993, Yen, 2007). However, with rise of temperature it is preferable to sustain higher ratio in order to reduce the possibility of ammonia inhibition. For mesophilic conditions between 30 - 40 °C the optimal ratio is 25:1 and for thermophilic conditions between 50 - 60 °C the ratio is 30:1 (Wang et al, 2014). Recommended C/N ratio can be achieved by appropriate combination of organic matters. Different materials input have different C/N ratio. This ratio may also vary according to location, especially due to the different diet of livestock. In general, a sufficiently high C/N ratio is in pig and cattle manure, while human and poultry are low. (SNV, 2011)

The influence of pH is crucial for the whole process of AD as it influences the enzyme activity (Mathew et al. 2014). For growth and activity of various microorganisms there are distinctive optimal pH values. Hydrolysis and acidogenesis take place efficiently at the pH value 5.5 pH respectively 6.5. Acid producing microorganisms can sustain low pH environment down to 5 pH. For occurrence of methanogenesis a pH in range of 6.5 - 8.2 is suitable (Lee et al., 2009).

2.6. Climate change

The Earth´s climate change is a phenomenon occurring periodically and can be traced dating decades to millions year to the past. The climate, global or regional, changes from the long-time average states. Historically, these changes were caused by natural processes such as the Earth´s orbit change affecting the amount of sunlight impacting the surface or by volcanoes releasing aerosols to the atmosphere. Current trend of climate change is global warming, long-term increase of global temperature. Global warming can be verified by long-term records of measured temperatures or by already visible traces, such as glacier melting (Thomas et al. 2004).

2.6.1. **Global Warming**

Global warming is an observed process of gradual rising of Earth´s climate systems temperature. It is a combination of the consequences of anthropogenic activity and natural based phenomena. Possible impacts of global warming indicate that it is one of the most important and urgent problems for the civilization. The possible consequences of global warming vary depending on geography. Although in some regions warming could bring better conditions for agriculture, it is possible to expect major problems in the countries of the global South whose economies are heavily dependent on agriculture. The most significant consequences of global warming for the countries of global South according to (Yohe & Tol, 2006) are contained in Table 1. At the present time the greenhouse effect is considered to be the major source of global warming.

Table 1. Problems caused by global warming.

Problem specification	Description
Glacier melting	heavy flood risk increase in wet season, reduction of water supply in dry season, intense droughts
Crop yields decline	problems for smallholders to produce sufficient amounts of food
Ocean acidification	impact to marine ecosystems due to increase of carbon dioxide levels
Sea level rise	floods in coastal areas, followed by permanent displacement of inhabitants
Malnutrition and heat stress	increase of number of deaths
Extension of mosquitoes	widespread of vector-borne diseases
Vulnerability of ecosystems	species extinction

Source: Yohe & Tol, 2006.

2.6.2. **Greenhouse Effect**

Greenhouse effect is considered as the major source of global warming. The effect is caused by heat entrapment in the Earth´s atmosphere. The original source of the heat is solar radiation, which comes with almost constant intensity and constant solar spectrum.

When solar radiation enters the atmosphere and affects atmospheric particles, three effects occur: reflection, scattering and absorption. Reflected radiation is redirected back by 180° and scattered radiation is sent to random direction without any alteration of the wavelength. When the radiation is absorbed, it is converted into longer-wave infrared (IR), so-called heat radiation. IR partially passes through the atmosphere and spills back to the space. The rest of the IR is scattered or reflected, finally affecting the Earth´s surface and causing warming. The greenhouse effect is believed to be enhanced by anthropogenic activity, which causes emissions of so-called greenhouse gases (GHGs), which are trapped and accumulated in the atmosphere.

2.6.3. **Greenhouse Gases (GHGs)**

GHGs are various gases with a common property causing the increase of greenhouse effect. These gases vary in the amounts in which they are trapped in the atmosphere, their precursors, sinks and capability of heat trapping. Some amounts of the GHGs occur in the atmosphere naturally and are part of natural cycles, i.e. carbon dioxide (carbon cycle) and water vapour (water cycle). The emissions caused by anthropogenic activities are believed to be the responsible for setting the greenhouse effect out of balance.

There are various GHGs caused by different human activities as fossil fuel combustion, livestock production, farming or cement manufacture (IPCC, 2014; FAO, 2014). Carbon dioxide, methane and nitrous oxide. Besides them, there are more as f. e. chlorofluorocarbons (CFCs), hydrofluorocarbons (HCFCs and HCFs) or ozone. Another gas, water vapour is not considered as a GHG since its greenhouse properties are not a direct cause of climate change. Water vapour is a part of the closed water cycle; therefore, the amount of water vapour in the atmosphere is close to constant.

Carbon dioxide is emitted by combustion of fossil fuels, waste, fuelwood, production of cement. It is sequestered by plants and oceans. The absorption by plants occurs by respiration of organisms or fermentation processes. It is considered the most significant GHG.

Methane can remain in the atmosphere around a decade. In addition GWP values are estimated (GWP of 28–36 over 100 years). Although methane remains in the atmosphere much shorter than carbon dioxide, methane particles can absorb much more energy.

2.6.4. **Global Warming Potential**

Global Warming Potential (GWP) is the most widely used environmental metric (Makhnatch and Khodabandeh, 2014). GWP is used to estimate the impact of different GHG's emissions on global warming.

GHGs have different GWP, as their heat trapping ability, abundance in the atmosphere and atmospheric lifetime are different. Some gases have a higher heat-trapping ability per molecule but are present in lower concentrations. Production of some GHGs has been banned or minimized, but the concentrations released so far are going to stay in the atmosphere for hundreds to thousands of years. The longer period of time the substance remains in the atmosphere, the more it captures the energy, causing a greater risk to a long-term climate change. The estimated lifespan of gas particles in the atmosphere before they are removed is called the atmospheric lifetime (Woodwell, et al. 1998). To consider the different GHG's lifespan, the value of GWP is typically expressed in a fixed period of 100 years (Liu et al., 2017). Values CO_2, the most frequent GHG, serve as the basic benchmark for quantification for other gases. GWP of an emitted quantity of a GHG is derived from the same quantity of CO_2 emission (Makhnatch and Khodabandeh, 2014). From this, a common unit is derived - the carbon dioxide equivalent (g CO_2 eqv. g^{-1}. CO_2eqv expresses the GWP as a given amount of a GHG to a fixed time-scale of 100 years. Therefore, the GWP of CO_2 is 1 CO_2 eqv. g^{-1}

3. Aims of the Thesis

The main objective of thesis is to quantify the influence of biogas from small-scale BGPs replacing traditional fuels (fuelwood and LPG) on GWP resulting from households cooking activities. The research aims to answer the following questions:

• To what extent did biogas replace the traditional fuels in purpose of households cooking activities?

• How is GWP reduced as a result of partial replacement of traditional fuels by biogas?

• What is the potential percentage of biogas loss from leakage and intentional release to reach the GWP of break-even point, when the BGP is no longer beneficial to the environment?

In favour to answer these questions, the thesis includes calculations of traditional fuels consumption with and without BGP based on primary data collected in target location. Based on assumption of households' equal energy requirements before and after BGP implementation, the calculation of daily energy budget for cooking activities is performed. Based on equation using previously mentioned values, the ratio of fuel mix is calculated and subsequently energy generated by biogas combustion.

Quantification of significant GHGs (CO_2, CH_4, N_2O, CO) emissions is based on values of energy requirements and fuel mix ratio, that were previously calculated and values of GHG emissions per MJ obtained from similar research papers. GHG emission calculation is carried out for every examined fuel before and after BGP implementation.

Calculation of annual GWP is based on standardized values of characterization factors and previously calculated GHG emissions. GWP is calculated for different scenarios:

1. Original scenario, accounting emissions of fuelwood and LPG before BGP implementation,

2. Zero loss scenario, accounting emissions of fuelwood, LPG and biogas, with 0% biogas loss,

3. Current state scenario, accounting emissions of fuelwood, LPG and biogas, with 40% biogas loss,

4. Optimal scenario: accounting emissions if biogas covered 100 % of daily cooking energy consumption, with 0% biogas loss.

4. Methods

Methodology of this thesis combines data from primary and secondary sources. Primary data were collected through semi-structured interviews among rural households. Another source of primary data was dataset of Biogas Research Team, which provided a framework and included part of additional data for calculations. The data collection for this thesis served to in-depth research and were collected from a smaller target group. All gathered data were converted to MS Excel for both qualitative and quantitative analysis, calculations of GHGs emissions and GWP.

4.1. Field data collection

Primary data were collected during field data collection in Province Thua Thien Hue, Central Vietnam in April to May 2017. The field collection included households' visits in rural areas surrounding the city of Hue, in five communes (Huong An, Phong Xuan, Huong Xuan, Phong An, Huong Toan) within two districts (Huong Tra, Phong Die). During the visits, semi-structured interviews were conducted and photographic documentation of households, biogas plants, accessories (gas stoves, pipelines) and animals was obtained. Face-to-face interviews were conducted in Vietnamese and the answers were concurrently translated and filled to English blueprints. The interviews took 45 minutes on average. Interviews were conducted among three target groups: farmers (owners of a BGP), masons (involved in BGP construction) and facilitators. The research team included the expert from Hue University of Agriculture and Forestry (HUAF) and the author of thesis. Following the previously assembled dataset of Biogas Research Team, the aim of interviews was conduct in-depth research required for the thesis.

4.2. Target groups

The first target group consisted of farmers (n = 22). Farmer's selection was conditioned by ownership and operation of a small-scale biogas plant. Meetings were arranged in cooperation with facilitators, who also secured visits.

The second target group covered masons, who participated in BGP construction (n = 5). Mason's selection was conditioned by previous training regarding BGP with certification by NGO´s (SNV or CZDA) and current activity in relation to BGPs (advisory and fixing operational problems).

The third target group covered facilitators of the biogas plant project (n = 5). Facilitators are commune's employees responsible for project coordination. Facilitators participated in selection of farmers for the project and provided them training about biogas technology. Facilitators know the local population. They accompanied the research team during field visits.

The interview blueprint was prepared in two variants according to the respondents – variant 1: farmers, variant 2: masons / facilitators. Every respondent received a financial compensation for the interview as indicated in Table 2. The compensations were given in Vietnamese dong (VND) and the equivalents of USD were calculated by central conversion rate of the State Bank of Vietnam (SBV, 2019).

Table 2. Financial compensation for the respondents.

Respondent type	Amount in VND	Amount in USD
Farmer	30,000	1.3
Mason	100,000	4.3
Facilitator	250,000	10.7

Source: Author.

4.3. Interviews

For the data collection, semi-structured interviews were used. Two different versions of blueprints were designed, the first for household and the second for facilitators and masons.

The household interview blueprint was divided into four sections (Table 3).

Table 3. Farmer´s interviews structure.

Section number	Section name	Content
1	Personal and regional information	Farmers´ personal and economical background, training
2	Biogas plant	Information about biogas construction, type, volume, lifespan
3	Energy and other energy sources	Energy consumption, influencing factors, energy sources, waste management
4	Problems with biogas technology	Typical problems with technology, frequency of occurrence, solutions

Source: Author.

The mason and facilitator interviews were divided into three parts (Table 4).

Table 4. Masons and facilitator interview structure.

Section number	Section name	Content
1	Personal and regional information	Years of experience, training, common work activities,

2	Process of gaining a BGP	Description of the process and its´ requirements
3	Life Cycle of a BGP	Description of construction, material, labor, lifespan
4	Transport of materials	Access to materials
5	Problems with biogas technology	Typical problems with technology, frequency of occurrence, solutions
6	Services, Other energy sources	LPG prices

Source: (Author, 2017)

To confirm and refine the data obtained from interviews, an email conversation the head of facilitators for the Thua Thien Hue region was also conducted.

4.4. Calculation of fuel use ratio and daily energy cooking budget

The original mix of cooking fuels included fuelwood and LPG, which both were partially replaced by biogas. While the composition of fuel mix changed, the energy required for cooking remained constant. The requirement of cooking energy is based on family size and diet composition, therefore was not affected by fuel replacement.

Based on assumption of constant energy requirement before and after biogas introduction. Formula (1) was created to calculate fuel use ratio.

$$B_{LPG} + B_{FW} = A_{LPG} + A_{FW} + A_{BG} \quad (1)$$

Where:

B_{LPG} = daily energy delivered to heating surface (LPG before BGP introduction)

B_{FW} = daily energy delivered to heating surface (fuelwood before BGP introduction)

A_{LPG} = daily average energy delivered to heating surface (LPG after BGP introduction)

A_{FW} = daily average energy delivered to heating surface (fuelwood after BGP introduction)

A_{BG} = daily average energy delivered to heating surface (biogas)

Formula 1 uses values of daily energy delivered to the heating surface during cooking activities. Input data about delivered energy were based on amount of fuels daily combusted and energy generated from their combustion. Amounts of combusted fuels (in kg) were calculated from data about households' annual expenses for traditional fuels and their price per kg. Average price paid for 1 kg of fuelwood is 1,000 VND (0.04 USD), LPG is usually purchased in 12kg bottles, which cost 270,000 VND (11.64 USD). The calculation of generated energy accounted for energy value of combusted to calculate amount of energy generated from combustion of materials and for energy loss caused by efficiency of cookers (Table 5). Results of these calculations were values of average daily energy delivered to the heating surface from combustion of fuelwood and LPG before and after BGP implementation. Substitution of these calculated values into formula (1) results in calculation of daily budget of delivered energy and subsequently energy delivered from biogas and fuel use ratio.

Table 5. Energy values of traditional fuels and cooker efficiencies.

Fuel	Energy value [MJ/kg]	Cooker/stove efficiency [%]
LPG	51	55.0
Fuelwood	16	17.5

Sources: BMZ, 2014; Kumar et al, 2013; World Nuclear Association, 2018.

4.5. Calculation of greenhouse gas emissions

Four scenarios were established in favor to obtain comparable results. These scenarios include past (before biogas implementation), ongoing (after biogas implementation) and two potential situations. Scenarios are more specifically listed in Table 6.

Scenario 1 includes direct emissions of traditional fuels (fuelwood, LPG) in the situation before biogas introduction. This scenario results in highest overall GHG emissions that were in practice one of motives to introduce biogas as energy source.

Scenario 2 accounts for emissions generated by combustion of current fuel mix, excluding methane losses. Therefore, it represents a potential situation, when proper treatment and good technical condition of BGP results in reduction of GHG emissions.

Scenario 3, analogically to scenario 2, accounts for current fuel mix emission, but in addition includes methane emissions corresponding to the 40% loss reported by Brunn et al. (2014). Calculation of fugitive methane emissions was based on amount of biogas production, which was estimated 1.5 MJ / day, considering volumes of biogas plants 6 m^3 and 9 m^3.

Scenario 4 accounts for situation of total replacement of traditional fuels by biogas, therefore BGP would provide energy to fulfill energy requirements for cooking.

Table 6. Scenarios of GHG emissions.

Scenario	Use of BGP	Accounted emissions
1. Original	No	combustion of fuelwood and LPG
2. Zero loss	Yes	combustion of fuelwood, LPG and biogas, methane loss 0 %
3. Current state	Yes	combustion of fuelwood, LPG and biogas, methane loss 40 %
4. Optimal	Yes	combustion of biogas, methane loss 0 %

Source: Author.

Calculation of GHG emissions generated during combustion of fuelwood, LPG and biogas was based on previously calculated amounts of daily average energy delivered to heating surface and potential emissions of significant GHGs – CO_2, CH_4, CO, N_2O, obtained from research of Brunn et al. (2014) (Table 7). Calculated daily emissions resulting from combustion of different fuels were subsequently converted to annual emissions for further calculations.

Table 7. GHG emissions per unit of delivered energy.

Gas emissions per 1 MJ of delivered energy				
Fuel	g CO_2	mg CH_4	g CO	Mg N_2O
Biogas	81.5	57	0.11	5.4
LPG	139	8.9	0.82	6
Fuelwood	532	600	14	4.3

Source: Brunn et al, 2014.

4.6. Calculation of global warming potential and break-even point analysis

Based on GHG emissions all four scenarios calculated previously in this thesis, GWP was calculated in favor to obtain a comparable indicator. Calculation of GWP was based on annual sums of selected GHGs [g/year] and their characterization factors [g CO_2 eqv. g^{-1}]. Values of characterization factors were obtained from IPCC and are listed in Table 8.

Table 8. Characterization factors of selected gases.

Gas	**Characterization factor [g CO_2 eqv $^{-1}$]**
Carbon dioxide (CO_2)	1.0
Methane (CH_4)	28.0
Nitrous oxide (N_2O)	265.0
Carbon monoxide (CO)	1.9

Source: IPCC, 2011.

Therefore, calculation of GWP was based on formula (3), which is used for calculation of scenarios 1, 2 and 4:

$$GWP = ECB_{CH4}CF_{CH4} + ECB_{CO2}CF_{CO2} + ECB_{CO}CF_{CO} + ECB_{N2O}CF_{N2O} \quad (3)$$

Where:

GWP = annual GWP resulting from fuel combustion [g CO_2 eqv. g^{-1}];

ECB = annual sum of emission of GHG released during the combustion of cooking fuels [g].

CF = characterization factor of GHG.

GWP calculation of scenario 3 accounts for 40% loss of methane, which is not combusted in the biogas stove. Therefore, emissions of methane loss, previously calculated in this thesis, are used for the calculation (formula 4):

$$GWPsc_3 = EL_{CH4}CF_{CH4} + ECB_{CH4}CF_{CH4} + ECB_{N2O}CF_{N2O} + ECB_{CO2}CF_{CO2} + ECB_{CO}CF_{CO} \quad (4)$$

Where:

GWP_{sc3} = annual GWP resulting from fuel combustion and methane loss [g CO_2 eqv. g^{-1}];

EL = emissions due to methane loss [g];

ECB = emissions of GHG released during the combustion [g].

CF = characterization factor of GHGs.

Break-even point analysis was based on GWP of scenario 1, which represents original GHG emissions before biogas introduction and GWP of scenario 2, which used current fuel mix ratio. Calculation was based on formula 5. The aim was to determine % of methane loss, when the both sides of equation are equal, therefore results in equal GWP.

$$GWPsc_1 = GWPsc_2 + EL_{BECH4}CF_{CH4} \quad (5)$$

Where:

GWP_{sc1} = annual GWP resulting from the Original scenario [g CO_2 eqv. g^{-1}];

GWP_{sc2} = annual GWP resulting from the Zero loss scenario [g CO_2 eqv. g^{-1}];

EL_{BE} = emissions due to methane loss [g].

5. Results and discussion

The first part of this chapter includes the primary data results of semi-structured interviews with farmers, masons and facilitators. The second part includes the results of calculations based on the primary data, GWP analysis and break-even point analysis.

5.1. Farmer interviews

The first target group were farmers (n = 22; 20 males, 2 females) who owned an operating BGP and participated in biogas project as subsidy recipients. Men were responsible for BGP operation in 91 %. Farmers' age ranged from 38 to 63 years, with average of 52 years. Data about farmers achieved education is listed in Table 9.

Table 9. Target groups level of education (n = 22).

Level of education	Percentage
No formal education	4
Primary school	32
Secondary school	50
High school	14

Source: Author.

The average number of household members was 4.9. The main source of income for households was in 86 % farming, in other cases construction work or car driving. Secondary sources of income were construction work, rice processing, car driving, repair services, retail selling and animal feed selling. 32 % of households did not report any secondary income. The average income of the interviewed households was 7,090,909 VND.

5.1.1. Small-scale biogas plants in the target area

In 86 % households, one family member was operating the BGP. Within projects focused on building BGPs supported CzDA and SNV, farmers received training with duration of one; respectively seven days. Selection of farmers for BGP projects participation was based on two main criteria: ownership of pigs and sufficient financial resources.

Financing of BGP construction was split between the farmers and the project. Information on the extent of farmers' financial contribution was obtained in facilitators' interviews. BGPs co-financed by the project were built in 2011-2014. There were two BGP types constructed in interviewed households – KT2 (64 %) and KT1 (36 %). BGPs size was chosen accordingly to the number of pigs kept on farm. 64 % of BGPs volume was in range of 6 - 6.2 m^3, 27 % in range of 9 – 9.2 m^3, 9 % plants volume was 8 m^3. At the end of the lifespan, 91 % of farmers planned to continue using biogas technology and construct a new BGP or reconstruct the original. 27.3 % of farmers estimated lifespan duration of BGP between 10-20 years, 4.5 % estimated 30 years and 68.2 % of farmers did not have any estimation.

5.1.2. **Energy and Energetic Sources in the target area**

68 % of farmers reported their biogas production as sufficient, 32 % insufficient. Farmers used LPG and fuelwood as traditional fuels before biogas introduction and in 91 % remain using them complementary. 9 % of farmers reported, that biogas suffices for whole cooking energy consumption. Every household had a H_2S filter installed on gas cooker.

Average monthly electricity bill in the interviewed households was 320,952 VND. Electricity is used for lamps and TVs in every household. An exhaustive list of electric appliances use in interviewed households is listed in Table 10.

Table 10. Electricity usage in households (n = 22).

Electric appliance	Number of households
Lamp	22
TV	22
Rice cooker	17
Fan	19
Water pump	14
Refrigerator	14
Rice processing machine	4

Feedstock chopper	1
Animal production	2
Washing machine	3
Sound system	1

Source: Author.

82 % households did not have the toilet connected to the BGP, as the toilet waste was led to the water septic. In most cases, it was the later time of BGP construction, as the septic had already been built. Several respondents stated, that toilet waste was too dirty to be used for cooking.

Besides biogas, liquefied petroleum gas (LPG) and fuelwood are used in surveyed households. After the biogas technology introduction, the consumption of these traditional fuels decreased due to the replacement. Fuelwood is usually obtained by farmers by collecting in surroundings of the farm. According to farmers own estimates, the time they used to spend collecting fuelwood was 12.07 hours a month in average (as indicated in Table 11). After the BGP implementation, they spend 2.41 hours a month in average collecting the fuelwood. As a result, the average collection time of the fuelwood was reduced by 80%. Due to this decline, a similar decline in the use of fuelwood for energy purposes and fuelwood consumption can be expected.

Table 11. Time intervals of consumption by fuelwood collection (n = 22).

Gathering time before BGP [h / month]	Number of households	Gathering time with BGP [h / month]	Number of households
1 – 10	11	1 – 10	21
11 – 20	7	11 – 20	1
21 – 30	3	21 – 30	0
31 – 40	1	31 – 40	0

Source: Author.

Due to information provided by masons, the average price of LPG is 270,000 VND per a 12kg bottle. Farmers were asked how much money they spent for LPG bottles monthly before and after BGP introduction (Table 12). Calculated averages show that the monthly purchase of LPG decreased by an average of nearly 51%.

Table 12. Households' monthly expenses for LPG before and after BGP implementation (n = 22).

LPG expenses [VND / month]	**Number of households**	
	Before BGP	**After BGP**
0 – 200,000	7	18
201,000 – 600,000	11	3
601,000 – 1000,000	3	0
1000,000 >	1	1

Source: Author.

Regarding the average bottle price of 270 000 VND, it can be concluded that, prior to the introduction of BGP, the average LPG consumption was 1.62 bottles per month, which decreased to 0.80 bottles per month after BGP introduction. After BGP, average consumption dropped to 0.80 bottles per month.

5.1.3. **Problems with biogas technology**

The most typical problems concerning small-scale biogas plants in target area were chosen based on research of Roubík et al. (2016) and dataset of Biogas Research Team. Farmers were asked, whether they experienced these problems during the existing life-time of BGPs. Table 13 lists the number of farmers who either had, had not encountered the problem or had not been aware of it.

Table 13. Occurrence of problems in target area (n = 22).

Problem	**Experienced [%]**	**Not experienced [%]**	**Do not know [%]**
Insufficient biogas production	77.3	22.7	0
Gas leakage (tank, holder, inlet, outlet)	40.9	59.1	0

Insufficient input (manure)	59.1	40.9	0
Problems with composition of input (C/N ratio, pH)	0	0	100
Problems with gas pressure (unstable, low)	18.2	40.9	40.9
Water condensate (gas supply system)	27.3	40.9	31.8
Process breakdown	4.5	86.4	9.1
Defect of biogas cooker	72.7	27.3	0
Health hazard (i.e. during cleaning)	13.6	86.4	0
Unpleasant odour (surrounding BGP)	40.9	54.6	4.5
Smell of biogas (using the gas cooker)	77.3	22.7	0
Gas combustion (poor flame, too much biogas in mix)	22.7	40.9	36.4
Low quality and amount of digestate	59.1	36.4	4.5

Source: Author.

5.2. Mason interviews

Masons built BGPs during the project implementation, their primary income occupation was in construction of buildings. After the construction of BGPs the masons remained available for repairs and consultations. The number of farmers attached to a mason varied significantly in range of 40 – 350. Masons visited farmers on requests, with an estimate of one visit per month. 80 % of masons received training funded by CzDA (within 5-7 days) and 40 % was trained by SNV (within 7-15 days). Both organizations granted a certificate of training accomplishment.

5.2.1. **Construction of the biogas plants**

Before the construction of the BGP, the masons carried out an inspection of the terrain. Suitable places for the construction were selected near the animal housings and close to the house. The volume of BGP was selected by farmers, with a minimum volume of 6 m^3. Two or three workers were required to dig the pit for the construction. This work was done by masons and their helpers or in some cases by the farmers themselves. The construction material was purchased by the farmers and was delivered to the building by the seller. Farmers did not have to go to the city for the material. According to the masons, there was enough of possibilities in the area of Hue to acquire all necessary material and components. Two or three workers were needed in the construction of the BGP. At this number, a construction of 6-m^3 BGP required for about 3 days. A construction of a 9-m^3 BGP required for about 3-4 days. Finally, the tubes from BGP to gas cooker were connected. Table 14 lists the materials and amounts required for BGP construction as listed by masons.

Table 14. Material for the BGP construction

BGP volume [m^3]	**Bricklaying style**	**Number of bricks**	**Amount of cement [kg]**	**Amount of sand [m^3]**	**Volume of water [m^3]**
6	Vertical	850 - 900	1000	2.0	1.0 – 1.5
6	Horizontal	1100 - 1300	1000 - 1300	1.5 – 2.0	1.0 – 1.5
9	Horizontal	1200 - 1600	1300 - 1600	2.0 – 3.0	1.0 – 1.5

Source: Author.

5.3. Facilitator interviews

4 facilitators from different communes (Phong Xuan, Huong An, Huong Xuan, Huong Toan) were asked to respond the questions about the process of BGP implementation. The head of facilitators was also asked to add information and more accurate data. Facilitators described the region as feed producing, fruit and grain growing and livestock processing. Most of them also described the region as with timber and non-timber forest production. The work experience in years as an extension center employee was rather

different in range of 6 to 18 years. The facilitators were asked to state, how many BGP was in their commune and for an estimation of the number of BGP coming out from a project of CZDA, the answers are shown in Table 15.

Table 15. Number of BGPs in the region.

Region	BGPs total	BGPs from CzDA
Phong Xuan	150	132
Huong An	140	120
Huong Xuan	390	n/a
Huong Toan	n/a	n/a

Source: Author.

5.3.1. Process of gaining a biogas plant

The process of receiving a BGP in accordance to the project conditions has several necessary requirements to be fulfilled. The basic premise was farming operations involving pig breeding. The minimum number of pigs was set at 5 or 6, with a total of their body weight of at least 200 kg.

One of the conditions was having enough finance to participate in BGP construction financing. Farmers were required to pay the full amount of the costs, with 60% of the total price being paid for by the project compensation after the BGP completion. According to the information provided by the head of coordinators, the amount of finance invested by farmers was 5,653,450 VND for a BGP. If the price of the construction exceeded the price agreed at the signing of the contract (e.g. because of the higher volume), this exceeding amount was paid by the farmer.

Implementation of the project in the area started with sending of a document with basic information about the project to every village. Then a meeting of village chiefs and representatives of the Peoples committee was held. At this meeting it was clarified how many biogas stations could be built in each village. This number was based on livestock production of the commune.

Another meeting was held between village leaders and farmers. Farmers were provided with project information. Farmers who were interested in BGP could register here. When the number of farmers willing to build a BGP was higher than the number stated by the project, the farmers were selected by commune. In some communes, this situation was solved by a random selection.

The list of chosen farmers was provided to the Peoples committee. The chosen farmers were visited by facilitators to check their fulfilment of requirements. Facilitators on site checked whether the farm is suitable to construct a BGP and the farmers met all the requirements. In some cases, conditions were not found to be good for construction due to inappropriate terrain, i.e. ground water or stony soil. The list of approved farmers was sent to the extension center of the province. The extension center representatives then carried out a final check. Farmers were subsequently invited to meet the Peoples committee. Then the final decision of the farmers followed, and a contract was signed between extension center and farmers.

The content of the contract from the side of extension Center was to provide information on technology, financial contribution, provision of training and training documents and introduction to the mason. Based on this contract, farmers paid the full amount of BGP construction and were refunded when the construction was complete. From the farmer's side, the contract contained the requirements for partial financial contribution to the total cost of the BGP; the construction of BGP in the garden and construction of the tank for storage of the wastewater; contract with mason introduced by the project; utilization and maintenance of the BGP according to the training; attendance of the training course.

In the next phase, extension center brought trained masons to construct the plant. The masons who constructed the BGPs passed through a training that lasted 7 days - 2 days of lectures and 5 days of practical training. Subject of the training for masons was - introduction to biogas technology and its benefits; structure of the BGP; differences and choice of size and type of BGP; process of construction of BGP; other devices (cooker, connector, gas filter); use and maintenance of the BGP; utilization of agricultural residues (plant and animal waste). The construction price varied depending on the reactor volume. The most frequently chosen size was 6 m^3. In this case a co-financing is 60% project - 40% farmer; if the BGP was bigger, the farmer paid the difference amount, and project did not provide more money. The whole process from the farmer's decision to build BGP until its completion took usually 1-2 months. Farmers were trained to handle the BGP operation in a one-day course. In some cases, training was carried out before construction and in some cases after. As a study material, leaflets and handbooks were provided to farmers. After the initial training, there were no further sessions for farmers.

5.4. Fuel use ratio and daily energy cooking budget

Table 16 indicates the average amounts of fuelwood and LPG combusted in interviewed households; both reduced to less than half after BGP implementation. These values were calculated from data about households' expenses for these fuels.

Table 16. Amount of traditional fuels combusted in households [kg / day].

Fuel	**Without BGP [kg / day]**	**With BGP [kg / day]**
Fuelwood	7.89	3.37
LPG	0.64	0.28

Source: Author.

Table 17 lists values of energy delivered to the heating surface during cooking per a day, accounting for scenarios before and after biogas introduction. Values of energy delivered from combustion of fuelwood and LPG were calculated from amounts of fuel, accounting for efficiency of combustion in wood and LPG stoves. Based on assumption of households' equal energy requirements before and after biogas introduction, therefore in both cases consisting daily energy budget of 40.14 MJ, the value of energy delivered from biogas combustion was calculated as 22.75 MJ / day. Resulted data were used for further calculations resulting to GHG emissions and GWP quantification. It is important to note, that this method of calculation is based more theoretically as the input values were calculated from available datasets of Biogas Research Team and the author; and more precise data would be possible to obtain with measured GHG emissions, then it would be beneficial to repeat this calculation and compare the results with results of this thesis.

Table 17. Amount of energy delivered to heat water in households [MJ / day].

Fuel	Without BGP [MJ / day]	With BGP [MJ / day]
Fuelwood	22.09	9.45
LPG	18.05	7.94
Biogas	-	22.75

Source: Author.

While energy, from biogas covered 56.68 % of daily cooking consumption (Table 18), replacement of traditional fuels resulted in reduction of traditional fuel use: fuelwood by 57.3 % and LPG by 56.3 %. Traditional fuels remain to complement the households' energy requirements significantly, which result from low biogas production or loss of uncombusted methane. Brunn et al (2014) emphasizes the importance of BGPs reliability and constant production, enabling farmers to adjust biogas consumption.

Table 18. Fuel mix ratio of cooking energy [%].

Fuel	Without BGP [%]	With BGP [%]
Fuelwood	55.02	23.54
LPG	44.98	19.78
Biogas	0	56.68

Source: Author.

5.5. Greenhouse gases emissions

GHGs emissions were calculated for 1. Original scenario, 2. Zero loss scenario, 3. Current state and 4. Optimal scenario. Emissions of scenario 1 quantifying emissions of traditional fuels before BGP implementation are listed in Table 19.

Table 19. Annual GHG emissions resulting from Original scenario (1) [g].

Fuel	g CO_2	g CH_4	g CO	g N_2O
Fuelwood	4288468.05	4836.62	112854.42	346.62
LPG	915864.73	58.64	5402.94	395.34
Sum	5204332.78	4895.26	118257.37	741.96

Source: Author.

Emissions of scenario 2 accounting for potential emissions in case of current fuel mix with 0% biogas loss are listed in Table 20. The figures indicate significant reduction of GHG emissions between scenario 1 and 2, due to lower emissions of biogas compared to fuelwood in terms of carbon dioxide and methane per unit of produced energy.

Table 20. Annual GHG emissions resulting from Zero loss scenario (2) [g].

Fuel	g CO_2	g CH_4	g CO	g N_2O
Fuelwood	1834840.12	2069.37	48285.27	148.30
LPG	402839.93	25.79	2376.47	173.89
Biogas	676687.04	473.27	913.32	448.36
Sum	2914367.09	2568.43	51575.05	770.55

Source: Author.

Calculations of emissions resulting from scenarios 3 and 4 were carried out analogically. Scenario 3 accounting for 40% biogas loss resulted in emissions of uncombusted methane by 96228.60 g / year, which resulted in rapid increase of methane emissions to 98797.03 g / year (Table 21). It is important to note, that biogas produced in target area contents approximately 65 % of methane and 30 % of carbon dioxide, as reported by Roubík et al, 2018. While calculation in this thesis accounts for gas emissions from combustion, considering, that fuelwood harvest often results to unsustainable deforestation; it does not account for the emissions of carbon dioxide released during biogas leakage, considering its recent fixation by plants, which were eaten by farm animals.

Table 21. Annual GHG emissions resulting from Current state scenario (3) [g].

Fuel	g CO_2	g CH_4	g CO	g N_2O
Fuelwood	1834840.12	2069.37	48285.27	148.30
LPG	402839.93	25.79	2376.47	173.89
Biogas	676687.04	96701.87	913.32	448.36
Sum	2914367.09	98797.03	51575.05	770.55

Source: Author.

Scenario 4, which quantified emissions in case of generating all energy by BGP, resulted in significantly lower GHG emissions, as indicated in Table 22.

Table 22. Annual GHG emissions resulting from Optimal scenario (4) [g].

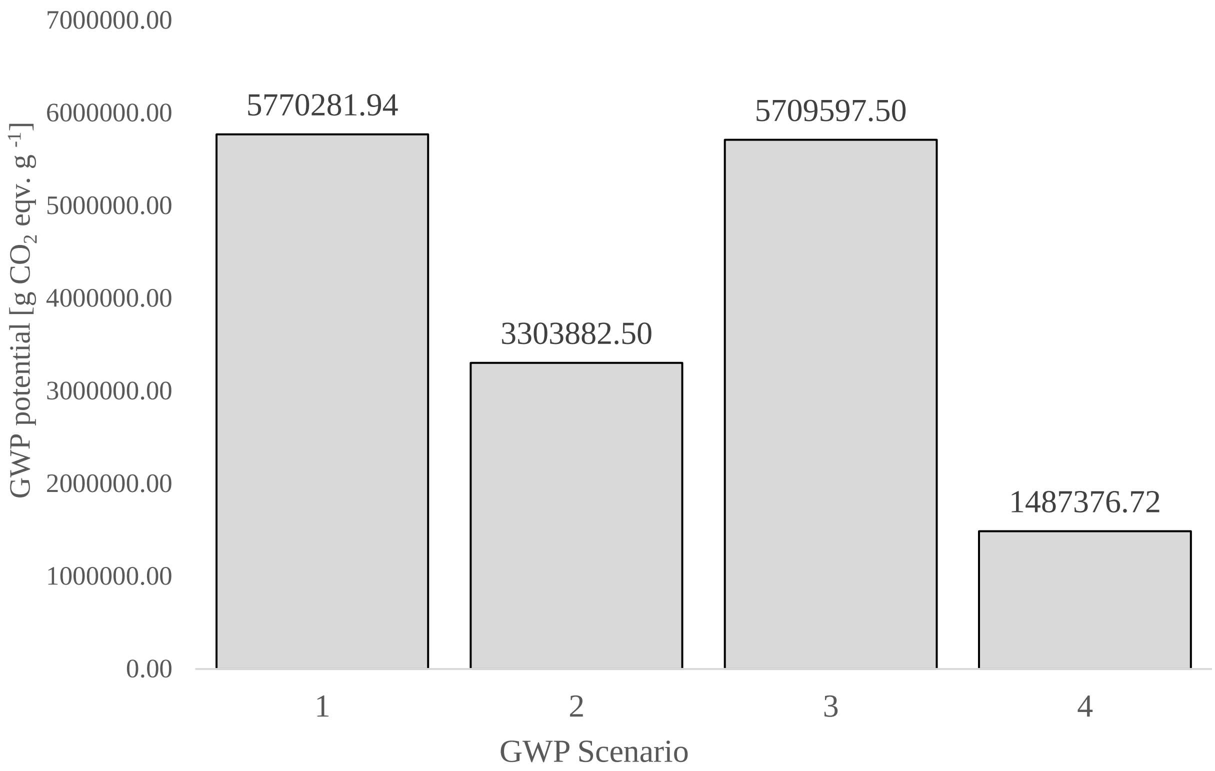
Fuel	g CO_2	g CH_4	g CO	g N_2O
Biogas	1223665.54	855.82	1651.57	810.77

Source: Author.

5.6. Global warming potential and break-even point

GWP calculations were performed for 1. Original scenario, 2. Zero loss scenario, 3. Current state scenario and 4. Optimal scenario based on previously calculated emissions of GHGs and their characterization factors. Figure 3 indicates reduction of GWP of all scenarios against scenario 1.

Figure 3. Annual global warming potential of different scenarios.



Source: Author.

Table 23 shows comparison of calculated GWP scenarios. Compared to the original state of using only fuelwood and LPG, every scenario using biogas resulted in GWP reduction.

Zero loss scenario draws from realistic data about households' energy consumption, however accounting for 0 % of methane loss can be considered as a barely achievable aim. In this case, the reduction of GWP by 42.74 % GWP represents a maximum extent of reduction while still using the current fuel mix.

Accounting for 40% methane aims to estimate current situation (scenario 3). Resulting GWP decrease by 1.05 % is a minimal change in comparison to the original state. The fraction of methane loss represents a worst-case scenario that can reasonably be projected to occur. The difference between the GWPs of Zero loss and Current state scenarios embodies a capacity to possible reduction. In reality, the amount of fugitive methane is often much lower. Study of Vu et al. (2015) suggests, that methane losses are between 5 % and 12 % of biogas production; usually made up by intentional release and then by technical difficulties; and as well concludes, that methane loss may outweigh the GHG emission savings.

In an optimal scenario of using biogas exclusively with 0% methane loss, GWP is reduced significantly, by 74.22 %. This represents best-case GWP scenario achievable by BGP utilization in the conditions of target area. To approach this scenario, it would be necessary to change the fuel mix ratio to prevalence of biogas. Preventing biogas leaks to minimum would also result to higher amount of biogas to be combusted, therefore generating more energy. Although this condition is rather difficult to achieve, it further emphasizes the dependence of energy generation and emission reduction on prevention of methane loss.

Table 23. Annual GWP reduction in comparison with Original scenario.

Scenario	GWP reduction [%]
Zero loss scenario	42.74
Current state scenario	1.05
Optimal scenario	74.22

Source: Author.

The break-even point of GWP was determined at 41 % of methane loss. At the break-even point, the negative impact of biogas production prevails in term of global warming. Break-even point was found close to the current worst-case scenario loss of 40 % reported by Brunn et al. (2014). The same research calculated break-even point of biogas replacing LPG at 16 % and fuelwood at 44 %. Results found in this thesis do not contradict the research of Brunn et al. (2014), although their research estimates break-even points for separate fuels and this thesis aimed to reflect the specific case of target area and calculated fuel mix. However, research results found in this thesis are providing support of conceptual premise building on previous results of Bruun et al. (2014) and further examining the topic at the real case studies.

6. Conclusions

The aim of this diploma thesis was to quantify the impact of using small-scale biogas plants in Vietnam to global warming. Data about households' energy consumption and fuel mix ratio were used to calculate current and potential GHG emissions resulting from cooking activities. These emissions were used to quantify the GWP of different scenarios, which were compared, and results were used to answer these research questions:

• To what extent did biogas replace the traditional fuels in purpose of households cooking activities?

Implementation of BGPs resulted in reduction of traditional fuel use, fuelwood by 57.3 % and LPG by 56.3 %, which results in financial benefits for the BGP owners. In addition, even partial replacement of fuelwood consumption by biogas results in reduction of the environmental pressure caused by unsustainable deforestation. While biogas covers 56.68 % of daily cooking energy, traditional fuels remain to complement the households' energy requirements. There is still a big potential for replacing traditional fuels by biogas to a greater extent, under the condition of better BGP management, especially by addressing the problem of biogas loss.

• How is GWP reduced as a result of partial replacement of traditional fuels by biogas?

Calculation of GWP in current state resulted in reduction by 1.05 % in comparison to the original state before BGP implementation. This reduction appears to be of a rather little significance to the reduction of global warming effect. GWPs of two potential scenarios were calculated in favour to quantify potential of GWP reduction. Zero methane loss, otherwise analogical to the current state, resulted in GWP reduction by 42.74 % in comparison to the state before biogas introduction; optimal scenario, using exclusively biogas resulted in GWP reduction by 74.22 %. These scenarios can only be approached, even if the technology is used appropriately, however the calculated results emphasize the potential of BGPs to reduce households' environmental impact.

• What is the potential percentage of biogas loss from leakage and intentional release to reach the GWP of break-even point, when the BGP is no longer beneficial to the environment?

Break-even point was found at 41 %, indicating that current state of BGP use is far below its potential in terms of global warming mitigation. This result also suggests that the problem of methane loss is crucial and should be addressed, to achieve, that the use of biogas technology is beneficial to the environment.

As environmental benefit is one of the reasons of small-scale BGP implementation, further research to identify their impact is recommended. Based on the results of this and other researches, it is recommended to support the improvement of BGP operation, ensure good technical condition and provide better training to the BGP owners.

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Appendices

List of the Appendices:

Appendix 1: BGP owners' interviews

Biogas Research Team

Household questionnaire – Field survey 2017

1. Basic and Regional Information:

1.1 Name ____

1.2 Region ____

1.3 Gender: ☐Male ☐Female

1.4 Age: __________ years

1.5 Highest achieved education of household head: ☐ Primary school☐ High school ☐University

☐ Without formal education

1.6 What is main household occupation?__________

1.7 Is your household involved in any off-farm activities? __________

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

1.9 How many members live in your household? __________

1.10 How many members of your household help to manage the BGP? __________

1.11 Who provided you training regarding BGP? ☐ AFFEC ☐ NGO, specify ______

☐ Private company ☐ Different, specify ____________

1.12 How much time (days) your training took? ____________

1.13 Have you received a certificate from your training? ☐ No ☐ Yes, specify________

2. Biogas plant

2.1 Please, describe (in detail) the process of requirements how did you get a BGP (including parameters, requirements (animals), administration procedure incl. approving):

____

____

2.2 Please, describe (in detail) the process of BGP construction (including preparation, construction):

____

____

____

2.3 What is the volume of your biogas plant? __________ m^3

3.11 How much money do you spend nowadays for fuels? __________ VND / month

3.12 Can you compare the environmental situation in your area before obtaining BGP and now?

____

4. Problems with biogas technology

4.1 In the table below are some common problems. If you have experienced this problem, please write how many times (a year) it occurred. Please write, what would you do in a case of this problem. Would you manage and what would be the solution? (a) Would you ask the facilitator for an advice? (b)

Problem	**How many times (a year)?**	**(a) Manage by yourself (b) ask for advice?**	**What is the solution?**
Insufficient biogas production			
Gas leakage (tank, holder, inlet, outlet)			
Insufficient input (not enough animals)			
Problems with composition of input (pH and C/N ratio)			
Problems with gas pressure (unstable, low)			

Biogas Research Team

Water condensate (gas supply system)			
Process breakdown (stopped working)			
Malfunction of a biogas cooker			
Malfunction of biogas lamp			
Health hazard (i.e. during cleaning)			
Unpleasant odour (around biogas plants)			
Bad smell of biogas (using the gas cooker)			
Gas combustion (poor flame, too much biogas in mix)			
Low quality and amount of digestate			

Other problems:			

5. Other comments / information:

____

____

____

Appendix 2: Masons' & biogas facilitators' interviews

Biogas Research Team

Facilitators questionnaire – Field survey 2017

1. Basic and Regional Information:

1.1 Name ____

1.2 Region ____

1.3 How would you describe your region?

☐ Feeding production region (for pork farming)

☐ Fruit growing region☐ Grain growing region ☐ Livestock processing (pigs, poultry)

☐ Forest products ☐ Non-timber forest products ☐ Other, specify ______

1.4 How many years of experience do you have as an extension worker? _____________

as a mason? _____________

1.5 How many BGP owners do you take care of? _____________

1.6 What is the frequency of visits of BGP owner per month? _____________

1.7 Who provided you with training regarding BGP? ☐ AFFEC ☐ NGO, specify ______

☐ Private company ☐ Different, specify _____________

1.8 How much time (days) the training took? _____________

1.9 Have you received a certificate from your training? ☐ No ☐ Yes, specify________

1.10 Do you have the opportunity to meet other facilitators/extension workers?

☐ No ☐ Yes, how often do you meet them________

1.11 What are your opportunities to study more and get new information about the technology?

____

1.12 Please, describe your weekly common activity? (i.e. training people, consultations, providing help with building, maintaining)

____

____

2. Process of gaining a BGP

2.1 Please, describe (in detail) the process of requirements how farmers gain a BGP (including parameters, requirements (criteria, animals, co-finance), administration procedure incl. approving):

____

____

2.2 How many days does the basic training about BGP management for BGP owners take?

_________ (days of training)

3. Life Cycle of Biogas Plant

3.1 Please, describe (in detail) the process of BGP construction (including preparation, construction):

____

____

____

____

3.2 How many workers are usually involved in the preparation of the terrain for the biogas plant?

________________ workers

3.3 How many workers are usually needed to build the biogas plant? ___________workers

3.4 How many days do workers usually work to finish the biogas plant? ___________days

3.5 How many bricks are usually used in the construction? ________________ bricks

3.6 How much cement is usually used in the construction? ________________ kilograms

3.7 How much sand is usually used in the construction? ________________ kilograms

3.8 How much water is usually in the construction? ________________ litres

3.9 What is the lifespan of the biogas plant? ________________ years

3.10 What do you advice farmers to do with the biogas plant at the end of its life?

____

3.11 Who is responsible for the biogas plant when it reaches the end of its life?

☐ Owners/households ☐ Government institutions (AFFEC) ☐ Other, specify_________

4. Transport of materials:

4.1 How the construction material is transported to farmers in your area?

☐ Farmers themselves ☐ Masons ☐ Construction company ☐ Other (please, specify _________)

4.2 Are there enough available possibilities in the area of Hue to acquire all necessary materials and components of the biogas plants?

☐ Yes ☐ No

4.3 Do farmers need to go to the city for materials and components of the biogas plants?

☐ Yes ☐ No

5. Problems with biogas technology

5.1 Here is a list of possible problems. Please write your advice to the problem. If you have been asked to advise the problem, please write if the owner acted according to your advice, managed to fix and how many times somebody asked you (per a year).

Problem	Your advice	Done according to your advice? (Yes / No)	How many times (a year) have you experienced this problem?
Insufficient biogas production			
Gas leakage (tank, holder, inlet, outlet)			
Insufficient input (not enough animals)			
Problems with composition of input (pH and C/N ratio)			
Problems with gas pressure (unstable, low)			

Biogas Research Team

Problem	**Your advice**	**Done according to your advice? (Yes / No)**	**How many times (a year) have you experienced this problem?**
Water condensate (gas supply system)			
Process breakdown			
Biogas cooker malfunction			
Biogas lamp malfunction			
Health hazard			

Biogas Research Team

Problem	Your advice	Done according to your advice? (Yes / No)	How many times (a year) have you experienced this problem?
Unpleasant odour surrounding BGP			
Bad smell of biogas (using the gas cooker)			
Gas combustion (Poor flame)			
Low quality and amount of digestate			

5. Services:

5.1 Do you offer advice when someone is interested in acquiring a biogas plant?

☐ Yes ☐ No

6. Other energy sources:

7.1 What are the major uses of electricity?

1) ____

2) ____

3) ____

7.2 What is the price for LPG (bottle of x m^3)? ____________ / VND

8. Other comments / information:

____

____

____