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Solutions and applications for biogas in Afogados da Ingazeira, Brazil

- A study of the social and environmental impact of biogas, and the potential for improvements

Bachelor of Science Thesis in the Bachelor Degree program Chemical Engineering

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Department of Chemical and Biological Engineering
Industrial Biotechnology
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Cover photo:
Feeding a small scale, family run bio-digester in Afogados da Ingazeira, Brazil.
See section 4.1.1 on page 28.

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Abstract

The natural ability of anaerobic microorganisms to recycle carbon and nutrients from organic waste material has proven to be a very useful process for the production of a clean and renewable energy source, biogas. The process can reduce greenhouse gas (GHG) emissions by replacing fossil fuels, while also reducing deforestation and polluting waste. It also produces a 'digestate', which is rich in nutrients and can be used as fertilizer, replacing fossil-based chemicals. In developing countries, where clean energy is crucial for development, people are benefitting from this technology by using simple, small-scale household digesters.

We were given the opportunity to study this technology up close in a rural, semiarid area of north-eastern Brazil through the charity organisation Diaconia. Our aim was to evaluate and investigate the environmental and social impacts of installing and running a household bio-digester, and to propose possible improvements. The study was based on the specific digester design used by Diaconia, a modified floating gas holder digester. Field studies in Brazil took place at the farms of seven families, and included observations, interviews, and sample taking. Sample analysis was performed at the University of Brasilia, and literature studies and results were compiled in Sweden.

Observations showed that well-running digesters using cow, pig or chicken manure, could supply households with more than enough biogas for cooking. The location provides an ideal atmospheric temperature for gas production, and pH analysis showed values which are beneficial for the microbes and their habitat. Social analysis clearly showed social benefits of having a digester, in regard to time savings, cleanliness, finances, and health issues. The families themselves primarily emphasised their improved financial situation, saving ca 40 Brazilian Reals a month by replacing butane with biogas. Environmental analysis indicated a decrease in GHG emissions and deforestation, and a reduction in polluting manure, due to the switch from butane and firewood to biogas. Analysis of the hydraulic retention time (HRT) indicated a high degree of carbon and nutrient conversion in the digester, and feedstock change analysis showed that, because of the long HRT, a switch in substrate would not affect biogas production. Feedstock and digestate analysis showed satisfactory nutrient levels in the substrates but mixed levels in the digestate, which showed that some families would possibly benefit more by using their manure as fertilizer instead of their digestate. Suggested improvements addressed sharing a digester between two households to use the excess gas; treatment and field applications of the digestate; digester management; the possibility of selling the digestate as fertilizer; reuse of drained liquid; digester placement; and using human faecal residues as feedstock.

Keywords: Biogas, bio-digester, renewable energy, waste pollution, deforestation, GHG emissions, anaerobic digestion, HRT.

Preface

During the cold, closing month of 2013, we came in contact with Bengt Carlsson, who is an ambassador for Diaconia. Working together with Bengt and Diaconia, we had a great opportunity to create a project which combined sustainable development with helping and meeting people living under hard conditions in the municipality of Afogados da Ingazeira, in Brazil. This has been a very interesting and instructive period for us, one which we will never forget, and we will take these valuable experiences with us into our future working lives. With this thesis we hope that we can spread curiosity and knowledge about renewable energy and Diaconia's work in Brazil.

We would like to thank Bengt Carlsson and Diaconia, who made this project possible. Bengt, we thoroughly appreciate all your hard work helping us arrange the visit – you are always so full of enthusiasm and thoughtfulness. Diaconia, thank you for hosting us, for providing us with information, and for welcoming us with open arms.

Thank you to all the families who welcomed us into your homes with great hospitality and kindness during our visits. We are truly grateful for your participation in our interviews, which proved to be one of the main sources of valuable information to our project.

Thank you to our supervisor Maurizio Bettiga for all your help, expertise and guidance. It has been a pleasure working with you and this thesis could not have been achieved without your support.

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We would also like to thank Ivo Marinho for meeting us at the bus stop in the middle of the night, for taking care of us, translating, and for helping out with general everyday things in Afogados da Ingazeira.

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Abbreviations and glossary

AD process – Anaerobic digestion process
Digestate – Effluent slurry seen as a by-product from the degraded organic material in the digester
Facultative anaerobic bacteria – Can function as aerobes when oxygen is present.
GHG – Greenhouse gas
HRT – Hydraulic Retention Time
LPG – Liquid petroleum gas
Obligate anaerobic bacteria – Strictly anaerobic.
ODM – Organic dry matter
POPs – Persistent organic pollutants
TS – Total solids
VS – Volatile solids
$\Delta_f H°$ – Standard enthalpy of formation for 1 mol of the substance, in the state specified, under standard state conditions, from its elements in their standard reference states.
$\Delta_r H°$ – Standard enthalpy change for a given reaction

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1. Introduction

This chapter provides background information on the project and introduces its motivation and purposes, as well as describing certain limitations it encountered. It also gives an outline of the structure of the report.

1.1 Background

The world's oil resources are running out, and the prices are rising [1]. The earth's climate is changing due to the greenhouse effect, disturbing ecosystems and causing floods, storms and droughts [2]. There is a vital need for a source of sustainable energy that can replace fossil fuel, both for a greener environment and to meet the growing energy demand of the world's population. Such a source needs to be produced and supplied at a price which does not lead to segregation [1]. A country's economic development depends on clean and affordable energy, but this is a scarce commodity in many developing countries. Around 2.6 billion people around the world rely on traditional biomass such as livestock manure, firewood and crop residues to provide energy for cooking and heating [3]. These resources cause environmental, social and health problems, and a failure in supply can force families to leave their land and communities in search for an alternative life [4]. A lot of people have started using liquid petroleum gas (LPG) and gas stoves because of a lack of firewood caused by over-consumption, but this makes them financially dependent for energy supply [5].

One answer to these issues in rural areas is small-scale household bio-digesters, which are actively being implemented in the homes of people lacking a sufficient supply of clean energy [4]. These digesters are closed, controlled compartments housing a variety of anaerobic microorganisms in a complex and balanced environment which, through digestion, can recycle carbon and upgrade organic household and farm waste to biogas, a renewable fuel [6][1]. This biogas is carbon-neutral, and can substitute for fossil fuels and traditional biomass, reducing deforestation and production of GHG and polluting waste. Biogas contains a mixture of 50-70% methane, 25-50% CO_2, and 2-8% other gases, with methane comprising the source of energy [1]. The composition and methane yield depend on the carbon content of the feedstock, which in rural areas mainly consists of cheap and easy accessible substrates such as livestock manure, crop residues, and human excreta [1][4]. The microbes also have the ability to upgrades the waste to nutritious digestate, a mixture of processed solid and liquid, by recycling organic nutrients into forms which are readily available for uptake by plants, such as NH_4^+ and PO_4^{3-}. The digestate can therefore act as a valuable bio fertilizer which can improve agricultural fields, replacing chemical fertilizers [1]. The technology and equipment needed for the household digesters are normally easy to access and maintain, but are not cheap in the context of a rural economy. Help is therefore needed from local governments or charity organisations, so that people in rural areas have the possibility to improve their lives, while at the same time caring for the environment by recycling carbon, reducing waste, deforestation and greenhouse gas emissions [4].

One such charity organisation is Diaconia, who provided the opportunity for us to conduct a case study of the bio-digesters they have installed, together with the Dom Helder Camara Project for the people in the rural semiarid areas of Afogados da Ingazeira, Brazil. The study was initiated through

Diaconia's Swedish ambassador Bengt Carlsson. There was an interest to study how the people and their environment have been affected by the installation of bio-digesters in the area, and to see if there were any improvements to be made. The project was divided into two parts, a literature study and a field study on-site in Brazil. During the field study, observations and interviews with families using a digester were made, and samples were collected which were later analysed at the University of Brasilia.

1.2 Diaconia

Diaconia in Brazil is a social, non-profit organisation initiated in Rio de Janeiro in 1967 by eleven Evangelical churches. Their initial aim to battle poverty has developed into working towards transforming society, and promoting justice and social development. In 1984 they moved their main office to Recife, focusing their work on the semiarid states in north-eastern Brazil where 40 % of the county's poorest people live [7]. Here, they run sustainable projects together with local organisations involving rights for children, teenagers and adults, the environment and climate, food and water security, gender relationships, and creation of employment and income [5].

Many of these projects are to encourage people to stay in their local area, and enable them to do so, despite poverty and hard living conditions. In 1978-1984 Diaconia saw a trend of people leaving the North East Region of Brazil for the larger cities, Rio de Janeiro and Sao Paulo, in the hope of a better life. The majority of these people ended up in slum areas without work or money to provide for themselves and their families [8].

A project called A Single Drop of Water was initiated by Diaconia to solve the water deficiency prevailing in the area. They started building water cisterns to store rain water received during the rainy periods. Today, over 500 000 cisterns have been installed. Diaconia wants to further improve living conditions for the locals, and also help them work against the irrational deforestation of Brazil [8].

Diaconia partnered with the Dom Helder Camara project, and in 2009 they began to install bio-digesters in the homes of agricultural families. This project promotes local development in an environmentally friendly way by supplying people with green energy that can replace or complement LPG, firewood and charcoal (see appendix 8.1) [5]. The Dom Helder Camara project is a decentralised activity of the Ministry of Agrarian Development, through the Department of Territorial Development, for combating poverty and supporting sustainable rural development in the semiarid region of north-east Brazil. The project is implemented with resources from the Federal Government, the International Fund for Agricultural Development (FIDA) and the Global Environment Facility (GEF) [5].

The digesters are built with simple equipment that can be maintained by the families themselves, and which is available in local shops [5]. The families are selected primary based upon their need for help, and it is also an advantage if they have collaborated with Diaconia earlier (see appendix 8.1). They can later choose if they prefer to cook with biogas instead of LPG or firewood [7]. At the time of this study, Diaconia had installed 137 bio-digesters in the Pajeu area in Pernambuco (see appendix 8.1).

1.3 Purpose

This thesis aims to evaluate and investigate the environmental and social effects of installing and running a small scale, family run bio-digester in Afogados da Ingazeira, Brazil, and to suggest improvements. It also aims to highlight the work that Diaconia is doing, both for a greener environment and for vulnerable people in the semiarid areas in north-eastern Brazil.

1.4 Clarification of purpose

The study was divided into environmental, social and improvement parts:

- Environmental assessment part: This aimed to collect quantitative data for calculations of greenhouse gas emissions, and to compare these with emissions from earlier used energy sources. It also included collecting samples of manure, feedstock and digestate for analysis and, where possible, collection of information to evaluate changes to the local ecosystem.
- Social assessment part: This aimed to evaluate the possible social impacts that installing bio-digesters may have had on the families, such as time savings, cleanliness, and financial consequences.
- Improvement part: This examines whether there could be any improvements made in regard to the organic material used in the feedstock, the biogas yield, leakage, nutrient levels in the digestate, spreading of digestate on the fields, and social enhancements.

1.5 Limitations

The field studies and experimental work were carried out at a sensitive site that had not been seen or visited by the researchers. The circumstances there, and exactly what could be investigated, were therefore unknown beforehand. Because of this, the different points intended to be examined were regarded as being provisional, rather than pre-determined, and what could actually be examined was to be discovered on-site. This was also dependent on the terms set by the families visited, as it was in their homes and on their land that the study was carried out. This places necessary limits on the purpose of the thesis, as well as its results.

The choice of families to visit was made by Diaconia. This influences the study in a somewhat subjective way, as no information was given regarding other families involved in their Dom Helder Camara project. This was known and discussed beforehand, and a request was made to visit at least four families, in order to provide a more statistically credible result.

During the preparation period, the extent of the study was constrained by the equipment available. In particular, the intended study of methane leakage from digesters suffered from this. In consequence, methane leakage was simply studied and evaluated qualitatively through direct observation. All the equipment needed to pursue the study was brought from Sweden, as it was not available on site. This placed limits on the amount it was possible to bring, and on the nature of what could be taken, because of customs regulations. Customs also prevented the samples we collected from being analysed in Sweden. Analysis was therefore carried out by Nádia Skorupa Parachin and Renato S. Oliveira from the University of Brasilia.

A further limitation recognised during the field studies was the weather. Health and safety aspects were taken into account while the work was being carried out. Both water and sunscreen were needed, and work was paused during the hours of greatest heat around lunch time.

The study is based on the type of small-scale bio-digesters supplied by Diaconia, which are designed and customised for the geographic location, and for the specific families that they aim to help. Therefore any recommendations and proposed improvements are developed for these, and only these, conditions. Information concerning the theoretical framework of the project has also been limited to what is relevant to these digesters, to ensure a more cohesive thesis.

1.6 Project outline

This report is divided into eight chapters, which are summarised below.

Chapter 1 – Introduction
This chapter provides background information on the project and introduces its motivation and purposes, as well as describing certain limitations it encountered.

Chapter 2 – Theoretical framework
This part describes the theory supporting the analytical framework, and includes information about biogas, different feedstock, the digestion process, process parameters, digestate and fertilizer. It also discusses the equipment that Diaconia use in the small scale digesters in north-eastern Brazil and potential risks.

Chapter 3 – Method
This chapter describes how the work in this thesis was carried out.

Chapter 4 – Results
In this chapter the results of the field studies and additional research are presented and analysed.

Chapter 5 – Discussion
In this chapter the results and possible lines of further research are discussed

Chapter 6 – Conclusion
The conclusion summarises the thesis and presents recommendations

Chapter 7 – References

Chapter 8 – Appendix
The appendix contains interviews with Diaconia staff and the families we visited, along with gathered data and measurements from the families' bio-digesters. It also includes bio-digester field study pictures and the safety data sheet for the insecticide, Tamron.

2. Theoretical framework

This chapter provides a theoretical background describing the nature of biogas, possible substrates which may be used as feedstock, the microbial digestion process, process parameters and the digestate produced. Further, the equipment used for digestion is also described, together with the advantages and disadvantages encountered with the digestion process.

2.1 Biogas

The majority of the energy consumed today is provided by burning oil. Some part comes from the nuclear industry, while energy from the renewable sector is almost negligible [9].

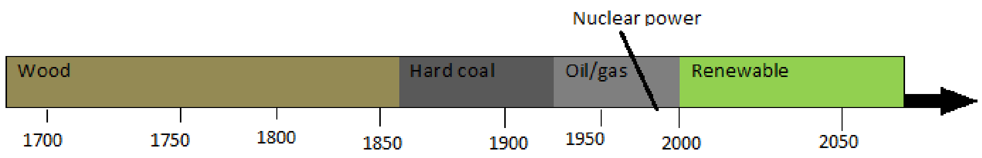

Figure 1. A timeline of different energy sources [9].

Figure 1 shows a timeline for different energy sources during the period 1700–2000. The figure also includes a prediction for possible energy sources in the future. Renewable energy is a sector with good potential for development, since its usage has been almost negligible for many years. An upward trend towards more environmentally friendly thinking has helped the renewable sector expand [9].

Shell International has published an energy source forecast for the period 1990–2100. They predict energy consumption during this period to increase by at least three times – in the worst case scenarios by seven times – because of population grown and economic expansion [9]. Further, the report states that the technology associated with renewable resources is expected to be beneficial in both economic and environmental terms by 2020. They claim that fast growth for green energy is necessary, and that by 2050, 50% of all consumed energy will be from renewable resources, primarily from solar energy and heat [9].

Biomass is only predicted to have a small contribution to the green energy supply. It has a high carbon content, but does not count as a fossil material. Biomass includes animals, plants, nutrients, excrement, and biological waste from households and industry. Combustion, carbonisation, gasification, and extraction are some of the processes used to transform biomass into energy [9].

Biogas mainly consists of methane and carbon dioxide. The methane content needs to exceed 45% for biogas to be classified as a flammable gas and for it to be able to be used for cooking. Some characteristics of biogas are presented in Table 1. Biogas also contains several impurities in minor amounts that pollute the gas. These, and their effects, are presented in Table 2 [9].

Table 1. General features of biogas [1][9]

Feature	
Composition	50-75% methane, 25-50% carbon dioxide, 2-8% other gases
Energy content	6.0–6.5 kWh/m^3
Fuel equivalent	0.6–0.65 l oil/m^3 biogas
Explosion limits	6–12% biogas in air
Ignition temperature	650–750°C
Critical pressure	75–89 bar
Critical temperature	– 82.5 C
Normal density	1.2 kg/m^3
Smell	Bad eggs, the smell of desulfurized biogas is barely noticeable
Molar mass	16.043 g/mol

Table 2. Gases present in biogas [10]

Compound	Content	Effect
CO_2	25–50%	*Lowers the calorific value *Increases the methane number and the anti-knock properties of engines *Causes corrosion (low conc. carbonic acid) if the gas is wet *Damages alkali fuel cells
H_2S	0–0.5%	*Corrosive effect in equipment and on pipes *Limit is often 0.05% *Spoils catalysts
NH_3	0–0.05%	*NOx emissions *Increases the anti-knock properties of engines
Water vapor	1–5%	*Causes corrosion of equipment and pipes *Condensates damage instruments and plants *Risk of freezing piping system and nozzles
Dust	5 µm	*Blocks nozzles and fuel cells *Lowers the calorific value *Increases the anti-knock properties of engines
N_2	0–5%	*Lowers the calorific value *Increases the anti-knock properties of engines
Siloxanes	0–50 mg m^{-3}	*Acts as an abrasive and damages engines.

2.1.1 The ratio between methane and carbon dioxide

The ratio between carbon dioxide and methane depends on several factors. These factors are a way of controlling the composition of the biogas. The main factors are [10]:

- The addition of long chain hydrocarbon compounds, typically fats, can help to improve the biogas. The methane content increases with a greater number of carbon compounds.
- A longer exposure to anaerobic microorganisms generally results in improved decomposition of the organic material.
- A homogeneously activated digester results in a quicker and more even fermentation process, which in turn can shorten the time of exposure.
- If there are a large number of lignin structures in the substrate, the type of disintegration becomes important. Rather than being cut, the structure should be disrupted or defibrated.
- A higher content of liquid in the digester results in a lower concentration of CO_2 in the gas phase.
- A higher temperature during the fermentation process results in a lower CO_2 concentration dissolved in water.
- A higher pressure results in a higher CO_2 concentration dissolved in water. If the material from the bottom of the digester is removed, CO_2 is discharged along with it, and the quality of the gas may be improved.
- A well prepared substrate aids and accelerates the decomposition [9].

2.2 Feedstock

Biogas can be produced from various kinds of organic material which are abundant worldwide. They need only contain carbohydrates, fatty acids, protein, cellulose and hemicellulose. It is important that the substrate chosen as feedstock does not contain impurities or pathogens that can pass unchanged into the digestate. At the same time, it is important that the feedstock has a high nutrition value to ensure a high methane yield and a nutrient-rich digestate, and to supply nutrients to the microbes [9]. The yield of methane in the biogas depends on the amount of volatile solids (VS) in the initial feedstock, and on the oxidative state of the carbon. The more reduced the carbon is, the larger the methane yield will be [10].

Developed countries use digesters which can process industrial, municipal and agricultural organic waste, whilst developing countries use simpler digesters which can process livestock manure, crop residues, or human excreta. It is estimated that approximately 1100 million dry tons of animal and human waste becomes available in developing countries for digestion each year, which corresponds to 280 billion cubic meters of biogas, and a possible decrease in CO_2 emissions of 1700 million tons per year [4]. Before digestion, the feedstock can be pre-treated so that the digestion process proceeds more efficiently, increasing the availability of carbon, and thereby increasing the methane yield. The type of pre-treatment depends on the material used as feedstock, and on finances and availability [1]. The following section talks about the most common feedstocks used for biogas production.

2.2.1 Animal manure and slurries

Biogas is mainly produced using waste from the agricultural sector, such as manures collected from cattle, pigs, poultry and chicken [1]. The agricultural sector stands for 18% of worldwide greenhouse gas emissions. GHGs are thought to be mainly produced from animal manure and slurries, and worldwide annual production is around 13 billion tons. For example, untreated cattle manure produces 4045.7 gCH_4/m^3. So by using manure as a feedstock it is possible to upgrade it from being an environmental pollutant to a valuable resource [1].

Animal manure is an exceptional feedstock, especially in developing countries, as it is cheap and readily available. It also naturally provides a diverse selection of anaerobic microbes, large amounts of nutrients for the growth of the microbes, a good C:N ratio of 1:25, and buffer capacity to help maintain a stable pH in the digester. Less favourable properties include low organic matter, which gives a low methane yield, and high amounts of ligno-cellulose which is not degradable by microbes because of its structure and composition [1]. Further pre-treatments of the substrate are needed before the carbon in the ligno-cellulose can be used [4].

In developing countries such as the location studied in this project, the manure is pre-treated by regulating the water content (see appendix 8.2). This helps achieve the right amount of total solids (TS) in the feedstock, (see section 2.4.5 for more detail). Fresh manure requires a manure-water ratio of 1:1, whilst relatively dry manure requires a ratio of 1:2.5 [11]. The yield of methane varies a great deal between different types of manure [1]. Also, the nutrients in the manure differ, as is shown in tables 3 and 4 which give the typical amounts of nutrients for different manures.

Table 3. Nutrient content of selected feedstocks [1].

Feedstock	TS (g/kg)	VS(g/kg)	Total N (g/kg)	NH_4^+ - N (g/kg)	Total P (g/kg)
Liquid dairy manure	110 +/- 23	90 +/-21	3.9 +/-0.9	1.7 +/-0.8	0.7 +/-0.3
Poultry broiler manure	452 +/- 30	256 +/-25	20.1 +/-3.1	12.5 +/-2.3	1.2 +/-0.4
Swine manure slurry	37	N/A	4.0	2.7	1.3

Table 4. Biogas yield from different manures [9].

Substrate	Biogas yield (m^3/kg of TS)
Liquid manure cattle	0.1–0.8
Excreta cattle	0.6–0.8
Liquid manure pigs	0.3–0.8
Excreta pigs	0.27–0.45
Excreta chicken	0.3–0.8
Excreta sheep	0.3–0.4
Excreta horse	0.4–0.6

2.2.2 Crops

Plant residues are mainly digested as a co-substrate with the animal manure. Otherwise, they often require treatment before feeding into the digester. Many different techniques are applied when using crops as feedstock. The most common is mechanical pre-treatment for decreasing the size, with a standard size of around 1 cm^3. Crops also hold large amounts of lingo-cellulose, which, as described above, is not a favourable characteristic when being degraded. Breaking the lingo-celluloses molecules is important to make the anaerobic digestion easier and to release more carbon for conversion to methane [1].

2.2.3 Crops in Brazil

Agriculture is very important in Brazil. The country produces twice as much as the USA, with coffee, soya beans and corn as the main products. This study was carried out in the State of Pernambuco, in the northeast of Brazil. The vegetation in Pernambuco area is varied due to the irregular weather. The State suffers periods of total dryness which makes it hard for many crops to grow continuously through the year. In the last 3–4 years, the area has also suffered a harsh drought in which many animals and crops have died, and recovery has been slow (see appendix 8.2).

2.2.4 Sewage sludge as organic material

When using sewage as slurry many pre-treatments are required to increase the methane yield. It is also necessary to consider the high content of pollutants which may harm the bio fertilizer [1]. Therefore, the usage of sewage as biomass is regulated by national legislation. Europe has had regulations for twenty years to limit the amounts of heavy metals, organic pollutants and pathogens in digestate used as fertilizer on fields [1].

Sewage sludge is often compared in efficiency to pig or cattle slurries when it comes to methane potential [1]. It is a very complex material for using as feedstock since it varies considerably with geographical area, consumption patterns, and local environments and waste treatments. It is also important to consider acceptance for using sewage sludge in the agricultural sector. Some counties in European have banned the usage of sewage, for example the Netherlands, Switzerland and Austria [1].

2.2.5 Human faecal residue

Human faeces are also a possible substrate for biogas production. This is a simple feedstock for people in developing countries, as it is produced in every home and it has the possibility of yielding the same amount of methane as animal manure [4]. However, it needs to be handled with caution, and according to health and safety regulations, due to its high content of unhealthy pathogens which can cause diseases [12]. Contact can be avoided by connecting the toilet to the digester. This is also avoids the problem where collection in septic tanks provides an opportunity for aerobic and anaerobic digestion to occur [4]. Further there should be no flies attending the excreta, or any worms escaping the latrine pit. The digestate should only be used as fertilizer for trees, and not for vegetables or fruit production, because pathogens may remain after digestion [14].

2.2.7 Physical impurities

It is important to be aware of any physical impurities in the feedstock as they are non-degradable, harmful to the environment, and can cause damage to pumps, pipes and stirrers [1]. They may also decrease the efficiency of a digestate if it is used as fertilizer on crops and vegetables. Plastics, stones, and glass are examples of physical impurities which are often found in household waste, and which can quite easily be separated from organic waste.

2.2.8 Chemical impurities

Unwanted chemical substances are often found in sewage sludge, mixed waste, and domestic waste water. Typical chemical impurities are heavy metals and organic compounds, some of which some are included in POPs [1]. There is also a risk of finding chemical pollutants in food waste and household waste.

2.3 Digestion process

Biogas is produced through anaerobic digestion of long carbon chains into short carbon molecules, CH_4 and CO_2. The process is divided into four main phases where the first two and the last two are closely linked, as is shown in Figure 2. The phases are carried out by different groups of microorganisms, which make up a balanced and complex ecosystem of symbiosis and mutualism [6]. Each phase requires a wide selection of microorganisms, mainly bacteria, including both obligate and facultative anaerobic bacteria, but protozoans and fungi may also be present. The type of anaerobic bacteria present depends on the material that is being processed [1]. Their relationship is very complex, but together they create suitable conditions for each other by regulating pH, removing toxic substances, and providing nutrition [6]. The entire process can fail if one or more bacteria are inhibited [10]. The bacteria only require a very small portion of the energy content of the feedstock to process the material, conserving the rest in the produced methane [1].

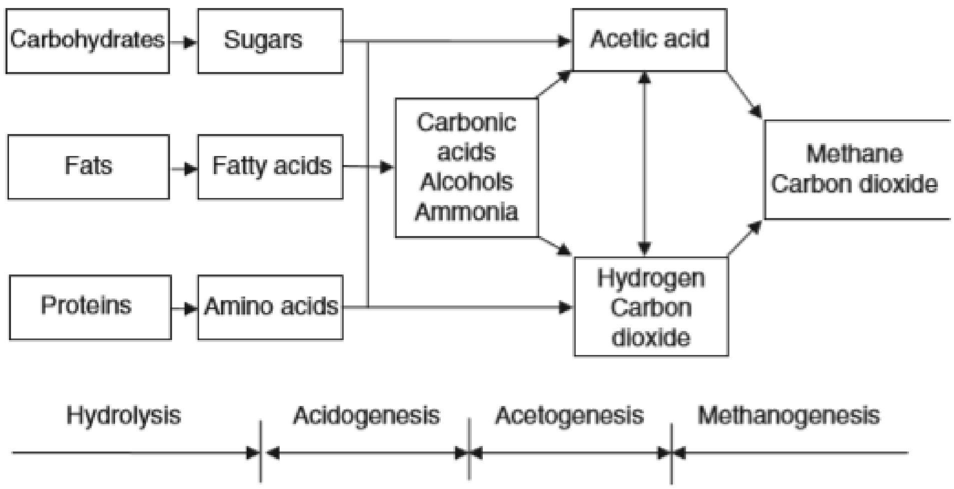

Figure 2. An overview of the four main digestion phases and the elements converted in each phase [6]

1. Hydrolysis – carbohydrates (1), proteins (2) and lipids (3) are hydrolysed by hydrolytic bacteria into their monomers and sugars, amino acids, and fatty acids, respectively [6]. This is carried out by extracellular enzymes, such as cellulases, amylases, proteases, and lipases. These are produced by bacteria to break down complex molecules for their own purposes. The main hydrolytic reactions at this stage where water is added to break the covalent bonds between the monomers are as follows [6]:

$$(C_6H_{10}O_5)_n + nH_2O \rightarrow nC_6H_{12}O_6 \quad (1)$$
$$(R\text{-}CHNH_2COOH)_n + nH_2O \rightarrow nR\text{-}CHOH_2OOH + nNH_3 \quad (2)$$
$$C_3H_5(OCOR)_3 + 3H_2O \rightarrow C_3H_5(OH)_3 + 3RCOOH \quad (3)$$

The lipids and proteins take a few days to dissolve, while it only takes a couple of hours for the carbohydrates [9].

2. Acidogenesis – Also known as the fermentation step [10]. Here, the monomers produced from the hydrolysis are further transformed by fermentative bacteria. The product is a mixture of volatile fatty acids such as acetic acid, propionic acid, butyric acid and traces of alcohols, ketones, CO_2, NH_3, H_2S and H_2 [6]. The amounts of CO_2 and H_2 that are produced are rather large. H_2 may be used for energy recovery [10].

3. Acetogenesis – The CO_2 and H_2 produced are continually reduced to acetic acid by homoacetogenic bacteria [9].

$$2\,CO_2 + 4\,H_2 \leftrightarrow CH_3COOH + 2H_2O \quad (4)$$

The propionic acid, butyric acid and alcohols are converted into hydrogen, carbon dioxide and acetic acid by acetogenic bacteria [6][10].

$$CH_3CHOHCOO^- + 2H_2O \rightarrow CH_3COO^- + HCO^-_3 + H^+ + 2H_2 \quad (5)$$
$$CH_3CH_2OH + H_2O \rightarrow CH_3COO^- + H^+ + 2H_2 \quad (6)$$
$$CH_3(CH_2)_2COO^- + 2H_2O \rightarrow 2CH_3COO^- + H^+ + 2H_2 \quad (7)$$
$$CH_3CH_2COO^- + 3H_2O \rightarrow CH_3COO^- + HCO^-_3 + H^+ + 3H_2 \quad (8)$$
$$4CH_3OH + 2CO_2 \rightarrow 3CH_3COOH + 2H_2O \quad (9)$$
$$2HCO^-_3 + 4H_2 + H^+ \rightarrow CH_3COO^- + 4H_2O \quad (10)$$

To be able to function, the acetogenic bacteria live in symbiosis with hydrogenotrophic methanogenic bacteria. They depend on each other to regulate hydrogen. Acetogenic bacteria require a very low level of hydrogen partial pressure, but they produce hydrogen in their own metabolism. The hydrogenotrophic methanogenic bacteria are a very efficient consumer of hydrogen, and the two work together to balance the level of hydrogen in the digester [6].

4. Methanogenesis – In this step, acetic acid, hydrogen, carbon dioxide, formic acid, methanol and methylamine are transformed into methane and carbon dioxide [6]. Methane is mainly produced from acetic acid by acetoclastic methanogenic microorganisms, which are sensitive and have low reproduction rate. About 70% of the methane in the final product comes from acetic acid [10]. The remaining part is produced by hydrogenotrophic methanogenic bacteria which utilise hydrogen and carbon compounds and have a relatively high reproduction rate [1][6]. The main reactions during the methanogenesis are as follow:

$$CH_3COOH \rightarrow CH_4 + CO_2 \quad (11)$$

$$CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O \quad (12)$$
$$HCOOH + 3H_2 \rightarrow CH_4 + 2H_2O \quad (13)$$
$$CH_3OH + H_2 \rightarrow CH_4 + H_2O \quad (14)$$
$$4CH_3NH_2 + 2H_2O + 4H^+ \rightarrow 3CH_4 + CO_2 + 4NH_4^+ \quad (15)$$

2.4 Parameters affecting the process

Several factors affect living conditions for the microorganisms and their activity. It is important that the digester is fed regularly, and that the feedstock and reactor conditions are correct, so that the anaerobic bacteria can grow, regenerate, and convert organic material into methane. If conditions are disturbed, it can take more than three weeks for the bacteria to produce gas again [9]. Because the bacteria coexist in conditions of symbiosis and mutualism, they will respond in different ways to changes in the environment [10]. The different parameters affecting the process are presented below.

2.4.1 Temperature

This important factor varies for different digesters within a span of 8–65 °C, although microorganisms have shown growth at -11 °C and methane production at -3 °C [6][9]. The microorganisms are generally divided into three groups, depending on the optimum temperature at which they grow; the psychrophilic range with temperatures below 25 °C, the mesophilic range with temperatures between 25–45 °C, and the thermophilic range with temperatures between 45–65 °C [6][10]. The production of gas increases with increased temperature because the degradation is faster. This means that feedstock digested at the thermophilic temperature range requires a shorter retention time (see section 2.4.6), and so the reactor volume can be smaller with the same amount of feedstock. High temperature also kills pathogens, but it enhances the conversion of ammonium to ammonia, which can inhibit the microbes [1]. The most common operating conditions are the mesophilic and thermophilic ranges, but the energy balance is more advantageous in the mesophilic range [6][9]. The most sensitive bacteria to temperature changes are the acetoclastic methanogenic bacteria. Changes larger then +/- 2 °C can drastically decrease the activity of the bacteria giving gas losses of up to 30% [9].

To keep the temperature at a steady level, it is important to not add cold water to the feedstock when pre-treating it for liquidised digestion. This will cause a high heating demand when added to the digester, heat which will be drawn from the reactor contents, decreasing their temperature. It is also important to keep in mind where a digester can be installed in terms of geographic location. This is because the heating demands of unheated, uninsulated digesters, such as those typically installed in rural, developing areas, depend on the atmospheric temperature [1][15]. These digesters do not work well in climates with temperatures below 15 °C. More advanced digesters are used in more temperate areas. These require a higher investment cost as they are equipped with heat exchangers and insulation [15].

2.4.2 pH

The acetoclastic methanogenic bacteria are also the bacteria which are most sensitive to pH. The most favourable pH for these bacteria is in the range of 6.7–7.5, which sets the pH for the rest of the microorganisms [9]. Fermentation usually proceeds at a pH slightly above neutral. The buffer capacity is controlled by the concentration of CO_2 gas, liquid ammonia, and water content [1].

2.4.3 Nutrients

Microbial growth requires C, H, N, O and S, which are the main elemental components of biomass. C, H and O are converted into CH_4 and CO_2, whilst S and N are either converted into new biomass or reacted into sulfides and ammonia, which are toxic to the methanogenic bacteria in larger amounts [1]. A balanced and constant C:N ratio of 20–30:1 is desirable, as the microorganisms use carbon 25–30 times faster than nitrogen [4][11]. If the ratio is not in this range, it can be adjusted by co-digestion (see section 2.4.4 below) [10]. If the ratio is too low, production of ammonia may increase, inhibiting the process by damaging the methanogenic microbes, and disrupting methane production [9]. If the ratio is too high there is a lack of nitrogen, leading to small changes to the volatile fatty acids which can cause drastic pH fluctuations [1]. Microorganisms also need other elements to be present at trace concentrations to survive. These elements include Ni, Fe, Mg, Cs, Zn, Co [10].

2.4.4 Co-digestion

By co-digesting different organic materials it is possible to increase the methane yield by creating a more stable digestion process. Co-digestion can provide a better buffer capacity, keeping the pH more stable, or it can give a more balanced C:N ratio [14]. Manure is typically rich in nitrogen but poor in carbon, and as mentioned above, microbes degrade carbon around 25–30 times faster than nitrogen, which may lead to an excess of ammonia and inhibition of the methanogenic bacteria. Crop residues have a higher carbon content then manure, which results in a high CO_2 content in the biogas [4]. By co-digesting these two, the C:N ratio of the mixture can be kept more stable by driving it to the optimum values of 20–30:1, improving the circumstances for biogas production [1].

2.4.5 Solid concentration

The total solid (TS) dry matter (DM) of the feedstock should range from 5–12%, and should contain mainly volatile solids, VS, and as little inorganic soils and sand as possible [11]. VS or organic dry matter (ODM) is the carbon-containing dry matter, carbohydrates, protein and lipids, from which the methane gas is produced. Too high TS can inhibit the metabolism of the microbes by affecting the transfer of heat and mass. Too low TS results in a low gas production because of the low amount of biological material available to degrade. The TS value is often regulated with water and the correct value is usually reached if fresh manure is mixed with equal amount of water [6].

2.4.6 Hydraulic retention time (HRT)

The microorganisms need time to convert the organic carbon in the digester into CH_4 and CO_2. The time the material stays in the digester is characterised by the HRT, as is described in Reference (16) [1]. The average time for which a given volume of feedstock remains in the reactor normally varies from ten to sixty days. The longer the retention time, the more time the microbes have to work through the feedstock, increasing the amount of carbon converted into methane, and thus increasing the methane yield. The same applies to the nutrients in the feedstock: these are more likely to have been converted to inorganic form with longer HRT (see section 2.9.1). Long retention times also inactivate a large proportion of pathogens, decreasing health risks [1]. HRT must be at least ten days to avoid the risk of washing out bacteria which are too young and active, thus disturbing the bacterial balance. This especially applies to the methanogenic microorganisms with the longest regeneration times of 5–16 days. This slow regeneration time dictates a start-up phase for a new digester of up to three months [9].

$$HRT\ (days) = \frac{\text{Net digester volume (m}^3\text{)}}{\text{Substrate input }(\frac{\text{m}^3}{\text{day}})} \quad (16)$$

2.4.7 Inhibition of biogas production

An inhibitor is an agent that disturbs a chemical compound and can thereby hamper the main purpose of that compound. This can either prevent or decrease the rate of a chemical reaction [1] [16]. Inhibition of biogas production depends on the concentration of the inhibitor, the substrate and anaerobic bacteria's adaption for the inhibitor. Anaerobic bacteria rapidly adapt to their environment, therefore it is hard to find collated facts regarding inhibitors and their effect on fermentation [9]. Some of the most common inhibitors during biogas production are oxygen and sulphur compounds, hydrogen, organic acids, nitrates, heavy metals, and ammonium or ammonia [1][9][17]. Inhibitors are affected by both temperature and pH and by other chemical compounds acting at the same time.

2.5 Equipment design

Various designs have been used for digesters around the world. A common division is made between digesters used for household purposes and those for industrial and larger scale production. Large scale production is often separated into wet and dry digesters. In this work, only the household digesters will be discussed. Two of the more common kinds of digesters used for household purposes are presented below [6].

2.5.1 Hydraulic pressure digester

This digester consist of three main parts; a fermentation chamber, a hydraulic gas storage chamber, and pipelines for feeding feedstock and discharging digestate. These are shown in Figure 3 [6]. A high pressure is built up in the fermentation chamber due to production of biogas, which causes the liquid in the digester to adjust its level in the fermentation chamber and the hydraulic pressure chamber. A level is reached where the pressure in the hydraulic pressure chamber is in balance with that in the fermentation chamber. Biogas can now be consumed and liquid flows back to the fermentation chamber. The liquid level controls the storage and discharge of gas [6].

This type of digester has become popular in recent years, especially in China. There are three main types or designs of this digester commonly found around the world: the feed hydraulic digester, the movable cover digester, and the strong swirl flow mixed digester. The approximate volume of these digesters is 6–10 m^3 [6].

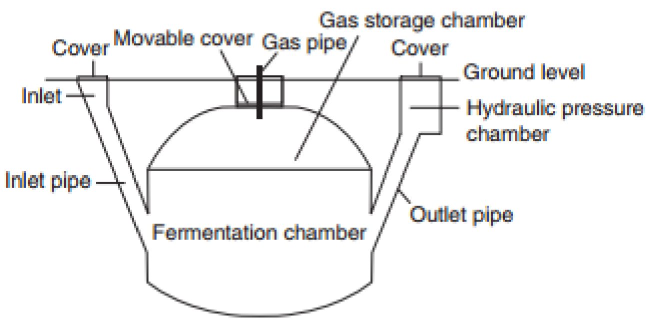

Figure 3. An overview of a hydraulic pressure digester [6].

2.5.2 Floating gas holder digester

This design presented in Figure 4 is commonly used in India and usually has a volume of 6–8 m^3. The theory behind this design is that the produced biogas is collected and stored in a floating gas holder. When the gas builds up the pressure increases and the gas holder rises until a balance is reached with the external pressure [6]. When consuming the biogas the pressure drops in the gas holder and it sinks until a new pressure balance is reached. The digester is made up of a mixing tank, an outlet tank, the floating gas holder, inlet and outlet pipes, the fermentation chamber and a partition [6].

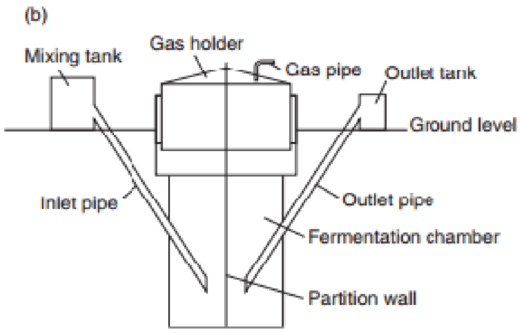

Figure 4. An overview of a floating gas holder [6]

2.5.3 Construction and installation of the small-scale digester used in Afogados da Ingazeira

The digesters installed in Afogados da Ingazeira follow the principle of the floating gas holder digester shown in Figure 4. They are always installed by a team made up of one family member and two people from Diaconia. This helps to involve the families in a natural way and there is also an opportunity to educate them about how to run the bio-digesters (see appendix 8.1).

When installing a bio-digester it is necessary to consider its location. It is important that the digester is close to the kitchen, but not next to the house. By placing the digester close to the kitchen the length of the gas pipe can remain short, which will increase its efficiency. It is also important to place the digester in the sun to increase the heat, and thereby the production of biogas [5]. The general features and dimensions of the digester installed by Diaconia are shown in Figure 5.

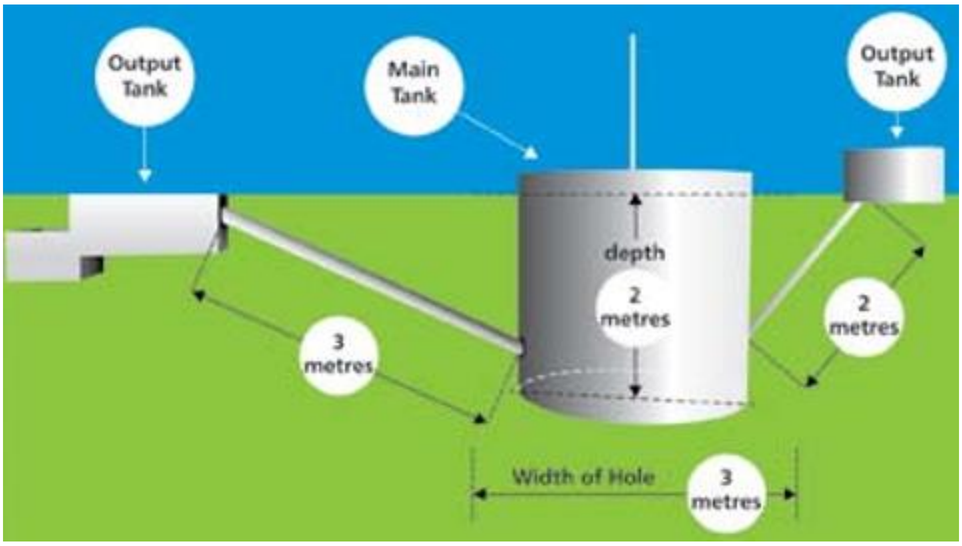

Figure 5. Features and dimensions of a Diaconia digester [5].

The construction work starts with concrete slabs being made on sand for the tank wall with the help of a curved wooden framework. The same technique is used for both the input tank and the main tank. Appropriate input and output holes are made in certain slabs. The next step is to place a 3.5 m guide pipe, made of iron on the inside and PVC on the outside, at the centre of the level base of a hole, dug to be approximately 2 m deep and 3 m wide. The floor is then filled with cement, leading to a new depth of around 1.8 m [5]. A safety girder is installed to make the construction more stable. Two beams are placed upright and fixed in the ground at the side of the hole, while a third is placed across the top with the guide pipe attached to it [5]. Thereafter the digester walls are created. The slabs are placed in a circular formation and fixed with cement; four tiers with twelve slabs in each tier are used to get the exact measurements. It is important that the wall reaches around 20 cm above ground level to protect the digester from rainwater. The tiers are tied together and stabilised with galvanized wire, as shown in Figure 6. The hole for the output pipe should be 30 cm from the ground level, while the input pipe hole should be 10 cm from the ground level [5]. Three hollow bricks are used to build a small wall which functions as a stanchion at the bottom of the digester. The purpose of the stanchions is to keep the gas holder tank, blue in Figure 7, separated from the bottom of the hole. It is important when constructing the stanchions that the bricks are higher than the output pipe [5]. It is also necessary to smooth the wall with a trowel, both outside and inside, to make it smoother and more stable.

Figure 6. Construction of the digester walls with cement slabs, galvanized wire and plaster [5].

The input tank should be placed at ground level with the connecting pipe dug down into the ground. A circular shape has been shown to improve the homogeneity of the feed, since it makes it easier to mix the manure with water [5]. It is formed with eleven small slabs together in two tiers, each of which is 0.4 m in radius. While the cement mixture is fresh and soft, a hole for the pipe is made, were the feedstock can flow from the bottom of the input tank into the digester. The output tank needs to be at a lower level than the input tank so that the digestate flows into it. This makes it necessary for the output tank to be dug down into the ground. The upper part of the output tank is provided with holes in order to drain water from the digestate. [5].

The gas holder tank, which holds around 3,000 litres is then installed [5]. The guide pipe is fastened in the middle of the tank so it can rise and descend without ruining the structure. The guide pipe is fastened to the central flange inside the tank. A wooden beam, two meters in length, is used as a base for the guide pipe and in the centre of the board a hole for the guide pipe is created, as is shown in Figure 7 [5].

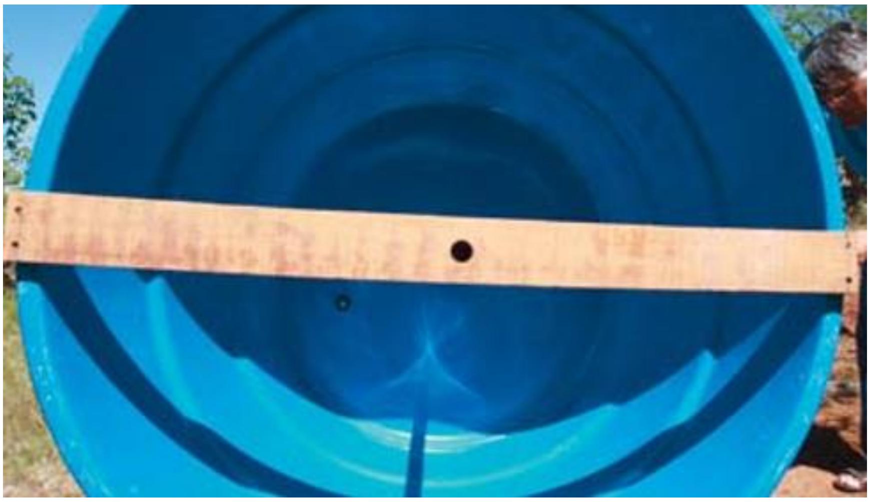

Figure 7. Gas holder tank with wooden beam and hole for guide pipe [5].

For a continuous stream of biogas to the stove, a weight that gives a constant and uniform pressure is added on top of the gas holder tank [5]. This also makes it possible to gather more gas in the tank per m^3 as a larger pressure is required to lift the tank. The weight added is soil or gravel which is held in place by a 30 cm wide zinc strip forming a circle on top of the digester. Diaconia encourages the families to use soil and grow vegetables on top of the tank. [5].

It is important to consider some kind of impurity filter for the biogas to minimise the risk of gases that produce a foul smell on burning. There are two main techniques used for this. The first is to connect the gas flow to a pipe filled with steel wool which removes the impurities [5]. However, the steel wool needs to be changed occasionally since the gas creates rust makes it less effective. The second technique is to use a water tank installed on top of the gas holder tank and allow the gas to flow through the water, which dissolves the impurities and leads to a gas without dross or any bad smells. Installing a water tank is a little more expensive, but is also a more efficient way to reduce dross [5].

In addition, a gas pipe should be placed underground, and connected to the stove inside the house. Since the biogas contains a large amount of liquid it is important to install a drainage system connected to the gas pipe. This reduces the liquid in the gas and improves its burning ability. The drainage system consists of a T-joint and a pipe immersed in water [5].

A normal procedure for a family using a digester is to load the input early in the morning with a mixture of manure and water, in a 1:1 ratio. The digester then produces biogas during the day that the family can use while cooking in the afternoon. The amount of manure used when loading the input varies somewhat, depending on the amount of gas the family needs, and also on the type of manure that is used [5]. For figures of a bio-digester examined during the field studies done in this thesis see Appendix 8.4.

2.6 Maintenance

As the anaerobic microbes in a digester are sensitive to changes, they need to be treated with care. It is important to avoid filling the digester with dirt, sand and gravel, all of which can be accumulated when collecting biological feedstock. Daily chores include preparing and loading the feedstock, collecting the digestate for use as fertilizer, or drying the liquid digestate to use for other applications on the farm [11]. Regular chores include cleaning the digester from solids which cannot be digested which may have built up at the bottom, and checking that the equipment is intact with no damage or leaks. Also, the metal components need to be checked to ensure they are free from corrosion, as both the gas and slurry are corrosive.

2.7 Potential risks

Health and safety are important aspects to be considered when running a bio-digester. There are both explosion and fire risks involved.

2.7.1 Explosion risk

Explosions can cause serious injuries, damages and other problems. The risk of explosion can be reduced by minimising the release of explosive gases into the atmosphere. Methane gas is flammable, and therefore represents a risk factor to be aware of. Potential risks are graded in zones due to the possibility of a dangerous explosive atmosphere. If the atmosphere is considered to be explosive the whole area is considered to be explosive [9].

Zone 0 is the area with the highest risk of explosion, and the area with a constant or a long term risk for explosion. In the biogas plant this area often consists of the gasholder, the stove and sometimes even the bioreactor itself [9].

Zone 1 is, if ventilation is sufficient, an area within one meter from the bio-digester and its equipment. However, if the area is closed with a little access to the air, *zone 1* is extended to 4.5 m [9].

Zone 2, 1–3 meters from the bio-digester and it´s equipment, if ventilation is adequate [9].

2.7.2 Fire risk

To minimise the risk of fire it is important to maintain distance between the different sectors where fire is possible: the bioreactor, the gasholder, the gas consumption equipment, and the gas compressor [9]. One option is to cover the sectors with earth or a suitable metal and then increase the safety distance between the sectors [9].

It is also important to consider safety aspects while designing a biogas plant. For example, the sectors should be free of buildings and the gas pipes well isolated so that the risks and consequences of leakages are minimised. The gasholders should be designed and constructed of non-flammable material. In the case of a factory or large plant, smoking, naked flames, and storing of flammable material should be totally forbidden [9].

This report is based on a digester design for smaller scale in households where it is hard to insist on strict guidelines to be followed. Nevertheless, it is important to follow a safety regime which is easy and simple. It is also important to try to minimise the risk of methane leakage which can be a serious hazard if it comes in contact with flames. Isolating pipes and being aware of the signs of leakage can help to decrease the risk [9].

2.8 Applications of biogas in rural areas

Biogas is an excellent fuel which may be used in stoves, lamps, gas refrigerators, and in combustion engines [15]. As the methane content in biogas varies depending on the feedstock used, the calorific value will also vary. A content of 60% provides a calorific value of 21.5 MJ/m^3 [4]. In the rural areas of developing countries, biogas is mostly used as fuel for cooking and lighting. Biogas has a low pressure in the distribution line, which requires modification of the equipment when using biogas [11]. Stoves designed for gasoline require larger gas jets and wider holes in their gas regulator [5]. The gas should burn with a clean blue flame, and provides a great deal more heat than traditional resources. If the flame is yellow, this indicates a lack of oxygen, and less heat will be produced. The efficiency of biogas stoves ranges between 20–56% and they typically consume about 0.22–1.10 m^3 gas per hour [4].

2.9 Digestate

As mention earlier, the digestion process generates digestate as well as biogas. Digestate contains a lower amount of dry matter then the organic material in the feedstock, because at least 50% of the material has been converted into methane and CO_2 [1]. Its composition and qualities such as nutrient levels are dependent upon the content of the feedstock, and having a stable digestion process with optimum process parameters (see section 2.2.1 [1]). The digestate can be used as agricultural fertilizer, soil improver, re-digested, used as animal feed or used for energy production.) Depending on its content, quality and the local nutrient situation, the digestate is appropriate for different purposes. The most sustainable use is as a fertilizer or soil improver, because of the microbes' ability to recycle nutrients and organic matter efficiently, which closes the nutrient cycle and provides a good substitute for synthetic fertilizer worldwide [1].

2.9.1 Fertilizer

Nitrogen is an essential element for the chlorophyll molecules, enzymes and amino acids in plants, and it is therefore one of the most important thirteen nutrient elements, together with phosphorus and potassium which plants need for their life cycle. The largest amounts of these thirteen elements are required of the macronutrients (nitrogen, phosphorus, potassium, magnesium, calcium and sulphur) whilst micronutrients (zinc, copper, boron, manganese, chlorine, molybdenum) are sufficient in smaller doses [1]. Plants can only use water-soluble inorganic nitrogen such as ammonium, NH_4^+, and nitrate NO_3^- [1]. Ammonium is stable in the soil and can fix to soil particles, whilst nitrate is soluble in the soil solution and does not fix. Both are immediately available for uptake by plants, but NH_4^+ is rapidly nitrified to NO_3^- when applied to the soil [18]. Anaerobic bacteria have the ability to convert organic nitrogen in proteins via hydrolysis into inorganic nitrogen in a process called mineralization. This increases the nutrient level of the digestate, making it a good bio fertilizer which can increase crop yield [1]. The mineralization rate is temperature-dependent, and works best above 4 °C [18]. Microbes also convert organic phosphorus to the inorganic form PO_4^{3-}, which plants can more easily take up [1]. It is important to not overfeed crops with nutrients, just meet their requirements. The amount needed depends on the type of crop, the yield potential, and the type of soil [18].

The amount of ammonium present in the digestate depends on several factors. First, on the amount of organic nitrogen in the feedstock that can be degraded into inorganic nitrogen (see Table 3). Animals are inefficient at digesting the nutrients in their food because they lack these microbes, so raw manure contains a fairly high proportion of organic nitrogen and phosphorus [1]. This makes manure less suitable as fertilizer than digestate because the nutrients need to be converted in the soil to inorganic form before plant uptake, a process which can take months. This makes nutritious digestate attractive as a potential fertilizer [1].

Second, ammonium levels depend on the process parameters pH, temperature and C:N ratio in the feedstock, all of which influence mineralization [1]. In addition to influencing the amount of ammonium present, these three factors also affect the levels of ammonia, which inhibits microbes, is more volatile, and is harder for crops to take up. Ammonium and ammonia levels are related by the equilibrium formula (17) [9]:

$$NH_3 + H^+ \leftrightarrow NH_4^+ + OH^- \qquad (17)$$

An increase in temperature and pH favours ammonia in the reaction, whilst a decrease favours ammonium. A C:N ratio lower than 20:1 gives a rapid conversion of organic nitrogen to ammonium, whilst a higher ratio gives a slow conversion [1]. In general, equation 17 implies that high concentrations of ammonium ions will shift the equilibrium towards formation of ammonia, and so the microorganisms need a well-balanced environment if they are not to be inhibited.

Upon application to the soil, nitrogen can be lost to water or the air, and thereby harm the environment, through volatilisation, leaching, run-off, and denitrification. For a nutritious digestate, a higher concentration of ammonium than ammonia is preferable because it is more stable in the soil and crops can more readily take it up [18]. Ammonium prefers the liquid phase of the mixture by 70–80%, as does potassium, hence it is important to keep the digestate moist. It is not favourable to only use the liquid as fertilizer as phosphorus has a preference for the solid phase by 55–65% [19]. It is also important to incorporate the digestate well or apply it to roots directly when it is produced, or within the following few hours [1]. The nitrogen may otherwise be lost to the atmosphere as ammonia vaporises due to its low boiling point of -33 °C and due to it not fixing well to the soil [1][20]. Incorporating the digestate can reduce ammonia emissions by up to 30–70%. The largest ammonia emissions come from agriculture, and can cause acidification and introduce nitrogen into habitats where it is harmful [18]. Denitrification causes nitrogen losses by producing N_2O, a strong greenhouse gas (see Table 6), and N_2 from nitrate. This occurs when there is a high concentration of ammonium and organic carbon which is easily degraded in anaerobic, warm, wet soils [1][18]. Leaching removes nitrogen when the soil is wet, and nitrate leaks into drains due to its inability to fix to the soil particles [18].

It is important to be aware of the local conditions when using the digestate as fertilizer so that areas with high nutrition in the soil (highly populated or intensively-farmed areas) are not overfed, causing eutrophication or pollution of the ground water. It is also important that the quality is right, not only in terms of nutrient levels, but also in regards to health and safety [1]. Of concern are heavy metals, pathogens, chemical impurities such as POPs, and physical impurities such as plastics, glass, stones, and other non-digestible materials (see sections 2.2.7 and 2.2.8). These substances can be avoided by using high quality feedstock, which gives a high quality digestate because those substances and nutrients present in the feedstock will also be present in the product. The quality is also dependent on the process parameters being right during the anaerobic digestion (AD) process (see section 2.4). Pathogens present in the feedstock can be killed by the sanitising effect of the AD process. The pathogens are efficiently inactivated by the combination of constant process temperature and retention times together with the environment of the microorganisms. Strict regulations regarding the quality of the digestate for use as fertilizer have been implemented in Europe over the last twenty years [1].

2.9.2 Other applications

As mentioned earlier, the digestate can be used for other applications. This usually occurs when it cannot be used as fertilizer because the quality is not up to standard, or when the ground already contains an excess of nutrients [1]. Digestate can then be used for energy in co-combustion for power generation. The solid matter can be used as bedding material in animal breeding stables, making composite material or fiberboards, or for production of high-quality earthworm compost. Re-feeding of the solid or liquid part of the digestate to the AD process is carried out to enhance the dry matter or liquid matter content of the digester.

2.9.3 Eutrophication

Eutrophication is a condition caused by high levels of phosphorus and nitrogen in the soil. Sewage and fertilizer often contribute to increased levels of these nutrients in the ground. When using a fertilizer it is hard to estimate exactly how much is needed for the crops [21]. When the crops are treated with too much nitrogen or phosphorus they lose their ability to absorb the nutrients, and the compounds will simply leak out in the soil. Possible side effects of the high level of nutrients in the ground include potentially toxic algal blooms, reduction of beta diversity, and problems with drinking water caused by algae [21].

2.10 Why bio-digester?

We have a long way to go before a sustainable future can be secured for our planet. Today, humanity's total ecological footprint is 1.5 planet Earths: that is, we use Earth's ecological services as if we had 1.5 planet Earths to take them from. Earth cannot renew these services as fast as we are consuming them [2]. Our habits need to change. One important change is to decrease atmospheric levels of greenhouse gases, which are a by-product of our energy consumption. Biogas is one step towards a greener planet. I can replace fossil fuel in areas such as energy, heating and as a fuel for vehicles. It contributes to recycling carbon and decreasing naturally produced and emitted greenhouse gases [9].

2.10.1 Greenhouse gas

One of our biggest environmental concerns is the increasing amounts of greenhouse gases in the atmosphere, causing changes to the climate such as droughts, tsunamis, rises in sea level, flooding, and storms. They are also making our oceans acidic and uninhabitable [2]. A greenhouse gas is defined by its ability to absorb and emit infrared radiation [22]. The greenhouse effect arises when these gases absorb infrared radiation, or heat, which has been reflected from earth and would otherwise leave our atmosphere, and emit it back towards the Earth, see Figure 8.

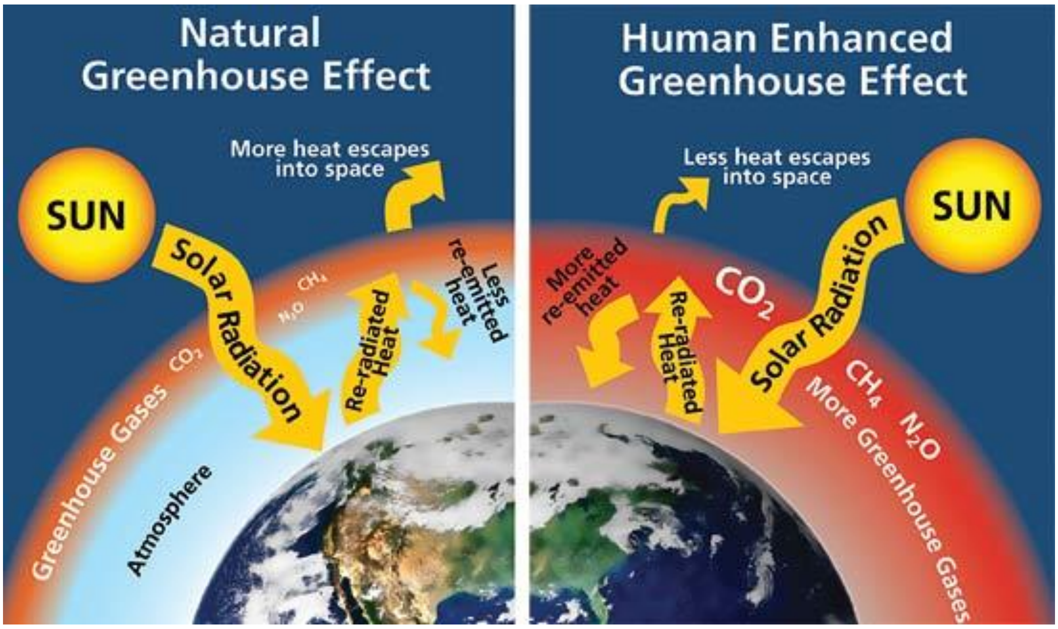

Figure 8. A description of how the greenhouse effect arises [23]

This phenomenon results in an increased atmospheric temperature and a global warming potential GWP [22]. Today, CO_2 represents more than half of all the greenhouse gases in the atmosphere because of its production by consumer-based societies. Greenhouse gases are mainly produced by the transport sector, followed by gases released from homes [9][24]. Some of the more abundant greenhouse gases are presented in Table 6. Their ability to absorb heat varies, making them more, or less, dangerous to our environment [24]. Because methane is such a strong greenhouse gas, with the ability to absorb twenty one times more infrared radiation than CO_2 (see Table 6) it is of extremely importance to consider the risk of methane leakage when running a bio-digester. If the risk of leakage is relatively large, the environmental benefit of installing a digester is decreased.

Table 5. The most abundant greenhouse gases in the atmosphere together with their lifespan and the magnitude of their relative absorption [9][24].

Greenhouse gas	Lifespan	Relative absorption
CO_2	100	1
CH_4	10	21
N_2O	100	310
O_3	0.1	2 000
CF_2Cl_2	100	20 000

2.10.2 Advantages of bio-digesters

There are several environmental, economic and practical advantages to using bio-digesters as an energy source, compared to fossil fuel and traditional biomass. These are presented in Table 6.

Table 6. Benefits of installing and running a bio-digester [4][25]

Environmental benefits	Economic and practical benefits
Reduction in greenhouse gases, deforestation and soil erosion	Displacing bought-in energy
Renewable energy replacing finite fossil fuel	Reduce fertilizer costs
Energy balance	Possibility to sell energy
Recycling nutrients	Economic development
Efficient electricity distribution	Reducing the costs of farm waste
Reducing smell	Time savings
Reducing pollution of water and land	
Decrease in pathogens and disease transmission	
Health benefits	

The biggest factors seen by society are the reduction in emitted greenhouse gases and that biogas provides an alternative fuel to crude oil. Biogas production is part of nature's carbon cycle, and so biogas can be reproduced repeatedly, using the same carbon – making it a green, renewable energy. The same amount of carbon consumed by photosynthesis is released into the atmosphere again when the biogas is burnt, thus giving no net production or consumption of carbon. (see Figure 9) [25].

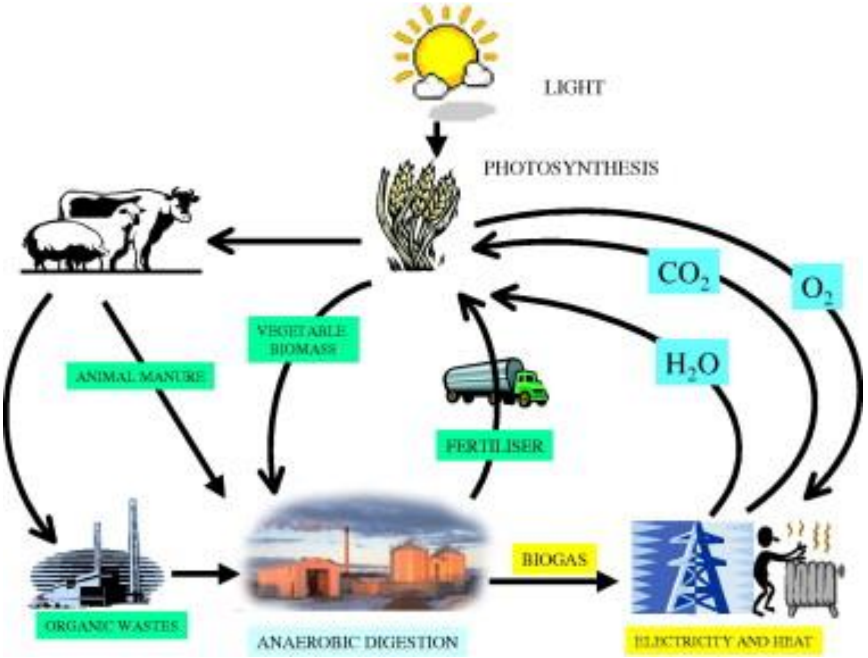

Figure 9. A schematic view of how biogas production and consumption creates a sustainable cycle for carbon and nutrients [26].

Fossil fuel, on the other hand, introduces new carbon into the atmosphere when burnt, increasing the greenhouse effect [2]. Fossil fuel is also a finite source of energy, and represents a short term solution, with prices that keep rising [1].

Greenhouse gases are also reduced by taking care of waste material that would otherwise degrade into methane through natural processes. By using anaerobic production in controlled equipment producing methane for energy usage, it is instead converted into CO_2, which is less harmful for the environment [11][15]. Further reduction in greenhouse gases are seen when biogas replaces firewood as fuel, decreasing deforestation and thereby conserving a resource that consumes atmospheric CO_2 through photosynthesis, (see reaction (18)) [9]. Deforestation in developing countries stands for 54% of the world's consumption, and has a major impact on the greenhouse effect [4]. A reduction in deforestation also reduces soil erosion, which can lead to desertification, land degradation and ecological collapse [2].

$$6\ H_2O + 6\ CO_2 + \text{solar energy} \rightarrow C_6H_{12}O_6 + 6\ O_2 \qquad (18)$$

When burning firewood, smoke with high levels of air pollutants such as carbon monoxide and small particles is produced, which is unhealthy when breathed in and is responsible for 2.7% of the world's diseases [20]. This is especially true if the burning is done indoors, where the pollutants are more easily accumulated, leading to a higher concentration in the breathed-in air. Biogas, on the other hand, burns with a cleaner flame, increasing the quality of indoor air [20].

The energy balance, the amount of energy consumed in order to produce the biogas, is better than many other energy producing processes, especially when it comes to local production. This is another positive aspect of biogas because production can be achieved very close to where the gas is consumed. This gives a more efficient distribution with less energy being lost as heat in the distribution system [25].

By degrading organic waste and animal slurries, nutrients are also recycled, and the process yields a nutritious fertilizer (see section 2.9). This can reduce the need for chemical fertilizer, and thereby hinder eutrophication and groundwater pollution [10]. By recycling waste, smell is also reduced. Also, anaerobic digestion reduces the pathogenic content of waste from humans and animals, and thereby reduces the spread of deceases [1]. A three week retention time in a mesophilic digester is sufficient to kill the pathogens which lead to salmonella, dysentery, cholera, typhoid, hookworm and schistosomiasis [1][15]. It is not enough to kill other pathogens such as tapeworm, E. coli and roundworm, so it is therefore not recommended to use fertilizer from digested human waste [15].

Biogas also has economic and practical benefits. It is a way of reducing fertilizer and energy costs by replacing synthetic fertilizer with digested biomass fertilizer and bought-in energy with biogas. Digesters could even work to provide an income through selling biogas and nutritious fertilizer. Disposal of certain farm waste requires payment of a fee, which can be overcome by increased waste recycling via the bio-digester [25]. Bio-digesters can also boost economic development. Due to the transition toward renewable energy, new jobs are created within the sector [27]. This can increase the country's economy, but also the economy of the local communities', by creating jobs and thus hindering urbanisation [1]. Depending on the fuel used for energy supply, there is also a time saving aspect to installing a bio-digester. This is relevant if firewood is used for fuel, in which case hours of wood collecting and making a cooking fire can be replaced with collection of biological material, for example manure, and feeding the digester [4].

Further advantages of importance for people living in rural areas as in this study, is the convenience of having a bio-digester situated at their remote location, mitigating the effects of price and supply fluctuations for fuel and fertilizer.

2.10.3 Disadvantages with bio-digesters

Despite several advantages with household bio-digesters, there are also a few disadvantages which have to be considered. All of the factors affecting the process, described in Section 2.4, need to be handled correctly. The process is sensitive, and disruption can cause a shutdown of gas production for more than three weeks [9]. This can leave people in rural areas unable to cook food. It is therefore always good to have access to firewood or some spare gasoline at home.

For unheated, uninsulated digesters (which usually applies to digesters in developing countries) the atmospheric temperature is an important factor which fluctuates with the season and depending on where in the world the digester is located. Gas production is limited below 15 °C and in many places it is too cold in winter for the fermentation to proceed without complications, restricting the geographic locations where the technology can be adopted [9][15]. Lack of feedstock, water, knowledge and other complications can also have a negative effect on the usage of bio-digesters, and lead to families tiring of their digester rather than encouraging them to produce green energy. It can spread a negative mood within the neighbourhood, making the digesters lose their credibility. Lack of knowledge can also lead to the digester being run or maintained in the wrong way, creating leakages of methane gas and thereby defeating the purpose of producing biogas and reducing the greenhouse effect. Methane leakages will instead increase the greenhouse effect, due to methane's high absorption of infrared radiation [15].

The cost of buying, installing and managing a household bio-digester is also a disadvantage for many families living on the bare minimum in rural areas with low incomes. To be able to manage the costs, alternative financial capital is needed. This could either take the form of subsidies from the government, or be funded by volunteer and charity organisations like Diaconia. Such organisations also need to supply knowledge and help with maintenance, so the digesters can be run efficiently and smoothly [15].

3. Method

This chapter describes and motivates the approach used in this study.

3.1 Literature study

To gather theoretical information and form a better understanding of biogas, the chemical reactions that take place under anaerobic digestion, and the parameters which affect it, a literature study was undertaken. Likewise, a literature study was used to build an understanding of the underlying techniques for managing a bio-digester, the equipment, and to identify potential improvements.

Literature was mainly selected using the Chalmers library function *summon* online, and search texts have been carefully selected to be relevant to the subject. Research has been carried out in both Swedish and English to ensure a broader view of the subject. Books addressing biogas and its properties have been used to improve our theoretical understanding.

3.1 Field study

The field study was performed in Afogados da Ingazeira in north-eastern Brazil. With help from an interpreter, Ivo Marhino, and a driver, Junior, we visited seven families living in the surroundings of the town who had had a bio-digester installed at their home by Diaconia. We started each visit by introducing ourselves and explaining the study we were carrying out, and what we would like to investigate. The families were all very helpful and kind, letting us into their homes and showing us around.

Thereafter, observations were carried out as we walked around their property, looking at their bio-digester and equipment, as well as at their animals and the farm in general. Pictures were taken and impressions were noted. When walking over their land, it was easier to get a feeling for how the families lived and what problems they might suffer from. At some of the families' farms, notes were taken regarding possible health and safety risks, such as leakage of methane, because of a noticeable smell.

Afterwards, samples and pH readings were taken of pure manure, feedstock (manure + water), and digestate. The feed and digestate tanks were measured. Further, we had the opportunity to measure consumption of biogas at one family's digester. We arrived just as they were starting to cook, which made it possible for us to measure the decrease in height of the floating gas holder over a specific period. At one family's farm we tried to measure the production of biogas. We went there early in the morning when they were feeding the digester and measured the changes in height over a period of time. Sadly the weather was a little too cold that day, around twenty degrees, which made production extremely, slow, and we were not able to obtain any results. All the samples collected from the seven families were sent to the University of Brasilia for nutrient and ODM analysis on the feedstock and digestate. The received results were then analysed to measure the nitrogen and phosphorus content. ODM values were not obtained. Feedstock and digestate were compared to each other in regards to their use as fertilizer, and compared to values reported in literature.

3.3 Interviews

Interviews with all seven families were carried out, inquiring about their daily chores with the digester, and to find out their opinions on the digester, and if it had in any way affected or improved their lives. Questions were asked concerning savings in money and time, as well as health aspects. For all the interviews we had help from an interpreter. At least one of the family members attended each interview, and in two cases both the husband and wife were present. However, we expect that some misunderstandings arose because on occasion there were some difficulties in understanding each other. In total, seven interviews were performed, with the same questions asked at each (see appendix 8.2).

4. Results

This chapter presents the outcome of this project through the information and samples collected during the field studies. First a section of social and environmental observations will be presented, followed by social and environmental impacts, which includes analysis and calculations.

4.1 Observations of the families' current situation

From visiting seven different families living in the surroundings of the remote town of Afogados da Ingazeira, Brazil, information was collected through interviews and observations, and samples were taken (see appendices 8.1, 8.2 and 8.3).

All families visited had fairly small, cement houses. These were simply furnished, but well equipped, and everyone had a TV. Their current circumstances, and for approximately 3-4 years previously, have been largely affected by a drought. As their water supply depends on the rain, this means that the people are limited when it comes to growing their own grains, fruit and vegetables to feed themselves and their animals, and to sell for extra income. Around 80 % of all animals have died, and the people are limited regarding what animals they can raise. All the families visited had a water cistern supplied by Diaconia to provide them with water for household use during the year.

Before the drought began, the year was more clearly divided into two seasons, wet and dry, so people knew when the rain was coming and could plan how to use their land. Now the rain does not come at all, or is very sporadic, and does not last for long periods – a couple of days, or a week or two. Thus, there is not enough rain for the crops to grow and be harvested. This could be seen by the lack of fully grown trees. The land was very green during the field studies as there was some very heavy monsoon rain on some of the days. However, the land was only green due to grasses and small bushes, there was not enough rain for the trees to grow tall and strong.

Previously, firewood was the main source of fuel for cooking. Collecting firewood is a time consuming and heavy chore, and when burnt, it pollutes the air, makes the house smell of smoke, and covers the floor with ash. Some families were also aware of that cutting down trees has a negative effect on the environment. Because of this most families used bottled butane before they received a digester. They did not seem aware of butane's effect on the environment. A bottle of butane cost a great deal of money for a family with no steady income from a job. With the lack of trees, and loss of income, the families struggled to provide themselves with fuel for cooking. A bio-digester was therefore a welcome addition to ease their everyday life.

4.1.1 Digester observations

Each digester supplied one family with gas according to the flow chart in Figure 10. Most Families use cow manure as feedstock, which is recommended by Diaconia as manure from cows has a relatively high water proportion with a liquid consistency. One of the families visited used pig manure, while another used chicken manure because they had been forced to get rid of their cows because of the drought. The rest used cow manure. None of the families used any food waste or sewage as biological material. They tried to use all the food they had, and the small amounts of waste they generated was given to their animals. Hence food waste would not be a possible substrate to use as feedstock. Sewage was collected in a septic tank.

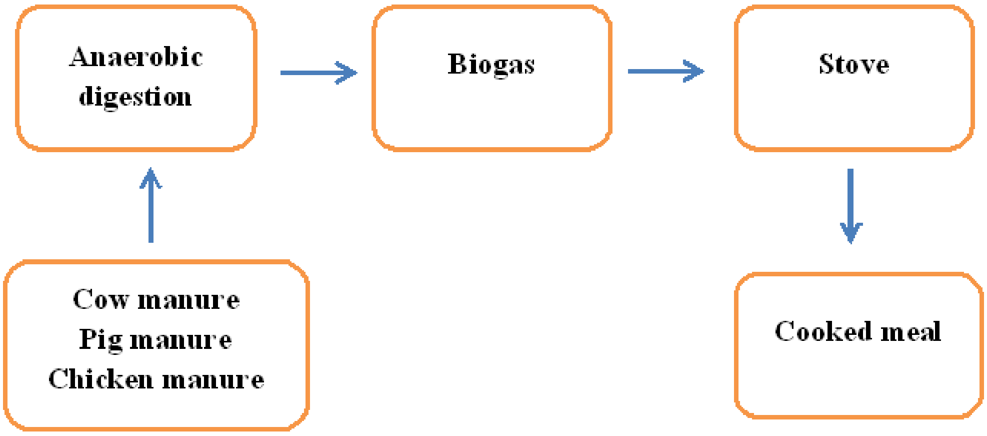

Figure 10. Flow chart for a family's production and use of biogas observed during field studies.

Which member of the household ran the digester varied from family to family. None of the families used exact amounts when managing the digester. All figures given in the interviews, and not measured, were approximate, as everything is done according to demand. The manure used as feedstock was produced during the night and collected fresh from the stables early in the morning to retain as much liquid as possible in the manure. It was then pre-treated with water to dilute the manure and achieve a creamy consistency. Fresh manure requires less water, thereby saving on this scarce commodity. The manure and water were then stirred to achieve a good mixture and ensure an even methane production in the reactor. Lack of equipment, technology and money prevented the use of any other pre-treatment techniques. Water has a good buffering capacity, and so helps keep the pH value between 6.8–7.5, which is favourable for the microorganisms' living conditions. Fresh cow and chicken manure were mixed with water in the ratio 1:1, whilst pig manure was drier and needed more water, and was mixed with an approximate water ratio of 1:1.5.

The location of the systems studied provided a hot climate, ideal for maintaining the reactor temperature. With annual temperatures ranging from 20 to 40 °C the reactor has a mesophilic digestion. The digesters were located in sunny spots to receive as much atmospheric heat as possible, as they were not heated and only insulated by the ground into which they were dug. These spots were observed to become as hot as 50 °C or more at midday, thus speeding up the process of degrading. During early mornings and cloudy days gas production was observed to be slow because of the lower temperature. This was especially noted when given the opportunity to measure the increase in the production on feeding. This attempt failed because no production at all was observed between 7am and 9am. The temperature was around 20 °C, with a cloudy sky. Considering all the negatives the drought has brought on the families, it has at least been positive for their gas production, as little rain and great heat is favourable for the microorganisms' activity.

All families found that the digester supplied them with enough gas for their preferred use, cooking (see Figure 10). On average, this took up 1–4 hours of each day. With cow manure, the digester was, in general, fed every second day in order to achieve the required amount of gas. With pig and chicken manure, the digester was fed every third day. This showed that there is a larger yield of biogas from pig and chicken manure then from cow manure, as the families used approximately the same amount of gas for cooking each month.

Faults and problems with the digester had been noted by all families except for one. These included overfeeding of the digester causing biogas leakage from the floating gas holder; water leakage from the water-purifier tank; a broken water-purifier tank, leaving them using the digester without one for the previous three months; a break in the wooden beam which keeps the floating bell in place; and unknown methane leakage so that no gas was provided. One of these problems was observed by us during the visit to Family 5 and their digester. It had been out of order for the previous week with an unknown leakage so that no gas was provided in the stove. The fault had not been reported. The wife was therefore heating wood to produce charcoal for fuel when we arrived. All of the families had had their stoves modified to suit burning methane instead of butane. However, 1–2 gas hobs were left unmodified in case of problems or insufficient gas production, making it possible to use butane if needed.

None of the families seemed aware of any risks, neither had they been informed of any, or given any health and safety manual. Some also stated that there are no risks.

When asked their personal opinion regarding the bio-digesters, all of the families were very happy with their digester and really thankful for all of Diaconia's help. They emphasised how simple the digester is to run, the difference in cleanliness, the 100% recycling, and the savings in money and time.

4.1.2 Fertilizer observations

Compared to the manure fed to the digester, the digestate had no smell and was less viscous. Plenty of digestate was produced. Many of the containers were overflowing and there were piles with dried, unused digestate next to the digester at some families' houses. Only one of the containers was covered with a piece of plywood; one was shaded by a small roof; one was partly shaded by trees; and the rest out in the sun. The digestate was used as fertilizer for vegetable and hay production by those families that had fields. An exception was the family with pigs: they thought the digestate was too dirty to use for their vegetables and only used it on the hay fields. A few families used some digestate to grow crops on top of the floating gas holder. This was recommended by Diaconia. The digestate was drained of liquid and then dried in the sun before being used as fertilizer. The drained liquid from the dried digestate was also used as nutrient on the fields, but was also left in the sun for a long while before application. Because the digestate containers were not covered or shaded from the sun, and the digestate and liquid not used straight away for fertilizer, and also because the digestate was dried, it can be assumed that many of the nutrients are most likely lost to the atmosphere because of their volatility (see 2.9.1, for consequences see 4.2.2.1). The liquid was spread by spraying with a pumping machine, whilst the fertilizer was applied by hand to their fields: some just brushed it on top, whilst others dug it in. Where the digestate was not dug in and incorporated into the soil, it is assumed that nutrients will also have been lost due to their volatility. It is important to thoroughly incorporate both the liquid and the solid (see 2.9.1). None of the families use any chemical fertilizer today. One family used to use what they thought was fertilizer, which on research turned out to be an insecticide (see 4.2.1 and appendix 8.2 and 8.5). It was replaced with digestate when they received their digester. Some families had been educated on the polluting effects of chemicals years ago. All animals were fed with organic food: hay, maize, herbs, native crops, food waste, leaves and soya, thus the digestate produced was assumed to be free from artificial chemicals. The feedstock and the digestate had a pH value ranging from 7–8 for all families (see appendix 8.3).

It could therefore be assumed that the pH in the digesters also ranged between these values. This indicates a favourable environment in which the microorganisms live and regenerate, and hence good conditions for methane production.

4.2 Impact

The impact on the environment and the families' social lives of using biogas as cooking fuel and digestate as fertilizer based on the consumption of manure as feedstock have been evaluated, and are summarised in Figure 11. The impact is in comparison with butane and firewood as cooking fuel, and fertilization with manure and chemical fertilizer. This section is divided into social and environmental impacts based on information, measurements and samples from the families and their digesters (see appendix 8.2 and 8.3).

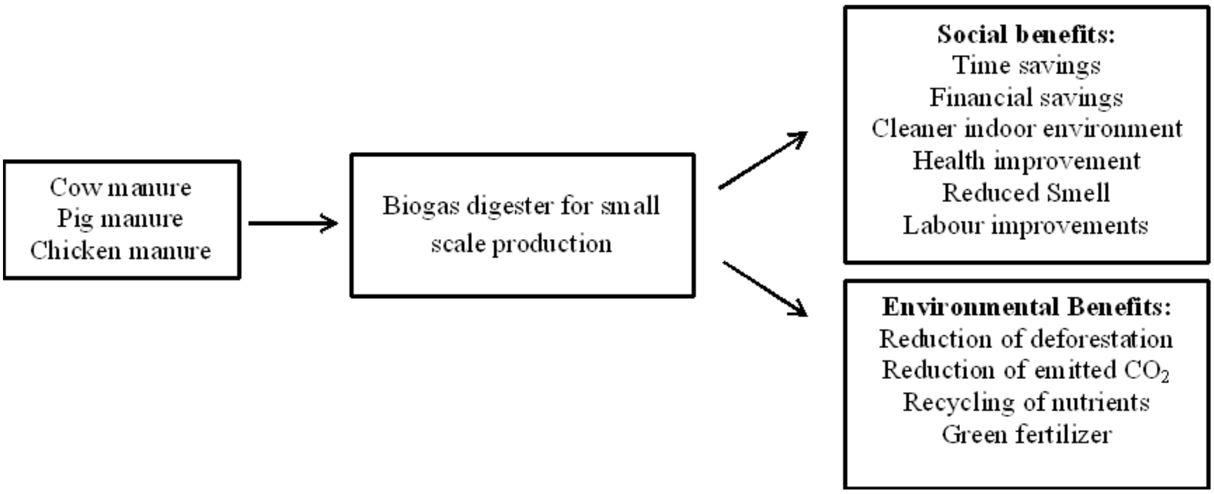

Figure 11. Digesting manure from livestock has benefited the families in several social and environmental ways.

4.2.1 Social impact

The families pointed out that the largest impact of digesters on their lives and surroundings were related to cleanliness inside the house, finances, smell, time, labour and health.

The largest differences regarding cleanliness were seen inside the house. Firewood and its ash produced a lot of dirt, making an unpleasant environment in which to cook. Firewood also created a lot of smoke, which is unhealthy to breath, and gave a bad smell to their furniture and clothes. They had seen no real differences regarding the cleanliness outside, around the house and on the farm. Improvement had been predicted beforehand because the manure was now being used instead of being left to lie and cause pollution. However, prior to the digester, the manure was used as fertilizer, avoiding it becoming a polluting factor. In the field studies, it was observed that it was not manure that was the polluting factor in the families' living environment, but plastics, tins, and cans left scattered or piled around the house. This rubbish is collected by the borough. This would be another interesting project, to inform about the importance of recycling non-biodegradable chemicals and materials and improve the recycling system.

Most of all, the families emphasised the money saving aspect of having a digester installed. In general, a family used one cylinder of butane containing 13 kg of gas for cooking each month. One cylinder cost around 40 Brazilian Reals, which is a large cost for someone with no income. The digester had made it possible to use that money on food and leisure instead. The fertilizer was not considered as a money saving factor as many families had previously used manure to nourish their fields. One family used chemical fertilizer up until the digester was installed, and had saved some money, but they could not estimate an amount.

There was no difference in smell outside the house. Most families farmed other animals for dairy and meat products. These animals were walking around close to the main house, so there was still manure of some sort lying around causing an unpleasant smell. In addition, the digester was not fed every day. Cow manure was collected for other use, such as fertilizer, prior to the digester being installed, whilst pigs and chicken manure were never used for anything and simply left lying on the ground.

The families found it hard to approximate how much time they had saved after the digesters had been installed at their homes. Even though bought-in butane was inconvenient to obtain from far away from their farms, and required a vehicle, they mainly stressed firewood as the more inconvenient and time consuming fuel. The families had different distances to travel to collect firewood. Some collected it on and around their farm, whilst others had to travel between fifteen minutes to an hour by car. A lot of time was then spent on making a cooking fire, getting it warm enough, maintaining it, and cleaning up afterwards. To cook took planning, maintenance and work both beforehand and afterwards. With the digester they only have to walk 50–100 meters for manure collection, which takes 10–30 minutes every second or third day. Feeding then takes another 5–30 minutes and is done in the early morning, so that when they want to cook they have enough gas and do not need to wait for fuel. Overall, the families on average estimate that they have saved 1.5–3 hours a day. This time they now spent working on the farm and fields, around the house, and relaxing by socialising and watching TV.

Less firewood collection also meant less hard labour and less bodily pain. This in turn meant fewer health issues. Although collecting manure requires labour, it is still not at the same level, as it takes less time and there is a smaller amount to collect. Not using firewood as fuel also meant less inhalation of smoke containing dangerous particles and carbon monoxide. For one family, there was also an improvement in health issues in regards to fertilizer. They used to use the chemicals “Tamron” and “Politron” on their fields as fertilizer before they received the digester, which had given the husband bad headaches and dizziness. The introduction of biogas and the switch to green fertilizer had therefore led to a large impact on his health. The reason they used chemicals, was that people who bought their fruit and vegetables at the market thought that they were more nutritious when grown with chemicals. During the analysis phase of this project, only one chemical could be identified and it turned out that it was, in fact, an insecticide.

Tamron or methamidophos is the trading name for the insecticide O,S-dimethyl phosphoramidothioate. It is used to control many insects and mites, and it is highly toxic if inhaled, comes into contact with skin, or is swallowed. It leads to the symptoms described by the husband in Family 1 when using the substance. The safety data sheet for Tamron is found in Appendix 8.5.

4.2.2 Environmental impact

This section analyses the feedstock and digestate sample results for selected families. There then follow calculations comparing carbon dioxide emission from cooking with butane to cooking with biogas, as well as calculations of deforestation, methane emissions from unused manure, HRT of the feedstock, and the time it takes to replace the reactor substrate when new organic material is introduced.

4.2.2.1 Nutrient analysis of the feed and digestate for use as fertilizer

Samples of the feedstock and digestate for families 1, 2 and 4 were analysed by The University of Brasilia, and the results are presented in Table 8. 1 litre of manure is approximated to weigh 1kg. The cow manure was diluted with an equal amount of water, 1:1, and the pig manure with 1.5 times the volume of water for every litre of manure, 1:1.5. These values were obtained from interviews and observations on-site. Values received for families 1 and 4 were thereby multiplied by a factor of 2, and for Family 2 by 2.5. The nutrition values varied quite significantly from family to family.

Table 7. Results from feedstock and digestate analysis.

	NO3-N (N as Nitrate) g/l	NH3-N (N as ammonia) g/l	Total N g/l	Total P g/l
Family 1 Feedstock, cow	0.2	2.4	2.6	0.2
Family 1 Digestate, cow	0.6	4.2	4.8	1.1
Family 2 Feedstock, pig	1.3	3.6	4.9	1.3
Family 2 Digestate, pig	2.3	0.5	2.8	0.6
Family 4 Feedstock, cow	1	1.9	2.9	0.9
Family 4 Digestate, cow	0.4	3.2	3.6	0.6

Family 1: The amount of total nitrogen and phosphorus in the feedstock is less than in the digestate. There has been a small increase in the readily available nitrate in the digestate, which has a positive effect on the digestate's nutrient value. Ammonia has increased by almost a factor of two, which is likely to be lost through volatilisation. This can be a positive from a nutrient point of view if the temperature is low, and pH is kept below 7.2, thereby producing ammonium. The feedstock values of total nitrogen and phosphorus are only slightly lower than those found in the literature (see Table 3), assuming that they are suitable for degradation.

Family 2: The amount of total nitrogen and phosphorus in the feedstock is greater than in the digestate. Nitrate shows a positive increase, increasing the nutrition value of the digestate. Ammonia has decreased, which could indicate that more nitrogen is present in the inorganic forms of ammonium and nitrate, and is more readily available for uptake by the crop. Less nitrogen is thought to be lost in the form of ammonia, but the high nitrate value can increase the loss of nitrogen through denitrification, hence increasing greenhouse gas emissions. The feedstock value of total nitrogen is slightly above the values found in the literature, and phosphorus is about the same (see Table 3), so they are assumed to be suitable for degradation.

Family 4: The amount of total nitrogen and phosphorus in the feedstock does not equal the amount in the digestate: nitrogen has increased whilst phosphorus has decreased. The nitrate level is lower in the digestate, indicating that the feedstock is more nutritious than the digestate, which has less readily available nitrogen. The higher ammonia levels in the digestate indicate less readily available nitrogen, which, as for Family 1, could become available with a change in pH and temperature. The feedstock values of total nitrogen and phosphorus are almost equal to those found in the literature, (see Table 3) assuming that it too is suitable for degradation.

In summary, Family 2's bio-digester supplies nutritious digestate that can increase crop yield and decrease the amount of ammonia volatilised. Family 1's digestate also supplies an increase in readily available nitrogen, but also has high ammonia values. Family 4's digestate is less nutritious then the feedstock, and has a high ammonia value which may result in increased nitrogen losses through volatilisation. Because of this, Family 4 would be better off using their feedstock as fertilizer. All the families have feedstock matching those found in the literature, and which are suitable for degradation by the microbes

The amount of nutrients needed by a particular crop depends on the desired yield, which means that the crop would also have to be evaluated to understand its nutrient requirements and to see if the digestate or manure provides enough. Whether the resulting nutrient values can cause eutrophication, can be assessed by investigating the local nutrient level of the soil where the manure or digestate is to be applied.

4.2.2.2 Calculations of CO_2 emissions

The amount CO_2 emitted has been evaluated in a comparative study. As it was not possible to gather any information regarding the amount of firewood cut down and burnt by each family, this comparative study has been limited to butane and methane. The environment is assumed to be ideal: that combustion of methane and butane is complete, all the gas is consumed, no leakages occur, and there is no failure of the bio-digester equipment resulting in butane usage in the downtime. Further, these calculations assume each family would consume 13 kg of butane per month, a figure based on information gathered during the interviews.

Butane

$$2\ C_4H_{10}(g) + 13\ O_2(g) \rightarrow 8\ CO_2(g) + 10\ H_2O(g) \qquad (19)$$

Table 8. The standard enthalpy of formation for the combustion of butane [20].

Substance	**$\Delta_f H^0$ (kJ/mol)**
$C_4H_{10}(g)$	-126
$O_2(g)$	0
$CO_2(g)$	-394
$H_2O(g)$	-242

$\Delta_r H° = -1*(-126)+6.5*0+4*(-394)+5*(-242) = -2660$ kJ/mol

Combustion of butane is an exothermic reaction, 2660 kJ/mol of energy flows into the surroundings as heat.

$M_{butane} = 58.124$ g/mol

$m_{butane} = 13000$ g

$n = m/M = 13000/58.124 = 223.66$ mol

223.6598 mol * 2660 kJ/mol = 594934.9667 kJ
The mol ration between butane and CO_2 is 1:4, see formula (19).
M_{CO2} = 44 g/mol
M_{CO2} = n * M = (4*223.66) * 44 = 39364.2 g.

<u>Burning 13 kg of butane produces 39364.2 kg CO_2</u>

<u>Methane</u>

$$CH_4\,(g) + 2\,O_2\,(g) \rightarrow CO_2\,(g) + 2\,H_2O\,(g) \qquad (20)$$

Table 9. The standard enthalpy of formation for the combustion of methane [20].

Substance	**$\Delta_f H^0$ (kJ/mol)**
$CH_4(g)$	-74
$O_2(g)$	0
$CO_2(g)$	-394
$H_2O(g)$	-242

$\Delta_r H°$ = - (-74)+2*0+(-394)+2*(-242) = -804 kJ/mol
Combustion of methane is an exothermic reaction, 804 kJ/mol of energy flows into the surroundings as heat.

How many mol of methane are equal to 13 kg butane? How much methane is required to receive the same amount of heat as supplied by butane?
n_{CH4} = 594934.9667 kJ/804 kJ/mol = 739.9689 mol
M_{CH4} = 16.0425 g/mol
m_{CH4} = n * M = 739.9689 * 16.0425 = 11870.9505 g ≈ 11.9 kg methane
The mol ratio between methane and CO_2 is 1:1, see formula (20).
M_{CO2} = 44 g/mol
M_{CO2} = n * M = 739.9689 * 44 = 32558.6 g

To receive the same amount of heat supplied by cooking with butane for 1 month, 11.9 kg of methane is needed, which when combusted produces 32558.6 g of CO_2.

39364.2 – 32558.6 = 6805.6 g

This comparative study of emitted CO_2 from combustion of butane and methane shows that 6805.6 g more CO_2 is release into the atmosphere during one month of cooking with butane compared to the same period cooking with methane. As the carbon in the methane is recycled via photosynthesis, it is not adding to the existing greenhouse effect, hence by replacing butane with methane, one family helps reduce the greenhouse effect by 39364.2 g CO_2 per month and 472369.9 g CO_2 per year.

Table 10. Data for total amount of CO_2 saved per year for a digester installed when the Dom Helder Camara project started in 2009.

Year after project started	kg CO_2 saved per digester installed
2010	472.4
2011	944.8
2012	1417.2
2013	1889.6
2014	2362

To date, Diaconia has installed 137 digesters in the area. Estimating that every family previously used one bottle containing 13 kg of butane per month gives:

137 * 13 kg * 12 months = 21379 kg butane, n = {m/M} = 21372000/58.124 = 367696.65 mol

$m_{CO2\ released\ from\ one\ year\ of\ butane\ consumption}$ = {n * M} = (367696.65 * 4 mol CO_2) * 44 g/mol = 64714610.14 g ≈ 64715 kg CO_2 released during one year's use of butane by 137 families.

The installation of 137 bio-digesters by Diaconia has decreased the amount of CO_2 emitted by 64715 kg per year.

4.2.2.3 Deforestation calculations

The normal amount of carbon dioxide consumed by tropical forests is about 2.5 ton CO_2/hectare/year [28]. The CO_2 emission calculations above show that if all 137 families using a bio-digester today were to go back to cooking with butane, the emission of carbon dioxide would be 64715 kg per year.

1 hectare = 10 000 m^2

Photosynthesis consumption tropical forest = 2.5 ton CO_2/hectare/year

CO_2 emitted per year through combustion of 21379 kg butane from 137 families = 64.715 kg

$64.715 * 10^3 / 2.5 *10^3 = 25.886$ hectare tropical forest

Approximately 26 hectares of forest would be required to consume the extra amount of CO_2 emitted if all the 137 families using biogas were now to return to cooking with butane. This equals approximately 37 football pitches.

4.2.2.4 Manure pollution calculations

Because methane emission from unused manure is a contributing factor to the greenhouse effect, the daily release of methane from the feedstock if it had not been used for biogas production was calculated. Only the families using cow manure have been reviewed, as the literature provided data for this. When calculating the amount of feedstock used, it has been estimated from interviews and observations that the families filled half-filled their feed containers with feedstock, except Family 4 who provided buckets to measure their manure and water. The dilution with water was 1:1. It has also been taken into account that feeding was performed every second day. Figures for the volume of manure in feed per day are obtained from Appendix 8.3.

Methane emissions from untreated cattle manure; 4045.7 g CH_4/m^3 [1].

Table 11. Methane emitted by undigested manure.

	Family 1 (cow)	Family 3 (cow)	Family 4 (cow)	Family 6 (cow)
Litres of manure in feed per day	8.5	14.5	9.8	17.7
Methane emission (g/day) from the families' manure if not used as feedstock (g CH_4)	34.6	58.5	39.7	71.5

Results show that methane emission resulting from the cow manure if it were not used for biogas production varied between approximately 35–72 g/day.

4.2.2.5 HRT Calculations

As mentioned earlier, each family fed their digester different amounts of feedstock at different times depending on when they were low on gas (see appendix 8.2). The families using cow manure fed their digester approximately every second day, whilst those using chicken and pig manure fed it approximately every third day. This has been taken into consideration when calculating the amount of feedstock per day. Based upon observations and interviews, these calculations also assumed that the families half-filled their feed container when feeding. Exceptions were families 4 and 7 who provided buckets for measuring manure and water when preparing the feedstock mixture. For details, see appendix 8.3.

$$\text{Feed} = \text{Substrate input } \left(\frac{\text{m3}}{\text{day}}\right)$$

$$\text{Volume} = \text{Net Digester volume (m3)}$$

$$HTR\ (days) = \frac{\text{Net Digester volume (m3)}}{\text{Substrate input } \left(\frac{\text{m3}}{\text{day}}\right)}$$

$D_{Digester} = 3$ m

$h_{Digester} = 2$ m

$Volume_{Digester} = \{r^2 * \pi * h\} = 1.5^2 * \pi * 2 = 14.137\ m^3$

Table 12. HRT for all families with a working digester.

	Family 1 (cow)	Family 2 (pig)	Family 3 (cow)	Family 4 (cow)	Family 6 (cow)	Family 7 (chicken)
Digester Volume (litre)	14137.2	14137.2	14137.2	14137.2	14137.2	14137.2
Feed rate, manure+water (litre/day)	17.088	34.130	28.925	19.635	35.363	12.593
HRT (days)	827.342	414.216	488.754	720.000	399.779	1122.594
HRT (years)	2.267	1.135	1.340	1.973	1.095	3.076

The calculated HRT shows a varied retention time between the families, ranging from just over a year to over three years. With these long retention times, it can be assumed that all the carbon in the feedstock has been converted to methane gas, thus giving a large methane yield and a nutritious digestate.

4.2.2.6 Calculations of feedstock change

In the year prior to the study, two families had changed the organic material in the feedstock because of changes in their living conditions caused by the drought. Therefore, calculations were made to determine the amount of time it would take until the reactor was only occupied by the new substrate, with the old substrate having left as digestate. Six months before the study, Family 2 had changed from cow manure to chicken manure, and Family 7 had changed from pig manure to chicken manure at the same time. Data have been collected through interviews, observations, and measurements when possible (see appendix 8.2 and 8.3). Again, because chores in their everyday life were carried out on demand and with no exact amounts of material, these calculations are approximate, and should be seen as estimates of the families' condition in preparation for future work with access to more advanced equipment. Therefore, 1 litre of the manure is assumed to weigh 1 kg. C_{in}, the concentration of feedstock fed the digester, refers to the manure as the total amount of substrate divided by the total volume of the feedstock, both the amount of manure and volume of feedstock being approximated using the relation given previously:

$$C_t = C_{in} - (C_{in} - C_o) * e^{-\frac{F}{V}*\Delta t}$$

Table 13. Data from Family 2 for substrate replacement calculation.

Family 2, pigs	
Δt =	$t - t_0$
$V_{digester}$ (litre)=	14137.2
$F_{Feed\ rate}$ (litre/day)=	34.13
C_0 (g/litre)=	0
C_{in} (g/litre)=	0.4
Manure:water ratio	1:1.5

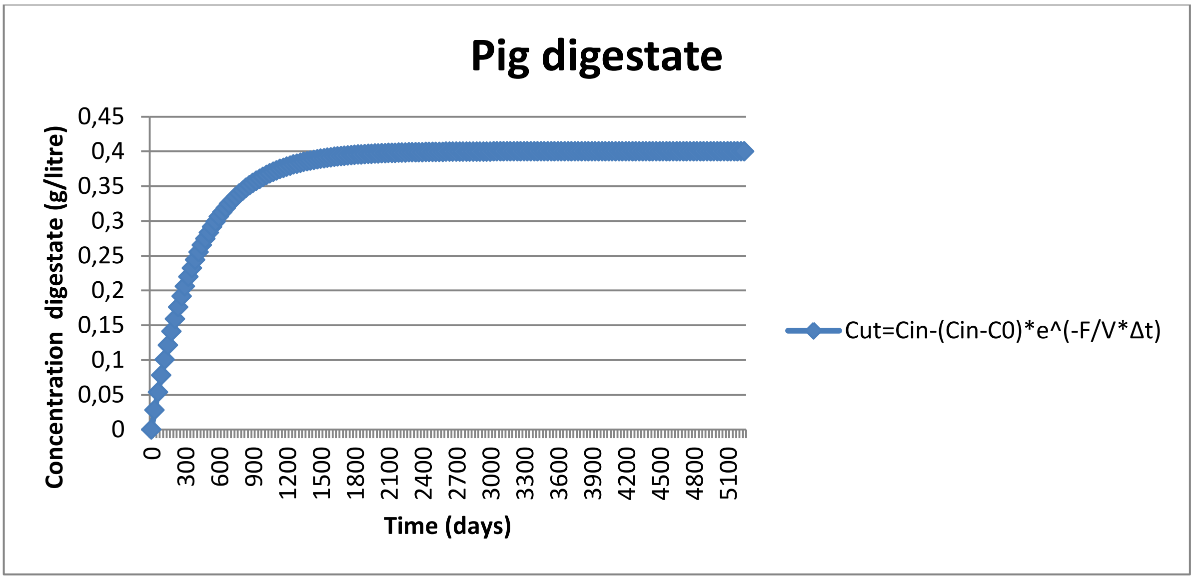

Figure 12. Plot showing the concentration of pig manure digestate leaving the reactor as a function of time.

As time goes on, more and more of the original substrate will be replaced by the new substrate, and the concentration of the digested new substrate in the digestate will increase. When the plot approaches the asymptote of the feedstock concentration, y = 0.4, the time required to replace the original substrate in the reactor will have been reached. The time required to replace the cow substrate for Family 2 in their digester is 1620 days, or 4 years and 160 days.

Table 14. Data from Family 7 for substrate replacement calculation.

Family 7, chickens	
Δt =	t - t0
$V_{digester}$ (litre)=	14137.2
$F_{feed\ rate}$ (litre/day)=	12.593
C_0 (g/litre)=	0
C_{in} (g/litre)=	0.5
Manure:water ratio	1:1

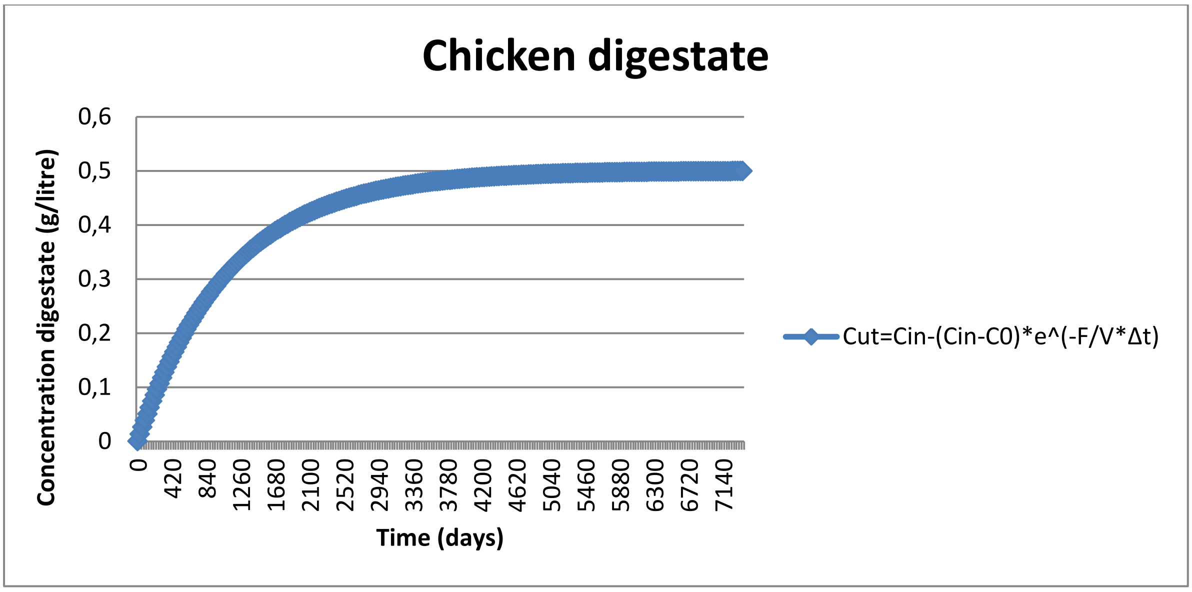

Figure 13. Plot showing the concentration of chicken manure digestate leaving the reactor as a function of time.

From the plot it was observed that to replace Family 7's original substrate with chicken substrate would take 4410 days, or 12 years and 30 days.

That the period of time for the original substrate to be replaced by the new is long for both families is further evidence that the digesters have a long retention time, giving the microbes a long time to thoroughly degrade the organic material, yielding more methane and inorganic nutrients. This also shows that the digester will not be noticeably affected by the input of a new substrate: because the old substrate remains for such a long time, biogas production will proceed as normal, which is positive for the families' energy use.

4.3 Improvements

None of the families had thought about using the digester to provide an income. This was one possible improvement which had been theoretically predicted beforehand. Unfortunately, selling gas at the market is not allowed in Brazil, since all energy and fuels are controlled by the Brazilian government. However, if it were permitted, the families would have the capacity to produce more gas by increasing feeding or by switching to pig or chicken manure.

The potential to produce excess gas was instead considered as an opportunity to provide more people with gas by sharing a bio-digester with neighbours living nearby. This would require a modification to the digester design. Instead of one gas pipe coming out of the gas bell, there would be two, leading to two neighbouring houses, presuming these houses are at a suitable distance from the digester. This thought came about when visiting Family 3. They lived in a row of small terraced houses where the digester was at a close distance to several of the neighbours. Sharing a digester would not only give more families clean sustainable energy, but would also ease the workload, reduce costs for more people, and further reduce the environmental impact with less consumption of butane or firewood.

One way to use the digester to generate income could be through selling both the solid and liquid digestate as fertilizer. One family sold fertilizer they produced in their worm farm with excess cow manure for 1.5 Reals. It was observed that there seemed to be an excess of fertilizer produced from all the digesters visited, which is positive from both farming and a financial point of view. The only difficulty with sales would be the need to apply the digestate straight away after production, so as to not lose any nitrogen through ammonia volatilisation.

Another improvement, related to the lack of water, would be to recycle the liquid drained off from the digestate. This can be reused to dilute the feedstock and achieve the correct level of TS. By doing so, microorganisms and nutrients are recirculated. Today, most families use the drained liquid as fertilizer, but for those who do not this would be an opportunity to still make gas when the water supply was running low.

Important improvements regarding management of the digestate and using it as fertilizer were deduced from the observations and interviews, and from the literature. The digestate was not being used to its maximum potential. To optimise the nutrient value of the digestate, the fertilizer should be applied straight away after being produced, with all liquid remaining, as this is where most of the ammonium is found. It should be well incorporated into the soil when applied, preferably being injected rather than broad spreading as is done by some. This hinders volatile ammonia from evaporating, and instead more nutrients are bound to the soil where they can be used by crops, increasing growth. Further, a nutritious fertilizer is low in temperature and has a pH less than 7.2, so shading the digestate container might hinder temperature rises and ammonia vaporisation, which otherwise cause even more nitrogen loss, further polluting the environment.

There is a lack of manure because the drought has killed 80 % of livestock, and there is not much food or agricultural waste, so a further improvement could be to use human faecal residue as a feedstock, or at least to co-digest it with livestock manure. Human faecal residues need to be handled carefully, as they can cause serious illness due to high levels of pathogens. When using human faecal residues for biogas production it is best to have a digester construction that is connected directly to the toilet, avoiding any contact with the substrate, see Figure 14.

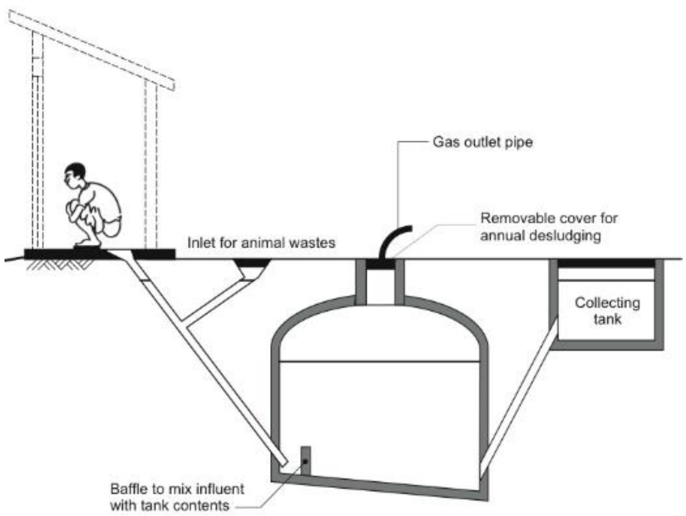

Figure 14. Possible setup of a bio-digester plant if human faecal residue were to be used as a feedstock [29].

Practical improvements could be made by connecting the livestock stables with the digester, as in Figure 15. This could save time, both in collecting manure and in feeding the digester. It could also decrease the labour associated with producing biogas, and improve hygiene.

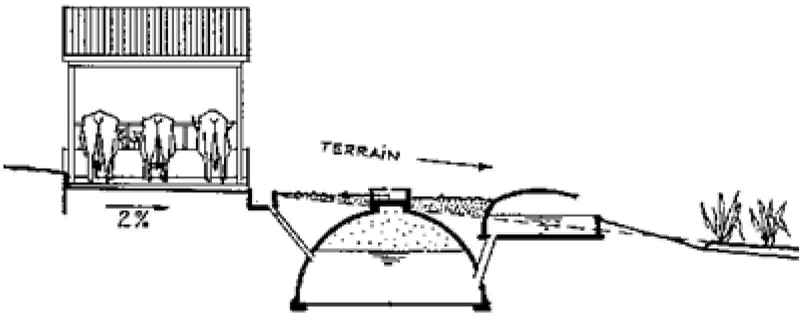

Figure 15. A schematic picture of how to achieve a more efficient bio-digester plant [13].

If a higher methane yield is desired, co-digestion could be used, combining manure with crop residues, because of their different nitrogen and carbon content, as described in Section 2.4.4. This is also useful if the methane content of the biogas is less than 45%, meaning that the gas is not flammable. This was not observed at any family's house but can be an important intervention if needed.

5. Discussion

In this part, our results, and some of the difficulties we encountered, are discussed in relation to the project's purpose, theoretical framework, and method. Suggestions about further studies are also presented.

Methane leakage is an important factor to study for small scale bio-digesters because of is large impact on the environment. Therefore it was of interest to see if any improvements could be made in this area. Unfortunately, due to lack of equipment, it was not possible to take measurements, so actual figures regarding leakage were not obtained. Neither was it possible to calculate leakage from measuring consumption of methane, as it was not possible to analyse values of ODM in the feedstock.

Because of the drought, it was hard to study some of the questions which we had intended to address. These include the impact of fertilizers on the crops, changes in land use, and the local ecosystems. Whether the fertilizer had any impact on the families' fields could not be studied as the lack of water masked the effects of other factors.

Eutrophication was sadly not evaluated due to lack of equipment, and of samples from the crop fields. From the interviews, there was one family who were considered to be in possible danger, as they had previously used a chemical insecticide on their fields. It is important to be aware of the effects, and consider the risks of using large amounts of nitrogen and phosphorus. It is also important to know how the fertilizer should be used on the families' land, which would improve its ability to act as a proper fertilizer, and would also minimise the risk of possible eutrophication, and of nitrogen leaking into the atmosphere and ending up in environments and habitats where it is harmful.

It was sadly not possible to evaluate any changes in land-use. Through the interviews we had hoped to gather information on the amount of wood the families used to cut for fuel. However, this was hard for them to estimate because they simply cut down as much as they needed on a particular day. Changes in land use would have been interesting to look at in regard to the reduction in greenhouse gases, deforestation, and soil erosion, but would also be complicated by not having observed the land before any digesters were installed.

It was planned that the local ecosystems should mainly be evaluated through interviews with the families. However, they could not really relate to the questions, and mostly referred to the drought which had caused large changes to the environment. These hard conditions require specific plants and animals. Evaluated from an ecosystem point of view, there had definitely been a land use change due to the reduction in cutting of firewood. That in turn has lowered the usage of the services provided by the local ecosystem.

Biodiversity was hard to investigate since the places where they formerly cut down wood were not visited. Questions regarding this were difficult for the families to answer, and they once again mentioned the drought as the major impact on both animals and the growth of crops. They felt it was hard to describe any specific area that had changed after the installation of their bio-digester.

It was possible to take samples for analysis from four different digesters fed with cow manure, and this is probably sufficient for the result from the analysed feedstock and digestate samples to be representative. Nevertheless, it is hard to draw a general result concerning cow manure, as the cows are given different food at the different farms. Therefore it is better to evaluate each farm and their analysed samples individually than to conclude a general result for all feedstock and digestate samples from digesters fed with cow manure. A more credible result would have resulted from analysing three or more samples from each farm. The result from the digester fed with pig manure cannot be considered as representative since it was not possible to take samples from more than one farm, and only one sample was taken. The chicken manure fed digester was not analysed.

Further analysis of inorganic and organic phosphorous is needed to be able to determine the nutrition value of the samples. It is also necessary to bear in mind that the samples were analysed by someone else, and it is not known exactly how it was done and if there were any discrepancies which might complicate interpretation of the tests. For example, it would be useful to know the detailed history and handling of the samples which contained more nitrate or ammonia in the feedstock than in the digestate, as according to the literature it should be the other way round: the digestate is supposed to be more nutritious then the feedstock (see 2.9.1).

In regard to the improvements discussed in Section 4.4, if the digesters were to be used to produce more gas, success would depend on what kind of animals and how many of them there is access to. More frequent feeding requires more manure. There would also have to be a balance with water use, as this is a scarce commodity. More feed implies more water for pre-treatment. On the other hand, producing more gas means using more manure, and hence decreasing its polluting factor by decreasing naturally produced and emitted greenhouse gases.

It was hard to evaluate changes in water usage. The installation of a digester requires more water because of the pre-treatment of the feedstock. However, the digesters have really helped the families by saving money on gas which they can use for buying food instead as they are unable to grow as much as they would like.

When discovering that one of the families used to use chemical fertilizer, there was an interest to compare the nutrition value of this with the family's digestate. Sadly, only one synthetic chemical could be identified, and it was discovered to be, in fact, an insecticide, not a fertilizer. It would be interesting to know if this was a translation fault, and to investigate further why this family was using insecticide. Had they been misinformed, and were wrongly thinking they were using fertilizer? If not, why are they not still using it – has the digestate got insecticidal properties? This would be interesting to look into in more depth.

5.1 Suggestion for further studies

- *Further investigations regarding methane leakage*
  As possible methane leakages were observed during the field studies we suggest that further and more in-depth studies should be made with equipment that can measure the scale of the possible leakages. This to minimise health and safety risks, as methane is a flammable gas, to see that the families do not lose valuable cooking gas, and because methane is a strong GHG with high energy absorptivity, so leaks decrease the bio-digesters' environmental benefits.

- *Sharing of a household bio-digester*
  During the field study in Brazil we saw that Diaconia had installed bio-digesters for families which had close neighbours. As discussed in the section on improvements, with the amount of gas that each digester could produce we believe that it in theory would be possible for close neighbours to share the biogas produced from one digester through modification and reconstruction of the equipment. This would improve more people's lives and further reduce the environmental impact. However, this requires further theoretical studies into the design, and construction, together with practical testing of the modified equipment.

- *Safety aspects*
  At the time of this study the families did not receive any manual with information regarding risks and the safety aspects of running a bio-digester. Talking to the families, it was noticed that they seemed to lack awareness regarding the health and safety aspects of running their bio-digesters. Because of this, we believe that additional studies would be of interest to further evaluate the knowledge that the families possess in this area, and possibly take action by running courses and teaching the families the importance of safety and awareness when handling a flammable gas like methane.

- *Digestate*
  Further analysis of the feedstock, digestate and the soil of the agricultural fields would be of interest to determine the nutrition level, any heavy metal content, pathogen levels, and physical or chemical impurities. This is to be certain that the families' environment is safe and provides healthy food and animals, and to ensure that their soil does not suffer from eutrophication or polluted ground water. It might also be possible to predict the carbon content, and thus the methane yield. By further analysis, including of all the different

feedstock, a comparison of nutrient content could also be made to establish which organic materials give the most nutritious digestate. It would also be of interest to investigate if the digestate has any insecticidal affects, as one family had stopped using chemical insecticide after installation of the digester.

6. Conclusion

This part draws conclusions on the outcome of this study and presents recommendations which have been discussed by comparing literature facts with observations made during the field study. The purpose of this study was to evaluate and investigate the environmental and social effects and suggest improvements with installing and running a small scale, family run bio-digester in Afogados da Ingazeira, Brazil.

As was observed during this study, Diaconia has through their work with installing bio-digesters succeeded in providing clean, renewable energy to people in the rural, semi-arid areas of north-eastern Brazil, while at the same time preserving the environment and decreasing the environmental impact of people living in the area. The digesters are easy to run, and are efficient in supplying the families with cooking gas. Interviews showed that they supply the families with more cooking gas then they need for their current consumption, and that the digesters could be fed more frequently if more gas was needed. The feedstock used was cow, pig and chicken manure. Cow manure was preferred because cows produce a lot of manure, and it is moist and so less water is required when diluting the manure during pre-treatment. Pig and chicken manure appeared to produce more gas, as these digesters had to be fed less frequently to provide their families with a similar amount of butane. The geographic location provides an ideal atmospheric temperature, and pH analysis showed values beneficial for the microorganisms' growth and regeneration, and hence for biogas production. Leakage of biogas, and therefore methane, was detected at one family's house, and in general the families were noted as not being aware of safety aspects and the potential fire and explosion risks that can arise due to methane leakage. It was also observed that most families used the digestate as fertilizer on their fields, but the digestate was not appreciated to its fullest potential in regards to retaining its nutrient content. Neither was the digestate applied in the optimal way by everyone, which would make further use of the nutrient content and increase the amount supplied the crop.

Social evaluation showed that the digesters have aided the families' lives in terms of cleanliness, health, time saving, labour, and most especially in financial terms. Environmental evaluation showed that a switch to biogas from the previously-used cooking fuels butane and firewood has reduced GHG emissions, polluting waste, and deforestation. Less CO_2 is introduced into the atmosphere while at the same time there are more undisturbed plants and trees to consume CO_2. HRT calculations showed that the feedstock spend a long time in the reactor, which indicates good conversion and recycling of carbon and nutrients by the microbes. Feedstock change analysis showed that a switch would not affect the biogas production for the families because of the long HRT. Feedstock and digestate analysis showed satisfactory nutrient levels in the substrates, but mixed levels in the digestate, suggesting that some families would be better off using their manure as fertilizer instead of their digestate.

Suggested improvements included sharing a bio-digester between two households to use the excess gas; treatment and field applications of the digestate; digester management; the possibility of selling digestate as fertilizer; reusing drained liquid; optimal placement of the digester; and using human faecal residues as a feedstock.

6.1 Recommendations

- Because methane is a flammable gas, we advise that the families should receive a health and safety manual stating the risks involved in running and managing a bio-digester. The importance of avoiding leaks and working towards preventing them, so as to minimise negative environmental impacts should also be stated in the manual, together with general maintenance.
- Diaconia are recommended to place the digestate containers in a shaded spot when installing them, and preferably cover them to decrease the loss of volatile nutrients.
- We recommend that the families receive information regarding how to handle their digestate if it is to be used as fertilizer, in order to retain as much of the volatile nutrients as possible. They should be taught to use the digestate as soon as possible after it has been produced, and to not keep it exposed to the sun. Liquid should not be drained from the digestate, as this takes time and some nutrients prefer the liquid state to the solid state. The digestate should also be well incorporated into the soil to retain as many nutrients as possible.
- We also believe that the families should be further informed about the environmental benefits they are contributing to by owning a bio-digester and using biogas instead of butane or firewood. This may help improve the bio-digesters' reputation with the local people, and help spread the word of its benefits, as it was found in the interviews that many people are suspicious and do not believe in the technology.
- Diaconia are also recommended to consider dividing a bio-digester between two neighbouring families who live close enough to each other. This would help improve the social lives of more people, and provide more people with green energy, thus decreasing the environmental impact on the area. Diaconia would also be able to help more people with less money. This would require modifications of the digester.

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8. Appendix

8.1 Interview with Jucier, Bio-digester technician at Diaconia

1. For how long have you worked at Diaconia?	6 years. Works mainly as a technician, but helps with everything that needs doing at the office and out on the field.
2. When did Diaconia start installing bio digesters in the Pajeú area?	2009
3. How many bio digesters have been installed in the area?	137 digesters, just in this area.
4. How do you select the families that will receive a digester?	It is usually families that they already work with that they install digesters for. A lot of families do not believe the technology until it is installed and in use in their own home. The families do not believe it even when they are shown bio digesters in use whilst families that they have already worked with are a bit more willing to try them. The more bio digesters they install, the more the word spreads about how good they are.
5. How are they financed?	By a project called Dom Helder Camera, initiated by the Federal government.
6. How often do you visit the families?	Every now and then and when they have problems. They have consistent contact with them and every family have their own contact person at Diaconia
7. Are there a lot of problems with the bio digesters?	No. The families contact us when problems occur.
8. Have calculations on the environmental affects ever been done or has the fertilizer ever been analysed?	No, never.
9. Any new projects going on?	There is a bank that wants to donate money which would finance 200-300 bio digesters.
10. How much does it cost to build one digester?	R$ 2000
11. How much does it cost to build a water cistern?	R$ 1000
12. How long time does it take to build and install a bio digester?	3 days
13. How many people does it require?	2 people from Diaconia together with the family so that they learn how it is built and how it works.
14. Do the families receive any education regarding safety aspects?	They talk to the families when the digester is installed but the families already know a bit about how to handle explosive gas because they have used gasoline (butane) before. They are not given any safety manual and there are no safety awareness classes to attend, but this is something they consider to introduce. The families are also informed about how much money they can save and environmental aspects of having a bio digester, fewer emissions by not using butane and fewer emissions from the cows. Usually, a family uses about 19kg butane each month.
15. Where did the technology come from?	It comes from India and was first introduced in Paraiba 1970. But when it first arrived the families did not use as much energy as they do nowadays so the demand was not as big. In 2008 Diaconia first looked at a digester and made some small changes so it would suit the families they were helping and in 2009 they started building them for the families. When they can build depend on finances coming in.
16. What kind of manure do you suggest for the families to use as feed?	Always cow manure as they only need a small amount of animals because cows produce a lot of manure. Cow manure is also quite watery so less water is needed to dilute it. You need about the same amount of water as manure.
17. Do you recommend the families to use the by-product as fertilizer?	Yes.
18. Any problems with corrosion of the equipment?	No
19. Has anyone studied the gas production before?	No

8.2 Interviews with the families visited

QUESTIONS	Family 1 - cow, Genedit	Family 2 - pigs, Ivan, Community Bom Sucesso	Family 3 - cow, Severina Arta
How much time on average do you spend on working with the bio digester per day?	5 min/day. The procedure to feed the bio digester is really quick. They feed the digester when every they are low on gas, this is usually every second day.	The bio digester is fed ones, maybe twice a week because the pig manure produces so much gas, enough for one weeks use. The feeding takes 20-30 min. If it is fed to much pig manure the gas will leak out on the sides.	10 min on average
How long does it take to collect the manure?	On average 10 min	10-15 min. Husband does the collection because of the smell	The bio digester is filled up every third / fourth day. It takes 15 min to collect the manure. They have no cows of their own so their neighbour provide them with cow manure from his cows.
How much manure do you collect per day and how much do you feed the digester per day?	They do not have an exact amount of manure collected each day but around 20 liters of manure is feed the digester. The rest of the manure is spread on the worm farm to produce bio fertilizer.	One wheelbarrow. The rest is used as fertilizer on the hay field or just left on the ground. The feed container is usally filled up to approximatly half	One wheelbarrow is mixed with 20 liters of water
Where do you collect the manure from?	The manure is collected just outside of the house. They collect the manure early every morning.	Where the pigs are, 50 m away from the digester.	Neighbours provide them with cow manure
How do you prepare the manure before you feed it to the digester?	20 liter of water and 20 liter of manure are mixed together before it is fed.	80 liters of water and on wheelbarrow of manure. Because pig manure is so dry it requires more water to become creamy.	20 liters of water is mixed with one wheelbarrow
How much water do you use for the preparations?	20 liters	80 liters of water	20 liters approximately
How much methane do you receive per day on average? Is it enough for what you use it for?	They receive enough for cooking, though it is hard to estimate how much gas that is produced.	The gas is used for cooking, the family cooks for approx 3h/day.	The amount of gas produced by the bio digester is enough for cooking.
How many household does the digester supply?	The bio digester supply one household.	1, but there is manure and gas to supply more homes. The brother in law about 70 m away is having a digester installed at the moment, but he will use cow manure	1
How much time do you spend on cooking each day?	Average time spent on cooking each day is 1.5 – 2 hours	3h	2-3h
Have you ever fed the digester something else? Any changes, good/bad result?	They have never fed the digester anything besides cow manure.	They have tried chicken manure which provided about the same amount of gas as the pig manure. The chicken manure is mixed with seeds and given to the cows as food or sold as fertilizer.	They have not tried anything else besides feeding the digester cow manure. Though they have heard that pig manure should be more efficient but they do not have any pig manure available. NOTE (Their neighbour (family 2) who lives 5 min down the road had an overflow of pig manure)
If it is only cow manure, is it mixed with something else?	The cow manure is mixed with 20 liters of water	Water	Water
How is the food situation?	Grow their own and buy because of the drought. They grow hay for their animals	Because of the drought they buy most of there food, but they would like to grow themselves as they have the land for it.	Their food situation is quite good. They buy most of their food on the market because of the drought. Severina would like to grow crops again.
What do you do with your food waste if you have any?	Left-over food is given to the pigs. The pig manure is not used for anything, nor is the chicken manure.	They try to use everything they can, food waste is given to the pigs, everything else is saved, conserved.	There is not that much food waste from the house. They try to use up as much of the food as they can. Though for example, banana skid is used for feeding animals (they used to have pigs).
What do you do with the sewage coming from your house?	Sewage from the house goes to a septic tank in the ground.	Septic tank	Sewage from the house goes to a septic tank in the ground.
What do you do with your remaining waste?	The remaining waste from the house is just burned	Burn	The remaining waste from the house is just burned
Do you know what the temperature is inside the batch?	x	Does not know, less then 34	x
How much time did you spend on collecting wood?	Time spent on collecting wood was around 2-3 hours every third day.	30 min	No collection of wood for fuel, only as child (Severina is about 70 years old)
How much wood did you have to collect?	No specific amount, as much as they thought was needed	Does not know, took whatever they needed from there land, within 50-100m reach. Took branches from trees that were dead.	x
How far did you have to walk to collect wood? Safe/dangerous walk?	The wood was collected both on their own property and about 1 hour away, which required a car, this was also where most of the wood was collected. Safe to walk and drive.	50-100m	x
Who does the collection, men/women/children?	Both men and women did the collection of wood, but no children	Everyone, same with the manure except the pig manure which the husband collects	x
If the fuel was bought and not collected, how much money did you have to pay to buy wood or gas cylinders?	43 Reais	They used coal (produced by themselves), wood and gasoline. One bottle of gasoline per month (13kg)	Before the bio digester was installed they used gas (butane) for cooking. It costs around 40 Reis/cylinder and lasted for approximately 27 days. There is no difference between using butane and the biogas
Have you saved any time after the bio digester was installed? If so, what have you done with it?	They have managed to save around 2-3 hours in time since the bio digester was installed.	Yes, at least it feels like it	They have managed to save a lot of time since the digester was installed. She compares to when she was young and had to collect wood for cooking. But when it is compared to cooking with butane it is mainly money that has been saved.
Have you seen any drastic environmental differences? Tree growth in the neighbourhood?	The environment has become much greener. The forest 1 hour away where they used to collect wood has regrown very good since they stopped cutting down trees 9 years ago.	Hard to say because there is a drought at the moment, but they only took wood for fuel from the dead trees.	There is no environmental change since the digester was installed. They did not have manure lying around before either.
Is the environment cleaner after the bio digester was installed?	The environment is much cleaner since the bio digester was installed.	The manure is in a stable so there has never been any manure laying around on the ground around the house. The pig manure is either used as feed, fertilizer on the hay or washed away just to digest on the ground.	x

What do you feed the cows?	The cows are fed with hay and sorghum	Food waste, corn mixed with the leftovers from what the chickens have been fed (they do not eat everything). Does not think any chemicals were used	x
Do you know if there are any chemicals in their food or drinking water?	No	Does not think so	x
How do you manage your agricultural fields? Do you use any fertilizer? Chemicals?	Chemical fertilizer was used before it was replaced with the bio fertilizer from the bio digester. They used it because people who bought their crop though that crop produced with chemicals were better in general (in taste and for the person).	Before the fertilizer from the biodigester they only used cow manure, never chemicals	Do not have a field for agricultual use, so the fertilizer is not used for anything.
Do you use the by-product from the digester as fertilizer?	The by-product is used as fertilizer.	The by-product is dried and grinded to a powder and then used as fertilizer for the hay fields, but they feel that the fertilizer produced from the pig manure is to dirty, unclean and unhealty to use on the vegetable fields. Before they used to use cow manure and the fertilizer from this was used for vegetable fields.	x
If so, how much of the chemical fertilizer have you been able to replace?	All chemical fertilizer (tamron and politrin) has been replaced. Since they stopped using Politrin which she says is a very strong fertilizer they have noticed some drastic changes. Her husband does not suffer from headaches anymore and the crops are also better in both flavor, smell and taste.	x	x
If it is used for farming, how do you spread it on the field?	They dig the dried fertilizer down just next to the crops. The liquid fertilizer is spread with a spray machine.	It is pushed down in the ground, corridors	x
Do you use a specific machine or is it manually spread?	Both	Spread manually	x
Have you ever had the fertilizer analysed?	The fertilizer has been analysed once but they have not received any results.	No	x
Have you had any problems with the bio digester?	There has been some leakage from the water tank.	No, except for the last 3 months they have not had a water filter. This has resulted in a dark flame that smells a bit in the beginning. This gas is not good for the stove	Last week they had a problem with leakage from the digester. They have suffered problems with the digester growing too fast which have caused big bubbles in the digester and probably some leakage as well.
Have you noticed any leakage?	There has been some leakage from the water tank.	No	They have suffered problems with the digester growing too fast which have caused big bubbles in the digester and probably some leakage as well.
Have you got any safety manual for the equipment or are you aware of the safety aspects that need to be considered when running the digester?	No safety manual but they were informed about safety aspects when the digester was installed.	No safety manual, instructions were given when it was installed	They did not receive any safety manual and she does not feel that there is any need for one either
Who runs the digester, same person every day?	Both Genedit and her husband run the bio digester	Both but with pig manure it is only the husband	Husband
What is your personal opinion about the bio digester?	Personal opinion about the bio digester is that it is really good and simple to run. They have also managed to save money.	Very good, really likes the 100% recovery, everything is used, it is a cycle.	Very good, saving money
In what ways has it affected your life?	Saved time and money	Their economy is a lot better since they do not have to by gasoline - a big outgoing finacially	Saving money
Have you seen any differences in spreading of diseases?	No. They did not have any problems with diseases before the bio digester was installed.	x	There was no big problem with diseases before.
Can an estimation if there has been a land use change be done?		x	x
Note: 3-4 years ago the drought started in Afogados da Ingazeira, 80% of the animals died. Note: One cylinder of butane contains 13kg and costs approxiamtely 40 reais	Note: By using the rests of the manure (not fed the digester) on the worm plants, fertilizer is produced and sold for 1.5 Reais / Kg	Note: The family has hade the digester for about 7 years. They used to use cow manure but because of the drought they had to get rid of their cows, so about six months ago they started using pig manure. When they used cow manure the digester was feed approx every second day. The fertilizer that was produced was a lot creamier and was drained from water before used as fertilizer on the fields. The fertilizer produced from the pig manure is a lot dryer and a lot less comes out from the digester. When we where there, what we say was the only thing that had been produced since they changed the feed. Pig manure contains a lot less water so it needs to be mixed with a lot more water to get the same consistancy as cow manure mixed with water. The pig house needs to be washed at least ones a day, require a lot of water. The family also has a chicken farm which requires a lot of gasoline when the chicks need warmth (without their moms), 12 days requires 50 cylinders of gasoline (butane). Minimum temperature that the chicks need to survive are 28-30 C.	Note: The family only consisted of husband and wife and they lived i a sort of attached house with neighbours on both sides so they did not have any land. Before they received the digester they used butane as fuel for cooking so there was no wood collection.

QUESTIONS	Family 4 - cows, Jorge and Antonia, Community Passagem da Cobra	Family 5 - cows, Renata
How much time on average do you spend on working with the bio digester per day?	The digester is feed every second day approximately and it takes about 15 min to feed the digester	It takes around 10 min and the digester if filled every second day
How long does it take to collect the manure?	30 min approximately	It takes 0,5 – 1 day to collect all the manure
How much manure do you collect per day and how much do you feed the digester per day?	1 bucket manure and 1,20 bucket water. (1 cylinder: d=25cm, h=35cm. For the water h=45cm)	100 kg manure is collected daily. 20 liter cow manure, 20 liter water.
Where do you collect the manure from?	200 m away from the digester, where the animals are	The fertilizer is collected from a farm 6km away from the house where the husband workes. They have no cows of their own
How do you prepare the manure before you feed it to the digester?	Mix it with water	With water, it takes about 30 min to prepare the mixture.
How much water do you use for the preparations?	See above	20 liters
How much methane do you receive per day on average? Is it enough for what you use it for?	Yes, receive more then enough, could produce more if needed as there is a lot of manure. The family has 3 stoves that are working for the biogas. The hole in the stove need to be bigger for biogas compaired to butane	Yes it is enough, it is used for cooking
How many household does the digester supply?	1	The digester only supplies this household
How much time do you spend on cooking each day?	5h	They spend 3-4 h cooking food daily
Have you ever fed the digester something else? Any changes, good/bad result?	No	No, they have not fed the digester anything else besides from cow manure
If it is only cow manure, is it mixed with something else?	Water	Water
How is the food situation?	Do not have much, they grow a little but most of the food they buy. Before the drought that started about 3 years ago they use to grow their own vegetables	They grow some crops but buy most of their food.
What do you do with your food waste if you have any?	Give to dog and cat	They don't have that much food waste, what is left over is used to feed the chickens and the cat
What do you do with the sewage coming from your house?	Water from the sink goes to feed the palm trees, bath and wash (mashine) goes to tanks where the water is filtered and treated so it afterwards can be used to feed fruit trees, toilet goes to a septic tank.	Their sewage goes in to a septic tank
What do you do with your remaining waste?	Collected by the town	They burn all the remaining waste
Do you know what the temperature is inside the batch?	x	x
How much time did you spend on collecting wood?	20 min	Before the digester was installed they used coal and wood for cooking. It took around 15 minutes to gather wood for cooking
How much wood did you have to collect?	Do not know, but there was not enough	It depends on how much they need for the day.
How far did you have to walk to collect wood? Safe/dangerous walk?	80 m	They drove about 15-20 min away to collect the wood.
Who does the collection, men/women/children?	Everyone	Both husband and wife
If the fuel was bought and not collected, how much money did you have to pay to buy wood or gas cylinders?	2 cyliners for 3 months	One cylinder of gas (butane) was enough for 4-5 month. Her husband works in another town and she does not cook that much when he is not home.
Have you saved any time after the bio digester was installed? If so, what have you done with it?	Yes on cooking, took a lot longer if wood was used as fuel (start fire, get it warm enough, keep it going). Also saved time on collection; wood every day, manure every second day.	Yes, saved about 2h which they have spent on working in the household. After asking she also said they have more time for social time, like watching tv.
Have you seen any drastic environmental differences? Tree growth in the neighbourhood?	The trees have recoverd, the stems are thicker, but the drought does not helpt	No
Is the environment cleaner after the bio digester was installed?	It is much cleaner in the house since their is no wood laying around, and less unhealthy smoke that makes the house smell bad.	No

What do you feed the cows?	Herbs, native crops, corn leaves when there is a lot of rain, beans and corn they have started giving again because there has been a bit more rain.	Do not know
Do you know if there are any chemicals in their food or drinking water?	No chemicals	x
How do you manage your agricultural fields? Do you use any fertilizer? Chemicals?	Before 2002 they used to use chemicals but then got educated and started using organic fertilizer	Yes fertilizer, used to use pure cow manure
Do you use the by-product from the digester as fertilizer?	Yes, it works just as well as the organic fertilizer	The fertilizer is used on the top of the bio digester
If so, how much of the chemical fertilizer have you been able to replace?	All	Before the bio fertilizer was used they used pure cow manure as fertilizer on the fields.
If it is used for farming, how do you spread it on the field?	Push it of the wheelbarrow and then brush over the fields with their hands. When they plant trees they digg a hole, the first bit of earth that is dugg up is put on the bottom of the hole and the rest is mixed with fertilizer from the digester and placed in the hole around the tree.	They spread the fertilizer only by hand. The seeds are pressed down in the fertilizer.
Do you use a specific machine or is it manually spread?	Manually	Manually
Have you ever had the fertilizer analysed?	No	No
Have you had any problems with the bio digester?	The wooden beam has broken once	Yes, see below
Have you noticed any leakage?	Yes many	They have a leakage of methane right now, only suffered one leakage before that. So totally two leakages in two years.
Have you got any safety manual for the equipment or are you aware of the safety aspects that need to be considered when running the digester?	No, but they have been educated when it was first installed + their son is one of Diaconia's bio digester technicians so if they have any problems they just talk to him	No, only instructions when the digester was installed 2 years ago.
Who runs the digester, same person every day?	The husband runs the digester, has done for 2 years.	Both husband and wife
What is your personal opinion about the bio digester?	Excellent	Her personal opinion is that the digester is really good. She can save time and she also feel like the house has become much cleaner since there is no smoke from the wood /coal cooking. She also says they have no need for running a worm plant anymore, now they have the bio fertilizer from the digester
In what ways has it affected your life?	Cleaner in the house, more time, more money.	More time for other things, saving on money.
Have you seen any differences in spreading of diseases?	x	x
Can an estimation if there has been a land use change be done?	x	x
Note: 3-4 years ago the drought started in Afogados da Ingazeira, 80% of the animals died. Note: One cylinder of butane contains 13kg and costs approxiamtely 40 Reals	Note: The Family has had a water cistern for 11 years and bio digester since 2009. They were the only family of the seven visited that had a lot growing on top of the bio digester; onions, dill, corn and coriander. They lived in Sao José do Egito about 1 hours drive from Afogados da Ingazeira.	Note: The family did not have cows of their own, her husband got cow manure from where he worked. They did have chickens and goats, but not enough to use the manure in the digester. The family consisted of husband and wife (she was 22 years old). Their digester was not working at the time of the visit so no samples were taken, only interview. Lived in Sao José do Egito.

QUESTIONS	Family 6 - cows, Ivoneide, Community Retiro	Family 7 - chicken, Adalberto and Fatima, Community Felipes
How much time on average do you spend on working with the bio digester per day?	They spend about 30 min working with the digester	They spend 1 h working with the digester every third day
How long does it take to collect the manure?	15-20 min	They collect manure when it is needed, it usually takes 25 minutes
How much manure do you collect per day and how much do you feed the digester per day?	They fed the digester 36 liter of manure and the same amount water	The feed usually consist of 1 bucket manure and 1 bucket water, always the same amount of water and manure
Where do you collect the manure from?	They collect the manure 30 meters away from the house	The manure is collected 20 m away from the house where the chickens are.
How do you prepare the manure before you feed it to the digester?	With water	With water
How much water do you use for the preparations?	36 liter	One bucket
How much methane do you receive per day on average? Is it enough for what you use it for?	They have enough of gas, they do not cook that much food since the mums husband past away as he was the one who liked to cook. Before the digester was installed they used wood and gas	They receive more gas then they need. They feel like the digester has become more efficient since they changed to chicken manure 8 months ago. They have tried both pig and cow manure before.
How many household does the digester supply?	The digester supplies only this household	The bio digester supply only this household
How much time do you spend on cooking each day?	1h	3.5 hours is spent on cooking food each day
Have you ever fed the digester something else? Any changes, good/bad result?	They have never fed the digester anything else besides cow manure. The family have goats, chicken and cows	They have used chicken manure for 8 months and before that pig manure for 5-6 months. There was no conversion time when the change was done. They just fed the digester with chicken manure and received gas in the afternoon.
If it is only cow manure, is it mixed with something else?	Water	Water
How is the food situation?	They mainly have goats for the meat. Before the drought they used to grow different kinds of vegetable for their own use but now they only grow cactus to feed the cows.	They grow maize, vegetables and raise chicken, goat and cows for their meat. They sell eggs and some vegetable at the market.
What do you do with your food waste if you have any?	The food waste is given to the chickens and the cats	The food waste is given to the geese
What do you do with the sewage coming from your house?	Their sewage is led into a septic tank	Their sewage goes to a septic tank
What do you do with your remaining waste?	Their remaining waste is burned but they recycle paper	The remaining waste is collected, arranged by the local council
Do you know what the temperature is inside the batch?	x	x
How much time did you spend on collecting wood?	It took around 1-1.5 h to collect wood for cooking	Before the bio digester was installed the family used butane. They do not want to cut down wood, they have always cherished the environment (neighbours call them the wild family with loads of flowers, bushes and plants).
How much wood did you have to collect?	They collected wood weekly, sometimes more for storage and sometimes less.	x
How far did you have to walk to collect wood? Safe/dangerous walk?	They had to walk 100-500 meters for wood collection	x
Who does the collection, men/women/children?	It was only the mother that collected the wood, the father worked on the fields every day	x
If the fuel was bought and not collected, how much money did you have to pay to buy wood or gas cylinders?	They used one cylinder of gas (butane) each month and the bottle cost 40 Reis	The butane cost 44 Reis/ cylinder and could supply them for 1 month
Have you saved any time after the bio digester was installed? If so, what have you done with it?	They feel like they saved 2 hour / day since the digester was installed. The time saved they have spent working on the farm	They feel that they have saved time and money after the digester was installed
Have you seen any drastic environmental differences? Tree growth in the neighbourhood?	They feel like the surrounding area has become much cleaner since the digester was installed. They also feel like the bio-fertilizer works much better than what they used before. The tomatoes are tastier now.	They never cut any trees because they have always thought about the environment - eco-thinking
Is the environment cleaner after the bio digester was installed?	Yes, for example the pots and pan are much cleaner underneath. They have also saved a lot of time by not having to collect wood. Also their health has improved by not having to carry heavy timber	No, because they use their land for chicken farming

What do you feed the cows?	They feed the cows hay and tart, which is a seed from when you process cotton.	The chickens are fed a mixture of crops, leaves, soya and salt
Do you know if there are any chemicals in their food or drinking water?	No chemicals are used.	They believe in organic production.
How do you manage your agricultural fields? Do you use any fertilizer? Chemicals?	No chemical fertilizer was or is used as they were informed about this by Diaconia.	The family has always produced without chemical fertilizer and since 2000 they have a totally organic farm.
Do you use the by-product from the digester as fertilizer?	The fertilizer is used on the cactus field. The cactus is fed to the cows.	They use the by product from the digester as a fertilizer. The liquid fertilizer is sprayed over the field with a pump machine while the solid is spread by hand.
If so, how much of the chemical fertilizer have you been able to replace?	x	Never used
If it is used for farming, how do you spread it on the field?	The fertilizer is spread manually, the liquid fertilizer is spread just with a cup while the solid fertilizer is spread with a wheelbarrow	See above
Do you use a specific machine or is it manually spread?	Manually	See above
Have you ever had the fertilizer analysed?	They have never had the fertilizer analyzed	The fertilizer has never been analyzed
Have you had any problems with the bio digester?	They have had one leakage but the husband could fix it pretty easily because he was very involved when they installed the digester and knows a lot about the digester. They were on of the first families to receive a digester, they really like Diaconia and their work and they believe in what they do (compaired to a lot of other families who are a bit suspisous).	They have never had any problems with the digester
Have you noticed any leakage?	1 but he could fix the leakage himself (husband of the daughter).	x
Have you got any safety manual for the equipment or are you aware of the safety aspects that need to be considered when running the digester?	No, only instructions	They have not received any safety manual but the father says that there is no need for one either
Who runs the digester, same person every day?	It is the mother in the house that runs the digester	The father runs the digester while the women (mother and one daughter) does the cooking
What is your personal opinion about the bio digester?	Their personal opinion is that the digester is very good	Their personal opinion about the digester is that it is great. They are very grateful to Diaconia who has helped them with many smart solutions.
In what ways has it affected your life?	More free time to spend in the house working with different things.	Saved a lot of money, greener environment
Have you seen any differences in spreading of diseases?	x	x
Can an estimation if there has been a land use change be done?	x	x
Note: 3-4 years ago the drought started in Afogados da Ingazeira, 80% of the animals died. Note: One cylinder of butane contains 13kg and costs approxiamtely 40 Reals	Note: The family consisted of husband, wife and wifes mother (wifes father died about 3 years ago). They have a big piece of land, 12 hectors. They farm 7 cows, 34 goats, an uncountable amount of chicken and 4 cats. Lived in Sao José do Egito.	Note: The family has had the digester for a bit more then 3 years. They started out with cow manure for about 2 years but because of the drought they got rid of the cows and started using pig manure. But after about 6 months they had to get rid of them aswell and started using chicken manure. They believe in ecologic production and living and have always strived towards this many years before Diaconia contacted them. Lived in Sao José do Egito.

8.3 Measurements and data gathered from the family visits

	Familj 1 (cow)	Familj 2 (pig)	Familj 3 (cow)	Familj 4 (cow)	Familj 6 (cow)	Familj 7 (chicken)
pH:						
Manure	7	7			7	7
Feed	7	7	7	7	7	7
Digestate	8	7	7	8	8	7
Drained liquid	8		7	7	7	
Dryer fertilizer		7				
Samples:						
Manure	x	x			x	x
Feed	x	x	x	x	x	x
Digestate	x	x	x	x	x	x
Drained liquid	x		x	x		
Amount:						
Manure	20 liter	1 wheelbarrow		{d=25cm, h=35cm} = 17180,58 cm3 = 17,18liter		{d=29cm, h=31cm} = 20476,12 cm3 = 20,5 liter
Feed container, measurments (cylinder) **Hight** (cm)	43	47	47	26,5	42	40
Feed container, measurments (cylinder) **Diameter** (cm)	45	74,5	56	64	65,5	61
Feed container, **Volym** (liter)	68,35	204,78	115,70	85,21	141,45	116,84
Digestate container	85cmx69cmx22cm(höjd)	d=78cm, h=54cm	104cmx48cmx32cm(höjd)	55,5cmx95cmx21cm(höjd)	110cmx64cmx20cm(höjd)	141cmx67cmx19cm(höjd)
Water	20 liter	80 liter		{d=25cm, h=45cm} = 22089,32 cm3 = 22,09liter		24cmx24cmx30cm(höjd) = 17280 cm3 = 17,28 liter
Drained liquid container					47cmx64cmx38cm(höjd)	42cmx67cmx28cm(höjd)
Feeding time approx	Every second day	Every third day	Every second day	Every second day	Every second day	Every third day
Manure:water	1.0:1.0	1.0:1.5	1.0:1.0	1.0:1.0	1.0:1.0	1.0:1.0
Amount fed (manure+water, liter/day) (based on used buckets, observations and interviews)	68,35/4 =17,088	204,78/6 =34,13	115,70/4 =28,925	(17,18+22,09)/2 =19,635	141,45/4 =35,363	(20,5+17,28)/3 = 12,593
		Water dilution is an approximated value based on observations and interviews				Note: The buckets for the manure and water were used for both substances, no specific for anyone.

8.4 Bio-digester in use at the farm of Family 1.

8.5 Safety data sheet for Tamron

VILLA CROP PROTECTION *Co Reg No 1992/002474/07*

Subject:	*TAMRON 585 SL*
Document no:	*130VM*
Effective Date:	*July 2008*
Revision:	*February 2013 (4)*
Product Code:	*IMETAM585SL/VM*

VILLA TAMRON 585 SL

MATERIAL SAFETY DATA SHEET

1. IDENTIFICATION OF THE SUBSTANCE

Product Name:	**TAMRON 585 SL** Insecticide
Common Name:	**Methamidophos**
Chemical Name:	*O,S*-dimethyl phosphoramidothioate **(IUPAC)**
CAS №.:	10265-92-6
Chemical family:	Organophosphate
Chemical formula:	$C_2H_8NO_2PS$ (Mol. wt.:141.1)
Use:	Systemic insecticide and acaricide with contact, stomach and residual action, used to control many insects and mites.
Formulation:	**Methamidophos**: 585 g/ℓ Soluble Liquid
UN No.:	2784
Supplier:	**Villa Crop Protection (Pty) Ltd.** PO Box 10413 Aston Manor, 1630, South Africa
Telephone:	(011) 396 2233
Fax:	(011) 396 4666
Website:	www.villacrop.co.za

24 Hour Emergency response:
Bateleur: 083 1233 911 or 0860 333 911
In case of Poisoning:
Red Cross Poison Information Centre: 021 689 5227
Tygerberg Poison Information Centre: 021 931 6127
Griffon Poison Information Centre: 082 446 8946

2. COMPOSITION / INFORMATION ON INGREDIENTS

Hazardous component:	**Methamidophos**
SYMBOLS:	F, T, N
RISK-PHRASES:	R 10, 24, 28, 50

3. HAZARD IDENTIFICATION

Toxicity class:
WHO Ib; EPA I

Methamidophos is a compound, which inhibits cholinesterase enzyme activity in the nervous tissue. It is of very high toxicity. Contact with skin, inhalation of dust or spray, or swallowing may be fatal. Toxic to fish and bees.

Likely routes of exposure:
May be absorbed from the gastrointestinal tract, through the intact skin, and through inhalation of fine spray mist or dust.

Eye contact:
Highly toxic. Irritating to eyes.

Skin contact:
Highly toxic, due to possible absorption. Mildly irritating to skin.

Ingestion:
Highly toxic by ingestion. See point 4 for symptoms.

Inhalation:
Highly toxic by inhalation depends on volatility of compound. See point 4 for symptoms.

4. FIRST AID MEASURES AND PRECAUTIONS

Symptoms of exposure to the product include: nausea, headache, tiredness, giddiness, blurred vision and pupillary constriction. Depending on severity of poisoning these symptoms become worse with the onset of vomiting, abdominal pain, diarrhoea, sweating and salivation. Confusion, ataxia, slurred speech, loss of reflexes are some of the central nervous system effects may lead to misdiagnosis of acute alcoholism.

Overexposure effects:

After **inhalation of vapours or aerosols** effects appear within minutes: ocular and respiratory effects generally appear first. This includes marked miosis, ocular pain, conjunctival congestion, diminished vision, ciliary spasm and brow ache.

With **acute systemic absorption**, miosis may not be evident due to sympathetic discharge in response to the hypotension. In addition to rhinorrhea and hyperemia of the upper respiratory tract, respiratory effects consist of "tightness" in the chest and wheezing respiration, caused by the combination of broncho-constriction and increased bronchial secretion. Gastrointestinal symptoms occur earliest after ingestion, and include anorexia, nausea and vomiting, abdominal cramps, and diarrhoea.

With **percutaneous absorption** of liquid, localised sweating and muscular fasciculation in the immediate vicinity are generally the earliest manifestations.

Severe intoxication is manifested by extreme salivation, involuntary defecation and urination, sweating, lacrimation, penile erection, bradycardia and hypotension.

The airway should be kept clear to maintain respiration, particularly when the patient is unconscious or has vomited. The mouth and pharynx should be cleared and dentures removed. The jaw should be supported and the patient placed in a face down position with the head down and turned to one side, with the tongue drawn forward. First aid should include, if necessary, mouth-to-nose respiration, cardiac massage and avoidance of injury in patients with trauma.

Inhalation:
Remove source of contamination or move victim to fresh air. Keep affected person warm and at rest. Supply oxygen if necessary. Treat symptomatically and supportively. **Seek medical advice immediately.**
Skin contact:
Remove contaminated clothing, shoes and leather goods. Gently wipe of excess chemical. Wash skin gently and thoroughly with water and non-abrasive soap. Seek medical advice if necessary. Persons who become sensitised may require specialised medical management with anti-inflammatory agents.

Eye contact:
Immediately flush eyes with gently flowing cold water or saline solution for 15 to 20 minutes, holding the eyelid(s) open. **Seek medical attention immediately.**
Ingestion:
Have victim rinse mouth thoroughly with water. Do not induce vomiting, due to the aromatic solvent. **Seek medical advice immediately.**
Advice to physician:
Atropine must be administered as early as possible and could save lives, if given in time and in an adequate dosage. Patients with organophosphate poisoning require amounts of atropine far in excess of doses usually employed in medical practice. The therapeutic objective is to achieve atropinisation, as evidenced by dilation of the pupils, drying secretion, pulse rate of over 120/min and flushing skin. To prevent gastrointestinal absorption in the unconscious that have swallowed this product, perform stomach lavage using bicarbonate solution and activated charcoal.
In **less severe** cases begin with 2 mg atropine intravenously for adults or 0.05 mg atropine/kg body weight for children under 12 years of age and repeat administration of the drug at 15 to 30 minutes intervals.
In **severe cases** a total atropine dose of 20 to 80 mg in the first hour may be necessary, with repeated drug administration at 3 to 10 minutes intervals. When signs of atropinisation appear, the dose and frequency of administration should be reduced to a schedule that will maintain full atropinisation for at least 24 hours. Over dosage with atropine is rarely serious, but under dosage may be fatal in poisoning with organophosphorous compounds. In any severe progressive case of poisoning a cholinesterase reactivator e.g. pralidoxime (2PAM), if available, should be administered, preferably within 8h after intoxication. An average dose is 1 g for an adult (up to 50 mg/kg for children), usually given half as a single intramuscular or intravenous injection and the other half as an intravenous infusion with glucose and or saline. In severe cases this treatment may be repeated in 1 to 2 hours, then at 10 to 12 hour intervals if needed, but not beyond 24 hours, or 48 hours at the most. Pralidoxime should be administered very slowly. If respiration is depressed during or after injection, pulmonary ventilation should be assisted mechanically.
Toxogonin is a more recent cholinesterase reactivator. It can be administered instead of 2PAM at a dose of 250 mg intramuscularly for adults (4 to 8 mg/kg for children) and, if necessary, repeat after 1 to 2 hours.
Diazepam should be included in the therapy of severe cases and whenever convulsions appear. Doses of 5 to 10 mg for adults (2 to 5 mg for children) can be administered intravenously or subcutaneously or per rectum, and repeated as required.
NB: Because of their respiratory-depressant effects, **morphine** and similar drugs are **contraindicated** for patients poisoned with organophosphorous compounds. **Avoid aminoglycosides** and **succinylcholine**, which have a blocking effect on the neuromuscular junction. **Phenothiazines, reserpine and theophylline** are **contraindicated** in organophosphorous poisoning.

5. FIRE FIGHTING MEASURES

Fire and explosion hazard:
Flammable.
Extinguishing agents:
Extinguish small fires with carbon dioxide, dry powder, or alcohol-resistant foam. For larger fires, use water spray, fog or standard foam.
Fire fighting:
Move containers from fire area if possible. Fight fire from maximum distance. Stay away from storage tank ends. Contain fire control water for later disposal. Do not scatter material, extinguish only if flow can be stopped. Use flooding amounts of water as a fog, solid streams may be ineffective. Cool containers with flooding amounts of water as far a distance as possible. Use water spray to absorb toxic vapours. Avoid breathing toxic vapours. Keep upwind. Consider evacuation of downwind area if material is leaking.
Personal protective equipment:
Fire may produce irritating or poisonous vapours. Fire fighters and others that may be exposed should wear full protective clothing and self-contained breathing apparatus.

6. ACCIDENTAL RELEASE MEASURES (SPILLAGE)

Personal precautions:
Avoid contact with skin and eyes. Do not breathe in dust or fumes. For personal protection see Section 8.
Environmental precautions:
Do not allow entering drains or watercourses. When the product contaminates public waters, inform appropriate authorities immediately in accordance with local regulations.

Occupational spill:
Do not touch spilled material. Stop leak if you can do so without risk. Use water spray to reduce vapours (contain any water used). Neutralise with sodium hydroxide and allow standing for 4 hours. For small spills, sweep up with sand or other suitable absorbent material, and place into containers for later disposal. Move containers from spill area. For larger spills, contain material far ahead of spill for later disposal. Keep spectators away. Isolate hazard area and deny entry. Ventilate closed spaces before entering.

7. HANDLING AND STORAGE REQUIREMENTS

Handling:
Highly toxic by absorption or if swallowed. Avoid contact with eyes, prolonged contact with skin, and inhalation of dust and vapour. Use with adequate ventilation. Wash hands before eating, drinking, chewing gum, smoking, or using the toilet. Remove clothing immediately if the insecticide gets inside. Then wash skin thoroughly using a non-abrasive soap and put on clean clothing. Do not apply directly to areas where surface water is present, or to intertidal areas below the mean high water mark. Water used to clean equipment must be disposed of correctly to avoid contamination.

Storage:
The product must be kept under lock and key. Keep out of reach of unauthorised persons, children and animals. Store in its original labelled container in shaded, well-ventilated area, away from heat, sparks and other sources of ignition. Not to be stored next to foodstuffs and water supplies. Local regulations should be complied with.

8. EXPOSURE CONTROL / PERSONAL PROTECTION

It is essential to provide adequate ventilation. The measures appropriate for a particular work site depend on how this material is used and on the extent of exposure. Ensure that control systems are properly designed and maintained. Comply with occupational safety, environmental, fire, and other applicable regulations.

Personal protective equipment:
If engineering controls and work practices are not effective in controlling exposure to this material, then wear suitable personal protective equipment including approved respiratory protection.

Respirator:
An approved respirator suitable for protection from dusts and mists of pesticides is adequate. Limitations of respirator use specified by the approved agency and the manufacturer must be observed.

Clothing:
Employee must wear appropriate protective (impervious) clothing and equipment to prevent repeated or prolonged skin contact with the substance.

Gloves:
Employee must wear appropriate synthetic protective gloves to prevent contact with this substance.

Eye protection:
The use of full-face protection is recommended.

Emergency eyewash: Where there is any possibility that an employee's eyes may be exposed to this substance; the employer should provide an eye wash fountain or appropriate alternative within the immediate work area for emergency use.

9. PHYSICAL AND CHEMICAL PROPERTIES

Appearance:
Yellowish liquid.

Odour:
Pungent odour.

Explosive properties:
Not explosive.

Corrosive properties:
Corrosive to mild steel and copper containing alloys.

pH:
Not available.

Vapour pressure:
2,3 x $10^{(-5)}$ mbar at 20 ^{O}C.

Relative density:
1.08 to 1.15 g/cm^3 @ 20 °C.

Storage stability:
Considered stable for a period of 2 years in normal air, warehouse and light conditions.

Persistent foaming:
Not available.

Suspensibilty:
Not available.

Dilution stability:
Not available.

Solubility in water:
Soluble in water.

Solubility in organic solvents:
(All solubility figures in for technical)

dichloromethane	<200 g/ℓ at 20 °C.
isopropanol	>200 g/ℓ at 20 °C.
hexane	0.1 to 1 g/ℓ at 20 °C.
toluene	2 to 5 g/ℓ at 20 °C.

Partition-coefficient in *n*-octanol/water:
K_{ow} logP = -0.8 *(Data for active ingredient)*

Flashpoint:
11,5 °C.

Melting point:
Technical: 20 to 25 °C.

10. STABILITY AND REACTIVITY

Stability:
Stable at ambient temperature but decomposes on heating without boiling.
Stable at pH 3 to 8.
Hydrolysed in acids and alkalis.
DT_{50} (22 °C): 1.8 year (pH 4),
120 hours (pH 7),
70 hours (pH 9).
Photodegradation is of minor importance.

Incompatibility:
Incompatible with alkaline materials. Compatible with most pesticides. Do not physically mix concentrate directly with other herbicides or pesticide concentrates; always dilute first. A compatibility test is required before using with other products.
Thermal decomposition:
When heated to decomposition, **Methamidophos** releases toxic fumes of oxides of nitrogen, phosphorus, and sulphur.

11. TOXICOLOGICAL INFORMATION

Acute oral LD_{50}:
20 to 55 mg/kg for rats.
Acute dermal LD_{50}:
130 mg/kg in rats.
118 mg/kg in rabbits.

Acute inhalation *(Active ingredient)*:
LC_{50} (4 h) for rats 0.2 mg/ℓ.
Acute eye irritation:
Slightly irritating to eyes.
Acute skin irritation:
Irritant.
Dermal sensitization:
Consider as if irritation may occur.
Reproductive, Teratogenic and Mutagenic Effects:
No information available.
Carcinogenicity:
Possible carcinogen.

12. ECOLOGICAL INFORMATION

Degradability:
Most organophosphate pesticides degrade relatively rapidly in the environment. All organophosphate esters undergo hydrolysis in water; generally the water-soluble products of hydrolysis are less toxic than the parent compound. Degradation is by hydrolysis with loss of the amino, *S*-methyl or *O*-methyl groups.
Mobility:
Due to the rapid degradation of the substance, it's leaching into deeper soil layers can be ruled out.
Accumulation:
Does not accumulate.
ECOTOXICOLOGY:
Very toxic to birds, fish and bees.
Birds:
Methamidophos is very toxic to birds.

Oral LD_{50}:	bobwhite quail:	8 to 11 mg/kg.
	Mallard ducks:	29.5 mg/kg

Fish:
Methamidophos is toxic to aquatic organisms.

LC_{50} (96 hours):	rainbow trout:	40 mg/ℓ

Bees:
Toxic to bees.
Earthworms:

LC_{50}:	*Eisenia foetida:*	73 mg/kg dry soil

Daphnia:

LC_{50}:	48 hours:	0.27 mg/ℓ

13. DISPOSAL CONSIDERATION

Pesticide disposal:
Contaminated absorbents, used containers, surplus product, etc., should be burnt at 1000°C in an incinerator, preferably designed for pesticide disposal, or buried in designated landfill. Hydrolysis under alkaline conditions (e.g. sodium hydroxide) is a suitable method to dispose of small quantities of the product. After hydrolysis, dilute and dispose of via the sewage system. Comply with local legislation applying to waste disposal.
Package product wastes:
Emptied containers retain vapour and product residues. Observe all labelled safeguards until container is cleaned, reconditioned, or destroyed. Combustible containers should be disposed of in pesticide incinerators or buried in an approved landfill. Non-combustible containers must be triple rinsed with water and then be punctured and transported to a facility for recycling or disposal in approved landfill site. Comply with any local legislation applying to disposal.

14. TRANSPORT INFORMATION

UN NUMBER:	2784
ADR/RID:	
Substance ID no.:	2784
Hazard ID no.:	36
Label:	3
Subsidiary risk:	6.1

IMDG/IMO:

Packaging group:	II
Label of class:	3
Subsidiary risk label:	6.1 **MARINE POLLUTANT**
Shipping name:	Organophosphorous pesticide, liquid, flammable, toxic (**Methamidophos**).

AIR/IATA:

Shipping name:	Organophosphorous pesticide, liquid, flammable, toxic (**Methamidophos**).
Class:	3
Subsidiary risk:	6.1
Hazard Label:	Flammable liquid & Toxic
Packaging Group:	II
Passenger Aircraft:	305 (max 1 L) Y305 (max 1 L)
Cargo Aircraft:	307 (max 60 L)
UK classification:	Not available.

15. REGULATORY INFORMATION

Symbol: F, T, N

Risk phrases:

R 10	**Flammable**
R 24	Toxic in contact with skin.
R 28	Very toxic if swallowed.
R 50	Very toxic to aquatic organisms.

Safety phrases:

S 1/2	Keep locked up and out of reach children.
S36/37	Wear suitable protective clothing and gloves.
S45	In case of accident or if you feel unwell, seek medical advice immediately (show the label where possible).
S60	This material and its container must be disposed of as hazardous waste.
S 61	Avoid release to the environment. Refer to special instructions.

Indication of danger: **Flammable.**
Toxic.
Environmentally dangerous substance.

16. PACKING AND LABELLING

Packed in 5, 10, 20 & 25 metal or fluorinated plastic containers and labelled according to South African regulations and guidelines.

17. OTHER INFORMATION

All information and instructions provided in this Material Safety Data Sheet (MSDS) are based on the current state of scientific and technical knowledge at the date indicated on the present MSDS and are presented in good faith and believed to be correct. This information applies to the PRODUCT AS SUCH. In case of new formulations or mixes, it is necessary to ascertain that a new danger will not appear.

It is the responsibility of persons in receipt of this MSDS to ensure that the information contained herein is properly read and understood by all people who may use, handle, dispose or in any way come in contact with the product. If the recipient subsequently produces formulations(s) containing this product, it is the recipients sole responsibility to ensure the transfer of all relevant information from this MSDS to their own MSDS.

18. REFERENCES

- Applicable own physical and chemical, toxicity and ecotoxicity research studies.
- *The Pesticide Manual;* Tenth Edition; Editor, Clive Tomlin; Crop Protection Publications, 1994.
- *The Pesticide Manual;* Eleventh Edition; Editor, Clive Tomlin; Crop Protection Publications, 1997.
- *Pestline*. Material Safety Data Sheets for Pesticides and Related Chemicals, Volume II, Occupational Health Services Inc.; 1991.
- *Agriculture and Public Health*; Guide to the Treatment of Poisoning by Chemicals, 1993.

END OF DOCUMENT

Compiled: July 2008
Reviewed: February 2013