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Life Cycle Assessment of Small-scale Biogas Technology in Vietnam

Master's thesis

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Declaration

I hereby declare that this thesis entitled "Life Cycle Assessment of Small-scale Biogas Technology in Vietnam" is my own work and all the sources have been quoted and acknowledged by means of complete references.

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Abstract

Biogas technology is currently a widespread decentralised source of energy in rural Vietnam. However, the environmental sustainability of biogas production from small-scale biogas plants is questioned. The main detriments are the intentional release of surplus biogas, the difficult handling of the digestate, and the biogas loss due to cracks. Yet, the benefits of BGP, such as minimization of air pollution and odour, more efficient way of cooking than firewood, saved time and money, can compensate the downsides. In this master thesis, Hybrid Life Cycle Assessment was used to assess the CO_2 emissions of the whole life cycle and emissions reduction potential of household small-scale biogas plants (BGPs). Moreover, the study involved 123 personal interviews with the owners of BGPs focused on central Vietnam. Furthermore, survey results suggest that there is a total lack of training for farmers, in the use of biogas technology - most only received a very brief instructions manual. BGPs efficiency may be compromised, e.g. the wasted digestate produced, which can be a great natural fertilizer. Thus, there is a need to plan long-term supervision to ensure the operational life of the BGPs and its benefits. Finally, in developing countries like Vietnam, BGPs are a reliable technology to invest on in order to improve the environment and provide better livelihoods. The main conclusions from this study are as follows: 1) Small-scale household BGPs can reduce CO_2 emissions, making them a reasonable alternative from a climate change perspective, 2) Replacing firewood combustion with biogas for cooking can reduce the global warming potential (GWP) and 3) By using BGPs it is possible to diminish the presence of manure discharge lagoons and thus, reduce their related greenhouse gases (GHG) emissions.

***Keywords**: LCA, anaerobic digestion, sustainable rural development, environmental impact, climate change, renewable resources.*

Nomenclature

BGP	Biogas plant
GHG	Greenhouse gases
GWP	Global warming potential
LCA	Life cycle assessment
LCIA	Life cycle impact assessment
VND	Vietnamese Dong

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1 INTRODUCTION

There has been a remarkable growing of livestock production in south-east Asia, traditional small-scale farms have been transformed or substituted by large-scale production (Gerber et al., 2013). In order to improve manure management and reduce environmental impacts, there is a need to use simple and efficient technologies such as biogas technology. Since biogas technology can produce renewable energy and lessen global warming.

The local practice of Vietnamese rural households is to clean swine housing by removing liquid manure with water and taking away the solids for composting or storage. Therefore, liquid manure is usually released in the surrounding environment into lagoons, evaporating or leaching into the land (Vu et al., 2007; Thu et al., 2012). Small-scale biogas plants (BGPs) offer a reasonable alternative with several benefits. The most significant advantages are odour reduction, contaminant emissions lessening and biogas fuel produced (Pei-dong et al., 2007; Yu et al., 2008; Rajendran et al., 2012).

Rural households can use biogas for cooking, reducing fossil fuels usage, which helps to improve their livelihoods. Usage of biogas compared to the use of biomass fuel, leads to a reduction of contaminant emissions. However, emissions reduction potential is influenced by several aspects. There are also some disadvantages, such as wasted solid manure, unusable diluted digestate and biogas losses (Thu et al., 2012; Vu et al., 2012; Bruun et al., 2014). Key factors to minimise contaminant emissions are energy consumption, methane leakages, intentional releases, digestate utilisation and use of feedstock. The Life Cycle Assessment (LCA) identifies potential contaminant emissions during the whole life cycle of the household small-scale BGPs. Thus, the findings can help to draw conclusions for the improvement of biogas technology.

As an alternative manure managament, to firewood use, and in particular for the reduction of contaminant emissions, the utilization of biogas appears to be a reasonable option. Yet, there are various aspects (such as construction of the BGPs) connected to production processes that need to be taken into consideration, linked to the current utilization of biogas, feedstock, and to the viability of BGPs for rural households.

2 LITERATURE REVIEW

2.1 Introduction

Many scientific papers have been written regarding the wide topic of biogas technology to try to improve the different designs, and develop improvements or new technologies. While the literature comprises a broad diversity of the many themes of biogas technologies, this literature review focus on ten key topics identified recurrently through the studied literature. These topics are summarized in subchapters and are the following:

1) Biogas technology overview.
2) Description of small-scale BGPs in Vietnam.
3) Feedstock to produce biogas in BGPs of developing countries.
4) Utilization of biogas and digested residue.
5) Problems of biogas technology.
6) Benefits of biogas technology.
7) Anaerobic digestion and its merits.
8) Current situation with BGPs in SE Asia / Vietnam.
9) Life Cycle Assessment.
10) Life Cycle Assessment of BGPs.

While these topics are described in the literature in an extensive collection of different backgrounds, this diploma thesis focus on household small-scale BGPs in central Vietnam.

2.2 Biogas technology overview

Several authors have defined biogas as the result of the anaerobic digestion, a process that decomposes organic matter, such as manure, household organic waste, industry waste, sewage sludge and energy crops (Börjesson and Berglund, 2006; Raven and Gregersen, 2007; EBA, 2011; IEA, 2012; Rossano and Cividino, 2013; Budzianowski and Postawa, 2015). The mixture of the gases generated is the such commonly named biogas. Numerous authors and international reports have proven that biogas is a potential renewable and clean alternative energy that can replace other non-environmental-friendly types of energy, to cook, to generate hot water or vapour, or to produce electricity (EBA, 2011; IEA, 2012; Rossano and Cividino, 2013). As biogas is a renewable energy source, the energy balance of a country can be enhanced by using this technology. Moreover, it helps to safeguard natural resources and the environment, for instance; diminishing deforestation. substituting fossil fuels and reusing waste (Vögeli et al., 2014). In addition, biogas can be produced at different scale, from industrial plants, mainly done in industrialized countries, and at small-scale more common in developing countries (IEA, 2012; Rossano and Cividino, 2013; Tilley et al., 2014). This diploma thesis focuses on the household small-scale BGPs.

It is known that biogas technology presents several environmental benefits, for instance, it has potential for producing energy from renewable resources, as mentioned before. However, the analysis of biogas technology requires complex formulas and computations that would take into consideration the different existing technologies, the variety of uses for the digestate and the biogas produced, and availability of raw materials for feedstock (Berglund and Börjesson, 2006).

A large part of the literature pay attention to the big potential of biogas technologies. Since the beginning of the 21st century, we can appreciate a major improvement for biogas technology as prevalence of BGPs has been increasing at a mean annual growth of 8%. In line with its great potential, it can be seen that biogas is a renewable energy source growing fast. For instance, biogas represented 1.5 % of the global renewable energy sources in the year 2012 (IEA, 2012). Moreover, biogas systems are a common solution in the investments intended to make available clean cooking devices by 2030 in the rural areas of developing countries (IEA, 2012). Whereas in developing countries the effort is aimed to household small-scale biogas plants, mainly for cooking, in develop countries large-scale biogas plants are predominantly used to generate power and heat (REN21, 2013). Hence, it is clear that the use of biogas technologies in developing countries could be very beneficial for improving local communities daily lives and local environment. Unfortunately, there are some barriers (e.g. financial resources) holding back the further expansion of the biogas technology in least developed regions (Ni and Nyns, 1996; Christiaensen and Heltberg, 2012; Schmidt and Dabur, 2014; Truc et al., 2016). For developing countries the biogas technology represents two main improvements, compared to other renewable energies: a) it is possible to produce fertilizers from the organic waste generated and b) it is a clean methane fuel in comparison to other technologies (Taleghani and Kia, 2005; Chen et al., 2010; Thu et al., 2012).

As organic waste is created in big quantities and in different forms in developing countries but no proper management of it is done, it can be used to produce biogas. Much of the literature agrees that there are several resources that can be employed for such purposes. Manure from livestock production, organic leftover and surpluses from industries and households, and sludge from sewage management plants are the common feedstock for biogas plants (Schunurer and Jarvis, 2009). For example, the use of manure in household simple small-scale BGPS is an acknowledged reliable and cheap source of energy. In addition, Asian climate is propitious for the use of biogas technology, substituting fossils fuels, saving costs, having less environmental impact and it is used mainly for cooking in regions like China and India (Jiang et al., 2011; Nautiyal et al., 2015; Truc et al., 2016).

Biogas production process is done in a technical structure, the denominated digester, a totally hermetically sealed container where the organic material is placed (Raven and Gregersen, 2007). Retention time, feedstock used, temperature and digestion methods among other factors; influence in some degree the composition and properties of biogas. The regular composition of the biogas consist of carbon dioxide (25 – 50%), methane (50 - 75%), and variable fractions of water vapour, nitrogen, hydrogen sulphide and another elements (Berglund and Börjesson, 2006; IEA, 2012; Rossano and Cividino, 2013; Tilley et al., 2014). Methane is an inflammable gas, and its produced in anaerobic conditions by bacterial transformation of the organic matter. Moreover, it is the most important generated gas from the process, ~21 MJ/Nm3 is the measured heating value of biogas determined for average methane content ~50%. From the anaerobic digestion, the energy contained in the biogas is, chemically speaking, combined in methane (Seadi et al., 2008).

As a result of the anaerobic digestion of the organic waste by the bacterial action, separately from the biogas, a remainder is also produced, known as digestate. The nutrients bounded in it remain, but are mineralized to less complex and more soluble forms, converting the nutrients to more biologically useful forms. As the minerals from the organic waste in the BGP are separated and collected in the end product (digestate) in greatly concentration, in the case it exhibits good quality, it would be suitable to be used as organic fertilizer to substitute chemically based ones (Schunurer and Jarvis, 2009). In addition, Chen et al. (2012) reported that the digestate can be employed as a substitute for top-dressing and for its utilization to seed soaking. Hence, we can conclude biogas technology is even more beneficial for developing countries because not only covers peoples' basic needs such as energy but also provides them with a close circle solution, re-using the resources and substituting the commercial synthetized agro-chemicals. Finally, even the biogas residues such as digested wastewater, microbial solids (sludge) and leftover fibre, can be re-used (Lincoln et al., 1996; Sooknah and Wilkie, 2004; Harris et al., 2008; Wilkie, 2015).

2.3 Anaerobic digestion and its merits

Most of the literature conclude that the use of manure and human excreta in simple small-scale BGPs as feedstock for the digestion, is advised as a beneficial method to manage manure in smallholder farms (Steinfeld et al., 2006; Rofiqul Islam et al., 2008; Bruun et al., 2014). Households from our study area without BGP discharged all the manure into the immediate environment which can have serious negative consequences for human and environment health. Thus, for Vietnam rural areas, biogas production can help to maintain a cleaner environment.

Also, much of the literature attributes to the biogas technology, in the cases of both solid waste and wastewater, that the anaerobic digestion (AD) is a noteworthy process recovering energy as biogas. AD is a reliable and simple method with numerous benefits. Both Gujer and Zehnder (1983) and Parawira et al. (2005) stated that organic input is partially transformed in methane, then used to produce energy resulting in a reduced amount of sludge; since no aeration is necessary, less energy is needed.

As Rossano and Cividino (2013) described, anaerobic digestion takes place inside the digester producing biogas. By bacterial action complex forms in the organic matter are decomposed in simpler forms. Thus, generating carbon dioxide, methane and other products. Process four key stages (Figure 1):

1) Hydrolysis
2) Acidogenesis
3) Acetogenesis
4) Methanogenesis

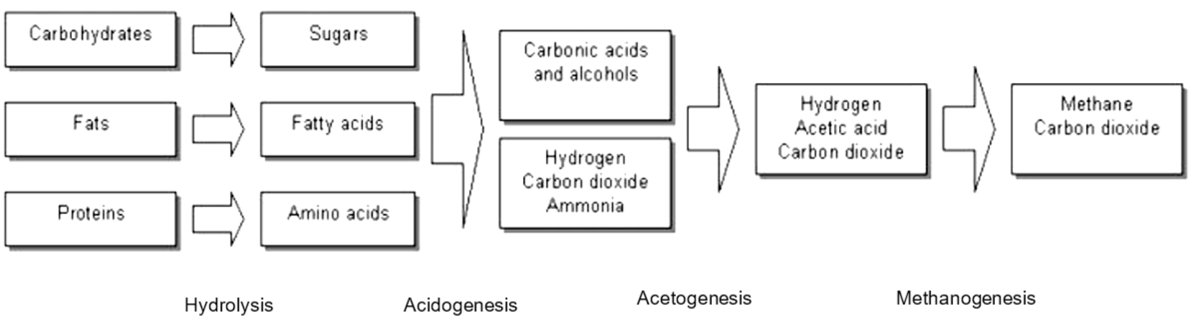

Figure 1. Stages of the anaerobic digestion and broken down of organic polymers into their smaller elements.

Source: (Rossano and Cividino, 2013)

The anaerobic digestion comprises numerous microorganisms, involving methane-forming archaea (methanogens microbes) and acid-forming bacteria (acetogens microbes). The initial feedstock is consumed by these microorganisms. Large organic polymers are broken down into their smaller elements, converted into intermediate molecules, such as acetic acid, sugars, and hydrogen, before ending with the biogas formed.

There are various temperature ranges in which species of bacteria can live. The psychrophilic bacteria live in temperatures of less than 25ºC, the temperature range of 35 – 40 ºC comprises the called mesophilic bacteria and the specie living in hotter temperatures, between 55 - 60 ºC are known as thermophilic bacteria (Balat and Balat, 2009; Rossano and Cividino, 2013). Balat and Balat (2009) provided similar classification for the bacteria depending on the temperature. Moreover, they concluded that for biogas production, anaerobic processes should be in the temperature ranges where thermophilic and mesophilic bacteria can proliferate, as they provide the most efficient conditions. In addition, to reduce the volume needed and the processing time, normally, high temperatures are required. According to Nijaguna (2006), temperatures below 10ºC interrupt the anaerobic digestion and consequently digesters build in cold climates must be insulated. Regarding process' pH, Seadi et al. (2008) determined that the pH also influences methanogens bacteria's growth and generally; the activity is optimum at pH values from 7.0 to 8.0, and acceptable between 5.5 and 8.5.

Another factor to take into account is the carbon/nitrogen ratio (C/N), since it can impact the production of biogas, depending in the amount of organic carbon and nitrogen existing in the feedstock. Ostrem (2004) clarified that high carbon/nitrogen ratios might reduce the methane produced, and a low carbon/nitrogen ratio may increase the pH to values higher than 8.5.

The following figure (Figure 2) summarizes the process of the anaerobic digestion from a supply chain perspective. It can be seen how the key three elements of the anaerobic digestion are expressed in more detailed, in a schematic way. These three key elements are: the substrate chain (input), the transformation process (AD process) and the product chain (output).

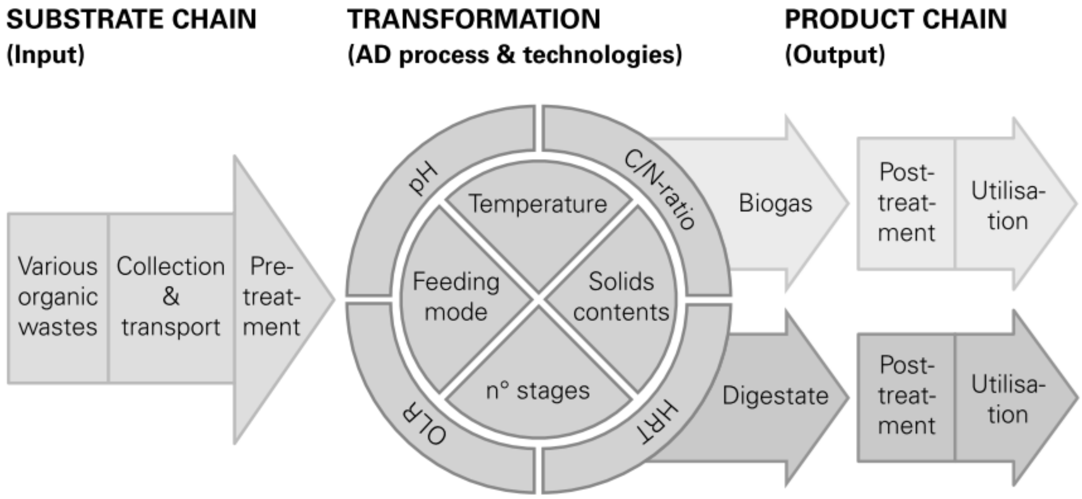

Figure 2. Process chain of the anaerobic digestion.

Source: (Vögeli et al., 2014).

2.4 Description of small-scale BGPs in Vietnam

A fundamental element in the design of a biogas system is a hermetically sealed tank called the digester and all digesters have two common elements: 1) a system to gather the biogas and the digestate (digested residue), and 2) a system to supply in feedstock (Seadi et al., 2008). The anaerobic digestion takes place inside the digester, and consequently the biogas is produced.

In the study area in central Vietnam, there are two common types of biogas plants (BGPs): the KT 2 and the KT 1 (Figure 3). Their designs are based on the Chinese fixed dome BGP design and the main parts are:

1) Mixing inlet tank
2) Digester
3) Compensation tank with an overflow outlet
4) Gas pipe

The difference in these biogas systems falls in the shape of the digester, designed either rounded as KT 2 or flat as KT 1 type. The KT 2 type has a flat shape strategic for the high water tables in Southern Vietnam, opposed to the KT 1 type that has a fixed dome shape - Figure 3 compares both BGPs types (Roubík et al., 2016). The KT 2 and KT 1 BGPs types have been designed in accordance to the standards 10TCN 97:102-2006 and 10TCN 492:499-2003 of the biogas sector, declared by the Ministry of Agriculture and Rural Development of Vietnam (Biogas Program for the Animal Husbandry Sector in Vietnam, 2012).

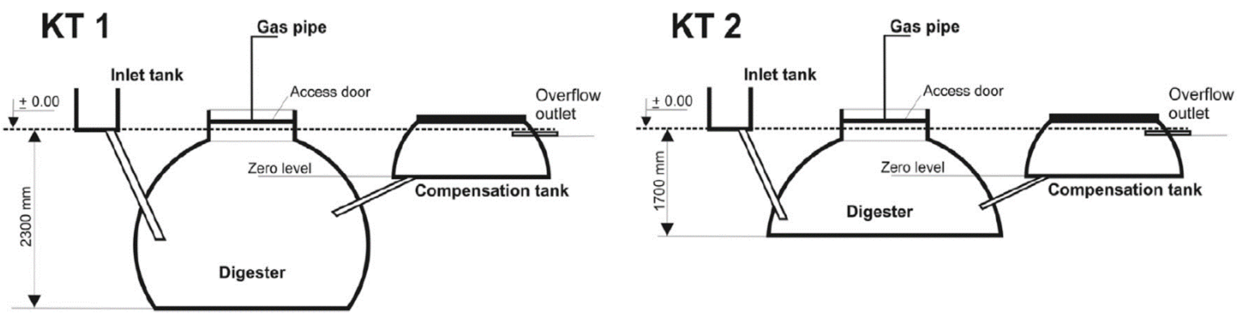

Figure 3. Scheme of KT1 and KT2 digesters.

Source: (Roubík et al., 2016)

2.5 Feedstock to produce biogas in BGPs of developing countries

The feedstocks or substrates are the organic input materials used for the anaerobic process, differing in moisture content, particle size and the easiness of decomposition (Vögeli et al., 2014). The sources of feedstock to produce biogas can be really diverse; from agricultural surpluses, slurry, industries by-products, to household organic waste and animal manure (Swedish Gas Centre, 2008). Therefore, the kind of feedstock employed in the biogas plants impact the quality level and the amount of biogas it can be produced (Seadi et al., 2008). Moreover, solid wastes like municipal and agriculture surplus were only began to be considered in the anaerobic digestion sector in the sixties, because of the great organic matter they contained. Thus, it could be used as a great potential source of organic matter for biogas production (Mata-Alvarez, 2003; Vögeli et al., 2014).

In many developing countries, for instance in South East Asia, where the climatic conditions are propitious for the use of biogas technology, the use of animal manure as feedstock to produce biogas has been acknowledged as a reliable and cheap source of energy (Truc et al., 2016). As seen from the literature the feedstock will depend on the local available feedstocks suitable for BGPs (Table 1). Whereas in China, the household small-scale BGPs are mostly the fixed dome type of digester and the main feedstock used comes from pig manure (Rajendran et al., 2012; Bruun et al., 2014); in India, is more used a mix of horse and cattle manure (Kalia and Singh, 1998; Bruun et al., 2014). Finally, in central Vietnam, pig manure is the principal source of feedstock for the BGPs and so it was used in our study area too. Farmers wash the manure out with water straight to the BGP inlet (Roubík et al., 2016). Table 1 presents a summary of all the general feedstocks that can be used for anaerobic digestion, from agricultural, industrial and municipal sources.

Table 1. Overview of the different feedstocks for biogas plants from different sources in developing countries.

Agricultural	Municipal	Industrial
Manure	Human excreta	Slaughterhouse waste
Energy crops	Organic fraction of municipal/household solid waste	Food processing waste
Algal biomass		Pulp and paper waste
Agro-industrial waste		Biochemical waste

Source: (Vögeli et al., 2014)

The content of dry matter in the feedstock defines the design of the digester. The types of digesters are typically categorized into dry digestion and wet digestion. A dry matter content of less than 15 % would relate to the wet digestion, while a dry matter content between 20 and 40 % would correspond to a dry digestion. Additionally, sewage sludge and manure are regularly related to the wet digestion, while crops and solid manure generally are associated to the dry digestion (Seadi et al., 2008).

Depending on the feedstock output and input, digesters are additionally categorized into: continuous and batch. In the batch-type, the digester is loaded at once, and when the feedstock is digested, then it is entirely removed. This type is often used for dry digestion and it is the easiest to build. Alternatively, in the continuous-type digesters the feedstock is constantly put in the digester and constantly removed. When compared side by side with the batch-type digesters, the continuous-type generate biogas uninterrupted (Seadi et al., 2008).

Finally, several factors such as the location, purpose and comparative size of the BGPs, and considering for instance the agriculture related biogas plants can be used to categorize biogas plants. The three categories are: centralized plants, household small-scale plants and commercial farm scale plants (Seadi et al., 2008). Therefore, it is possible to design and build the best biogas plant which will provide the most efficient results for each region because many factors must be taken into consideration.

2.6 Utilization of biogas and digested residue

Much of the literature coincides that biogas can have multiple applications, such as its utilization to generate vehicle fuel, electricity and heat. Likewise, it can be also used for cooking or lightning, directly burning the biogas (Lantz et al., 2007; Seadi et al., 2008; Swedish Gas Centre, 2008). Therefore, the application of biogas will depend on the socio-economic situation of each case.

It is known that the main use of the biogas produced in household small-scale BGPs in developing countries is for cooking (Ferrer et al., 2009; Gautam et al., 2009; Rajendran et al., 2012). For instance, the quantity of biogas utilized for cooking can be up to 30 - 45 m^3 monthly (Rajendran et al., 2012). In countries like China and India, simple biogas technology is being used by millions of households and small farmers to satisfy their main demand of household energy (e.g. cooking and lighting) (Jiang et al., 2011; Nautiyal et al., 2015; Truc et al., 2016). Specifically, in Vietnam the most suitable application is taking advantage of biogas by small-scale BGPs to treat pig manure and produce the biogas for cooking purposes. Therefore, for developing countries' households, the simplest and straightforward way to benefit from biogas energy is the direct burning in stoves for cooking and consequently they are substituting other tradition cooking fuels like wood or charcoal (Bond and Templeton, 2011). Finally, in general, CO_2 and H_2S gases are not eliminated from the gas mix regarding cooking purposes (Vögeli et al., 2014).

Moreover, the remaining biogas in the BGPs, could be utilized for heating (Axaopoulos and Panagakis, 2003; He, 2010; Rajendran et al., 2012). Unfortunately, most of the literature does not mention electricity generation in developing countries, as it is complicated given the circumstances of precarity people from rural areas face in countries like Vietnam. In addition, the costs and amount of biogas production required to use the biogas to generate electricity make it unsuitable for small-scale BGPs in rural communities.

As described in Biogas technology overview (subchapter 2.2), separately from the biogas, in the anaerobic digestion, the feedstock is reduced to the digestate and that can be used as organic fertilizer straightforward in farming (Shyam and Sharma, 1994; Rajendran et al., 2012). In the digestate we can find concentrated nutrients from the feedstock, organic material, water and microorganisms which are appropriate to be used as natural fertilizer (Vögeli et al., 2014). The digestate product is an improved fertilizer easier to be absorbed by the plants as it has more inorganic nitrogen and better nitrogen – phosphorus balance (Garfí et al., 2011a, 2011b; Rajendran et al., 2012). In addition, as a general rule, the digestate from the anaerobic digestion is a valuable fertilizer regarding its chemical conformation; plant nutrients like potassium (K), nitrogen (N) and phosphorus (P) as well as trace elements critical for the plants to grow are present in the digestate (Lansing et al., 2008; Gautam et al., 2009; Rajendran et al., 2012; Vögeli et al., 2014). Moreover, previous research have proven that the raw manure is a worse option as natural fertilizer than the digestate (Seadi et al., 2008). Additionally, the digestate can be employed as pesticide too, for vegetables and fruit trees (Song et al., 2014). However, there is a risk of pathogens existing in the digestate, for this reason, spray irrigation directly onto vegetables should not be done without a pre-treatment (Mang and Li, 2010; Vögeli et al., 2014). Finally, the solid surplus and the remaining clean fluid of the digestate can be used together with the feedstock employed, to feed pigs to speed up the growth of the animals (Qi et al., 2005).

2.7 Problems of biogas technology

As mentioned in previous chapters, many types of raw materials from numerous sources, can be utilized as feedstock for BGPs. However, waste recycling, storage, transportation, processing, collection and ultimate use can implicate different kind of problems. For instance, agricultural surpluses often need to be processed and shredded to improve the anaerobic digestion and to have an unproblematic flow into the digester. Some raw materials will also need a drying time to improve the efficiency of the digestion and produce more gas. Furthermore, the storage of raw materials can present certain problems as the possible start of bacterial action if the conditions are not suitable, therefore limiting the time the materials can be stored. Whereas, bacterial action can cause some gas losses, but at the same time it benefits the process of the digestion reducing the time need for the digester to start functioning (Da Silva, 1979).

The difficulty involved in the daily operation of small scale BGPs, such as do not overfeed the digester with water and/or manure; is one of the most decisive factors for households. Moreover, the need to be user-friendly is essential considering that the constant operation of the plant is more important than its setting up, and in addition, because the economic savings are not so significant for majority of rural households.

Furthermore, in the BGPs the digester requires to be fed on a regular basis with a certain amount of manure. This factor can also cause a problem if the user is not entirely committed to take care of the feedstock to ensure a good long term operation or if the availability of the manure is limited. The labour and time needed for the digester regular maintenance, e.g. gather the feedstock and mix it with water, should be taken into account as an operational cost (Mulinda et al., 2013). This leads us to talk about the economic costs of the biogas production in developing countries. As the economical situations of the individuals interested in biogas technology can play a limiting role in developing countries (Ni and Nyns, 1996).

The high initial investment might be the main drawback in most of the cases. Moreover, apart from the construction, the labour required for maintenance should be taken into consideration. The investment will depend, mostly on the location, the subsidies available and the size of the system (Sectors, 2014). In addition, investment in maintenance, repairs and operation of the technology in developing countries is necessary for the long term successful development of the technology (Bond and Templeton, 2011).

Therefore, studies like that by Roubík et al. (2016) reported several findings (Table 2), which show the problems of biogas technology in central Vietnam.

Finally, the biogas technology in rural areas is usually promoted thru subsidies by governments, but after some time using the technology, if the users find that their needs cannot be covered, they lose the interest on it because they expect few problems and convenience of unstopped biogas production. Accordingly, regarding the interest of the adopters of BGPs, there is a need for more efforts in the future; improvements in the technology and in the implementation of strategies in order to take advantage of the multiple benefits of the biogas technology (Ni and Nyns, 1996; Rajendran et al., 2012).

Table 2.Subsystems and failure criteria description and recommendations for the biogas technology.

Subsystem	Failure description	Further studies describing similar problems and country of study	Recommendation, possible solutions and notes
Structural components	Problems with the inlet pipe	Cheng et al. (2014) Nepal	Clean the inlet pipe with stream of water or with a long stick
	Unstable BGP in rainy season	N/A	Appropriately selected BGP and higher skills from masons
	Inconvenient position of BGP components	Cheng et al. (2014) Nepal	The BGP is too far from animal sheds, the inlet pipe is at an inappropriate slope, the outlet tank is too remote to be reached. These are in the competence of skilled masons and facilitators
Piping system	Leakage in piping system	Sovacool et al. (2015) Kenya, Cheng et al. (2014) Nepal	When the pipe is not connected adequately. The connections between the valve and the pipe or between pipe and nipple are not working properly. The gas pipe is corroded. When necessary, the pipe line should be replaced or repaired by facilitators/masons.
	Blockage of piping system	Cheng et al. (2014) Nepal	When the pipe line is overhanging for long time, and if no water filter is available water may be condensed within the pipe. Use of a water filter and regular use
Biogas utilisation equipment	Malfunction of biogas cooker	Pipatmanomai et al. (2009) Thailand, >Thu et al. (2012) Vietnam, Cheng et al. (2014) Nepal	Malfunctions of biogas cooker are diverse in origin such as corrosion, a broken gas tap, and a broken flame pedestal or a blocked air injection hole. Corrosion can be reduced with a H_2S filter, other problems solved by appropriate use of fire and higher quality cookers, which should be recommended by facilitators
	Malfunction of biogas lamp	Cheng et al. (2014) Nepal	Biogas lamps are rarely used due to the low price of electricity and its accessibility
Digestate disposal system	Poorly accessible reservoir for digestate	N/A	When the reservoir is inappropriately located, it creates difficulties with further digestate management. It is the responsibility of masons and facilitators to think it through
	Lack of organic matter in digestate	Thu et al. (2012) Vietnam	High water levels: manure ratios cause a lack of OM in the digestate. The ratio should be around 3–6:1. Knowledge should be transmitted via local facilitators
AD process and biogas production	Leakage in reactor	Chang et al. (2011) China, Lam and >Heegde (2012) Asia and Africa	When the digester is not made properly, the pressure from inside the digester pushes the gas out. It can lead to the elimination of the functionality of the BGP. Masons must be skilled enough to avoid problems with digester. In cases of significant leakages, the BGP must be fully rebuilt.
	Solid digestate incrustation >floating in the main tank	Cheng et al. (2014) Nepal	A scum layer on the surface preventing biogas from going through it. The BGP must be opened and cleaned
	Lack of biogas	Thu et al. (2012) Vietnam	Can be caused by the poor quality of biogas (a slow concentration of methane), or by a lack of organic matter. Can also be caused by process breakdowns. BGP owners should be sufficiently informed by facilitators
	Poor quality of biogas	Pipatmanomai et al. (2009) Thailand	The quality of biogas depends on the individual components and its methane concentration. This is affected by temperature, the presence of oxygen, feedstocks, hydraulic retention time etc.
	Smell of biogas	Pipatmanomai et al. (2009) Thailand, >Thu et al. (2012) Vietnam	Any bad smell from biogas can be removed by the use of a H_2S absorbent. In the case of a simple carbon filter, it must be cleaned every two months
	Lack of feedstock/Over-size of BGP	Singh and Sooch (2004) India, Chen et al. (2012) China, >Thu et al. (2012) Vietnam, Cheng et al. (2014) Nepal	When farmers reduce the number of animals, there are no longer appropriate amounts of manure, animals are not feed regularly or manure is not moved to the inlet tank. Also over-size a BGPs are a problem, partly due to the reasons mentioned above (can also be caused by the under-sizing of the BGP leading to an oversupply of biogas. Facilitators and masons should be aware of importance of proper BGP sizing
	Breakdown of AD process	Thu et al. (2012) Vietnam, Cheng et al. (2014) Nepal, >Chang et al. (2011) China, Sovacool et al. (2015) Kenya	There are many parameters affecting the AD process, such as: an inappropriate pH, an unbalanced C:N ratio, low temperature and large temperature fluctuations, and the existence of inhibitors. Inhibitors can originate from inappropriate cleaning chemicals in pig-pens, feeding additives like growth hormones, antibiotics and heavy metals. There is a need to consider all of aspects and BGP owners must receive sufficient information concerning them.
	Oversupply of biogas	Limmeechokchai and Chawana (2007) Thailand	Consequences are because of farmers releasing biogas into the atmosphere: making a contribution to the GHG due to the presence of methane.
Knowledge related problems	Lack of knowledge by respondents Unsatisfactory knowledge of masons Unsatisfactory knowledge of facilitators	Zhou et al. (2011) China, Zurbrugg et al. (2012) Indonesia, >Uddin and Mezbah-ul-Islam (2012) Bangladesh, >Amjid et al. (2011) Pakistan, Agyenim and Gupta (2012) Ghana	There is need for a functioning transmission of information from the large-scale level via local facilitators to the target group of BGP owners
Further non-technical problems	Proliferation of mosquitoes (*Anopheles* sp.) >on the outer surface of BGP	N/A	The solution may be to cover the surface of the BGP, even if we lose direct access to its surface and risk possible leakages.
	Lack of finance Cultural and social obstacles Political restrictions Lack of land	Singh et al. (1996) Himachal Pradesh, Chen et al. (2012) China, >Zhou et al. (2008) China, Zhou et al. (2011) China, >Thu et al. (2012) Vietnam	Solving non-technical problems should be within the competence of local facilitators, local authorities and national level authorities

Source: (Roubík et al., 2016)

2.8 *Benefits of biogas technology*

Nowadays, developing countries need to face many challenges like the complicated environmental pollution and its complex effects in human and environmental health among others, as well as economic development and lack of access to modern technologies (Smith, 2013). Therefore, the adoption of the biogas technology will implicate a positive impact for the environment. For instance, regarding the deforestation caused by collection of firewood, and the reduction of time and labour invested to collect and transport coal or wood. Such aspects consequently help with the conservation of local energy resources and ecosystems services. Moreover, biogas technology can improve the living conditions and health of the rural communities because the waste products generated by the families can be re-used. Furthermore, it helps killing pathogens and parasites and maintaining a pollution-free environment in the households. As a final point, the adoption of biogas technology has the benefits of self-sufficiency and self-reliance for the users (Da Silva, 1979).

Several authors agreed and reported that biogas technology decreased odours and creates less smoke inside the house compared to other types of fuels employed in developing countries. In addition, it also originated job opportunities, and the demand of firewood and fossil fuels diminished, which is a positive signal for environmental protection (Yu et al., 2008; Chen et al., 2010; Khoiyangbam, 2011; Bruun et al., 2014).

The development of the biogas technology and its distribution should consider the interests of the users and be implemented at the national level. Biogas plants present exceptional application value because of the relative advantages offered compared to other technologies. Therefore, developing countries have a great opportunity with the multiple benefits of the biogas technology (Ni and Nyns, 1996). Much literature concludes that household small-scale BGPs have been supported by governments and development organizations. Many of them in Asia, particularly in Vietnam, China, Bangladesh, India, Tibet and Pakistan (Feng et al., 2012; Ghimire, 2013; Bruun et al., 2014). This fact can also be read in many international and/or national organizations and institutions, such as the SNV development organization.

The studies stress out the benefits of using biogas technology to solve problems with electricity and fuel availability. In addition, they mention biogas products provide organic fertilizer for crops and it can offer other socio-economic benefits (Da Silva, 1979;

Seadi et al., 2008; Bond and Templeton, 2011). For example, the Sustainable Energy Technology Management (SETM) of Nepal reported several socio-economics benefits related to the biogas use. Male participation in the kitchen activities increased, biogas technology was recognized as social capital, it allowed more time for other household activities, it creates better health status and it generates employments opportunities (Katuwal and Bohara, 2009; SETM, 2014). This benefits are consistent and similar results can be read in other scientific papers and reports cited in this subchapter, such as the benefits reported by Ni and Nyns (1996) reviewed before.

Farmers do not need to waste time going to collect or buy firewood because the feedstocks needed for the biogas plans are generated in the house (Xiaohua et al., 2007; Thu et al., 2012). Therefore, the use of biogas technology can also positively reduce the amount of working-hours farmers must dedicate to their fields. In addition, Teune (2007) agrees and added that this way BGPs can help to lessen farmers' poverty and favour sustainable development.

2.9 *Current situation with BGPs in SE Asia / Vietnam*

Ho et al. (2015) and Vu et al. (2012) detailed that there are approximately 90 million people in Vietnam, about 70 % depend on agriculture. Moreover, they agree that the rapidly increasing demand for meat and growing population have caused the quickly expansion of the livestock sector. In Vietnam, livestock farms are mainly household-scale and the current development of these farms is causing challenges to be tackled. Numerous problems connected with the management of the animal waste; for instance, environmental contamination by human pathogens, GHG emissions and odour (Vu et al., 2012; Ho et al., 2015). In addition, several authors agreed and concluded that the animal waste (urine or manure) is mostly not treated because of the lack of governmental regulations, money and awareness of the farmers, which clear the waste straight into the environment, creating lagoons (Ho et al., 2015; Vu et al., 2015).

Typically, in Vietnam, the farms are run by a single family at small-scale level. Usually, pigs and the pigs housing, is cleaned with water to remove the solids in the excrements and cleaning also the liquids (Vu et al., 2007; Thu et al., 2012). Much of the literature agrees that the adoption of biogas technology can be a great alternative, considering the multiple benefits that it can offer. Biogas production, lessening of contaminant emissions and odour, are the most important benefits (Pei-dong et al., 2007; Yu et al., 2008; Rajendran et al., 2012).

Moreover, it has been analysed and stated by several papers and international reports that it is possible to decrease the use of liquid petroleum gas (LPG), coal and firewood with the adoption of the biogas technology (IEA, 2006; Chen et al., 2010; Bruun et al., 2014; Singh and Gundimeda, 2014; Vu et al., 2015). Heating, cooking and lightning are the main possible uses of biogas for households, therefore impacting in a positive way helping to improve the livelihoods of the farmers.

Nowadays, in Vietnam exists a wide offer of subsidies to support the biogas technology. Most of these subsides come via non-governmental organizations offering sustainable development aid from the World Bank, the Netherlands and the Asian Development Bank. Furthermore, the Vietnamese government also gives its support. Hence, during the last two decades there has been a considerably increasing in the number of biogas plants. For instance, in 2007, more than 200,000 biogas plants were operating in Vietnam (Teune, 2007). Currently, according to Mayhew (2015) and Ho et al. (2015), there are about 500,000 installed BGPs in the country used predominantly for pig farms.

On the other hand, the solid manure that would be usually gathered and added after to fishponds, gardens, or fields, is all mixed into the digester (Vu et al., 2012). Solid manure, water, and urine are washed out into the digester and, consequently, diluted. As a result, the digestate is not reused in gardens or fields because its liquid state represents a problem for its transportation and distribution (Thu et al., 2012). Another common problem is the release of contaminant emissions, like methane, potent GHG. Methane release is often caused due to cracks in the digester. Also, it is due to intentional releases of biogas when excess of production (Bruun et al., 2014).

Another common problem in BGPs is the presence of high amounts of solids from the digestate that are floating in the digester, that cause a reduction in biogas production. Unfortunately, local facilitators are normally incapable of provide the necessary technical help in order to fix the problem (Roubík et al., 2016). BGPs originally designed for a smaller scale are filled with more amount of feedstock than the original design allows. Thus, impacting negatively the retention time and the methane production potential. Additionally, this might produce more biogas exceeding the needs, due to the increased input of manure (Ho et al., 2015; Vu et al., 2015). Then, the surplus of biogas production would be intentionally discharged into the air (Bruun et al., 2014; Ho et al., 2015; Vu et al., 2015). For instance, in the south of Vietnam, biogas losses due to intentional releases was assessed as up to 36 % of the biogas production (Bruun et al., 2014; Vu et al., 2015). Therefore, the avoidance of intentional releases of biogas is necessary to have a reliable energy supply of biogas. Adjusting then the consumption to prevent the excess of biogas production. According to Vu et al. (2015), intentional releases could be even worse due to the growing usage of commercial animal feed. Farmers do not have the necessity to prepare and cook traditional feeding for the animals, rich in fibre. For example, as in the north of Vietnam pig farms are usually smaller and consequently biogas production lower during winter, the intentional release is supposed to have a smaller print than in southern Vietnam (Vu et al., 2015).

Additionally, it would be worthy for the farmers to keep operational the digester and prevent possible leaks or cracks (Bruun et al., 2014). The loss of methane (CH_4) due to leaks from cracks and the intentional release of the surplus of biogas has a substantial impact in global warming (Vu et al., 2015).

Unfortunately, with the intensification of the livestock production, the mentioned problems in the previous paragraphs are becoming graver (Costales et al., 2006; Steinfeld et al., 2006; Zhu, 2006; Jiang et al., 2011; Vu et al., 2012; Vu et al., 2012; Vu et al., 2015). Even though, there are positive solutions for most of the mentioned problems. For instance, Vu et al. (2015) concluded that BGPs can be a potential technology to reduce global warming reasonably easily if the methane (CH_4) emissions can be limited.

2.10 Life Cycle Assessment

Over the last decades the environmental awareness and concern has been on the rise, for this reason assessment tools were designed to define what are the environmental performances of different services and products (Klöpffer, 2006; Simonen, 2014). Improvements in the technologies are required, from an environmental point of view and a sustainable development, thru the life cycle of a particular service or product.

According to Simonen (2014), the support of decision making with scientific facts and data, expertise, and sets of standards; represent the major benefit of the Life Cycle Assessment (LCA) methodology. The general framework for a LCA is represented in Figure 4.

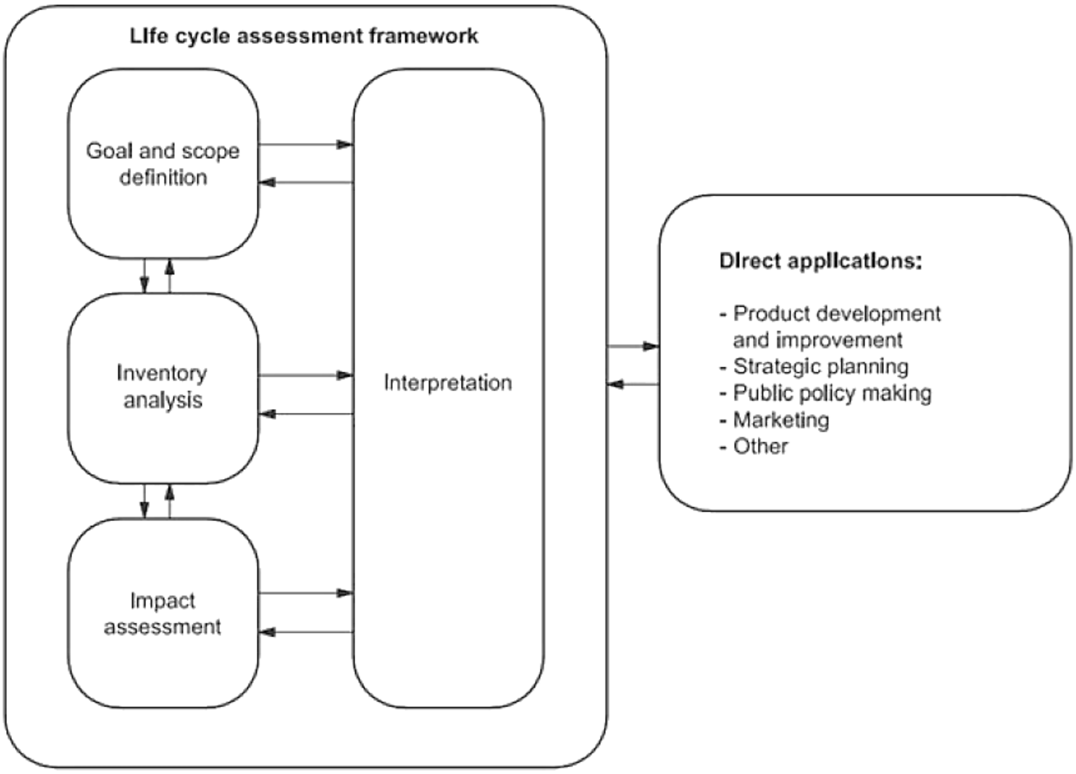

Figure 4. General framework for LCA.

Source: (Curran, 2017).

The right questions must be planned for a relevant LCA study in order to get the expected results as the goals defined influence the planning of the methodological framework of the study. Determination of the function of the studied system involves establishing performance characteristics, consistent with the goal and scope in order to determine a functional unit; with a quantitative measure that can be compared with all the modelled flows (Klöpffer, 2006; Curran, 2017).

Interpreting an LCA study implies assessment of the results and drawing conclusions. The findings should coincide with the defined goal and scope; but an LCA might lead to unexpected results and then might be disconnected from the original study goals and scope. There is an inventory analysis stage which structures a flow model of the relevant environmental flows, activities that will form a flowchart in accordance with the system boundary and data collection. Then the calculation follows connected to the functional unit. The impact assessment step of the LCA transforms the data collected into the shape of environmental impacts, letting the study results to be environmentally comprehensive and applicable (Klöpffer, 2006; Curran, 2017).

According to the intention of the study, it is possible to anticipate by the goal definition of the LCA to work with a narrow choice of environmental impact categories, for instance climate change in carbon footprint studies. In addition, impact categories must be coherent with the LCA goal. All significant environmental problems of the evaluated system should be covered by the choice of environmental impact categories. An exception is possible if the limitations were defined in the goal definition of the LCA study. For instance, in carbon footprint studies, which climate change impact category is the solely significant influence to be contemplated (Joint Research Centre, 2010). Among other tasks, impact categories selection is something that all LCA experts need to confront regularly, it is a crucial choice for which minimum assistance exists in the literature (Curran, 2017). Life Cycle Impact Assessment (LCIA) purpose (Figure 5) is to use the inventory data to get to the findings and conclusions (Joint Research Centre, 2010).

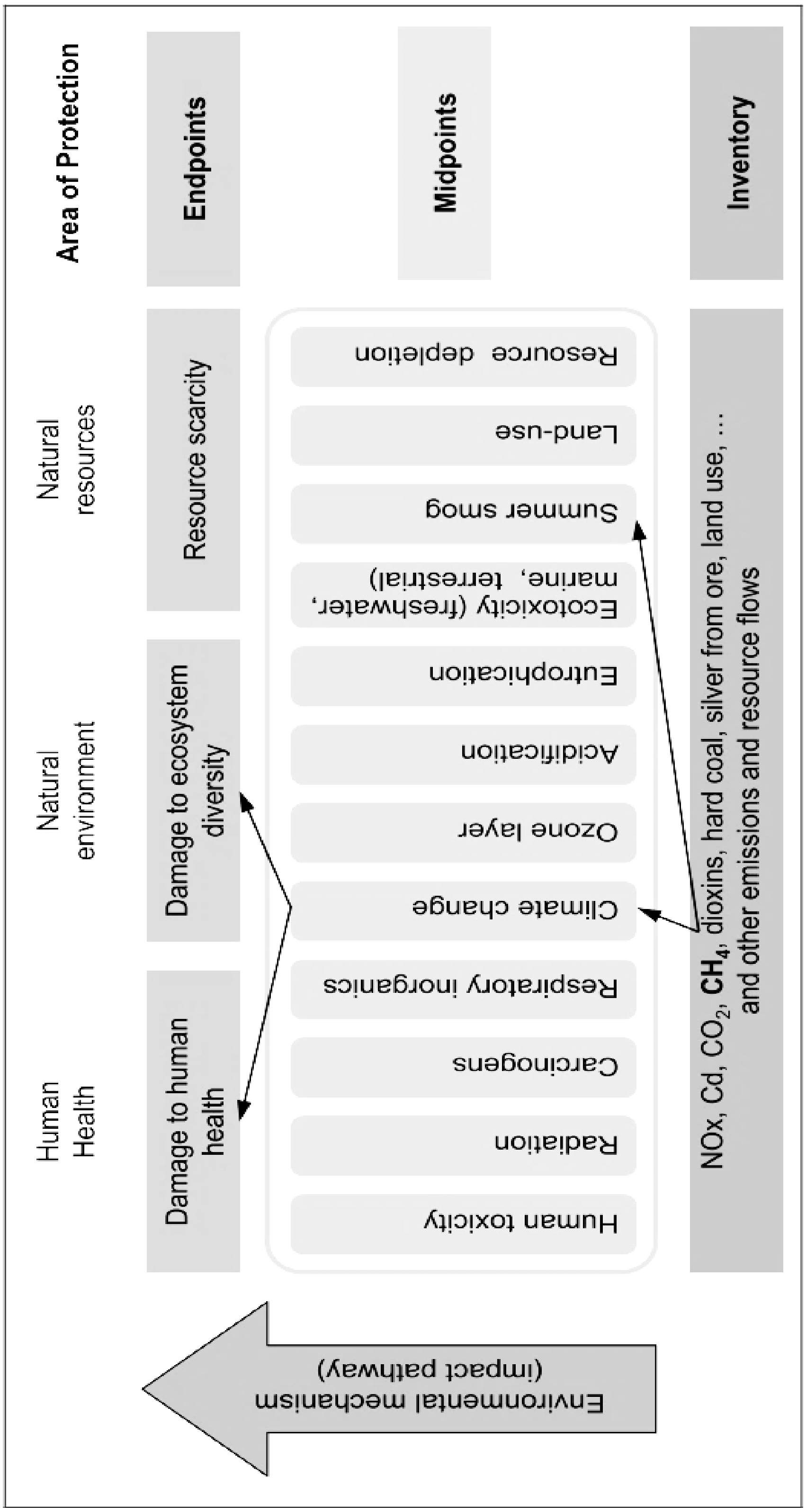

Figure 5. Life cycle impact assessment - schematic steps from inventory to category endpoints. Source: (Joint Research Centre, 2010).

2.11 Life Cycle Assessment of BGPs

Wolf et al. (2012) stated that a useful function of LCA is to compare how, thru their life cycle, different products impact the environment. Hence, deciding which one is a better option for each particular situation. Accordingly, with the intention to compare different biogas technologies, the life cycle assessment has been used in some studies (Rehl and Müller, 2011; Poeschl et al., 2012). Biogas technologies to produce biogas from co-substrates and from manure have been the aim of various studies (Rehl and Müller, 2011; De Vries et al., 2012; Poeschl et al., 2012). However, the enormous number of small scale BGPs being installed in developing countries have received the attention of only a limited number of studies. Only a few studies have covered the issues of methane leaks and the recycling of nutrients, as Vu et al. (2015) observed. It is a big problem that even carefully maintained and advanced BGPs systems can present important unintended emissions of methane (Flesch et al., 2011).

Regarding the life cycle, the energy efficiency of fossil fuels is considerably better than biomass fuels, but fossil fuels are non-renewable resources and therefore, they are not sustainable (Singh and Gundimeda, 2014). On the other hand, biogas is an appropriate option, as it is a sustainable solution for cooking purposes. For instance, India has three decades of experience in biogas technology and biogas can be generated from renewable organic waste (Singh and Gundimeda, 2014). Moreover, in the Indian context, the availability of waste resources provides with better life cycle energy efficiency. In China, LCA clarifies that household small-scale BGPs projects would be an effective approach to encourage the mitigation of harmful environmental emissions (Zhang, 2016). Vu et al. (2015) did an LCA study of small-scale BGPs and concluded that it can be an effective technology to reduce global warming if methane (CH_4) emissions can be limited. Biogas as renewable energy is of special importance regarding the reduction of CO_2 footprint of energy systems, always that efficient biogas technology and best practices are employed. For instance, in certain regions biogas technology could reduce the CO_2 footprint and enhance the health and livelihoods of inhabitants. Therefore, biogas technology can improve regional sustainable development (Budzianowski and Postawa, 2015).

2.12 Brief conclusions of the literature review

Based on the literature review we can summarize the major achievements in the field of small-scale BGPs as follows:

- Proven benefit through LCA methods of the possible mitigation of climate change if the household small-scale BGPs are maintained and handled properly by the farmers.
- Socio-economic benefits reported by numerous scientific papers and international reports.

On the other hand, we concluded the main topics of current debate such as:

- Methodological problems, little guidance of LCA methods and indicators, as well as a lack of more general standard adopted by all the studies on the small-scale BGPs topic in order to compare them easily.
- There are two important points that the existing literature fail to analyse in more detail.
    1) The specific reasons why the owners of BGPs are not better trained in biogas technology and what is the origin of this problem;
    2) Lack of studies focusing, specifically, on how to improve the incorrect operation and maintenance of BGPs, either focusing on designing better training programs and supervision plans, or finding other solutions.

3 AIMS OF THE THESIS

The main aim of this thesis is to study whether the use of biogas for household consumption is reasonable from a climate change perspective, identifying potential contaminant emissions to assess the suitability of biogas technology. Our research aims to answer the following questions:

- Is small-scale biogas production in central Vietnam a better alternative than the traditional use of firewood?
- Is the use of biogas for household consumption reasonable from climate change perspective?

To answer the research questions, this diploma thesis focuses on the calculation of contaminant emission during the life cycle of the small-scale BGPs. Quantification of CO_2 emissions is carried out by using life cycle assessment (LCA) methodologies and approaches based on standard protocols of the Intergovernmental Panel on Climate Change (IPCC) and on similar research papers.

Based on primary data from the interviews and the modelled flowchart of the LCA, it is possible to create a parameter model for the focused scenario of this thesis. It permits to identify the limitations and constraints of the model and to propose strategies for future improvements as well as investigating the possibility of using the parameter model on other biogas projects or studies.

The specific aim of this LCA study is to figure out the CO_2 emissions during the phases of the life cycle; as well as the calculation of the CO_2 emissions reduction potential of the biogas technology. Therefore, we use LCA methodology to assess the environmental impact associated with small-scale household BGPs in central Vietnam, in order to determine whether the current employment of small-scale household BGPs has a positive or negative environmental impact in the region.

4 METHODOLOGY

The methodological approach used in this diploma thesis includes primary and secondary data of quantitative and qualitative nature. Moreover, triangulation of different research methods has been used.

4.1.1 Primary data sources

The primary data source was our survey using personal interviews based on structured questionnaires (Appendix 1). The questionnaire was divided into different sections: 1) Personal details; 2) Farm data; 3) Livestock; 4) Feedstock and digestate; 5) BGP use; 6) Maintenance and operation; 7) Construction; and 8) Information about biogas technology. The focus was to collect inventory data for the LCA of BGPs, as well as information about the benefits and problems the BGPs owners have. Table 3 shows the questionnaires characteristics.

Table 3. Questionnaire characteristics.

Characteristic	Description
Type of questionnaire	Structured
Number of questions	68
Number of pages	9
Sections	9
Type of sampling	Convenient sampling
Interview duration	~15 minutes
Number of respondents	123

Source: Author.

Face-to-face interviews with 123 BGPs owners was carried out in central Vietnam, near Hué, in the districts Phong Dien and Huong Tra. Always with the help of the experts of the Hue University of Agriculture and Forestry (HUAF) and local authorities. Observation was also used as a method of data collection.

The survey's objective was to examine the feedback of local people, their responses and observations on biogas technology. These questionnaires presented a great opportunity to observe the actual situation of the BGPs, apart from collecting data to understand government policies, economic aspects, environmental measures, technologies and social factors involved in the development of small-scale household BGPs.

The collection of the primary data was carried out during a two-month period in July and August 2016. No more time or respondents was possible, due to budget available and other everyday problems found in the data collection process, such as “not at home” farmers or problems with authorisations.

4.1.2 Secondary data sources

Case analysis: a number of scientific articles regarding current development of household small-scale BGPs in developing countries, especially South East Asia and Vietnam were analysed. They offered valuable information regarding the ability to scientifically expose the situation of biogas development in rural central Vietnam and similar regions. Likewise, for inventory analysis an extensive variety of data was collected, factors considered to have a greater effect on the results were the main focus. For factors or processes with no available data a review of literature was carried out, such as standard protocols and emissions factors necessary for the LCA (Table 4).

Table 4. Data collected from secondary sources to perform the intended LCA calculations.

Description of factors	Source
GHG emissions of biogas and wood	(IPCC, 2000; Bruun et al., 2014)
GWP per MJ supplied energy equations	(Bruun et al., 2014)
Methane emissions from swine during storage equation and reference values	(IPCC 2000, 2006)
Manure management methane emission factors	(Jun et al., 2000; IPCC 2000, 2006)

Source: Author.

4.2 Site Descriptions

The research was carried out in central Vietnam, in Thua Thien-Huế province, in the districts Phong Dien and Huong Tra. Our research was focused on the communities under the development project “*Renewable Energy Resources for Rural Areas in Thua-Thien Hue Province (2011-2013)*” funded by the Development Cooperation of the Czech Republic and implemented by the Czech University of Life Sciences Prague in order to keep track over the project outcomes.

Hương Trà (marked in Figure 6) is a rural district of Thua Thien-Huế province in central Vietnam. The district has 518.53 km² of area and the capital is Tứ Hạ. In 2011 the average population in Hương Trà district was 118.534 inhabitants (General Statistics Office of Vietnam, 2016). District’s communes were the interviews were carried out were: Hương An, Hương Xuân and Hương Toàn. Hương Trà capital is located on the north of Huế, the main city in the district. Hué (green point in Figure 6) is the second biggest city in central Vietnam after Da Nang.

Figure 6. Map of the study area.

Source: (Google Maps, 2014).

Phong Điền (marked in Figure 6) is another rural district of Thua Thien-Huế province and in the 2011 the average population was 212,369 inhabitants (General

Statistics Office of Vietnam, 2016).The capital is also named Phong Điền. The district has 953.8 km² of area. District's communes where the interviews were carried out were: Phong Sơn, Phong An, and Phong Xuân. Phong Điền is located in the north of Thua Thien-Huế province, bordering the provinces of Quang Tri and the city Hương Trà.

4.3 Target groups

Sample selection was done by governmental authorities, as they targeted small-scale household BGPs which were willing to participate (convenient sampling) in the survey. The research was carried out in accordance with permits and scheduled by the local authorities of the rural villages. The two districts of Phong Dien and Huong Tra are mainly rural, but also have main cities (capitals) respectively. Communes under our research were purely rural, based on livestock and agriculture production. Target communes were approximately ~20 to ~40 km from Hué city.

Table 5. Respondents per district (N=123).

District	Frequency	Percent
Hương Trà	74	60.2
Phong Điền	49	39.8

Source: Author.

As can be seen from Table 5, we had more number of respondents in the Hương Trà district, 25 respondents more than in the Phong Điền district, mainly due to our authorization limitations and sample selection of the local authorities.

4.4 Statistical analysis

Survey's descriptive statistics were carried out using IBM SPSS statistical and Microsoft Office Excel software. A Spearman correlation analysis was done to determine if there was relationship between usual amount of biogas (regarding enough biogas needs), price willing to pay now for a BGP in comparison with the price paid for the original BGP, and household income using the sample of 123 participants of the survey.

4.5 Life Cycle Assessment (LCA)

A life cycle assessment (LCA) was performed to assess the CO_2 emissions climate change impact during BGPs' life cycle. Other LCA indicators, such as acidification, eutrophication, energy use and land use and emission of toxic substances, were not included in this study as they do not correspond to the aims of this diploma thesis. Additionally, in order to support our research question we also determined the GWP (Table 6) of the employment of biogas and compared it with the GWP derived from the usage of firewood.

Table 6. LCA assessment category, indicator of contribution to environmental issues, brief description, and units of measure.

Impact Category	Indicator	Brief description	Unit
Climate change	Global Warming Potential (GWP)	A measure of GHG emissions, such as CO_2 and methane. The natural greenhouse effect is magnified because these emissions are producing an increment in the absorption of radiation emitted by the earth.	kg CO_2 equivalent

Source: (Houghton JT et al., 2001).

Additionally, for further support of the research questions and aim of the thesis, GHG quantifications of the usage of firewood and the usage of biogas were also carried out and compared. These results provide more reliability to our other findings.

4.6 Definition of Goal and Scope of the LCA

The goals of the LCA were: 1) To develop a small-scale household BGP LCA model for our study; and 2) To study the three phases considered for the small-scale household BGP in central Vietnam, determining the CO_2 emissions impact during the whole life cycle.

The scope of the LCA covers the phases: 1) Construction of the BGP; 2) Operation of the BGP; and 3) Demolition phase.

The system modelled and boundaries are represented in the flowchart (Figure 7).

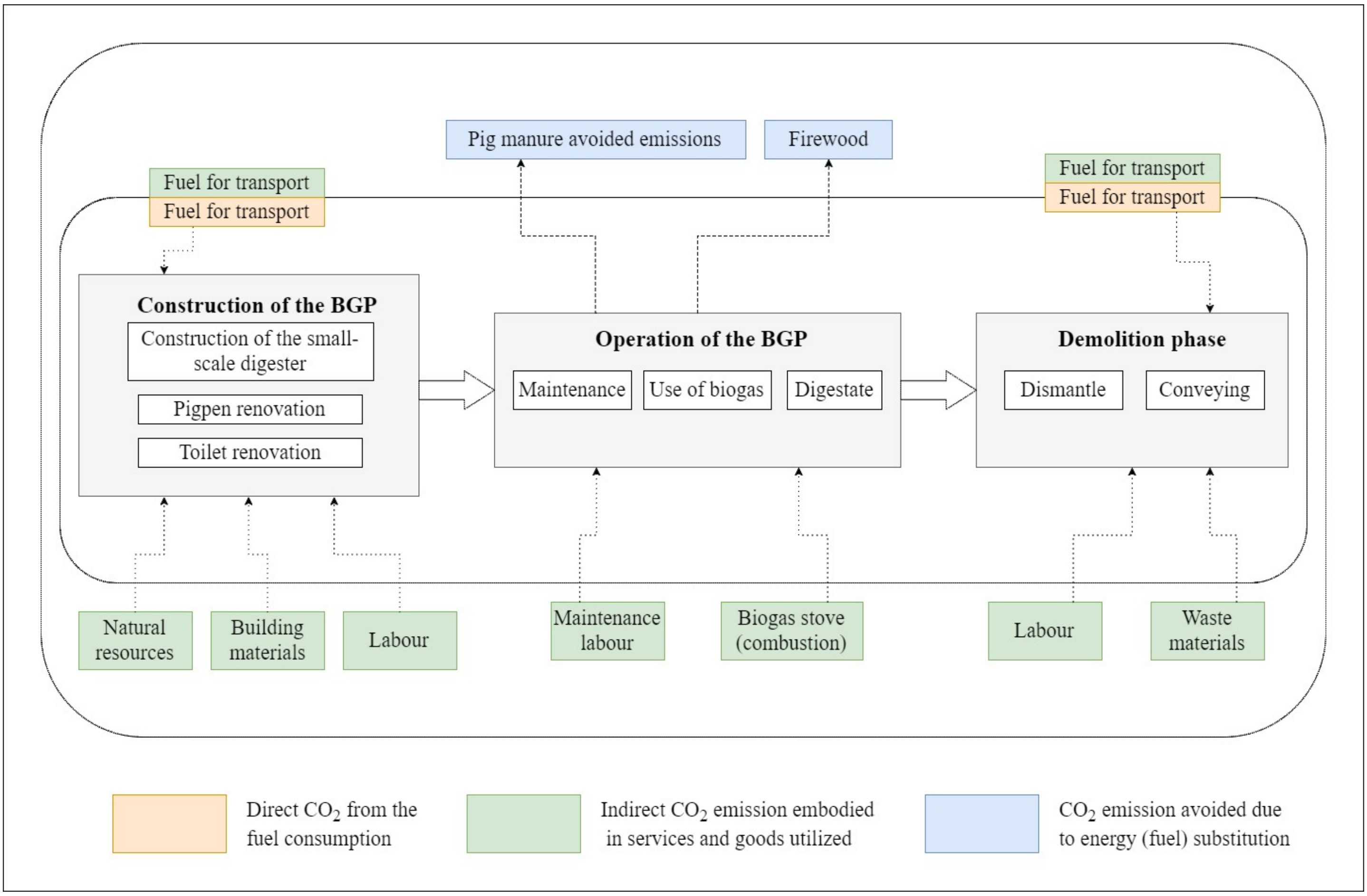

Figure 7. LCA flowchart of household small-scale BGPs.

Source: Author.

4.7 Assumptions for the LCA calculations

The data of materials and construction of the BGP was taken from the survey data. The composition of biogas is obtained from the data Vu et al. (2015) reported. The functional unit (FU) for the study is: the usage of a small-scale household BGP during a lifetime of 20 years.

Gas emissions were based from the data Bruun et al. (2014) reported. Pig housing emissions were not taken into consideration, because we assumed that these emissions are the same in the scenarios of households with biogas digesters and without, since the pig housing emissions as such are not avoided.

We assumed that the emissions taking place during the storage of manure and digestate include CO_2, CH_4, NH_3, and N_2O. Solid and liquid manure composition was taken from the data Vu et al. (2015) reported. N, P, K and ash content of the digestate was calculated by assuming that all of these components, entered the digester and also left it over. Likewise, the ammonium concentration in the digestate should be the same that the ammonium concentration in the digestate leaving the storage plus the estimated emission of ammonia nitrogen during storage of the digestate.

The amount of fuel that can be substituted was determined based on the cooking efficiency of the different fuels. During the combustion of biogas and other fuels such as firewood, CO_2 and other gases are emitted into the atmosphere. The CO_2 emitted during the combustion of biogenic fuels, such as biogas, was considered neutral CO_2. Additionally, combustion of fuels also releases low quantities of N_2O, CH_4, and CO into the atmosphere. These gases also have climate warming potential (IEA, 2012, 2015). Combustion of biogas is one source of emissions but there are two other sources reported of biogas emissions:

1) Leakages/cracks in the BGPs and/or piping.
2) Intentional releases, done by the farmers when excess of biogas is accumulated in the digester.

Data regarding cracks and intentional releases were obtained from other previous studies done in the topic (Bruun et al., 2014; Vu et al., 2015; Roubík et al., 2016). Total biogas losses due to intentional releases and leakages are assumed to be as high as 40%, worst-case scenario estimation, based on (Bruun et al., 2014). The annual biogas output is assumed 300 m^3 based on Daxiong et al. (1990) and Zhang et al. (2013).

4.8 LCA Calculations

The hybrid LCA method based on Zhang et al. (2013) was used to quantify indirect CO_2 emissions embodied in input materials and services, and direct CO_2 emissions associated with fuel combustion, during the life cycle of the small-scale BGPs. Therefore, we determined the potential to lessen climate change of household small-scale BGPs systems considering inputs-outputs over its life cycle of non-renewable energy supplies. The life cycle phases and elements considered can be seen in the flowchart (Figure 7), three phases were considered: construction of the BGP, operation of the BGP, and demotion phase. Data inventory was made from the data collected in the survey and from other scientific papers of the topic. In order to determine total CO_2 emissions of the BGP, equation (1) was used:

$$E_{Total} = E_D + E_{ECA} \quad (1)$$

Where:

E_{Total} = tons of total CO_2 emissions linked to the BGP within its life cycle;

E_D = tons direct carbon emissions due to fuel combustion, expressed as the sum of the products emissions in each stage;

E_{ECA} = tons embodied carbon emissions from hybrid LCA, which is including indirect emissions linked to resource and labour inputs and outputs of the entire supply chain.

Then for the CO_2 emission reduction potential of the household BGP system, equation (2) was used:

$$E_{RP} = E_A + E_{Total} \tag{2}$$

Where:

E_{RP} = tons of CO_2 emission reduction potential of the household BGP system;

E_A = tons of carbon emissions directly and indirectly avoided due to the substitution of energy by alternative solution, as well as counting with chemical fertilizers substitution due to possibility of digestate usage.

4.9 Global Warming Potential

The Global Warming Potential (GWP) by standards of the Intergovernmental Panel on Climate Change (IPPC) (IPCC, 2006; JRC European commission, 2011) was calculated by the sum of the emissions of all GHG. Expressed in CO_2 equivalents (CO_2-eq), determined from their relative global warming (IPCC, 2006; JRC European commission, 2011; Wolf et al., 2012).

4.9.1 Global Warming Potential of biogas compared to the replaced fuel

In order to further consistency of the findings and conclusions of this diploma thesis, we also determined GWP of biogas and firewood usage. We compared the impact of biogas production and biogas GHG emissions with the fuel substituted. Consequently, the GWP of CH_4 emissions from BGPs and CH_4, CO_2, N_2O, and CO emissions from the combustion of biogas were contrasted with subsequent emissions of the same gases during the combustion of the substituted firewood. Based on equations that Bruun et al. (2014) defined, we calculated the methane that must be produced per unit of energy supplied to boil water using equation (3):

$$M_p(f_l) = \frac{1}{59\ (MJ\ kg^{-1})\ 0.57\ (1-f_l)} \tag{3}$$

Where:

$M_p(f_l)$ = Methane that it is needed to be generated per unit of energy supplied to heat water (MJ kg^{-1});

f_l = biogas lost thru intentional releases or leakages (%);

Value of 59 MJ kg^{-1} = CH_4 energy content (Bruun et al., 2014);

Value of 0.57 = biogas stove efficiency (Smith et al., 2000).

Bruun et al. (2014) reported that total biogas losses from household small-scale BGPs can be up to 40 %. In this study we assumed also the worst-case scenario of 40 % of total losses of the biogas produced in the digester. When part of the biogas is lost, more quantity of biogas must be produced to fulfil the same energy requirement as in a system without leakages/cracks. Therefore, fraction lost is accounted in the formula (3).

The GWP, as Bruun et al. (2014) determined, was calculated per unit of energy delivered by equation (4):

$$IPB_{GW}(f_l) = M_l(f_l)CF_{CH_4} + ECB_{CH_4}CF_{CH_4} + ECB_{N_2O}CF_{N_2O} + ECB_{CO_2}CF_{CO_2} + ECB_{CO}CF_{CO} \quad (4)$$

Where:

$IPB_{GW}(f_l)$ = GWP of biogas per unit of energy delivered (g CO_2 eqv. g^{-1});

ECB = (g GHG) GHG emissions during fuel combustion;

CF = (g CO_2 eqv. g^{-1}) characterization factor of CO, CO_2, N_2O, and CH_4. These are 295 g CO_2 eqv. g^{-1} for the N_2O, 1.9 g CO_2 eqv. g^{-1} for the CO, 25 g CO_2 eqv. g^{-1} for the CH_4, and 1 g CO_2 eqv. g^{-1} (Joint Research Centre, 2010; JRC European commission, 2011; Wolf et al., 2012; Bruun et al., 2014);

ECB = emissions generated during the combustion of biogas, based on Bruun et al. (2014) reported data (Table 7) on GHG emissions during the combustion of biogas and wood in the standard stoves of households in developing countries for biogas and wood.

Table 7. GHG emissions during the combustion of biogas and wood.

	Gas emissions per MJ of supplied energy			
	g CO_2	g CO	mg CH_4	mg N_2O
Biogas	81.5	0.1	57.0	5.4
Wood	532.0	14.0	600.0	4.3

Source: (Bruun et al., 2014).

As for the substituted fuel (wood) GWP emissions, as these emissions are not linked to the losses of CH_4 of BGPs, following analogue equation (5) was employed:

$$IPR_{GW} = ECR_{CH_4}CF_{CH_4} + ECR_{N_2O}CF_{N_2O} + ECR_{CO_2}CF_{CO_2} + ECR_{CO}CF_{CO} \quad (5)$$

Where:

IPR_{GW} = GWP of the substituted fuel per unit of energy delivered (g CO_2 eqv. g^{-1})

ECR = (g GHG) combustion GHG emissions of the replaced fuel (Table 7);

CF = (g CO_2 eqv. g^{-1}) characterization factor of CO, CO_2, N_2O, and CH_4.

Consequently, avoided emissions acknowledge by usage of biogas replacing firewood was estimated by the following relation (6), considering energy equivalencies of biogas and firewood used in rural households:

$$Avoided\ GHGs\ emissions\ (\%) = \frac{(GHGs\ emissions\ of\ firewood - GHGs\ emissions\ of\ biogas)}{GHGs\ emissions\ of\ firewood} \quad (6)$$

4.9.2 Methane emissions without using BGP

We also determined the potential of avoided CH_4 emissions from swine, during storage, in a no BGP scenario. It was calculated through equation (7) according to (IPCC, 2000; Izumi et al., 2016):

$$EF_{CH_4} = (VS \cdot 365) \cdot \left[B_o \cdot 0.72\frac{kg}{m^3} \cdot \frac{MCF}{100} \cdot MS\right] \quad (7)$$

Where:

EF_{CH4} = annual CH_4 emission factor (kg CH_4 animal^{-1} yr^{-1});

VS = daily volatile solid excreted (kg dry matter animal^{-1} day^{-1});

Value of 365 = annual VS production, days yr^{-1});

B_o= maximum methane producing capacity for the manure generated (m^3 CH_4 kg^{-1} of VS

excreted).;
MCF = methane conversion factor for the manure management by system and climate region (%);
MS = manure fraction handled using manure management system in climate region (dimensionless).

Based on the IPCC guidelines (IPCC, 2006) the methane conversion factor of m^3 CH_4 to kg of CH_4, was set to 0.72, in reference to warm climate and local practice. The local practice in non-BGPs households with swine production is to accumulate certain solid and liquid manure on the floor for a short period of time and then remove it towards the surrounding environment.

4.10 Target Audience and Intended Use of the Study

The main goal of this study is to be presented as the required master final thesis, and be defended in the final defence. The LCA results are intended for the field of environmental and sustainable rural development related studies which will be primarily used internally by the Czech University of Life Sciences Prague (CULS).
Additionally, the results might be of interest externally to other researchers in the field and the biogas development sector of Vietnam.

4.11 Applicability of the Study

The development of biogas technologies in Vietnam has its focus to small-scale household BGPs, this study will reflect the potential and the environmental impact of this technology in the central region of the country.

The results will provide knowledge in regards to the subsequent environmental effect, considering CO_2 emissions, and thus allow future improvements and advancements in the system. As well as, GWP and GHG emissions findings will further consistency to fulfil the aim of this diploma thesis.

5 RESULTS

The first part of this chapter shows the results drawn from the primary data obtained from the structured interviews with the farmer's owner of small-scale BGPs. The second part of this chapter present the results of the Life Cycle Assessment (LCA).

5.1.1 Demographic characteristics of respondents

The survey involved 123 owners of BGP. Distributions of age and sex of the study respondents are outlined in Appendix 2. Farmers' age ranged from 25 to 85 years, and the average age of the farmers was 51 years old. The major percentage of respondents were males. Most respondents (60.2 %) were from Hương Trà district (Appendix 2). 96.7 % of the respondent's main occupation was farming, other 2.4 % were goods sellers, and a remaining 0.8 %, builders (Appendix 2). Average number of persons living in the household, was 5 people as reported by General Statistics Office of Vietnam (2016). Most households had an income of less than 10,000,000 VND[1] per month (Appendix 2).

5.1.2 Biogas Plants

The predominant (97 %) BGP design was the KT 2 type (Appendix 2). The standard size of the biogas digesters in the study area was 6 m^3. The majority (45.5 %) of BGPs dated from the year 2013 (Appendix 2). From a list of reasons, the respondents were asked to choose their three main motivating reasons to install the BGP, "*being able to use the biogas for cooking*" was the most important reason for 96 % of the respondents. The second was found to be "*clean environment*" by 71 % of respondents; and the third was "*cleaner animal housing*" with a 58 % of respondents (Appendix 2).

All respondents use their biogas for cooking purposes only. Only 5.7 % respondents were not using any other fuel sources, using just the biogas they produce. 93.5 % were using less alternative fuel source (biomass) compared with the amount they were using before installing a BGP. The amount of firewood, on average, was reduced from ~282 to ~120 kg/year/household. Additionally, 98.4 % noticed an improvement in their living environment, regarding environmental pollution. Majority of the respondents (56.1 %) reported as the BGP's main benefits as follows:

1) Free time for other activities.

[1] (1 USD = 22,727.21 VND; 1 EUR = 24,192.04 VND)

2) Smoke-free and ash-free kitchen (no respiratory problems).
3) Cooking with biogas is faster and easier than using wood.
4) Money saved.
5) Clean environment in the farm.
6) Greatly reduced odour.

97.6 % respondents reported to do more cooking versus 2.4 % that release the biogas into the air every month due to the high pressure. The most common problem with BGPs was the presence of cracks in the BGP, 53 % farmers reported leakages/cracks in their BGP. We also observed many BGPs with leakages, detected by odour or bubbles on the top access door, so the percentage could even higher. 99.2 % farmers did not have enough access to spare parts for their BGPs.

Regarding the household investment on BGPs, our results suggest farmers are willing to invest in biogas technology despite their low household incomes and the costs related to the construction of the plant. The Spearman's correlation indicated there was a weak positive correlation between the usual amount of biogas farmers have to cover their needs and the price willing to pay for the BGP ($r_s = 0.304$, $p = .001$). Moreover, there was weak positive correlation between the household income and the price farmers are willing to pay for a BGP ($r_s = 0.196$, $p = 0.030$). Additionally, despite the problems presented, 67.2 % of the respondents would be willing to pay the full (~12,000,000 VND) price (without subsidy) of a BGP once again (Appendix 2).

From the questionnaires, we also obtained additional information regarding the benefits of having a BGP for rural households. For instance, 98.4 % noticed an improvement in their living environment, regarding environmental pollution. Hence, BGPs reduce the environmental pollution of the farmers' house as no smoke is generated in the kitchen area and it is a faster and easier way to cook compared to the use of firewood.

Also, in reference to the digestate from BGPs, from interviews responses and observation in the agriculture systems of the study area. Survey have shown that farmers do not use the digestate as fertilizer replacement, they always use chemical fertilizers. Liquid digestate is unworkable and unrealistic for the local farmers. Mainly due to its liquid state, digestate transportation is unfeasible. Farmers are not able to use it and therefore, they are not able to substitute the usage of conventional fertilizers. Thus, more research should be carried out on this topic to study the feasibility of the digestate employment for rural households. In general, as we saw in person in the study area, the digestate is just released into the surrounding environment, what means unrecovered nutrients and fibre.

5.1.3 Trainings on biogas technology

In our study, the responses from the interviews told us that the lack of training in the BGPs maintenance and operation is a big difficulty for the farmers in order to make a proper handling of the technology and fully use all its benefits.

93% respondents received only a one-day theoretical biogas training; remaining 6% received no training at all, and only 1 farmer scored 2 trainings from the Vietnamese National Biogas Programme. Moreover, respondents seem to have insufficient training in maintenance and operation of BGPs. On the other hand, even with the problems presented, 67.2 % respondents would be willing to pay the full price (without subsidy) of a BGP if they would have to buy it again (Appendix 2).

5.1.4 Surveyed Farms with Biogas Plant

Main animal production was swine (piglets, fattening pigs and sows). Only some farmers had also poultry, duck, cattle and sometimes rabbit. The mean numbers of swine production were: 65 piglets, 31 fattening pigs, and 3 sows. BGPs feedstock was always the swine manure. Swine housing was always connected to BGP's inlet. Housings of other possible animals in the farm were not connected to BGPs. Additionally, 33.3% respondents had their toilets connected to the BGP to add the human excreta.

5.1.5 Life cycle emissions of BGPs

The different CO_2 emissions during the phases of the life cycle of the small-scale BGPs were determined estimating the direct emissions of CO_2 of fuel combustion and the embodied indirect emissions of CO_2 in the materials and services (Appendix 4). Using equation (1) we determined total CO_2 emissions of the BGP. Table 8 shows the calculations of the CO_2 emissions during the life cycle of the small-scale BGP system designed for the study area. Both, direct and indirect emissions are divided considering the three phases of the modelled biogas system; which are construction, operation and demolition phases. Regarding the emissions linked to the different life cycle phases, most of the emissions were firstly consequence of the construction phase (79.41 %). Secondly, the emissions of the operation phase (15.40 %). And finally the demolition phase (5.19 %). Accordingly, it appears like the construction phase is where most effort should be taken in order to find a solutions able to decrease those contaminant emissions.

Table 8. CO_2 emissions in each phase of the small-scale biogas modelled system during 20 years' life cycle (Unit: tons).

	Construction	**Operation**	**Demolition**	**Subtotal**
Direct CO_2 emissions	0.017	0.000	0.010	0.027
Indirect CO_2 emissions	1.757	0.344	0.110	2.211
Total CO_2 emissions	1.774	0.344	0.120	2.234
Percentage (%)	79.41 %	15.40 %	5.19 %	100.00 %

Source: Author.

Considering the assumption that the BGPs would be operating during the 20 years of the life cycle, and would replace firewood fuel and would potentially substitute chemical fertilizers with the digestate from BGPs. Then, we determined CO_2 emission reduction potential of the household BGP system using equation (2). As a result, the CO_2 emissions that can be avoided by energy substitution were found to be 0.95 annual tons of CO_2.

5.1.6 GWP comparison of biogas and biomass

The most common size of the digesters in the study area was 6 m^3, therefore calculations are based on this modelled size. Also, survey and observation showed that most digesters were not well maintained.

Consequently, the GWP of the biogas emissions was calculated from the quantity of CH_4 lost per unit of energy supplied, based on the equations that Bruun et al. (2014) determined. First, we calculated the methane that must be produced per unit of energy supplied to boil water using equation (3), in order to determine the GWP of biogas taken into consideration both, efficiency of the biogas stove and losses of biogas in the BGP system (e.g. cracks in the digester, leakages from pipes). Thenceforth, we determined the GWP of biogas using equation (4). In the same way, we determined the GWP of firewood using equation (5). Therefore, the GWP of CH_4 emissions from BGPs and CH_4, CO_2, N_2O, and CO emissions from the combustion of biogas are contrasted with subsequent emissions of the same gases during the combustion of wood. The GWP (per 100 years) per unit of energy of the biogas combustion and fraction of production lost, was found to be 134.3 g CO_2 eqv. g^{-1}; compared with 574.8 g CO_2 eqv. g^{-1} for firewood combustion.

Stoves used for biomass combustion are considerably less efficient than biogas stoves. For the calculations, we assumed efficiencies of 15 % for firewood stoves versus 57 % efficiency for biogas stoves correspondingly, based on Smith (2002) and Cutz et al. (2017). Consequently, our results indicate that GHG emissions, per unit of energy supplied, are superior for firewood than for biogas stoves. These results were based on Bruun et al. (2014) reported GHG emissions for each type of fuel (Table 9).

Table 9. GHG emissions considered for the GWP results for biogas and wood.

	Gas emissions per MJ of supplied energy			
	g CO_2	g CO	mg CH_4	mg N_2O
Biogas	81.5	0.11	57	5.4
Wood	532	14	600	4.3

Based on: (Bruun et al., 2014).

5.1.7 Avoided GHG emissions Potential

GHG emissions of biogas production and combustion, as well as for firewood combustion were calculated in order to compare them and determine the percentage of avoided GHG emissions. The GHG emissions generated by biogas are 381.66 kg CO_2-eq·year^{-1}, and GHG emissions from firewood combustion are 473.91 kg CO_2-eq·year^{-1}. As a result, we determined the percentage of avoided GHG emissions using formula (6). It was obtained that the use of biogas leads to 20 % of avoided GHG emissions compared with the usage of firewood.

Additionally, if a BGP is not present, the normal manure management practice in the study area consists of discharging the manure into the environment, in a lagoon next to the household. Considering this scenario, from the CH_4 emissions of this manure management, using equation (7), we determined that the avoided GHG emissions are 384.1 kg CO_2-eq·animal^{-1}·year^{-1}. For instance, taking into consideration a household with 2 sows, those avoided manure management GHG emissions would be 768.2 kg CO_2-eq·year^{-1}, accounting respectively for avoided GHG emissions percentage of 50 % compared with biogas combustion emissions. Because N_2O and CO_2 emissions from the manure in biogas digesters are almost zero, methane emissions were the only GHG considered (Zhang and Wang, 2014).

6 DISCUSSION

The aim of this diploma thesis was to study whether the use of biogas for household consumption is reasonable from a climate change perspective, identifying potential contaminant emissions to assess the suitability of biogas technology. We focused on the calculation of those emissions during the life cycle of the small-scale BGPs. CO_2 direct emissions, as well as indirect emissions embodied in materials and services were determined for the most common size of the digesters in the study area, which was 6 m^3 KT 2 BGP type, with assumed life cycle of 20 years.

To our knowledge, only one other study (Vu et al., 2015), has examined the life cycle of small-scale BGPs in rural areas of Vietnam. However, they did not take into consideration the same factors and those results were determined based on different comparison than ours. They used another method called ReCiPe and considered other LCA indicators. They compared the BGPs emissions with traditional pig manure management systems. However, their findings and conclusions of this study can be extrapolated to our case. Despite they did not consider other factors, such as the construction of the BGPs. they support the positive environmental potential of biogas technology. Vu et al. (2015) showed that the biogas technology can be an effective way to lessen climate change gas emissions Moreover, they suggested it is a realistic alternative to traditional manure management and a decentralised renewable energy source for the rural households of central Vietnam. As we mentioned before**,** Vu et al. (2015) study failed to consider other elements of the whole life cycle of the BGPs. Such elements are the construction, demolition or any other implied activity than can harm the environment or contribute to climate change, such as pigpen renovation.

Our findings regarding CO_2 emissions, concur with the study from Zhang et al. (2013) which determined mostly similar results. Zhang et al. (2013) also stated that regarding the emissions linked to different life cycle phases, most of the emissions were firstly consequence of the construction phase (75.73 %) versus our study results (79.41 %). Secondly, the emissions of the operation phase (20.37 %) versus our study results (15.40 %). We determined 0.95 tons of annual CO_2 emissions reduction potential of BGPs, which is also broadly similar to Zhang et al. (2013) findings of 1.25 tons of CO_2 for their study.

The CO_2 emissions results can be explained by having a close look at the construction process and materials. Because of the great quantities of building materials, such as cement and bricks, emissions associated with those inputs of the construction phase represent the biggest part of the CO_2 emissions. The results from our study and Zhang et al. (2013) can differ due to several factors like digester size, surveyed area and the number of input materials. Whereas our surveyed zone was the rural areas of central Vietnam, which were using digesters of 6 m^3, Zhang et al. (2013) studied digesters of 8 m^3 in a Chinese rural scenario. Subsequently, Zhang et al. (2013) considered more inputs materials in the system than we did, as well as, scenario-specific factors, such as type and amount of fuel substituted between other elements.

Biogas offers a direct impact in the reduction of CO_2 emissions because it acts as an alternative fuel source for the rural households and can indirectly work as an alternative to conventional chemical fertilizers. However, we have noticed that the use of the digestate was null in the surveyed farms. Hence, we suggest this is an unexploited benefit from the BGPs in our study area. The main reason for this lack of use is due to the liquid state of the digestate, which makes its transportation unachievable for the farmers. Thus, its use is unrealistic as also other studies have found (Thu et al., 2012). Additionally, Roubík et al. (2016) also found that digestate tank is usually not well located, making it access problematic. Thus, it limits further management of the digestate. Additionally, Roubík et al. (2016) suggested builders and facilitators should deliberate a solution to the problem.

Furthermore, much of the literature agrees that there is a need to improve the biogas technology. However, it is essential to avoid further complexity of the technology in order to keep it as simple as possible, also empowering a realistic and practical use of the digestate (Ni and Nyns, 1996; Rajendran et al., 2012; Bruun et al., 2014; Vu et al., 2015). From our experience, we would suggest to install a very basic and simple system of channels along the farm that would enable the farmers to reach the digestate product easily. The channels could start from the outflow tank of the BGP and channelize the collected digestate into another tank. From the second tank, digestate product could be shared along the farm avoiding its discharging into the surrounding environment. As a result, this liquid product could be used as a natural fertilizer to substitute conventional chemical fertilizers.

Another benefit of the biogas technology is the use of the generated gas for cooking purposes. The usable energy for cooking is defined by the efficiency of the stove.

As other studies have shown, stoves used for biomass combustion are considerably less efficient than the biogas stoves (Hulscher, 1997; Gustavsson, 2000; Center for Energy Studies, 2001; Bhattacharya and Abdul Salam, 2002; Smith, 2002; Cutz et al., 2017)**.** Hence, the inner properties of firewood plus the minor efficiency of the combustion generates GHG emissions per unit of energy supplied, superior for the firewood than for the biogas combustion. Additionally, the use of biogas improves the air conditions inside the rural households as less smokes is generated. Thus, represents an especially important benefit for the peoples' health (Smith, 2002; Cutz et al., 2017).

Our observations that firewood is a bigger source of GHG emissions are not new, but our findings corroborate this fact and coincide with the existing literature. Other studies show biogas as a cleaner energy source than firewood and a feasible technology for many developing countries which still rely in firewood for cooking (Indraprahasta and Alamsyah, 2014; Berhe et al., 2017). Our findings on the biogas GWP compared with firewood GWP have shown that the usage of biogas presents a substantially lower GWP per unit of energy supplied than the use of firewood. These findings are consistent with the results that Bruun et al. (2014) reported, and it is evident that the replacement of firewood fuel by biogas can help diminish the global warming impact of this fuel. In addition, in the study area, survey results showed that BGPs contributed to a firewood usage reduction of ~42.5 %. Meaning these findings further support our research questions, reinforcing that biogas technology offers a better alternative than the traditional use of firewood in central Vietnam, and that household consumption of biogas is noticeably realistic from a climate change point of view.

As well as BGPs losses of biogas, which are mainly methane (CH_4) emissions, since biogas has a regular composition of 50 to 70 % of methane (Berglund and Börjesson, 2006; IEA, 2012; Rossano and Cividino, 2013; Tilley et al., 2014; Ho et al., 2015). Another GHG source of methane, which is a potent GHG, originates mainly from the pig manure storage in the traditional management systems, where this manure is discharged into lagoons in the surrounding environment. Henceforth, we stress that biogas technology is an effective strategy to address the environmental problems associated with the previously mentioned GHG emissions. Moreover, BGPs offers a realistic way of manure management avoiding a great potential amount of GHG release from the typical manure lagoons. Specifically, we estimated that 384.1 kg CO_2-eq·animal^{-1}·year^{-1} GHG emissions can be avoided using the biogas technology. Moreover, the proper management of the manure eliminates the presence of toxic lagoons, reduce the odours and farmers save money not buying firewood.

Furthermore, the second potential source of methane emissions are the cracks in the BGP digesters and the third one are the intentional releases of biogas. As previous studies have analysed, cracks and intentional releases need to be limited or they can compromise the benefits of biogas technology (Bruun et al., 2014; Ho et al., 2015; Vu et al., 2015). Bruun et al. (2014) determined that total biogas losses from household small-scale BGPs can be up to 40 % due to cracks and intentional releases. However, they also found that biogas losses can be up to 44 % to reach the GWP of firewood. Our results of the GWP between biogas versus firewood have shown that biogas has a considerable lower GWP than firewood per unit of energy delivered (134.3 g CO_2 eqv. g^{-1} compared with 574.8 g CO_2 eqv. g^{-1}). Hence, it is clear that biogas is a better alternative than firewood to use e.g. as cooking fuel.

Another area to debate regarding the implementation and use of biogas technology is the training approach and maintenance of the BGPs. Improving these areas, it is possible to ensure a longer operational life of the BGPs and offer a stable reliable biogas production. As our results indicate, there is a lack of theoretical and practical knowledge on biogas technology. Whereas, most of the respondents (93%) received only a one-day theoretical biogas training, the remaining 6% received no training at all and only 1 farmer had a two-day training. Moreover, some respondents expressed their concerns on not having a proper service to contact in case of problems related to the BGPs. Thus, we can foresee that in developing countries like Vietnam, biogas projects are implemented and after the first years without proper supervision, many plants stop operating due to unsolved management problems (Singh et al., 1997; Rajendran et al., 2012; Mulinda et al., 2013). For instance, Berhe et al. (2017) reported that 58 % of the installed BGPs were not operational anymore because of technical flaws and limited supervision in a rural region of Ethiopia. Thus, the lack of long-term supervision can expectedly compromise the benefits of the biogas technology. Therefore, knowing these results, our suggestion would be to invest more time and resources on properly training the farmers in the management and maintenance of BGPs. We also suggest that more personal expert on BGPs should be available for the farmers in order to solve operation problems (e.g. accumulation of floating materials).

Aside from the difficulties mentioned in the previous paragraph, the use of BGPs in general, reduce the human health diseases thanks to a cleaner environment within and outside the houses. Additionally, farmers have more free time to invest in other activities as they do not need to deal with firewood (e.g. collect and prepare it for cooking). Some respondents could invest more time in farm activities and to free time with their relatives.

7 CONCLUSION

This diploma thesis was set out to study whether the use of biogas for household consumption is reasonable from a climate change perspective, identifying potential contaminant emissions to assess the suitability of biogas technology. LCA methodology was used to assess the environmental impact associated with small-scale household BGPs in central Vietnam in order to figure out the emissions during the phases of the life cycle as well as the calculation of the emissions reduction potential of the biogas technology. GWP and GHG emissions of biogas and firewood substituted were determined and compared in order to answer the research questions:

(1) Is small-scale biogas production in central Vietnam a better alternative than the traditional use of firewood? Not only the survey showed that after installation of BGPs there was a significant reduction in firewood usage. In addition, biogas usage contributes to lessening climate change by having a smaller GWP than firewood. Specifically, the use of biogas leads to 20 % of avoided GHG emissions compared with the usage of firewood.

(2) Is the use of biogas for household consumption reasonable from a climate change perspective? The findings indicate that with the use of BGPs it is possible to diminish the presence of manure discharge lagoons and thus, avoid the related GHG emissions to them. And the LCA results have shown that small-scale household BGPs can reduce 0.95 tons of annual CO_2 emissions. Considering the findings, it would seem legitimate to say that the use of biogas is a reasonable alternative from a climate change perspective. BGPs can be a valuable manure management system that could reduce contaminant emissions, therefore lessening climate change. However, it is essential to guarantee BGPs' appropriate operation. Therefore, cracks in the digester due to poor maintenance and intentional releases because of poor biogas technology handling are the major concerns that can compromise the overall benefits.

The survey has shown that there is a need to improve the farmers training to ensure a better use and maintenance of the BGPs. 93% respondents received only a one-day theoretical biogas training; remaining 6% received no training at all in biogas technology from the Vietnamese National Biogas Programme. Thus, respondents seem to have insufficient training in maintenance and operation of BGPs.

While research findings support the benefits of the use of biogas for household consumption. Even it appears reasonable from climate change perspective, it is clear that there is a need to plan long-term supervision and improve training programmes to ensure the appropriate operation, maintenance and operational life of the BGPs. Higher quality research is needed, but improvement of supervision and trainings seems key factors to consider in order to guarantee the benefits of biogas technology regarding climate change diminishment.

Using LCA methodologies it is possible to extrapolate and compare the main findings regarding the implementation of BGPs in developing countries. However, it should be kept in mind, the choice of the impact category (in our case, Climate Change) and indicator (CO_2 emissions) when interpreting the LCA results. This way the results from different specific LCA studies can be compared. Therefore, even if our study was modelled in a specific region of central Vietnam, the findings are applicable to fellow Southeast Asian countries. Additionally, biogas related projects of the Czech University of Life Sciences Prague are on-going and in the upcoming future, our results might be of use in other similar LCA studies.

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Appendixes

List of Appendixes

Appendix 1. Questionnaire

Biogas questionnaire – Field survey 2016

1. Personal Details:

Family name, first name	
Gender	☐ Male ☐ Female
Age	
District	
Village	
GPS position	

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

1.2. Are you in charge of maintenance of biogas plant? ☐ Yes ☐ No

1.3. How many members does your family have? ____________________________________

1.4. How many people live in the household (HH)? ____________________________________

1.5. How many people work in the farm? ____________________________________

1.6. Number of children under 15 years living in HH ____________________________________

1.7. What is your occupation? ____________________________________

1.8. What off-farm activities are held in your HH? ____________________________________

1.9. What is your household income in cash per month?

☐ Less than 1.000. 000VND/month/household

☐ Less than 2.000. 000VND/month/household

☐ Less than 4.000. 000VND/month/household

☐ Less than 6.000. 000VND/month/household

☐ Less than 10.000. 000VND/month/household

☐ Less than 20.000. 000VND/month/household

☐ Other, please specify ____________________________________

2. Farm data:

Total farm area	Sao (1sao = 500m2)
- **area used for crops**	Sao
- **area used for animal housing**	m^2
Biogas plant size	m^3
When was your biogas plant built?	year
Average distance between biogas plant and field	m

2.1. Biogas plant type:

☐ KT 1 ☐ KT 2

2.2. What is the source of water used for the BGP?

Please choose: ☐ public water supply ☐ river ☐ pond ☐ well

☐ other (________________________________)

3. Livestock:

	Type of animal (X = yes)	**Number of animals/year**	**Average weight per head (kg)**	**All manure used in the BGP (X = yes)**	**Solid faeces are collected, liquid go to the BGP (X = yes)**	**Some waste goes to the BGP, some directly to the river/canal (X = yes)**
Piglets						
Fattening pigs						
Sows						
Boar						
Chicken						
Ducks						
Cattle						
Other						

	Amount of water for animals Litres/day	Amount and type of feedstock for animals
Piglets		
Fattening pigs		
Sows		
Boar		
Chicken		
Ducks		
Cattle		
Other		

3.1. Do you plan to increase the number of your livestock in future (next year)?

Pigs ☐ Yes ☐ No

Cattle ☐ Yes ☐ No

Chicken ☐ Yes ☐ No

Other, please specify ____________☐ Yes ☐ No

3.2 Type of housing

Pigs

☐ Temporary ☐ Semi-concrete ☐ Concrete ☐ Other, please specify _______________

Cattle

☐ Temporary ☐ Semi-concrete ☐ Concrete ☐ Other, please specify _______________

3.3. Did you build or repair any of the animal housing because of the BGP?

If yes, for what animals___________________________

4. Feedstock and digestate

4.1. Do you use anything else (other feedstock) apart from manure into your biogas plant?

1) ____

2) ____

3) ____

4.2. Do you use human excreta for the BGP? ☐ Yes ☐ No

4.3. Is there a pond close to the farm?

☐ Yes

☐ No, but there is potential possibility to build a pond and keep the fish

☐ No, and there is no possibility to make pond

4.4. Do you use all the digestate on your fields?

☐ Yes ☐ No (reason ____)

4.5. Are you aware of possibility to use digestate for feeding fish?

☐ Yes (from whom____)

☐ No

4.6. Are you willing to use digestate for feeding fish to help them grow faster?

☐ Yes

☐ No, (reason ____)

5. Biogas plants use:

5.1. Please, provide 3 main motivating reasons (highlight the priority one) for installing the biogas plant: 1/____

2/____

3/____

5.2. Do you use your biogas for cooking? ☐ Yes ☐ No

Hours of cooking ________ hours/day

5.3. Do you use your biogas for lightning? ☐ Yes ☐ No

5.4. Are you still using alternative fuel sources (like wood and LPG) for cooking?

☐ Yes ☐ No

5.5. Do you use those sources less than before you had the biogas plant?

☐ Yes ☐ No

5.6. Have you noticed any improvement in your living environment with the biogas plant?

☐ Yes ☐ No

5.7. What was the final (total) cost of your biogas plant? ______________________ VND

5.8. What was the subsidy you received? ____________________________ VND

5.9. What was your financial contribution? ____________________________ VND

5.10. Please, choose the main benefits of the biogas plant for you:

Free time for other activities	☐
Smoke-free and ash-free kitchen (no respiration problems)	☐
Cooking with biogas is faster and easier than using wood	☐
Digestate is good fertilizer for the farm	☐
Generation of electricity	☐
Money saved	☐
Use of biogas for lightning	☐
Clean environment on my farm	☐
No odour	☐

Other (specify ____)

5.11. How much would you be willing to pay for the biogas plant now, when you recognize all these benefits?

Wouldn´t purchase it	Less money	Same amount	A little bit more	Full price of the BGP (without subsidy)

5.12. How much money do you save by using biogas plant per year? _____________ VND

5.13. How much money did you spend for wood/charcoal/sawdust/gas for cooking before/after have biogas before biogas plant? Before biogas plant _________ VND after biogas plant _______ VND

5.14. How much biogas do you normally have?

☐ Not enough ☐ Enough ☐ Too much

5.15. How much time did you spend collecting materials for cooking (wood, rice straw, sawdust) before having a biogas plant?

__________________ hours/day

5.16. How much time do you spend by collection of materials for cooking now?

__________________ hours/day

Hours of cooking ________ hours/day

5.17. Money for firewood per month:

Now ________________ VND

Before biogas plant ________________ VND

Price per kg ________________ VND

6. Maintenance

6.1. How many people take care of your biogas plant? ______________________________

6.2. How much time do you/does person spend doing maintenance of your biogas plant?

__________________ hours/month

6.3. In case of high pressure in the biogas plant, do you release the biogas into the air?

☐ Yes (how often: ☐ Every day ☐ Every week ☐ Every month)

(how many hours _______)

☐ No

6.4. Have you noticed leakages/cracks in your biogas plant? ☐ Yes ☐ No

6.5. Do you have any problems with your biogas plant? ☐ No ☐ Yes (if yes, please write them down)

1) ____
2) ____
3) ____
4) ____

6.6. Have you attended some trainings regarding to the biogas plants?

☐ No

☐ Yes (how many times? _________)

How satisfied were you with the training?

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

6.7. Do you have access to water near (less than 10 minutes away) your biogas plant?

☐ Yes ☐ No

6.8. Do you mix the manure of your biogas plant with an equal amount of water?

☐ Yes ☐ No (what ratio do you use ______________________________)

6.9. How many litres / buckets of water do you use per day for watering manure into BGP and cleaning/bathing the animals? ______________________________

6.10. Do you collect all manure of your animals (for biogas plant or for use in the fields)?

☐ Yes ☐ No

6.11. Have you experienced any problems with floating layers on top of the substrate in the biogas plant?

☐ Yes ☐ No

6.12. Have you experienced any problems that clog the gas pipeline, and/or the outlet of the digester?

☐ Yes ☐ No

6.13. Do you have enough access and offer of spare parts and biogas equipment in your area?

☐ Yes ☐ No

6.14. How satisfied are you with the BGP?

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

6.15. How satisfied are you with the biogas cookers?

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

7. Construction of the biogas plant (Type KT 1, KT 2, or other type with bricks)

7.1. What did you do to prepare the terrain for the construction of your biogas plant?

____

____

____

____

____

7.2. How many workers were involved in the preparation of the terrain for your biogas plant?

________________ workers

7.3. How many workers were needed to build your biogas plant?

_________________ workers

7.4. How many days were they working to finish your biogas plant?

_________________ days/person

7.5. How many bricks were used in the construction?

_________________ bricks

7.6. How much cement was used in the construction?

_________________ kilograms

7.7. How much sand was used in the construction?

_________________ kilograms

7.8. How much water was used in the construction?

_________________ litres

7.9. What is the lifespan of your biogas plant?

7.10. What will you do with your biogas plant at the end of its life?

____

____

8. Information about biogas technology

8.1. Is information about the biogas technology easily available for you?

____

8.2. In what form?

____

8.3. What sources of information do you use/have you used about the biogas technology?

____

8.4. How demanding was the procedure of gaining a BGPs for you? (From the administrative perspective – approvals etc.)

1 (very simple)	2	3 (moderate)	4	5 (very demanding)

9. Other comments / information:

____

Appendix 2. Descriptive Statistics of Characteristics of Respondents

Collection of tables related to the questionnaires’ statistics and additional information.

Appendix Table 1. Age × Gender - Cross tabulation (N=123).

			Gender		Total
			Male	**Female**	
Age Intervals	Up to 25	Frequency	0	2	2
		% of Total	0.0%	1.6%	1.6%
	26 - 55	Frequency	50	36	86
		% of Total	40.7%	29.3%	69.9%
	56 plus	Frequency	21	14	35
		% of Total	17.1%	11.4%	28.5%
Total		Frequency	71	52	123
		% of Total	57.7%	42.3%	100.0%

Source: Author.

Men were, normally, the responsible for the maintenance of the biogas plants.

Appendix Table 2. Respondents per district (N=123).

District			**Gender**		**Total**
			Male	**Female**	
	Phong	Frequency	28	21	49
	Dien	% of Total	22.8%	17.1%	39.8%
	Huong	Frequency	43	31	74
	Tra	% of Total	35.0%	25.2%	60.2%
Total		Frequency	71	52	123
		% of Total	57.7%	42.3%	100.0%

Source: Author.

Appendix Table 3. Main occupation of the respondents (N=123).

Occupation			**Gender**		**Total**
			Male	**Female**	
	Farmer	Frequency	68	51	119
		% of Total	55.3%	41.5%	96.7%
	Goods Seller	Frequency	2	1	3
		% of Total	1.6%	0.8%	2.4%
	Builder	Frequency	1	0	1
		% of Total	0.8%	0.0%	0.8%
Total		Frequency	71	52	123
		% of Total	57.7%	42.3%	100.0%

Source: Author.

The range of persons living in the household between respondents was between a minimum of 2 to a maximum of 9 persons, being the mean household size in the country is 4 people per household. The average family members were also 5 members and the average number of children under 15 years old was 1 child. Regarding the farm activities, the average number of persons working in the farm was 2 persons. Some of the households had off-farm activities too, like noodle-making, rice processing, driver, mechanic, carpentry, coffee shop and others.

Appendix Table 4. Household income among respondents (N=123).

VND/month/household	**Frequency**	**Percent**
< than 20,000,000	9	7.3
< than 10,000,000	84	68.3
< than 6,000,000	25	20.3
< than 4,000,000	5	4.1
Total	123	100.0

Source: Author.

Appendix Table 5. Type of biogas digester and built year (N=123).

BGP built year		BGP Type 1	BGP Type 2	**Total**
2000	Frequency	0	1	1
	% of Total	0.0%	0.8%	0.8%
2004	Frequency	0	1	1
	% of Total	0.0%	0.8%	0.8%
2009	Frequency	1	0	1
	% of Total	0.8%	0.0%	0.8%
2011	Frequency	2	19	21
	% of Total	1.6%	15.4%	17.1%
2012	Frequency	0	43	43
	% of Total	0.0%	35.0%	35.0%
2013	Frequency	0	56	56
	% of Total	0.0%	45.5%	45.5%
Total	Frequency	3	120	123
	% of Total	2.4%	97.6%	100.0%

Source: Author.

In reference to a question about how demanding was the procedure of gaining a BGP, 100 % farmers reported “very easy”; in a scale of one to five, one meaning “very easy” and five “very difficult”.

Appendix Table 6. List of the main motivating possible reasons for installing the BGP, given to the respondents to choose (N=123).

Main motivating reasons to install a BGP	**Frequency**	**Percent of respondents**
Use of biogas for cooking	118	95.9
Clean environment	87	70.7
Cleaner animal housing	71	57.7
Saved money	56	45.5
Support for the project	48	39.0
Clear garden	17	13.8
More free time	12	9.8
Odour reduced	4	3.3
Digestate is a good fertilizer	2	1.6
Limited wood for cooking	1	0.8

Source: Author.

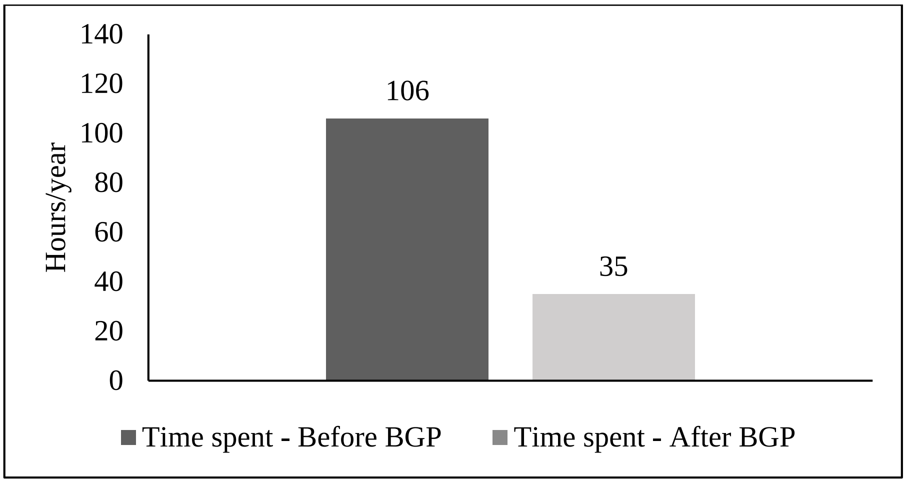
Appendix Table 7. Usual amount of biogas × respondents still using alternative fuel sources for cooking – Crosstabulation (N=123).

			Still using alternative fuel		**Total**
			NO	**YES**	
Usual amount of biogas	**Enough**	Frequency	7	99	106
		% of Total	5.7%	80.5%	86.2%
	Not enough	Frequency	0	17	17
		% of Total	0.0%	13.8%	13.8%
Total		Frequency	7	116	123
		% of Total	5.7%	94.3%	100.0%

Source: Author.

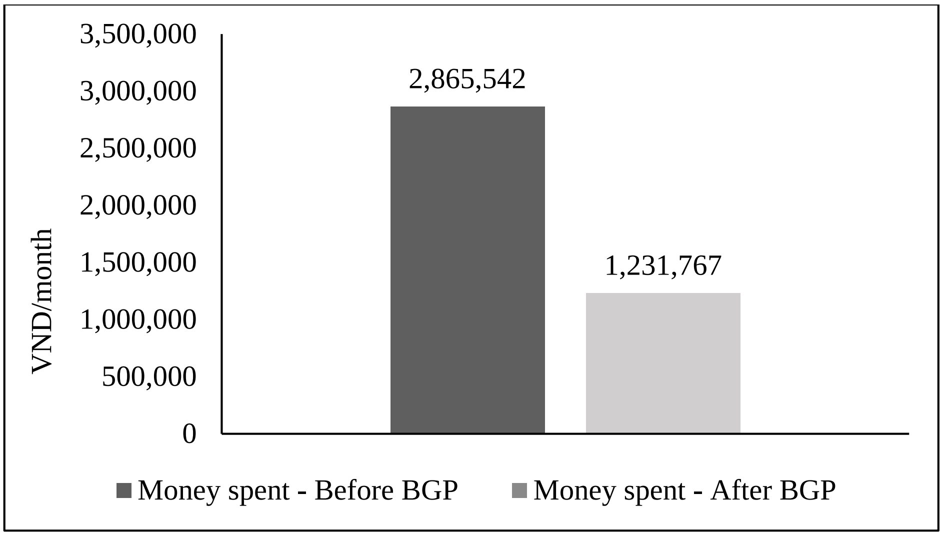
86.2 % respondents reported to often had enough biogas production, in reference to their requirements. When asked about how long it took to them for collecting materials for cooking before BGP in terms of hours per year, the approximate average was found to be 106 hours/year. To compare the findings between the time spent collecting materials before the BGP and after the BGP, they were again asked about how long it took for collecting materials for cooking now with the BGP installed. The average time was approximately 35 hours/year.

Furthermore, the average amount of money spent in firewood before the BGP was 2,865,542 VND[2] per month and the average after the BGP was 1,231,767 VND per month, meaning 43 % of money saved.



Appendix Figure 1. Time spent collecting materials for cooking, before and after the BGP (hours/year) (N=123).

Source: Author.



Appendix Figure 2. Money spent in firewood for cooking, before and after the BGP (VND/month) (N=123).

Source: Author.

[2] (1 USD = 22,727.21 VND; 1 EUR = 24,192.04 VND)

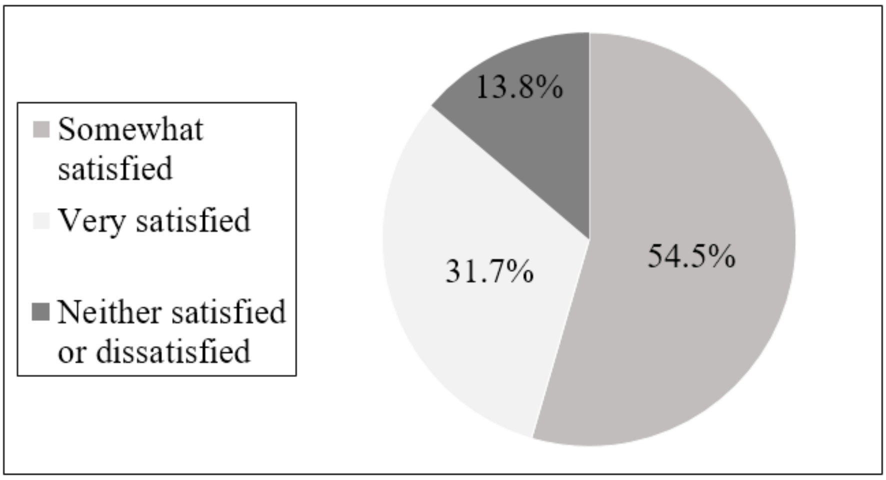
In all the cases, only 1 person was responsible to take care of the BGP. It was found that the average time spent doing maintenance (mainly cleaning of animal housing dispersing the liquid and solid manure with water into the inlet of the BGP) of the BGP was 1.81 hours per month.

Appendix Table 8. Main BGP problems reported (N=123).

Main BGP problems	**Frequency**	**Percent**
Cracks/leakages	65	52.8
No problems	54	43.9
Floating layer in the digester	3	2.4
Problems in the biogas filter	1	0.8

Source: Author.

Problems found from the interviews in the study area, in case any were reported. It also showed the percent of respondent that said they did not have any problem. It should be keep in mind that in any case the respondents were not experts in biogas or BGPs, neither had advanced knowledge about the topic, and those were their personal ideas about what were the problems they had in each particular situation. The most commonly found problem was cracks in the BGP (52.8 % reported it), many times easy to detect by the bubbles on the top access door of the digesters and/or the odour liberated.



Appendix Figure 3. Level of satisfaction with BGP (%) (N=123).

Source: Author.

In reference to the general satisfaction with the BGP, the majority of the respondents (54.5 %) said that they were “somewhat satisfied” (scale 1 to 5).

Regarding the trainings, there were other complements to theoretical training in the forms of TV programs, handbooks or brochures. In reality these methods were reported to be not efficient, as the farmers said that nobody pays attention neither have the time to study or understand the technology by these methods.

Appendix Table 9. Spearman correlation (N=123).

Correlations							
			Usual amount of biogas (regarding farmer's needs) (enough vs not enough)	**Information about the biogas technology easily available**	**Household Income (cash/month)**	**Price willing to pay for the BGP now (VND)**	**Level of general satisfaction with BGP**
Spearman's rho	**Usual amount of biogas**	Correlation Coefficient	1.000	0.110	0.125	,304**	-0.081
		Sig. (2-tailed)		0.225	0.170	0.001	0.371
		N	123	123	123	122	123
	Information about the biogas technology easily available	Correlation Coefficient	0.110	1.000	-0.013	0.053	0.098
		Sig. (2-tailed)	0.225		0.889	0.559	0.283
		N	123	123	123	122	123
	HH income	Correlation Coefficient	0.125	-0.013	1.000	,196*	0.068
		Sig. (2-tailed)	0.170	0.889		0.030	0.455
		N	123	123	123	122	123
	Amount willing to pay for the BGP	Correlation Coefficient	,304**	0.053	,196*	1.000	0.017
		Sig. (2-tailed)	0.001	0.559	0.030		0.852
		N	122	122	122	122	122
	Level of satisfaction with BGP	Correlation Coefficient	-0.081	0.098	0.068	0.017	1.000
		Sig. (2-tailed)	0.371	0.283	0.455	0.852	
		N	123	123	123	122	123

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).

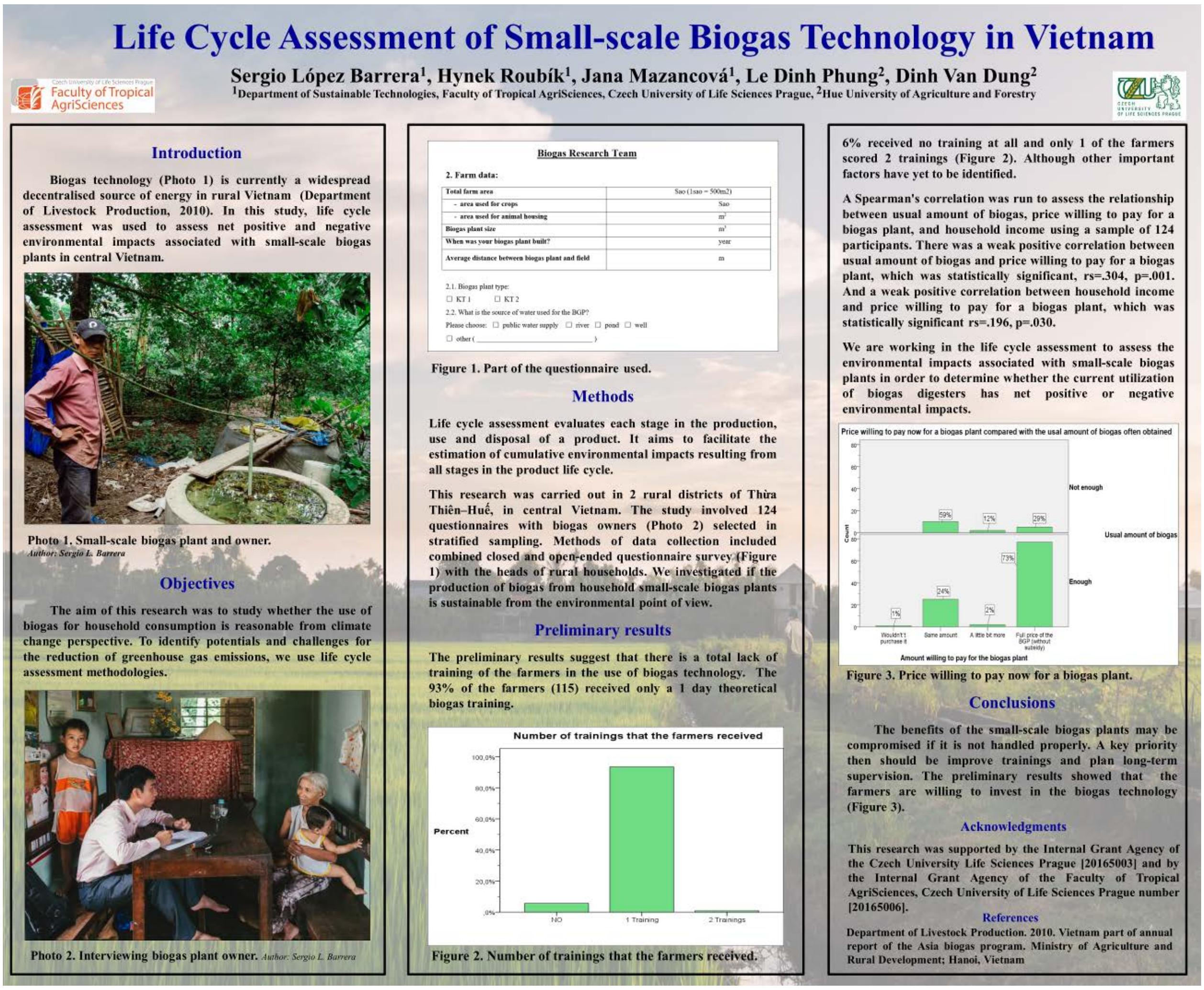
Source: Author.

Additionally, the survey data showed that from the total farmers that have enough amount of biogas for their needs, 73 % of them would be willing to pay the full price (without any subsidy) of a BGP if they would have to buy it again. From the other farmers than cannot fulfil their needs due to insufficient amount of biogas, likewise, 53 % of them would be willing to pay the same price (with subsidy) that they paid in the past for their actual BGP.

Regarding the farms, it was found that the farms had an average total area of 5,230 m^2, the mean area used for crops was 4,260 m^2, and regarding animal housing the average space was 30 m^2.

Appendix 3. Thesis contribution

This diploma thesis was presented in the form of a conference poster, in the "*3rd Tropical Biodiversity Conservation Conference*" held in 2016 at the Czech University of Life Sciences Prague, during 8th and 9th of November. Figure 4 shows a preview of the poster.



Appendix Figure 4. Tropical Biodiversity Conservation Conference Poster.

Source: Author.

Furthermore, it contributes to report the actual situation of the past project, regarding biogas technology implementation "*Renewable Energy Resources for Rural Areas in Thua-Thien Hue Province (2011-2013)*". Additionally, in the near future, this thesis could probably derive in a manuscript to be submitted and published as a journal article.

Appendix 4. LCA additional information

Appendix Table 10. Inventory of inputs used in the modelled BGP system.

	Item	Materials	Quantity	Unit	Unit price	Total price (VND)	Total price (US Dollars)
Construction	Digester building	Bricks	1,100	piece	0.04 US/piece		44.00
		Cement	1,500	kg	1,550 VND/kg	2,325,000	102.30
		Steel rod reinforcement	6	kg	17,600 VND/kg	105,600	4.65
		Plastic tubing	1	unit	17.41 US		17.41

		Diesel	7	l (litres)	0.61 US/l		4.27
		Labour	X	total price			50.00
	Toilet renovation	Cement block	1,800	piece	0.04 US/piece		72.00
		Cement	400	kg	1,550 VND/kg	620000	27.28
		Steel rod reinforcement	2.5	kg	17,600 VND/kg	44000	1.94
		Wooden door	1	unit	14.50 US		14.50
		Labour	X	total price			14.60
	Pigpen renovation	Cement block	3164	piece	0.04 US/piece		126.56
		Cement	600	kg	1,550 VND/kg	930000	40.92

	Precast hollow slab	16	m^2	5 US/m^2	80.00
	Labour	X	total price		43.53
Operation and maintenance	Plastic tubing	1	Unit	17.41 US	17.41
	Stove & accessories (kitchen)	1	unit	36.27 US	36.27
	Labour	X	total price		72.55
Demolition	Diesel	3.9	l (litres)	0.61 US/l	2.38
	Labour	X	total price		36.76