HOUSEHOLD BIOGAS SYSTEMS IN LOW-INCOME RURAL REGIONS

By

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A research project report submitted in partial fulfilment of the requirements for the award of the degree of Master of Science of Loughborough University

August 2010

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DEDICATION

This research is dedicated to my girlfriend and family for unquestionable support during my time in Loughborough, as well as earlier in my life.

ACKNOWLEDGMENT

I would like to express my sincere gratitude to the following people:

- The research participants, for their time and effort to share their experience;
- Mr. Brian Skinner, my project supervisor who provided me with valuable guidance;
- Ms. Tricia Jackson, for her ability to keep track of all those hard find books and articles; and
- the WEDC staff, for their sharing of knowledge and experience during my time in Lougborough.

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GLOSSARY AND ABBREVIATIONS

Acid	Any chemical compound that, when dissolved in water, gives a solution with a pH less than in pure water (i.e. 7.0)
Aerobic	With air
Amino acids	The building blocks of proteins
Anaerobic	Without air
Ascaris	A genus of parasitic nematode worms
Base	Any chemical compound that, when dissolved in water, gives a solution with a pH greater than in pure water (i.e. 7.0)
Bio-slurry	See effluent
C:N	Carbon-to-nitrogen-ratio
Co-digestion	Simultaneous digestion using two or more materials
COD	Chemical Oxygen Demand
Digester	The enclosed container where the anaerobic biogas process is taking place
Eco-san	Ecological sanitation
Enzyme	Proteins that catalyse (i.e. increase the rates of) chemical reactions
ESCAP	United Nations Economic and Social Commission for Asia and the Pacific
Eutrophication	Increased concentration of nutrients
Effluent	Slurry leaving the digester
FAO	Food and Agriculture Organisation of the United Nations
Feed-stock	See ―influent”
Fertiliser	Soil amendments with nutrients applied to promote plant growth

GO	Governmental Organisation
GRP	Glass-Reinforced Plastic
Gross enrolment ratio	Number of students enrolled in primary, secondary and tertiary levels of education as a percentage of the population of official school age
GTZ	Deutsche Gesellschaft für Technische Zusammenarbeit (German Society for Technical Cooperation, a private international enterprise)
HBP	Household Biogas Plant
Helminth	Parasitic worm
Humus	Organic matter that has reached a point of stability, where it will not break down any further
HRT	Hydraulic Retention Time (the average time a liquid is retained in a tank)
Influent	Slurry entering the digester
IRC	International Sanitation Center
LPG	Liquefied Petroleum Gas (a flammable mixture of hydrocarbon gases used as a fuel)
NGO	Non Governmental Organisation
Nucleic acid	A large molecule composed of chains of monomeric nucleotides, e.g. DNA and RNA
OLR	Organic Loading Rate
pH	Approximates but is not equal to the negative logarithm (base 10) of the molar concentration of dissolved hydronium ions
Protozoa	A group of animal-like microorganisms of which some cause diseases
Siloxane	Any chemical compound composed of units of the form R_2SiO

SNV	Netherlands' development organisation
Slurry	The thick liquid passing through the digester
Soil conditioner	Soil amendments without nutrients applied to promote plant growth
SIDA	Swedish International Development Cooperation Agency
Specific yield	Volume of gas per volume of digester per day
TS	Total Solids
Volatile acids	Fatty acids with a carbon chain of six carbons or fewer, created by digestion
VS	Volatile Solids (a solid that can easily transform into a gas)
UN	United Nations
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
WEDC	Water, Engineering and Development Centre
WHO	World Health Organisation

1 INTRODUCTION

1.1 BACKGROUND

The theory of biogas is simple and brilliant – convert dangerous waste into benefits. The gas produced can be used for cooking, lighting, engines and other applications, providing benefits such as a smoke-free indoor environment, reduced amount of time for household chores, lit environment for home-work, fuel for pumping water and much more. And, after the process, the previously dangerous waste that was put into the biogas plant is now a fertilising bio-slurry. Used in agriculture it will increase the crop yield and by re-circulating the nutrients.

The transformation effect, from dangerous waste to bio-slurry, also has a benefit that has received more attention during the last years. While traditionally using mostly cattle dung and other animal waste, the biogas plant can also be fed with human excreta, thus acting as a sanitation solution as well.

The Millennium Development Goals, set up to end poverty, include such things as improved health, more time for income generating activities, opportunities for school work, increased food production and proper sanitation (UN, 2010). In theory, biogas technology would be very suitable to help fulfilling these goals that has been set up by the world community.

In fact, *UNESCO* (United Nations Educational, Scientific and Cultural Organization) regarded biogas as a ―promising approach to decentralised rural development" as early as the 1970's (DaSilva, 1979) and *SNV* (the Netherlands' development organisation), in the late 2000's, say that ―SNV firmly believes households raising livestock are able to benefit from domestic biogas plants for the production of sustainable cooking fuel and potent organic fertiliser" (van Nes, 2005: 2). Still, the big household biogas boom is yet to come.

In 2007 the author was involved in building a prototype of a household biogas plant in Nyanza Province, Kenya. When the prototype was finished it seemed to be a success – it was producing gas, a nearby kitchen could use the gas, a local farmer was in need of the *effluent* (slurry leaving the digester) as fertiliser, people seemed to enjoy using the toilet connected to it, and the construction cost was relatively low. However, two months after leaving the area, people stopped using the system. What went wrong? Had the digester started to leak? Was it too much of an effort to keep it running? Did the gas not ignite? Was the previous option just more convenient to use?

Surprisingly few implementers have asked themselves the same questions.

This research will ask the question of why biogas technology has not been able to deliver its much sought results where it has been put into action. The research will focus on already published material as well as the experience, knowledge and opinions from the people that are involved in constructing, developing, promoting, researching and selling the technology.

1.2 AIMS AND RESEARCH QUESTIONS

The aim of this research is to explore the problems using biogas in low-income rural areas, find reasons for failed projects and why the technology has not fulfilled the intentions.

While the author's primary objective is not to explore the solutions in depth, he aims to find areas of future research and giving introductory guidelines to personnel implementing biogas projects in the field.

In order to fulfil the aims of this project, the research attempts to address the following research questions:

1. What are the benefits for households to use biogas in low-income countries?
2. Why have many of the benefits not been delivered?
3. What are the solutions to the limitations?

1.3 WHO WILL USE THIS RESEARCH?

It is the author's intention that this dissertation and research will benefit professionals working for governmental, non-governmental and donor organisations involved with biogas for rural households. It should benefit those who want to improve their implementation projects by providing thoughts on design, people's expectations and support.

The research also intends to help those who are considering the option of implementing biogas – this report will provide both identify as well as disadvantages of household biogas.

1.4 LIMITATIONS

When exploring the benefits of biogas, there will be a focus on the entity rather than the effect. For example; the energy benefits of biogas will be limited to how it can be used rather than how people's lives are affected. The reduced time needed for fire wood collection, improved health, empowered women and other effects have already been researched by others.

The reader is recommended to have a look at the bibliography at the end of this report. The literature can be used to gain knowledge of how energy, sanitation, agriculture, gender roles, and income will be affected by biogas.

1.5 Structure of Dissertation

This report consists of five chapters. The content of each chapter, except for this introduction, are as follows:

- Chapter Two: Literature Review
  This chapter aims to introduce the reader to what has already been written on the subject by others. It also reflects on the quality of their work and the methods used.

- Chapter Three: Methodology
  This chapter describes how the research has been carried out. It justifies the methods and then describes how the literature review has been conducted and the data collected. The methodology is also assessed from a critical point of view to find weaknesses in order to minimise them.

- Chapter Four: Results and Analysis
  This chapter presents the findings of the data collection and highlights the most important findings. The chapter will also analyse and discuss the findings.

- Chapter Five: Conclusions, Recommendations and Suggestions for further Study
  This chapter answers the research questions with help of the analysis and discussion previously performed. It also provides recommendations for how the biogas sector can be improved and suggestions for future research. Finally, the research will also be evaluated.

If the reader is accessing the electronic version of this report; clicking on a heading in the table of contents while holding [ctrl] will take you to the specific section. Also, the function is alike for the cross references used in the text.

This first chapter has introduced the research and the questions it will attempt to find answers to. In order to solve these questions, the next chapter will explore what is already known about the topic.

2 LITERATURE REVIEW

This chapter will present what others have written in publications related to biogas and its use by households. It is hoped that the literature review will provide the reader with a background and show the relevance of this research. It will also explore the gaps in the published literature and how this research will fill those gaps.

The methodology used for the literature review is described in detail in Chapter 3 - Methodology. In brief, it is a controlled search for literature using mainly online Internet resources. Key words have been used in different combinations together with follow-ups of references quoted in any documents that are discovered (known as "snowballing").

The review begins by establishing the context in which biogas can be used and the environment and every day situation the possible users face.

The technology of biogas is then described in order to introduce the reader to the complexity and different parameters that affect the effectiveness of a biogas plant. The review continues with a description of how biogas can match the problems described. The author considers the scope of issues quite complex and in general he has used a "description-problem approach". For each sub-chapter; theoretical technical and social benefits have been explored. After the description, the author has identified experience from surveys, project evaluations etc. to compare the theoretical benefits with what have been achieved in reality.

Finally, the review finishes with a summary of the literature together with an evaluation of it.

2.1 SANITATION, ENERGY AND SUSTAINABLE AGRICULTURE IN THE LOW-INCOME COUNTRIES

2.1.1 Need for Sanitation

People's access to sanitation is a main component to improve health and well-being. Insufficient treatment of human waste, particularly faeces, can cause diseases originating from the waste to spread to people. Of all epidemics, 5.7 per cent is caused by polluted water or insufficient sanitation (Huuhtanen and Laukkanen, 2006: 14). People without improved sanitation tend to be the most marginalised communities - living in material poverty; lacking economic, social and political resources and frequently facing several vulnerabilities linked to gender, age, ethnicity, health and social status (UNU-INWEH, 2010: 10).

2.1.1.1 Conventional Rural Family Sanitation Systems

The conventional sanitation solution, for the rural poor, is pit-latrines in various forms; including on-site pour flush latrines etc. They are relatively cheap and easy to operate and maintain in low-density populated areas (Franceys, Pickford and Reed, 1992: 23-32) (Huuhtanen and Laukkanen, 2006: 26-29). The pit latrine is normally designed so that the liquid will disperse into the surrounding soil while the solids remain in the pit where they will decompose. When full, the latrine will be abandoned or emptied for reuse (Paterson, Mara and Curtis, 2007: 902). Pit latrines, in various forms, have been implemented in most low-income countries and where successful they have reduced diseases. Where used in combination with water supply and hygiene education they have saved millions of lives (Esrey et al., 2001: 11).

2.1.1.2 Eco-San

Ecological sanitation, or eco-san, claims that although the conventional water-borne sewerage and pit-latrines (that critics often call “drop-and-store models”) have solved many problems, they are also responsible for causing many other problems. The problems include water pollution, scarcity of water, destruction and loss of soil fertility and lack of food security (Esrey et al., 2001: 11). Conventional methods, in particular water-borne sewerage, are also unable to make any considerable impact on serving the backlog of approximately half the world’s population that are without any form of sanitation (GTZ, 2006: 4).

Eco-san, according to its promoters, is based on an overall perspective of material flows as part of an ecologically and economically sustainable wastewater management system, suitable to the requirements of the users and to the local conditions. Eco-san does not favor a specific technology but adheres to all that fulfils the following principles (Werner et al., 2003: 15-16):

- reducing the health risks related to sanitation, contaminated water and waste;
- improving the quality of surface- and groundwater;
- improving soil fertility; and
- optimising the management of nutrients and water resources.

2.1.2 Energy

1.5 billion people lack access to electricity resulting in reduced development and human suffering (UNDP, 2009: 1).

WHO (World Health Organisation) calls using solid fuels indoors “the kitchen killer”. The fumes produced are estimated to be responsible for 1.6 million deaths (during the year 2000) – only malnutrition, unsafe sex, lack of safe water and lack of adequate sanitation are considered greater threats to the population in the low income countries (WHO, 2006: 12).

Depending on which source is used, solid fuels (e.g. twigs, dung, coal, etc.) are used for cooking by two to three billion people (Bates et al., 2005: 1) (WHO, 2006: 8). Only 27 per cent of the households using solid fuels use improved stoves (UNDP, 2009: 1). Other stoves cause high levels of indoor pollutions (Bates et al., 2005: 1), often exposing the people inside to smoke equivalent to them smoking two packs of cigarettes per day (WHO, 2006: 8).

Finding a figure for the cost in human suffering of indoor kitchen smoke is difficult, but diseases caused includes acute infections of the lower respiratory tract, chronic obstructive pulmonary disease, lung cancer, asthma, cataracts and tuberculosis (WHO, 2006: 11).

2.1.3 Agriculture and Soil Degradation

UNEP (United Nations Environment Programme) claims that environmental degradation will be a major constraint in future world food production, which will affect both food prices and food security (UNEP, 2010: 17).

Nutrient depletion is the decline in the levels of plant nutrients (e.g. nitrogen, phosphorous and potassium) and organic matters, which result in declined soil fertility. This will occur when the harvest and crop residues are removed without replacing the nutrients (UNEP, 2007: 96).

Replacing the nutrients by usage of inorganic fertilisers is, for the average farmer in a low-income country, not only expensive – there is also limited availability. In parts of sub-Saharan Africa as little as one kilo of nutrients per hectare is applied (which can be compared to the high-income countries where 10-20 times as much is applied) (UNEP, 2007: 97).

2.1.4 One Solution?

Although the low-income countries are suffering from many problems the three problems previously explored (lack of sanitation, using solid fuel indoors and soil degradation) are some of the larger ones. So a solution combating all of these three problems at the same time would be very attractive.

A possible solution was proposed as early as the seventies (DaSilva, 1979)[1]. Da Silva claims that ―biogas systems have attracted considerable attention as a promising approach to decentralised rural development” (DaSilva, 1979: 84). He lists biogas with the following benefits:

- renewable source of energy;
- public health and hygiene;
- bio-fertiliser;

[1] Although biogas has been used since long before, and other researchers have published similar conclusions earlier, Da Silvas's work seems to be the one that most later researchers make reference to.

- waste recycling;
- rural development;
- pollution control;
- environmental management;
- appropriate technology; and
- technical cooperation.

30 years later *ESCAP* (United Nations Economic and Social Commission for Asia and the Pacific) has a similar list of benefits (although they add reduced workload for women), highlighting the benefits of energy and fertiliser (ESCAP, 2007: 5-6).

Biogas clearly has the potential to battle the three problems described in Section 2.1. Hence, biogas technology and its potential will be further investigated in the following sections.

2.2 BIOGAS PROCESSES AND ITS PARAMETERS

2.2.1 Introduction to Biogas

Biogas is a widely used energy source in Asia. It originates when organic matter, such as faecal and/or solid waste, is degraded in an *anaerobic environment* (without air) and it can be used for a large variety of applications – gas lamps, stoves, generators etc. The effluent is also valuable as soil fertiliser. The materials flow chart for a typical system is shown in Figure 2-1.

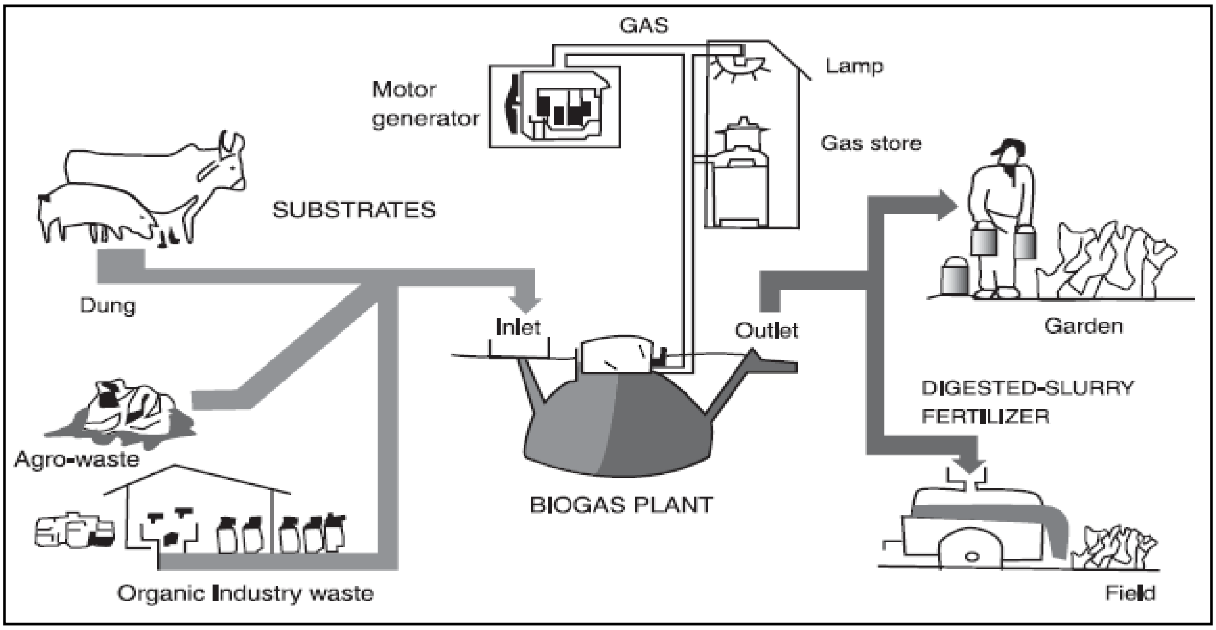

Figure 2-1. The figure shows a sketch of a typical biogas system. Wastes from different sources are put into a biogas plant. The waste will then be converted to fertiliser; suitable for agriculture, while combustible gas will be produced as a by-product (ESCAP, 2007: 5).

2.2.2 The Anaerobic Digestion Process

The anaerobic digestion process is the process of decomposition and decay of organic matter in an anaerobic environment. The organic matter is digested by microorganisms, which produce methane and carbon dioxide as end-product (Monnet, 2003: 7). The gas also contains small amounts of hydrogen sulphide, nitrogen, hydrogen and traces of carbon monoxide and oxygen (Igoni et al., 2008: 4).

The process is considered quite complex with many biologic variables (Marchaim, 1992: 22-36) but can be simplified into two (Sasse, 1988: 9) or three phases (Monnet, 2003: 7); hydrolysis, acidogenesis and methanogenesis, see

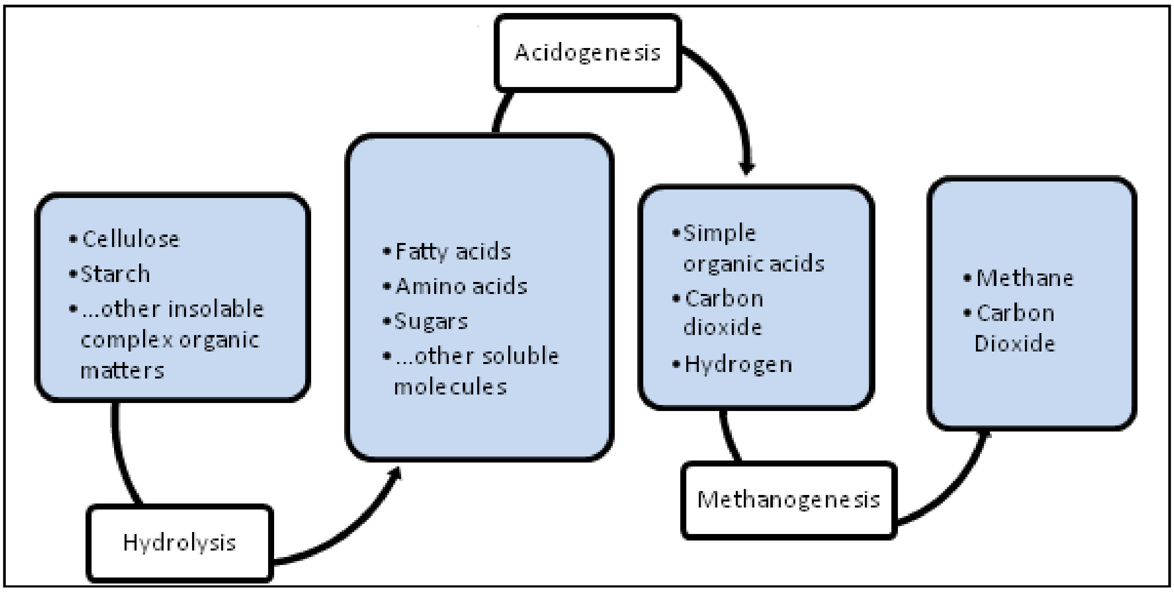

Figure 2-2. The methane fermentation equation is shown in Equation 1.

$$C_nH_aO_b + \left(\frac{n-a}{4} - \frac{b}{2}\right) H_2O = \left(\frac{n}{2} - \frac{a}{8} + \frac{b}{4}\right) CO_2 + \left(\frac{n}{2} + \frac{a}{8} - \frac{b}{4}\right) CH_4$$

Equation 1. The equations shows the mass balance between the influent composition and methane production. As it can be seen, different organic matter and water is transformed into carbon dioxide and methane (Marchaim, 1992: 23).

According to Monnet (2003: 7), insoluble complex organic matter (e.g. cellulose) is converted into soluble molecules (e.g. fatty acids, *amino acids (*the building blocks of proteins) and sugars) by fermentative bacteria during the hydrolysis. The hydrolytic phase is important and is often rate-limiting.

In the second phase, acidogenis; the acetogenic bacteria (also known as acid formers) form simple organic acids, carbon dioxide and hydrogen out of the product from the first phase.

Finally, methane forming bacteria generate methane. The process consists of cleaving two acetic acid molecules thus generating methane and carbon dioxide and by reduction of carbide dioxide with hydrogen.

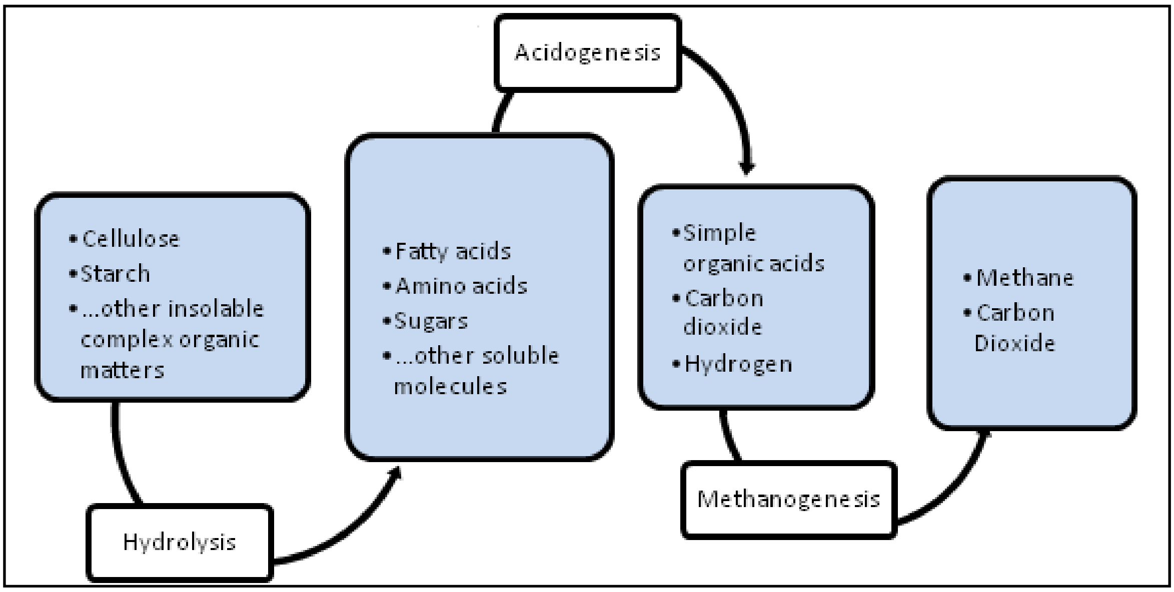

Figure 2-2. Visualisation of the three digestion phases.

Some organic materials, such as lignin, remain undigested, together with non-organic inclusions (Monnet, 2003: 7).Biogas can, in principle, be obtained from any organic material. To start the process cattle manure is often used to provide the right microorganisms (Sasse, 1988: 9).

2.2.3 Digestion Parameters

Numerous parameters affect how effective the process will be at digesting the organic matter. Some of the most important parameters, which are important to be aware of in order to understand difficulties of the operation, are discussed in the following sections.

2.2.3.1 Solids

TS (Total Solids) are the percentage, or weight, of all solids in a liquid. The Volatile Solids parameter (usually designated as ―VS parameter"[2]) describes how much solids of the TS that are volatile. The relation is described in Equation 2.

$$\frac{Weight\ of\ Volatile\ Solids\ in\ a\ liquid}{Weight\ of\ Total\ Solids\ in\ a\ liquid} = VS\ parameter\ (\leq 1, or \leq 100\%\ )$$

[2] In some literature, ―VS" is used as term for ―VS parameter", which the author considers to add confusion since ―volatile solids" is not the same as the ―VS parameter".

Equation 2. Calculating VS.

The volatile solids are what the organisms feed on, creating biogas. Knowing the VS parameter of an undigested material allows the potential gas yield to be estimated (Jenangi, 2000: 6). A TS level of ten per cent is a general recommendation of the proportion that seems to generate the highest amount of gas per cubic metre of *slurry* (the thick liquid passing through the digester) (Igoni et al., 2008: 9). At higher TS levels the retention time needs to be increased (Sing et al., 1984: 256).

2.2.3.2 Temperature

Optimal temperature in the digester will vary depending on *influent* (what goes into the digester) and type of digester, but it should be kept at a constant value (Monnet, 2003: 8).

There are three different temperature ranges that can be used for biogas production (Wendland, 2009: 12):

- The psychrophilic range (10 to 20 °C);
- the mesophilic range (20 to 40 °C); and
- the thermophilic range (50 to 60 °C).

Each temperature range has its own specific microflora, and it is recommended that temperatures are kept within one of the ranges (Wendland, 2009: 12).

Thermophilic conditions require less *retention time* (see below) and will increase the gas yield. However, external heating is needed and the process is more sensitive to operation and environmental variables (Monnet, 2003: 8). Most household digesters are therefore operated within the mesophilic range due to the robust large diversity of bacteria species (Wendland, 2009: 12).

2.2.3.3 Hydraulic Retention Time

HRT (Hydraulic Retention Time), or just retention time, is the time needed to degrade the organic matter and is usually measured in days (Monnet, 2003: 8). If the retention time is too short, the undigested slurry will be "washed out" without producing gas and with its pathogens still active. It the retention time is too long, the digester has to be very big and therefore expensive (Jenangi, 2000: 5).

The required retention time varies depending on type of digester, type of slurry, climate etc. Recommendations also vary between different authors, as will be shown.

Monnet (2003: 8) claims that digesters in the mesophilic range (which is the common small scale range in low-income countries) should have a retention time of 15 to 30 days. Barnett, Pyle and Subramanian (1978: 35), on the other hand, suggests a retention time of 30-

60 days. Marchaim (1992: 63-68) recommends 30-80 days for digesters in the mesophilic range, depending on type and climate.

A recent study (Yadvika et al., 2007: 441) claims, with support from their experiments, that digesting cattle dung for more than 30 days will not increase the gas yield. It is, as stated, the yield they have used as a parameter for when the slurry is digested enough – not the destruction of pathogens in the slurry. Since the longer retention time results in death of more pathogen (Sasse, 1988: 8) it is likely that the 30-60 days recommended by some do not only reflects the time to maximise the gas outcome but also to achieve a relatively safe effluent.

2.2.3.4 pH

In general, the majority of microorganisms grow fastest during neutral *pH*[3] conditions (i.e. a value of 7). Other pH values may adversely affect the metabolism by changing the chemical equilibrium of enzymatic reactions and/or by destroying the *enzymes* (proteins that catalyse chemical reactions). Of the three phases, or types of microorganisms, the methanogenic group is the most sensitive to changing pH. If the pH is very low the digestion may cease completely (Wendland, 2009: 11).

Different studies have shown different values for the pH that is most suitable for producing biogas, but most agree that it should be kept somewhere between 6 and 7.5 (Wendland, 2009: 11).

2.2.3.5 Carbon to Nitrogen Ratio

An important aspect when considering what to feed a digester with is the *carbon-to-nitrogen-ratio* (C:N). It describes the amount of carbon in relation to the amount of nitrogen.

Nitrogen in the slurry has two benefits. It is an essential element for synthesis of amino acids, proteins and *nucleic acids* (large molecules composed of chains of monomeric nucleotides, e.g. DNA and RNA). It is also converted to ammonia, which is a strong *base* (a chemical compound that, when dissolved in water, gives a solution with a pH greater than in pure water), thus neutralising the volatile acids produced by the fermentative bacteria. Too much nitrogen, on the other hand, can lead to excessive ammonia formation with toxic effects (Marchaim, 1992: 41).

A C:N ratio of 20 – 30 (i.e. there are 20 – 30 times as much carbon than nitrogen) is recommended for general use (Monnet, 2003: 8) and 30 is often considered as optimal (Marchaim, 1992: 41). However, since not all of the carbon and nitrogen in the organic material is available for digestion (due to influent characteristics and digestion operational parame-

[3] Approximates but is not equal to the negative logarithm of the molar concentration of dissolved hydronium ions.

ters) the overall C:N ratio can often vary from less than 10 to over 90 and still allow effective digestion (Marchaim, 1992: 41).

By mixing different feedstock materials (with different characteristics), an optimum C:N ratio can be reached (Monnet, 2003: 8). For example, by mixing kitchen waste (which has a low amount of nitrogen) with urine (which has a high amount of nitrogen) in correct proportions a desired C:N ratio of 30 can be reached. See Table 2-1 for examples of C:N ratios for different organic materials. When using different feedstock in a mix, it is known as *co-digestion*.

Table 2-1. C:N ratios for different organic materials (Barnett, Pyle and Subramanian, 1978: 51).

	N (% of dry weight)	C:N ratio
Night soil	6	6-10
Cow manure	1.7	18
Chicken manure	6.3	7.3
Hay, grass	4	12
Wheat straw	0.5	150
Saw dust	0.1	200-500

2.2.3.6 Mixing

Improved contact between the microorganisms in the slurry can be achieved by mixing within the digester. The improved contact will advance the bacterial population’s ability to obtain nutrients. Mixing will also prevent formation of scum and temperature differences within the digester. Too much mixing, however, may disturb the micro-organisms – deliberate mixing is therefore preferred (Monnet, 2003: 9).

If the slurry consists of different sub-parts, i.e. co-digestion, the slurry should thoroughly mixed before entering the digester (Monnet, 2003: 9).

2.2.3.7 Organic Loading Rate

OLR (Organic Loading Rate) is the biologic conversion capacity of the system. It is expressed in kilograms of Volatile Solids (VS) per cubic metre of digester, or sometimes kilogram *COD* (Chemical Oxygen Demand) per cubic metre of digester (Monnet, 2003: 9).

2.2.4 Biogas Plants for Household Use

Anaerobic digestion needs adequate volume for the biological reaction to take place without stress and this demands some key technical requirements. The levels of these “key technical requirements” will vary from very rudimentary to quite sophisticated systems.

The following is a summary of the main *digester* (where the anaerobic process takes place) types available for household use. More “sophisticated” types, usually associated with biogas for institutional use in high-income countries, e.g. continuous stirred tank reactors and up-flow anaerobic sludge reactors etc., have not been included.

Digesters are often referred to with regards to their volume, in cubic metres. The volume usually includes both the space which the slurry occupies as well as the space where the gas is being stored. Common digester sizes are between 4 and 16 cubic metres (Walekhwa, Mugisha and Drake, 2009: 2755) (Biogas Project Office, 2006: 12).

2.2.4.1 Batch and Continuous Flow Digesters

Digesters are usually of a batch or continuous type. In a batch type, the feedstock is charged into the digester and then left until all feedstock has been digested. The alternative, the continuous flow digester, is fed on a daily basis with the material near the outlet overflowing as the same amount is added on the other side of the digester (Barnett, Pyle and Subramanian, 1978: 32). All digester types mentioned below are of the continuous flow type, since batch digesters are now rarely used (Holm-Nielsen, Al Seadi and Oleskowicz-Popiel, 2009).

2.2.4.2 Fixed Dome Plants

A fixed dome plant (aka “the Chinese type” or “the Luo GuoRui type”) consists of a gas-tight chamber (see Figure 2-4) where the gas is stored in the higher part of the digester. The digested slurry is emptied continuously to a compensation chamber (a.k.a. displacement chamber) as new slurry is entered into the mixing tank (Sasse, 1988: 13). The system is constructed of bricks, stones or concrete which, in reality, is impossible to keep entirely gas-tight (Marchaim, 1992: 63). The maximum gas pressure is proportional to the amount of gas (and therefore the size of the system) and a digester volume more than 20 cubic metres is therefore not recommended (Sasse, 1988: 13).

Figure 2-3. A fixed dome digester during construction. When finished most of the plant will be covered by earth (Acres Wild, 2008).

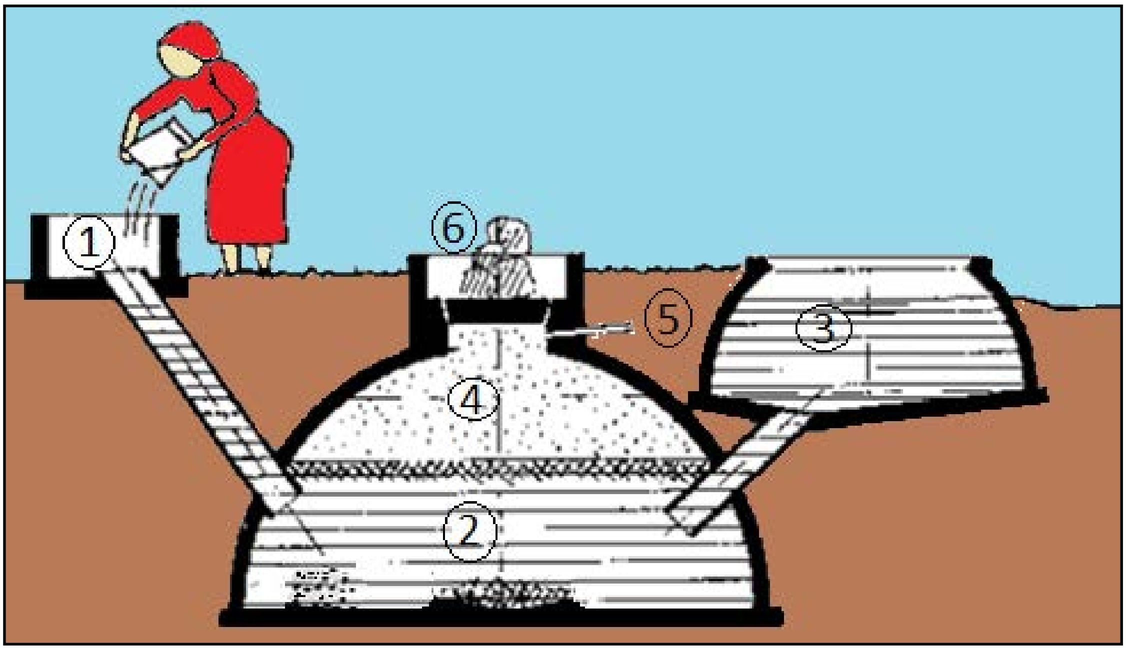

Figure 2-4. Sketch of a fixed dome digester (adapted from Sasse, 1988: 13). Influent is added into the mixing tank (1), entering the digester (2). When influent is added, effluent exits into the compensation chamber (3), which also pressurise the gas (3). The pressurised gas can then be subtracted from the pipe (5). A gas-tight manhole (6) enables maintenance and repairs.

To obtain the gas-tight chamber; the inner surface has to be painted with a gas-tight paint. Latex or synthetic paints (e.g. PVC or polyester) are suitable while epoxy resin paints are particularly good. Polyethylene paint is not gas-tight (Sasse, 1988: 41). Since the year

2 000, digesters have also been available in *GRP* (Glass-Reinforced Plastic). The benefits of GRP are the longer lifespan, lower maintenance cost and a shorter construction cycle (Chen et al., 2010: 546).

A gas pressure regulator or floating gasholder is required for gas used at a constant pressure (e.g. engines and generators) (Sasse, 1988: 13).

The amount of TS should be five to eight per cent for cow manure and four to seven per cent for pig manure. As always, the gas production will vary a lot, but it is often between 0.15 and 0.6 cubic metres per day per cubic metre of digester (Marchaim, 1992: 63).

The construction costs for a fixed dome digester is comparatively low and, as long as they are well-constructed, they have a long expected life span. Since most parts are located underground not much space is required and it will be protected from temperature differences (unfortunately this may cause a problem where the slurry will not reach a good temperature). Maintenance costs are low due to the absence of moving parts (ESCAP, 2007: 15).

A frequent problem is leakages from the gas chamber. Even a small leak will cause substantial loss of gas. A general recommendation is therefore to only use this type of digester where construction can be supervised by experienced biogas technicians (ESCAP, 2007: 7).

There are two types of fixed dome digester used on a larger scale. The first to be implemented was the Janta model in 1978 (Singh and Sooch, 2004: 1331), and it is the Janta type that is shown in Figure 2-4 (on the previous page).

The Deenbandhu (“friend of the poor” in Hindi) was developed by Action for Food Production as a response to the high cost of the Janta model. The main design difference is the minimising of the surface area. It consists of two spheres of different diameters joined together at their bases (Singh and Sooch, 2004: 1332).

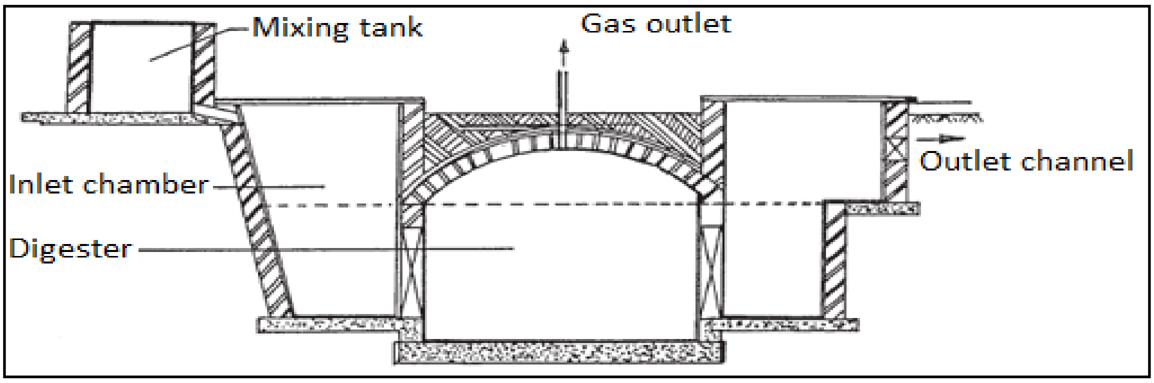

Figure 2-5. Sketch of a Deenbandhu biogas plant. Notice the inlet chamber between the mixing tank and digester compared to the Janta type (adapted from Household Energy Network (2007)).

There are also several variations of the fixed dome type available in different regions, but except for being slightly modified for the local conditions there are few differences. The Thai-German developed KT.2 for example (Biogas Project Office, 2006: 12) is a model designed to be used in areas of high groundwater, such as the Vietnamese Mekong Delta, see Figure 2-6.

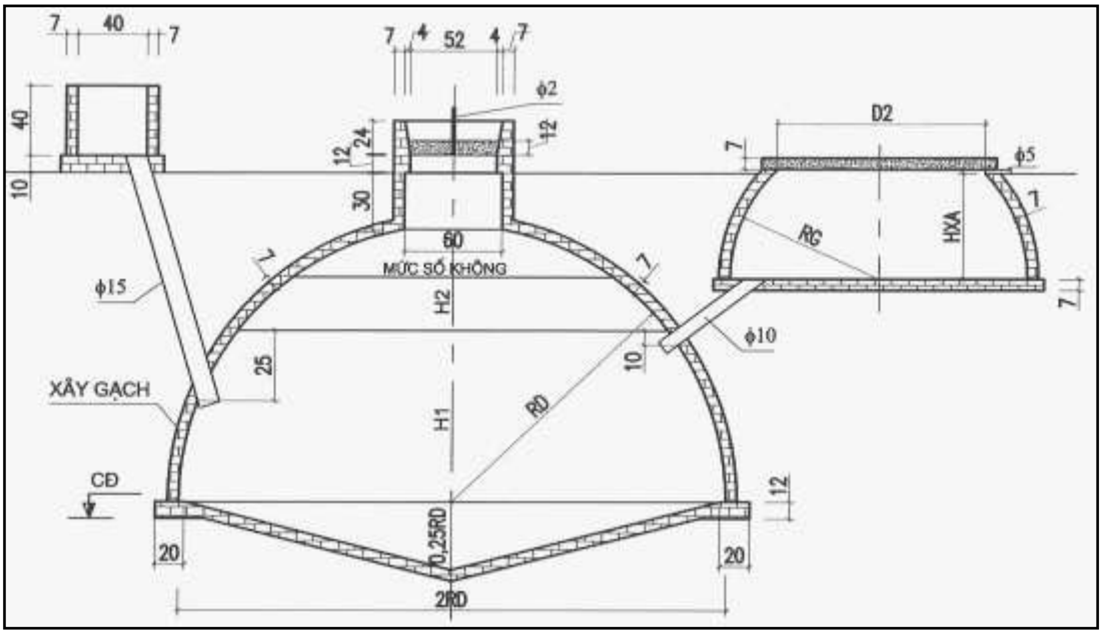

Figure 2-6. Sketch of the KT.2 biogas plant. The conical bottom (compare it to the bottom in Figure 2-4) makes the plant more resistant against upward forces associated with high groundwater levels (Biogas Project Office, 2006: 12).

2.2.4.3 Floating Drum Plants

A digester of the floating drum type (a.k.a. floating dome, Indian type or KVIC, see below) consists of a fixed chamber covered with a moving cylinder (see Figure 2-8). The moving cylinder (the actual ―floating drum") floats on the slurry, or in some models in a separate water seal. The gas created during digestion is collected in the cylinder which rises as the volume of gas increases. The approximately amount of available gas can be visually seen by inspecting the height which has risen, see Figure 2-9 (Sasse, 1988: 14). The specific model most commonly used was standardised in India in 1962 by the Khadi & Village industry Commission (KVIC) and is therefore known as the KVIC model (Singh and Sooch, 2004: 1331).

Figure 2-7. Photo of a floating drum plant in India (engINdia, 2005).

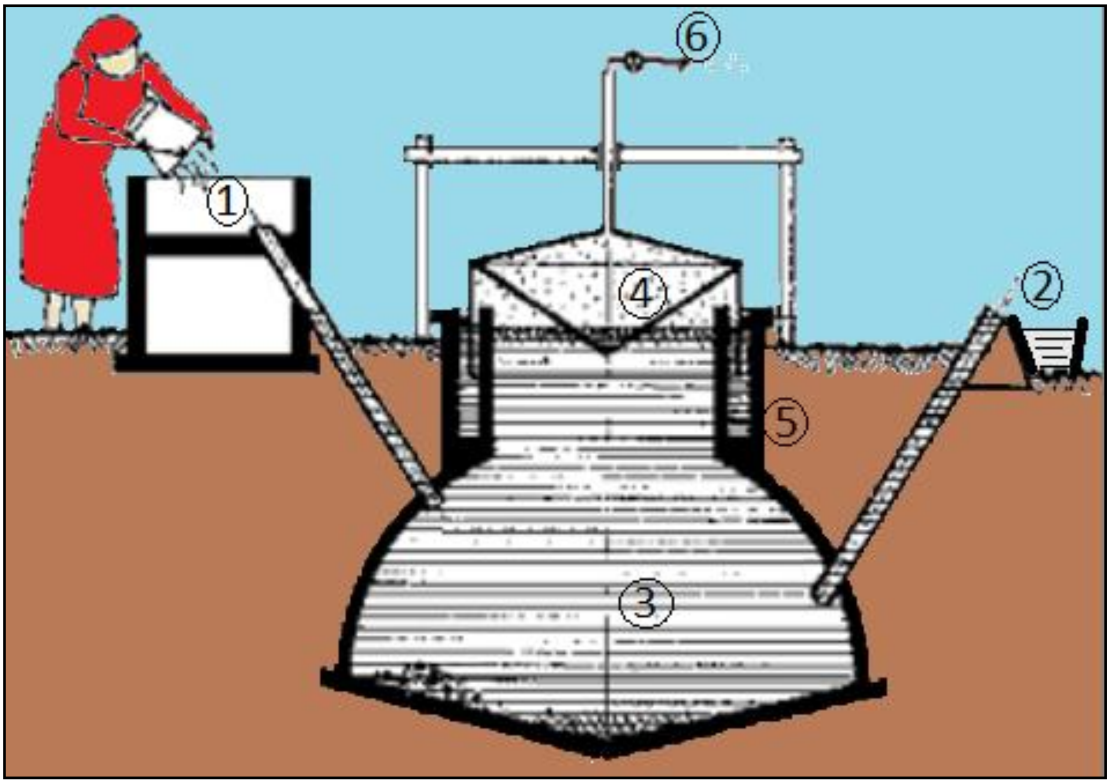

Figure 2-8. Sketch of a floating drum digester (adapted from Sasse, 1988: 14). Influent is added (1) which will cause effluent to exit (2). The slurry is digested (3), creating biogas which is collected in the cylinder (4). Gas is prevented to leak by a water seal (5) and instead exits through a pipe system (6).

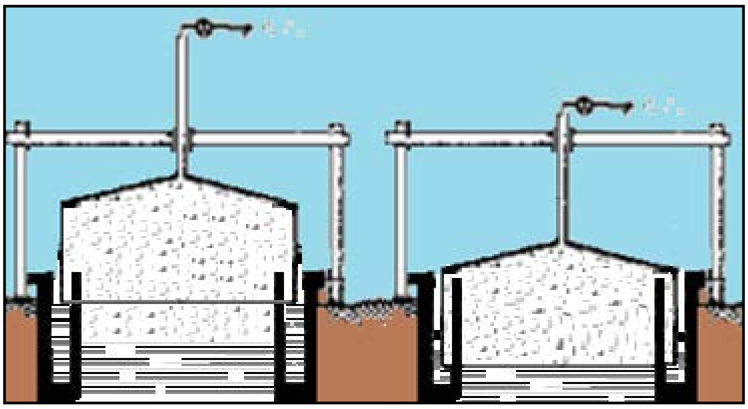

Figure 2-9. Two floating drum plants with different amounts of biogas. The one to the left has lots of gas, while the on to the right, the same plant but with less gas. The gas pressure is approximately the same in both cases (the figure is a segment of Figure 2-8, modified by the author).

The main feedstock for most floating drum plants are cattle manure but human waste and plants, such as water hyacinth, have often been used in a mix with the manure (Marchaim, 1992: 63).

In the late 1980's and early 1990's the floating drum, made from mild steel, was exchanged with one made from GRP (Sasse, 1988: 15) (Marchaim, 1992: 63), however recent literature shows that it has been changed back to mild steel (Singh and Sooch, 2004: 1331). The reasons are, unfortunately, unknown.

2.2.4.4 Plug Flow Plants

The plug flow digester was introduced in South Africa in 1957, but did not reach popularity at first due to high costs. A typical digester consists of a concrete trench (see Figure 2-10 for details). The length has to be significantly greater than the width and depth to ensure that a ―plug" will form – that is the slurry is only mixed laterally, see Figure 2-11 (Marchaim, 1992: 67).

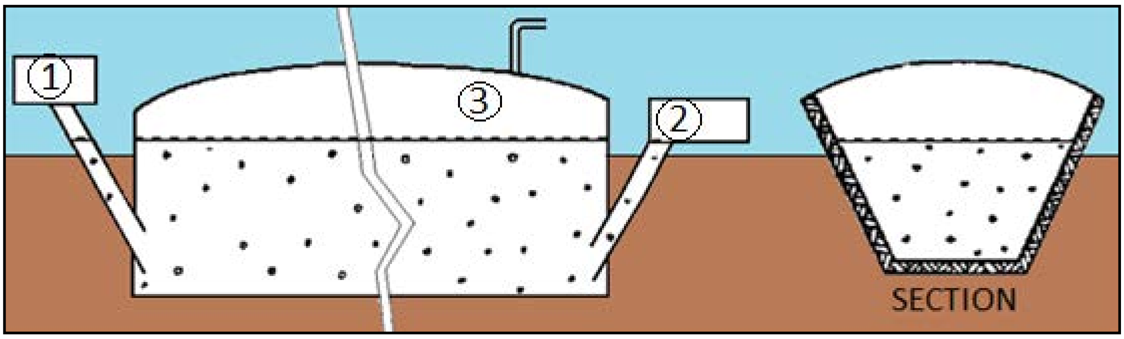

Figure 2-10. Sketch of a plug flow digester (adapted from Marchaim, 1992: 238). The influent is added at the inlet (1) and exits at the outlet (2). The gas is collected at the top of the digester (3) but can also be stored in an external bladder.

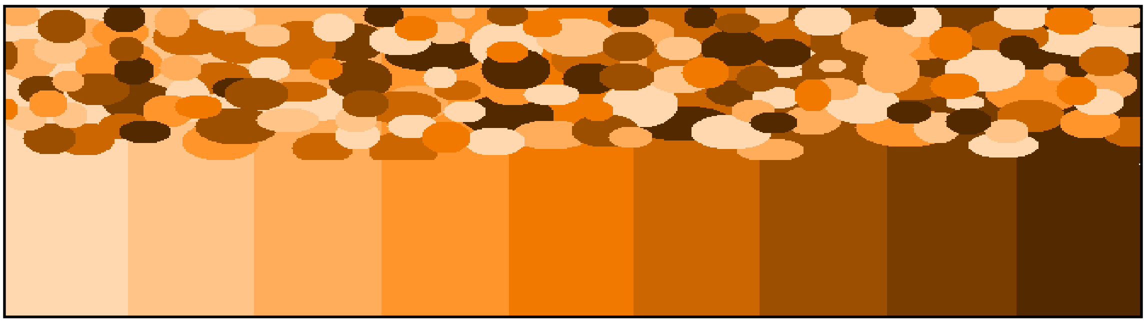

Figure 2-11. The picture is a representation of the so called "plug" in a plug flow biogas digester (and bag digesters). The colour represents the time it has been digested - darker symbolise long time and lighter short time. In the upper section, the plug has been disturbed; the contents have been mixed laterally. The lower section on the other hand, shows a perfect plug where the slurry close to the outlet, to the right, has been digested for a long time while all slurry near the inlet, to the left, has been digested for a short time. When more influent is added, at the left, everything will, in theory, move to the right and the content closest to the outlet, at the right, will exit.

A plug flow digester will have a higher yield compared to the types where the slurry is completely mixed (Marchaim, 1992: 68).

2.2.4.5 Bag Digesters

Big digesters are similar to the plug flow in their function. It is a long cylinder (the length:diameter is around 3:14 (Marchaim, 1992: 66)) made from PVC with a thickness of approximately 3-5 millimetres. The gas is stored in the upper portion of the cylinder. The gas pressure is achieved by the ―balloon effect" and weights (e.g. stones) on top (ESCAP, 2007: 6). Since it is easy to install (dig a trench) and is simple in its construction the cost is extremely low (ESCAP, 2007: 6) (Marchaim, 1992: 66).

Figure 2-12. Bag digester outside Nairobi, Kenya. The inlet is positioned close to the camera and the outlet in the far (picture from author).

Where exposed to sunlight the temperature inside the digester will increase, especially if the bag is black. The slurry in a bag digester is often two to seven degrees higher compared to the inside of a dome type plant (Marchaim, 1992: 67).

Although competitive, the bag digester has a lower life expectancy compared to other types. The membrane making up the cylinder is sensitive to puncture and weather conditions, such as the UV radiation in sun light (Marchaim, 1992: 67). Another disadvantage is the construction of the actual cylinder; taking place somewhere else and not creating local employment (ESCAP, 2007: 6).

2.2.5 Operation and Maintenance

Marchaim (1992: 139) identified poor maintenance of biogas plants as one of the key reasons of plant failure.

The following activities are vital to ensure stable operation (Rietzler, 2009: 23):

- frequent draining of condensed water from the gas;
- cleaning of stoves and lamps;
- oiling of gas valves and gas taps;
- cleaning of overflow outlet;
- checking for and fix gas leakage; and
- adding sufficient organic materials to slurry pits.

If maintenance is carried out regularly a biogas plant can have an operational life span exceeding 20 years (Rietzler, 2009: 23). When problems do arise with the plant, it is usually the appurtenances rather than the digester that is faulty. Where biogas-lamps have been installed they are, compared to the other parts of the plant, the most likely part to fail. In most cases the problems can be repaired by the owner (Chandararot and Dannet, 2007: 25) although a study from Bangladesh claims that the users do not usually have the capacity to manage even small technical problems (Quazi and Islam, 2008: 260).

2.2.5.1 Feeding the Digester

Livestock often graze outside during the day and are only kept inside or near houses (and the biogas system) during night. This makes it challenging to collect the dung for digestion (Rietzler, 2009: 24). Although challenging, a user survey In Lao DPR found that most users fed the digester every day (85 per cent). Most people used a correct dilution as well (also 85 per cent) (Rietzler, 2009: 27).

When feeding the biogas plant, the influent is collected in the mixing tank, which is a vessel connected to the digester inlet. It is collected either by pipes, channels or containers. When the influent has been collected in the mixing chamber, water (usually at the same amount as the waste) is added and mixed together with a stick, or similar (see Figure 2-13). When the mixture is liquid, a gate is opened so the feed-stock can flow into the digester (Koottatep, Ompont and Hwa, 2002: 94 -96).

Figure 2-13. The photo shows a woman mixing waste and water for her biogas plant. Notice that the mixing tank is uncovered and she is not wearing any protective clothing (Koottatep, Ompont and Hwa, 2002: 95).

The effluent will exit automatically from the outlet when influent is added. The outlet should however be washed with water after each time the plant has been fed. If the outlet is clogged, a wooden stick is usually all that is required to clear it (Koottatep, Ompont and Hwa, 2002: 99-100).

The previously mentioned user survey in Lao DPR also found that 76 per cent of users provide the needed influent from their own animals. However, 15 per cent report that they do not own any livestock at all – stating that they have neighbours who have enough manure from livestock for them to use (Rietzler, 2009: 24). Lack of influent in sufficient quantities have been reported in other cases as well. See Section 2.6.5 - Biogas and the Really Poor, for an example and how they solved the problem.

2.2.6 Technical Problems

There is limited research available regarding technical problems of the plant types used by households.

Technical problems reported are often caused by bad masonry work. The reasons for the bad masonry work include (Chandararot and Dannet, 2007: 19):

- leakage from valve and rubber hose due to carelessness;
- construction workers that lack skills;
- construction workers that do not pay attention to their work;
- waiting time until construction is long; and
- construction of plant was too long.

Chen et al. (2010) recently studied opportunities and constraints using biogas in rural China. The technical problems they identified were that the digesters were not properly designed for the influent and climate. The influent had high levels of cellulose, hemi-cellulose, lignin, pectin and wax in the straw (straw is used extensively as feeding material in China). The result is slurry with lack of effective nitrogen and phosphorous components, leading to an inefficient and time consuming process. Regarding the climate it was considered too cold in the northern regions, restricting the biogas process to eight or nine months per year.

It should also be mentioned that biogas requires access to water (ter Heegde and Sonder, 2007: 8).

2.3 Using Biogas as Sanitation in Low-Income Countries

To connect a toilet to a biogas plant is fairly simple. A squatting pan is installed which is usually connected directly into the biogas digester or a mixing chamber where other types of wastes can be added. The squatting pan requires 2.5 to 3 litres of water for flushing each time it is used (Sustainable Sanitation Alliance, 2009: 1-3).

2.3.1 Potential of Biogas to Treat Waste

The pathogenic removal in the biogas process has been studied since at least 1979. Marchaim (1992: 14) refer to Feacham et al (1983), McGarry and Stainforth (1978), van Buren (1979) and Klinger and Marchiam (1987), claiming that anaerobic digestion can reduce the parasitic and pathogenical counts by over 90 per cent. The subject has been researched in several studies (e.g. Wagner, Gstraunthaler and Illmer (2008) and Wagner et al. (2009)) after that but it is not clear how relevant those studies are for a small-scale biogas system in a low-income country sanitation context.

The only research identified, that studied bacteria reduction in actual biogas plants in low-income countries, was conducted in Nepal by Poudel et al. (2008). Pre- and post-samples were taken from institutional, household and experimental biogas plants, comparing total coliform and e-coli bacteria. The slurry was defined as ‗human and animal waste dominated" in half of the samples, and although it is unclear exactly what sample was taken from which plant, the majority of the samples had a harmful bacteria reduction of more than 99 per cent (refer to Table 2-2 for details).

Table 2-2. Reduction of bacteria in study of mesophilic biogas plants (Poudel et al., 2008: 185).

Reduction Load Category (log_{10})	No. of Biogas Plants
Total Coliform Reduction	
0-2	3
2-4	12
4-6	1
Faecal Coliform Reduction	
0-2	6
2-4	8
4-6	1

Another study, using a laboratory approach simulating ―Western biogas plants" found that when using a two stage digestion process, in the mesophilic range (12 days of digestion and 14 days of post-treatment), a coliform bacteria die-off of more than 99 per cent was reached (Horan et al., 2004: 1119).

No recent relevant research has been found that had studied how virus, *protozoa* (a line of microorganisms, some cause diseases) and *helminth* (a parasitic worm) eggs survive during anaerobic digestion. The research conducted has focused on heavily polluted waste (mainly from abattoirs) treated in thermophilic conditions or with separate heat treatments[4].

Marchaim (1992: 51) found that several studies have shown that human viruses such as Coxsachievirus, Poliovirus, Echovirus, and several others are to a large extent inactivated during anaerobic treatment. It is however unclear to what extent. Although viruses will not last long if they are unprotected, they can absorb to solids which will prolong their survival time. Marchaim concludes that more investigations are necessary – something that the author has not been able to find.

Anaerobic treatment is very effective against protozoa, such as Entamoeba and Gtardia. Eggs of parasites are, unfortunately, more resistant towards anaerobic conditions. The effectiveness depends on time and temperature (Marchaim, 1992: 50). According to a 1981 source, 90 to 95 per cent of parasitic eggs are destroyed while *ascaris* (a genus of parasitic nematode worms) are only reduced by 30 to 40 per cent (UNEP, 1981). But, a reduction of

[4] For example, refer to Sahlström et al. (2008).

helminths and other parasites is progress, even if some parasites remain. Some regions in China[5] reported large improvements where biogas plants were installed during the 1970's – even though the problem was not eradicated (Marchaim, 1992: 50).

A universal conclusion from several studies establishes that the retention time, together with the temperature, is the single most important parameters to achieve a high die-off of pathogens (Sahlström, 2003: 163) (Kim et al., 2006: 328).

The effluent should receive post-treatment to reduce the pathogens even more. Simple methods for post-treatment include storage in a compost pit or flown through a gravel bed or root treatment system. The *aerobic* (with air) conditions will remove pathogens and reduce bad odour. The effluent should be exposed to the post-treatment for at least two days (GTZ, 2007).

2.3.2 Current Users of Biogas as Sanitation

Although by many being considered one of the most appropriate technologies for treating human waste it has not been used widely outside of China (Karki, Shrestha and Bajgain, 2005: 65). According to George (2008: 126), the Chinese government claims that there are 15.4 million rural households in China that have their toilet connected to a biogas plant. Similar figures have been estimated by Rockström et al. (2005: 48) but according to Chen et al. (2010: 547), quoting the Ministry of Agriculture, only 2.65 million households use biogas (no mentioning of how many of those have a toilet connection). Liming (2009: 1098), quoting Hodes (2003), claims that 18 million Chinese households have biogas plants and two million household plants have been built every year. The author speculates if there is a mix-up of plants installed in China and the total amount. Nevertheless, biogas seems to be common in most rural regions of China (Chen et al., 2010: 546).

A Bangladeshi survey claims that it is unacceptable to connect a latrine to a biogas plant out of socio-cultural and religious reasons, see Section 2.3.3 for details. Still, 15 per cent of the households visited by surveyors systems had a latrine connected to them (Ghimire, 2005: 27).

ESCAP (2007: 22) puts focus on biogas as a solution to public toilets. They mention the *NGO* (Non Governmental Organisation) Sulabh that has installed 150 public toilets in India. According to Sulabh themself, they consider themselves to be the pioneering organisations within biogas generation from public toilets. They regard the sanitation part of biogas to be the most important benefit and claim that their design does not require any manual handling of human excreta. The reason for not implementing the technology earlier is said to

[5] For convenience, People's Republic of China will be referred to as –China" in this dissertation.

be that biogas has not been socially acceptable; something that people now have overcome (Sulabh International, 2010).

Another example is Nepal, where almost 20 000 plants were installed in 2004-2005 (ESCAP, 2007: 22), many of them with toilet connections (George, 2008: 126) (Karki, Shrestha and Bajgain, 2005: 65). Connecting the toilet to existing biogas plants has also been described as an ―increasing trend" in Nepal (Katuwal and Bohara, 2009: 2671).

2.3.3 Cultural, Religious, Personal Preference and the Reuse of Human Waste

Although biogas has been popular as sanitation in some regions it is less popular in other areas – even though they use biogas to treat animal waste. A survey in Lao DPR shows that it is very uncommon to connect a latrine to the biogas system (no one had done it). However, the majority of the interviewees saw no problem with such connection (see Table 2-3) but approximately 30 per cent had reasons why the idea was unacceptable.

Table 2-3. Responses on a survey regarding connecting a latrine to the digester in Lao (Rietzler, 2009: 28).

Response	Amount
No problem	67%
Gas from toilet attached plants are considered to be unsacred	13%
People are hesitant to handle the effluent from toilet attached plants	13%
Afraid of destroying biogas bacteria by toilet cleaner	7%

Some of the people in the Lao DPR interview are examples of people with an irrational fear of using treated and safe excreta. Another example can be found in Box 2-1 where a respondent tells of a tea stall which had to close when the customers found out that the tea was cooked using biogas made from human excreta.

Box 2-1. Quote from biogas user regarding treating human waste.

"I am in favor of attaching latrines with biogas digester. I know there is no difference between gas produced from cattle dung and night-soil. But what can I do? My father and mother do not allow me to attach toilet to biogas plant. I would have joined it if they had not opposed. Moreover, people do not accept food cooked with biogas produced from latrine-attached plant. I cannot overlook the incidence that took place in front of my eyes. The owner of the tea stall who had good business in the town had to close his business once the customers knew that the tea is cooked with biogas produced from latrine attached biogas plant."

- A respondent in Manikgunj (Bangladesh) replies on why he did not attach latrine to biogas digester (Ghimire, 2005: 27)

2.3.3.1 Cultural Reluctance

Although urine is considered quite harmless in most cultures (Avvannavar and Mani, 2008: 5) the case is not the same for faeces, see Box 2-2 for examples of historic urine usages. People who consider human faeces as something to "stay away" from can be classified as faecophobic while people who consider human faeces as part of the natural cycle can be classified as faecophilic (George, 2008: 124).

Box 2-2. Examples of historic urine usages in different cultures.

In Denmark urine was stored and used as detergent for washing clothes, and in nearby Sweden urine was used to smear wounds and dry skin. Several regions have also used it for production of gunpowder and tanning of hides (Höglund, 2001: 1). Other usages include therapy (in South Africa) and industrial purposes (Europe) (Avvannavar and Mani, 2008: 5).

Avvannavar and Mani (2007: 5-6) argues that the social disgust towards excreta has evolved with the enhancement of social stature. This has led to an idea of contamination, not by contamination itself. This idea leads to disgust, with the natural societal response of avoidance behaviour – by the physical contact as well as the sight and smell of it. However, the repulsion of excreta is changed significantly with the change of their physical appearance. Treated excreta are often looked upon with less disgust; Avvannavar and Mani conclude that "cultural avoidance of handling well-processed faecal material is little reported".

2.3.3.2 Religious Reluctance

Avvannavar and Mani (2008: 6) have investigated religious influences to excreta usage. For Islam they have found decrees associated to sanitation but most of them relate to the defecation process (e.g. not to face or turn your back towards Mecca) rather than the handling. Reuse of excreta is permitted as long as the impurities have been removed.

Another study of Islam and reuse of excreta has highlighted some problems. Quazi and Islam (2008: 250) argue that Muslims often profess the avoidance of all contact with human excreta, which are regarded as spiritual pollutants. They have, however, also found approval to reuse treated wastewater as granted by then Eminent Scholars of Saudi Arabia, even for purposes including religious washing (Quazi and Islam, 2008: 251). The author concludes that although there are no religious taboos against reusing human excreta in Islam, people may use it as an ―excuse" (and is therefore a cultural or personal preference problem rather than a religious one).

Avvannavar and Mani (2008: 6) states that no relevant decrees could be found with regards to Christianity.

In Hinduism, extensive use of water for hygiene is important as specified in the ancient scriptures *Artha Veda* (detailed code of conduct for rituals). The act of defecating is described in the 1 500 BCE scriptures Manusmriti Vishnuparan, and although extensive with different rules depending on gender, time of day, caste, travel, sickness etc. anything restrictive to reuse of excreta cannot be found (Avvannavar and Mani, 2008: 6).

In Buddhism the dimension of reincarnation also effects reuse of excreta. Excreta are treated as an earthly resource, and as all of life's treasures it should be treated in a harmonious concept of recycling (Avvannavar and Mani, 2008: 6).

Other religions' (e.g. Sikh, Animism, etc.) views of handling and re-using excreta have not been researched by the author.

2.3.3.3 People's Personal Reluctance

As previously mentioned, biogas has a very distinctive smell. There is also a risk of contaminating the ground and surroundings of the biogas plant with untreated waste which could attract flies and vermin. There is of course, also a risk of coming into contact with the pathogens when handling the waste and distributing the effluent if used as fertiliser. When exposed to these disturbances, even if to a small degree, it can cause people to feel disgust and reluctance. It would not be surprising if people rejected biogas technology due to the sight and smell of it.

The author has searched for research dealing with these issues. Numerous user surveys and pre-feasibility reports for biogas projects and programmes have been scanned as well – only one relevant piece of information has been found. Parawira (2009: 194) has studied biogas in Sub-Saharan Africa and found that some people were reluctant to use biogas due to the sanitary risk. They were afraid of coming into contact with the waste when maintaining the plant. Parawira dismissed the opinion since, he claims, it is possible to design plants so no manual handling of the excreta is necessary.

Even if it is possible to design plants so no manual handling is necessary, most plants available today are not, as can be seen in Figure 2-13, where a woman mix the influent. There is as mentioned, also a risk of coming into contact with the effluent if used in agriculture.

2.4 Using the Energy From the Gas

The energy obtained from the gas is, in most cases, the major reason for a household to invest in biogas. The energy in the gas can be transformed into a range of different forms, such as mechanical energy (to run machines) and heat (for cooking etc.).

2.4.1 Characteristics of Biogas

Biogas is primary composed of methane, carbon dioxide and small amounts of hydrogen sulphide (which is what gives biogas the characteristic smell of rotten eggs) and ammonia. There are also trace amounts of hydrogen, nitrogen, carbon monoxide, saturated or halogenated carbohydrates and oxygen. The gas is usually saturated with water vapor and sometimes small dust particles and *siloxanes* (chemical compound composed of units of the form R_2SiO) are present (Monnet, 2003).

Biogas has different levels of methane depending on the influent. A typical gas composition for a carbohydrate influent is 55 per cent of methane while an influent with high amounts of fats can create gas with as much as 75 per cent methane. Other factors such as temperature, pH and pressure will also have influence (Marchaim, 1992: 81).

The biogas is approximately 20 per cent lighter than air and has an ignition temperature of 700° C (FAO, 1996). The calorific value depends on the percentage of methane and pressure. Marchaim (1992: 81) claims 20-29 megajoule per cubic metre at one atmosphere while *FAO* (Food and Agriculture Organisation of the United Nations) (1996: 1-2) claims 20 megajoule per cubic metre as an average.

As a comparison, coal has a calorific value of 29 megajoule per kilo (Niu et al., 2010: 2071) and charcoal 33 megajoule per kilo (Hyman, 1986: 150). The energy available in firewood depends on type of wood, moisture and other variables which make it difficult to come up with a general value. But, the most common trees available in India (Jain, 1991: 182) and Botswana (Tietema et al., 1991: 44-45) both have calorific values between 16 and 20 megajoules per kilo, with some exceptions (the Indian *Gardenia Latifolia*, for example, has a value of 25.6 megajoules per kilo). For firewood collected from shrubs the calorific value usually varies between 16 and 18 megajoule per kilo (Singh, Khanduja and Srivastava, 1984: 318).

2.4.2 Expected Biogas Volumes

The available gas production will vary depending on environmental, feedstock, type of plant and maintenance factors.

The *specific yield* (volume of gas per volume of digester per day) for household biogas plants varies between 0.20 to 0.6 cubic metres of biogas per cubic metre of digester, according to Marchaim (1992: 64-67). According to his research the major impact is the climate – biogas users in hot climate zones can expect values of up to 0.6 while users in cold climates can expect the lower values.

Examples from different plants are shown in Table 2-4 where an average is estimated to 0.35 cubic metre of gas per cubic metre of digester. It should be noted that the listed data comes from different types of digesters, different climates and the gas have different qualities[6].

Table 2-4. Different sizes of plants and output.

Location	Plant Size (m^3)	Gas Production (m^3/day)	Specific Yield	Reference
Lao DPR	4	0.8-1.6	0.30	(Rietzler, 2009: 26)
Lao DPR	6	1.6-2.4	0.33	(Rietzler, 2009: 26)
Lao DPR	8	2.4-3.2	0.35	(Rietzler, 2009: 26)
Lao DPR	10	3.2-4.0	0.36	(Rietzler, 2009: 26)
Costa Rica	0.25	~0.065	0.26	(Lansing et al., 2010: 4364)
Hainan Province, China	6	2.4	0.4	(Bi and Haight, 2007: 515)

A biogas plant can be fed solely with kitchen and garden waste but the yield will be less compared to a plant fed with human and/or animal excreta. However, by mixing different wastes, a feedstock with close to ideal nutrient and chemical composition can be created. A Chinese-American study found that when they mixed cow dung with kitchen waste, at a 1:1

[6] A ―high quality biogas" is a gas with a high amount of methane and a small amount of carbon dioxide.

ratio, there was a significant increased biogas yield. The total gas increase is unknown, but the methane increase was 44 per cent compared to only digesting cow dung (Li et al., 2009: 2228).

When users in Cambodia were asked, the volume of gas produced was generally what they expected. When users are disappointed of the capacity it seems that the size of the digester have been chosen to provide gas for cooking and lighting, but later the household has installed generators for electricity (Chandararot and Dannet, 2007: 21).

2.4.3 Applications for Burning Biogas

Like other combustible gases, biogas can be used for a variety of applications (Sasse, 1988: 44).

2.4.3.1 Cooking and Lighting

Figure 2-14. Single burner biogas stove (left) and biogas lamp (right). Both are made by Indian company Rupak Enterprises (tradeindia.com, 2010). A LPG burner can be modified for biogas by enlarging the nozzle holes to compensate for the lower pressure.

Cooking and lighting are the primary domestic uses for the biogas produced. Due to the different properties of biogas (especially the low pressure) special biogas stoves has to be used rather than common *LPG* (a flammable mixture of hydrocarbon gases used as a fuel) burners. Refer to Figure 2-14 for an example of a biogas stove. Chinese and Indian burners usually have an efficiency of approximately 60 per cent (Marchaim, 1992: 81-82).

Usually 0.33 to 0.41 cubic metre of biogas is required per day per family member, or approximately 2.2 cubic metres per household, for cooking (FAO, 1996: C2, P5) (Marchaim, 1992: 82).

Using the data in Section 2.4.1 – Characteristics of Biogas, 2.2 cubic metres of biogas with a calorific value of 25 megajoule per cubic metre equals approximately 3 kilograms of fire-wood.

Miaha, Al Rashid and Shin (2009) studied how much firewood households in Bangladesh use per year for cooking. They found that the average family needs 4.24 metric tons of firewood, which equals 11.6 kilograms per day. The energy in 11.6 kilograms of firewood corresponds to 8 cubic metres of biogas. Another study has researched fire wood con-sumption in Lao DPR. They found that the average consumption varies between 6.8 and 8.2 kilograms of firewood per day and household (Mustonen, 2010: 1043), which corre-sponds to approximately 5.4 cubic metres of biogas. It should be mentioned that the study by Mustonen includes firewood for lightning and washing clothes as well.

It should also be mentioned that the energy efficiency is higher when using gas compared to fire wood. A traditional wood stove requires almost twice the energy to boil water com-pared to a gas cooker (Anozie et al., 2007: 1286).

The above data shows that the energy demand varies between regions, but that the figures from FAO and Marchaim are questionable if considered as general recommendations – 2.2 cubic metres of biogas per household will only be enough where the energy demand is low. A more realistic general figure would, using the limited data researched in this literature review, be anywhere from three to seven cubic metres – which, when using the findings in Section 2.4.2 – Expected Biogas Volumes, require a biogas digester of 6 to 17 cubic me-tres.

Lighting is usually generated by a gas mantle (the alternative is using an electricity genera-tor powered by a combustion engine fed by the biogas). High output lamps are quite un-common due to the required pressure. The highest efficiency lamps require a pressure of 0.4 metres of water, which can only be achieved from a fixed dome digester (Marchaim, 1992: 82). The low efficiency makes them very hot and if placed directly under the ceiling or other objects there is a fire risk (Sasse, 1988: 47). According to FAO (1996: C2, P8) 0.07 to 0.14 cubic metre of gas is required per hour for household lighting. Most lamps are manu-factured in India, and according to FAO (1996: C2, P8), they are strong, well built and easy to adjust. They do state that they are more difficult to operate and maintain compared to stoves, see Section 2.4.4 – Users' Experience of Using Biogas Energy, for other user opin-ions.

2.4.3.2 Generators, Engines and Refrigerators

By running mobile and stationary engines on biogas, the energy can be used to gain motive power, pump water, drive machinery or generate electricity. Booth spark and compression engines can be used, although spark ignition engines are the easiest to convert. Often the only modification needed is a gas carburetor and minor timing adjustments (Marchaim, 1992: 82). In a study by Tippayawon, Promwungkwa and Rerkkriangkrai (2007: 26) where they operated a biogas-modified single-cylinder direct-injection compression engine generators for 2 000 hours, they found that minor layers of carbon deposits were built up on the piston, combustion chamber wall, the intake port and exhaust valve stems. Although some minor surface wear occurred there was no deterioration in the engine performance. It performed well and they concluded it to have great potential for on-farm utilisation. It is unclear if the biogas was used ―raw” or if it was cleaned before use.

Biogas has also been reported to be used for refrigeration (FAO, 1996: C1, P15) and in Nepal biogas powered refrigerators are used to keep medicines and vaccines cool (FAO, 1996: C2, P8). There is however a risk using refrigerators due to the daily variation in biogas composition and pressure. According to Sasse (1988: 47) there is a risk for the flame to go off at every ignition. If this happens the gas will discharge without being burned, causing a risk for explosion. See Section 2.7.3 – Safety, for details regarding the explosive risk of biogas.

Due to the hydrogen sulphide and vapour that condenses, corrosive *acids* (a chemical compound that, when dissolved in water, gives a solution with a pH less than in pure water) may form during use of the gas. Combustion chambers and burners should therefore be made of cast steel or similar stain resistive material (Sasse, 1988: 45).

The hydrogen sulphide can be removed from the gas but it is usually a very expensive process. A study by Pipatmanomai, Kaewluan and Vitidsant (2009) suggests a process to purify the gas using two per cent potassium iodide impregnated activated carbon adsorption. The carbon boasts the activity of the catalytic oxidation to form elemental sulfur. It is simple and cheap compared to other methods (such as chemical absorption, which is only feasible in larger plants). They conclude that it removes all hydrogen sulphide but heavy subsidies would be required to make it possible for a family to use the technology (they do, however, highly recommend it).

Several gray literature sources (Aguilar, 2001) (Rural Costa Rica, 2007) (Integrated Energy Industries Pte Ltd, 2007) (Biogas hydrogen sulfide scrubbing project, 2009) mention the use of steel wool. By letting the gas pass through pieces of steel wool some impurities will be removed by oxidation. The steel wool will corrode taking up the hydrogen sulphide by converting it to black iron sulphide. The author has not been able to locate any published journal articles that deal with small scale plants and purifying biogas using steel wool[7].

2.4.4 Users' Experience of Using Biogas Energy

According to many case studies the main usage for the gas seems to be cooking (Chandararot and Dannet, 2007: 25), which is also something that users in general seems to be satisfied with. Many users report that the gas is easier to use than previous energy sources (Quazi and Islam, 2008: 260) and many households have reported that their health has improved since they started using biogas instead of wood and coal because it produces far less fumes (Katuwal and Bohara, 2009: 2671).

Few problems have been reported, although Chandararot and Dannet (2007: 26) found one woman claims she is afraid when lighting her stove. Some users have expressed a desire for auto-firing of the stoves to avoid release of gas, which the researcher seems as a possible indicator of unconscious discomfort (Quazi and Islam, 2008: 260).

Sasse (1988: 46) also has a comment on the appearance of stoves. He found that people were much keener to take care of their investment if they feel that it was modern and good looking.

According to Sasse (1988: 45) experience has shown that it is seldom worthwhile using gas from small plants to run engines. The literature review has not been able to identify any larger programmes where biogas is used by households to generate electricity. For slightly larger applications, such as churches etc., a few examples have been found in gray literature and video clips. A video clip published on the video website YouTube by ECHOAsia (2010) claims that the agriculture training centre featured in the video runs a three kilo watt generator for 45 minutes twice a day. The electricity generated powers light and an electric pump that extract water from the centre's well for storage in an elevated tank.

In Lao DPR most households investing in biogas technology already have access to electricity through the national grid. The implementing organisation has therefore argued that electrification could be used as an indicator for potential biogas users (Rietzler, 2009: 8,10).

2.5 Using the Effluent in Agriculture

When non-commercial fuel is burned, such as dung and agriculture residuals, it leads to a severe ecological imbalance when the nutrients, nitrogen, phosphorous, potassium, and

[7] On a side note, the author has tried using steel wool purifying gas used for a stove. Although it is unclear if it had any positive effect the process did generate rust on the wool. It also generated heat, while it may not be a danger in small scale, it is the author's opinion that care should be taken if using the technology in larger scale.

micro-nutrients are lost[8] from the ecosystem (Marchaim, 1992: 14). As seen below, that is not the case when using biogas – energy can be extracted at the same time as the high quality *fertiliser* (soil amendments with nutrients applied to promote plant growth) is obtained.

The effluent from a biogas digester is the residue from the inputs that exits from the outlet. It is an almost pathogen free (when the digestion process is successful, see Section 2.3.1) stabilised manure that can be used to maintain soil fertility and increase crop production (Sasse, 1988: C1, P15).

The nutrients in the influent are not lost during the digestion process. The nutrients are not only retained, but the fermentation also makes the nitrogen more available to the crops. The *bio-slurry* (another word used for the effluent, usually used in a fertilising context) also provides *humus*[9] thus acting as a *soil conditioner* (soil amendments without nutrients applied to promote plant growth) as well (Marchaim, 1992: 14) and is almost free from odour (ter Heegde and Besselink, 2005: 8).

2.5.1 Using Bio-Slurry in Agriculture – A Forgotten Research Subject

In 1986 Dahiya and Vasudevan (1986: 68) concluded that very few studies are available on using bio-slurry for crop fertilising. Their own study focused on using slurry compared to chemical fertilisers and unfortunately very little scientific material has been added since they published their work. Marchaim (1992) quotes several research works, which range from 1963 to 1988.

The belief that there is a total absence of studies during the last years is further strengthened when examining the references in the latest literature review found. Kocar (2008) refers entirely to pre-2000 sources when describing what is known of using biogas effluent as fertiliser. In the very extensive book ―Biogas as Renewable Source of Energy in Nepal; Theory and Practice”, the subject is described very well but once again the references are pre-2000. The year from which the references are used are visualised in Figure 2-15.

[8] Lost as in ―transferred to another state which cannot be easily reused”.
[9] Organic matter that has reached a point of stability, where it will not break down any further.

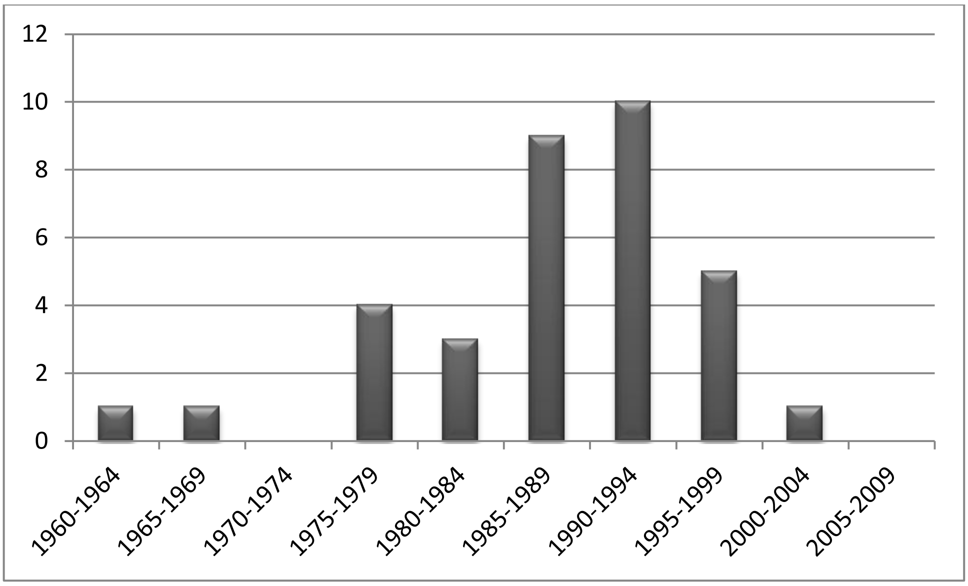

Figure 2-15. Number of references and year of publication (total number of references: 34) in the chapter Bio-slurry as Feed and Fertiliser in Karki, Shrestha and Bajgain (Karki, Shrestha and Bajgain, 2005).

Three large research projects were carried out by the Vietnamese Biogas Program in 2003-2004. They studied bio-slurry for use as fertiliser for vegetable production, crop production and feed stock for pigs (Biogas Project Office, 2006: 25). Unfortunately, the results have not been located by the author, in English or French.

2.5.2 Increased Crop Production with Bio-Slurry

Improving soil fertility by replenishment of nutrients has proven to be a very effective way of increasing the agricultural production. Usually the production is doubled or tripled on a sustainable basis through even a humble application of fertiliser (UNEP, 2007: 103).

In general, crop yields are increased when using bio-slurry as fertiliser. Most vegetable crops, such as potato, carrot, cabbage, onion, etc., and many types of fruits, such as orange, apple, mango, etc., appear to react favourably to biogas effluent. On the contrary, crops such as wheat, oilseed, and cotton react less favourably (ESCAP, 2007: 16).

Compared to most other fertiliser types, digested biogas effluent has a reduced rate of nitrogen washout, due to elevated ammonium content (ESCAP, 2007: 16).

The most common way of using the bio-slurry, at least in Cambodia, seems to be in its liquid form (approximately half) of users – even though it is possible to dry it before application (Chandararot and Dannet, 2007: 24).

In Vietnam the bio-slurry is used extensively as fertiliser and feed for animals. Improved harvests have been made and in some places pipes have been installed to share the abundance of slurry with neighbours (Biogas Project Office, 2006: 28).

More than 70 per cent of users in Cambodia are using the bio-slurry for fertilising purposes. The main reason for not using it is reported to be lack of agriculture land (Chandararot and Dannet, 2007: 23). Most biogas users learnt of bio-slurry at the start of construction of their plants. Some received information when the construction was complete but only four out of 108 visited household were aware that the effluent could be used as fertiliser before construction started (Chandararot and Dannet, 2007: 23).

From studying users in China van Groenendaal and Gehua (2009: 5) found that farmers did not use the bio-slurry correctly. They claim that there is a fundamental problem within the organisation and how they regard the benefits of biogas. According to them, biogas technology is treated too much as renewable energy and the fertilising effect of the bio-slurry just as an added bonus.

It is unclear exactly what happens with the effluent when it is not used in agriculture but there are examples where the effluent has been disposed in the open or directly into water bodies (Quazi and Islam, 2008: 256), in Bangladesh around 16 per cent – leading to *eutrophication* (increased concentration of nutrients) (Rietzler, 2009: 52).

2.5.3 Other Uses of the Effluent

The effluent can also be used for animal feed. It has been successful for fish ponds in South-East Asia where the farmers increase their income with the ponds or have it as their main source of income. Most farmers were satisfied with their ponds and claimed that their fish grow faster compared to those who did not add extra feed in their ponds. Nevertheless, the researchers concluded that proper use of effluent required more skills than is currently available to most farmers (Vu, Tran and Dang, 2007: 296).

Recent tests have been conducted using dried biogas effluent as fuel. The calorific value is of similar levels as wood. However, due to the characteristic odour the utilisation may be limited, at least in small-scale use (Kratzeisen et al., 2010).

2.6 Finance and Economy

Aspects relating to cost of biogas seems to be one of the topics, contrary to much else relating to biogas that has continued to be studied after the early 1990’s.

2.6.1 Cost of Biogas

In Lao DPR a complete biogas system for a household costs between US$ 350 and US$ 500 depending on the size, location and availability of labour and construction materials

(Rietzler, 2009: 21). In Cambodia the average price for the whole system is US$ 382 but some users report that they have lowered the cost substantially by employing extended family members or providing the labour themselves. For example, one man only spent US$ 160 for a four cubic metre plant by hiring his cousin – a trained mason (Chandararot and Dannet, 2007: 17). In Bangladesh a biogas system cost US$ 180-210 (Quazi and Islam, 2008: 259), in China US$ 450-820 (van Groenendaal and Gehua, 2009: 1) in India US$ 500 (Singh and Sooch, 2004: 1333) and in Vietnam US$ 360 (ter Heegde and Besselink, 2005: 5). Although most sources mentions ―complete system", it is unclear what the exact composition is and how it varies between them. However, it is likely that the cost in China (which includes renovation of kitchen, toilet connection, upgrade of pigpen etc.) reflects the actual cost for the user – where large-scale production is taking place.

Figures from Africa have been identified but the author regards them as unreliable due to the lack of any major implementation programmes. Amigun and von Blottnitz (2007) have written a very interesting article exploring how the price increases with increasing capacity. In their study they have collected costs from Africa for different plants concluding that a 4-10 cubic metre system will cost around US$ 1 000. The author suspects that the high cost, compared to Asia, origins in the low amounts of plants installed in Africa.

The cost of US$ 450 – 820 can be compared to the cost for different sanitation options in Table 2-5, although a biogas system provides more benefits than just sanitation.

Table 2-5. Average construction cost for different sanitation options in Africa, Asia, Latin America and the Caribbean, 1990-2000 (Paterson, Mara and Curtis, 2007: 903)

Sanitation Option	Construction Cost (US$)
Simple pit latrine	26-60
VIP latrine	50-57
Pour-flush toilet	50-91
Conventional sewer-age	120-160
Simplified sewerage	52-112

ter Heegde and Besselink (2005: 2) identify one of the significant problems of biogas as the considerable upfront investment in combination with limited access to fund by farmers. Subsidies are widely used but the farmers still have to pay around 75 per cent of the cost. ter Heegde and Besselink (who themselves work with biogas implementation) also claim that they are often under attack with what they call ―the sustainability argument" – how do they know that people really want and will take care of the biogas plant if they receive it for free? See Section 2.7.2 - Support by Implementers, for an example from Uganda.

A case study from South-West Tanzania reveals that the problem with the high investment is not limited to Asia. Mwakaje (2008: 2250) concludes that there are several opportunities for biogas in the district – a large number of households using indoor-fed cattle and pigs, high scarcity of firewood, large potential to generate job opportunities and many households that are willing to use biogas. Unfortunately, the cost of several hundreds of dollars is too high for most people to afford.

The subsidies available for households vary depending on location and implementing agency. In China the central government subsidy US$ 120 to US$175 per household, depending on location (Chen et al., 2010: 547), in India households receive US$ 40 (Singh and Sooch, 2004: 1333) while households in Lao receives US$ 130 to reduce the initial investment (Rietzler, 2009: 21).

There are micro-credit schemes and micro-financed initiatives where customers can borrow money at a low interest rate in order to invest in sanitation. It is available in Lesotho, Indonesia, Ghana, South Africa, India and Pakistan, at least (Paterson, Mara and Curtis, 2007: 905). Very few households seem to take loans to pay for the capital investment and the few who do it often borrow from friends (Rietzler, 2009: 23) (Chandararot and Dannet, 2007: 18).

Reliable data of maintenance cost have been hard to locate but the very informative “Technical Study of Biogas Plants Installed in Bangladesh” found that the average maintenance cost (in Bangladesh) was US$ 4.8 per year (Rietzler, 2009: 30), or 1.5 per cent of the capital cost for the biogas plant.

2.6.2 The Economic Benefits of Biogas

For the households using biogas there are two major economic benefits – the actual gas and the digested slurry. Although there are several other benefits, e.g. improved health etc. and numerous macro economic advantages, such as job opportunities, these are also considered to be gained with “competing” solutions, so they are not explored furthered in this dissertation.

2.6.2.1 Gas

According to ter Heegde and Besselink (2005: 8) the economic benefits of using the gas for cooking etc. is only noticeable when firewood is scarce and expensive. But, as with other resources, such as water, where people collect it for free spending their time rather than money they state it is hard to measure the exact benefits in finance terms. They continue with the results from a study in Nepal (without naming it) where the women collecting firewood saved three hours per day once they started to use biogas.

Gebrezgabhera et al. (2010), investigating larger biogas plants in the Netherlands conclude that the type of plants they have studied cannot be profitable but rather require subsidies. It is however not the results that are interesting (they studies offsite treatment on high cost land, generating electricity from the gas, has little resemblance to the situation this research is dealing with) but the approach. In their research the economic performance of the digestion for a specific plant is calculated using Net Present Value and Internal Rate of Return concepts. Refer to Appendix A – Brief Explanation of NPV and IRR Concepts for an explanation.

Singh and Sooch (2004) have used a similar but simplified method. They have a different opinion than ter Heegde and Besselink – saying it is very easy to set an economic value to the biogas and its value should be compared to that of LPG. In their example, they have therefore concluded that a six cubic metre plant will generate an income, or savings, of US$ 240 per year.

Mwakaje (2008: 2249) uses a model where the gas is valued using a combination of estimated time for collecting firewood and the market value for charcoal and kerosene. According to the article women spend three to four hours per day collecting firewood which would correspond to a cost of US$ 5 per month (it is unclear what this is based on). Using biogas should also decrease charcoal and kerosene consumption with US$ 5.5 and US$ 3.9 per month. Assuming not all firewood can be replaced; Mwakaje concludes that a household using biogas would save US$ 14 per month, or US$ 168 per year.

2.6.3 Effluent

According to ESCAP (2007: 16), no clear conclusions can be drawn with the regards to the economic value of using the effluent as fertiliser and soil conditioner compared to using chemical fertilisers. This official opinion from the UN office is argued against by several articles identified.

In the article, already mentioned, by Singh and Sooch (2004) the profit is calculated using a model where the value of the slurry is estimated by comparing it to commercially available fertilisers. In their calculations the value of the slurry from a six cubic metre will generate an income of US$ 90 per year.

ter Heegde and Besselink (2005: 8) claims that the slurry does not receive the attention it deserves, they say that most farmers do not recognise the increased value of slurry compared to the raw feedstock. Although hard to argue for with hard facts, it should be mentioned that several studies exploring the benefits of biogas does not calculate the added value of the slurry (e.g. Mwakaje (2008)).

2.6.4 Increased Income

Several studies conclude that biogas leads to an increased income, as described in this literature review, but it is investigated further by van Groenendaal and Gehua (2009). They oppose what they describe as “theoretical knowledge” (van Groenendaal and Gehua, 2009: 5) claiming that there is not enough empirical knowledge to support an increase of income among biogas users. First of all, they oppose the term “increased income” – pointing out that at best biogas will free up money and time, rather than generating income. Secondly they found, conducting research in a Chinese province, which the resources households spend on energy are not of a significant difference between biogas users and non-users. Finally, they also found that farmers, on average, using bio-slurry for agriculture actually use more commercial fertiliser than farmers using only commercial fertilisers. In their own words (van Groenendaal and Gehua, 2009: 9): “What was shown here is that the effects of the bio-digester on income from farming are actually small, and as a result the bio-digesters’ effect on poverty alleviation is also small”. But, they also conclude that more research on a larger geographical area is needed to validate the result. The overall situation with biogas described in the article stands out in contrast to the official Chinese opinion on their programme, as expressed in Box 2-3, or as in an article concluding that “The construction of biogas digesters leads to the obvious decrease of per capita energy consumption in rural families” (Xiaohua and Jingfei, 2005: 235). However, van Groenendaal and Gehua do not consider the Chinese biogas programme as a failure. They particularly mention the indoor and outdoor environmental benefits of improving kitchen and pigpens – something that is hard to put a money value on.

Box 2-3. Extract from a text describing a visit at a family using biogas (George, 2008: 129).

“Sitting on an expensive sofa next to a huge TV screen in Mrs Tien’s living room, I ask the officials if biogas has any disadvantages. They say there are none. Any problems can be dealt with by the technicians of the Biogas Management Unit, whose telephone number, since I ask, is 65980212.”

2.6.5 Biogas and the Really Poor

According to Quazi and Islam (2008: 259) biogas is not feasible for the poor due to high costs and lack of availability for biodegradable material. The claim is supported by several surveys. In Lao, 23.8 per cent of the households using biogas at least one household member had a bachelor degree (Rietzler, 2009: 7). This can be compared to the *gross enrolment ratio*[10], for tertiary level of education in Lao, of 13.4 per cent (World Bank, 2009).

In Lao DPR it has also been noticed that the households using biogas lives in ―good houses" (in this case usually brick houses) (Rietzler, 2009: 8) and that the average household income among the biogas users (in the survey) is approximately US$ 2 800, which 91 per cent of the users considered to be ―reasonable" (Rietzler, 2009: 10). In Lao DPR that means that a *HBP* (Household Biogas Plant) cost approximately 15 per cent of the annual income for a user (see Section 2.6.1 - Cost of Biogas).

Although too expensive for the poor to pay, Quazi and Islam (2008: 259) have some interesting comments on how the poor and rich can both benefit if the rich invest in biogas. They found that although they could afford to invest in biogas, the single household could still not provide enough waste to run the plant efficiently. In order to collect sufficient biodegradable material the owners had therefore installed toilets that were available for the community (or a limited amount of neighbours). The richer household would therefore have all the benefits associated with biogas while as the same time the poorer members of the community gained proper sanitation.

2.7 OTHER FINDINGS

2.7.1 Motivation by Households to Invest in Biogas Technology

When asking potential biogas users, in Lao DPR, why they invested in biogas, the main reasons and expectations include the wish for a cooking stove (41 per cent), saving time for other activities (31 per cent) and lighting (16 per cent). Other reasons mentioned are fertiliser replacer and fuel wood replacement. None mentioned hygiene and sanitation improvement (Rietzler, 2009: 14). The result is approximately the same in Cambodia where the reduction of firewood is the main reason for investing in biogas technology. Other reasons in Cambodia include (from major reasons to less) convenient cooking, saving time, smokeless kitchens, fertilising with the bio-slurry, lighting, get rid of foul smell and finally the subsidy provided (Chandararot and Dannet, 2007: 15). An interesting figure comes from Bangladesh where 47 per cent claims that environmental factors were a main motivational reason to install biogas (including saving the forests and having clean surroundings). It is also notable that the number one reason in the study is economic benefits (which the report specify as ―saving time and energy") while using the slurry as fertiliser is number nine on the list (Ghimire, 2005: 21), further indicating how the economic value of biogas effluent is neglected.

[10] Number of students enrolled in primary, secondary and tertiary levels of education as a percentage of the population of official school age.

The decision to invest in biogas for the individual household is often a conclusion by both the husband and wife in a family. Case studies has found that in less than half of the families it is a decision by the husband while in less than ten per cent of the cases the wives made the decision. However, in a majority of the cases it is a common decision by both husband and wife (Chandararot and Dannet, 2007: 16) (Ghimire, 2005: 22). In matters related to ―technical aspects" of the construction, e.g. location and selection of mason, the males often makes the final decision (Chandararot and Dannet, 2007: 16).

To implement biogas and make potential users to make an informed choice the user has to have knowledge of the following (Rietzler, 2009: 12):

- requirements for installing biogas plant (sufficient livestock and financial capacity);
- financing possibilities;
- advantages of using biogas (reducing cooking fuel, health improvements etc.);
- usage of the by product (replace chemical fertiliser by using the slurry etc.); and
- technical understanding of the plant.

Those households that have invested it biogas appear to be satisfied with their decision. In a user survey in Cambodia all plants visited were active and producing gas (Chandararot and Dannet, 2007: 22). Indications have also been found that the quality of Chinese biogas plants are good and the users will keep use them until they have enough money to pay for more easily available fuel, such as LPG, or stop farming because changes in local economic conditions (van Groenendaal and Gehua, 2009: 2).

2.7.2 Support by Implementers

Not much research is available regarding how implementers (e.g. governments and NGOs) support their present and potential users.

A few national biogas programmes publish user surveys. Three user surveys have been found that analyse the progress and the function of their biogas plants very thoroughly but do not reveal much regarding their follow-up. It can be found that the masons in Nepal and Cambodia usually have follow-up visits to the plants they have built (National Biodigester Programme, 2007: 24) (Integrated Resource Management Consultancy, 2007). A surprising finding is from Lao DPR, where 30 per cent of the users did not receive any kind of training and 26 per cent only received a leaflet, booklet or manual (Rietzler, 2009: 29). The fact that they have surveyed the users should indicate that they (the biogas programmes) also follow up on the problems they find. Unfortunately no confirmation of this has been found and the reports do not mention anything with regards to previous user surveys.

Chen et al. (2010) found that the programme in China did not have enough training, resulting in lack of combining the biogas technology with eco-agriculture. Instead, biogas is used only for lighting and cooking.

They (Chen et al. (2010)) also found that the programme had poor follow up services and management. The Chinese biogas programme focuses on construction of new plants and fails to consider management. The arguments they bring up include that only 60 per cent of the 26.5 million plants in the rural regions are operating normally, most provinces only have small county level rural energy offices with a staff of three to seven employees, staff are unable to adapt to new developments in technology and lack of biogas lamps, stoves and similar equipment on the public market.

A study in Uganda reveals that there is a need to further improvement of support services, financial incentives and technical information. The study claims that governments and donors are rarely available to provide the technical support required to maintain the systems. Since many households only pay a minimal installation fee, they regard the systems as externally owned, especially when problems occur, and expect support to maintain them. The systems often break down completely or are abandoned (Walekhwa, Mugisha and Drake, 2009: 2761).

The promotion of biogas seems to be limited as well; at least outside of South East Asia (the previously mentioned user surveys give examples of promotion by poster campaigns etc.). To deal with this problem the Biogas for Better Life initiative was launched in 2007. Their aim is to provide 2 million African households with biogas by 2020. At the moment they are working mainly with promotion and establishing contacts (Ukpabi, 2009). Their current progress is unknown but at the moment this is the only identified larger imitative to promote biogas in Africa.

2.7.3 Safety

Biogas mixed with air at a five per cent composition[11] is highly explosive. Pipes and other sources of leakages in enclosed spaces are therefore a hazard (Sasse, 1988: 44). Biogas is lighter than air and will therefore elevate up towards the sky, compared to LPG that is heavier than air and therefore remain on the ground if leaking. There is a risk that leaking biogas will be caught under roofs etc. and areas where biogas are in use should therefore be well ventilated. There is a small risk that biogas will backfire when used for combustion so proper flame traps should be used between the where the gas is burned and the storage vessel or digester (University of Adelaide, 2010). Refer to Appendix B – Sketch of a Simple Flame Trap, for an example of a flame trap.

[11] The exact percentage varies depending on the amount of methane (Pipatmanomai, Kaewluan and Vitidsant, 2009: 670).

Up until 1988 no explosions were reported (Sasse, 1988: 44). The author has tried to find any reference to explosions after 1988 using research articles, gray literature and online news media. Only one accident has been found and it did not involve a household plant. The accident occurred in India 2009 during the final phase of the construction of a large biogas waste treatment plant. The system had been filled with large quantities of waste before being finished and then exploded, killing four construction workers. The cause of the actual explosion is, according to the 2009 new article, unknown but according to the police the owners failed to take necessary safety measures (The Hindu, 2009).

Hydrogen sulphide, which is present in biogas, is poisonous even at low concentrations – it kills instantly at a 0.117 per cent concentration and within 30 minutes at 0.05 per cent (Marchaim, 1992: 84). Biogas from farms usually have a concentration of 0.0036-0.0115 per cent (Rasi, Veijanen and Rintala, 2007: 1377). The gas should therefore not pose an extreme threat to human life if inhaled, but can still cause health implications. However, if biogas is released into air the concentration will of course be even lower so the author considers the risks extremely low.

2.8 SUMMARY OF REVIEWED LITERATURE

The literature review has revealed interesting data and analyses by others. The main findings will now be presented and in some cases discussed furthered.

There are three major benefits of using biogas for households; sanitation, energy and increased (or maintained) crop production by bio-slurry. While using untreated or composted waste, only one benefit will usually be achieved. Dung, for example, can be burned or used as fertiliser but not both. When using biogas, both the energy in the gas as well as the fertilising effluent can be used.

Different types of digesters have been developed during the years. The types used by most households today have been designed at least 20-30 years ago, although minor improvements and modifications have taken place. The designs do have shortcomings; such as being expensive, require manual handling of waste and effluent and difficulties to maintain gas tight.

Research has shown that anaerobic treatment used in biogas plants by households can reduce the dangerous bacteria count by 99 per cent. It has also shown that there are occasions where the process fails and bacteria decrease less. The anaerobic process is also less effective against pathogen eggs and there is a lack of research regarding the effect on viruses. Biogas effluent should therefore be handled with care and post-treatment is recommended.

In theory, a biogas plant can digest most organic materials, but the process will be much more effective if the influent fulfils proper parameters. Most references claim that households have sufficient amounts of waste available, but that there are also those who lack the required amount. The amounts are considered high for an average household. For example, a HBP with a digester volume of eight cubic metres will require 90 litres of waste each day[12].

During the last years, the usage of toilets in combination with household biogas plants has been increasing – up until the 1980's it was mainly limited to China. Still, many are reluctant to use bi-products of human waste. Cultural reasons are part of the reluctance but studies have found that most cultures are tolerable as long as the waste has been treated. There are also potential users that refer to religious reasons for not using biogas, something religious experts and authorities do not agree of (at least for Islam, Christianity, Hinduism and Buddhism). There are probably personal reasons of not using biogas that are covered by cultural and religious excuses, but there is a lack of research in this area.

The biogas generated during the anaerobic process is the main benefit people are looking for when investing in an HBP. It is questionable if a HBP is able to supply an electricity generator or any kind of combustion motor.

The bio-slurry generated by the anaerobic processes is suitable to use in agriculture – even more than the influent put in the digester. Where used, most farmers are satisfied with the effects' of the bio-slurry but there is a problem if it is not being used, which pose as an environmental risk. There is also a lack of research regarding how to use the bio-slurry in order to increase crop yield as much as possible.

A HBP will usually cost US$ 450-820 including kitchen improvements and all necessary appurtenances. This cost is very high for most rural households in low-income countries. Implementing organisations normally subsidy the cost, which enables more households to afford biogas. If the subsidy is too high the users have a tendency of not caring and maintain their plants.

The economic benefits of the biogas and bio-slurry are a highly debated topic. Since biogas for cooking stoves often replaces fire-wood, which is collected for free, there is not actual money that will be saved by using gas. They are opposed by those that claim that they spend time collecting fire-wood, time that could be used for income generating activities.

[12] A digester of 8 cubic metres will have 2/3s available for slurry, the rest being used for gas storage. Assuming a retention time of 30 days, 1/30s of the slurry will have to be replaced each day. Also assuming the influent is mixed with water at a 1:1 ratio, approximately 90 litres of waste is needed every day.

Although there are several major biogas programmes around the world it is unclear how successful they are. A lot of HBPs are being built but the numbers of HBPs being built is unfortunately the main measurement from the implementing organisation how successful they are.

2.8.1 Evaluation of Reviewed Research

The literature has used a variety of references, such as journal articles, books, manuals, user surveys, reports, feasibility studies, news articles and a video film.

The quality of the literature used is considered good in most cases and where different references discuss the same topic similar figures and data have usually been found. An example of where the references have not matched each other can be found in Section 2.3.2 - Current Users of Biogas as Sanitation, where the current users of biogas in China are discussed. And it should be mentioned that China is a special case. There is no doubt that China is the leading nation when it comes to biogas as sanitation. However, it has been hard to identify references in English that are available to the public. Although it is hard to find up-to-date Chinese biogas literature in English it should also be mentioned that the Chinese Biogas Institute has assisted other countries in developing national biogas programmes (e.g. Romania and Rwanda) (George, 2008: 127).

The type of research methods used in the reviewed literature has varied depending on type of research. As shown in this review, biogas is a very broad subject. It involves chemistry, mechanics, social science, biology, thermodynamics, hygiene science and much more.

Literature involving natural science, such as those investigating how effective the anaerobic processes kill pathogens, how much gas that will be generated etc. have of course used proper scientific methods for their particular field of science that gather observable, empirical and measurable evidence.

The literature dealing with how biogas technology has been working when used in reality has used either qualitative or quantitative methods.

Most journal articles have used case studies with a limited number of households that have been surveyed and evaluated, while some have used qualitative methods on a larger scale involving a lot of travel and semi-structured interviews. The author is of the opinion that most articles have used a good methodology, perhaps with exception of a few examples where figures from *GO*s (Governmental Organisations) have not been further investigated. Once again, see Section 2.3.2 - Current Users of Biogas as Sanitation for an example.

The user surveys have all used quantitative methods were a large portion of the users (in some cases all users) have been approached to participate in structured interviews or questionnaires. The data has then been analysed, probably with the help of computer software, and conclusions drawn upon the outcome from the analysis. The author considers the surveys as being of high quality. However, in some cases the methodology can be questioned if it really is the most appropriate to achieve the goal of the survey – which is to improve the performance of the biogas plants and maintain or increase the programme. It may be that the programmes do more surveys and collect other information as well, but the author of this dissertation would have found surveys asking not only the users but also the employees of the programme and contractors used for construction valuable when investigating the programmes performance.

The most important piece of literature identified is the book Biogas Processes for Sustainable Development by Marchaim (1992). Although almost 20 years old it is still the most comprehensive piece of literature dealing with small scale biogas. In his introduction he claims that most technical data dealing with small scale biogas relies on experience from the floating drum and fixed dome type of digesters. He described, what he calls, “promising new techniques” such as dry fermentation, plug flow and similar. Unfortunately the research has not been continued – at least not developed to the extent that Marchaim looked forward to. Journal articles have been published but the scattered knowledge in them has not been collected, in for example a book. Where attempts have been made the main sources of information is mostly pre-1995. One example is Kocar (2008), where a visualisation of his references used in his research show a distinctive peak during the early 1990’s (see Figure 2-15). Another example is the Biogas Handbook by D. House, published by Alternative House Information (2006), a book with the latest reference published in 1981[13].

The author has had a look at a preliminary version of a technology review by *GTZ*[14] (Deutsche Gesellschaft für Technische Zusammenarbeit). It is refreshing compared to other literature since it does not follow the habit of the other publications but uses mostly recent published material. Unfortunately it is quite short rather than an extensive book.

Research on biogas for the high income countries has also decreased. At least according to an article by Holm-Nielsen, Al Seadi and Oleskowicz-Popiel (2009: 5483), who claims that the western style plants moved forward with “huge steps, in terms of maturation of biogas technologies and economic sustainability” during the 1990’s.

No other research has been identified dealing with as broad a topic as this one. Where similar research questions have been asked it has been applied to a local context using methods were a large sample size of the total population has been approached. No re-

[13] The author has not had access to the actual book but the content and reference lists are available online, http://www.completebiogas.com/toc.html [4 August 2010].

[14] GTZ (2010) *Biogas sanitation for blackwater, brown water, or for excreta treatment and reuse in developing countries*, Eschborn, Germany: GTZ [Unpublished as of 4 August 2010].

search has been identified using a method were experienced people involved in different biogas programmes has been questioned.

This chapter has introduced biogas, and has mentioned some of its limitations. The research gaps identified have also been addressed as well as how other studies have approached the subject. Chapter 3 will now introduce the methodology used in this research.

3 METHODOLOGY

As previously mentioned, this research will answer the following research questions:

1. What are the benefits of using biogas in low-income countries?
2. Why have many of the benefits not been delivered?
3. What are the solutions to the limitations?

In order to answer the above questions a research methodology has been prepared and implemented. In this chapter the details of the methodology and the reasons behind its choice will be explained.

3.1 CHOICE OF RESEARCH METHODS

As concluded in the literature review, the previous research has focused on observations, interviews and case studies. This has produced data and conclusions for household biogas in different regions of the world, but no one had brought the conclusions together.

Research question one deals mainly with the potential benefits and can be answered using existing literature. Research question two and three can partially be answered with existing literature. However, due to the lack of published material dealing with those specific questions, information needs to be received from people in the field with knowledge and experience.

To collect this data, a combination of qualitative and quantitative research methods was considered necessary. By using qualitative and quantitative methods together, the results will cross-check each other, achieving a triangulation of the results.

As qualitative method the interview was regarded as suitable. Although focus groups and group interviews has potential to reveal in-depth data by challenging the participants (Bryman, 2001: 338) it would pose an logistical problem to gather the limited experts to the same location. The interview, and its exact type, is discussed further in Section 3.4.1 – Type of Interview.

As quantitative method, a questionnaire survey aimed towards experts was considered as the best option. Data could be collected directly from the users, but it would require numerous respondents to collect data that is representative for the users worldwide. By running the survey online, experts from a wide range of projects, regions and backgrounds would be able to respond and share their experience. The questionnaire survey is discussed more in detail in Section 3.3 – Questionnaire Survey.

But before describing the interview and questionnaire survey, the methodology for the literature review will be presented.

3.2 LITERATURE REVIEW PROCESS

To explore the context of the research subject a literature review was considered necessary. The review aimed to identify, evaluate and interpret published material by researchers, scholars and practitioners, as recommended by Blaxter, Hughes and Tight (2001: 120).

The literature review is mainly used to answer the first research question about the benefits of biogas.

3.2.1 Search Strategy

The search for literature was divided into three steps or phases in order to maintain a structured strategy.

3.2.2 First Step – Preliminary

Early in the research, a preliminary literature review was used to collect data for an overview of the subject and to help specify suitable research questions.

Sources included the *WEDC Resource Centre* (Water, Engineering and Development Centre) and Internet searches using Google. General information on biogas could be found, however, none of the references from the resource centre has been referenced in the final review due to its age.

3.2.3 Second Step – Core

Most of the literature referred to in the review was found during the core step. First, the literature found during the first step was –snowballed”, i.e. the references in that literature were followed to find more literature. The strategy, combined with using Metalib, ScienceDirect and SpringerLink (three online search engines for finding articles published in scientific journals), identified many high-quality articles. Unfortunately, but as excepted, articles dealing with this research main topic, the present overall situation for HBPs, could not be located.

Examples of word used for searches are shown in Box 3-1. Usually they have been used in different strings, combinations and with truncations to allow different endings. One example of search sting used is –biogas AND rural AND constraint? OR problem?”.

Box 3-1. Words used for searching.

Biogas	Anaerobic	Waste	Treatment	SHTEFIE	Gas stove
Rural	Sanitation	Eco-san	NGO	Program/me	Floating drum
Constraints	limitations	Pathogen	Kill-off	Asia	Hazard
Problems	Energy	Sustainable	Bio-slurry	Institutional	Promotion
Low-income	Fertilizer	Gobar-gas	Fixed dome	Fixed dome	Religion
Developing	Africa	Industrialized	User-survey	Support	Gender

Journal articles were complemented with so called grey literature, i.e. articles and reports often published by NGOs, governments, UN branches and individuals not associated with universities or research institutes. Grey literature often lacks ―full disclosure" so extra care needs to be taken to confirm its reliability and objectivity. Some of the organisations and websites used to find grey literature are identified in Box 3-2.

Box 3-2. Organisations and their web-sites used for searching.

SustainableSanitationAlliance (http://www.susana.org/)	IRC (http//:www.irc.nl)
SIDA (http://www.sida.se/English/)	GTZ (http://www.gtz.de/en/)
WaterAid (http://www.wateraid.org)	SNV (http://www.snvworld.org/en)

A large amount of time was spent to identifying books. However, as mentioned in Section 2.8.1 - Evaluation of Reviewed Research, no relevant books dealing extensively with bio-gas have been produced since the early 1990's. Older books have been used mainly as a reference for biogas in general rather than the exact topic of this research – constraints and problems afflicting users today.

Google Scholar has proven to be useful for finding articles that referenced other articles. This was used to search for known articles with useful conclusions, thus seeing if any newer articles have been published in support or contradict. Although other search engines have an automatic function to do this it was found that it was more reliable to do it in a ―manual" way.

Efforts was made to identify literature from several sources and where sources contradicted each other this has been furthered investigated and in some occasions pointed out in the written review.

3.2.4 Third step - Confirmation

As a final step, before finishing the research, the search engines and websites were used again. The purpose was to ensure that no new relevant research had been published. Unfortunately, due to a limited amount of time, this step could not be conducted as thoroughly as desirable.

3.3 Questionnaire Survey

The questionnaire survey was conducted in three steps;

- identify the most appropriate questionnaire tool;
- design the questionnaire; and
- invite respondents to participate.

Each of the stages will now be described in detail.

3.3.1 Questionnaire Tool

Several online tools for publishing questionnaires were found using Google, recommendations from research fellows and dissertations in the WEDC Resource Centre. Quite soon it became obvious that there are numerous tools available that enable easy creating and publishing of professional-looking questionnaires. Most of them were discarded due to costs, since there were quality free-of-charge options available. Five free tools, or ones with a free trial period, were evaluated and among those a UK-based company named Kwik Surveys was selected. The five options are presented in Table 3-1.

Table 3-1. The five survey providers evaluated and their main reason not being chosen.

Tool Name	Web Address	Constraint
SurveyMonkey	http://www.surveymonkey.com/	Limited to 20 questions
FreeOnlineSurveys.com	http://freeonlinesurveys.com/	Limited to 20 questions
surveygizmo$_{TM}$	http://www.surveygizmo.com/	Limited to 14 days of free trial
smart-survey^{TM}	http://www.smart-survey.co.uk/	Limited to 50 responses per month
Kwik Surveys	http://www.kwiksurveys.com/	-

Kwik Surveys has an unlimited response limit, unlimited number of questions, high security and good anonymity for the responders. There are numerous types of questions and types of answers. When extracting the data it can be analysed for each respondent or as a collective. Although completely free of charge to use, Kwik Surveys encourage donations (Kwik Surveys, 2010).

3.3.2 Design of Questionnaire

The main purpose of the questionnaire survey was to confirm the findings of the literature review and find answers to the questions that were not answered by it.

The questions were developed using the findings from the literature review, see Section 2.8 - Summary of Reviewed Literature. To do this, the questions were designed in five blocks; see Figure 3-1 for the contents. Each block incorporated questions dealing with performance, costs and social issues, among others (see Appendix D – Questionnaire for the complete set of questions).

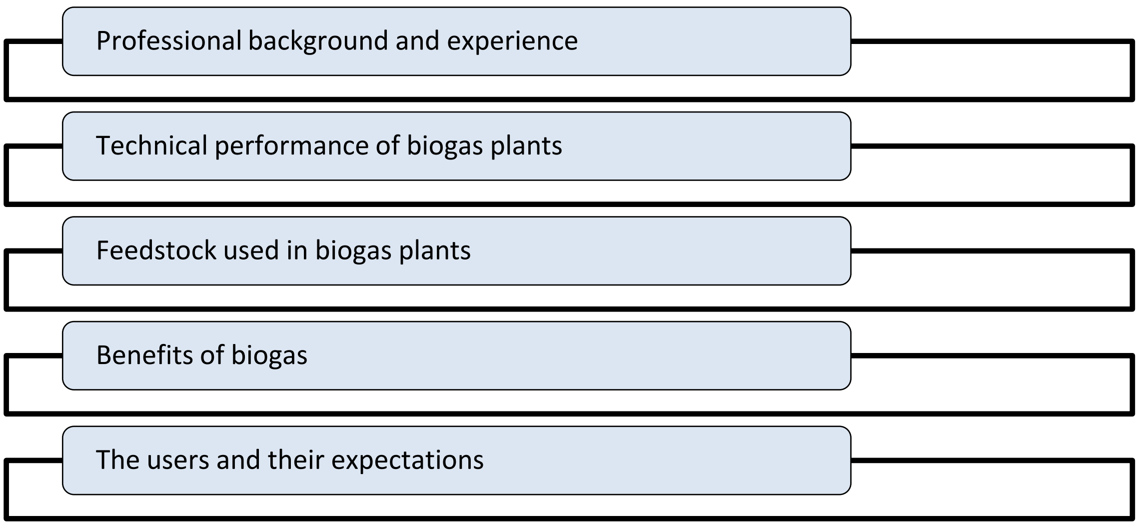

Figure 3-1. The blocks of the questionnaire.

To be able to have several questions, thus being able to collect data on a variety of subjects, the majority of questions were designed as closed questions. Closed questions, which are questions with a limited range of answers, will be less time consuming for the respondents compared to open questions. They do however have a tendency of bringing the conversation to a stop (Barr and Birn, 2004: 55-56) and do not encourage the respondent to reflect on the question. This will therefore limit the depth of the question and its answer.

At an early stage of the research it was found that it would be difficult to find experts willing to participate in an interview, see 3.4.3 – Interviewees . In order to collect more qualitative data it was therefore decided that every question should have a textbox where the respondent could enter any additional comments that he or she thought was relevant. This would allow respondents who felt that they were not able to spend too much time participating in the survey to finish the survey in a short amount of time. Those that were willing to spend more time could on the other hand elaborate on their answers.

To further increase the qualitative data, an option was added in the end of the questionnaire where the respondent could enter his/her email address for further questioning or clarification.

The questionnaire was limited to 30 questions to lessen the time needed to complete it. It was also given an appealing design to encourage people to complete it. In its final stage it was tested by research fellows who gave opinions on the type of questions, proof-read, estimated the time needed to complete it and evaluated its technical functionality. It was also evaluated by a WEDC associate who assessed it from similar standpoints.

3.3.2.1 Ensure Respondents with Proper Knowledge Participate

Since a link to the questionnaire was sent to open email lists there was a risk of non-professional answering the questionnaire without proper knowledge. Two measures were taken to solve this problem.

The first measure was an open design of the questionnaire. Instead of having to answer all the questions on each page before being able to access the next page, participants were allowed to move between pages without having to answer. This made it possible for curious people to stroll through the entire questionnaire without answer questions.

The second measure was to create a few cross-referencing questions. For example, a implementer active in China would raise suspicion if he/she has the floating drum biogas plant as his/her only experience.

3.3.3 Questionnaire Survey Respondents

The questionnaire aimed to gather knowledge and experience from an as broad a spectrum possible. The spectrum would ideally include implementers, researchers and commercial actors.

Respondents have been found using a combination of contacts, online forums, email lists and secondary contacts. Secondary contacts are those that have been identified via already established personal contacts, or have come into contact with the research without the right background, but have shared details of their their own contacts – a snowballing approach similar to that used in the literature review.

To promote a high response rate, other than those previously mentioned, a reminder was sent to the contacts before the questionnaire was closed.

It should also be mentioned that contact was made with potential respondents prior to the actual survey. This was to scan the potential and profile the respondents' background in order to identify which groups were not represented.

The process of how respondents were invited is described further in Section 4.2 – Questionnaire survey.

3.4 INTERVIEWS

The interview process went through similar stages as the survey:

- decision on type of interview;
- design of questions; and
- identify respondent and conduct interview.

Each step will now be discussed.

3.4.1 Type of Interview

Interviews can be a very useful technique for collecting data that would not be accessible using other techniques such as observations and questionnaires (Blaxter, Hughes and Tight, 2001: 172). To find as much qualitative data as possible, but at the same time not go off topic during the interview the semi-structured interview was believed to be suitable.

Due to limited people with the desired background available for face-to-face interviews in the author's geographical area, it was decided to use Skype[15] instead.

To record the conversations different options were considered. The options included a regular recorder positioned close to the speakers or software to do it digitally. The first option was discarded due to the risk of bad audio quality. Different software options were therefore evaluated using a similar method as the one for evaluating the questionnaire tool options; see Section 3.3.1 – Questionnaire Tool. In the end, the software Pamela for Skype[16] was selected together with the author taking notes. It should also be mentioned that the interviewees were informed that the conversations was recorded.

3.4.2 Design of Questions

The questions were selected in a similar way as for the questionnaire; see Section 3.3.2 – Design of Questionnaire. By using the same framework, the results would be straightfor-

[15] Skype is a computer software for telephone like conversations. It can be used to call people with a Skype account as well as to regular telephones.
[16] Available at http://www.pamela.biz/en/ [11 August 2010].

ward and easy to compare to the questionnaire survey. The wording of the questions was rephrased to encourage detailed and freethinking answers and the question alternatives were removed. Thought was also given to minimise the personal information that would be revealed,

The answers were followed-up by more questions for clarification and details. The questions can be found in Appendix C – Interview Questions.

3.4.3 Interviewees

Initially interviewees were identified at the same time as searching for questionnaire respondents. However, it became obvious that when people had a ―choice between two options”, one being a quite simple questionnaire and the other a time consuming interview, the latter was very much overlooked. The strategy was therefore changed where people were asked only if they were willing to participate in an interview and if rejected they were given the option of participating in the survey instead.

Other than that, the interviewees were identified using the same process as for the questionnaire respondents; see 3.3.3 – Questionnaire Survey Respondents.

3.5 ANALYSING DATA

3.5.1 Analysing the Questionnaire Survey

Using a computer programme designed for statistical analysis, such as SPSS, was considered. But, since the number of respondents was so limited it was considered more time efficient to use a simple program that the author had previous experience of. Microsoft Excel 2007 was therefore used for all quantitative analysis.

The first step when analysing the data from the questionnaire survey was to export it from Kwik Survey. All data came tabulated in an excel-file which could be manipulated by the user.

An unedited master copy was created to ensure that the raw-data would not be manipulated by mistake.

The data was then sorted further and diagrams sketched to visualise the data. This made it easier to find links between the data and come up with conclusions. The most important graphs were then exported from Excel into the text editing software.

3.5.2 Analysing the Interviews

The interviews were analysed using a method where the answers were organised into categories. Patterns were then identified and conclusions could be drawn from those.

3.6 Ethical Issues

As all research should (Blaxter, Hughes and Tight, 2001: 154), the ethical issues has been addressed when designing the methodology and analysing the data. Due to the nature of this research, the ethical issues are considered minimal since:

- the vast majority respondents were familiar with social research;
- the answers to the questions do not reveal any personal information from the respondents or persons they are referring to; and
- the subject is not of a sensitive art.

Although minimal ethical issues, it cannot be denied that if some of the data is tracked back to certain individuals they may be compromised. E.g. a person criticising the organisation he/she works for may suffer from negative treatment from it. Care has therefore been taken to:

- guarantee complete anonymity;
- clearly communicate the purpose of the research with the respondents;
- delete all data on third party assets when the research was finished ; and
- act professionally when communicating with the respondents.

3.7 Limitations of the Methodology

There are limitations to the methodology used in this research. Due to the limited people with experience within the research field as well as a limited sample size there is a risk for bias.

It can be argued whether or not the partly snowballing approach to find respondents is random. By using someone who know someone else (and who know more people, and so on) there is a risk that segments of the populations is not reached. Care has therefore been taken to use as many channels as possible and contact people that do not have a known link between them.

A second risk is a potentially inadequate sampling frame, i.e. the type of people used in the research (“the experts”) does not have the proper knowledge. The alternative would be to use the users themselves, something that already been argued against in this methodology. However, the users’ opinion will be compared to the experts since the literature review incorporates several user surveys. A cross check is therefore performed when comparing the literature review outcome with the interview/survey outcome.

The third risk identified is the issue of non-response. Those who agree to participate may have a different opinion compared to the ones who refuse to participate (Bryman, 2001:

86). To minimise the risk of excluding a group/opinion/view due to this problem the researcher aimed for a high response rate to evaluate the characteristics of the respondents from this point of view.

The final source for bias identified is the language used in the interviews, questionnaire survey and invitations to them. Since English has been used there is a risk that people with valuable knowledge will reject the invitation or avoid detailed answers due to lack of confidence in using English. The questions were therefore designed without too many complicated words and in some cases the respondents have been offered to answer in other languages.

3.8 Concluding Comments

This chapter has been the bridge between the research questions and the data collection. It has described and justified the methodology applied to gather and analyse the data. The next chapter will describe the output of data obtained when the methodology was used.

4 DATA AND ANALYSIS

This chapter deals with the analysis of the data collected. The chapter includes a presentation of the results as well as discussion of the findings.

The interviews will be described first. A short introduction and description will be followed by the outcome and summary of the findings. After that the questionnaire survey will be described with a similar structure: description, results and a summary.

4.1 SEMI-STRUCTURED INTERVIEWS

Two interviews were held in July 2010. The background of the first interviewee can be described as having an overview of household biogas and other technologies dealing with energy, sanitation and agriculture. The second interviewee has a very in-depth perspective with a lot of detailed knowledge.

4.1.1 Background Information

The interviews were held to answer the research questions as well as gain knowledge and an overview from the practitioners of biogas, as further described in Chapter 3 – Methodology.

4.1.1.1 The Interviewees and the Interview Processes

The first interview was held with a consultant employed by a large government organisation. During the last years he has been evaluating agriculture development projects in Asia and Africa. The projects evaluated have mainly been dealing with income and suitability of using different animals by small to medium scale farmers in poor rural regions. He has evaluated biogas projects, but those have mainly involved larger plants. While not actively involved in small-scale biogas he has come across numerous projects and plants around the world. In the text and quotes, he will be referenced to as ―the Consultant”, and although referred to as ―he”, the individual may or may not be a man.

The actual interview took place in July 2010 via a Skype conversation. The interview lasted for approximately one hour. During the interview the Consultant answered the questions (which can be found in Appendix C – Interview Questions) that were sent to him in advance together with follow-up questions from the author. A follow up interview was held via e-mail after the interview with the NGO worker (described in the next section) in order to give him a chance to give feedback to some of her opinions.

The second interview was held with an international staff member of an NGO, which is operating in a low-income country. The NGO is involved in agriculture projects – implementing organic plantations, small-scale income generating activities and biogas. The biogas plants constructed are partly financed by another NGO while the remainder is paid by the user. The plants are fed with mainly cow dung but the NGO usually installs a toilet connection as well. The interviewee has a background as an agronomist and has now been involved in implementing biogas for four years. In the text and quotes, she will be referenced to as –the NGO worker”, and although referred to as –she”, the individual may or may not be a woman.

The interview was held using email. It would have been preferable to conduct it in the same manner as described in the methodology, i.e. via Skype, but due to the NGO worker’s unforeseeable schedule email was considered a more suitable option. The NGO worker received the questions in Appendix C – Interview Questions, answered them and sent them to the author. The author then asked follow up questions based on the answers received.

4.1.1.2 Discussion of the Interviewees’ Backgrounds

The mix of knowledge and perspective between the interviewees is considered as very suitable for the purpose of this research. The Consultant has a very broad knowledge base, having seen a variety of implementations and has met many different users around the world. The NGO worker, on the other hand, has specialist skills; having experienced the entire project cycle of implementing biogas projects.

4.1.2 The Interviewees Experience of Technical Performance of Biogas Plants

As pointed out in the literature review, there is a lack of general data regarding the weaknesses of operational biogas plants. This was the first issue that the interview tried to approach.

The interviewees agree that the fixed dome digester is a very proven design and functional as long as the gas leaks are comparatively low. Unfortunately it is often difficult to repair and maintain after a few years. When the NGO worker’s organisation locates a plant that is leaking, the down time for repairs, which usually includes plastering and painting the inside, is often more than one month. Even though the actual repair time is quite short, the plants often have to be emptied.

The Consultant points out that even if the gas leakages are not severe enough to motivate a repair, most biogas plant designs have leakages. Too often, he adds, the execution of construction is flawed.

The NGO worker explained that when constructing new plants, a mason, with assistants, is employed, and is given drawings and instructions. Seldom do they use the same mason again, so the lessons learned are often lost. She reported that they would rather use a mason who is located as locally as possible rather than having one who has to travel a lot.

The Consultant has seen similar things and agrees that locality can serve a purpose but claims that the production time by an experienced mason and his team is often less than half of an inexperienced one. Also, once in a while the inexperienced requires extreme construction times and sometimes do not finish at all.

The Consultant, who works with other agriculture infrastructure as well, is surprised that most biogas programmes rely on pre-1980 designs. The silos and biogas plants in high-income countries are much more reliable. He would like to see more cheap air-tight materials and centralised manufactured biogas plants that are transported to the site and assembled by well-trained teams.

The NGO Worker has similar thoughts regarding the performance of the plants and thinks that they are inadequate in many aspects. But she also thinks that decentralised manufacturing removes one of the benefits of biogas – that the local production supports the local commerce and creates more sustainable solutions.

4.1.3 The Interviewees' Experience of Feeding the Plants

The literature review found that comparatively few people use human waste as feedstock in their biogas plant. This section will deal with the reasons for this and the possible potential for households to use a biogas plant for sanitation. It will also investigate other issues involved with the feeding, such as lack of feedstock etc.

Both interviewees state that most plants use cow dung as a base but it is often mixed with other waste as well. The Consultant claims that there is often a problem with users who also dump non-degradable waste in their plant. Most metals will corrode in the slurry and as long as too much is not added it is usually not a problem. Both claim that it is more of a problem when such things as plastics, old cloths and sanitary napkins are added.

The author regards this as a ―sweeping-it-under-the-rug mentality". As long as you put waste that does not come out in the same form in the other end it is not regarded as a problem. Although metal parts will be broken down this behaviour will, naturally, negatively affect the process – the worst case scenario is that the change in pH will stop the digestion entirely.

The consultant has encountered some situations where the biogas users do not have enough feedstock to run their plant with but considered it is a minor problem. That is, assuming that the local conditions are assessed and projects are adapted to the local situation. The organisation the NGO Worker is hired by, only implements their systems for households with cattle and she states that this approach has been successful. When asked what happened when a household changes the amount of cattle they have, she is not sure.

She confirms that it is a potential problem that the economic investment will not correspond to the future needs.

It was also found that it is usually not a problem, in terms of acceptance, to have people already using biogas to also connect their toilet to the system. It is a big step to go from not using any kind of waste recycling to literally preparing food with the remains of their faeces. The Consultant has seen and heard of some examples where households using pit-latrines considered it disgusting to use the gas for cooking but changed their minds after using a biogas system digesting cattle dung for a few years. “It is all about explaining logic sequences”, the NGO worker reported. In her organisation they usually have several meetings with the potential users trying to explain the “big picture”. When they understand how human waste is re-circulated most people are at least willing to considerer connecting their toilet in the future. When asked whether it is a concept that non-farmers will embrace she believes so. In her experience most people living in rural regions have farmers in their family and those who do not are usually well educated.

4.1.4 The Interviewees’ Experience of Using Biogas’ Benefits

The first research question asks what the benefits of biogas are, and the literature review has partly answered it. It is, however, unclear how well the theoretical benefits are used and if the users appreciate them. This section will help to answer that question.

4.1.4.1 Using the Biogas

Both the Consultant and the NGO Worker speak very positively of the gas and how people use it. It is interesting to notice how they both react and express themselves very emotionally. While most reports, manuals and articles talk of the time saved for collecting firewood both the Consultant and NGO Worker speaks of how the day-to-day has changed for the women in those households where biogas is used. They both stress what a quality of life improvement it is to have a smoke-free kitchen and how easy it is to clean it.

Like the plants themselves, the Consultant regards the current stoves as “in need of improvement”. In his experience, most stoves are comparatively reliable but he considers them to lack effectiveness – a lot of heat is lost due to a design that assumes an unlimited source of gas.

4.1.4.2 Using the Effluent

The Consultant has seen good examples of how the effluent has been used in agriculture and believes it is significant to reach an economic break-even point.

Where the effluent is wasted this is mainly due to lack of knowledge on how to use it. The households are often afraid that it will ruin the harvest, according to the Consultant.

The NGOs are on the other hand well aware of both the problem that people dump it and that the effluent is usable as fertiliser – in fact, the Consultant claims that the reasons many NGOs receive financial support is because they stress the emerging situation with depleted soils.

According to the NGO Worker, the reason that many implementing NGOs do not promote the effluent as fertiliser to a higher degree is that they, like the users, are not certain of the effects. She states that her organisation uses its own standards and recommendations but many other NGOs lack them. She believes that the guidelines originated in the organisation's own experience and that their outcome has been satisfactory.

4.1.5 Users' Reasons to Invest in Biogas, According to the Interviewees

The benefits and some of the problems with household biogas have been described but what are the main reasons that potential users hesitate to make the investment? The following will deal with some of the reasons households invest or do not invest in their own biogas plant.

The NGO worker believes that most households located in a suitable climate and producing waste in adequate amounts will benefit from a biogas plant. Although expensive the investment will with its extensive estimated life expectancy pay off sooner or later – as long as the plant is used and not abandoned.

When the NGO promotes biogas they do not concentrate on a particular type of households in particular except to some extent farming households. They use mainly posters, meetings and visits to a demonstration site. The NGO Worker says that they have many potential users but the high cost makes most of them reluctant to adopt biogas. Although she and her organisation speak very highly of the benefits for the women of biogas they do not run any special promotion campaign towards women. In her experience deciding on an investment benefitting the household a mutual decision between husband and wife, but she agrees that many women may be unaware of many of the benefits of biogas due to the non-targeted promotion.

The Consultant is also positive about biogas in general and believes that those capable (possessing the economic means, land, cattle and stable circumstances) of investing in a plant should do so. He is concerned about the cost but believes that a generated economic profit is not the only reason to justify the cost. Just like other home improvements people should not look blindly at the economy but also at personal benefits and subjective reasons.

4.1.6 The Interviewees' Experience of Support to Households during Operation

An important factor to ensure sustainability of projects, whether in biogas or other fields, is provision of adequate support by the implementer and the enabling environment. This section will reveal the interviewees' experience in this area.

Most of the projects that the Consultant has witnessed have provided adequate support during operations. The households have been visited and where problems have appeared the implementer has provided the households with solutions. He thinks that most implementers provide very cost-effective solutions for the users but sometimes they take a lot of time. He emphasises that he has not looked further into the matter, but wonders if perhaps the implementing organisations should be less afraid to charge the users in order to solve the problems much faster.

The NGO Worker states that their support could be improved. However, the expenses for the staff required would be high. She says that they have a special group providing user support and that they operate on a reaction basis rather than doing prevention work. If resources allowed, she believes, it would be useful to have a team working full time visiting the users; providing them with maintenance advice and guidance on how to run the plant more effectively. When presented with the Consultant's query regarding charging more for repairs in order to have the plants operational sooner she does not agree at all. "The families have paid a lot already, we can't tell them to give us more money when they are already in debt because of the system they bought from us" – she responds.

She does agree that the average waiting time for users facing problems is, in general, too long. She is concerned about the situation and that it in the long-run will damage the reputation of biogas. In the short-term, though, she has found that some households speak more highly of biogas after a down time. When households have to go back to using coal and wood for cooking, the benefits of biogas is even more appreciated, see Box 4-1.

Box 4-1. Quote by "NGO Worker".

> “We have a family who lives quite far [from] the area where we normally operate. Just a couple of weeks after we finished the construction of their fixed dome plant they broke their stove (I’m not sure what happened but I think their little too curious children dissembled it and lost some parts…). They contacted us and we promised to fix it as soon as possible. Something happened and whoever was responsible forgot about the problem, despite that they called us several times. When we realized that they had been without a stove for well over a month I went out to them personally. I felt embarrassed and thought that these people would not speak highly of biogas to their neighbors. When I arrived they were very disappointed with [the name of the NGO] but not with biogas! They were so happy to be able to use the gas stove again, being without it they really appreciated it!”

The interviewees have limited knowledge of the private sector involved in small-scale biogas, except for the construction. However, the restricted experience the Consultant has had has been positive. He has visited some sites in Eastern Africa where the plants have been sold to households without any forms of subsidies. Being without subsidies and only able to implement a few plants at the time has made them very sensitive to current customer opinion. The enterprises had therefore been very responsive to customer feedback. The Consultant also claims that the cost of the plants is distinctly less where the private sector offers biogas plants to households, compared to NGO and government run programmes (when comparing private enterprises implementing the same numbers of plants as the other programmes).

4.1.7 Summary of Interview Findings

The two interviews have revealed a lot of interesting information. The most important factors are summarised in the following bullet points:

- The types of plants currently in use are working but have shortcomings. Their repair is time-consuming and gas leakages are common. One way of combating this is to develop new designs manufactured where quality control can be assured.
- Using biogas created by cow dung is seldom a problem for people. Although the users may be reluctant at first to use human waste, the negative feelings will usually fade with time and education.
- Not having enough waste to feed a biogas plant is a potential danger for a project if the local conditions are not evaluated at first. Different households have different needs and the implementer has to be thorough and assess the future as well.
- Although most users are happy with cooking with gas the stoves are in need of improvement.

- Where the effluent is being used, most users are satisfied with the results. It is however a problem that many implementers are unaware of exactly how to use it.
- The major problem when implementing biogas is the cost for the user. Although the expense may be returned due to decreased energy and fertiliser expenses it still acts as a reason not to acquire the technology for many potential users.
- Users often receive support after construction of their plants but frequently it takes a lot time for customer support to respond.
- There is a potential efficiency improvement to be gained by further inviting the private sector.

Although the interviewees are experienced and the combination of the specialist and generalist represents a variety of knowledge it should be mentioned that these findings originate from only two individuals. Their experience may not be shared by the biogas community as a whole. It is therefore necessary to compare the results from the questionnaire survey (which covered 20 people) to the results from the interviews in order to correlate qualitative and quantitative data and investigate whether they validate each other.

4.2 QUESTIONNAIRE SURVEY

The questionnaire survey was conducted in June-July 2010 in accordance with the methodology described in Chapter 3. 20 people responded and the results will be presented in the following section.

The following seven topics will be discussed:

- discussion regarding the sample, data collected and how it was analysed;
- background and experience of the respondents;
- technical performance of biogas plants;
- feedstock;
- respondents experience of using biogas' benefits;
- user's reasons to invest in Biogas; and
- support during operations.

4.2.1.1 Number of Respondents and Response Rate

As described in the methodology, 3.3.3, respondents were identified prior to the actual survey. Emails were sent to 31 individuals, three email lists and one web forum.

The individuals were identified from existing literature, conference proceedings, organisations' websites and personal contacts, but also from recommendations from people responding to the email lists and forum. A few respondents accepted to participate as response to the email lists (which reached more than 1 000 individuals[17]) but the majority accepted upon being contacted by a personal email. The author was also contacted by one individual who had heard of the research from elsewhere and wanted to participate. At this stage, 17 persons had agreed to participate.

When the survey started reminders were sent to the email lists with a direct link to the survey, urging people to participate.

In total 20 people completed the questionnaire, which can be found in Appendix D – Questionnaire.

Although 20 completed the questionnaire, 3 additional respondents started filling out the questionnaire without finishing it. Since links to the questionnaire was published on email lists it is not surprising that a few curious people started the questionnaire just to have a look at it. The three unfinished questionnaires were removed before the data were analysed.

Due to the unknown number of people involved in biogas and the application of this research it is hard to determine whether the sampling size is adequate or not. However, using the method described, it is the author's opinion that a large fraction of the English-speaking people involved in household biogas has been reached.

None of the email lists used to find respondents was focused on biogas but rather adjacent areas such as low income sanitation, energy and eco-san. In other words, the invitation to participate in this research has not reached only biogas professionals. It would thus be unfair to compare the number of responses to the number of people who received the invitation via email. A more suitable comparison would be the number of respondents compared to the number of personal invitations sent. Using that method, this research has a response rate of 65 per cent, which is considered acceptable by Bryman (2001: 132).

4.2.1.2 Respondents' Feedback to Questionnaire

The survey finished with a short thank-you text and the possibility to enter contact details and comments regarding the survey. One of the first respondents commented on a few spelling and grammar mistakes – which were corrected (the questionnaire tool allows some modification of the questions without deleting the responses). After the modification no respondent left any feedback regarding the quality of the survey or on other matters.

Kwik Survey has a useful tool that reveals the time each respondent used to complete it. A few respondents used several hours and it is assumed that these individuals started the

[17] The email list with most subscribers, ―EcoSanRes", had 698 members [6 July 2010]; the other lists' membership numbers are unknown.

questionnaire but had a break half-way through in order to attend to some other matters. When the respondents who used more than 45 minutes were removed, the average response time was 19 minutes. The author considers 19 minutes to be reasonable, a questionnaire requiring more than 30 minutes would have been too much to ask for.

4.2.1.3 Follow-Up on Answers

As described in the methodology, the survey was anonymous but the respondents had an option of sharing their contact details if they would not mind being contacted for more in-depth answers. This has been conducted in several cases and the results presented include the additional answers from these individuals.

With the background of the survey explained, the actual results will now be described.

4.2.2 Background and Experience of the Respondents

The first part of the survey, questions one to six, dealt with the respondents' background and experience. There were three reasons for this.

- Firstly, by showing that the sample has adequate experience, it can be argued that the conclusions of this research's are valid.
- The second reason is to ensure that a variety of opinions are presented. Instead of presenting a viewpoint from a specific individual, type of digester, region etc. it will show that this research represents a general opinion.
- And third, by asking questions related to the respondents' background, conclusions can be drawn in combination with later questions. It will enable the author to cross-reference experience of certain technologies with different geographic areas etc.

4.2.2.1 Results of Question 1-6

While one of the respondents has been working with biogas for a year, and a few for more than ten years the majority of the participants have been involved for one to ten years (see Figure 4-1).

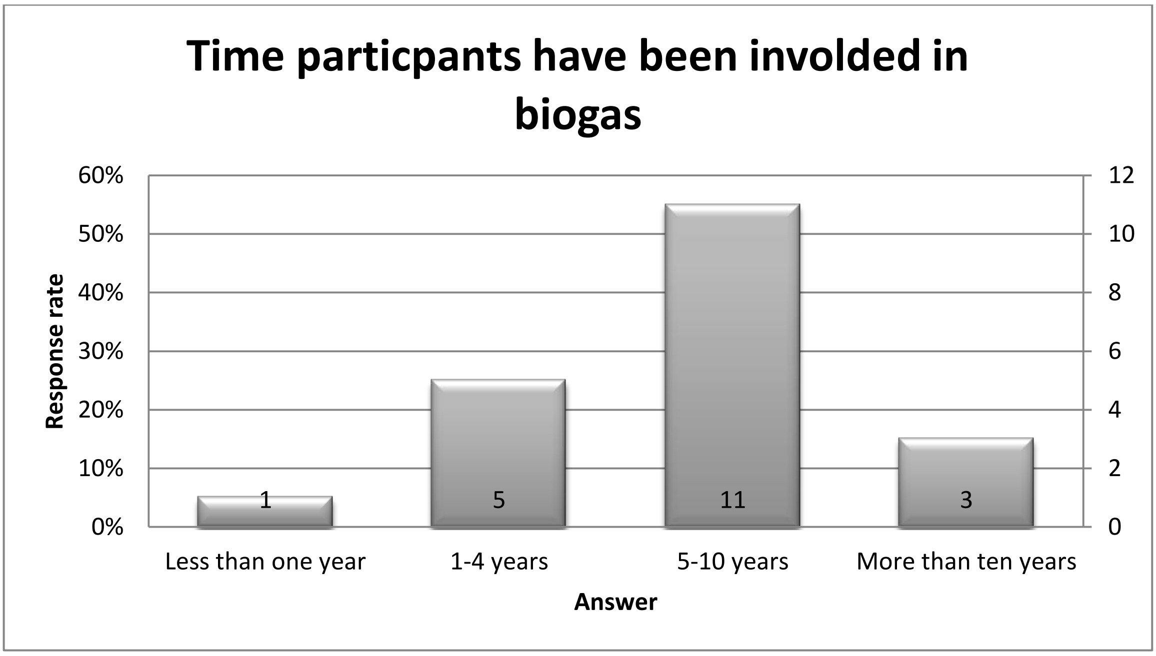

Figure 4-1. Response to the second question. "For how long have you been involved in biogas (professionally full- or part-time, as amateur or as user)?". The result shows that the respondents represents a long time of experience.

As indicated in Figure 4-2, the respondents also have a variety of geographical experience; in total they have experience from 17 countries. The two largest countries, with regards to household biogas, India and China, are both represented. Other important biogas countries with respondents are Nepal, Bangladesh and Vietnam. Several African countries are represented (e.g. Kenya, Tanzania, Rwanda, Senegal etc.) as well as one Latin American country (Mexico). One of the respondents is also active in Iran and several have backgrounds from European countries. However, none have a ―high-income country" as their only country of experience.

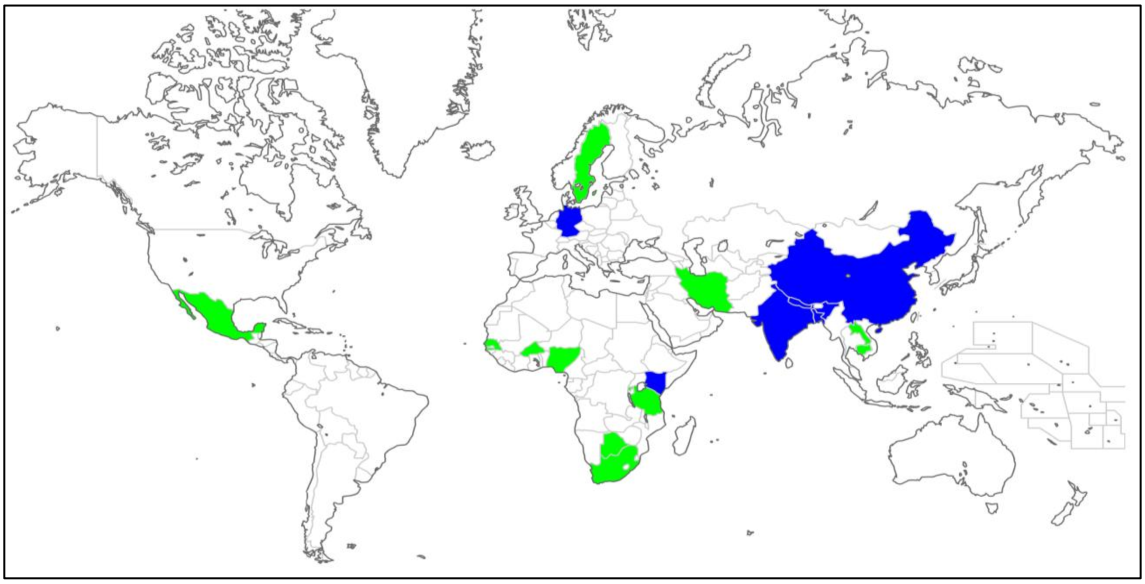

Figure 4-2. The map visualises the response to Question 3 - Countries that the respondents have experience from. Countries marked in green represents one respondent while blue indicate two or more, and as it can be seen; the respondents have experience from most part of the world where household biogas is in use. The map was created using ―Freemap”[18].

In response to Question 4, which deals with the respondents professional background, most of the participants categorise themselves as implementer (44 per cent) and/or academic (28 per cent) while some also categorize themselves as user, policy maker and/or business (approximately ten per cent for each category). All ―users” also categorise themselves in another group as well.

Everyone but one claims that, in response to Question 5, they have experience of biogas on a household level while approximately 50 per cent also have experience of biogas on an institutional or communal level.

The final question, Question 6, related to which types of plants the participants have experience of. It is obvious that the plant that most people have worked with is the fixed dome type (65 per cent) while people with experience of the alternatives are roughly the same in total (floating drum: 25 per cent, bag digester: 30 per cent, plug flow: 20 per cent and anaerobic filter: 10 per cent)[19].

4.2.2.2 Discussion about the Sample

The fact that more than half of the participants have five to ten years of experience indicates that the respondents possess valuable knowledge. The knowledge is mostly within of

[18] Available at http://english.freemap.jp/ [15 August 2010].
[19] Notice that several questions are of multi-choice, type thus enabling the total percentage to exceed 100.

this research topic, which is household biogas, and with the digesters that are currently being used.

Most regions with extensive biogas programmes are represented. The author is not surprised that so few from Latin America have participated due to their lack of active programmes. A region that is not represented, with experience that would be valuable, are the insular nations in the South East Asia (e.g. Malaysia, Philippines and Indonesia), where bag digesters are common.

4.2.3 Technical Performance of Biogas Plants

As pointed out in the literature review, there is a lack of general data regarding the weaknesses of operational biogas plants. This was the first issue that the questionnaire tried to approach.

4.2.3.1 Results of Question 7-8

As shown in Figure 4-3, there are three problems that stand out in the response rate. The three problems are low quality masonry work, gas leakages and failing appurtenances.

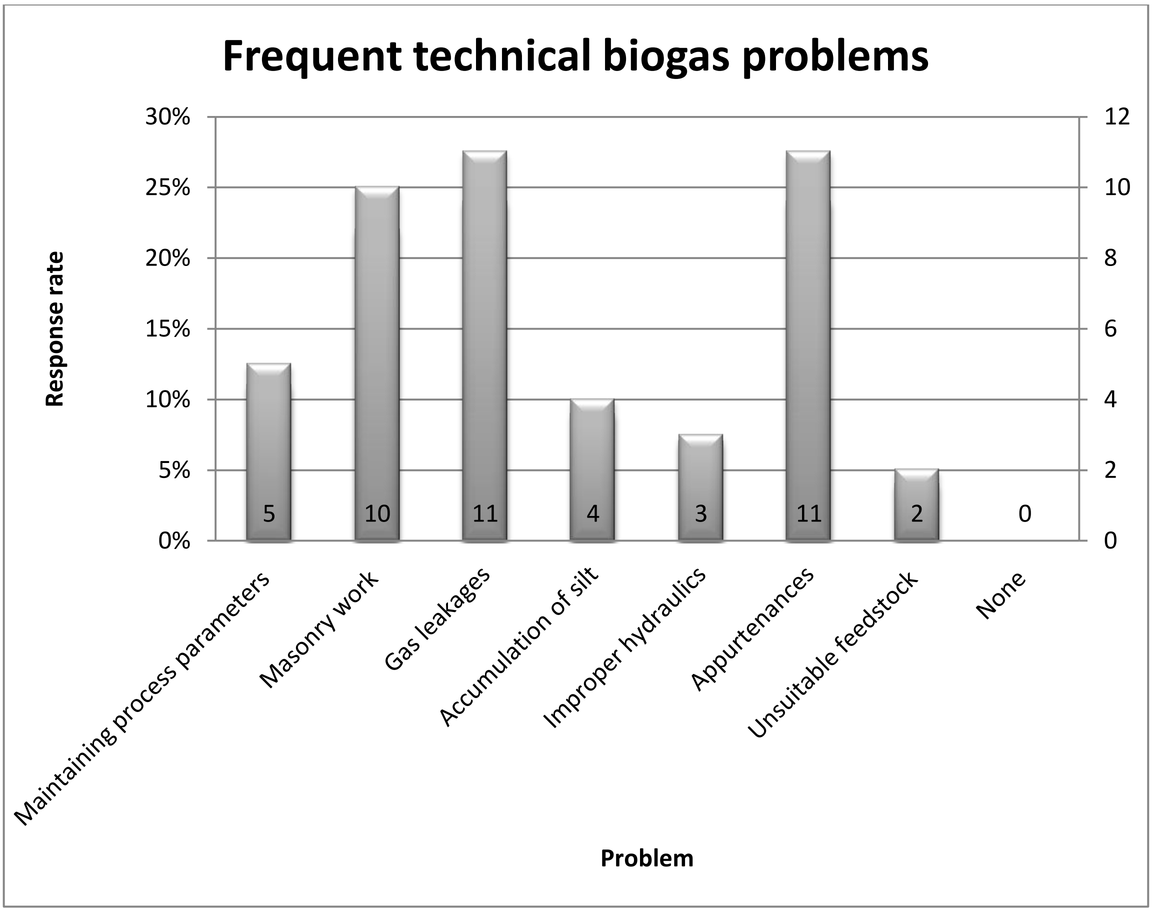

Figure 4-3. The figure visualises frequent technical problems, as asked in Question 7. It can be seen that three problems are commonly reported.

Masonry work problems are mostly reported by those with experience from fixed dome digester – which is not surprising since masonry work is mostly associated with that type of digester.

As shown in Figure 4-4, 85 per cent with experience of fixed dome digester report that they have had frequent problems of gas leakages. For those reporting that they have experience of other types of digesters, all digester types have less than 50 per cent who report frequent gas leakage problems. A correlation between gas leakages from fixed dome and bad masonry work can also be found. One comment claims that leakages are very common for both floating drum as well as fixed dome, but with the modernised types with GRP the problems have been almost absent.

No clear correlation between process parameters and digester type or geographic area can be found. There is however, a possible connection between the process parameters and feeding the digester with human waste. All respondents reporting problems with the parameters also say that they have been using human waste.

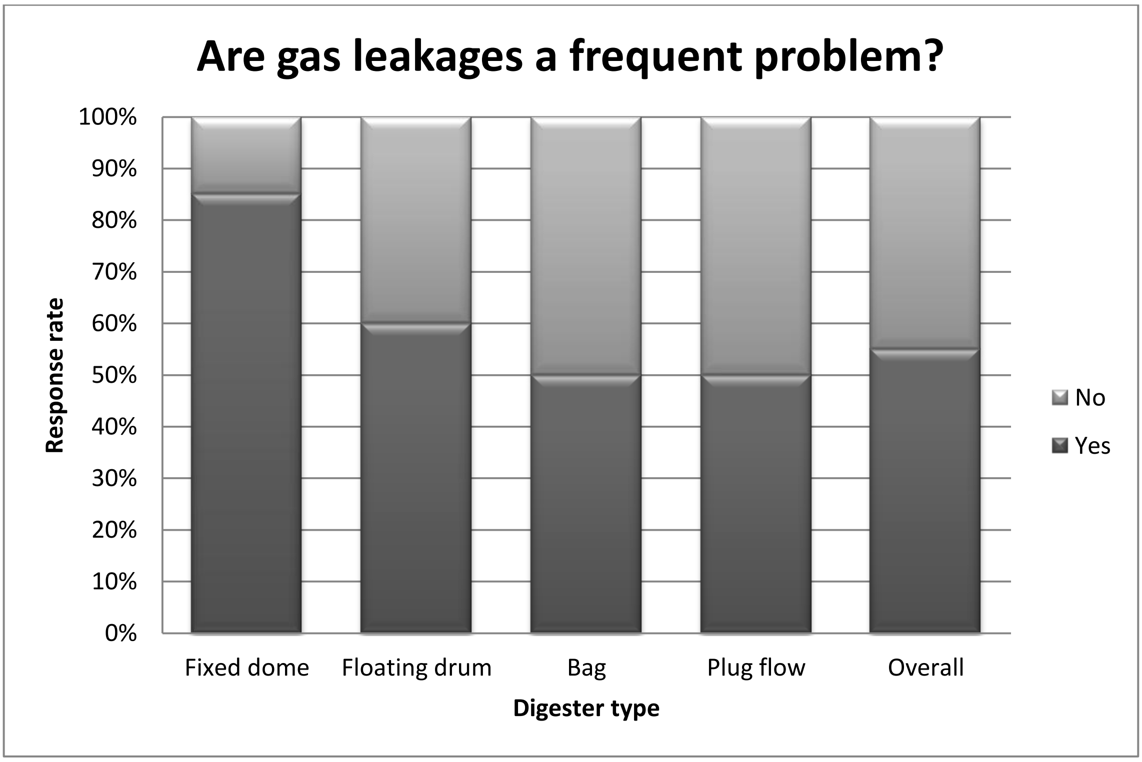

Figure 4-4. Diagram indicating occurrence of gas leakages in different biogas plant types. The diagram shows how data from the question asked in Figure 4-3 have been cross-referenced with the type of digester the respondent's have experience of (Question 6). Gas leakages are clearly a more frequent problem in fixed dome models, compared to the others.

For those reporting problems with the appurtenances, no correlation can be found to geographic area, type of appurtenance or burner. One respondent commented that they had a lot of problems with stoves, but that this has mainly been caused by bad maintenance. This person receives support from another respondent who claims that most problems, not only stove-related, are “people-problems" rather than "technology-problems", and “many users do not maintain their system according to instructions”. A slight correlation can be found when comparing the frequent appurtenance problems with the corrosion problems.

The results from those with experience from bag digesters are interesting to have a closer look at. Of the four that only have experience from bag digester, they all claim that they encountered accumulation of silt and problems with improper hydraulics. It should also be noted that for those that do not have experience of the bag digesters, only one reports accumulation of silts and only 10 per cent report problems with the hydraulics.

When asked what the respondents regard as underdeveloped, the two most frequent answers are the digesters and the appurtenances. One comment claims that the floating drum type is very unreliable.

4.2.3.2 Discussion about Technical Performance

When the data is analysed it becomes obvious that it is a weakness to ask such general questions related to the problems, without specifying what exact type of plant they refer to. In this case, where the respondents have reported that they have knowledge of more than one plant (approximately 35 per cent) conclusions should be drawn with caution.

It can however be concluded that present biogas plants, especially fixed domes, have a problem with gas escaping from the system. Faulty or bad quality masonry work is a common cause for the problem – as well as causing other problems. As a lot of the respondents comment, the digesters have to be improved to deal with this problem. Escaping gas is not only lost gas, but if the pressure is low, air may also enter the digester. If this happens the anaerobic process will be disturbed causing undigested waste to exit the biogas plant.

The problems with gas leakages seem to be less common with the bag digesters. However, the age of the bag digesters are unknown and as pointed out in the literature review, Section 2.2.4.5 – Bag Digesters, bag digesters are not as resistant to wear and weather conditions as the other models. The problem with improper hydraulics is likely to be caused by sloping foundations.

The cause for the appurtenances failing should be investigated furthered. Even if the main reason, as stated by some comments, is improper maintenance and use, the reason people use them in this manner is vital to understand in order to improve the function of the appurtenances.

4.2.4 Feedstock

The literature review found that comparatively few use human waste as feedstock in their biogas plant. This section will deal with the reasons for this and the possible potential for households to use a biogas plant for sanitation. It will also investigate other issues involved with the feeding, such as lack of feedstock etc.

4.2.4.1 Results of Question 9-12

When asked what the biogas plants they encountered have been fed with, a variety of answers was given, as can be seen in Figure 4-5. But when organising the options into categories, it can be seen that more than half of them (55 per cent) claim that they encountered human waste being digested in some form. However, none of them has worked with small-scale biogas plants fed entirely by human waste.

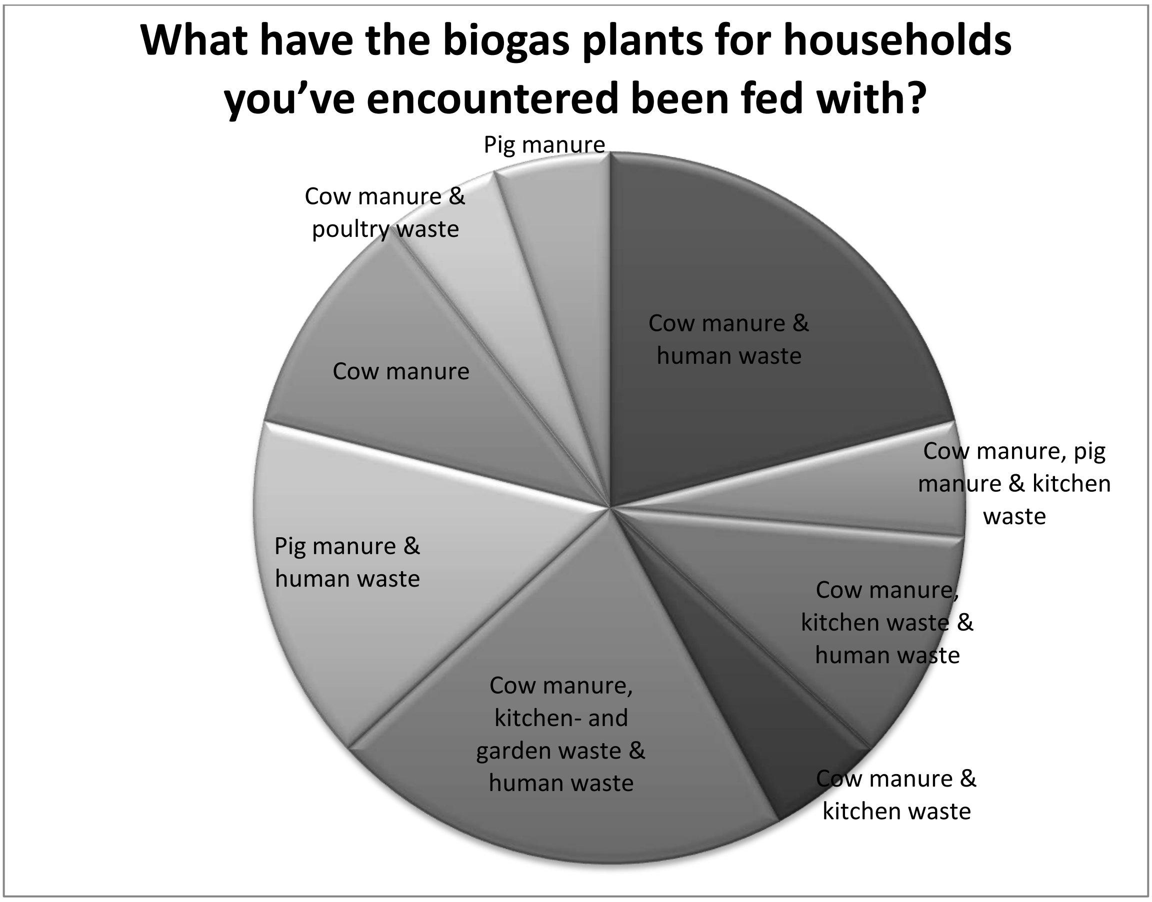

Figure 4-5. This is an illustration of the diversity between the answers received regarding what the plants have been fed with (Question 9). 20 respondents gave 9 different answers.

Almost one third claims that pre-treatment of the feedstock are needed. Most of these respondents are those that have experience of garden and kitchen waste as feedstock. The pre-treatment includes cutting grass into smaller pieces and grinding kitchen waste. Those who claim that “other types” of waste often need pre-treatment have not been able to specify what kind of treatment.

Few of the respondents report that the majority of users have a shortage of feedstock, but almost half of them agree that there are a considerable amount of users who have it as a problem. However, it is likely that the users actually have enough waste to feed the plant with but find it hard to collect it. This theory is supported by several comments, one saying “often plenty of waste – the problem is to collect it” and a respondent from Lao DPR claims that most cattle are kept outside of the village. When it comes to water, few claim that it is a problem for those that have biogas systems – although there is sometimes a problem of transportation from the water source.

4.2.4.2 Discussion about Feedstock

A variety of feedstock is used worldwide and according to the comments there is also a variety within local areas. Although most users have cattle or cow dung as a foundation for their biogas plants it is likely that many users add whatever is available. This can both increase the gas yield as well as decrease it – since parameters, such as C:N and pH, will be affected. As previously mentioned, in Section 4.2.3.1 – Results of Question 7-8, difficulties maintaining process parameters are not an uncommon problem. In Section 4.2.5.1 – Results of Questions 13-22, it will also be revealed that those who feed their plant with only cow dung have less problems of extracting sufficient gas volumes.

It could be argued that other waste than cow dung should be used, but in the author’s opinion that is to ignore the other problems. As found in the survey, many households have problems finding enough waste to feed to their biogas plant. Feeding the plant with other types of waste is an indicator of lack of cow dung. Constructive solutions need to be found instead of negated “thought-to-be easy” fixes.

Experience from larger plants used for waste water clearly shows that sufficient gas amounts can be generated from most biodegradable materials. The problem is rather the plants used. As one of the respondents comment; “[the] digesters [now being used] are not designed for agri-waste. This was not recommended by the implementer”.

As found in the survey, and supported by the literature review, it is worth mentioning that it is unrealistic to run a household biogas plant on only human waste.

4.2.5 Respondents Experience of Using Biogas’ Benefits

One of the research questions asks what the benefits of biogas are, and the literature review has partly answered it. It is, however, unclear how well the theoretical benefits are used and if the users appreciate them. This section will help to answer that.

4.2.5.1 Results of Questions 13-22

It was found that the most common use of the biogas is cooking, using a modified LPG burner or biogas burner (see Figure 2-1). A few mention lamps and refrigerators but they are in a minority. The same goes for generators – only a few report that they have been used for household-sized systems – and the majority of those who have experienced it question the suitability, except in a few niche situations.

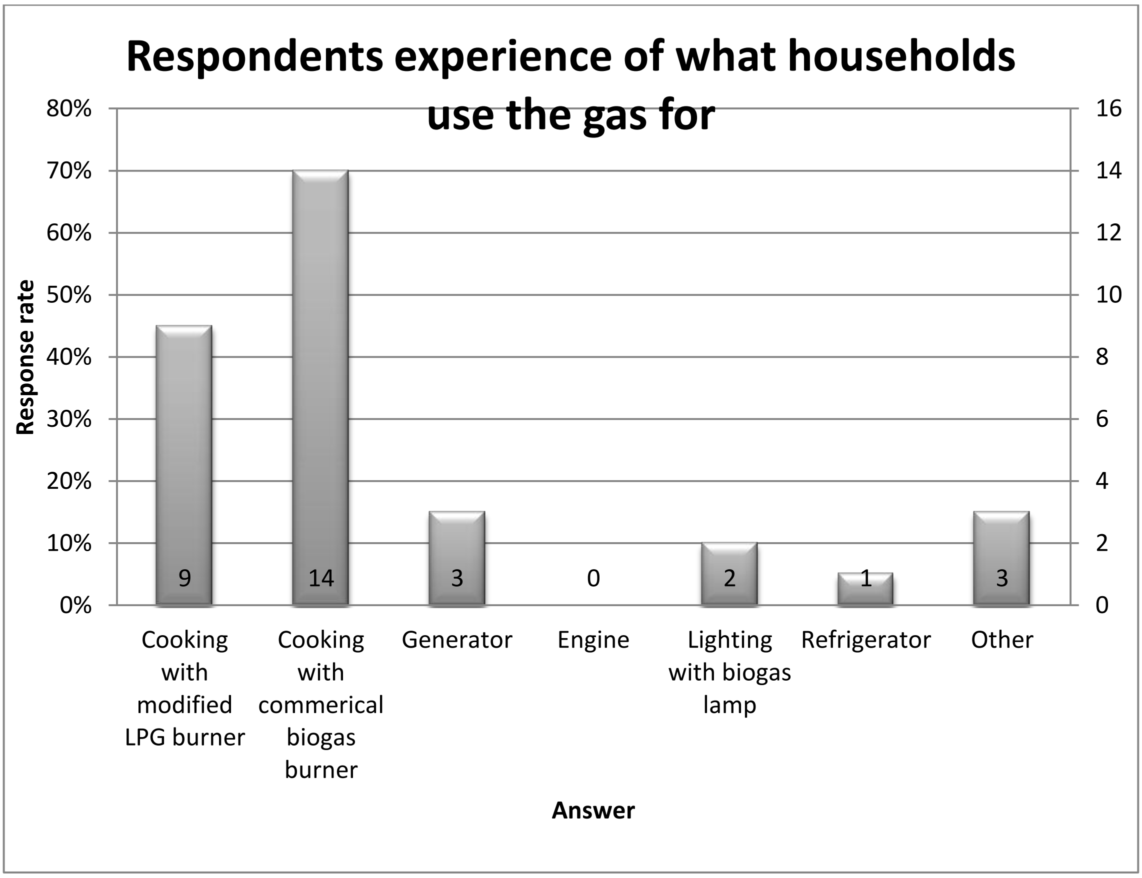

Figure 4-6. Column chart showing what the households are using their gas for, according to the respondents (Question 17). All of the respondents have experienced households using biogas for cooking in some form.

Some usage of modified equipment to suit a specific need was also reported – such as a modified rice cooker and heater for sculpturing plastic key ring ornament (which the person sold to tourists).

Most respondents consider the quantity and quality of the generated biogas to be sufficient in most cases. There is a tendency that more of those who have experience of commercial biogas burners considers the quantity to be sufficient, but there is too little data to drawn any absolute conclusions. A clear correlation can, however, be found between quantity and those who use cow dung as feedstock.

It has been found that use of the treated effluent as fertiliser is widespread – almost every one of the respondents have experience of it. Most of the farmers who have used it this way are also satisfied with the results – even though few of the respondents experience a noticeable increase in crop production compared to using commercial fertilisers, the cost-reduction has freed the limited amount of cash available for farmers. Many users also appreciate the convenience of having fertiliser conveniently available in the near vicinity compared to transporting fertiliser from the retailer.

Although most of the respondents have experienced the effluent being used as fertiliser almost all of them have also experienced the effluent being dumped into collections ponds, water bodies or in the open. Many report that it is often, but far from always, post-treated by storing on site for further die-off before being released, but an potential danger for the surroundings can be found. In Figure 4-7 it can be seen that it is more common in the South-East of Asia (China, Vietnam, Lao DPR, India and Nepal) to dispose the effluent untreated, compared to Africa.

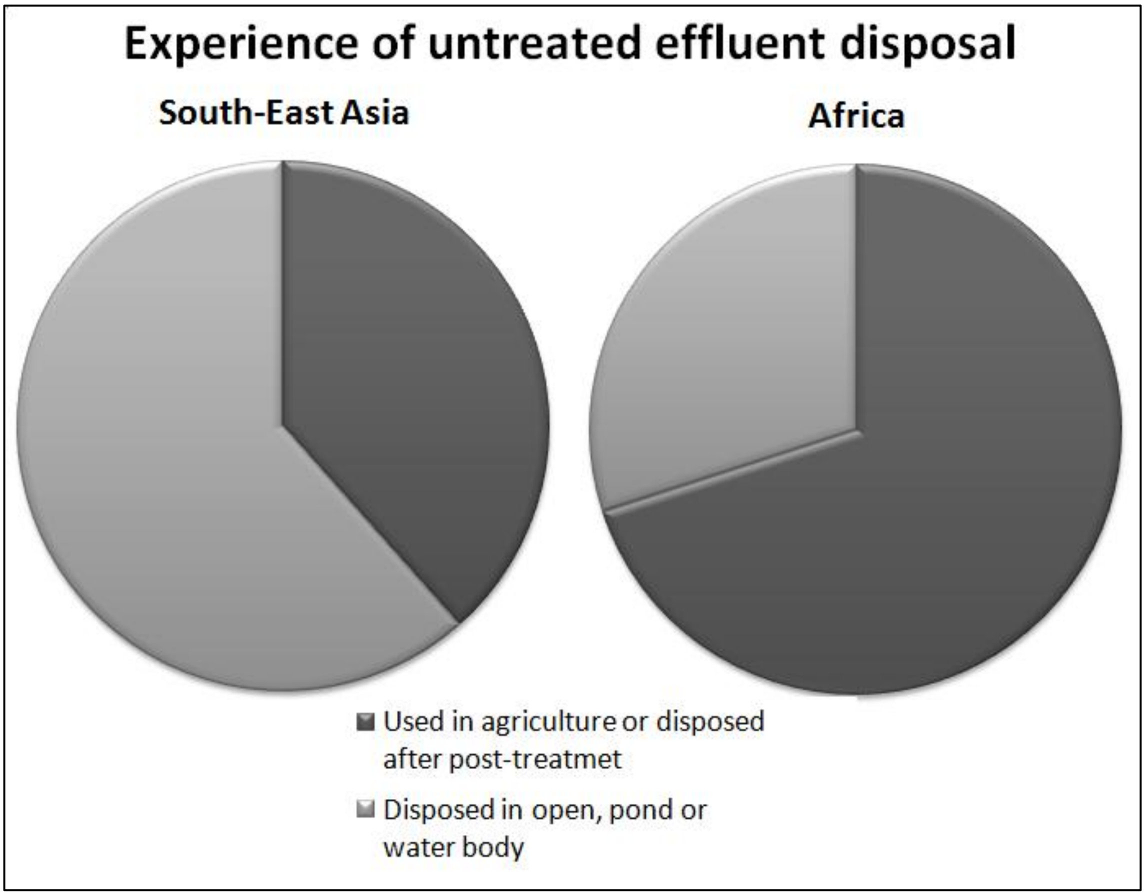

Figure 4-7. The diagrams show the amount of respondents who have encountered disposal of untreated effluent in the open, into ponds or into water bodies (Question 13). By the results it seems that users in South-East Asia dump their effluent rather than using it.

A disturbing finding is that the effluent handling is potentially dangerous for the users. Many users to not use designated containers and a “risk awareness approach”. Instead, many use containers that are leaking, difficult to handle, without handles and lids and used for other purposes as well (such as distributing animal feed, carrying tools, etc.). When carried they are often handled recklessly, resulting in dropped containers and splatter – which is further exacerbated by lack of hand hygiene and designated protective clothing. The respondents report that there is a widespread lack of awareness that the effluent can be dangerous.

4.2.5.2 Discussion about Biogas Benefits

It is interesting to notice that many users do not hesitate to adapt the technology to their own needs, although the majority only use the gas for cooking.

It is also interesting that there is a correlation between feeding the plants with cow dung and generating sufficient amounts of gas. It has partly been discussed in Section 4.2.4.2 how present plants are designed for cow dung, but there are two other possible explanations. “Established biogas programmes” often use cow dung, but they also have the most experienced users, which should mean that they also know how to best maintain their plants from other perspectives as well. The other possible reason is that cow dung is naturally partly digested and therefore easier to use (and therefore used to start biogas plants as mentioned in Section 2.2.2 – The Anaerobic Digestion Process.

It is surprising that there seems to be a much more widespread disposal of untreated effluent in South-East Asia. It would be logical that the more established programmes in Asia would have come further in spreading other benefits than just the gas due to their long history (compared to most other programmes). The explanation may be found in the nature of pilot projects. As found in the literature review, biogas has a longer history in Asia. Biogas programmes outside of Asia are less established and at a smaller scale. It may therefore be that the users are receiving more frequent instructions and guidance. It is likely that another contributing reason is the design of the questionnaire. The respondents are not asked to quantify their response – they are only asked if they have encountered it. A respondent that have encountered more biogas plants, which is likely in South-East Asia, is therefore likely to also encounter improper effluent use.

Those respondents that have been followed up, partially confirm the above theory (both parts) although they are too few to draw any clear conclusions.

4.2.6 User's Reasons to Invest in Biogas

The benefits and some of the problems with household biogas have been described but what are the main reasons that potential users hesitate to make the investment? This section will deal with the reasons households invest or do not invest in their own biogas plant.

4.2.6.1 Results of Questions 27-31

Biogas is clearly associated with the gas – as supported by the other studies the reason people are prepared to pay for a biogas system is to use the combustible gas for cooking, as can be seen in Figure 4-8.

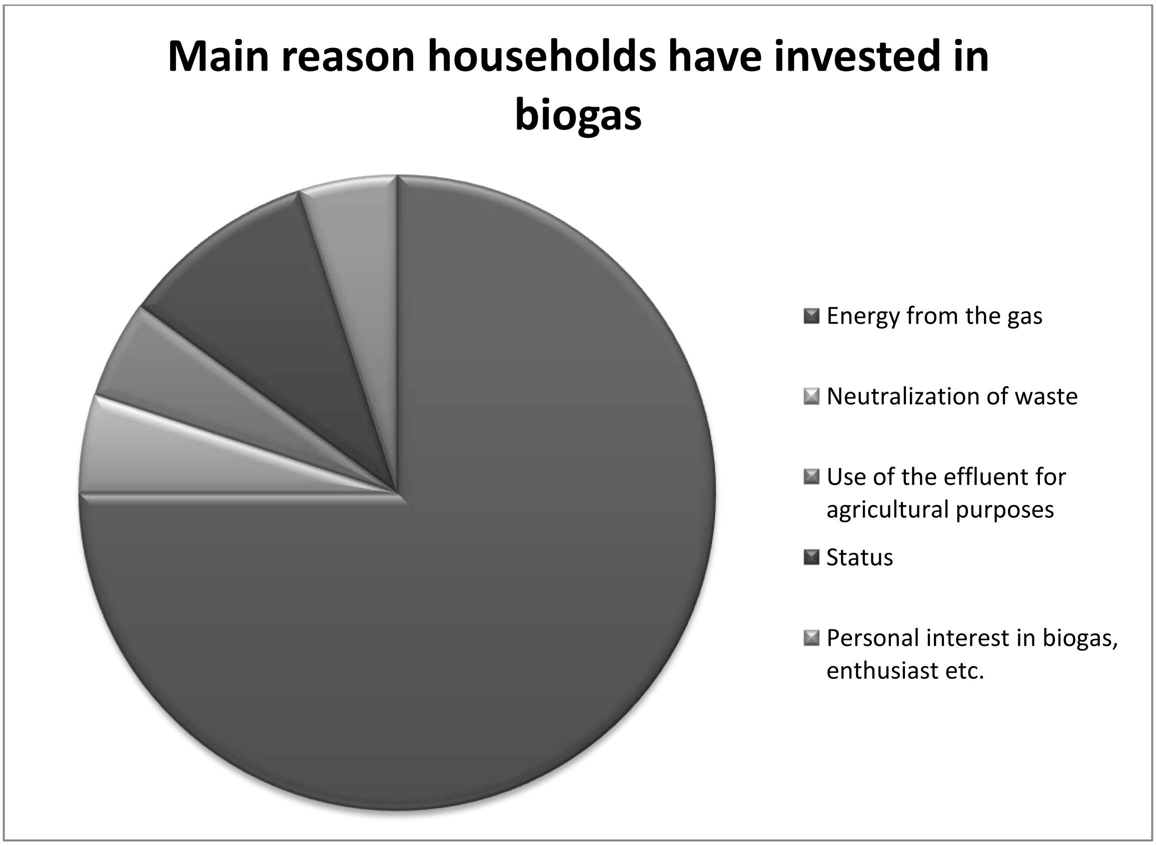

Figure 4-8. Respondents' answer to the main reason households invest in biogas (Question 27).

Of the reasons to not invest in biogas technology, cost is, according to the survey, the most common reason. It is clear that although subsidised, the investment is still considered too high for many households, refer to Figure 4-9.

It is interesting to notice that very few respondents have encountered a widespread cultural or religious reasons to avoid biogas – especially when using only animal waste. Of those who oppose biogas for these reasons no correlation can be found between any specific region, culture or religion. However, the question asked by the author does not encourage naming any specific religion, culture or ethnic group. The conclusion has only been drawn by examining the region where the respondents are active rather than what social groups are present in his or her specific area.

It has been found that a comparatively large portion of the potential users are thought to doubt that the biogas will deliver the benefits promised. Many of these are regarded by respondents as being reluctant to adopt a new technology. However, many of those that are not covered by this ―technophobia‖ are people that have heard of a bad experience of biogas from neighbours or someone else.

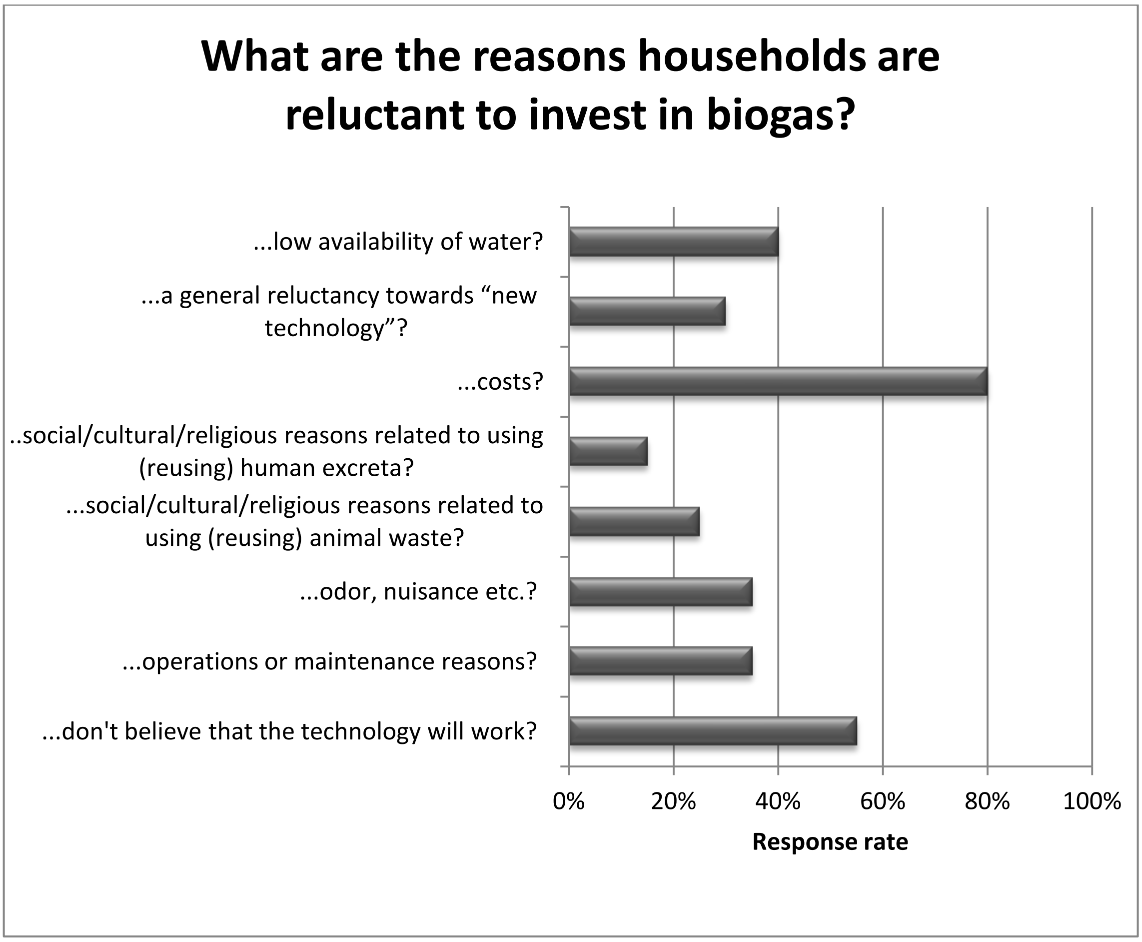

Figure 4-9. The respondents’ opinion on why households do not invest in biogas.

4.2.6.2 Discussion about Reasons to Invest in Biogas

When further exploring the users of biogas, two types of families are common in the respondents’ area of knowledge, according to the comments. The first one, the author designates as the ―convenient farmer”, while the second is the ―informed enthusiast”.

The convenient farmer has a relatively wealthy living with their extended family. They own their own land, or have a documented long-term rental agreement. Their primary income comes from crop farming, while a small cattle herd is used mainly for the family's need but with some surplus for the local market. The main motivation to invest in biogas among these families is the gas, which will lower the amount of resources spent on cooking fuel. Although the gas being the main motivation, the respondents report that when the system has been established, the other benefits are often appreciated almost as much as the gas. Respondents have commented that when farmers with biogas systems describe the benefits to neighbours, the fertilising abilities of the bio-slurry is often mentioned first when discussing the payback.

The other type of households using biogas is the informed enthusiast. Rather than being a full time farmer, these families have their primary income from elsewhere. They are relatively well-educated – not necessary with a university degree, but with completed elementary school, working with non-manual tasks. To lower the expenses they have a garden where vegetables are grown, mostly for the family's need. They also have some zero grazing cattle. These households have gas as their primary concern when they take the decision to invest in biogas but an almost equal motivation is the overall kitchen improvement. These households are not only concerned with the convenience of using gas instead of collecting firewood but also the consequences of a cleaner kitchen and making it easier to cook.

When designing a biogas programme the different types of users should be assessed and the promotion should accommodate the users and their preferences. This is, as far as this research has found, not being achieved by the implementing organisations.

4.2.7 Support during Operations

An important factor to ensure sustainability of projects, whether it is biogas or something else, is adequate support by the implementer and the enabling environment. This section will reveal the respondents experience within this area.

To simplify the discussion it is presumed that the implementer is either a *non-governmental organisation* (NGO) or *governmental organisation* (GO).

This section will be based mostly on the comments by the respondents. In order to present a more coherent text, the author has chosen to integrate the same section as that which reports the result.

4.2.7.1 Overview

A general opinion is that, outside of People's Republic of China, few agree that the implementers are providing enough support. Also, outside of South East Asia, very few agree that the implementers are doing anything at all. As it can be seen in Figure 4-10, only one out of four of the respondents have experienced that the implementer support the users enough[20]. When only taking the implementers themselves into account, the result is similar – only 35 per cent agrees that enough support is provided.

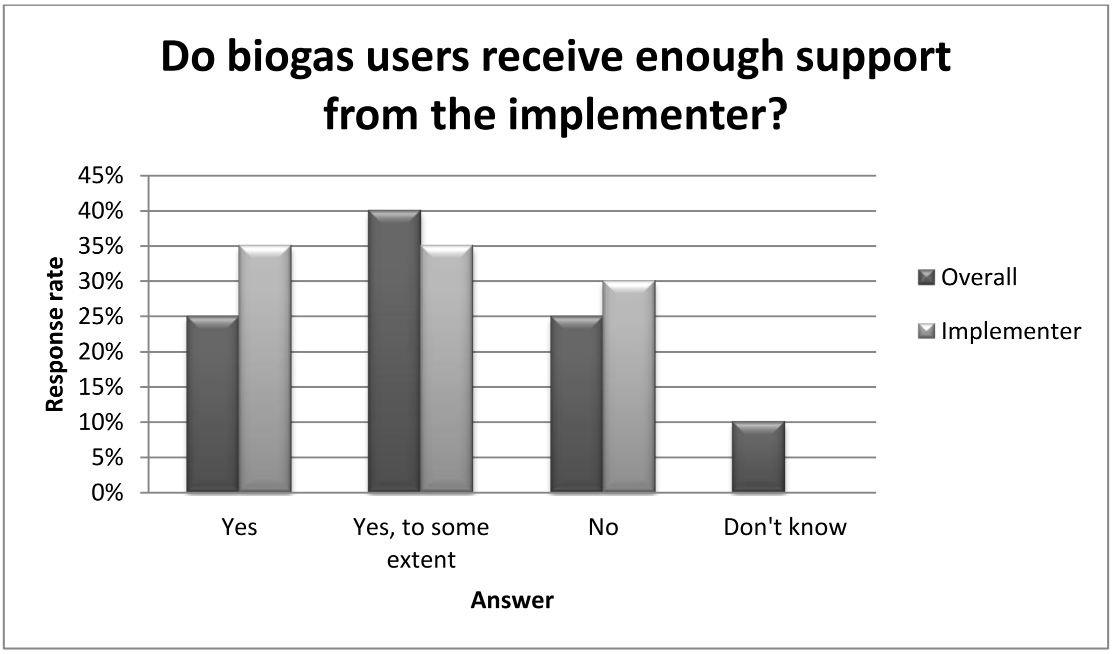

Figure 4-10. The respondents' answer to what they think of the implementers' support to the users, as asked in Question 23. The blue bars represent all respondents, while the red represents the implementers themselves. Only a minority of the respondents find the support to be adequate.

4.2.7.2 Support from NGOs

Those not employed by NGOs, such as GO members, academics or consultants, have a quite widespread view that NGOs have a genuine interest in doing good and are effective in establishing biogas system. However, they are also considered to lack focus and with time lose interest in already established systems.

One respondent shares an experience where a local branch of an international NGO partly financed 12 biogas systems in a community. The biogas users received support in terms of partly financed plants, operations and maintenance guidance and a repair team. However, when the NGO employees was rotated, after 18 months, the new staff had no interest in continuing supporting the households. The plants were soon abandoned and the local community had to spend their resources to clear the sites from undigested waste and non-

[20] ―Enough" is, of course, a vague expression and different people have a different perception and definition of the word. But, in the context of also asking questions of sustainability it is assumed that the respondents interpret it as ―providing support to ensure long term operation".

functional biogas plant. Needless to say, when new NGO staff arrived after another 18 months, eager to implement biogas projects, the interest in the region was close to zero.

The NGOs show self-criticism; mentioning that they have experience of bad follow-ups (see quotation in Box 4-2). One explanation they give is the previously described problem with international staff that is often temporary. The NGO representatives also defend themselves by saying that it is very costly and time consuming to monitor biogas systems in rural areas, particularly since the households using biogas often live far from each other.

Box 4-2. Example of an NGO self-criticism comment.

“After installation, follow up service is limited to one or two visits. Considering that the plant should have a life expectation of 20 years a follow up training on maintenance or proper feeding should be done”.

4.2.7.3 Support from GOs

Where biogas programmes have been established, government support has mainly been focused on economic support for construction. In the South East Asian countries, most governments have some kind of subsidy to households, as found in the literature review; see Section 2.6 – Finance and Economy.

The non-governmental respondents in the survey are generally satisfied with the type of subsidies provided by governments, claiming that they are effective. Although aware that the high costs are discouraging households from installing biogas plants, none of the respondents express any wish for more than partial financial support to each plant.

The main criticism against GOs can be found in lack of legislation, co-ordination and consistency. Most governments do not have any proper legislation in terms of standards and monitoring of biogas effluent. This causes consequences that put the user in potentially discomfortable situations. For example, one respondent from Nigeria claimed that many biogas users are blamed for causing pollution.

One reason for uncoordinated support from the government is the difficulty of defining where biogas belongs. One respondent with experience from Kenya complains that governments are too sectionised, and since biogas address so many problems it “falls between two stools”.

An example of lack of consistency can be found in Nepal where the government provides support for plants based on cow dung – but not for those that feed their plant with solid waste.

It is unfortunate that not one of the GO representatives in the survey commented on their own work and none provided any contact details for follow-up questions.

4.2.7.4 Support from Contractors and Suppliers

When asked for their opinions regarding the contractors and supplier, the answers from the respondents are much more positive, compared to the response for the NGOs and GOs. As it can be seen in Figure 4-11, most responders have positive experiences from the contractors and suppliers.

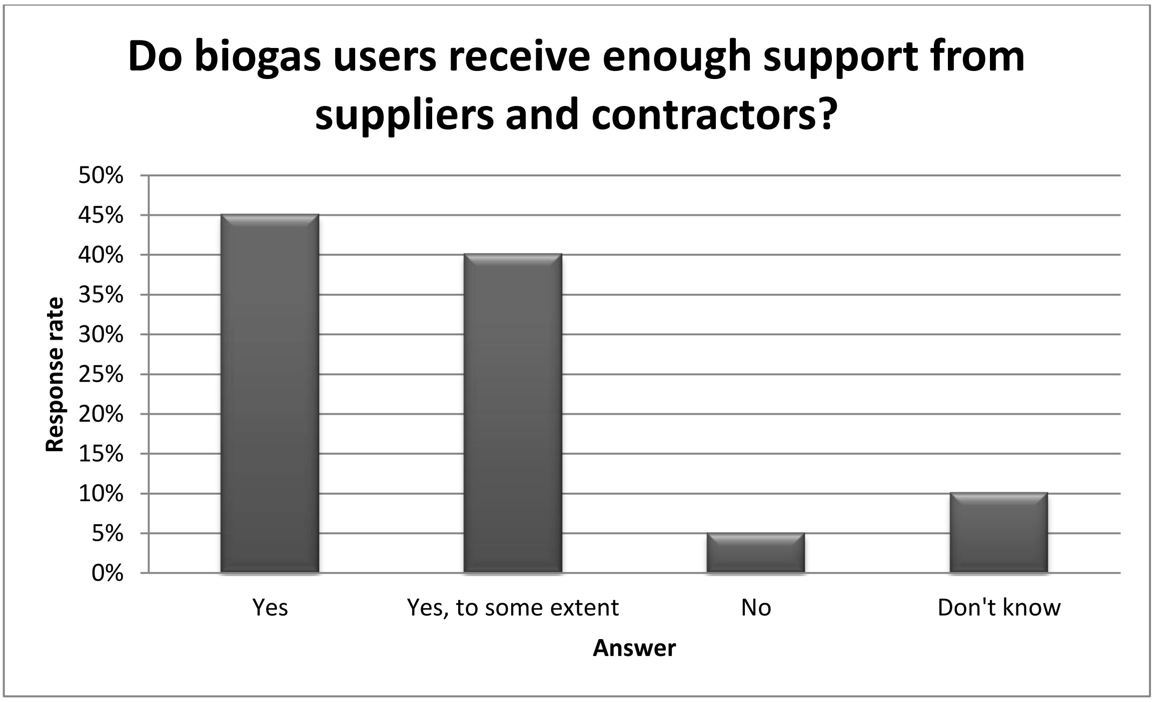

Figure 4-11. The respondents' answer to what they think of the suppliers' and contractors' support to the users (Question 25). Compared to the respondents' opinion on NGOs' and GOs' support it has to be considered as good.

Only one of the responders can be categorised as a contractor. It would be interesting to ask him/her more in-depth questions, especially with regards to his/her experience with NGOs and GOs and their responsibilities. The person has, however, not shown a willingness to answer follow-up questions.

4.2.8 Summary of Findings from Questionnaire Survey

The most important findings from the questionnaire survey can be summarised in the following bullet points:

- The respondents represent a large variety of those involved in household biogas and can be considered as a valid cross section of the sought experts.

- Gas leakages are a very common problem. The main reasons are bad masonry work as well as designs that are difficult, in some cases impossible, to keep gas-tight.
- Many appurtenances have a bad track record. Bad maintenance by users is one of the reasons but the respondents' answers indicate that it is probably more complex than that.
- Most plants operate on cow dung mixed with other wastes. Users are, in general, quite innovative when it comes to feeding biogas plants with this mixture. The mixture of cow dung, kitchen waste and human waste can in theory generate good quality. However, most plants are not optimised for that kind of waste.
- The digested effluent from the biogas plants is by many users appreciated as a fertiliser. There is unfortunately a lot of effluent that is dumped as well – posing a potential hazard.
- The most sought-after benefit for potential households is the gas, but the underlining factors often vary and different user categories appreciate different benefits.
- NGOs do not provide enough support to their established plants, something that they are well aware of.
- Most governments do not have cohesive regulations that small-scale biogas plants fall under.
- Where NGOs and governments have failed to earn the trust of users, the private sector has often succeeded.

4.3 FINAL REMARKS

This concludes the data and analysis chapter. The research has revealed interesting data which has been described and discussed. Both research methods (the interview and the survey) have provided the author with data that will help answer the research questions.

Where the two research methods have investigated the same issues, the data collected from one method has supporting the other and the summary of the results are similar.

The following chapter, which is the last, will answer the research questions and evaluate the research.

5 CONCLUSIONS, RECOMMENDATIONS AND SUGGESTIONS FOR FURTHER STUDY

This final chapter will summarise the results into conclusions, recommendations and suggestions for further study. The research and its methodology will also be evaluated.

The conclusions and recommendations will be answered by answering the research question asked in Chapter 1.

5.1 ANSWERS TO RESEARCH QUESTIONS

The reader was introduced to the research in Chapter 1. This is the research questions that were asked:

1. What are the benefits of using biogas in low-income countries?
2. Why have many of the benefits not been delivered?
3. What are the solutions to the limitations?

The questions will now be answered one at a time, using the data and analyses previously presented in this dissertation.

5.1.1 What are the benefits of using biogas in low-income countries?

The first research question is answered mainly using the findings from the literature review. The review found that the energy is the main benefit for households using biogas. It is also what the users are looking for and the main reason used to justify the investment.

The energy, i.e. the biogas, is suitable to be used for direct combustion within the vicinity of the biogas plants in simple, robust and easy-to-maintain stoves for cooking. From the data collected most users also have good experience of using biogas for lighting but more data should be collected before making any clear conclusions. Although the author is convinced that the technology itself is robust and functional, the author does not have enough data to make any conclusions regarding the cost-effectiveness compared to alternatives, such as solar power and generators.

The second benefit is the fertilising bio-slurry that can be used in agriculture. It is a complete substitute for commercial fertiliser and for most crops a better option compared to using the influent directly on the fields. The exact effect is unknown but it is safe to say that it is a good fertiliser that the farmer will have available nearby where it is supposed to be used.

Treatment of waste is the last of the major benefits. Some pathogens remain after the anaerobic process, but it is a better option compared to several alternatives. There is a risk for exposure of pathogens for households using biogas plants, but the risks will be there even if the biogas plant is not. There are simple waste treatment technologies, such as pit latrines and pour flush toilets, but for a farmer it is unrealistic to treat all available excreta from farm animals using those technologies. The waste with its pathogens will pose a risk for the household, but if a biogas plant is used the risk is severely reduced.

The data collected, especially the interviews, highlighted some of the benefits that is difficult to put a monetary value on. Lighting a biogas stove is very easy compared to a wood stove and a kitchen without charcoal is much easier to keep clean.

This research has deliberately avoided secondary effects, as stated in Section 1.4 – Limitations. However, the author wants to complete the benefits with the main beneficiary – women. In the low-income countries, women are often responsible for collection of firewood and kitchen work. Giving them more time for other chores and leisure is a tool for women empowerment.

5.1.2 Why have many of the benefits not been delivered?

The financial costs of constructing household biogas plants are a major limitation. As long as the costs are higher than the total savings caused by the biogas and effluent it is unlikely that biogas will be widely used. Subsidies can lower the costs for the household but the feeling of ownership will decrease and with that the care for the plant

The literature review, interviews and questionnaire has revealed that a lot of household biogas plant users do not have enough waste to use as influent for their biogas plants. There is a balance between available waste and volumes of extracted biogas. On one hand there are those that do not have enough waste to use as influent, and would need a smaller plant. On the other hand are those that do not extract enough gas for their needs but still have waste that they cannot fit in the plant. Implementing organisations need to be better at matching the offered plant capacity to users' available amounts of waste.

Even where households manage to maintain fairly large HBPs it is unlikely that they will be able to extract sufficient biogas to run electricity generators and engines. Biogas can therefore not be considered as a compensation for electricity.

Using the effluent as fertiliser has in some cases had a limited success. The main reason identified is the lack of knowledge. Both the HBP owners as well as many implementing organisations do not know how to use the bio-slurry in an efficient way.

Many household biogas plants have been abandoned prior to the end of their estimated service life. Part of the explanation can be found in the design and quality of the current designs, but lack of support is an even bigger problem. Many biogas programmes do not have proper follow-up procedures and do not offer the users proper training. This causes the plants to fail due to rather simple issues.

Two reasons are believed to cause this problem. Biogas programmes fail in their support due to the promoters wish to construct as many biogas plants as possible. This mentality leaves the support part of the programmes with limited resources. The second reason is that support and training of user is believed to be expensive. Biogas users are often spread out in rural areas, causing expensive travel time. However, in the long term it is obvious that not maintaining the plants are much more expensive.

Many of the identified problems are made worse by the HBPs' technical problems. Some of the problems include gas leakages, failing appurtenances, manual handling and high costs.

There is also a large group of potential users that oppose biogas due to the principle of using or reusing by-products from excreta, particularly human excreta. Religious and cultural reasons are sometimes used as reasons – people can for example argue that they can become tainted. Where this opinion exists biogas is difficult to spread regardless of the potential benefits it can provide.

5.1.3 What are the solutions to the limitations?

There is a need to develop new models of biogas plants. Focus should be put on the identified problem areas; such as function, appurtenances and costs. The biogas community should also investigate the different options regarding were the plants should be assembled. So far, most plants are built from scratch on site. The results have been good were a large number of construction workers have received proper training. However, there are also many cases, particularly during smaller implementations, where the construction has been very ineffective. This research does not have enough data to side with those proposing centralised or decentralised construction of HBPs. They both have their economic advantages and disadvantages. However, it is suggested that centralised construction is evaluated. Modern construction materials and technologies should also be further investigated. Examples of modern materials could include different types of plastics. Lightweight plastic digesters could also make users less vulnerable to changes in capacity of digestible waste. Although difficult to modify, their light weight makes it possible to sell them to other users. An example of using new technology is isolated stoves where less heat is lost to the surroundings. The private sector can play an important role both for development and manufacturing.

Implementing organisations also have to assess local conditions better. When households spend a large portion of their wealth the digester size has to match their capacity.

The implementing organisations also have to take more responsibility for the built plants. Better maintenance models have to be developed and the author believes that the biogas community can learn from the experiences of the different hand pump maintenance systems. Like handpumps, biogas technology can require different repair skills. Frequent simple problems that can be repaired by the user or a local service man have to be compared to a system that fails seldom but requires a skilled professional when it does.

More research is needed regarding the effects of using bio-slurry. Research is especially needed concerning how to use it. Current knowledge is outdated and hard to find for the practitioners in the field. When the implementers feel more confident increased use should follow

Although cultural and religious reasons have been used as excuses for not using biogas, it is rather personal feelings against using bi-product from human waste. The research has also indicated that it is feelings that can be decreased with time, education and a gradual adaption.

To summarise the recommendations:

- develop new plants;
- implementing organisations have to ensure that plant size is suitable for the users;
- implementing organisations have to ensure adequate support and training for users;
- research how the fertilising effects of bio-slurry can be maximised; and
- oppose taboos against biogas using time, education and a gradual adaption.

5.2 SUGGESTIONS FOR FUTURE STUDY

Parts of the suggestions mentioned above consist of research. However, the author has in his own research found more shortcomings that are in need of study.

The author has the following suggestions for future study:

- more detailed knowledge of the plants' shortcomings;
- the effects to crops when bio-slurry is applied on a daily basis;
- current development of biogas plants;
- the economic benefits of biogas;
- how widespread is it to use the effluent in agriculture;
- the effect of anaerobic processes on virus and pathogen eggs;
- current legislation and its shortcomings;

- economy of using biogas lamps compared to other alternatives; such as solar cells and generators; and
- the impacts of centralised compared to decentralised production of HBPs.

5.3 Evaluation of Research

The author considers the research to be successful and the research questions answered.

The topic for this research was very broad and extensive. At the beginning of the research the author expected more research to be available regarding the general view of household biogas that this research has aimed at. However, as it can be seen in the literature review, most research has been focused on details rather than the general situation. This has lead to more time required to compile what is known, which has taken time from the actual research. Time has therefore been the limited resource in this research.

It would be desirable to further explore the second and third research question (dealing with the problems and solutions) but due to the limitations in time it is unfortunately not possible. More data, both qualitative and quantitative, would improve the results and enable the author to draw more conclusions.

The author considers the methodology appropriate, but if time had allowed, the results would be improved if more interviewees and questionnaire respondents were used, as well as if more time could be spent on the analysis.

The questionnaire could have been better designed. The lack of details in some of them made it hard to draw clear conclusion. It would have been better to use fewer questions, and instead used follow-up questions asking for details.

The time consuming literature review has also had a negative effect on the questionnaire and interview questions, other than reducing the time available to spend on them. Since the questionnaire survey and interviews had to start before the literature review was finished, all conclusions and findings could not be incorporated in the questions.

The online tool used for the questionnaire survey, Kwik Survey, worked better than expected. It was very easy to use and has a lot of capacity.

A problem occurred when using the software for recording the interview of the Consultant. It turned out that the shareware version the author had access to do not allow the recorded sound to be saved as a file. The author was therefore forced to take extra notes when re-listening to the interview, before the program was shut down. If the author would do similar research in the future, he would use the software SoundTap Streaming Audio Recorder[21]. It has the wanted abilities and is available free of charge.

The author has also used the software Dropbox[22] which is a program than enables automatic backup of files together with access of them at any computer with Internet access. It has been very secure and convenient when working at different locations. No installed software is required which makes it convenient when working at public computers.

[21] Available at http://download.cnet.com/ [6 August 2010].
[22] Available at http://www.dropbox.com/ [6 August 2010].

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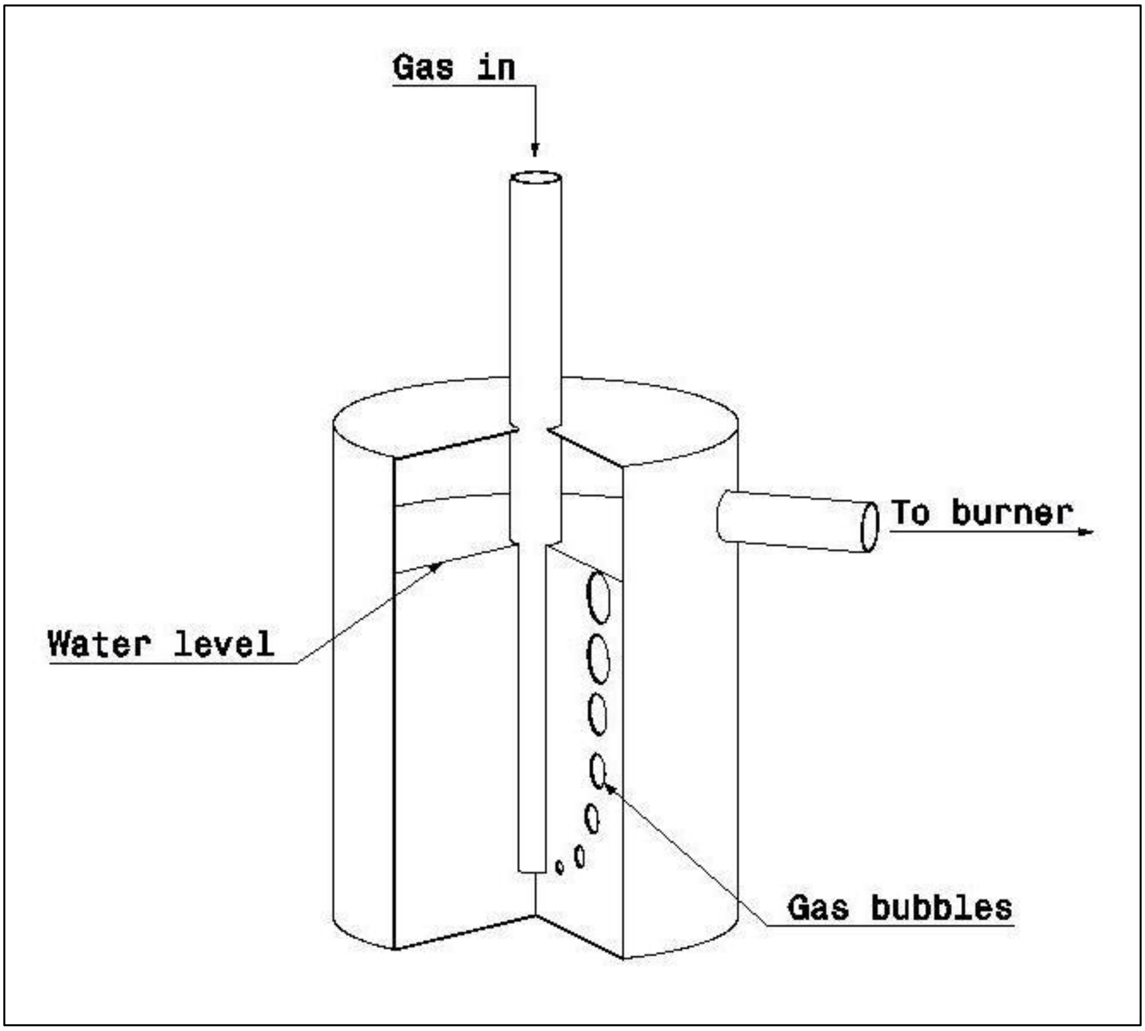
APPENDIX A – BRIEF EXPLANATION OF NPV AND IRR CONCEPTS

Net Present Value (NPV) is a method used to calculate if a project is economically viable or not. The value of the monetary assets right now is compared to the value of the same assets in the future, taking inflation and return into account. If the NPV of a proposed investment is positive, it should be accepted. In contrast, if the NPV is negative, the investment should be rejected since the cash flow will also be negative (Investopedia, 2010).

Internal Rate of Return (IRR) is a method used in capital budgeting to measure and compare the profitability of different investments. The higher IRR a potential investment is calculated too, the higher the profit will be. IRR can therefore be used to rank different investment in order to choose the one that will generate the highest profit. The actual rate of return will usually differ from the one calculated, but an investment with a substantially higher IRR is likely to provide a better chance of strong growth (Investopedia, 2010).

APPENDIX B – SKETCH OF A SIMPLE FLAME TRAP



The figure shows a simple flame trap. If the gas should back-fire; the flame cannot travel further than the water level in the flame trap. However, gas from the digester can bubble up through the water and continue towards where the combustion is taking place. Figure by author after a sketch by University of Adelaide (2010).

APPENDIX C – INTERVIEW QUESTIONS

1. How would you describe your professional background? (With what have you been working, for how long time, what is your academic background, etc.)
2. With what type of biogas plants do you have experience of, and what is the capacity of those?
3. What kind of technical issues and problems would you describe as frequent for those biogas plants and what kind of technical improvements do you think would be appropriate?
4. With what has the biogas plants been fed with and do the users generally have enough of this feed-stock?
5. For those plants fed with human waste, how has the waste been entered into the digester?
6. How has the users handled the effluent? If it has been used in agriculture, what is your experience of it?
7. What has the gas been used for and has the daily available volume been sufficient?
8. What kind of support is given to the users from the enabling NGO and/or government during operations?
9. What are the main reasons that more biogas projects are not being implemented in your area?
10. What feelings and though have you encountered from potential users regarding biogas as a sanitation solution?

APPENDIX D – QUESTIONNAIRE

Household Biogas Survey

1. Welcome to the Household Biogas Survey.

This survey is part of my research trying to find opportunities and constraints using biogas technology as a sanitation solution for households.

The survey is, unless you share your contact details on the last question, completely anonymous.

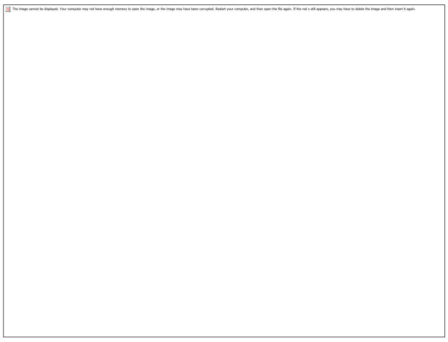
Most questions are of a multi choice type where boxes indicate that it is possible to choose several choices, while circles indicate that only one choice is possible. Most questions have a textbox as well for you to leave any additional comments or information. I would like to ask you to use them as much as possible so I can have as much qualitative data as possible.

Finally, if you have any contacts with experience of biogas from low-income countries, please do not hesitate to send them a link to this survey.

Yours sincerely

Sören Säf

soren.saf@gmail.com



2. For how long have you been involved in biogas (professionally full- or part-time, as an interest or as user)?

○ Less than one year

○ 1-4 years

○ 5-10 years

○ More than ten years

3. From which country or region (or countries and regions) do you have experience and knowledge of (with regards to biogas)?

4. How would you specify your background?

□ Implementer

□ User

□ Policy maker

□ Business

□ Academic

Other/comment

5. Select your experience and/or knowledge categories as appropriate:

□ Biogas plants used by one or two households

□ Biogas plants used on a communal or institutional level

□ Biogas used as treatment of sewage (piped or transported)

Other/comment

6. What type of biogas plant (or plants) would you consider yourself as knowledgeable of?

Feel free to comment on details regarding design, size and exact model.

□ Fixed dome

□ Floating drum

□ Bag digester

□ Plug flow

□ Anaerobic filter

Other/comment

7. Which of the following technical problems would you describe as frequent for the biogas plants you have encountered?

Feel free to add describing comments in the text box (e.g. "problems with feed stock due to bad mixing")

□ Difficulties maintaining process parameters (e.g. temperature, pH, C:N, etc.)

□ Low quality masonry work

□ Gas leakages

□ Accumulation of silt in digester

□ Improper hydraulics (causing newly entered slurry to exit to soon etc.)

□ Failing appurtenances

□ Unsuitable feedstock

□ None

□ Don’t know

Other/comment

8. Which of the following do you consider underdeveloped (in terms of reliability, cost effectiveness, etc.) for the majority of biogas plants, designed for households (e.g. fixed dome, floating drum, small scale plug flow, etc.)?

Feel free to elaborate in the textbox below, e.g. ―I find biogas stoves to be under developed due to the low degree of efficiency").

- □ Digesters
- □ Inlet and outlets
- □ Masonry work
- □ Appurtenances (e.g. biogas stoves, lamps, refrigerators etc.)
- □ Distribution of gas
- □ System as a whole
- □ None
- □ Don't know

Other/comment

9. What have the biogas plants for households you've encountered been fed with (select multiple for co-digestion)?

- □ Cow manure
- □ Pig manure
- □ Kitchen waste
- □ Garden waste
- □ Human excreta
- □ Human urine

Other/comment

10. In your experience, do households with biogas plants usually have enough waste to feed the plant with (to run the plant as expected)?

- ○ Yes, almost everyone
- ○ Yes, most of them
- ○ Yes, some of them
- ○ No or very few
- ○ Don't know

Comment

11. In your experience, do households with biogas plants have enough water to feed the plant with?

○ Yes, almost everyone

○ Yes, most of them

○ Yes, some of them

○ No or very few

○ Don't know

Comment

12. In your experience, would you say that users have to pre-manage the influent, other than mixing it with water (e.g. cutting it into smaller pieces)?

○ Yes

○ No

Comment

13. In your experience, how has users handled the effluent (slurry)?

If you select multiple options, please comment if you mean a combination or different occasions (e.g. "local post treatment followed by disposal into water body" or "the majority of users I've met dispose it in the open while some post treat it first").

□ Local post treatment

□ Centralised post treatment

□ Soil fertiliser (and/or soil conditioner)

□ Animal feed

□ Fish ponds

□ Dried and burned

□ Disposal in the open

□ Disposal into collection pond

□ Disposal into water body

□ Do not know

Other/comment

14. If you answered that the effluent was used as fertiliser or in fish ponds, were they satisfied with the result?

○ Yes

○ No

Comment

15. Do you consider the effluent handling you has encountered to be sanitary safe?

○ Yes, in almost all cases

○ Yes, in most cases

○ No, or in less than most cases

○ Never

Comment

16. Have you encountered special arrangement of the effluent (slurry) due to heavy metals in it?

○ Yes

○ No

Comment

17. For the households and institutions you've encountered that have been using biogas, what has the gas been used for?

□ Cooking (modified LPG burner)

□ Cooking (commercial biogas burner)

□ Generator (please specify what the electricity was used for in the text box)

□ Engine (please specify what the engine was used for in the text box)

□ Refrigerator

□ Don't know

Other/comment

18. Have you encountered gas from households being used for generators?

○ Yes, I have witnessed it with my own eyes.

○ Yes, I have heard of it from reliable sources.

○ No.

○ Don't know.

Comment

19. Have the gas produced been of sufficient quantity for the intended purpose?

○ Yes, in almost all cases

○ Yes, in most cases

○ No, or in less than most cases

○ Don't know.

Comment

20. Have the gas produced been of sufficient quality?

- ○ Yes, in almost all cases
- ○ Yes, in most cases
- ○ No, or in less than most cases
- ○ Don't know.

Comment

21. Have you encountered corrosion problems to gas appurtenances?

- ○ Yes, to a large extent
- ○ Yes, to some extent
- ○ No
- ○ Don't know

Comment

22. Have the gas distribution systems you've encountered been designed with corrosion problems in mind (e.g. sloping pipes etc.)?

- ○ Yes
- ○ Yes, but could have been better
- ○ No
- ○ Don't know

Comment

23. In your experience, do biogas users receive enough support from the enabling NGO/government/etc. during operation?

- ○ Yes
- ○ Yes, to some extent
- ○ No
- ○ Don't know

Comment

24. With regards to the previous question, give reasons why.

25. In your experience, have the contractors and suppliers of biogas system to households provided the users with adequate support during operations?

○ Yes

○ Yes, to some extent

○ No

○ Don't know

Comment

26. Have the majority of household biogas plants you've encountered been operational ten years after construction?

○ Yes

○ No

○ Don't know

Comment

27. In your opinion, what has been the main reason that households has invested in biogas? Select one option.

○ Energy from the gas

○ Neutralisation of waste

○ Use of the effluent for agricultural purposes

○ Only option available, received free, high subsidies, etc.

○ Status

○ Personal interest in biogas, enthusiast, etc.

○ Don't know

Other/comment

28. Have you experienced people being reluctant to invest in a household sized biogas plants due to...

○ ...don't believe that the technology will work?

○ ...operations or maintenance reasons?

○ ... odour, nuisance, etc.?

○ ...social/cultural/religious reasons related to using (reusing) animal waste?

○ ...social/cultural/religious reasons related to using (reusing) human excreta?

○ ...cost?

○ ...a general reluctant to ―new technology”?

○ ...low availability of water

○ Don't know

..or other/comment?

29. Would you say that the total work load for families using biogas have decreased, compared no their previous situation?

○ Yes

○ No

○ Don't know

Comment

30. Pick the attribute that, in your experience, are common traits for households using biogas.

□ Comparative rich

□ Comparative poor

□ Well educated

□ Farmers

□ Academics

□ White collar workers

□ Government employee

□ Unemployed

□ Land owner

□ Have access to electric grid

□ Don't know

Comment

31. Thank you for participating in this survey.

As previously mentioned, this survey is completely anonymous but if you want to you can leave your contact details for follow up questions. Also, feel free to share any comments or thoughts regarding the survey or biogas in general.

Yours sincerely

Sören Säf

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