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Social aspects and economic benefits of using biogas by rural and peri-urban households in central Vietnam

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Declaration

I hereby declare, that I have written this master thesis "Social aspects and economic benefits of using biogas by rural and peri-urban households in central Vietnam" myself with help of the literature listed in references.

In Prague 6-Suchdol, on April 25, 2013

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Petra Macháčková

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Abstract

Access to affordable and efficient energy sources is crucial for economic development and improvement of living standards. Biogas energy has proved viability in a number of developing countries, particularly due to relatively easy maintenance and abundance of input material. Moreover, biogas is environmentally friendly and has several socio-economic advantages over traditional energy sources, such as cost effectiveness and reduction of workload.

Large biogas dissemination started in Vietnam ten years ago as a response to unsustainable farming practices and rapid depletion of natural resources in densely populated parts of the country. The aim of this study is to evaluate social and economic aspects of using biogas plants among resource-poor small-holders settled in rural and peri-urban areas of Thua Thien - Hue province, central Vietnam. The research was carried out in August 2012 in two districts of Thua Thien - Hue province, Phong Dien and Huong Tra. Data was collected via semi-structured questionnaires filled in by biogas plant owners.

Results reveal economic benefits linked to biogas plants usage, such as saved money for firewood, electricity and LPG that equals to 41,233,000 VND per month. NPV of the investment in biogas plants is 30,713,000 VND and IRR 42.2% for lifespan of 15 years and discount rate of 4%. However, it is disputable whether farmers save money on fertilizer or not. In terms of social impact, hygiene conditions in the household improved considerably, environment is cleaner in 75% of households and smoke is reduced in 90%. The environmental impact is also considerable: firewood usage was reduced by 57% and production of CO_2 was reduced by 699.24 tonnes and methane by 68.87 tonnes of CO_2-eq per year. Farmers from rural areas have more problems with biogas plant operation or maintenance (33%) than from peri-urban areas (18%), probably because of less access to water in rural areas. Further training and workshops focused on the use of bio-slurry and biogas plant maintenance are recommended.

Key words: Biogas, renewable energy, small-holders, peri-urban and rural development, environment, survey, Central Vietnam

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List of Abbreviations

ADB	Asian Development Bank
AFFEC	Agriculture, Forestry and Fishery Extension Centre
BP	Biogas Plant
BPAHS	Biogas Program for the Animal Husbandry Sector
CH_4	Methane
CO_2–eq	Carbon Dioxide Equivalent
CO_2	Carbon Dioxide
CULS	Czech University of Life Sciences
DECC	Department of Energy and Climate Change
DEFRA	Department for Environment Food and Rural Affairs
Fig	Figure
GHG	Greenhouse Gas
GSOV	General Statistics Office of Vietnam
HUAF	Hue University of Agriculture and Forestry
IRR	Internal Rate of Return
LPG	Liquefied Petroleum Gas
MARD	Ministry of Agriculture and Rural Development
MCQ	Multiple Choice Question
MDG	Millennium Development Goal
N_2O	Nitrous Oxide
NPEEC	National program on energy efficiency and conservation
NPV	Net Present Value
OECD	Organisation for Economic Co-operation and Development
ODA	Official Development Assistance
PSE	Penn State Extension

SNV	Netherlands Development Organization (Stichting Nederlandse Vrijwilligers)
SQ	Sub-Question
Tab	Table
TLU	Tropical Livestock Unit
TTHP	Thua Thien Hue Portal
UCLG	United Cities and Local Government
USD	United States Dollar
VAC	The Traditional Vietnamese Farm (Vuon – Ao – Chuong)
VND	Vietnamese Dong
WB	World Bank
WWF	World Wildlife Fund

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Exchange Rate

1 USD = 20,872.47 VND

1. Introduction

Energy plays undoubtedly one of the most important roles in economic development all over the world and it is closely linked to the improvements in living conditions and social status. In developing countries there is a significant number of the population living in rural and semi-urban areas with limited access to affordable and viable energy source (Amigun *et al*., 2008). Demand for energy is usually supplied by fossil fuels or firewood. However, unlimited usage of these traditional energy sources is highly unsustainable due to the fast depletion of sources and related ecological problems such as deforestation, soil erosion, air pollution or production of greenhouse gases (Teune, 2007; Walekhwa *et al*., 2009). Moreover, smoke from burning firewood is causing diverse health problems such as an eye infection and respiratory diseases (Katuwal and Bohara, 2009). Due to a significantly higher demand for fossil fuels in the recent years there is a considerable increase in prices worldwide and the energy supplies based on fossil fuels are becoming less cost-effective (Payne and Dutzik, 2009). Therefore an access to affordable, effective and sustainable energy also in rural areas is crucial in terms of country's development (Amigun *et al*., 2008).

Rural and semi-urban households' demand for energy can be partly fulfilled by renewable energy sources such as solar photovoltaic system, wind generator or biogas reactors. These decentralised energy sources bring certain advantages over both traditional fossil fuels and firewood in terms of renewable and environmentally friendly energy, but also over electricity because of the proximity to households which avoids expensive transmission costs (Nguyen, 2006).

Biogas technology seems to be suitable for a wide range of households not only because of relatively easy operation and maintenance but also because the input material is organic substrate which is usually in abundance in rural and semi-urban areas. Moreover, the opportunity to reuse organic waste as an input material for biogas production is promoting effective manure management and improving hygiene conditions on the farm and in the house (Ramachandra *et al*., 2000; Teune, 2007).

Despite of the advantages of biogas technology as an accessible and environmentally friendly source of energy, the adoption rate varies among developing countries and remains disputable. This situation could be explained particularly by insufficient promotion of biogas technology, poorly managed training and low government support (IGAD, 2007; Teune, 2007; Mirigi *et al*., 2009). Considering differences in biogas technology adoption in diverse countries, a detailed assessment of each region is necessary in order to assure successful and sustainable operation of biogas digesters.

2. Literature Review

2.1 Production and use of biogas

Biogas is the product of fermentation or anaerobic digestion of biodegradable material. It typically contains methane (55-65%), carbon dioxide (35-45%), hydrogen sulphide (0-3%), nitrogen (0-3%) and hydrogen (0-1%) (DEFRA/DECC, 2013). Production of biogas represents clean and carbon neutral process, during which an organic material such as energy crops, residues and wastes, is converted into biogas and organic slurry (Weiland, 2010). Calorific value of biogas depends on the methane content and usually varies from 4800 to 6900 kcal/m^3 (Harasimowicz *et al*., 2007).

The efficiency of the production process is influenced by several parameters including characteristics of feed material such as its composition, pH, water content and quantity, environmental conditions such as temperature and technical parameters of the digester (DEFRA/DECC, 2013). In order to provide the feed material with maximum biogas potential, type of substrate must be considered. Based on the study by Bond and Templeton (2011), the following table 1 describes basic characteristics of the most common types of substrate.

Tab 1 Biogas potential according to substrate

Animal	Substrate	Daily production of manure per animal (kg)	Dry material content (%)	Daily biogas yield per animal (m^3)
Pig	Manure	2	17	1.43
Cow	Manure	8	16	0.32
Chicken	Manure	0.08	25	0.01

Source: Bond and Templeton, 2011

In order to ensure optimal density of substrate for biogas plant, manure should be mixed with water before being inserted to into the digester. According to Thu *et al*. (2012), optimal manure-water ratio is 3:1. Another parameter that needs to be taken into account is the ration between carbon and nitrogen in the substrate. According to Martins *et al*. (2009), the optimal carbon : nitrogen ratio is between 20 and 30. Too low or excessively high ratio can result in lower efficiency of biogas plant performance. Based on the study of Barnett *et al*. (1978), carbon to nitrogen ratio is 20 for pig manure, 18 for cow manure and 7.3 for chicken manure. The best pH value of the slurry in the digester is approximately seven and a necessary condition for optimal biogas production is pH value within the range of 6.4 – 7.4 (Balat and Balat, 2009). The retention time also influences biogas yields as it expresses the time needed for decomposition of organic material, for mesophilic digestion the optimal retention time is between 11 and 15 days (Vu *et al*., 2007). The temperature in digester affects the rate of reaction and influences the solubility of heavy metals, carbon dioxide and the composition of gas. For mesophilic bacteria involved in biogas production, the optimal temperature in the reactor ranges between 25 – 37 °C (Nijaguna, 2006).

Production of biogas requires a minimum daily intake of substrate that equals to daily manure production of six pigs or two cows for individual family plants (MARD/SNV, 2010). One cubic meter of biogas produced per day provides 2.5 to 3.5 stove hours (Lam and ter Heegde, 2012).

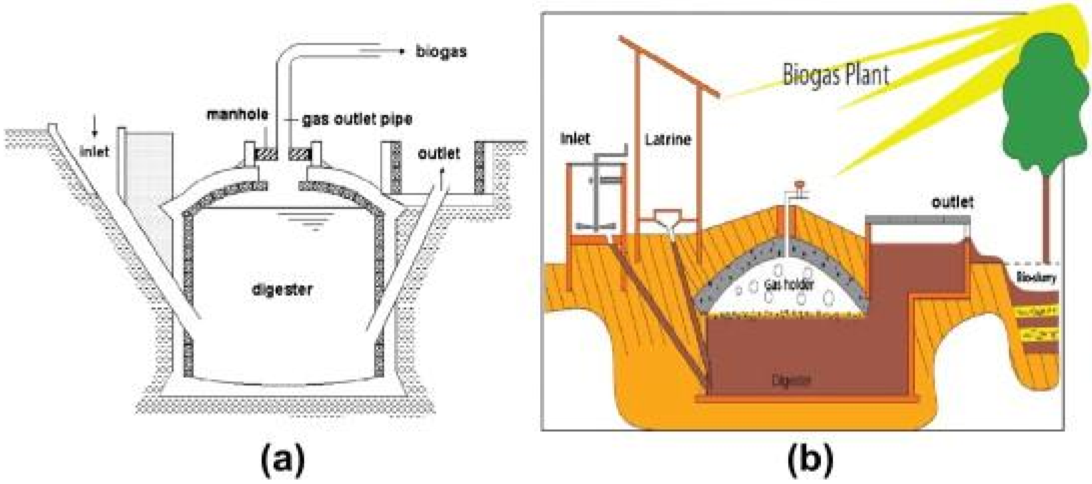

Fig 1 Scheme of digester

(a) general scheme of a fixed home biogas digester, (b) fixed home digester with a coupled latrine.

Source: Nzila *et al*., 2012

A structure of a home biogas digester is shown in figure 1. Organic substrate is inserted through inlet into digester where the biogas production starts. Gas is rising up to the top of digesting tank where the gas pipe is connected. Through this pipe biogas flows into the stove. The organic residue of biogas production is kept in the Outlet until it is used as bio-slurry.

2.2 Biogas energy in developing countries

Biogas is an environmentally friendly source of renewable energy and it is an alternative for traditional and commercial fuels such as firewood, petroleum, electricity and coal. Biogas energy has a wide range of use including cooking, heating of water, breeding and lighting (Xiaohua *et al*., 2005; Katuwal and Bohara, 2009). As a decentralized energy source, it has certain advantages over grid extension such as proximity to consumer allowing decrease in transmission costs and opportunity to cover also isolated and remote households (Nguyen, 2006).

This technology is a convenient source of energy for rural areas in developing countries due to common excess of organic substrate on farms which can be used as an input material for biogas production and also due to relatively easy operation and maintenance of plant (Yu *et al*., 2008; Thu *et al*., 2012).

Moreover, domestic biogas has direct relation with four out of eight Millennium Development goals:

MDG 1 Eradicate extreme poverty and hunger

Firstly, biogas reduces use of traditional energy sources and thus increases availability of these sources for very poor member of community and secondly, construction of biogas digesters creates job positions for people in rural areas.

MDG 3 Promote gender equality and empower women

Biogas technology reduces the workload on providing traditional energy sources, such as collection and preparation of firewood and cleaning soot, which is usually done by women and girls. Moreover, biogas used for lighting provides conditions for education, reading or income generating activities.

MDG 6 Combat HIV/AIDS, malaria and other diseases

Substitution of firewood as a main energy source for biogas largely reduces smoke in house and thus prevents development of diseases such as respiratory illnesses or eye ailments. Biogas improves manure management on farms and thus increases sanitary conditions and lowers the risk of water or environment pollution.

MDG 7 Ensure environmental sustainability

Target 9 of this millennium goal refers to integrating principles of sustainable development into country policies. Particularly large biogas projects are supported by local governments therefore national policies on sustainable development are promoted. Moreover, domestic biogas helps to achieve sustainability of energy sources, digestate improves soil fertility and fresh water pollution is decreased as a result of improved manure management (Lam and ter Heegde, 2012).

2.2.1 History of biogas in developing countries

History of the biogas technology in developing and emerging economies is relatively long, to name few examples, in 1930s biogas was popularized throughout China, in 1950s the first biogas digesters were implemented in Uganda and Kenya and in 1960s in Vietnam. However, in this period biogas digesters did not reach dissemination at large scale or long-term operation sustainability (Teune, 2007; Chen *et al*., 2009; Walekhwa *et al*., 2009; Mwirigi *et al*., 2009). Only after the two oil shocks in the 1973 and 1979 the production of energy from renewable sources started to be considered as a tool in the energy policy (Balassa, 1985; Klass, 1998). Therefore, a rapid and wide dissemination of biogas technology started in developing countries in the 1970s, represented principally by small digesters in rural and remote areas. However, in many countries production of biogas was not successful and up to 50% of the plants built in the earlier period are not functional nowadays (Bond and Templeton, 2011).

In the recent two decades, biogas technology has become widely considered as a solution not only to economical improvement of households in rural areas, but also as a way to deal with increasing environmental problems rising from excessive use of traditional and commercial energy sources. As a consequence, local governments in many Asian and African countries together with local or foreign non-governmental organizations started biogas promotion and implementation on a large scale (Singh and Sooch, 2004; Teune, 2007; Feng *et al*. 2009; Katuwal and Bohara, 2009). In the table 2 the number of biogas plants that were built in diverse countries with the support of non-governmental organization

SNV is shown. A country with the highest number of biogas plants in rural areas is China where 30 millions of digesters were built by the year 2009 (Jiang *et al.*, 2011).

Tab 2 Biogas plants implemented by SNV

Country	Programme took off in	Number of BP in 2011	Country	Programme took off in	Number of BP in 2011
Nepal[1]	1992	19,246	Rwanda	2007	785
Vietnam[2]	2003	23,309	Ethiopia	2008	1,641
Bangladesh	2006	5,049	Tanzania	2008	1,444
Cambodia	2006	4,826	Kenya	2009	2,399
Lao PDR	2006	439	Uganda	2009	1,276
Pakistan	2009	860	Burkina Faso	2009	609
Indonesia	2009	2,97	Cameroon	2009	33
Bhutan	2011	40	Benin	2010	20
			Senegal	2010	95

[1] Including plants financially supported by WWF between 2007-2011

[2] Including plants under ADB and WB supported programmes between 2010-2012

Source: SNV, 2012

2.2.2 Benefits of using biogas

Benefits arising from biogas technology are various and have impact on both household level and on the level of society. In the following section, the main benefits influencing particularly the micro level are mentioned.

Economic benefits

Certain studies prove a positive impact of biogas energy on household economic situation in countries such as China, Vietnam or Nepal, in particular due to savings for other energy sources and fertilizer. Moreover, biogas technology brings several indirect economic benefits that are usually difficult to calculate such as lower expenses on healthcare due to cleaner environment. However, economic sustainability in each country can vary considerably as a result of different farm production, income, traditions and locality (von Eije, 2007; Katuwal and Bohara, 2009; Feng *et al*., 2009; San *et al*., 2012).

In order to determine positive impact on overall household economic situation, all the costs and both direct and indirect benefits has to be taken into account. Based on the data by Lam and ter Heegde (2012) and Gwavuya *et al*. (2012), table 3 summarizing costs and benefits of a biogas plant was designed.

Tab 3 Economic costs and benefits of a biogas plant

Costs	Benefits
Total investment costs	Savings for other energy sources
Cement	Savings for fertilizer
Materials	Labour time
Labour	Employment
Appliances	Reduction of CO_2-eq
Fees and charges	Savings for health care
Annual maintenance costs	
Water costs	
Manure value	

Source: Lam and ter Heegde, 2012; Gwavuya *et al*., 2012

According to OECD (2012), projects focused on renewable energy are considered as economically feasible if the net present value is positive, internal rate of return is at least 20% and the payback period is equal to seven years or less. Taking this information into account, viability and economical feasibility of biogas projects vary significantly according to the farm location and other socio-economic aspects. For example, biogas energy in Ethiopia is economically feasible only for households that purchase firewood as a source of energy (IRR ranges from 28% to

35%) while for those who collect firewood or dung is not (IRR ranges from 11% to 15%). However, mainly due to lower investment costs and different manure management, biogas plants proved economic viability in many other countries, for instance in Tibet, China with IRR equalling to 37% and in Senegal with IRR ranging between 29% – 50% for 15 and 10 years of lifespan respectively (ter Heegde *et al*., 2007; Feng *et al*., 2009).

Due to difficulties with estimation of biogas price because it is a commodity that is not purchased on market, calculation of shadow prices of energy sources can be helpful in order to compare costs on biogas with other energy sources. According to Gwavuya *et al*. (2012), shadow prices of collected energy sources such as dung or firewood is increasing with the income of the household. Thus, biogas energy is more rentable for well-off households.

Social and household benefits

As a result of using biogas, households save time that would be otherwise used on collection and preparation of firewood. The extra time per day that a household gains ranges from 94 minutes to almost three hours. Additionally, members of the household who save time on the firewood collection and preparation are mostly women and children thus biogas technology promotes empowerment of women and reduces the workload of children (Bajgain *et al*., 2005; Bohara and Katuwal, 2009). However, biogas technology does not only save time because a basic maintenance must be carried out every day in order to keep the biogas production on the optimal level. Such activities include fetching water and feeding biogas plant. Based on the data from Bohara and Katuwal (2009) following table and figure were designed, table 4 shows the changes in time spent on different activities by women and figure 2 displays utilization of saved time by both genders.

Tab 4 Changes in time spent on different activities by women

Activities	Time spent before BP installation (min/day)	Time spent after biogas plant installation (min/day)	Saved time (min/day)
Livestock caring	174.2	177	- 2.8
Fetching water	47.5	70	- 22.5
Feeding biogas plant	0	29.7	- 29.7
Firewood collection/dung cake preparation	224.8	143.3	81.5
Fodder collection	103.6	104.3	- 0.7
Cooking	140.4	97.5	42.9
Cleaning utensils	55.43	30.4	25.3
Total balance	745.93	652.2	93.73

Source: Bohara and Katuwal, 2009

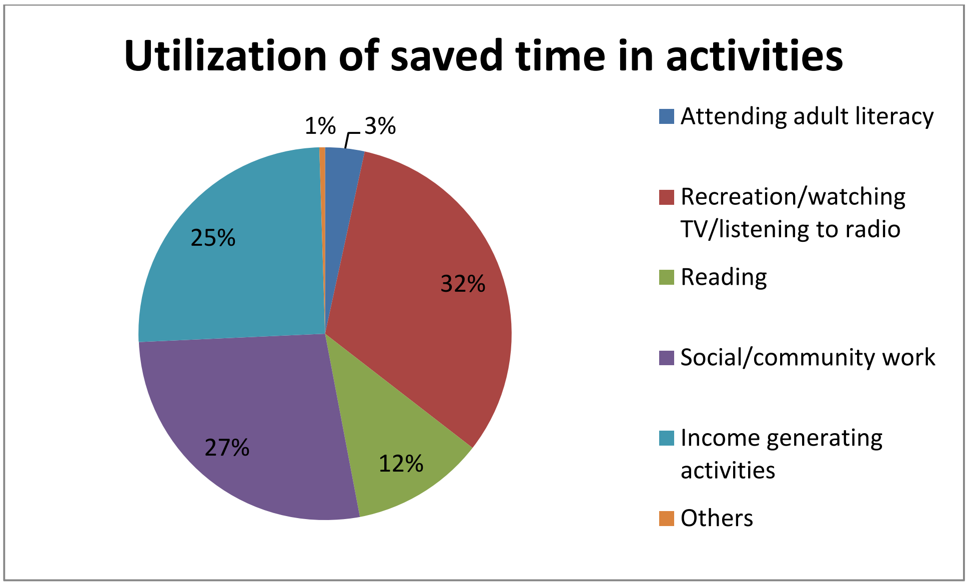

Fig 2 Utilization of saved time in various activities

Source: Bohara and Katuwal, 2009

Higher employment as a result of job creation and training of skilled work force is another positive impact on local economy. It is estimated that in Vietnam the dissemination of biogas plants offered job for 1,000 skilled workers and another people are expected to be employed by an agricultural sector focusing on bio-slurry (NPEEC, 2010). In Nepal the biogas industry was able to generate 11,000 job positions (Katuwal and Bohara, 2009). However, estimating the actual employment effect is difficult due to the fact that jobs can be displaced within the economy (Vining *et al*., 2005).

Adoption of biogas technology has a considerable impact on improvement in manure management. In many developing countries, manure and other organic waste used to be freely disposed into the environment, causing pollution and threatening hygiene conditions of the household. As most of the waste is used as a substrate for biogas plant, odour is being significantly reduced as well as occurrence of insect (Bohara and Katuwal, 2009). However, according to the study by Karki (2006), some farmers perceive higher occurrence of mosquito because of their breeding in bio-slurry. Due to the increased use of biogas and cut in usage of traditional energy sources such as firewood, a noticeable reduction of smoke in the house was registered. All these aspects have an important positive impact on the health of household members, mainly women and children who are usually dedicating their time to activities such as cooking and taking care of livestock (Bohara and Katuwal, 2009).

Environmental benefits

Economic development of countries is strongly linked to increased demand for energy sources, in developing countries these energy sources are principally firewood and its charcoal form. As a consequence, uncontrollable deforestation is taking place in many countries (Dang, 1993). According to Kumar *et al*. (2003) Vietnam has lost 30% of its forest cover in the last 30 years. The use of firewood is no longer sustainable due to higher demand than supply resulting in distant travelling of the firewood collectors. Using biogas energy can improve the balance between demand and supply for energy sources and it can reduce deforestation and slow down the soil erosion that is closely related to occurrence and frequency of floods (Morup, 2012).

One of the main aspects of the biogas plants is the emission reduction that is a result of substitution of non-renewable biomass such as firewood and fossil fuels as energy sources for CO_2 neutral biogas energy (Haque *et al*., 2011). It is estimated that burning of one kg of non-renewably harvested firewood generates 1,500 g of carbon dioxide (Habermehl, 2007). Biogas reactor can also capture most of methane (CH_4) that is being produced by livestock. As the CO_2 and CH_4 are the principal contributors to climate change, reduction of this compound is crucial in order to keep the balance in the environment (UNFCCC, 2012). In rural China during the 14 years of biogas plants performance in millions of households the total energy provided is estimated to be 832,749 TJ and the reduction of greenhouses equals to 84,244 Gg CO_2 and 3,560 Gg CO_2–eq of CH_4 emissions (Yu *et al*., 2007).

2.3. Biogas technology in Central Vietnam

Vietnam is a country that has experienced a very fast economic growth and success in poverty reduction during the last two decades (World Bank, 2011). As a result of this development, agricultural sector offers better conditions for farmers than before, mainly due to the allocation of land to peasants and promotion of the new approaches, such as the VAC integrated agricultural system. The VAC system involves small-scale bio-intensive farming connecting animal husbandry, aquaculture and gardening and it emphasizes the optimal use of land in order to be efficient (Hop, 2003; GSOV, 2011; BPAHS, 2012). However, maintaining high economic efficiency of the farms together with increasing population density adversely influence local environment. Due to no effective law on waste management in Vietnam, organic waste such as animal manure can be freely disposed in the nature (Morup, 2012). Therefore, the main threats are environmental pollution as a result of inadequate treatment of animal waste and deforestation due to traditional collection of wood for cooking (Teune, 2007). Firewood is still used widely mainly among the households in rural areas because of high connection costs of electricity (Morup, 2012). In order to maintain sustainability of farms and the environment and improve social and economic situation of farmers, adoption of biogas technology seems as an appropriate solution.

Dissemination of biogas technology is a governmentally driven project that has been actively promoted by the Biogas Project Division of the Vietnamese Ministry of Agriculture and Rural Development (Teune, 2007). Thua Thien - Hue province has taken part in this project in the earlier years, activities within the Biogas Program for the Animal Husbandry Sector of Vietnam took place between the year 2003 and 2005. Project had two objectives, firstly exploiting effectively biogas technology and developing sustainable biogas sector and secondly contributing to rural development and environmental protection. Within this biogas project 2,226 digesters were constructed in 122 communes of Thua Thien - Hue province (Dung *et al*., 2009). Biogas digesters on the household level were also supported by the project "Renewable energy resources for rural areas in Thua Thien - Hue province, Vietnam", which is run by the Faculty of Tropical AgriSciences at University of Life Sciences in Prague (CULS, 2013). Nevertheless, biogas dissemination in this province had experienced certain difficulties due to spread of cattle's epidemic diseases affecting livestock and increasing considerably food prices, and inconvenient weather conditions including floods (Dung *et al*., 2009).

The viability of particular biogas digester depends on the environment where it operates (Sharma and Pellizzi, 1991). Due to specific environmental conditions of the Thua Thien - Hue province as well as turbulent history including large destruction of this area during the Vietnam War (TTHP, 2013), a detailed study of biogas plants viability in this province is necessary. However, any research assessing social aspects and economic benefits of biogas usage by small holder farmers in rural and peri-urban areas of this province has not been carried out.

3. Objectives

This research is focused on the assessment of social, economic and environmental benefits of using biogas energy by small holder farmers in central Vietnam, particularly in rural and peri-urban areas of the Thua Thien – Hue province.

Thus, the objectives of this study are to:

(i) evaluate social and economic aspects of using biogas plants in Thua Thien - Hue province in central Vietnam;

(ii) determine how different social and economic groups of farmers are favourable to biogas plants implementation; and,

(iii) specify the main restrictions and farmer's future expectation of biogas plant adoption in this zone.

4. Materials and methods

4.1 Study area

Research was conducted in Thua Thien - Hue province which is located in the Central Vietnam with population of nearly one million inhabitants out of which 69% live in rural areas. During the last decades, this province has experienced fast development and diversification in economic structure from agricultural oriented to one consisting of agribusiness, infrastructure, construction and services focused especially on financial sector and tourism. Due to historical consequences and recent socioeconomic changes in the society, unequal distribution of benefits prevails at rural-urban level. Since the year 2003, Thua Thien - Hue province has taken part in the Biogas Programme promoting household size biogas digesters implementation (Dung *et al*., 2009; TTHP, 2013).

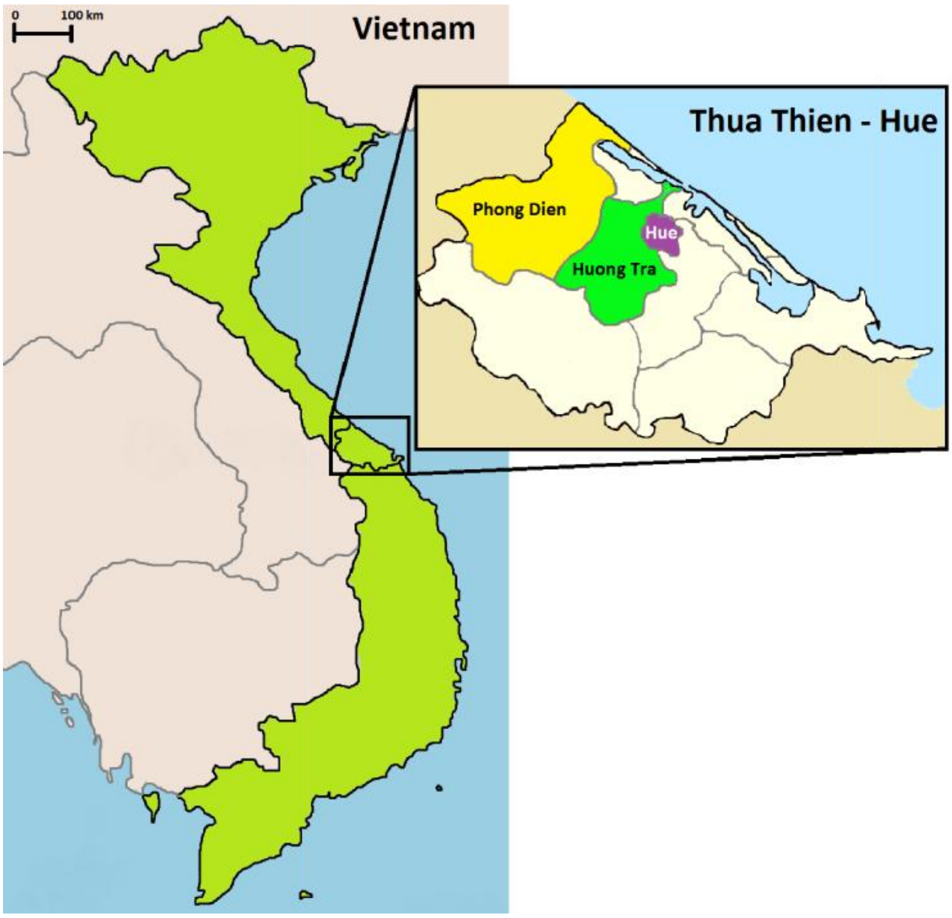

Fig 3 Map of Thua Thien - Hue province

4.2 Data collection

In correspondence with other published studies (see e.g. Xiaohua *et al*., 2005; Katuwal *et al*., 2009; Gwavuya *et al*., 2012), we focused this research on those households, which derived their livelihood mainly from agricultural activities, as displayed in table 4.

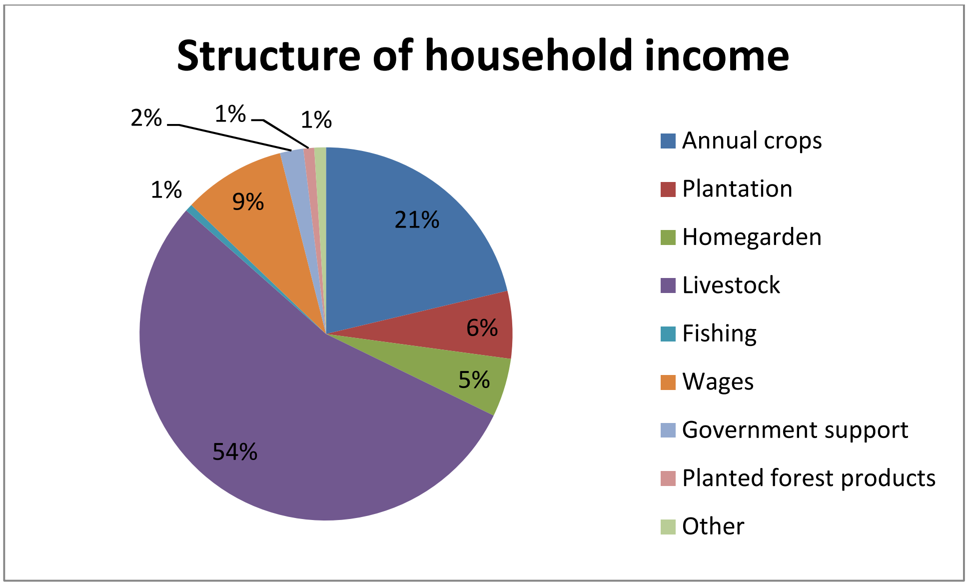

Fig 4 Structure of cash income of focused households

In order to consider different socioeconomic and natural conditions of the province, the study area includes both rural and peri-urban districts. District Phong Dien is situated in rural areas, between 18 and 30 km far away from the Hue City, while district Houng Tra is considered as peri-urban with communes situated not further than 10 km from the provincial capital.

Additionally, in order to understand the attitudes and practice of the households regarding management, operation and maintenance of biogas plants, the number of years of owning biogas digester was also considered for choosing the respondents. List of the households as well as the data about the age of biogas plants were obtained from local People Committee Administration Offices.

Questionnaires were used for the household survey during August 2012. The total number of collected questionnaires was 143, while 61 were from rural areas (communes Phong An, Phong Son and Phong Xuan) and 82 from peri-urban (communes Thuong Toan, Huong An and Phuong Huong Xuan) areas.

Tab 5 Spatial distribution of questionnaires

Commune	District	Distance from Hue City	Classification	Number of questionnaires
Phong Sơn	Phong Điền	24 km	rural	17
Phong Xuân	Phong Điền	30 km	rural	24
Phong An	Phong Điền	18 km	rural	20
Hương Toàn	Huong Tra	5 km	peri-urban	31
Hương Xuân	Huong Tra	7 km	peri-urban	29
Phường Hương Xuân	Huong Tra	9 km	peri-urban	22

Questionnaires were designed according to previous studies focused on similar issues (see e.g. Xiaohua *et al*., 2005; Gwavuya *et al*, 2012) and were based on the experience of the authors. Household heads were invited to one room and they filled in the questionnaires with the assistance of our trained personnel, recruited from local Hue University of Agriculture and Forestry (HUAF) and Agriculture, Forestry and Fishery Extension Centre (AFFEC). The questionnaires contained 31 questions covering demographical data, farm resources and activities, household income and expenditures, supply and demand for energy, biogas plant utilization, benefits and problems connected with biogas energy, and, overall self-evaluation of the biogas technology usage.

List of questions from the questionnaire:

1. Personal information

SQ: Gender, age, school attendance, association membership, economic group

2. Household members

SQ: gender, age, occupation

3. Farm structure
4. Number and kind of livestock
5. Events and problems during the year (MCQ)
6. Cash income from diverse activities (MCQ)
7. Cash expenditures on diverse activities (MCQ)
8. Proportion of food bought on market
9. Expenditure on different kinds of energy
10. Firewood used before biogas plant implementation
11. Firewood used after biogas plant implementation
12. Time spent on firewood collection
13. Source of firewood (MCQ)
14. Technical information about biogas plant

SQ: size of BP, year of implementation, use of biogas energy (MCQ), toilet attachment

15. First information about biogas provided by (MCQ)
16. Reasons for purchasing biogas plant (MCQ)
17. Number of people and days for building biogas plant
18. Wage for workers who built biogas plant
19. Necessity of loan for BP
20. Attendance on training for BP maintenance and operation
21. Understanding of instructions for BP maintenance
22. Information about their BP maintenance

SQ: number of times digestate was removed, treatment of digestate (MCQ)

23. Plans about usage of digestate in future (MCQ)

24. Expenses related to biogas production
25. Problem with BP operation or maintenance
26. Problems with gas cooker
27. Changes in household after BP implementation (MCQ)
28. Use of digestate as fertilizer on different plants (MCQ)
29. Extra time spent on various activities (MCQ)
30. Satisfaction with biogas for cooking and lightening
31. Recommendation of biogas technology without subsidies

Questions marked as MCQ are multiple choice questions, SQ stands for sub-question.

4.3 Data analysis

Questionnaires were translated back from Vietnamese to English and obtained data were transferred to MS Office Excel and consequently processed via statistical software Gretl 1.7.1 and MS Excel 2010 and analysed with statistical techniques such as regression model and t-test. Most of the results are based on 143 questionnaires, the exact number of questionnaires used for particular calculation is written in the results.

In order to make certain calculations more precise, respondents were divided into different groups considering:

- Location of farms

    Rural

    Peri-urban

- The household monthly income per capita

  Poor households (less than 400 thousand VND)

  Semi-poor (400-520 thousand VND)

  Better off (more than 520 thousand VND)

- The age of the biogas plant

  Biogas plant implemented between the years 1997-2006 (six and more years old)

  Biogas plant implemented between the years 2007-2009 (three to five years old)

  Biogas plant implemented between the years 2010-2012 (less than three years old)

Tab 6 Number of questionnaires in the subgroups

	Subgroups	Number of questionnaires
The farm location	Rural	61
	Peri-urban	82
The household income	Poor	8
	Semi-poor	25
	Better offs	108
Age of the biogas plant	6 years and more	31
	3-5 years	27
	Less than 3 years	84

Tab 7 Evaluation of economic, social and environmental aspects

Indicator	Justification	Question number	Description
Economic parameters			
NPV	Ghimire (2007), Gwavuya *et al*. (2012)	1; 7; 9; 10; 11; 12; 24	Net present value
IRR	Ghimire (2007), Gwavuya *et al*. (2012), Feng *et al* (2009)	1; 7; 9; 10; 11; 12; 24	Internal rate of return
Shadow price of economic sources	Gwavuya *et al* (2012), Kanawaga and Nakata (2007)	1; 9; 22	Formula by Kanawaga and Nakata (2007)
Opportunity cost of labour	Gwavuya *et al*. (2012)	1; 22	Daily cash income
Social parameters			
Health impact	Katuwal and Bohara (2009)	27	Perception of disease occurrence (% of respondents)
Hygiene conditions	Katuwal and Bohara (2009)	27	Perception of smoke and odour reduction (% of respondents)
Reduction of workload	Katuwal and Bohara (2009)	10; 11; 12; 27	Time spent on wood collection and preparation (hours)
Environmental parameters			
Reduction of firewood usage	Feng *et al* (2009)	10; 11	Reduction of firewood per month
Reduction of greenhouse gases	Yu *et al* (2008), Cornejo and Wilkie (2010), Habermehl (2007)	9	Estimation based on the amount of produced biogas

4.3.1 Economic evaluation

Cost-benefit analysis

For economic evaluation, net present value (NPV) and internal rate of return (IRR) were calculated. Lifespan for biogas plant was 10, 15 and 20 years, which reflects both topic-related articles (see e.g. Teune, 2007; Feng *et al*., 2009; Singh and Sooch, 2004) and expectations of biogas plants implementers. Additionally, NPV and IRR models were calculated firstly on the basis of data from implementer's studies and related articles including von Eije (2007) and Cuong (2005), and secondly with the usage of data from this survey only. As one of the indirect economic benefits of using biogas plant is saved time which can be used for income generating activities, two additional calculations of NPV and IRR were done with the assumption that this time will be used for income generating activities with the same salary per hour as the average monthly salary.

Discount rate was in the calculation represented by three different figures (12%; 8%; 4%).

Shadow price of energy sources

According to the work of Gwavuya *et al*. (2012) and Kanagawa and Nakata (2007), the price of an energy source that is not purchased on market and therefore cannot be expressed in the cost of use, can be determined by the time spent on collection of source by following formula.

$$OCE_i = \frac{OCL}{DE_i} \times T_i$$

Where OCE is the shadow price per unit of energy (1,000 VND per MJ), OCL are the opportunity costs of labour (1,000 VND per hour), DE is the energy (MJ per year) and T is the time spent (hours per year) for collection (Gwavuya *et al*, 2012).

In this study, shadow price was determined for biogas energy, therefore the time for energy source collection was replaced by time for biogas plant maintenance including filling biogas plant with bio-slurry.

Opportunity cost of labour

Opportunity cost of labour is calculated on the basis of data from questionnaires. It equals to the average cash income per hour multiplied by the time that is dedicated to biogas plant maintenance and operation per day.

4.3.2 Social evaluation

The society gains several benefits as a result of biogas technology implementation. Social aspects such as health impact and hygiene conditions were assessed on the basis of farmer's perception and divided into groups used in other studies (Katuwal and Bohara, 2009; Thu *et al.*, 2012). In the table 8 different social aspects are shown.

The reduction of workload was calculated on the basis of reduced time spent on firewood collection and preparation and considering extra time dedicated to biogas plant maintenance.

Tab 8 Evaluation of social aspects

Social aspect		Perception
Hygiene conditions	Smoke in house	Less/the same/more
	Cleaner environment	Less/the same/more
	Insect occurrence	Less/the same/more
Health impact	Illnesses from smoke	Less/the same/more
	Illnesses from insect	Less/the same/more
	Digestive problems	Less/the same/more

4.3.3 Environmental evaluation

Excessive usage of firewood is causing pressure on the environment in terms of deforestation and subsequent soil erosion. Moreover, when firewood is being burnt, greenhouse gases such as carbon dioxide are arising (Gwavuya, 2012). Reduction of firewood was calculated on the basis of question n. 10, firewood used before the biogas plant implementation and question n. 11, firewood used now. The unit of measurement is one bundle that is approximately 13 kg.

Climate change is caused by greenhouse gases including CO_2, N_2O and CH_4. As a result of effective biogas digester performance, all three gases should be reduced. Due to the fact that methane is the most significant GHG produced by livestock and its warming potential is 21 times higher than CO_2, determination of this particular gas was done together with calculation of carbon dioxide which is strongly connected to firewood burning (Lam and ter Heegde, 2012). Reduction of GHGs was calculated on the basis of data in the study by Cornejo and Wilkie (2010), describing CH_4 content in livestock manure. Estimation of reduction of CO_2 emissions was done according to data by Habermehl (2007) calculating CO_2 emissions from certain amount of burned firewood.

5. Results

5.1 Demographic data and livelihood strategies

The research reveals that a typical household in the study area has five members out of whom two works on the farm. Average age of household members is 31.9 (± 8.4) years. Household head is on average 48 years old man, with the level of school completion equal to 8 out of 12 years, earning 1,363 thousand VND per month and is member of farmer association (76% of respondents). The number of years spent at school has a statistically significant impact ($p=0.004$; $n=143$) on monthly salary while the age of household head does not. Monthly salary is negatively correlated with the average age of family members ($p=0.026$, $n=106$). Average farm size is equal to 0.53 ha (± 0.6), while majority of land is devoted to rice (*Oryza sativa*), and annual crops that are used particularly for self-consumption (fig 5).

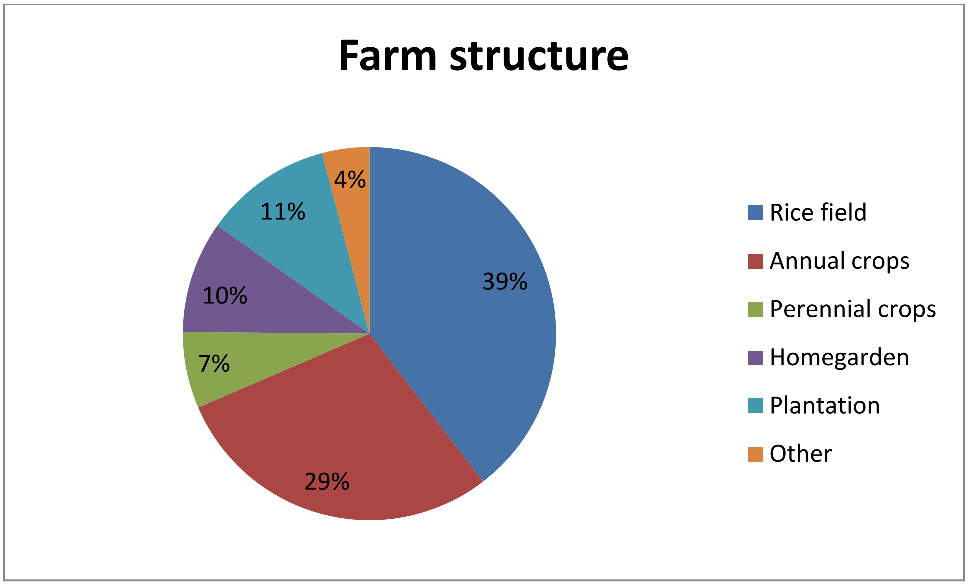

Fig 5 Farm structure (n=143)

In terms of livestock, average household owns 10 pigs, 3 sows and 40 heads of poultry. The figure 6 shows the distribution of livestock owned by 143 farmers in the study area expressed in tropical livestock units (TLU).

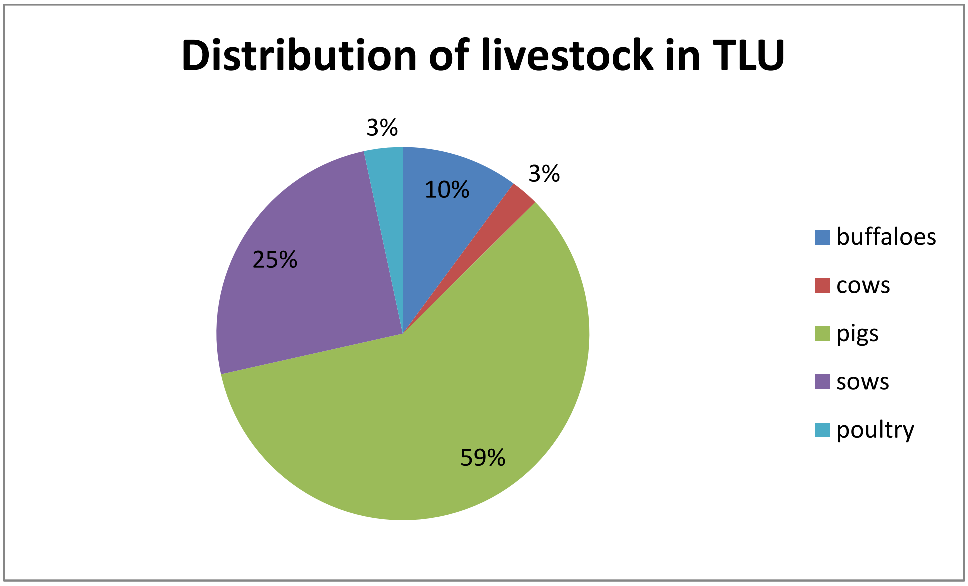

Fig 6 Distribution of livestock in TLU (n=143)

Target households can be described by subsistence and market oriented farming system with very low interaction with market. Most of the households (42%) purchase 10-50% of food on the market, relatively high proportion of households (26%) buys even less than 10% of food on market (fig 7). No statistically significant relationship between the percentage of food bought on market and size of homegarden, number of pigs or number of heads of poultry was found.

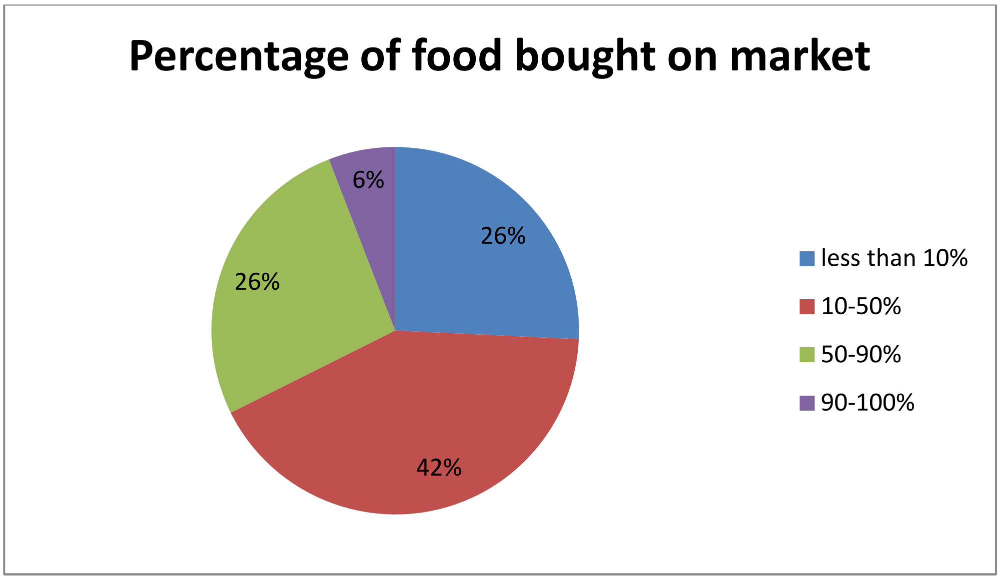

Fig 7 Percentage of food bought on market (n=143)

5.2 Characteristics of biogas utilization in the study area

Figure 8 identifies from which source most of the farmers from the study area gained the initial information about biogas technology. Farmers learned about biogas mainly from the local government or administrative representative (39%), followed by non-Vietnamese development worker (15%) and mass media (14%).

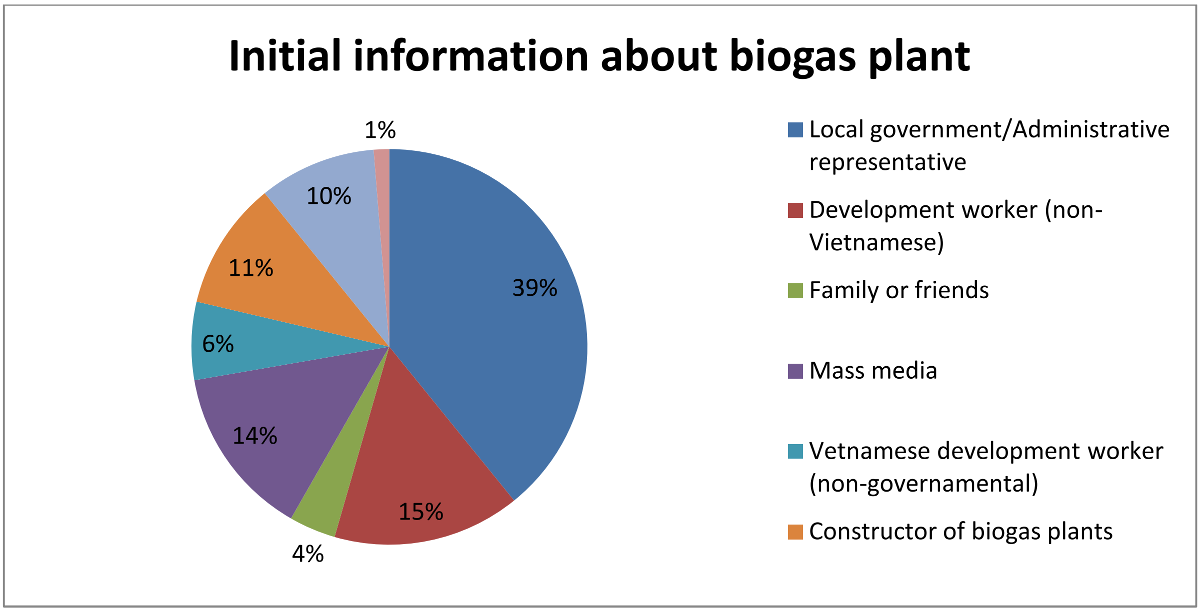

Fig 8 Initial information about biogas plant (n=142)

The principal reasons for purchasing biogas plant were cleaner environment (29%) and saving of energy costs (28%).

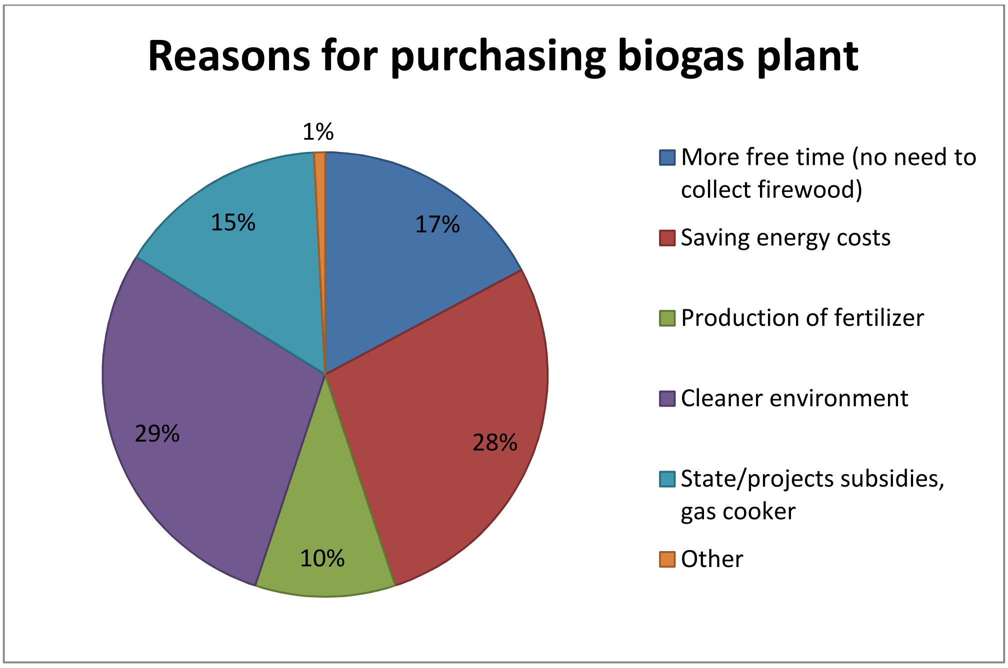

Fig 9 Reasons for purchasing biogas plant (n=126)

In the study area the biogas digesters were built between the years 1997 and 2012 with the average size of 7 m^3. Biogas energy is used principally for cooking for people (49%) and cooking for animals (39%), in a smaller scope for lighting (12%).

According to the survey, 66% of farmers were trained for biogas plants maintenance and 52% totally understand instructions for the maintenance and operation, 43% understand partially and 2% not at all.

Overall satisfaction with biogas technology for cooking is mostly positive, 110 respondents were very satisfied, 15 somewhat satisfied. Out of the 15 respondents who were either somewhat dissatisfied or very dissatisfied, 93% experienced problems with biogas plant operation or cooker or had additional expenses related to biogas plant maintenance.

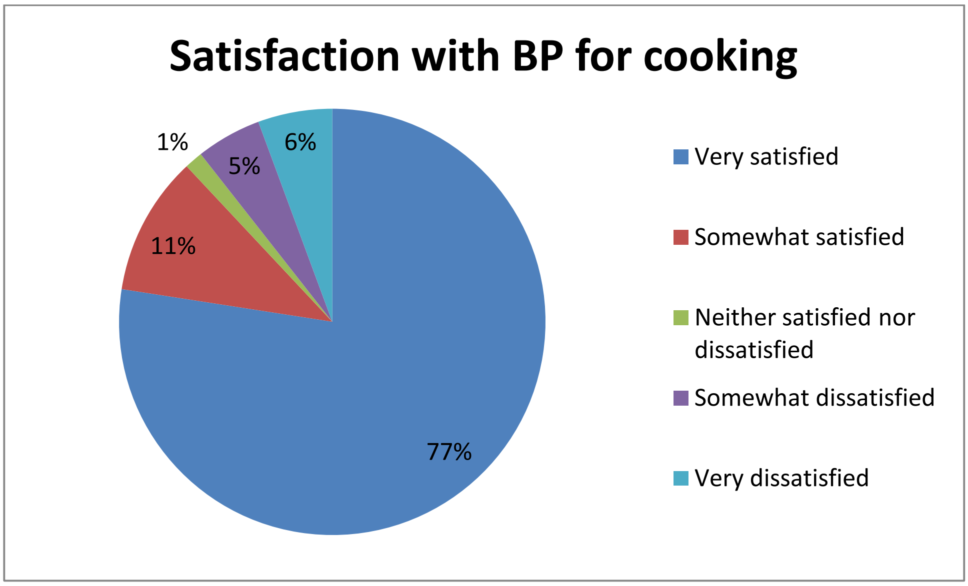

Fig 10 Satisfaction with biogas technology for cooking (n=142)

On the question regarding recommendation of biogas technology even without subsidies, majority of the farmers (76%) answered that they would definitely recommend it.

Respondents had also an opportunity to comment on project and biogas technology. Figure 11 displays farmer's comments and recommendations to future project. 21 respondents are very satisfied and hope that biogas technology will be available for more households. Three of them suggested other way of biogas usage – for providing hot water in the bathroom, nine heads of household would appreciate more equipment provided by project, mainly gas cooker. 14 respondents described their problem with biogas plant including no or few biogas and increased incidence of mosquitoes. Two farmers recommended building biogas technology in dry season and five would like to receive project support for removing digestate from their digester.

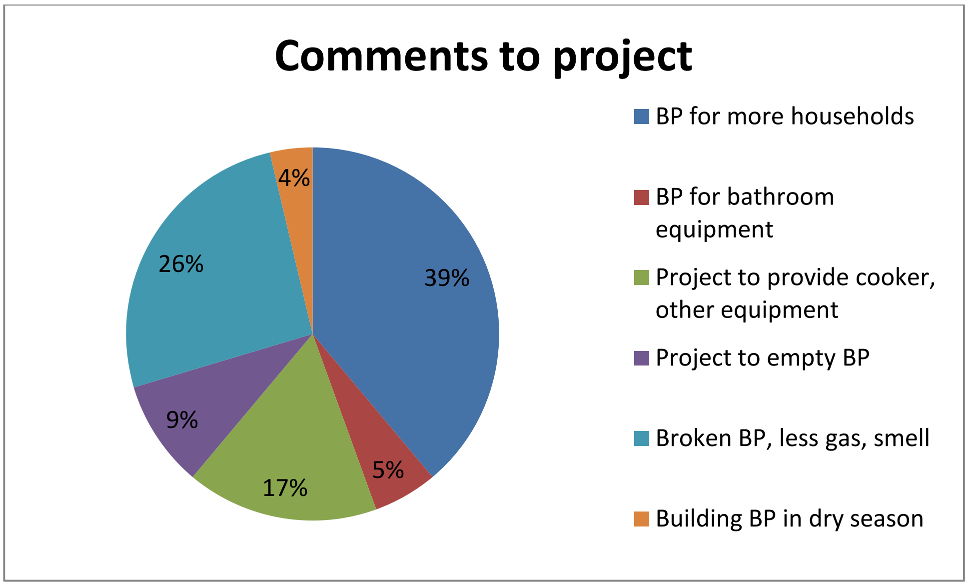

Fig 11 Farmer's comments and recommendations (n=54)

5.3 Benefits from biogas utilization at household perspective

5.3.1 Economic benefits

Cost savings

Traditional energy sources in the study area are firewood, electricity, LPG and charcoal. According to the results, there was a distinctive decline (56%) in the use of firewood after the biogas plants implementation, based on the expenditure figures. Smaller decrease in the use of electricity, LPG and charcoal (24%; 38%; 34% respectively) was detected. In total, farmers saved 29,895,000 VND per month for firewood; 7,715,000 VND per month for electricity and 3,623,000 VND per month for LGP. Figure 12 indicates differences in expenditures for energy sources in total of all respondents.

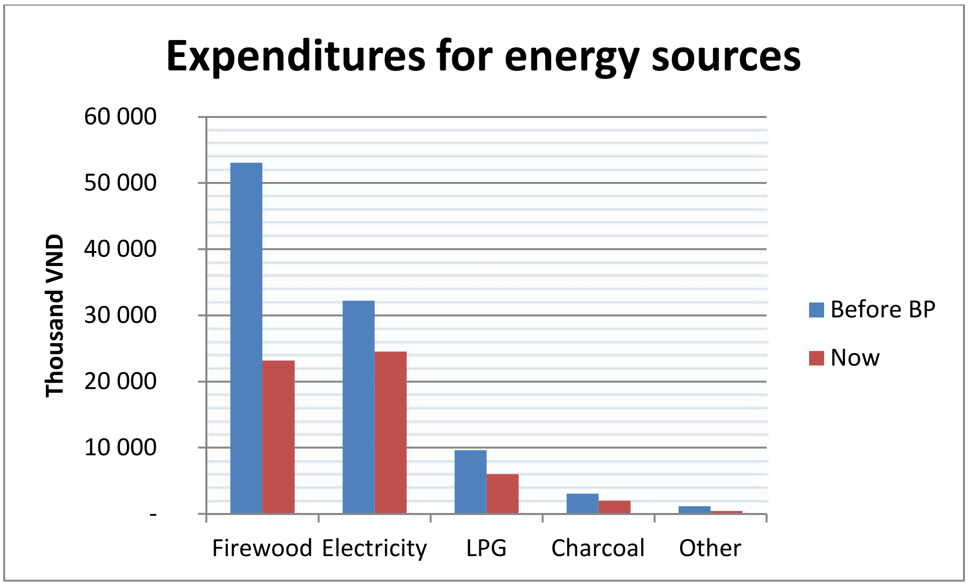

Fig 12 Differences in monthly expenditures for energy sources before and after biogas plants implementation

(thousands VND, n=135)

Respondents stated that the average time that they saved on firewood collection and preparation is 2.5 hours per day while the time used for daily maintenance of biogas plant is in average 0.5 hours per day. In the case that saved time would be spent on income generating activities with the same salary per hour as the average monthly salary, farmers would earn extra 4080 thousand VND per household and year.

Cost-benefit analysis

For the calculation of cost-benefit analysis two models were designed. Firstly, NPV and IRR were estimated using data from related articles and secondly, NPV and IRR were calculated on the basis of data from our questionnaires.

I. Estimation of NPV and IRR using data from related articles. Table 9 displays NPV and IRR calculated only with direct benefits, table 10 shows the same parameters including direct and indirect benefits.

Tab 9 Cost-benefit analysis of biogas plants performance in Vietnam (thousands VND)

Lifespan (years)	Internal rate of return	Net present value Discount rate		
		12%	8%	4%
10	30.9%	9869.5	13961.1	19422.6
15	32.9%	14618.8	21528.8	31729.2
30	33.3%	17313.9	26679.4	41844.5

Tab 10 Cost-benefit analysis of biogas plants performance in Vietnam (thousands VND)

Lifespan (years)	Internal rate of return	Net present value Discount rate		
		12%	8%	4%
10	78.1%	35917.0	44894.6	56813.8
15	78.3%	46016.9	60988.0	82985.0
20	78.4%	51748.0	71941.0	104495.9

II. Calculation of IRR and NPV on the basis of data from this survey. Figures in table 11 are calculated with only one direct benefit, saved costs for other energy sources. Saved costs for fertilizer were not taken into account due to contradictory answers: 48% of the respondents saved money on fertilizer after adoption of biogas digester however 41% spent less money on fertilizer before BP implementation. Table 12 reveals IRR and NPV values if direct and indirect benefits are included.

Tab 11 Cost-benefit analysis of biogas plants performance in the study area (thousands VND)

Lifespan (years)	Internal rate of return	Net present value Discount rate 12%	8%	4%
10	40.5%	11130.0	14566.6	19012.6
15	42.2%	15993.0	22038.7	30713.6
20	42.4%	18752.4	27124.1	40331.1

Tab 12 Cost-benefit analysis of biogas plants performance in the study area (thousands VND)

Lifespan (years)	Internal rate of return	Net present value Discount rate 12%	8%	4%
10	88.5%	32869.2	40053.9	49348.7
15	88.8%	43035.9	55675.2	73811.2
20	88.8%	48804.7	66306.7	93917.5

Shadow prices of energy sources

The shadow price of biogas represents 1,537 VND per MJ, which is considerably lower in comparison to average price of electric energy (5,400 VND per MJ). Thus, replacing electrical energy with biogas leads to a 71% saving in annual household expenses.

Opportunity cost of labour

Based on the results, the time spent per day on biogas plant maintenance is 0.5 hours per household. Considering the average salary per hour, the opportunity cost of labour is 85,000 VND per month and household. However, it was proved that the time used on firewood collection and preparation decreased by 2.5 hours per day, therefore a household gains 340,000 VND per month by decreasing the opportunity cost of labour for firewood processing.

5.3.2 Social benefits

Hygiene conditions

According to data from questionnaires, 90% of the respondents claimed that after biogas plant installation there is less smoke in their house, 5% stated that the amount of smoke has not changed and 5% that there is more smoke than before. However, out of the last group 86% of respondents had the biogas plant for two years or less and expected that there will be less smoke in the future and 14% had problems with biogas plant operation.

Other results reveal that 75% of the farmers in the study area confirmed that environment is cleaner after biogas plant installation, for 2% the environment did not change and 23% considered the environment as clean as before. According to 81% of the respondents, the occurrence of insect and mosquito decreased after biogas plant implementation.

Health impact

Majority of the respondents claimed that their family is healthier after the biogas plant implementation. Reduction of illnesses caused by smoke experienced 81% of the households, 82% of the respondents stated that there is lower occurrence of illnesses caused by insects and less digestive problems were noticed by 80% of the respondents (fig 13).

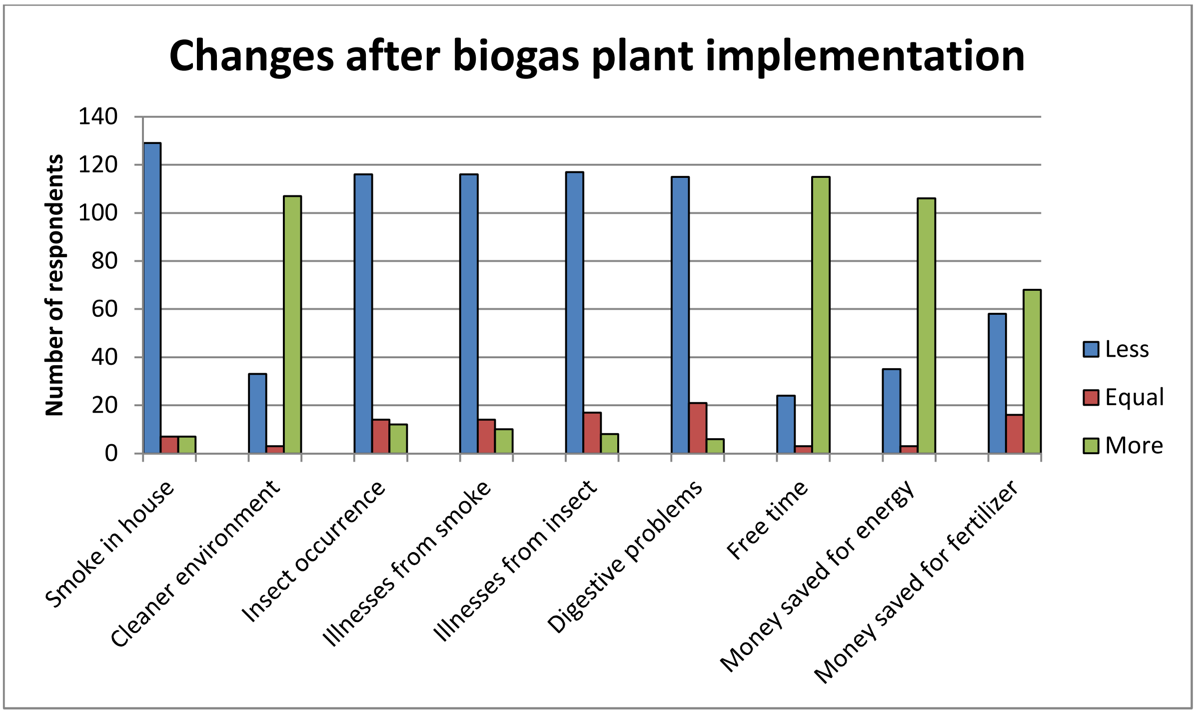

Fig 13 Changes after biogas plant implementation (n=143)

Reduction of workload

Based on the data from questionnaires, 80% of farmers stated that using of biogas technology gave them more free time. In average, farmers saved 2.5 hours per day and household as a result of reduced consumption of firewood energy and thus decrease in time demanding activities such as collection and preparation of wood and soot cleaning. Average household spend 0.5 hours per day on biogas reactor maintenance. As a result of saving two extra hours daily per household, farmers can dedicate their time to other activities. Figure 15 describes different kinds of activities and demonstrates how many farmers dedicate the additional time to each one.

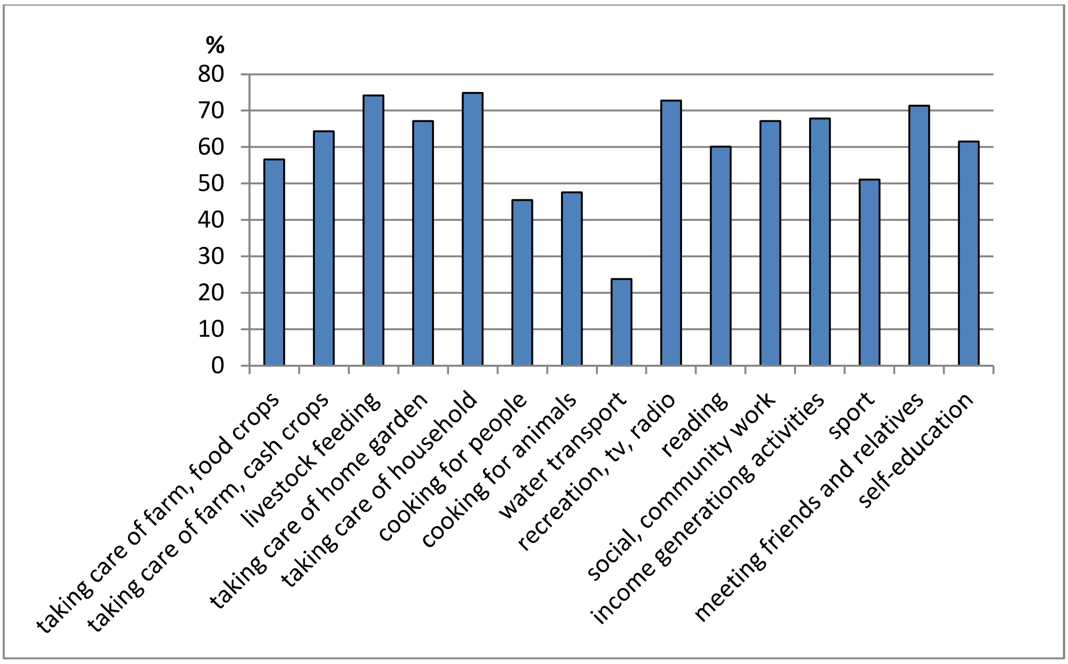

Fig 14 Extra time dedicated to certain activities (n=135)

5.3.3 Environmental benefits

Reduction in firewood usage

Firewood is the most common traditional source of energy in the surveyed communes. According to this study, the main source of firewood in the study area is collection (68%), followed by purchase on market (19%) and by external supplier (13%). Due to biogas technology adoption, the decline in the use of firewood in terms of quantity was registered. The average amount of wood used for cooking before the biogas plant implementation was 35 bundles per household and month, now it is 15 bundles per household and month. This difference is statistically significant (p=0.002; n=137).

GHG reduction

Due to the reduction in firewood burning the total amount of CO_2 emissions that are not released into the environment is 669.24 tonnes per year.

As a result of effective manure management, amount of methane that equals to 68.87 tonnes of CO_2-eq was captured in digester. In the table 13 a detailed description of captured methane from livestock manure is provided.

Tab 13 Methane captured in biogas plants

Animal	Number of heads	Tonnes of CO_2-eq (year)	Tonnes of methane (year)
Buffaloes	52	2.188	0.104
Cows	25	0.526	0.025
Pigs and sows	2,143	62.524	2.98
Poultry	5,766	3.63	0.171
Total		**68.868**	**3.28**

5.4 Households comparison regarding to biogas plants management

This study describes certain differences between social and economic groups of farmers. Several events and issues occurring to farmers were compared with an emphasis on farms location – rural or peri-urban area. Statistically significant differences were observed among focused households at peri-urban/rural level in livelihood strategies and in ensuring of need-supply balance. Rural households suffer more from lack of food and water supplies (p=0.021, p=0.008 respectively; $n_{peri\text{-}urban}$=82; n_{rural}=59) and water quality (p=0.000; $n_{peri\text{-}urban}$=82; n_{rural}=59). On the other hand, peri-urban households perceive more odour from animals during the year compare to rural households (p=0.002; $n_{peri\text{-}urban}$=82; n_{rural}=59). As displayed in figure 15, results also show higher market orientation and livelihood diversification among rural households (p=0.027, p=0.089 respectively; $n_{peri-urban}$=82; n_{rural}=59).

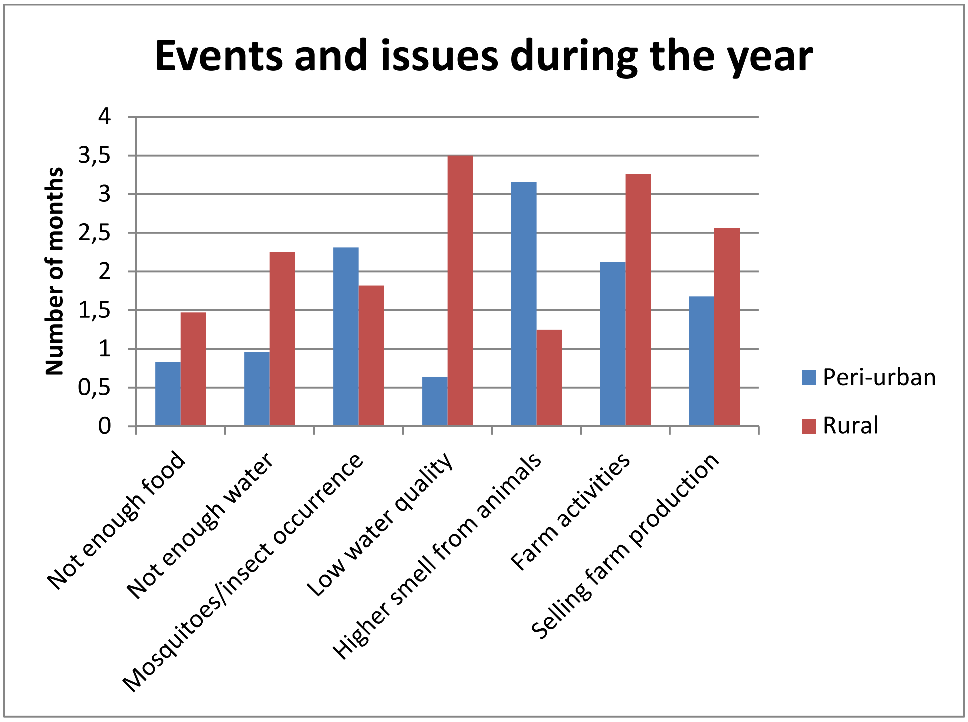

Fig 15 Self-perception of main issues during the year in the peri-urban and rural areas ($n_{peri-urban}$=82; n_{rural}=59)

The research reveals statistically significant difference in acquiring firewood between farmers from rural and peri-urban areas. In peri-urban areas, 50% of firewood is collected in the forest, 33% is bought on the market and 17 % is gained by external supplier. In rural areas, the breakdown of the acquisition of firewood is 85% from collection in the forest, 6% from the market and 9% from external supplier. There is a statistical significant difference (p=0.002) between the share of collected firewood in peri-urban and rural areas ($n_{peri-urban}$=61; n_{rural}=54). Differences in acquiring firewood are also among income groups. However, even though there was a strong reduction in firewood usage due to biogas technology adoption, no significant difference in the reduction of firewood between households from rural or peri-urban areas was found.

Poor households spend on average 0.5 hours per day on firewood collection preparation, semi-poor and the better off households spend 1 hour. There is no statistically significant difference in time needed for firewood preparation between households from peri-urban or rural areas.

Poor households buy 53% of firewood on market and collect 47% in plantation, semi-poor collect 83% of firewood in the plantation and the better offs gain 64% of firewood from collection. There is a strong negative correlation between years of school completion and percentage of collected firewood ($p=0.0291$; $n=143$).

According to division on poor, semi-poor and better off households, poor households decided for biogas plant principally because of savings of energy costs and cleaner environment (both 100%), among semi-poor households prevails benefit of savings of energy costs (72%) over cleaner environment (60%) however better off households consider cleaner environment as the most significant reason (72%) over savings (69%).

Based on the three income subgroups the survey reveals that the poor households have the highest ratio of use of biogas energy for lighting (25%), but on the other hand relatively low ratio of use of biogas energy for cooking for people and animals (both 63%). On the other hand the social group with the highest salary use biogas mainly for cooking for people (82%) and in smaller scale for lighting (20%).

Only 25% of poor households have their toilet attached to biogas plant. In comparison, 32% of semi-poor households and 56% of the better offs have their toilet attached to biogas plant.

A connection between the age of biogas plant and familiarity of its owner with maintenance and operation instructions was found. Out of the group of farmers that have a biogas plant for six and more years 48% understood the instructions totally and 48% partially, owners of biogas technology for three to five years understood instructions totally from 52% and partially from 44% and among the owners of the newest biogas plants 54% understood instructions totally and 42% partially.

The owners of the newest biogas plants have predominantly no expenses related to biogas production (91%), no problems with biogas cooker (92%). However, 21% of them have experienced problems related to biogas plant operation or maintenance. As it is displayed in the figure 16, majority of these respondents have not removed digestate from their plants yet.

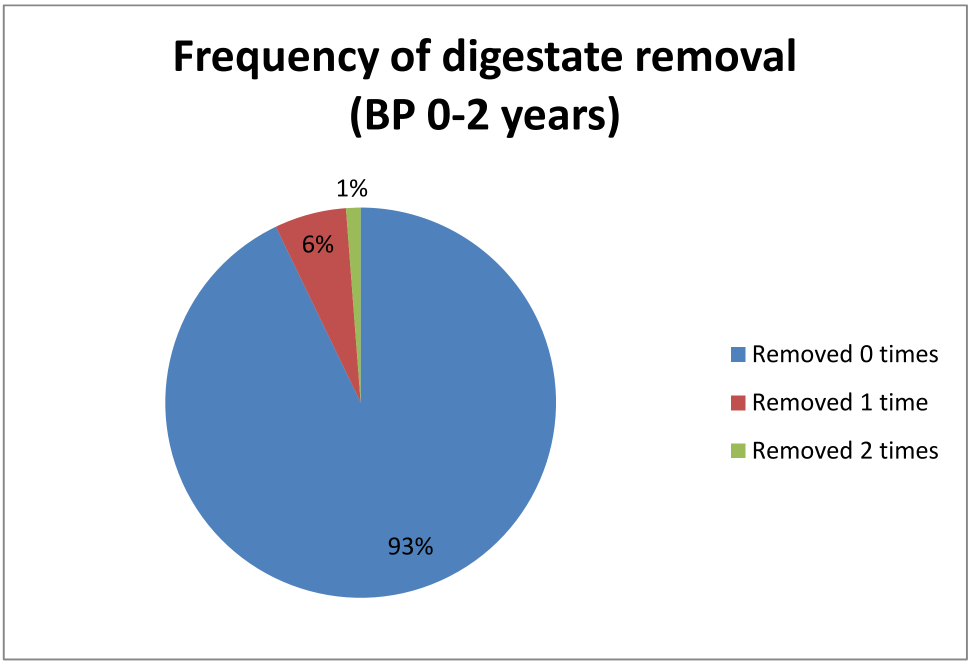

Fig 16 Frequency of digestate removal (BP is not older than 2 years; n=84)

Majority of the farmers whose biogas plants were implemented three to five years prior to the survey had no expenses related to biogas production (81%) but one third of them experienced problems with biogas plant operation and 22% with biogas cooker. The frequency of removal of digestate is illustrated in the figure 17.

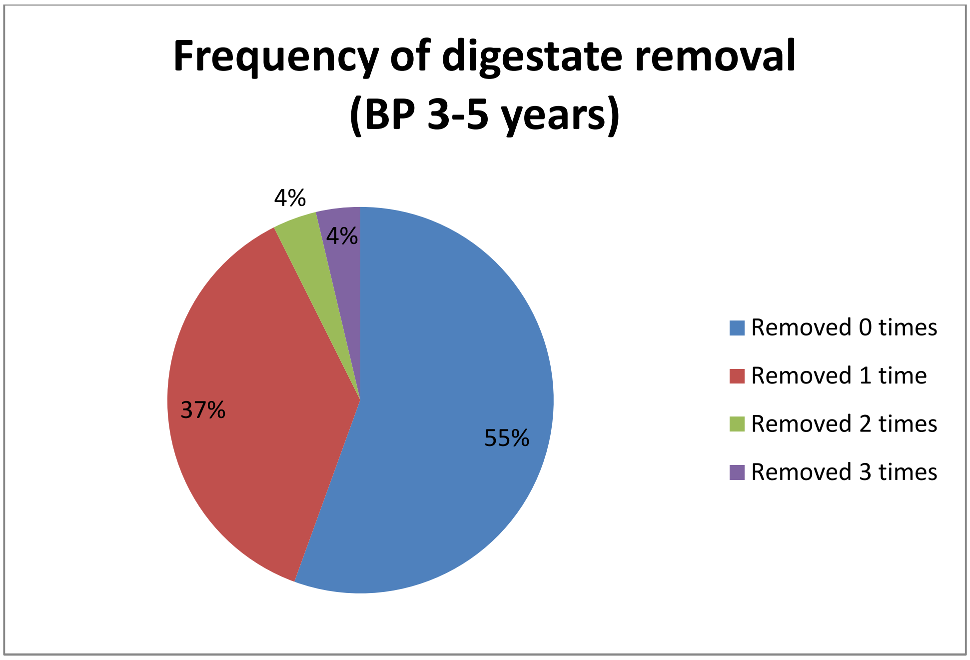

Fig 17 Frequency of digestate removal (BP is three to five years old; n=37)

Majority of the owners of the biogas plants for six and more years have experienced problems with biogas cooker (58%), however, lower number of respondents had problems with biogas plant maintenance or operation (33%). Expenses related to digester performance had 33% of respondents and more than half of them have not removed digestate from their biogas plant yet, on the other hand, 4% or farmers carried out the removal of digestate five times (fig 18).

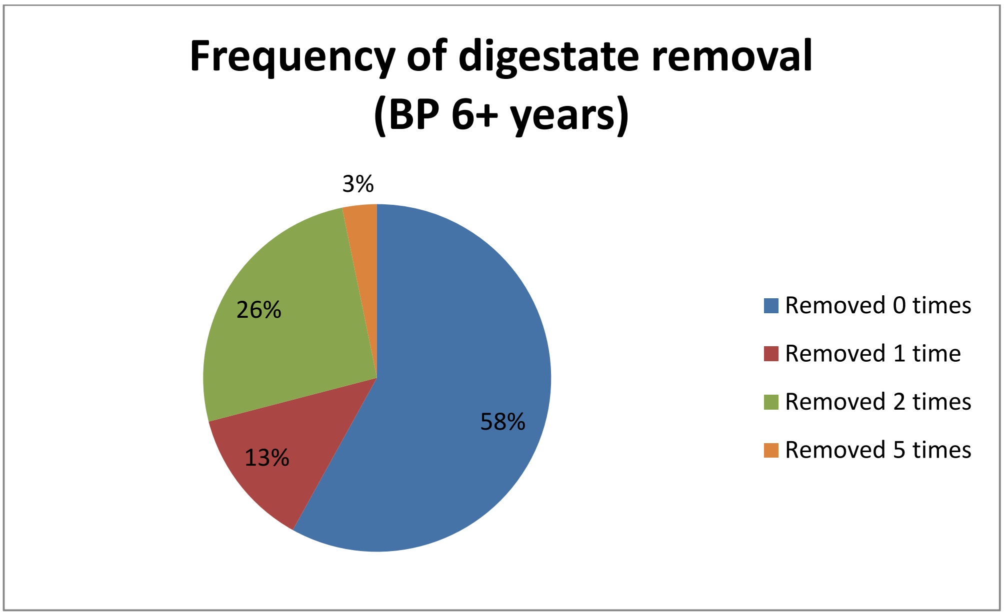

Fig 18 Frequency of digestate removal (BP is six or more years old; n=31)

In total, 30 respondents stated that they removed digestate from their biogas plant at least once and 97% of these used at least some part of the digestate as fertilizer. Other way of digestate treatment was discharging, most often in the garden, bag but also into the river (1%).

In the future, respondents from both rural and peri-urban areas planned to use digestate principally as fertilizer (82%; 93% respectively) or discharge it in the garden (8%; 7% respectively). Farmers from rural areas also considered giving the digestate to others (5%).

Expenses related to biogas production are distinctive in the rural areas where 20% of the respondents had some expenses, mostly related to usage of water and emptying of the biogas plant. On the other hand, in peri-urban areas 11% of farmers spent extra money on biogas production, mostly because of repairs.

In rural areas, 33% of respondents experienced certain problems with biogas plant operation or maintenance, most of them stated that their biogas plant produce less or no biogas, other problem was connected to leakage of biogas. 18% of the farmers from peri-urban areas had problems mainly with less or no gas and slow process. No difference between respondents from rural or peri-urban areas was discovered in relation to problems with biogas cookers.

6. Discussion

Our survey reveals that biogas technology is economically profitable for most of the interviewed households and it is beneficial also from the social point of view. However, some of the benefits which are expected to go along with the usage of biogas are questionable.

6.1 Comparison with other published studies

According to results of this study, economic benefits were together with cleaner environment principal reasons for biogas plants implementation. Even though our respondents saved in total more than a half of the expenditures for other energy sources as a result of using biogas, not everybody found this technology so profitable. 35 respondents stated that they spend more money for other energy sources after the biogas plant implementation than before. This issue can be explained by problems with plant operation or gas cooker (49%) causing little or no production of biogas and by extra expenses connected to biogas plant maintenance (37%). Problems related to biogas cooker are mentioned also in the work of Thu *et al*. (2012). According to our survey respondents who experienced problems with the cooker are principally those who have biogas plant for six and more years. The main gas cooker problem described by Thu *et al*. (2012) was corrosion, 5% of our respondents have the same problem and they are forced to purchase new cooker every two or three years. In order to avoid corrosion, a filter which absorbs H_2S in the biogas should be used before using gas for cooking (Thu *et al*., 2012).

The work by Vinh (2010) considers digestate as a cheap source of nutrients for plants and thus allows farmers to save money on fertilizers. According to Katuwal and Bohara (2009) almost all households in Nepal apply bio-slurry on their fields as fertilizer. However, both our results and study by Cuong (2005), reveal that slurry is not being widely used to increase soil fertility or plant growth. According to Thu *et al*. (2012), some Vietnamese farmers used fermented manure as a fertilizer but more than 50% of them discharged digestate into the environment. One of the reasons for refusing bio-slurry as a fertilizer can be the fact that the exact benefit of using digestate on field is not certain due to low pH in the digester caused by the loss of ammonia in the effluent (Morup, 2012). In spite of this argument, studies show increase in crop yields up to 30% after applying bio-slurry on the fields (Sharma and Pellizzi, 1991; Kossmann, 1997).

According to data from the questionnaires, 58 respondents out of 143 claimed that they spend more money on fertilizer after the biogas plant implementation than before. This can be possibly explained by the usage of animal waste as a substrate for biogas plants and not as a fertilizer, so in the period when fermented bio-slurry is not available fertilizer has to be purchased on the market. However, according to Dung (2011), only 20% of the farmers use pig manure directly as fertilizer. The other reason can be a failure in the effective biogas plant maintenance. 5% of the respondents stated that their additional expenses are related to removal of digestate from biogas plant because they use a paid service provided by fertilizer producing companies that provide removal and disposal of digestate. This service costs between 500,000 and 600,000 VND and farmers have no use of the fermented bio-slurry because the fertilizer producing company takes it away. However, regular removal of digestate is important in order to ensure a balanced performance of biogas plant. According to some respondents their biogas plant produces lower or no amount of biogas because the digester is too full. Problems with removal of digestate was demonstrated also in the part of the questionnaire dedicated to farmer's comments, 9% of them suggested that the project could help them with taking the fermented bio-slurry away from the biogas digester.

From the economic point of view, projects are assumed to be feasible if the net present value is positive and internal rate of return is at least 20% and the payback period is equal to seven years or less (OECD, 2012). Taking this into account, biogas plants that were implemented in the Thua Thien – Hue are economically feasible because the NPV is positive and IRR is at least 40.5%, depending on the lifespan. In the case that also indirect benefits are going to be taken into account, IRR equals to 89%. However, the main indirect benefit used in the previous calculation, saved time for collection and preparation of firewood, is considered to be spent on income generating activity with the same salary per hour as is the average household salary. Not all the farmers spend this extra time on income generating activities, though.

Cleaner environment is closely linked to the biogas technology utilization (Teune, 2007; Chang, 2011) due to more effective manure management and it was one of the main reasons for purchasing biogas plants in the study area. Three quarters of the respondents are indeed satisfied and consider their environment cleaner than before the implementation of the biogas technology. However, 23% of the farmers think their environment is less clean than before, in particular due to higher odour perception from biogas tank. This problem involves primarily households with technical problems related to biogas plants, because biogas is odour-free in normal conditions (PSE, 2013).

Together with other researches on similar issue (see e.g. Bajgain and Shakya, 2005), this study confirms a rapid decrease in smoke pollution and smoke related diseases such as respiratory problems and eye infections due to increased usage of clean energy. However, most of the households still use firewood in a limited amount as a source of energy for cooking. Farmers probably do not want to give up the firewood energy in the case that they would have problems with biogas plant operation or cooker.

Together with other studies (see e.g. Omer and Fadalla, 2003; Yu *et al*, 2008) our research prove a significant decrease in firewood consumption as it was replaced by biogas energy. Limited use of firewood has a positive impact on environment including deceleration of the global warming due to reduction of CO_2 and CH_4 emissions and a decrease in deforestation (Weiland, 2009).

In the study made by Karki (2006) based on farmer's perceptions it is arguable whether a biogas plant does decrease or increase mosquito breeding and occurrence around the farm. According to this study, most of the respondents (81%) perceive lower insect occurrence after biogas plant implementation connected to decrease in number of diseases caused by insects. However, 8% of the farmers believe that insect occurrence is higher mainly due to biogas plant, because stagnant water that is leaking from digester is favourable to mosquito breeding.

Problems connected to biogas plant operation, such as less or no gas, are mostly caused by broken components of digester or pipes and according to some farmers also because of full digester. Due to the fact that only 52% of the respondents understand totally instructions for biogas operation, most of the problems can be caused by mistakes during maintenance of digester. Insufficient maintenance of biogas digesters was registered also by other authors, according to Chen *et al*. (2009) many biogas projects in China failed due to lack of follow up services and poor management of digesters. Therefore, a well functioning biogas plant due to proper management and maintenance is a crucial condition for sustainability of biogas technology in the study area.

This study also assessed the differences of perception of biogas technology among diverse social groups. Focusing on the income groups, an unexpected result was that only 25% of poor households have their toilet attached to biogas plant, even though they usually have only few animals so they cannot produce much biogas (Wargert, 2009). However, this research did not find significant differences in sustainability of biogas plants among different income groups, confirming the hypothesis cited in the research of Mwirigi *et al* (2009).

A significant difference was found between rural and peri-urban study areas considering the level of functionality of biogas plants. In the rural area 33% of households have problems with operation or maintenance of their plant and 20% have additional expenses related to biogas production, compared to the peri-urban area where 18% of farmers have problems with operation or maintenance and 11% have extra expenses. Since the water availability is important in biogas production in order to optimize the performance of biogas plant (Thu *et al*., 2012), the phenomenon of less effective technology in rural areas can be explained by higher shortage of water, lasting in average for 2.25 months per year. Higher profitability of biogas plants in peri-urban areas is also supported by a study by ter Heegde *et al*. (2007) from Senegal, where the internal rate of return of biogas plants in peri urban areas was over 50% and in rural areas only 29%, considering a lifespan of 10 years.

Considering the age of the biogas plant, a significant difference was found between households with a biogas plant older than six years and those whose biogas technology is less than three years old. Among the new owners, only less than 10% of households have expenses related to biogas plant operation and 8% have problems with gas cooker, in the case of households that adopted biogas technology more than six years ago, the figures are 23% and 60%, respectively. Problems with biogas reactor operation consist mainly in less or no gas therefore the fault is probably in neglected maintenance, but can be also caused by corrosion of gas cooker which needs to be replaced regularly.

Successful cooperation with local government can be beneficial a for a sustainable development project (UCLG, 2011). Biogas programme in the study area was held in cooperation with Vietnamese Ministry of Agriculture and Rural Development (Teune, 2007) and the governmental impact is also visible in the results, 39% of biogas plant owners stated that they learned the first information about biogas technology from the local government or administrative representative. Compared to Kenya where the governmental support is not that strong, only small percentage of farmers adopted biogas technology and according to study by Mwirigi *et al.* (2009), only 12% of respondents heard about biogas from a governmental officer. However, biogas dissemination in China is promoted by government, but according to Chen *et al*. (2009) development of household size digesters is focused principally on construction and neglects follow-up services and management, thus a number of biogas plants are not functioning and projects fail.

6.2 Recommendations for policy-makers and other stakeholders

Even though biogas technology caused a significant improvement in the social and economic situation of the majority of respondents, our research found several arguable issues concerning biogas plant management and operation. In order to avoid problems with lower gas production and expenses for repairs of biogas plants and new cookers, further workshops organized by biogas plant implementers or local authorities are recommended. These workshops should inform farmers about the means that are assuring the optimal performance of digesters and methods to prevent the cooker corrosion or other problems. Similar recommendation for Vietnamese stakeholders was also suggested by Thu *et al.* (2012). Furthermore, workshops and training focused on the importance of regular biogas plants maintenance and benefits of usage of digestate as fertilizer would be appropriate.

6.3 Implications/ Suggestions for further research

According to our results, there is a very limited use of bio-slurry as fertilizer in the study area, thus other studies focused on the potential use of digestate are recommended. Our data reveals that some farmers pay the fertilizer producing company for taking away digestate from their biogas plants therefore a detailed study of the fertilizer industry would be appropriate.

Based on results from this research as well as on other studies (see e.g. Feng *et al.*, 2009; Thu *et al.*, 2012), one of the principal advantages of biogas usage as well as the main reason for adoption of this technology is a cleaner environment and improved hygiene conditions. Considering the proximity of houses in neighbourhoods of the study area, there is a real possibility that also non-biogas users can benefit from biogas digesters owned by their neighbours. Therefore, a research focusing on non-biogas users and evaluating benefits of biogas implementation in the neighbourhood is recommended.

Our study reveals that 8% of the households perceive higher mosquito occurrence because of their breeding around biogas digester and inside of the plant and this speculation is also supported by other studies (see e.g. Karki, 2006). Thus, a subsequent study about mosquito occurrence on the farms with implemented biogas digester is suggested.

6.4 Limitations of the survey

During the research all the possible means assuring relevant and objective data were employed, nevertheless certain factors might have affected respondents' answers and our results.

Firstly, the research took place in a specified area including two communes in the Thua Thie – Hue province therefore our results might be different from the results of the whole province. Moreover, the research was conducted in summer at the end of the dry season, thus farmers could have more problems with biogas plants operation than in other months. Some of the respondents were also busy due to the harvest season and the religious festival that was taking place in August 2012 in the Quang Tri province, therefore they possibly did not dedicate enough time to questionnaires. Additionally, few small errors could have been caused by the language barrier such as misunderstanding in the translation of questionnaires. This research could be partly influenced also by the fact that biogas dissemination projects are driven by the Vietnamese government and the local authority usually attended the data collection process.

7. Conclusion

Biogas technology is an effective source of renewable energy that is appropriate particularly for households in rural and semi-urban areas in developing countries mainly because the input material is organic substrate and operation and maintenance of biogas plant is relatively easy (Ramachandra *et al*., 2000; Teune, 2007). However, the adoption rate of this technology varies among the countries and a detailed survey of each region is necessary in order to ensure sustainable and effective performance of biogas digesters (Sharma and Pellizzi, 1991).

Therefore, this research focused on the evaluation of socioeconomic aspects of using biogas plants in Thua Thien - Hue province in the Central Vietnam. This province has experienced large biogas dissemination in the recent years (Teune, 2007) but no survey assessing social and economic situation of small-holder farmers has been done in this area apart from this one. According to the results, farmers have certain economic benefits linked to biogas plants usage. The main one is saved money for other energy sources that equals to 29,895,000 VND per month for firewood; 7,715,000 VND per month for electricity and 3,623,000 VND per month for LGP of all surveyed households. Net present value of investment in biogas plants is 30,713,000 VND for lifespan of 15 years and discount rate of 4%, internal rate of return with the same variables is 42.2%. Due to the difficulty of determining market price of biogas in Vietnam, shadow price of biogas was calculated and it equals to 1,537 VND/MJ. By replacing electrical energy with biogas, farmers can save up to 71% of their expenses for energy. However, the question of saved money on fertilizer is arguable because 40.8% of the interviewed farmers spend more money on fertilizer after biogas plant implementation and 47.8% spend less money on fertilizer. Moreover, some of the farmers paid to the fertilizer producing company to remove the digestate from their biogas plant and take it away.

In terms of social impact, due to the reuse of organic waste in the digester, hygiene conditions in the household improved considerably, 75% of respondents stated that the environment is cleaner than before and 81% of farmers believe that insect occurrence is lower. As a result of reduced use of firewood, 90% of respondents perceive less smoke in the house. Improved hygiene conditions affect the health of farmers and their families, the occurrence of diseases from smoke, insect and digestive problems were reduced in 81%; 82% and 80% of the households respectively. Workload was decreased by two hours per day and household due to less time spent on firewood collection and preparation, activities that are usually being done by women or girls.

Certain effects of biogas digesters on environment were registered. First of them is the reduction in firewood usage by 57% which can slow done the process of deforestation. The second one is a lower production of GHG, carbon dioxide is limited as a result of decreased burning of firewood and methane produced by livestock manure is captured in biogas digesters.

This survey also determines the relation between different socioeconomic groups of farmers and their approach to biogas technology operation, maintenance and use of the energy. Farmers from rural areas have more often problems with biogas plant usage or maintenance (33% of households) than farmers from peri-urban areas (18% of households). This can be explained by longer period without access to sufficient amount of water in rural areas, because water should be added to biogas plant in order to maintain effective performance of digester. Respondents who own biogas plant for six and more years have considerably more problems related to biogas cooker and biogas plant operation and maintenance than those respondents who have biogas plant for five and less years.

This research also tried to specify the most considerable restrictions of biogas technology adoption in Thua Thien - Hue province. The main problem that has been found by this survey is ineffective maintenance and operation of biogas digesters which results in lower or no production of biogas and additional expenses. This is caused by incomplete or incorrect understanding of how farmers should operate the biogas digester. Other issue is relatively low use of digestate and high expenses on its removal from the digester. Further training and workshop focused on the biogas plant maintenance and use of fermented bio-slurry is recommended.

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9. Appendix

List of appendices:

Appendix 1 Copy of questionnaire, English version

Assessment of biogas plant construction and utilization in Thua Thien Hue province

Questionnaire

District:

Commune:

Village:

Good day,

Together with DFA Hue and AFFEC we would like to carry out a survey on importance of biogas plants for households, in the terms of both economic, environmental and social benefits, and we would like to identify any changes regarding to farm (e.g. livestock, rice fields) or household management.

In this case, we would kindly ask you to cooperate and to participate in our survey (which is anonymous and would take about one hour) in order to help us come out with valuable, helpful and meaningful results.

Thank you for your time, patience and willingness!

First of all, we need to know how many people live with you in your house and how they contribute to the household livelihood.

1. Please write down your personal information:

Are you male or female?	
When were you born? (year)	
For how many years did you visit a school?	
Since which year your family live in this village?	
Since which year have you run your agricultural production?	
Are you a member of any cooperative or association (yes=1)?	
How much VND do you earn per person and month? If you don't know, rank if you are listed as □ poor (< 400.000 VND/month/person) □ semi-poor (< 520.000 VND/month/person) or □ other?	

2. Now, write down the details on people who live together in your house (parents, children, other relatives, friends etc.):

Household member – relationship to household head (parents, husband/spouse, siblings, children…)	What is the gender of household member? M= male F= female	What is the year of birth? years	Are they working on farm? Yes=1	Does anybody have off-farm job? Yes=1	Do they attend school? Yes=1

Now we will ask you some details about your farm.

3. Please specify in the table bellow the structure of your farm, i.e. which (and how many) parts are dedicated to (annual crops, perennial crops, homegarden …) and what is their area (m^2, ha).

Plot	
What is the total area of your farm	
How large is the area dedicated for rice fields	
How large is the area dedicated for annual crops (cassava, peanuts etc.)	
How large is the area dedicated for perennial crops (trees, fruits, pepper, rubber etc.)	
How large is the area dedicated for homegarden	
Forest (acacia, etc.)	
Other (house, drying place etc.)	

4. Now tell us please more about your animals (livestock) on your farm. We would like to know how many heads of particular animal do you usually have during this year, how many of them did you approximately have in the past (if any) and how many animals do you plan to have in following, 5 years (if any)?

Animals	Now (usually)	5 yrs ago	5 yrs ahead
Buffaloes			
Cows			
Pigs total			
Pigs (females/sows only)			
Poultry			

5. In which months do you consider following situations to be affecting your livelihood or to be anyhow important for the life of your household (mark as "X")?

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	N/A
Not enough food													
Not enough water													
Not enough money													
Mosquitoes/Insect attacks													
Water quality is not good													
Higher smell (from animals)													
Farm activities (e.g. harvest, tillage)													
Selling farm production on market													

6. Please, try to estimate your cash income (in thousands VND) per one year from particular activities listed below. If you have no income from some activity, write down zero "0". Example bellow helps you to link the income to particular activity. If you have any questions, do not hesitate to ask the interviewer

Annual crops	Plantation	Home-garden	Livestock	Fishing from rivers, lakes, ponds, sea	Wages	Govern-ment support	Planted forest products	Old forest	Other
(e.g. rice, peanuts, corn)	(e.g. rubber, acacia, bamboo, sugar cane)	(e.g. cassava, pomelo, jackfruit, pineapple pepper, vegetable)	(e.g. meat, animals, services, eggs)		(e.g. work for other farmer, running shop, restaurant, work shop)	(e.g. pension, subsidies)	(e.g. firewood, war wreckage)	(e.g. plants, honey, rattan, leaves, herbs, animals)	(e.g. gifts, money from relatives)

7. What are your cash expenditures (thousands VND) during the month according to particular purpose?

Energy	Farm expenditures (crops) (fertiliser, seed, equipment, transport on market, etc.)	Farm expenditures (animals) (fodder, stable, veterinary fees, transport on market, etc.)	Household (food, clothes, tax etc.)	Health care	Education	Paying back for credit	Other

8. Try to estimate how much of your farm production, in general, serves for supplying of your household needs for food.

☐ up to 10%, we have to buy almost all food on market
☐ 10 – 50%, we have to buy a lot of food on market, but still we have a lot of our own production
☐ 50 – 90%, we have to buy only some food on market, but not regularly
☐ 90% and more, we have to buy only some small amount and specific kind of food on the market

Now we need to understand how you (your household) supply your demand for energy.

10. Specify VND spent after and before biogas installation and if possible, the amount of energy used.

Energy type	VND spent per month (now)	specify if can kg, kW, litres, bundles etc.	VND spent per month Before biogas	specify if can
Electricity				
Firewood				
Charcoal				
LPG				
Others (such as farm residues, dung, paraffin, kerosene, solar)				

11. How much firewood in bundles/month did you use before biogas plant installation? ______
12. How much firewood in bundles/month do you use now? ______

13. How much time per day you spend for firewood maintenance (collection,preparation,storage, cleaning) except time for cooking? _______

14. What is the source of firewood and how much do you pay for it?

Source	How many %	
Collection		
Buying on market		Price per kg:
external supplier (transport to household)		Price per kg:

Now we would like to ask you some questions regarding to biogas utilization.

15. At the beginning, please write down following technical information on your biogas plant:
What is the size of your biogas plant (m³)? ____________________
When the biogas plant was built (year)? ____________________
Do you use biogas (mainly?) for? ☐ cooking for people ☐ cooking for animals ☐ lighting
Is toilet (latrine) attached to your biogas plant? ☐ yes ☐ no

16. From whom did you get information about biogas (multiple choice)?
☐ local government/administration representative
☐ Vietnamese development worker (non-governmental)
☐ development worker (non-Vietnamese origin)
☐ constructor of biogas plants
☐ family members or friends
☐ neighbours, other users
☐ mass-media (newspapers, magazines, TV, radio …)
☐ other: __________

17. What were the reasons for purchasing BP? Consider all of them and rank according to their importance from 1 to 6 (1= lowest importance, 6 = highest importance)

More free time (no need to collect firewood)	
Saving energy costs	
Production of fertilizer	
Cleaner environment	
State/project subsidies, gas cooker	
Other (please specify): ______	

18. How many family members or friends (who you didn't pay) helped you to build/prepare place for your biogas plant? _____
And how many days did they spend in total? _____

19. If you had any labourers, how much did you pay them in total? _____

20. Did you need any loan when buying biogas plant?
□ Yes, please specify the source: ____________ □ No

21. Have you or any other member of your family been trained to maintain BP in good conditions?
□ Yes □ No

22. Do you understand instructions about biogas plant maintenance?
□ Yes, totally □ Yes, partially □ No

23. Have you already emptied your biogas plant?
□ Yes

Please write how many times: _____
Please write how many years after biogas plant installation did you empty it for the first time: _____
What did you do with digestate?

Use as fertilizer (in %)		
Discharge (in %)		Please specify where:
Feed for animals (in %)		
Others:		

□ No, I have it only for a short time, but I will empty it according to extension service advices
□ No, I have it only for a short time, I will empty it when it is necessary (when no biogas will be produced or when the plant is full)
□ No, I should have done it before, but the plant still works well
□ No, I should have done it before and the plant produces less biogas now

24. What will you do with digestate after emptying biogas plant (multiple choice)?
□ use as fertilizer
□ discharge (please explain where): ________
□ other: _______
□ I don't know yet

25. Do you have any expenses related to biogas production? Cleaning, tax, water, repairs …
□ Yes, please specify: ____________ □ No

26. Have you had any problem with BP operation or maintenance?
□ Yes, please specify: ____________ □ No
27. Do you have any problem with gas cooker?
□ Yes, please specify: ____________ □ No

Think about the positive and negative changes that occurred in your household since the biogas plant was established.

28. Do you notice any positive or negative effects of biogas plant installation on environment, smoke reduction, etc.?

				Rank if you expect more or less in future
smoke in the house	□ more	□ less	□ same	□ more □ less
cleaner environment	□ more	□ less	□ same	□ more □ less
mosquitoes/insect occurrence	□ more	□ less	□ same	□ more □ less
illnesses from smoke (respiratory)	□ more	□ less	□ same	□ more □ less
illnesses from insect	□ more	□ less	□ same	□ more □ less
digestive problems, diarrhoea	□ more	□ less	□ same	□ more □ less
Free time for other activities	□ more	□ less	□ same	□ more □ less
Money saved on energy	□ more	□ less	□ same	□ more □ less
Money saved on fertilizer	□ more	□ less	□ same	□ more □ less

29. Do you use or do you expect to use of digestate as fertilizer? If yes, for what purpose (rank):

rice field	
annual crops (cassava, etc.)	
trees	
home garden	
livestock	
Expect selling digestate	

30. Considering that use of biogas also saves time, do you spend more or less time on following activities in comparison with the time when you didn't have biogas plant?

				Rank if you expect more or less in future	
Operation of biogas plant	☐ more	☐ less	☐ same	☐ more	☐ less
Taking care of farm (food crops)	☐ more	☐ less	☐ same	☐ more	☐ less
Taking care of farm (cash crops)	☐ more	☐ less	☐ same	☐ more	☐ less
Livestock feeding	☐ more	☐ less	☐ same	☐ more	☐ less
Taking care of home garden	☐ more	☐ less	☐ same	☐ more	☐ less
Taking care of household	☐ more	☐ less	☐ same	☐ more	☐ less
Cooking for people	☐ more	☐ less	☐ same	☐ more	☐ less
Cooking for animals	☐ more	☐ less	☐ same	☐ more	☐ less
Water transport	☐ more	☐ less	☐ same	☐ more	☐ less
Recreation/watching TV/radio	☐ more	☐ less	☐ same	☐ more	☐ less
Reading	☐ more	☐ less	☐ same	☐ more	☐ less
Social/community work	☐ more	☐ less	☐ same	☐ more	☐ less
Income generating activities	☐ more	☐ less	☐ same	☐ more	☐ less
Sport (pool, volleyball etc.)	☐ more	☐ less	☐ same	☐ more	☐ less
Meeting friends and relatives	☐ more	☐ less	☐ same	☐ more	☐ less
Self- education	☐ more	☐ less	☐ same	☐ more	☐ less

31. What is the general satisfaction rate with the biogas? Rank if it fulfils your need for: (1= not at all, 5= totally)

	1	2	3	4	5
Cooking					
Lightening					

32. Would you recommend biogas plant to your friends even if there was no state or other subsidy? (1= not at all, 5= definitely)

1	2	3	4	5

33. Do you have any other idea or comment you would like to share with us?

Thank you for your time

Appendix 2 Data collection in Phong Dien district

Appendix 3 Data collection in Huong Tra district

Appendix 4 Family size biogas digester

Appendix 5 Farmer in rural areas of Thua Thien – Hue province