CZECH UNIVERSITY OF LIFE SCIENCES PRAGUE

Faculty of Tropical AgriSciences

Department of Sustainable Technologies

Environmental Impact of Small-scale Biogas Plants in Central Vietnam

Master Thesis

Prague 2015

Supervisor: Ing. Jana Mazancová, PhD.

Author: Bc. Hynek Roubík

Declaration

I hereby declare that I have written presented master thesis "***Environmental Impact of Small-scale Biogas Plants in Central Vietnam***" by myself and acknowledge by means of complete references.

I agree with use of the thesis by the library of the Czech University of Life Sciences Prague for study purposes.

Prague, 24th April 2015

Bc. Hynek Roubík ____________________

Bibliographic citation

Roubík H, 2015. Environmental Impact of Small-scale Biogas Plants in Central Vietnam [MSc.]. Prague: Czech University of Life Sciences Prague. 61p.

Acknowledgement

I would like to express my honest gratitude and deep appreciation to my supervisor Ing. Jana Mazancová, PhD. for all the time she dedicated me and my work. And for her valuable advices and comments during the research and its compilation.

Thanks belong also to my friends and colleagues, who supported and encouraged me during the intensive studies and challenging times.

Furthermore, this research was conducted within the development project: *"Renewable Energy Resources for Rural Areas in Thua Thien Hue Province*" funded by the Government of the Czech Republic. Also support was given by the Internal Grant Agency projects [2013511] and [20145024] at the Faculty of Tropical AgriSciences, Czech University of Life Sciences Prague. So, thanks for institutional support belongs to the Government of the Czech Republic, to the Czech University of Life Sciences Prague and especially to the Faculty of Tropical AgriSciences.

Finally, I would be remiss if I would not acknowledge the innumerable sacrifices made by my parents, who dedicated me a lot of time and enormous support during my studies and research in faraway countries, as well as in my whole life. Mom and Dad, thank you for all your love and support.

Abstract

Given the rising expectations for the substitution of fossil fuels with renewable energy as one of the main solutions to cope with climate change, sustainable energy sources are therefore prerequisite for the sustainable development. Anaerobic digestion is considered as a significant technology in improving environment; as it solves waste management problems, produces biogas, as a main product, and as a by-product digestate, which can also be used as yield and soil improver.

The major objective of this study was to find out environmental aspects and impacts of small-scale biogas plants (BGPs) in central Vietnam. Current problems with BGPs in the target area were analysed and possible solutions were outlined in line with local conditions using problem analysis approach to identify and describe major problems and potential risks, intending to adopt some relative improvements and prevent failures. The study revealed 29% problem rate with biogas technology. Failures were recognized in all six main subsystems: anaerobic digestion processes and biogas utilization (37.2 %), biogas utilization equipment (25.2 %), digestate disposal system (17.1 %), knowledge related problems (9.1 %), piping system (6.2 %) and structural components (5.0 %). Also, current manure management practices were deeply investigated, analysed and described with all its aspects. Further so, motivating factors and current benefits were revealed. In target area types of BGPs KT1 and KT2 are predominant with average size of 7.45 m3 (±2.23). Most common source of information about biogas technology are commune staff and local facilitators (77 %), than neighbours (13 %) and public media (10 %). An average farm have 2.2 working people and size of 2,821 m^2 for farm with BGP and disposes by 13-14 piglets and 2-3 sows. A biogas potential per household is 2.32 m^3/ day. However, if recalculated with actual usage of manure in BGPs, biogas outcome per household is 1.09 m^3/day. Showing two time higher biogas potential, if manure used appropriately.

In conclusion, this study analysed the current situation surrounding problems with biogas plants and manure management in target area. Investigating of such a topic is within continuing concern about environmental issues connected with small-scale biogas plants and manure management in rural areas of developing countries.

Keywords: small-scale biogas technology, anaerobic digestion, environmental aspects, technology difficulties, manure management practices

Abstrakt

Vzhledem k rostoucím očekáváním pro nahrazování fosilních paliv se energie z obnovitelných zdrojů stává jedním z hlavních řešení pro boj se změnou klimatu. Udržitelné zdroje energie jsou proto nezbytným předpokladem pro udržitelný rozvoj. Využití anaerobní digesce je považováno za vhodnou technologii pro zlepšení životního prostředí; protože řeší problémy nakládání s odpady, jako hlavní produkt vyrábí energii ve formě bioplynu a jako vedlejší produkt digestát, který má využití jako zlepšovatel zemědělských výnosů a půdních vlastností.

Hlavním cílem studie bylo zjistit dopady rodinných bioplynových stanic (BPS) na životní prostřední ve středním Vietnamu. Byly analyzovány současné problémy s BPS a byla vypracována možné řešení v souladu s místními podmínkami za využití analytického přístupu identifikujícího hlavní problémy a potenciální rizika s přihlédnutím k prevenci dalších poruch. Studie zjistila problémovost u 29 % BPS. Problémy byly zjištěny ve všech šesti hlavních subsystémech: anaerobní procesy a využití bioplynu (37,2 %), zařízení na využití bioplynu (25,2 %), výtok digestátu (17,1 %), problémy spojené se znalostmi (9,1 %), potrubní systém (6,2 %) a konstrukční prvky (5,0 %). Také praktiky nakládání s hnojem byly analyzovány a popsány. Dále byly prozkoumány motivační faktory a aktuální benefity dle respondentů. V cílové oblasti převažují typy BPS KT1 a KT2 s průměrnou velikostí 7,45 m3 (±2,23). Nejčastějším zdrojem informací o BPS jsou místní facilitátoři a zastupitelé v komunách (77 %), sousedi (13 %) a veřejná média (10 %). Na průměrné farmě o velikosti 2,821 m2 pracuje 2,2 lidí a mají 13-14 selat a 2-3 prasnice. Potenciál bioplynu na domácnost je 2,32 m^3/den. Aktuální využité je však 1,09 m^3/den. To poukazuje na dvojnásobný potenciál v množství vyprodukovaného bioplynu, pokud je vhodně nakládáno s exkrementy.

Závěrem, tato studie analyzuje současnou situaci kolem problematiky rodinných bioplynových stanic a nakládání s hnojem v oblasti středního Vietnamu. Problematika spadá do širšího kontextu v rámci pokračujících obav o environmentální problematiku spojenou s rodinnými bioplynovými stanicemi v rozvojových zemích.

Klíčová slova: technologie malých bioplynových stanic, anaerobní digesce, environmentální aspekty, problémy s technologií, praktiky nakládání s hnojem

Content

List of tables

List of figures

List of contractions

AD	Anaerobic digestion
AFFEC	Agricultural Forestry Fishery Extension Centre
BGP	Biogas plant
BPAHS	Biogas Programme for the Animal Husbandry Sector in Vietnam
DC	Developing country
DMP	Decision making process
FGD	Focus group discussion
GHG	Greenhouse gases
HH	Household
PA	Problem analysis
PB	Payback period
SNV	Dutch development organization
UNDP	United Nation Development Programme
USD	United States dollar
WHO	World Health Organization

1. Introduction

The consumption of fossil fuels produces serious pollution and global warming. Reducing the dependency on fossil fuels through the development of sustainable energy sources is therefore a prerequisite for the sustainable development (Jiang *et al.*, 2011). The resource limitations of fossil fuels and problems arising from their combustion have led to the widespread utilization of renewable energy resources. Energy and environmental issues have become one of the most important problems of common concern and one of the first problems needing to be solved by mankind to further sustainable development (Zhou *et al.*, 2011). Ensuring modern household energy services is a key focus for national governments of many developing countries in case of support sustainable development efforts (Tigabu *et al.*, 2015a; Nguyen, 2006). In developing countries still over two and half billion people do not have access to adequate energy services (Tigabu *et al.*, 2015a; Tahama *et al.*, 2011). And lack of access to modern energy services is a daunting development challenge in developing world (Tigabu *et al.*, 2015b). Among the measures, promotion of renewable energy has often been considered as one of the desirable and practicable options (Qurashi and Hussain, 2005; Chaurey *et al.*, 2004), which is considered by development partners and government organisations as one way of meeting the development challenge (Tigabu *et al.*, 2015b). Coming from outcome of conclusion that sustainable modern energy can and should be generated from locally-accessible and –affordable natural resources through the use of renewable energy technologies (Tigabu *et al.*, 2015a; REN21, 2010). One of such an option is application of small-scale biogas plants with anaerobic digestion.

Anaerobic digestion (AD) is considered as a significant technology in improving the environment; as it solves waste management problems, produces biogas, as a main product, and as a by-product digestate, which can also be used as fertilizer (Muller, 2007; Molino *et al.*, 2012; Adu-Gyamfi *et al.*, 2012). A biogas plant is a piece of technological equipment using an AD process for biodegradable waste treatment. Utilization of AD can be an appropriate solution to health, hygiene and environmental problems (Katakiza, *et al.*, 2012; Jha *et al.*, 2011; Jingura and Matengaifa, 2007). Production of biogas through the process of anaerobic digestion shows significant advantages against other forms of renewable energies (Lu Shu-Guang *et al.*, 2006). It has been evaluated as one of the most energy-efficient and environmentally friendly forms of energy and of technologies for renewable energy production (Raposo *et al.*, 2011; Weiland, 2010). It can also significantly decrease negative health effects of indoor air pollution and improve environmental sustainability (Tigabu *et al.*, 2015b; Arthur *et al.*, 2011).

Economic prosperity and quality of life in rural areas are closely linked to the level of their per capita energy consumption and the strategy adopted is to use energy as a fundamental tool to achieve the same (Singh and Sooch, 2004; Aggarangsi *et al.*, 2013). Also energy demand required to meet economic growth is high and growing every year (Aggarangsi *et al.*, 2013; Nguyen, 2006). Economic growth and improvement of people´s living standard are all directly or indirectly related to the increasing utilization of energy (Nguyen, 2006).

The energy consumption in the rural areas of central Vietnam can be covered by use of household-sized biogas plants and can point to a healthier and more sustainable way of living. One can expect that a higher number of biogas plants (BGPs) in developing countries will also bring a significant number of various problems and complications regarding their operation. It is important to notice, that a significant number of problems can fundamentally reduce the benefits of using this technology. The aim of this paper is to analyse current problems with BGPs in the target area and outline possible solutions in line with local conditions and easily applicable to the target area. This paper will also have value for fellow developing countries in the region.

2. Literature review

In the following section the comprehensive review is presented. It offers insight into the fundamental facts about small-scale biogas technology and its aspects.

2.1. Biogas plants in developing countries: History and future prospects

There are suggestions that biogas was used already in Assyria in 10^{th} century B.C. and that AD of solid waste has been applied in ancient China (He, 2010). In any event, well documented attempts of AD of biomass by humans are dated into middle of 19^{th} century in New Zeeland, India (Meynell, 1976) and UK (McCabe and Eckenfelder, 1958). Then development of microbiology as a science has led to the identification of anaerobic bacteria and further conditions that promotes methane production during the AD process (Buswell and Hatfield, 1936). In Germany AD was firstly used in 1920 with the gas supply into the public network and first large scale BGP started to operate in 1950 (Ni and Nyns, 1996). In China AD was firstly commercially used on household level in 1921 by Guorui Luo (He, 2010). The break point of biogas technology came in 1970s with high oil prices, which motivated research for further alternative energy sources (Bond and Templeton, 2011). It brought exponential growth of number of medium- and large-scale BGPs and interest into technology in USA (Hashimoto and Varried, 1979; Chen *et al.*, 1978) and Europe (Smith *et al.*, 1979) and the fast growth of small-scale biogas technology in Asian, Latin American and African countries.

In 1984 more than 7 million BGPs were already in the world, mostly in Asian countries (Steiner and Kandler, 1984). Currently millions of BGPs can be found in developing countries; the most common is so-called Chinese type (Maithel, 2009). There is no sign of slowing in current expansion of biogas technology, which is showing us importance of this topic and further research. There is still enormous potential for more biogas plants implementation in the world (Ravindranath and Hall, 1995; Hossain, 2003; Dimpl, 2010; Singh and Maharjan, 2003; Chen *et al.*, 2010). It suggests us considerable scope for continued expansion based mainly on existing designs and government support only with specific adjustments.

Currently, millions of BGPs can be found in developing countries. The most common BGP type is the so-called Chinese type (Maithel, 2009). In China one can find around 38 million BGPs (Chen *et al.*, 2012), in India more than 3.7 million (Rao *et al.*, 2010), in Vietnam over 100,000 BGPs (Ghmire, 2013), in Bangladesh 60,000 and an increasing number in Peru and African countries (Thu *et al.*, 2012).

However, the increasing number of BGPs in developing countries also means an increasing number of problems and complications connected with them (Aburas *et al.*, 1995). Generally, there are many advantages of biogas production, but also many disadvantages. If these cons outweigh the pros, small-scale farmers leave BGPs abandoned; as is the case in China (Zhou *et al.*, 2011). One of the most important problems hindering any biogas technology in developing countries is cost, which can create difficulties for the installation of such plants, together with sourcing spare parts (An *et al.*, 2006). It has been widely reported that the development of BGPs came in speedily because of substantial support from governments, development projects and aid agencies (Mwokaje, 2008; Kristoferson and Bokhalders, 1991), but afterwards, when the subsidies were reduced, the number of BGPs built each year fell dramatically (Desai, 1992). Technical and operational problems are common in the case of small-scale biogas plants, but suitable solutions are often produced (Aburas *et al.*, 1995). Further political measures may be needed to encourage adoption, including training and capacity building programmes, flexible financing mechanisms and dissemination strategies (Karekezi, 2002; Greben and Oelofse, 2009; Zhou *et al.*, 2011). System failures of small-scale biogas plants can be divided into six main subsystems, as adopted from Cheng *et al.* (2014a): structural components, biogas utilization equipment, piping systems, biogas production, digestate disposal systems, and knowledge related problems. Problems with structural components were found in studies conducted by Chang *et al.* (2011) in Inner Mongolia and by Lam and Heegde (2012) in Asia and Africa. Problems with biogas utilization equipment such as biogas cookers or biogas lamps are described by Pipatmanomai *et al.* (2009), Piechota *et al.*, (2013) and Thu *et al.* (2012) in Vietnam. With piping systems, problems such as leakages or blockages in the system were found in the case of Piechota *et al.* (2013) and problems with biogas production, such as leakage in biogas digesters were found in the studies of Chang *et al.* (2011) and Thu *et al.*

(2012). Solid digestate incrustation floating in the main tank prevents biogas from escaping as in studies from China done by Chen *et al.* (2012, 2010) and Chen *et al.* (2010). Digestate disposal systems are important for the sustainability of BGPs, because without appropriate disposal and operating procedures there can be no long-term sustainability (Alburquerque *et al.*, 2012). There is a need for quality supervision, inspection, maintenance, quality controls, effectiveness evaluations and technical guidance (Chen *et al.*, 2012). And to ensure that BGPs continue to function properly there is a need for improvements in the knowledge (Cheng *et al.*, 2014a; Thu *et al.*, 2012; Vu *et al.*, 2007), which should be transferred from the local facilitators to small-scale biogas owners (Jha *et al.*, 2011; Maithel, 2009). However, technology transfer in developing countries is often problematic (Klintenberg *et al.*, 2014). Common challenges are insufficient resources for operation and unsatisfactory maintenance after project implementation (Klintenberg *et al.*, 2014; Schillenbeeckx *et al.*, 2012).

2.2. Process of Anaerobic Digestion

The process of AD is process of microbial conversion of organic matter without air access and by assistance of mixed cultures of microorganisms and formation of biogas and stabilized biomass called digestate (Molino *et al.*, 2012; Yu *et al.*, 2008). The AD processes occurs also spontaneously in nature without human intervention (in swamps, marshes, sea bottoms, waterlogged soils, mammalian gut, sediments etc.), but also it occurs in controlled technological processes such as in biogas plants. The production of biogas through AD offers significant advantages among other forms of waste treatment (Lu Shu-Guang *et al.*, 2006), for example: it is successful in treating wet wastes (Mata-Alvarez, 2002), as well as organic solid wastes (Mata-Alvarez *et al.*, 2000), less biomass sludge is produced in comparison to aerobic digestion (Ward *et al.*, 2008), more effective pathogen removal (Sahlstrom, 2003), less odour emissions decomposed during combustion (Smet *et al.*, 1999), produced digestate is and improving fertilizer (Alburqueque *et al.*, 2012) and it is a source of carbon neutral energy in form of biogas (Ward *et al.*, 2008). AD has several other synonyms that are completely or partially overlapping: anaerobic fermentation, methane fermentation, manure fermentation, manure digestion, bio-methanization and others. For our reasons anaerobic digestion is the most suitable concept. Similar conceptual fragmentation is also in the case of digestate, which can be called as well: bio-slurry, fermented matter, stabilized biomass, digested slurry and biogas waste.

2.2.1. Product of Anaerobic Digestion: Biogas

Biogas and its production has undergone an extensive research, which results in a multitude of research papers dealing with such a topic from different point of view (Havukainen *et al.*, 2014), such as: biogas production (Banks *et al.*, 2011; Prade *et al.*, 2012), improvement of biogas production (Ward *et al.*, 2008) and different process configurations (Poeschl *et al.*, 2012). Biogas consists of mixture of gases and contains 50-75% of methane (Bond and Templeton, 2011), 23-43% of carbon dioxide with the variable component of water vapour (Prade *et al.*, 2012). Other substances are oxygen, sulphur and nitrogenous compounds, which may be the source of odour; further problematic compounds are chlorine and fluorine (combustion of these compounds produces aggressive products such as: SO2, SO3, HCl or HF and consequentially it can have negative effects on the equipment and fittings). At present, the calorific value of biogas is in general considered of 25MJ/m^3 with content of 60% methane (Váňa, 2010); however, in the countries of global South, thanks to different input materials and technical imperfections is calorific value between 21 and 24 MJ/m^3 (Bond and Templeton, 2011; Pipatmanomai *et al.*, 2009).

2.2.1. By-product of Anaerobic Digestion: Digestate

With growing number of biogas plants, quantities of digestate are gradually increasing. As a result, in recent years, researchers have started to focus on this issue, mainly how digestate positively influence yields (Shi *et al.*, 2001; Kouřimská *et al.*, 2012), enhances resistance against abiotic stresses (Mahmoud *et al.*, 2009), effects on photosynthetic characteristics (Zhang *et al.*, 2010), its advantages in comparison with manure (Massé et al, 2007; Lansing *et al.*, 2010; Thy *et al.*, 2003), and its soil physical and chemical improvement influences (Mahmoud *et al.*, 2009; Li *et al.*, 2006). Many studies also focus on comparative studies of digestate, mineral fertilizers and other fertilizers and their influences on plant growth, soil quality and fertility and yields improvements (Alburquerque *et al.*, 2012; Del Amor, 2007; Garfí *et al.*, 2011; Li *et al.*, 2006). By previous studies it was verified that digestate can be used to replace chemical fertilizers (Liu *et al.*, 2008) and contribute to reduction of use of non-renewable energy sources used for chemical fertilizers production (Li *et al.*, 2012).

2.3. *Merits of Anaerobic Digestion*

There are number of advantages using AD for waste management on farms, including savings on firewood or fossil fuels, reductions in odour and greenhouse gas emissions (Bruun *et al.,* 2014). It also creates jobs, produce less indoor smoke than other fuel types used in DCs (Chen *et al.,* 2010; Huboyo *et al.*, 2014). Furthermore, biogas can be used in HHs for cooking, heating and lightning, and can contribute towards farmers´ livelihoods (Vu *et al.*, 2015). AD of organic wastes in simple BGPs, is recommended as a way of managing on small-holders farms (Islam *et al.,* 2008; Vu *et al.,* 2015).

2.3.1. Environmental benefits of biogas technology

Anaerobic digestion utilization is an appropriate solution to environmental problems and can play fundamental role in conditions improvement (Katakiza, *et al.*, 2012; Jha *et al.*, 2011). The extensive use of firewood for energy purposes, especially in DCs, has fundamental effects on local forests (Surendra *et al.*, 2014). Fuelwood accounts for 54 % of deforestation in DCs (Osei, 1994) and worldwide is deforestation responsible for up to 25 % of all anthropogenic GHG emissions (Strassburg *et al.*, 2009). Also, deforestation has impact on soil erosion and land degradation (Gautam *et al.*, 2009). In Nepalese study done by Katuwal and Bohara (2009) it was estimated that annually a small-scale BGP spares the direct burning of 3 metric tons of firewood and 576 kg of dung; subsequently, eliminating around 4.5 metric tons of CO_2 emissions to the atmosphere. Therefore, a significant reduction in deforestation, especially in DCs, can be achieved by replacing firewood with BGPs (Surendra *et al.*, 2014).

2.3.2. Health benefits of biogas technology

AD of waste provides sanitation by reducing pathogenic content of substrate materials (Bond and Templeton, 2011). Hence, BGP installation can dramatically improve the health of users. In addition, installation of biogas technology often requires to construct toilet (construction of toilet is mandatory by most of the subsidy programs promoting HH BGPs in developing countries), the actual issue of open defecation which is largely responsible for cholera, typhoid and other water borne disease is minimized (Surendra *et al.*, 2014).

Also, in rural areas of DCs, still about three billion people rely on biomass such as fuelwood, crop residues and animal dung and charcoal to meet their energy needs (UNDP/WHO, 2009). The smoke from indoor open fires, which are widely used by farmers, exposes families to harmful levels of gases, particles and dangerous compounds, such as carbon monoxide, benzene and formaldehyde coming from combustion. There are many diseases connected with indoor air pollution like lung cancer, respiratory diseases and pneumonia problems, or other diseases such as asthma, bronchitis, tuberculosis, low birth weight, heart diseases and other (Pope *et al.*, 2010; Lohani, 2011; McCracken *et al.*, 2007; Slama *et al.*, 2010; Surendra *et al.*, 2013; Huboyo *et al.*, 2014; Chowdhury *et al.*, 2013). Majority of victims of exposure to the indoor air pollution are women and children, mainly from low-income homes in rural areas (Lohani, 2011; WHO, 2002; Surendara *et al.*, 2014). Globally, in 2010, nearly three and half million deaths were attributed to household air pollution from solid fuel use (Lim *et al.*, 2012).

2.3.3. Social / Gender benefits of biogas technology

Gender equality is an important issue in many spheres of development (Potrafke and Ursprung, 2012). That is the reason why "gender consideration" has become obligatory in almost all development assistance programmes of past decades (Scott and Chuyen, 2007) and is highly examined factor (Roubik *et al.*, 2014). Gender issue is an important social category; which can affect adolescent´s lives in multiple ways (Daniels and Leapers, 2011).

As discussed, in the majority of DCs, women and children are still responsible for firewood and dung collection, which are both exhausting and time consuming activities (Surendara *et al.*, 2014). Based on a case study from Nepal, small-scale BGP can save approximately two hours per day of woman´s and child´s time (Kutuwal and Bohara, 2009). Time can be used for various recreational activities, social work, income-generating activities and further education (Surendara *et al.*, 2014; Li, 2009). Thus, the installation of BGP at the HH level can directly provide better opportunities for gender equality in rural areas of developing countries and provide long-term social benefits (Surendara *et al.*, 2014; Roubik *et al.*, 2014; Thu *et al.*, 2012).

2.4. Small-scale Biogas Plants in DCs and their Advantages and Disadvantages

Implementing efficient technologies is especially challenging in remote areas of DCs (Thu *et al.*, 2012). And efficient utilization of human and animal waste provides an opportunity to produce renewable energy and also reduce GHG emissions (Pham *et al.*, 2014). Other of significant factors for BGP purchase is the factor of construction costs. While the construction costs of BGPs vary between different countries, they are often high relative to the income of HH owners and other potential users. For example, in studies from China done by Li (2009), and from Thailand by Limmeechokhai and Chawana (2007), as well as in the study from Kenya by Mwirigi *et al.* (2009) the investment cost were identified as a major barrier to technology uptake. Further, in the study from seven African and Asian countries, almost 95 % of farmers who adopted biogas technology fit into categories of medium or high income (Ni and Nyns, 1996). In Kenya, more than half of farmers received subsidy covering over 25 % of construction cost, otherwise they would not be able to finance construction of BGP (Mwirigi *et al.*, 2009).

Sanitation and environmental improvements play major role in factors motivating farmers to build BGP. Traditional animal farms in Thailand normally manage their livestock wastes by dumping them into a pond or series of ponds (Thiengburanathum, 2006; Prasertsan and Sajjakulnukit, 2006). This waste can leak or discharge into a natural stream, groundwater or impoundment, leading to depleting of oxygen into a surface water and increasing amounts of nitrogen and phosphorus as well as chance of disease transmission (Aggarangsi *et al.*, 2013).

Farms also produce severe odour emissions which plague their neighbours, leading to social problems and reducing the property value of neighbouring areas (Huong *et al.*, 2014; Aggarangsi *et al.*, 2013). In fact, in some studies farmers perceived bad strong odours and air to be a direct cause of human disease, e.g. through airborne transmission of pathogens (Huong *et al.*, 2014; Rheinlander *et al.*, 2013). Nearly all farmers interviewed in the study by Huong *et al.* (2014) reported that installation of the biogas system reduced the problems with bad smells and flies and that these benefits were the main reasons for building a biogas plant. Further major advantages and disadvantages are presented in Table 1.

Table 1: Advantages and disadvantages of biogas technology*

Advantages	Disadvantages
Less demand for fossil fuels	**Construction costs**
-lower pollution	-high construction costs in comparison to income of target groups
-lower effects on global warming	**Limited lifespan**
Less demand for alternative fuels	~20 years lifespan for majority of BGPs
-conservation of woodland	**Laborious operation and maintenance**
-less soil conservation	**Unsuitability into arid regions**
-time saved by wood collecting	**Dependence on stabile feed source**
Reduced emissions	**Requires reliable outlet for digestate**
-carbon dioxide	**Poor hygiene of digestate from mesophilic digestion**
-nitrous oxide	
-greenhouse gases	
Improved indoor air quality	**Dependence on key players**
Improved sanitation	Dependence on governmental / non-governmental key actors
-reduced pathogens	
-reduced disease transmission	**Technology adoption**
Low cost energy source	-negative perception where low functionality of existing plants
-cooking	**Low recycling of nutrients**
-lightning	
-electricity generation	
Improved crop yields	
-low cost fertilizer	
Improved living conditions	
-socio-economic improvements	

*Advantages and disadvantages based on Vu *et al.* (2015), Thu *et al.* (2012), Lam and Heegde (2012), Bond and Templeton (2011), Remais *et al.* (2009), Mwirigi *et al.* (2009), Li (2009), Oenema *et al.* (2005), Hossain (2003), de Alwis (2002), ISAT/GTZ (1999a), ISAT/GTZ (1999b), ISAT/GTZ (1999c), ISAT/GTZ (1999d)

2.4.1. Experience with Small-scale Biogas Plants in Asia

Generally, effective and widespread implementation of small-scale BGPs has occurred in countries, where governments have been involved in the subsidy, planning, design, construction, operation and maintenance of technology. Such experiences are especially from China, India, and Vietnam, where massive campaigns have been run to popularize the technology. Surveys in various regions are giving various proportions of problem rates. Studies from India have found problem rate from 40 % up to 81 % (Bhat *et al.*, 2001; Dutta *et al.*, 1997). To reverse this phenomenon, system of advisory centres is needed. Each country has it set in slightly different way. However, mostly local, provincial and national levels are set up as it is in China (Li *et al.*, 2015), India (Singh and Sooch, 2004) or Vietnam (Roubik and Mazancova, 2014). If BGPs do not work properly, they reduce BGP owner's enthusiasm and the use of technology is generally decreasing (Li *et al.*, 2015). In China, seven millions of HH BGPs were built in 1970s; however in 1980 around half were already abandoned from various reasons (He, 2010). Main reasons cited were technical issues (gas leakages, insufficient feedstock, blockages) and lack of maintenance (He, 2010). Currently, around 60 % of BGPs in China is believed to be in operation (Chen *et al.*, 2010). Maintenance, which lack is often main reason for failure, should not be underestimated. Qualified technical supports are needed (He, 2010). Such trends reflect an emphasis on BGP construction rather than operation, maintenance or reconstruction (Chen *et al.*, 2010). Further factors constraining successful implementation of small-scale biogas technology in DCs is presented in Table 2.

Table 2: Factors constraining successful implementation of biogas technology*

Excluding factors	Critical factors
Climate	**High building costs**
-too cold	-low income of target group
-too dry	**Unfavourable macro and micro economics**
Gas demand	**Lack of gas appliances**
-irregular	**Good energy supply throughout the year**
-low	**Low qualifications**
Lack of input	-of masons
-under 20 kg dung/day available	-of facilitators
-under 1000 kg of live weight per HH or 2000 kg in night stabling	
No stabling or large pens	**Limited access to target group**
Lack of building material	
Lack of water	**Lack of interest**
Adoption of technology	-government
-Impossible incorporation of technology into farm/HH routines	-key actors
-cultural disagreements	
Missing institution	
-suitable institution for dissemination	

*Advantages and disadvantages based on Bond and Templeton (2011), Thu *et al.* (2012), Lam and Heegde (2012) Remais *et al.* (2009), Mwirigi *et al.* (2009), Oenema *et al.* (2005), Hossain (2003), de Alwis (2002), ISAT/GTZ (1999a), ISAT/GTZ (1999b), ISAT/GTZ (1999c), ISAT/GTZ (1999d)

2.5. Current situation with BGPs in Vietnam

Since 2003, Vietnam has implemented a national program for the use of biogas in the animal sector – *The Biogas Programme for the Animal Husbandry Sector in Vietnam* (BPAHS). The BPAHS is put into practice by the Biogas Project Division of the Ministry of Agriculture and Rural Development in collaboration with the Dutch development organization SNV. Since 2003, more than 100,000 household biogas plants have been built under this programme, including 2,900 family biogas plants in the Thua Thien Hue province, central Vietnam. In addition, builders and facilitators, and technical teams to control the quality and viability of BGPs and provide training to users have been trained. Currently running program sets up goal to build further 200,000 household biogas plants from 2013 to 2018 (Thu *et al.*, 2012). The country Biogas Program has won an international recognition as a winner of the 2006 Energy Globe Award, the 2010 Ashden Award for sustainable energy, and the 2012 World Energy Award (Cheng *et al.*, 2014b).

3. Aims and objectives

The major objective of this thesis it to find out environmental aspects and impacts of small-scale biogas plants in central Vietnam. For this reason, several specific objectives were established.

First specific objective is to analyse current problems with BGPs in the target area and outline possible solutions in line with local conditions and easily applicable to the target area. Second specific objective is to investigate and to determine current manure management practices in central Vietnam with all its aspects (Environmental, Economic, Technological, and Social). Thus, contribute so to uncovering manure management practices in order to contribute to the current discussion related organic waste recover consequences within the long-term sustainability and natural resources management, because inappropriate practices can lead to the environmental and health risks.

This thesis intends to provide in-depth understanding about the issue with taking into accounts possible risks. Investigating of such a topic is within continuing concern about environmental issues connected with small-scale biogas plants and manure management in rural areas of developing countries.

4. Methodology

4.1. Target area

The survey was conducted in the province of Thua Thien Hue in central Vietnam (Figure 1). Its population consists of 1,045,134 inhabitants (Thua Thien Hue, 2000) which represent 1.13 % of the population of Vietnam. One third of this population lives in and around Hue City. Population density is lower compared to the national average (219 and 265 persons per km2 respectively) and varies across the province (General statistics of Vietnam, 2013). Our survey took part in the districts of Huong Tra and Phong Dien. The climate in the region is tropical humid (Cong Vinh, 2007), the average temperature is about 25°C and the amount of rainfall is in the range of 1,600 - 4,000 mm per year (Thi Mui, 2006). These rains can be very sudden and heavy, causing not only possible decreases in agricultural activity and school attendance, but also losses in property, environment and human lives. These limitations (floods, storms, drought and coastal erosion) need to be taken into consideration. For example, coastal erosion is widely represented and causes loss of life, prevents socio-economic development (Ngoc Ca *et al.*, 2005) and leads to economic weaknesses in the area.

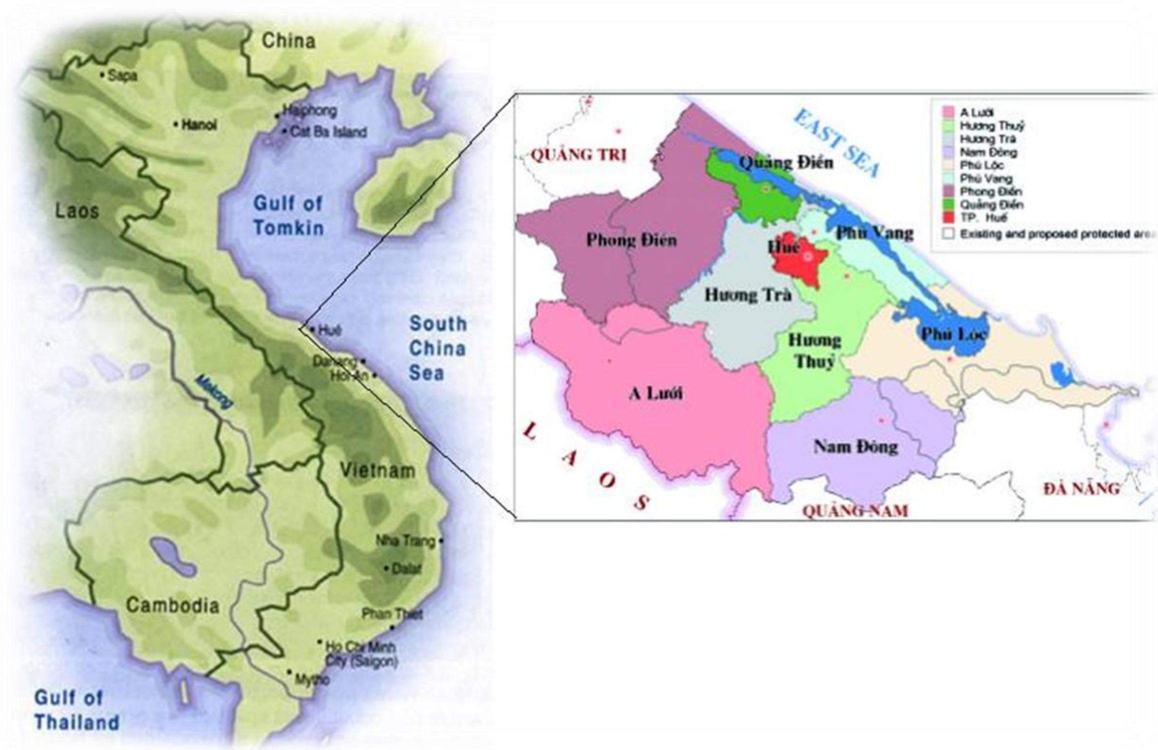


Figure 1: Map of target area (MPA, 2007; adjusted by author)

4.2. Data collection

The survey was carried out from June to September 2012 at the level of owners of BGPs (*n=141)* randomly selected, small-scale farmers (*n=50*) randomly selected, local authorities and facilitators (*n=9*) in the area of the districts Huong Tra and Phong Dien (Figure 1). Methods of data collection included focus group discussions (*n=41*), semi-structured personal interviews and a questionnaire survey (*n=150*) and observation. As follows, the survey was carried out in 2013 from July to September at the level of randomly selected owners of BGPs (*n=100*) and local authorities and facilitators (*n=9*). In table 3 basic division of researched area, names of villages and characteristics of surveyed districts is shown.

Table 3: Basic division of research area

District	Commune	Village	Number of respondents	Basic characteristics of the district
Huong Tra				
	Huong Toan	Huong Toan	12	
		Duong San	20	
		Duong Son	28	
		An Van	28	Approximately 20,000 inhabitants. There are 19 villages. Main activity in the district is agriculture connected with rice. Also there is noodle factory in the district. Farmers are also often focused on noodle or rice wine production.
		Huong Chu	19	
	Huong An	Huong An	12	
		Dong Tram	11	
		Binh Thanh (Tam Hiep)	12	
		Xuan Dai	16	
Phong Dien				
	Phong Son	Ca Bi 3	17	
		Ca Bi 10	14	Approximately 17,000 inhabitants. 13 villages. Main activities are agriculture, livestock, partly forestry.
		Hien Si	11	
	∑	**12**	**200**	

BGP owners and facilitators were interviewed via a semi-structured interview; each interview took around one hour. To increase the range of study four focused discussion groups were conducted with farmers. The results of these participatory methods were compared with the results of observation of the target groups. The questionnaire was designed to map the reality of the current situation about the issue. The questionnaire included different types of questions such as open, closed, semi-open, evaluation and multiple choice questions. It included two main categories: a socio-economical part and a part related to biogas technology (Table 4). The questionnaire went through pilot testing, and was afterwards adjusted and approved by experts from the Agricultural Forestry Fishery Extension Centre (AFFEC) before final distribution.

Table 4: Main categories of the questionnaire

Category	Focus of the questions
Socio-economical part	District, villages, sex, role in household, size of family, amount of members living in farm, education, occupation, income, farm size, crops, equipment in household
Biogas technology and manure management related part	Motivation, technology related costs, main benefits of using BGP, saved money related to using BGP, manure management practices, use of human excreta to BGP, time for fuel wood picking, satisfaction with technology, trainings about BGP, problems with biogas technology, attitude to the technology, currently used solutions to the difficulties, knowledge about related topics

4.3. Data analysis

Collected data were categorized, coded and analysed using the statistical program package *Statistica 10*.

Differences in the manure management practices of small-scale biogas owners and small-scale farmers were determined based on Chi-square tests in cross tabulations. F-test was used to determine independent variances between farm sizes and yields of BGP owners and non-BGP farms. Data on the minimal biogas yield and biogas potential per household were calculated using method according to Adeoti *et al.* (2014). Disparity (D) between motivating factors and current benefits were calculated as follows:

$$D = A_{MF} - A_{CB} \qquad [1]$$

Where: A_{MF} stands for average among motivating factors for technology adoption, A_{CB} stands for average among current benefits recognized by BGP owners. An analogous formula was used for finding out time and money disparity before and after BGP construction.

4.4. Conceptual framework of problem analysis

This paper uses a problem analysis (PA) approach to identify and describe major problems and potential risks, intending to adopt some relative improvements and prevent failures. PA is structured according to several chief problematic subsystems (Table 5) which are as follows: structural components, piping systems, equipment utilizing biogas, digestate disposal systems, AD processes and biogas utilization, and knowledge related problems. This results in subsystems and failure criteria description and recommendation output. Subsystems and a description of their failure criteria and relevant recommendations were assembled with respect to problematic subsystems and based on technical problems recognized during the field research and based on further secondary data from various studies. The six subsystems together cover the entire small-scale biogas system and all main aspects essential for it to function properly. When a failure happens, it is usually due to events occurring in one or more of these subsystems. The average occurrence of all problems for each subsystem is individually calculated in these problematic subsystems.

Table 5: Main problematic subsystems categories

Main subsystems
AD process and biogas production
Biogas utilization equipment
Digestate disposal system
Knowledge related problems
Piping system
Structural components

4.5. Methodology for calculating Payback Period (PB)

The equation [2] was used to calculate PB, where *D* is payback time [years], *I* is biogas installation costs [USD], P_r annual benefits [USD] and N_{pr} annual operating costs [USD]. Installation costs of a BGP represent the total construction expenses that owners paid. It was calculated both with and without subsidies. Data collected from the respondents on savings through the use of BGPs was used to determine annual economic benefits. To determine the annual operating costs, the figure of 5% of the costs of BGPs was used, as the value given for the average cost of repairs and operation. For BGPs where problems arose, an amount of 23.5 USD was included (= the modus of the most common amount paid for its repair in the case of any given complication).

$$D = \frac{I}{P_r - N_{pr}} \ (years) \qquad [2]$$

5. Results and Discussion

5.1. *Socioeconomic characterization of biogas plant owners in the target area*

The average size of a rural family in central Vietnam is four to five people which correspond with the findings of Thu *et al.* (2012); with actively working 2.2 people on average. These numbers are comparable with the official population statistics in Vietnam with 3.9 people per family in rural areas of central Vietnam (General Statistics Office of Vietnam, 2009). However, respondents report their families to be of five- to six-members. This means there are on average two members of each family who do not reside on the farm, but who are mostly studying or working in another city, in our case in DaNang or Ho Chi Minh City. The education of respondents, taken by the highest educational attainment in a household were tertiary (34%), secondary (55%), primary (10%) and without education (1%). There is an expectation that the greater the education, the greater the ease of adaptation to new possibilities (Behrman and King, 1999), which can in turn be connected to the better maintenance of BGPs and better digestate management. It must be said, that in terms of education and accessibility to education, Vietnam has displayed noticeable achievements (Ahn *et al.*, 1995), mainly due to long-term government policy. The ratio of education in Vietnam is high, as evidenced also in the study Bélanger and Lui (2004). Respondents (BGP owners) in our survey attended training (related to BGPs) in 79% of cases and on average they attended 1.9 training sessions with reported satisfaction in 61 cases (48.2%). The importance of focusing on this topic is linked to the view that education is one of the principal routes for poverty alleviation in developing countries (Glewwe and Jacoby, 2004) and with greater education the ease of transfer to new possibilities increases (Behrman and King, 2001). Based on this, we assume a connection between training and satisfaction with training and the management of technology and attitude of BGP owners.

5.2. *Socioeconomic characterization of local farms*

An average farm size with BGP involves 2821 m^2 with almost 2000 m^2 attributed for rice production. Average size of farms without BGP covers 3332 m^2 with almost 3000 m^2 attributed on rice production. We assume difference between farms with and without BGP is caused by focusing of farmers without BGP more on crop production contrast to farmers with BGP must also focused on livestock, to be able to provide sufficient amounts of organic matter for BGP. However, there is statistically significant difference between farm size of farmers with and without BGPs due to the F-test statistics (0.298; $p < 0.05$) finding out differences between variances. In addition, this data shows larger size of farms against the state average. This can be caused by lower density in area. Regarding the number of larger farms (defined by selling its products for 1800 USD per year), their amount is increasing annually; in 2001 there were 149 larger than small-scale farms, in 2005 already 489 and in 2010 591 and are constantly increasing (General Statistics of Vietnam, 2010).

Respondents reported their occupation as farmers in 90% of cases. For 72 % of these respondents farming is the main source of income. 28% make their living also from non-farming activities, such as trade (7.2 %), rice noodle production (5.6 %) and rice wine production (4.0 %). Our respondents reported total income less than 92 USD per household in 49 % of cases, less than 46 USD per household per month in 24% of cases, then less than 184 USD per month per household in 16% of cases. Both farmers with BGP as well as those without BGP produce rice as a main commodity; however there are some slight differences between crop productions between them. Even so, for rice their variance differences are not statistically significant according to F-test: (0.862; $p > 0.05$ and $F=0.812 > F_{critical}=1.584$).

5.3. *Biogas plants in the target area*

Types KT1 and KT2 are predominant in the target area. That is corresponding with results from studies by Thu *et al.* (2012), Huong *et al.* (2014a) and Huong *et al.* (2014b). KT1 is an appropriate type for a quality of substrate with a good soil structure, where it is easy to excavate soil. KT2 is used in places where it is harder to dig into the soil or where there is significant groundwater (BPAHS, 2013). The most common volumes are 6 m^3 (49%), 9 m^3 (16%), 8 m^3 (15%), 12 m^3 (7%) and 7 m^3 (6%). Average size is 7.45 m^3 (±2.23).

Most BGPs are 2 years old (54%), then 1 or 3 years (9%), 8 years (6%), 6 and 10 years (5%), 4 and 12 years (3%), 5 and 9 and 11 years (2%).

Farmers with BGP reported as a main source of information about biogas technology mainly commune staff and local facilitators (77%), than neighbours (13 %) and public media (10%). Even if the role of public media is important for further propagation, especially on national level, in central Vietnam was proved a major influence within the community level with facilitators. This was confirmed also in study by Thu *et al.* (2012) from Vietnam and similar results by Qu *et al.* (2013) from China.

5.4. *Animal production and biogas potential*

Pigs manure is a main source of organic matter for BGP in Vietnam. An average farm disposes by 13-14 piglets and 2-3 sows. Other animals are hens, ducks, buffalo and cattle. As shown in table 6, average weight of piglets is over 35 kg (± 19.98), respectively almost 100kg for sows (± 25.24). Pigs were fed mostly with a commercial high protein and carbohydrate feeding, with a local feeding or with a mixture of both. Local feeding was usually consisted of agricultural residue, such as rice and rice bran mixed with kitchen waste residue (used by all households), sweet potatoes, banana tree parts, water hyacinth, soybean or cassava leaves and others. This finding was confirmed also in the study by Thu *et al.* (2012). As energy sources for preparation of pig feeding biogas or firewood are used depending on the amount of accessible biogas. The ratios are different and highly variable with time; mostly depending on current conditions and feed resources availability, resulting so in a high variability volumes and outlet composition of manure.

Table 6 also presents amount of excrements created per household and its minimal biogas yield. Minimum biogas yield per household was estimated for 2.32 m^3/day. However, if recalculated together with actual usage of manure in BGPs, biogas potential per household is estimated to 1.09 m^3/day; showing us more than two times higher biogas potential than it is used.

Farmers mostly prefer a mix feeding as it is less finance demanding and the growth rate is still acceptable. Some interviewed farmers (18%) also used antimicrobials or antibiotics as feed additives in the last year. Such a practice can lead to an increase risk for development of antimicrobial- or antibiotic-resistant bacteria potentially affecting the environment subsequently (Huong *et al.*, 2014; Vu *et al.*, 2007). Feed composition differences lead to different qualities and quantities of gas produced in BGP. Therefore there is a need of further research and assessment of biogas potential from household livestock systems (Tuan *et al.*, 2006). Also it is important to realize that livestock manure contains many microorganisms, protozoa and viruses that may pose a risk to human and animal health such as food-borne diseases (Vu *et al.*, 2007; De *et al.*, 2003). In pigs feed besides nutrients like phosphorus or nitrogen can be found growth hormones, antibiotics and heavy metals according to studies by Thu *et al.* (2012) and Ribaudo *et al.* (2003). These substances if over-applied may cause water quality degradation. Therefore high contents of N, P, heavy metals and pharmaceuticals in pigs feed should be more observed. It is an obvious need for further focus on feeding practices in relation to manure management (Gollehon *et al.*, 2001) if there is an effort of environmentally friendly manure management practices achievement.

Table 6: Animal production at BGP farms (N=141)

	No. of heads	Average weight (kg)	Excrements per HH (kg)	Minimum biogas yield from manure (m3)	Usage for BGP (%)	Biogas potential per HH (m3)
Piglets	13.5	35.1	36.74	0.80	96.0	0.76
Hens	6.7	1.8	1.21	1.21	16.0	0.19
Sows	2.3	99.8	9.81	0.14	97.0	0.13
Ducks	1.6	-	0.20	0.04	2.0	0.001
Cattles	0.5	60	4	0.14	1.0	0.0014
			$\sum$	**2.32**		**1.09**

5.5. *Pigpen housing system*

All surveyed households housed their pigs in concrete pigpens with natural ventilation, a concrete floor and mostly a corrugated iron roof. Pigpen walls are made of concrete or bricks. These solid floors are usually connected to the BGP inlet and ease watering manure into the tank. It is important to mention, that some of households have improved their pigpens because of BGP installation (26%) through reconstruction and renovation. Pigpens are usually cleaned (watered) twice a day in summer and once a day in winter time. Watering in summer serves also for cooling pigs. Per pig farmers use approximately 20-30 litres/pig/day in summer time, which is corresponding with the study by Vu *et al.* (2007).

5.6. Manure management practices

Surveyed farms reported following forms of manure: slurry, liquid manure and solid manure. Solid manure consists mainly of excrements, liquid manure mainly of urine and faeces remaining after watering, and slurry is a mixture of faeces, urine and water. Manure management is affected by the presence or absence of BGP. The current practice of manure management in central Vietnam can be divided in to the following categories: feed for BGP, composting, storage without treatment, storage with subsequent treatment and no treatment with direct disposal. However, firstly it is important to focus on manure and excreta practices on BGP and non-BGP farms. Manure and digestate management reported during the questionnaire survey, FGD and observations in the households is summarized in Table 7. Utilisation only with manure was reported on 54% of BGP farms, respectively on 86% of non-BGP farms. Pig slurry together with human excreta is treated in 41% of BGP farms, but in none of non-BGP farms; do not treat human excreta at all. The common practice in households without BGP is to leave human excreta in the reservoirs under the house or toilet where it soaks into the ground. Such a manure management can lead to the environmental consequences and further problems. Such an environmental risk is in accordance with study of authors Chai *et al.* (2009) from Southeast Asia. Difference in the use of human excreta is caused by possibility of connection toilets to the biogas plant and transforms this kind of waste into the clean energy (Bond and Templeton, 2011). 16% of BGP farms use for biogas production pig manure, human excreta and excrements from other animals, such as chickens, ducks, or cattle. 45% of BGP owners breed hens or chickens, but only 16% of them add their manure into the BGP. This practice is mainly caused by persistent concerns about *avian fluenza*, to the similar conclusion get research by Vu *et al.* (2007). In every BGP household surveyed the pigpen is connected with a digester and in 35% cases with a toilet outflow; however, there are no connections between chicken sheds and digesters. So, this manure must be transferred to the inlet tank manually, making inconvenient manure management to the BGP users.

Table 7: Manure and digestate management

	BGP Owners[1] (%)	Non-BGP Owners[1] (%)	P value[3]
Manure and excreta use			
Pig	54	86	**
Pig & Human excreta	41	0	NS
Pig, Human & others	5	14	*
Manure treatment			
Feed for BGP	100	0	NS
Composting	0	10	NS
Storage and treatment	0	14	NS
Storage without treatment	0	8	NS
Direct disposal (no treatment)	0	68	NS
Digestate management / Treated manure			
Pre-treatment	5	0	NS
Crop fertilizer	33	12	**
Vegetable & home-garden fertilizer	25	20	**
Feed for fish	1	0	NS
Discharge to environment	10	68	*
No treatment	26	0	NS

[1]BGP Owners N=100, Non-BGP Owners N=50
[2]In case of Non-BGP farms composted or treated manure is considered
[3]In calculations *means that p-value is less than a 0.05, **means that p-value is less than 0.01, NS means not significant

Manure represents a valuable energy and nutrition resource, if used appropriately. All respondents with BGP use manure as a feed for biogas plant and none of them use any other forms of manure treatment. Similar results are in study by Thu *et al.* (2012). This leads us to the assumption that all farmers with BGP adapted the technology and left over the ineffective methods. On the other hand farmers without BGP are using different methods, such as; composting (10%), storage and treatment (14%), storage without treatment (8%) and the most common direct disposal (68%). Both direct disposal and storage without treatment consequently lead to the environmental threats, air and water pollution, risks to human and animal health through spread of pathogens (Ribaudo *et al.*, 2003; Tigabu *et al.* 2015b; Burton and Turner, 2003; Vu *et al.*, 2007; De *et al.*, 2003). Another challenge is uncovered storage of manure, as a source of unpleasant odour and ammonia emissions (Martinez *et al.*, 2003; Vu *et al.*, 2007).

Digestate management is also one of the current concerns in developing countries. We found out that pre-treatment was done in 5.0 % of cases, this involves mainly sun-drying in front of house to ensure easier transportation of digestate to the rice field. However, important is that 33.0 % of farmers use digestate as a crop fertilizer. This involves mainly rice fertilizing; common practice is to use mainly solid parts of the digestate. Further use is limited partly by long distance between BGP and field (1031 m in average). Farmers see labour input into transportation and lack of transport vehicles/devices as the main barriers. These findings are in agreement with studies from Vietnam (Thu *et al.*, 2013) and Tanzania (Jackson and Mtengeti, 2005). In 25% of cases, farmers use digestate as a fertilizer for vegetable and home-garden. This is a very popular way of digestate management, because it is quite simple for the farmers, but on the other hand it has very often similar effects as discharge to the environment, because farmers do not reflect needs of vegetable and just let flow digestate out constantly. This was also confirmed in the study from Uganda (Bos and Kombe, 2009).

Home-garden crops are shown in table 8; mainly banana, pommel, cassava, peanut, sweet potatoes are cultivated. These crops are fertilized with digestate in 25% of cases on farms with BGP and in 20% in non-BGP farms using composted or otherwise treated manure. Only 1% of questioned farmers use digestate as feeding for fish. Thu *et al.*, (2012) reported higher frequency of such usage, especially in areas around Hanoi where according to their study better conditions for establishment of fish ponds exist. But even in central Vietnam has pond access for fish raising around 20% of farmers. Showing twenty times higher possibility to use digestate as feeding compared to the current situation. This is caused mainly by peoples´ disbelieve about the safety of using treated manure as feeding for fish. Feed for fish, which appears to be quite satisfactory method was already confirmed by research from Vietnam (Vu *et al.*, 2007) and Cambodia (Sophin and Preston, 2001). However, for preventing of pathogen spread it is recommended to keep hydraulic retention time at least 45 days (Hong *et al.*, 2011).

Table 8: Comparison of crop production

Farms with BGP *n=100*			**Farms without BGP** *n=50*		
Crop	Percentage (%)	Yields t/ha	Crop	Percentage (%)	Yields t/ha
rice	87	5.58*	rice	74	5.03*
banana	34	-	banana	60	-
pomelo	24	-	pomelo	58	-
cassava	28	14.89	jackfruit	32	-
peanut	22	4.3	bamboo	30	-
sweet potatoes	18	-	mango	20	-
jack-fruit	13	-	lemon	18	-
grapefruit	11	-	grapefruit	18	-

*means differences significant on the level of 0.05

However, there was observed in Vietnam (Thu *et al.*, 2012) that with large dosing of digestate into ponds, fish can die. Therefore, it is essential to focus more on knowledge transmission from implementers to facilitators, consequently on BGP owners. 10% of households discharge digestate to the environment, basically it means discharge to canals, lakes, rivers, ditches or into soil and same case it is with no treatment (26%). Problems with the digestate management arise as a fundamental issue calling for an immediate solution.

Similar opinion can be found in the study by Zhou *et al.* (2011) where lack of knowledge was identified as a main cause, or in study from China done by Chen *et al.* (2010).

Table 7 also shows that more than one third of digestate volume stay without appropriate utilization. Proving that the situation about digestate management in the area is quite unsatisfactory. One of the reasons for deficient use of digestate is lack of organic matter, caused by usage of too high water: manure ratios and it causes lack of nutrients decreasing so added value of digestate, which can be used as efficient fertilizer (Li *et al.*, 2012).

There are used an excessive amounts of washing water in the pigpens. This was found out both in BGP farms and Non-BGP farms. Such practices are causing problems for BGPs. It is common for farmers to use as much cleaning water as needed to spray all the manure out of the pigpen until the pigpen is clean; however, this usually leads to the high water/manure ratios in BGPs. Respondents answered that they were not aware of any rules connected with use of appropriate amount of water. This should be in competence of local facilitators and it should be more discussed during workshops. Average ratio of washing water/manure was 15/1 in summer and 12/1 in winter at BGP farms and smaller ratios were found in Non-BGP farms. It was 12/1 in summer, respectively 10/1 in winter. Probably caused by an effort of owners of renovated pigpens, to maintain pigpens cleaner. But, such volumes of water are causing low contents of solid parts in final digestate and making any further management considerably more difficult. For optional operation of BGP and its performance, according to the SNV recommendations, the ratio should be around 1-3/1. This can be achieved by use of less water, or increase use of manure; in some cases (35 % of BGP has a potential of easily connected toilet) connection with toilet can be done for increase of BGP input. In case of Cambodia specific trainings for quantity of water to be added were provided and it leads to better quality of the digestate coming out from the digester and to the improvement of using this valuable by-product and appreciation of its properties (Schmidt and Jordan, 2008).

Currently there are many system possibilities for digestate treatment and management such as: composting, conventional digestate management, use of belt dryer or drum dryer, thermal concentration, physical-chemical treatment or solar drying (Rehl and Muller, 2011), but not all of them are applicable for small-scale farmers. Therefore, there is need to set up appropriate digestate treatment and management methods in accordance with local conditions and abilities.

5.7. *Biogas technology adoption*

Farmers' attitude to the biogas technology is also an important factor for technology adoption. In recent years large number of BGPs has been installed in Vietnam. Main increase came with the introduction of financial compensation. According to farmers at Non-BGP farms odour and hygienic problems connected with manure were recognized as main problems. As mentioned in study by Thu *et al.* (2012) reducing odour is an important purpose of using biogas.

Reasons for adopting biogas technology at BGP farms in general can be divided as follows: Environmental, Economic, Technological and Social. These factors are taken into account from micro-level perspective, referring to the household, however most of them are influencing society and can be considered as macro-level factors. The most important factor for biogas technology adoption was clean environment (70.0 %), saving money (57.0 %) and gas for cooking (48.0 %), further factors are save time (15.0 %), solution to waste problems (14.0 %), gas for lightning (12.0 %), cooking for pigs (7.0 %), manure management (2.0 %) and subsidy from organization (1.0 %). If we compare it with current benefits of using biogas for farmers, we can see as main benefits saving money (79.0 %) and clean environment (70%), higher calorific value than wood (39%) for further benefits see table 9. This is shows us opinion consistency in relationship with environment and large inclination for considering economic benefits.

Table 9: Current benefits recognized by BGP owners (N=141)

Current benefits recognized by BGP owners	%
saving money	79
clean environment	70
higher caloric value than wood	39
free time for other activities	35
getting rid of smoke (respiration problems etc.)	26
energy	10
simple regulation of fire	7
using biogas for lightning	7
good fertilizer	6
generating of electricity	1

Factors distribution into Environmental, Economic, Technological and Social factors provides us more complex view on motivating factors and current benefits with its disparity (Table 10). There is a positive disparity in Environmental and Economic factors and negative in Technological factor. It could be mostly influenced by complications with technology and equipment. However, also should be mentioned more recognized technological factors in current benefits, showing us valuation of the technology in new ways. This can be compared with results from Cambodia, where main recognized benefits were "time-saving" (from cooking) and healthier environment (Phanthavongs and Saikia, 2013) and results from Nepal, where main benefit was also "time-saving" (Singh and Maharjan, 2003).

Table 10: Motivating factors and current benefits (N=141)

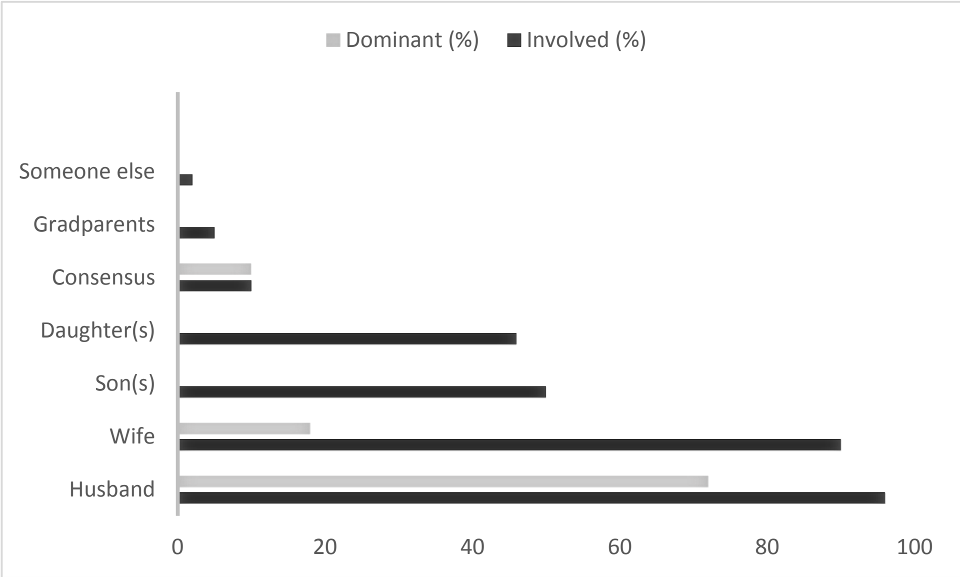
Factors	Motivating factors for adopting biogas technology (%)	Average frequency (%)	Current benefits recognized in using biogas technology (%)	Average frequency (%)	Disparity
Environmental	clean environment (70), waste problems (14), manure management (2)	28.7	clean environment (70), healthy improvement (26), soil fertility (6)	34.0	5.3
Economic	save money (57), save time (15), support from organization (1)	24.3	economic benefit (79), save time (35)	57.0	32.7
Technological	gas for cooking (48), cooking for pigs (7), gas for lightning (12)	22.3	higher calorific value than firewood (39), energy (10), regulation of fire (7), use for lightning (7), electricity generation(1)	10.7	11.6
Social	local facilitators (77), neighbours (13), public media (10)	33.3	0	0	33.3

5.8. *Financing of Biogas Technology and Decision Making Process of Technology Acquisition*

Only 6% of households fully financed BGP construction with own savings. Subsidy from the Biogas Program was used by 88.0 % of households. And only 32.0 % stated that they would consider building BGP without the subsidy. For construction the loan was very common as well, it was used in 44.0 % of cases with average amount of 154 USD (± 91.5). These loans were coming from different sources such as from bank (38.6 %), relatives (54.6 %) or other sources (6.8 %).

There was a high degree of participation of family members in the process of deciding on building a BGP; however, in the final decision male role, as a head of household, was dominant. The head of the household was dominant in Decision Making Process (DMP) in 72% of cases, followed by wife in 18% of cases and by family consensus in 10% of cases (Figure 2). This can be compared with involvement in DMP, where the husband was involved in 96% of cases, wife in 90% of cases, followed by son(s) in 50% and daughter(s) in 46% of cases. Then there was family consensus in 10% of cases (in families with family consensus about DMP was also consensus in the dominant final DMP) and in 2% there was involvement of someone else, mainly local facilitators and promoters as advisers. However, local facilitators and their importance were proven in the study by Roubik and Mazancova (2014), showing their influence on further biogas technology maintenance as essential. Similar conclusions about DMP were done in Cambodia by Schmidt and Jordan (2008), only with slightly higher involvement and dominance of male in the final DMP.

Figure 2: Decision making process



5.9. *Problem analysis of biogas technology in the target area*

The survey revealed that 29% of BGP owners have experienced a problem with biogas technology. The two populations of the districts were considered statistically directly comparable. Failures were recognized in all six main subsystems with the highest average occurrence of problems in AD process and biogas production subsystems, biogas utilization of equipment subsystems and digestate disposal systems (further information on the average occurrence of problems and descriptions of their failure criteria and relevant recommendations are shown in Table 11 and Table 12, respectively). Table 12 is presenting six subsystems (and further non-technical problems) and their failure description, which is essential for problem recognition. It presents also further studies describing similar problems and countries of origin. For each failure, recommendation and possible solutions with notes are presented. Specific chief failures and their frequency are then presented in Table 13.

Table 11: Main problematic subsystems

Main subsystems	Average diameter of problems (%)
AD process and biogas production	37.2
Biogas utilization equipment	25.2
Digestate disposal system	17.1
Knowledge related problems	9.1
Piping system	6.2
Structural components	5.0

5.9.1. Problem analysis: Structural components

The most frequent problems with structural components were with the inlet pipe (6 cases), the inconvenient location of BGP components (3 cases) and instability of the BGP in the rainy season (1 case). In this category the most serious fault identified lay in problems with the inlet pipe; similar results were found in Nepal in the study by Cheng *et al.* (2014a). This problem is mainly connected with an inappropriate angle of the inlet pipe leading to problems with organic matter getting into the digester. Any blockage of the inlet pipe can be usually fixed by a stream of water or with a long stick. The next problem identified was with inconvenient location of the BGP such as distance from pig sheds or toilets or from the farm, resulting in poor accessibility and more difficulties in the operation of the BGP and in its maintenance. The third problem described centred on the unstable construction of BGPs, especially in rainy season. This problem can be connected with low-quality workmanship. It is important to realize that skilled builders are a prerequisite for avoiding failures connected with improperly conducted construction.

Table 12: Subsystems and failure criteria description and recommendation

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 skills of masons.
	Inconvenient position of BGP components	Cheng *et al.* (2014) Nepal	BGP is too far from animal shed, inlet pipe has inappropriate slope, and outlet tank is too remote to be reached. It is in competence of skilled masons and facilitators.
Piping system			
	Leakage in piping system	Vu *et al.* (2015) Vietnam, Piechota *et al.* (2013) Poland, Cheng *et al.* (2014) Nepal	When 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 pipe line is overhanging for long time, and if no water filter is available, the water may be condensed within the pipe. Involvement of water filter and regular use.
Biogas utilization equipment			
	Malfunction of biogas cooker	Pipatmanomai *et al.* (2009) Thailand, Thu *et al.* (2012) Vietnam, Cheng *et al.* (2014) Nepal, Piechota *et al.* (2013) Poland	Malfunctions of biogas cooker are diverse such as corrosion, broken gas tap, broken flame pedestal, blocked air injection hole. Corrosion can be reduced with H2S filter, other problems with appropriate use of fire and more quality cookers, which should be recommended by facilitators.
	Malfunction of biogas lamp	Cheng *et al.* (2014) Nepal	The 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 reservoir is inappropriately located, it creates difficulties with further digestate management. It is responsibility of masons and facilitators think it through.
	Lack of organic matter in digestate	Vu *et al.* (2015) Vietnam, Thu *et al.* (2012) Vietnam	High water: manure ratios are causing lack of OM in digestate. Ratio should be around 3-6:1. Knowledge should be transformed through local facilitators.
AD process and biogas production			
	Leakage in reactor	Vu *et al.* (2015) Vietnam, Chang *et al.* (2011) China, Lam and Heegde (2012) Asia and Africa, Bruun *et al.* (2014) developing world	When the digester is not made properly, the pressure from inside the digester is pushing the gas out. It can lead to stopping the functionality of BGP. Masons must be skilled to avoid problems with digester. In case of significant leakages, BGP must be fully repaired.

	Solid digestate incrustation floating in the main tank	Cheng *et al.* (2014) Nepal, Shu-guang *et al.* (2007) Japan	Scum layer on the surface is preventing biogas to go through. BGP must be opened and cleaned.
	Lack of biogas	Thu *et al.* (2012) Vietnam	Can be caused by poor quality of biogas (small concentration of methane), or by lack of organic matter. Also can be caused by some process breakdowns. BGP owners should be sufficiently informed by facilitators.
	Poor quality of biogas	Piechota *et al.* (2009) Poland, Pipatmanomai *et al.* (2009) Thailand	Quality of biogas depends on individual components and methane concentration. It is affected by temperature, oxygen presence, feedstock, hydraulic retention time etc.
	Smell of biogas	Pipatmanomai *et al.* (2009) Thailand, Thu *et al.* (2012) Vietnam	Bad smell of biogas can be removed by use of H2S absorbent. In case of 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 number of animals, there are no longer appropriate amounts of manure, animals are not feed regularly and manure is not moved to the inlet tank. Also over-size of BGP is a problem, partly due to the reasons mentioned above (also can be cause of under-dimension of BGP leading to oversupply of biogas. facilitators and masons should be aware of importance of proper BGP dimension.
	Breakdown of AD process	Thu *et al.* (2012) Vietnam, Cheng *et al.* (2014) Nepal, Chang *et al.* (2011) China, Ribaudo *et al.* (2003) U.S.	There are many parameters affecting AD process, such as: inappropriate pH, unbalanced C:N ratio, low temperature and large temperature fluctuations, and existence of inhibitors. Inhibitors can originate from inappropriate cleaning chemicals in pigpens, feeding additives like growth hormones, antibiotics, heavy metals. There is need to be considered all of the aspects' and BGP owners must receive sufficient information.
	Oversupply of biogas	Limmeechokchai and Chawana (2007) Thailand	Consequences are because of farmers releasing biogas to atmosphere: contribution to the GHG by methane presence.
Knowledge related problems			
	Lack of knowledge by respondents	Zhou *et al.* (2011) China, Zurbrugg *et al.* (2012) Indonesia, Uddin *et al.* (2012) Banghladesh, Amjid *et al.* (2011) Pakistan, Agyenim and Gupta (2012) Ghana	There is need for function transmission of information from large-scale level through local facilitators to the target group of BGP owners.
	Unsatisfactory knowledge of masons		
	Unsatisfactory knowledge of facilitators		
Further non-technical problems			
	Proliferation of mosquitoes (*Anopheles sp.*) on the outer surface of BGP	N/A	Solution can be to cover the surface of BGP, even if we lose direct contact to surface and possible leakages.
	Lack of finance	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)	Solving non-technical problems should be in competence of local facilitators, local authorities and national level authorities.

5.9.2. Problem analysis: Piping systems

The average occurrence of problems in the subsystem of piping system was 6%. The two problems described in this subsystem were leakages in the piping system and its blockage. Leakages in the piping system (6 cases) were described in the study by Cheng *et al.* (2014a). The second problem described, which was also mentioned in a study from Nepal, was blockage of the piping system (3 cases). This problem occurs when the pipe line is left unused for a long time and if no water filter is available. It can result in a build-up of water within the pipe line. Therefore constant use of the BGP and use of a water filter is recommended.

5.9.3. Problem analysis: Equipment Utilizing Biogas

The second highest average occurrence of problems was reported in the biogas utilization equipment subsystem (25%). The main failure in this subsystem was a failure of biogas cookers to function correctly (22 cases), which was also second most common failure in our survey (Table 13). Malfunctions of biogas cookers are diverse in nature, such as consequences from corrosion, a broken gas tap, a broken flame pedestal or blocked air injection hole. Corrosion can be reduced with the use of H_2S filter (desulfurizer). Some other problems can be prevented by appropriate treatment (use of a suitable level of fire and better maintenance of the cooker), or through the use of better quality cookers. Similar conclusions and problems were found in other studies from Thailand, Vietnam and Nepal (Pipatmanomai *et al.*, 2009; Thu *et al.*, 2012; Cheng *et al.*, 2014a). The second problem mentioned by the respondents was linked to malfunctions in biogas lamps (7 cases). However, it is important to say that the use of biogas lamps is on the decline due to the very favourable price and accessibility of electricity in rural areas.

5.9.4. Problem analysis: Digestate disposal systems

The average occurrence of problems with the digestate disposal system was 17 %. This system encounters problems connected with the lack of organic matter (OM) in the digestate and with poorly accessible reservoirs. These problems occurred in 14 and 6 cases, respectively. A lack of organic matter in digestate is usually caused by use of overly high water/manure ratios. Knowledge about the use of adequate amounts of water during watering should be conveyed to BGP owners through local facilitators. A lack of OM and lack of nutrients decreases the added value of the digestate which can be used as an efficient fertilizer (Li *et al.*, 2012). When used as a fertilizer, digestate can improve soil fertility (Alburquerque *et al.*, 2012), show advantages in comparison with raw manure (Thy *et al.*, 2003) and when used instead of chemical fertilizer can save non-renewable energy and reduce carbon dioxide emissions (Li *et al.*, 2012). Secondly, poorly accessible reservoirs contribute to the underuse of digestate. This happens when a reservoir is inappropriately located and results in further complications with digestate management.

5.9.5. Problem analysis: AD processes and biogas production

The AD process and biogas production subsystem is the chief problematic subsystem with the highest average occurrence of problems (37%). This subsystem is linked to the main goal of BGPs - to produce biogas. The production of biogas depends on a series of factors, which must be adhered to, such as: temperature, pH, nutrients, microorganism concentration, and the absence of oxygen and process inhibitors, otherwise the process and its effectiveness is threatened. In this category we find leakages in the reactor, which was the most common problem with small-scale biogas systems. This problem occurs in 49 cases surveyed. Leakage in a reactor can be the result of several causes: e.g. unskilled builders and poor construction, high pressures in the digester and the use of inappropriate materials. Problems with leakage in reactors was found in other studies from China (Chang *et al.*, 2011), Nepal (Cheng *et al.*, 2014a) and Asia and Africa (Laam and Heegde, 2012). Further problem occurs with solid digestate incrustation floating in the main tank (19 cases) which is the third most common problem associated with small-scale BGPs (Table 13). This happens when a solid scum layer forms on the surface, to prevent biogas from passing through, leading the system to stop functioning. When such a problem occurs, the BGP must be opened and the solid surface removed. A further problem was with collapse of the AD process (19 cases) this could be divided into various sub-problems in the subsystem where the cause was known. Another problem described was the lack of feedstock (connected with an over-sized BGP), this was reported in 16 cases surveyed. This usually happens when farmers reduce the number of animals on the farm and they are no longer able to provide sufficient amounts of organic manure for the BGP. It can also happen when animals are not fed regularly leading to irregular excretion. This is closely connected with the over-sizing of BGPs (or under-dimensioning of BGPs). Similar problems were found in India, China, Nepal and Vietnam (Singh and Sooh, 2004; Chen *et al.*, 2012; Cheng *et al.*, 2014a; Thu *et al.*, 2012). The under-dimensioning of BGPs is connected with an oversupply of biogas, which can also be considered a problem. A common practice when there is oversupply of biogas is to release some of the biogas into atmosphere, but methane is a fundamental greenhouse gas which contributes to global warming. Similar conclusions were reached in a study from Thailand (Limmeechokchai and Chawana, 2007). Facilitators and builders should be highly familiar with the current situation of prospective BGP owners and be able to calculate a suitable size of BGP for their needs. Another problem mentioned was with the smell of the biogas (13 cases), which was identified in households without a desulfurization unit or without the proper maintenance of a unit. This problem was described also in Thailand and Vietnam (Pipatmanomai *et al.*, 2009; Thu *et al.*, 2012). The simple solution is to use a desulfurization unit and maintain it properly. Knowledge about this should be transmitted through facilitators. The last problem found in the target area was with the insufficient biogas production (11 cases), which can be linked with the poor quality of biogas (low concentration of methane), or with the lack of the OM inserted, or with process collapse. The quality of biogas relies on several factors and is affected by temperature, the presence of oxygen, feedstock, and hydraulic retention time.

Table 13: Main failures in central Vietnam associated with small-scale BGPs

Main failures at BGPs	**Frequency of appearance (N=141)**
Leakage in a reactor	49
Malfunction of a biogas cooker	22
Solid digestate incrustation in the main tank	19
Breakdown of anaerobic digestion process	19
Lack of feedstock/Over-size of BGP	16
Lack of organic matter in digestate	14
Smell of biogas	13
Lack of biogas	11
Lack of knowledge of the owner of BGP	11
Malfunction of biogas lamp	7
Leakage in piping system	6
Poorly accessible reservoir for digestate	6
Problems with the inlet pipe	6
Blockage of the outlet pipe	3
Inconvenient position of BGP components	3
Unsatisfactory skills of masons	3
Unstable BGP construction in rainy season	1
Blockage of piping system	1
Unsatisfactory knowledge of facilitators	1

5.9.6. Problem analysis: Further non-technical problems

Further non-technical problems are not included in the chief subsystems as listed, but naturally they must be brought into our analysis as and when they appear. One of the problems is the proliferation of mosquitoes (*Anopheles sp.*) on the outer surface of BGPs.

Respondents reported their fears of the possibility of a higher risk of malaria transmission. Other problems were diverse in nature and stemmed from a variety of sources: lack of finance for maintenance and repair of BGPs, cultural and social obstacles (use of human excreta as feedstock for BGPs), and certain political restrictions. Non-technical problems with small-scale biogas plants were mentioned in other studies from different countries like India, China and Vietnam (Singh *et al.*, 1996; Chen *et al.*, 2012; Zhou *et al.*, 2008; Thu *et al.*, 2012). The ability to solve non-technical problems should feature among the competences of local facilitators, local authorities, and authorities at a national level.

5.9.7. *Problem analysis: Knowledge related problems*

The importance of proper and adequate knowledge was mentioned several times above and it is an essential part of any technology implementation. The average occurrence of problems in this subsystem was 9.1%, but there is a substantial overlap with other subsystems. The most common occurrence was a lack of knowledge of the BGP owners (11 cases), followed by the unsatisfactory state of skills of builders according to BGP owners (3 cases) and the unsatisfactory state of knowledge of facilitators according to BGP owners (1 case); more relationships and consequences are shown in chapter below (5.13. Relationships across small-scale biogas technology). Problems with a lack of knowledge were recognized and described in other studies - from China, Indonesia, Bangladesh, Pakistan, Vietnam and Ghana (Zhou *et al.*, 2011; Zurbrugg *et al.*, 2012; Amjid *et al.*, 2011; Roubik and Mazancova, 2014; Agyenim and Gupta, 2012). These studies also highlight the importance of knowledge and its transmission. There is an essential need for the efficient transmission of information from the large-scale (national) level \via local facilitators to the target group of BGP owners. A properly working information flow is an essential key to the proper functioning of the system and its long-term sustainability.

5.10. *Payback Period (PB) of Small-scale Biogas Plant*

Based on information from respondents the payback period was calculated using a PB formula (1). An average installation cost of a BGP was 336.2 (± 94.1) USD, average donation from the BPAHS programme was 163.6 (± 94.9) USD and average financial contribution by the BGP-owners was 175.1 (± 99.2) USD. The average PB for a BGP with a subsidy was 2.25 (± 2.04) years; alternatively 4.46 (± 3.22) years without any subsidy. That indicates 2.26-year change in PB caused by the programme subsidy. This funding is essential to the rapid development of the technology, because the main increase in take-up always comes with the introduction of financial compensation. Large variances are returned in cases where BGP provides minimal benefits due to inappropriate maintenance of BGPs, collapses in the functioning of BGPs or due to the decision of the BGP owners to reduce use of this technology (Table 14).

Table 14: Payback Period (PB)

PB [comparison between payback time (D) with subsidy and without subsidy] in years				
	Mean	Standard deviation	Minimum	Maximum
D with subsidy (n=98)	**2.25**	2.03	0.26	15.43
D without subsidy (n=98)	**4.46**	3.22	0.53	17.14

6. Conclusion

This study extends our knowledge about the environmental aspects and impacts among small-scale farmers in central Vietnam. It provides an in-depth understanding about the issue with taking into account all relevant aspects.

Small-scale biogas plants can play a vital role in farming systems and add value to agricultural waste and livestock excreta. This technology offers significant advantages; especially in regard to energy, the environmental and economic development. It can also be a very useful manure management tool and may help reduce global warming impacts if used appropriately.

In order to allow a more in-depth examination, small-scale biogas technology was divided into six chief subsystems, namely: structural components, equipment utilizing biogas, piping systems, biogas production, digestate disposal systems, and knowledge related problems. There was created subsystems and failure criteria description with adequate recommendations. The survey revealed that 29% of BGP owners surveyed had experienced problem with this technology, mainly with biogas production process and biogas utilization subsystems. The programme also allows decrease in payback period by 2.26 years in comparison with the payback period with no subsidy.

We found out that small-scale farms have 2.2 working people on average, out of whom 79 % attended some training. Average farm size is 2,821 m^2 for farm with BGP, respectively 3,332 m^2 for Non-BGP farm. Almost half of the HHs (49 %) have income less than 49 USD per month with the main source of income from rice farming.

A biogas potential per household was also calculated and estimated for 2.32 m^3/day. However, if recalculated together with actual usage of manure in BGPs, actual biogas outcome per household was estimated to 1.09 m^3/day. This shows more than two times higher biogas potential, if manure used appropriately.

Reasons for adopting biogas technology were divided into Environmental, Economic, Technical and Social. This provides us complex view on motivating factors and also view on currently valuated benefits by BGP owners. It is important to highlight that only small quantity of BGP owners fully financed their BGP. Also phenomena of high degree of family members participation in DMP is interesting and higher compared to other fellow countries. Also participation of family members in is interesting high degree of DMP. Generally, knowledge about biogas technology among farmers is quite high (exception is lack of knowledge about digestate management); however, lack of finance is the main barrier in wider dissemination of this technology.

In conclusion, this study analysed the current situation surrounding problems with biogas plants and manure management in Thua Thien Hue province in central Vietnam. It showed the need for further research on the eradication of problems with this technology and with manure management practices. There is also a need for more studies to shed light on the health-threatening components of the use of BGPs, not least because, with further enhancements, we will be able to promote alternative ways of using BGPs in developing countries. It is important to facilitate and make this technology more effective for end users.

The final findings with appropriate recommendations will be provided to local authorities, especially to facilitators at the local level. Systematic empirical studies of this topic are a high priority for further research activities.

7. References

Aburas R, Hammad M, Abu-Reesh I, Hiary SE, Qousous S, 1995. Construction and operation of a demonstration biogas plant, problems and prospects. Bioresource Technology, 53:101-104.

Adeoti, O., Ayelegun, T.A., Osho, S.O., 2014. Nigeria biogas potential from livestock manure and its estimated climate value. Renewable and Sustainable Energy Reviews, 37:243-248.

Adu-Gyamfi N, Rao Ravella S, Hobbs PJ, 2012. Optimizing anaerobic digestion by selection of the immobilizing surface for enhanced methane production. Bioresource Technology, 120:248-255.

Aggarangsi P, Tippayawong N, Moran JC, Rerkkriangrai P, 2013. Overview of livestock biogas technology development and implementation in Thailand. Energy for Sustainable Development. 17:371-377.

Agyenim JB, Gupta J, 2012. IWRM and developing countries: Implementation challenges in Ghana. Physics and Chemistry of the Earth. 48:46-57.

Ahn TS, Knodel J, Lam D, Friedman J, 1995. Education in Vietnam: Trends and Differentials. Population Study Center, Michigen.

Alburquerque JA., de la Fuente C, Compoy M, Carrasco L, Nájera I, Baixauli C, Caravaca F, Roldán A, Cegarra J, Bernal MP, 2012. Agricultural use of digestate for horticultural crop production and improvement of soil properties. European Journal of Agronomy. 43:119-128.

Amigun B, Sigamoney R, von Blottnitz H, 2008. Commercialization of biofuel industry in Africa: a review. Renewable and Sustainable Energy Reviews. 12:690-711.

Amjid SS, Billal MQ, Nazir MS, Hussain A, 2011. Biogas, renewable energy resource for Pakistan. Renewable and Sustainable Energy Reviews. 15:2833-2837.

An BX, Preston TR, Dolberg F, 2006. The introduction of low-cost polyethylene tube biodigesters on small-scale farms in Vietnam: documents, tools and resources. In: The AgSTAR Programme.

Artur R, Baidoo MF, Antwi E, Biogas as potential renewable energy source: a Ghanaian case study. Renewable Energy. 36:1510-1516.

Banks C, Chesshire M, Heaven S, Arnold R, 2011. Anaerobic digestion of source-segrageted domestic food waste: performance assessment by mass and energy balance. Bioresource Technology. 106:612-620.

Behrman JR, King EM, 2001. Household schooling behaviours and decentralization. Economics of Education Review. 20:321-341.

Bélanger D, Liu J, 2004. Social Policy reforms and daughters schooling in Vietnam. International Journal of Educational Development. 24:22-38.

Bhatt PR, Chanakya HN, Ravindranath NH, 2001. Biogas plant dissemination: success story of Sirsi, India. Energy for Sustainable Development. 5(1):39-46.

Biogas Program for the Animal Husbandry Sector in Vietnam, 2013. Available online: http://www.biogas.org.vn/english/Cong-nghe/Cong-nghe-ung-dung.aspx.

Bond T, Templeton MR, 2011. History and future of domestic biogas plants in developing world. Energy for Sustainable Development. 15:347-354.

Bos P, Kombe S, 2009. Mission Report on Design Selection of Domestic Biogas Plant for the Uganda Domestic Programme. SNV 2009. Available online: http://www.snvworld.org/en/regions/world/publications.

Bruun S, Jensen LS, Vu VTK, Sommer S, 2014. Small-scale household biogas digesters: An option for global warming mitigation or a potential climate bomb? Renewable and Sustainable Energy Reviews. 33:736-741.

Burton CH, Turner C, 2003. Manure Management: Treatment Strategies for Sustainable Agriculture, 2nd edition. Silsoe Research Institute, Bedford, UK.

Buswell AM, Hatfield WD, 1936. Anaerobic fermentations. Bull. 32. Urbana, Illinois. Available online: http://webh2o.sws.uiuc.edu/pubdoc/B/ISWSB-32.pdf.

Chang S, Zhao J, Yin X, Wu J, Jia Z, Wang L, 2011. Comprehensive utilization of biogas in Inner Mongolia, China. Renewable and Sustainable Energy Reviews. 15:1442-1453.

Chai JY, Shin EH, Lee SH, Rim HJ, 2009. Foodborne intestinal flukes in Southeast Asia. Korean Journal of Parasitology. 47:69-102.

Chaurey A, Ranganathan M, Mohanty P, 2004. Electricity access for geographically disadvantaged rural communities-technology and policy insights. Energy Policy. 32:1693-1705.

Chen L, Zhao L, Ren Ch, Wang F, 2012. The progress and prospects of rural biogas production in China. Energy Policy. 51:58-63.

Chen Y, Yang G, Sweeney S, Feng Y, 2010. Household biogas use in rural China: a study of opportunities and constraints. Renewable and Sustainable Energy Reviews. 14:545-549.

Chen RC, Varel VH, Hashimoto AG, 1978. The effect of temperature on methane fermentation kinetics of beef manure. Biotechnology Bioengineering. 10.

Cheng S, Li Z, Mang HP, Neupane K, Wauthelet M, Huba EM, 2014a. Application of fault tree aproach for technical assessment of small-sized bigas systems in Nepal. Applied Energy. 113:1372-1381.

Cheng S, Li Z, Mang HP, Huba EM, Gao R, Wang X, 2014b. Development and application of prefabricated biogas digesters in developing countries. Renewable and Sustainable Energy Reviews. 34:387-400.

Chowdhury Z, Campanella L, Gray Ch, Al Masud A, Marter-Kenyon J, Pennise D, Charron D, Zuzhang X, 2013. Measurment and modeling of indol air pollution in rural households with multiple stove interventions in Yunnan, China. Atmospheric Environment. 67:161-169.

Daniels EA, Leaper C, 2011. Gender Issues. Encyclopaedia of Adolescence. Academic Press. 151-159.

de Alwis A, 2002. Biogas – a review of Sri Lanka´s performance with a renewable energy technology. Energy for Sustainable Development. 6:30-37.

De NV, Murrell KD, Cong LD, Cam PD, Chau LV, Toan ND, Dalsgaard A, 2003. The foodborne trematode zoonoses of Vietnam. Southeast Asian Journal of Tropical Medicine and Public Health 34, 12–34.

Del Amor FM, 2007. Yield and fruit quality response of sweet pepper to organic and mineral fertilization. Renewable Agriculture and Food Systems. 22:233-238.

Desai AV, 1992. Alternative energy in the third world—a reappraisal of subsidies. World Development. 20:959–65.

Dimpl E, 2010. Small-scale Electricity Generation from Biomass. Part II: Biogas. Deutsche Gesselchaft fur Technische Zusammenarbeit (GTZ)-HERA.

Dutta S, Rehman IH, Malhotra PVRP, 1997. Biogas: the Indian NGO experience. New Delhi, India: Tata Energy Research Institute.

Garfí M, Ferrer-Martí L, Velo E, Ferrer I, 2012. Evaluating benefits of low-cost household digesters for rural Andean communities. Renewable and Sustainable Energy Reviews. 16:575-581.

Gautam R, Baral S, Herat S, 2009. Biogas as sustainable energy source in Nepal: present status and future challenges. Renewable and Sustainable Energy Reviews. 13:248-252.

Glewwe P, Jacoby HG, 2004. Economic growth and the demand for education: is there a wealth effect? Journal of Development Economics. 74:33-51.

Gollehon N, Caswell M, Ribaudo M, Kellogg R, Lander C, Letson D, 2001. Confined Animal Production and Manure Nutrients. Agriculture Information Bulltin No 771. Resource Economics Division, Economic Research Service, U.S. Department of Agriculture.

Greben HA, Oelofse SHH, 2009. Unlocking the resource potential of organic waste: a South African perspective. Waste management & Research. 27:676-684.

Hashemi SM, Mokhtarnia M, Erbaugh JM, Asadi A, 2008. Potential of extension workshops to change farmers´ knowledge and awareness of IMP. Science of Total Environment. 407:84-88.

Hashimoto AG, Varried RH, 1979. Factors affecting methane yield and production rate. American Society of Agriculture Engineers (ASAE).

Havukainen J, Uusitalo V, Niskanen A, Kapustina V, Horttanainen M, 2014. Evaluation of methods for estimating energy performance of biogas production. Renewable Energy. 66:232-240.

He PJ, 2010. Anaerobic digestion: an intriguing long history in China. Waste Management. 30:549-550.

Hossain MMG, 2003. Improved cookstove and biogas programmes in Bangladesh. Energy for Sustainable Development. 7:97-100.

Huboyo HS, Tohno S, Lestari P, Mizohata A, 2014. Characteristics of indoor air pollution in rural mountainous and rural coastal communities in Indonesia. Atmospheric Environment. 82:343-350.

Huong LQ, Madsen H, Anh LX, Ngoc PT, Dalsgaard A, 2014a. Hygienic aspects of livestock manure management and biogas systems operated by small-scale pig farmers in Vietnam. Science of the Total Environment. 470-471:53-57.

Huong LQ, Forslund A, Madsen H, Dalsgaard A, 2014b. Survival of *Salmonella* spp. and fecal indicator bacteria in Vietnamese biogas digesters receiving pig slurry. International Journal of Hygiene and Environmental Health. 217:785-795.

ISAT/GTZ, 1999a. Biogas Digest Volume I. Biogas Basics, Information and Advisory Service on Appropriate Technology (ISAT). Deutsche Gesselchaft fur Technische Zusammenarbeit (GTZ).

ISAT/GTZ, 1999b. Biogas Digest Volume II. Biogas – Application and Product Development. Information and Advisory Service on Appropriate Technology (ISAT). Deutsche Gesselchaft fur Technische Zusammenarbeit (GTZ).

ISAT/GTZ, 1999c. Biogas Digest Volume III. Costs and Benefits and Biogas – Programme Implementation. Information and Advisory Service on Appropriate Technology (ISAT). Deutsche Gesselchaft fur Technische Zusammenarbeit (GTZ).

ISAT/GTZ, 1999d. Biogas Digest Volume IV. Biogas – Country Reports. Information and Advisory Service on Appropriate Technology (ISAT). Deutsche Gesselchaft fur Technische Zusammenarbeit (GTZ).

Islam MR, Islam MR, Beg MRA, 2008. Renewable energy resources and technologies practice in Bangladesh. Renewable and Sustainable Energy Reviews. 12:299-343.

Jackson HL, Mtengeti EJ, 2005. Assessment of animal manure production, management and utilization in Southers Highlands of Tanzania. Livestock Research for Rural Development. 17:110. Available online: http://www.lrrd.org/lrrd17/10/jack17110.htm.

Jiang X, Sommer SG, Christensen KV, 2011. A review of the biogas industry in China. Energy Policy. 39:6073-6081.

Karekezi S, 2009. Renewables in Africa – meeting the energy need of the poor. Energy Policy. 30:1059-1069.

Katuwal H, Bohara AK, 2009. Biogas: a promising renewable technology and its impact on rural households in Nepal. Renewable and Sustainable Energy Reviews. 13:2668-2674.

Klinenberg P, Wallin F, Azimoh LC, 2014. Successful technology transfer: What does it take? Applied Energy. 130:807-813.

Korte B, Forster M, Kleinsschmit B, 2007. Land use chase resulting from increased bioenergy production in Germany. In: Framing Land Use Dynamics II-Conference processing. Utrecht University, Netherlands. 105-106.

Kouřimská L, Poustková I, Babička L, 2012. The Use of Digestate as a Replacement of Mineral Fertilizers for Vegetable Growing. Scientia Agriculturae Bohemica. 43:121-126.

Kristoferson LA, Bokhalders V, 1991. Renewable energy technologies – their applications in developing countries. London: Intermediate Technology Publications.

Lam J, Heegde F, 2012. Domestic Biogas, Technology and mass dissemination, Version: March 2012, SNV. 64.

Lansing S, Martin J, Botero R, Silva NDT, Silva DDE, 2010. Wastewater transformations and fertilizer value when codigesting differing ratios of swine manure and used cooking grease in low-cost digesters. Biomass Bioenergy. 34:1711-1720.

Li J, 2009. Socioeconomic barriers to biogas development in rural Southwest China: an ethnographic case study. Human Organisations. 68(4):415-430.

Li JS, Duan N, Guo S, Shao L, Lin C, Wang JH, Houb J, Hou Y, Meng J, Han MY, 2012. Renewable resource for agricultural ecosystem in China: Ecological benefit for biogas by-product for planting. Ecological Informatics. 12:101-110.

Li Ch, Liao Y, Wen X, Wang Y, Yang F, 2015. The development and countermeasures of household biogas in northwest grain for green projects areas of China. Renewable and Sustainable Energy Reviews. 44:835-846.

Li Z, Wang Z, Li Q, Xu W, Li CH, Liu CH, Wu G, 2006. Effects of combined application of biogas digestate and chemical fertilizer on yield and quality of lettuce. China Biogas. 2:24-26.

Lim SS, Vos T, Flaxman AD, Danaei G, Shibuya K, Adair-Rohani H, *et al.*, 2012. A comparative risk assessment of burden disease and injury attributable to 67 risk factors and risk factor clusters in 21 regions, 1990-2010: a systematic analysis for the Global Burden of Disease Study 2010. The Lancet. 380:2224-2260.

Limmeechokchai B, Chawana S, 2007. Sustainable energy development strategies in the rural Thailand: The case study of the improved cooking stove and the small biogas digester. Renewable and Sustainable Energy Reviews. 11(5):818-837.

Liu Y, Kuang YQ, Huang NS, Wu ZF, Xu LZ, 2008. Popularizing household-scale biogas digesters for rural sustainable energy development and green-house gas-mitigation. Renewable Energy. 33:2027-2035.

Lohani SP, 2011. Biomass as a Source of Household Energy and Indoor Air Pollution in Nepal. Iranica Journal of Energy & Environment. 2:74-78.

Lu Shu-Guang, Imay T, Ukita M, Sekine M, 2006. Start-up performances of dry anaerobic mesophilic and thermophilic digestions of organic solid wastes. Journal of Environmental Sciences. 19:416-420.

Mahini F, Forusan ZJA, Haghani F, 2012. The importance of teacher´s role in technology based education. Procedia – Social and Behavioural Sciences. 46:1614-1618.

Mahmoud E, Abd El Kader N, Robin P, Ak Kal Corfini N, Abd El Rahman L, 2009. Effects on different organic and inorganic fertilizers on cucumber yield and some soil properties. World Journal of Agricutltural Sciences. 5:408-414.

Martinez J, Guiziou F, Peu P, Gueutier V, 2003. Influence of treatment techniques for pig slurry on methane emissions during subsequent storage. Biosystem Engineering. 85:347-354.

Massé DI, Croteu F, Massé L, 2007. The fate of crop nutrients during digestion of swine manure in psychrophilic anaerobic sequencing batch reactors. Bioresource Technology. 93:2819-2823.

Mata-Alvarez J, 2002. Biomethanization of Organic Fraction of Municipal Solid Wastes. IWA Publishing.

Mata-Alvarez J, Macé S, Llabres P, 2000. Anaerobic digestion of organic solid wastes: An overview of research achievements and perspectives. Bioresource Technology. 74:3-16.

McCracken JP, Smith KR, Mittleman M, Diaz A, Schwartz J, 2007. Chimney stove intervention to reduce long-term wood smoke exposure lowers blood pressure among Guatemalan women. Environmental Health Perspectives. 115:996-1001.

McCabe J, Eckenfelder WW, 1985. Biological treatment of sewage industrial wastes. Vol. 2. Reinhold.

Meynell PJ, 1976. Methane: Planning a Digester. Prism, Detroit.

Molino A, Nanna F, Ding Y, Bikson B, Braccio B, 2012. Biomethane production by anaerobic digestion of organic waste. FUEL. 103:1003-1009.

MPA, 2007. Mekong Protected Areas. Available online: http://www.mekong-protected-areas.org/vietnam/docs/vietnam-field.pdf.

Muller Ch, 2007. Anaerobic digestion of biodegradable solid waste in low- and middle-income countries. Overview over existing technologies and relevant case studies. Eawag-Sandec Publications.

Mwakaje AG, 2008. Dairy farming and biogas use in Rungwe district, South-west Tanzania: A study of opportunities and constraints. Renewable and Sustainable Energy Reviews. 12:2240-2252.

Mwiriki JW, Makenzi PM, Ochola WO, 2009. Socio-economic constraints to adoption and sustainability of biogas technology by farmers in Nakuru Districts, Kenya. Energy for Sustainable Development. 13:106-115.

Nguyen KQ, 2006. Alternatives to grid extension for rural electrification: Decentralized renewable energy technologies in Vietnam. Energy Policy. 35:2579-2589.

Ni JQ, Nyns EJ, 1996. New concept for the evaluation of rural biogas management in developing countries. Energy Conversion and Management. 37:1525-1534.

Oenema O, Wrage N, Velthof GL, Groenigen JW, Dolfing J, Kuikman PJ, 2005. Trends in global nitrous oxide emissions from animal production systems. Nutrient Cycling in Agroecosystems. 72:51-65.

Osei WY, 1993. Wood fuel and deforestation – answers for sustainable environment. Journal of Environmental Management. 37:51-62.

Pham CH, Vu CC, Sommer SG, Bruun S, 2014. Factors Affecting Process Temperature and Biogas Production in Small-scale Rural Biogas Digesters in Winter in Northern Vietnam. Asian-Australasian Journal of Animal Science. 27(7):1050-1056.

Phanthavongs S, Saika U, 2013. Biogas digesters in small pig farming systems in LAO PDR: evidence of an impact. Livestock Research for Rural Development. 25:216. Available online: http://www.lrrd.org/lrrd25/12/phan25216.htm.

Piechota G, Bartolomiej I, Buczkowski R, 2013. Development of measurement techniques for determination main and hazardous components in biogas utilized for energy purposes. Energy Conversion and Management. 68:219-226.

Pipatmanomai S, Kaewluan S, Vitidsant T, 2008. Economic assessment of biogas-to-electricity generation system with H2S removal by activated carbon in small pig farm. Applied Energy. 86:669-674.

Poeschl M, Ward S, Owende P, 2012. Environmental impacts of biogas demployment – Part II: Life Cycle Assesment of multiple production and utilization pathways. Journal of Cleaner Production. 24:184-201.

Pope DP, Mishra VK, Thompson I, Siddiqui AR, Rehfuess EA, Weber M, *et al.*, 2010. Risk of low birth weight and stillbirth associated with indoor air pollution from solid fuel use in developing countries. Epidemology Review. 32:70-81.

Potrafke N, Ursprung HW, 2012. Globalization and gender equality in the course of development. European Journal of Political Economy. 28:399-413.

Prade T, Scensson SE, Mattsson J, 2012. Energy balances for biogas and solid biofuel production from industrial hemp. Biomass Bioenergy. 40:36-52.

Prasertsan S, Sajjakulnukit B, 2006. Biomass and biogas energy in Thailand: Potential, opportunity and barriers. Renewable Energy. 31:599-610.

Qurashi M, Hussain T, 2005. Renewable Energy Technologies for Developing Countries Now to 2030. ISECO 2005.

Raposo F, de la Rubia MA, Fernandes-Cegri V, Baa R, 2011. Anaerobic digestion of solid organic substrates in batch mode: An overview relating to methane yields and experimental procedures. Renewable and Sustainable Energy Reviews. 16:861-877.

Ravindranath NH, Hall DO, 1995. Biomass, Energy, and Environment: A Developing Country Perspective from India. Oxford University Press, Oxford. 390. ISBN: 978-0-19-856436-2.

Rehl T, Muller J, 2011. Life cycle assessment of biogas digestate processing technologies. Resources, Conservation and Recycling. 56:92-104.

Remais J, Chen L, Seto E, 2009. Leveraging rural energy investment for parasitic disease control: schistosome ova inactivation and energy co-benefits of anaerobic digestors in rural China. PloS One. 4:4856.

REN21, 2010. Energy for Development: The Potential Role of Renewable Energy in Meeting the Millennium Development Goals.

Rheinlander T, Kereita B, Konradsen F, Samuelsen H, Dalsgaard A, 2013. Smell: An overlooked barrier in sanitation promotion. Waterlines. 32:106-112.

Ribaudo M, Gollehon N, Aillery M, Kaplan J, Johansson R, Agapoff J, Christensen L, Breneman V, Peters M, 2003. Manure Management for Water Quality: Cost to Animal Feeding Operations of Applying Manure Nutrients to Land. Agriculture Economic Report 824. Department of Agriculture, Economic Research Service, Resource Economics Division.

Rodrigez-Hernandéz V, Espino-Gudino MC, Gudino-Bazaldua J, Gonzalez-Perez JL, Castano VM, 2012. Adapting learning objects to e-learning and b-learning in materials science curricula. Journal of Materials Education. 34/1-2:29-44.

Roubik H, Mazancova J, 2014. Identification of Context Specific Knowledge as Tool for Facilitators and their Quality Involvement. Proceedings of the 11th International Conference of Efficiency and Responsibility in Education (ERIE 2014), Prague. 664-670. ISBN 978-80-213-2468-8.

Roubik H, Valesova L, Verner V, Mazancova J, 2014. Gender inequality in rural areas of central Vietnam – case study on Thua Thien Hue biogas plant owners. SGEM2014 Conference Proceedings. 1-9. ISBN 978-619-7105-23-0.

Sahlstorm L, 2003. A review of survival of pathogenic bacteria in organic waste used in biogas plant. Bioresource Technology. 87:161-166.

Scott S, Chuyen TTK, 2007. Gender research in Vietnam: Traditional approaches and emerging trajectories. Women´s Studies International Forum. 30:243-253.

Seetanah B, 2006. The economic importance of education: Evidence from Africa using dynamic panel data analysis. Journal of Applied Economics. 7:137-157.

Shi YJ, Meng FQ, Yang LS, Li GX, 2001. Effects of anaerobic fermentation residues on nitrate accumulation in leaf vegetables (in Chinese). Agro-environmental protection. 20:81-84.

Schillenbeeckx SJD, Parikh P, Bansal R, George G, 2012. An integrated framework for rural electrification: adopting a user-centric approach to business model development. Energy Policy. 48:687-697.

Schmidt UW, Jordan A, 2008. Report on the Biodigester User Survey 2008. Commissioned by the National Biodigester Programme, July 2008, Phom Penh, Cambodia.

Singh M, Maharjan KL, 2003. Contribution of biogas technology in well-being of rural hill areas of Nepal: a comparative study between biogas users and non-users. Journal of International Development and Cooperation 9:43-63.

Singh KJ, Sooch SS, 2004. Comparative study of economics of different models of family size biogas plants for state of Punjab, India. Energy Conversion and Management. 45:1329-1341.

Singh SP, Vatsa DK, Verma HN, 1996. Problems with biogas plants in Himachal Pradesh. Bioresource Technology. 59:69-71.

Slama K, Chiang CY, Hinderaker SG, Bruce NG, Vedal S, Enarson DA, 2010. Indoor solid fuel combustion and tuberculosis: is there an association? International Journal of Tuberculosis and Lung Disease. 14:6-14.

Smet E, van Langenhoove H, De Bo L, 1999. The emission of volatile compounds during the aerobic and the combined anaerobic/aerobic composting of biowastes. Atmospheric Environment. 33:1295-1303.

Smith RJ, Hein ME, Greiner, 1979. Experimental methane production from animal excreta in pilot-scale and farm size units. Journal of Animal Science. 48:202-212.

Sophin P, Preston TR, 2001. Effect of processing pig manure in a biodigester as fertilizer input for ponds growing fish in polyculture. Livestock Research for Rural Development. 13: 6. Available online: http://www.lrrd.org/lrrd13/6/pich136.htm.

Steiner A, Kandler O, 1984. Anaerobic digestion and methane production of grass and cabbage wastes. Third European Congress on Biotechnology. 3:3-8.

Strassburg B, Turner BK, Fisher B, Schaeffer R, Lovett A, 2009. Reducing emissions from deforestation – the combined incentives mechanism and empirical simulations. Global Environmental Change. 19:265-278.

Surendra KC, Takara D, Hashimoto AG, Khanal SK, 2014. Biogas as a sustainable energy source for developing countries: Opportunities and challenges. Renewable and Sustainable Energy Reviews. 31:846-859.

Takama T, Lambe F, Johnson, F, Arvidson A, Atanassov B, Debebe M, Nilsson L, Tella S, Tsepel S, 2011. Will African consumers buy cleaner fuels and stoves? A household energy economic analysis model for the market introduction of bio-ethanol cooking stoves in Ethiopia, Tanzania and Mozambique, research report. Stocholm Environmental Institute.

Thiengburanathum P, 2006. Impacts of biogas system implementation to piggery farm industry in Thailand. Chiang Mai, Thailand: International Conference on Green and Sustainable Innovation.

Thy S, Preston TR, Ly J, 2003. Effects of retention time on gas production and fertilizer value of biodigester effluent. MSc Thesis, MEKARN-SLU. Available online: http://www.mekarn.org/msc2001-03/theses03/santhyexp1apr26.html.

Tigabu AD, Berkhout F, Beukering P, 2015a. Technology innovation systems and technology diffusion: Adoption of bio-digestion in an emerging innovation system in Rwanda. Technological Forecasting and Social Change. 90:318-330.

Tigabu AD, Berkhout F, Beukering P, 2015b. The diffusion of a renewable energy technology and innovation system functioning: Comparing bio-digestion in Kenya and Rwanda. Technological Forecasting and Social Change. 90:331-345.

Tuan VD, Porphyre V, Farinet JL, Toan TD, 2006. Composition of animal manure and co-products. In: Porphyre, V., Coi, N.Q. (Eds.), Pig Production Development, Animal Waste Management and Environmental Protection: A Case Study in Thai Binh Province. Northern Vietnam PRISE Publication, France, 127-143.

Uddin J, Mezbah-ul-Islam M, 2012. The flow of, and acces to, information in Bangladesh: A village level case study. The International Information and Library Review. 44:224-232.

UN Report, 2004 Data (2012-07-20), United Nations Population Division. Available online: http://www.un.org/esa/population/publications/sixbillion/sixbilpart1.pdf.

United Nation Development Programme (UNDP)/World Health Organization (WHO), 2009. The energy access situation in developing countries: a review focusing on the least developed countries and Sub-Saharan Africa UNDP, New York, United States.

Ward AJ, Hobbs PJ, Holliman PJ, Jones DL, 2008. Optimization of the anaerobic digestion of agricultural resources. Bioresource Technology. 99:7928-7940.

Weiland P, 2010. Biogas production: curent state and perspectives. Application of Microbiology and Biotechnology. 849-860.

WHO, 2002. The Health Effects of Indoor Air Pollution Exposure in Developing Countries. WHO Press, Geneva, Switzerland.

Váňa J, 2010. Biogas plants for usage of biowastes (in Czech). Biom.cz. Available at: http://biom.cz/cz/odborne-clanky/bioplynove-stanice-na-vyuziti-bioodpadu. ISNN: 1801-2655.

Vu TKV, Tran MT, Dang TTS, 2007a. A survey of manure management on pig farms in Northern Vietnam. Livestock Science. 112:288-297.

Vu TKM, Vu DQ, Jensen LS, Sommer SG, Bruun S, 2015. Life Cycle Assessment of Biogas Production in Small-scale Household Digesters in Vietnam. Asian-Australasian Journal of Animal Sciences. 28(5):716-729.

Yu L, Yaoqiu K, Ningsheng H, Zhifeng W, Lianzhong X, 2008. Popularizing household-scale biogas digesters for rural sustainable energy development and greenhouse gas mitigation. Renewable Energy. 33:2027-2035.

Zhang FF, Cao SH, Chen JW, 2010. Effect of different treatments of biogas fertilizer on photosynthesis characteristics of Alfa-alfa (in Chinese). Journal of Anhui Agricultural Science. 38:13741-13842.

Zhang LX, Wang CB, Song B, 2013. Carbon emission reduction potential of a typical household biogas system in rural China. Journal of Cleaner Production. 47:415-421.

Zhou X, Ou S, Huang Ch, 2011. Problems and Solutions Based on Comprehensive Utilization of Biogas. Energy Procedia. 5:42-47.

Zhou Z, Wu W, Chen Q, Chen S, 2008. Study on sustainable development of rural household energy in northern China. Renewable and Sustainable Energy Reviews. 16:861-877.

Zurbrugg Ch, Gfrere M, Henki A, Brenner W, Kuper D, 2012. Determinants of Sustainability in Solid Waste Management – gianyar Waste Recovery. Waste Management. 32:2126-2133.

8. The author´s relevant publications

During the studies, some results, which several of them are also incorporated in this thesis, were presented or published in conferences and journals. Enumeration of relevant publications is listed below. Some of them included in Web of Science™.

Major part of this research was also submitted in November 2014 to the *Journal of Cleaner Production* (Impact Factor: 3.590, 5-Year Impact Factor: 4.088), where there is currently under review.

Roubik H, Mazancova J, 2014. Identification of Context Specific Knowledge as Tool for Facilitators and their Quality Involvement. Proceedings of the 11th International Conference of Efficiency and Responsibility in Education (ERIE 2014), Prague, pp. 664-670. ISBN 978-80-213-2468-8.

Roubik H, Valesova L, Verner V, Mazancova J, 2014. Gender Inequality in Rural Areas of Central Vietnam – Case Study in Thua Thien Hue Biogas Plant Owners. SGEM2014 Conference Proceedings, ISBN 978-619-7105-23-0/ ISSN 2367-5659, September 1-9, 2014, Vol. 2, 319-326. DOI: 10.5593/SGEMSOCIAL2014/B12/S2.042.

Roubik H, Mazancova J, Banout J, Verner V, 2014. Optimization of information flow of biogas plant issue – case study or rural areas in central Vietnam. Proceedings of the ELLS Scientific Student Conference 2014 – "Brave New Thinking, Brave New Sciences, Brave New World", Warsaw University of Life Sciences, SGGW, 14.-15.11.2014. ISBN: 978-83-7583-592-2.

Roubik H, Mazancova J, Banout J, Verner V, 2014. The design of effective digestate treatment – case study in rural areas of central Vietnam. Proceedings of the ELLS Scientific Student Conference 2014 – "Brave New Thinking, Brave New Sciences, Brave New World", Warsaw University of Life Sciences, SGGW, 14.-15.11.2014. ISBN: 978-83-7583-592-2.

Roubík H, Slocar J, Nam S, Mazancova J, Banout J, 2014. Small-scale biogas plant issue and its information transmission process – case of Vietnam and Cambodia. 1st International Tropical Biodiversity Conservation Conference, Czech University of Life Sciences Prague, 22.-23.10.2014, ISBN: 978-80-213-2497-8.

Roubik H, Mazancova J, Banout J, Verner V, 2013. Analysis of Information Flow of Biogas Plant Issue in Central Vietnam – a Case Study in Thua Thien Hue Province, 2013. 7th Scientific Conference of Faculty of Tropical AgriSciences, 2013: Economic Aspects of Natural Resources Management in Tropics: Social Capital and Microfinance. Czech University of Life Sciences Prague. DOI: 10.2478/ats-2013-0024.

Roubik H, Mazancova J, 2013. Analysis of possibilities of digestate management in central Vietnam, 2013. ELLS Scientific Student Conference 2013 - "Sustainability Challenge - Technological advancements and other solutions", the University of Natural Resources and Life Sciences, Vienna (BOKU), 14 – 16.11.2013.

Roubik H, Mazancova J, Banout J, 2013. Analysis of Problems with Family Biogas Plants in Central Vietnam, 2013. Conference Tropentag 2013, International Research on Food Security, Natural Resource Management and Rural Development - Agricultural development within the rural-urban continuum, University of Hohenheim, September 17.-19.9.2013. ISBN: 978-3-95404-498-6.

Roubik H, 2013. Analysis of possibilities of digestate management in central Vietnam, 2013. Bachelor thesis. Czech University of Life Sciences Prague, Faculty of Tropical AgriSciences. Prague (In Czech)

Machackova P, Verner V, Banout J, Mazancova J, **Roubik H**, 2012. Social aspects and economic benefits of using biogas by rural and peri-urban households in central Vietnam. 6th Scientific Conference of Institute of Tropics and Sutropics, 2012. Czech University of Life Sciences Prague. ISBN: 978-80-213-2305-6.