

An explorative study analyzing differences in economical feasibility at large scale biogas plants in Sweden

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Preface

This MSc thesis is part of the final project for the specialisation management of the MSc study Management Economics and Consumer studies at the Wageningen University. This MSc thesis was carried out at the Business Economics group, Wageningen University, the Netherlands and the Economics group, SLU, Uppsala, Sweden. From September 2007 until December 2008 I worked part-time on this thesis at the Wageningen University. From January 2008 until June 2008 I worked full-time on this thesis at the SLU, in Uppsala.

With enthusiasm and lots of pleasure I have experienced the duration of writing my MSc thesis in an international environment. First of all I want to thank prof. dr. Lansink from the business economics group in Wageningen and prof. Surry of the economics group at the SLU in Uppsala to facilitate this international experience. Secondly my gratitude are going to my Dutch supervisor dr. ir. Miranda Meuwissen and my Swedish supervisor dr. Monica Campos. I want to thank them for the time and patience they devoted on me to stimulate the improvement of this Master thesis. Without their critical comments on structure, content, language or text my thesis would not have been such a wonderful learning experience!

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Uppsala, June, 2008

Summary in English

The aim of this explorative study was to analyse whether biogas production at biogas plants in Sweden is economical feasible in terms of operational profitability further described as profitability for the years 2004-2006. In addition specific cost or revenue items are identified with a t-test affecting different levels of profitability at the biogas plants. A profit function model was used calculating revenues, costs including emissions of CH₄, NO₂ and CO_{2 as} cost items.

Results within the boundary of the profit function model, assumptions and empirical data of the eight biogas plants were that there was a positive profitability for the plants of Uppsala, Kalmar, Vetlanda, Boden, Linköping and Borås for the years 2004-2006¹. The plants of Huddinge and Göteborg had negative profit results i.e. losses for the years 2004-2006. Positive results on profit are related to higher revenues of gate fees and biogas revenues stimulating the profitability except for the plant of Kalmar. Increasement of these revenues affecting the profit was mainly explained by the treatment of more waste. Negative results on profitability for the plant of Huddinge and Göteborg were related to higher transport costs and relatively low revenues of heat for the Huddinge plant.

Other costs factors besides transport costs affecting the differences of profit between the biogas plant of Uppsala and the plants of Göteborg and Kalmar were labour, energy, water, emission and biogas upgrading costs. It appeared that waste quantities, the type of waste, distances from supplier to the biogas plant, means of transport, pre-treatment processes, digestion technology, dry content of the waste, quantity of energy used and prices of energy explaining differences in costs and affected the profit.

¹ For the plants of Vetlanda, Boden and Linköping data was only available for the years 2005-2006. The plants were profitable for the years 2005-2006.

Samenvatting in het Nederlands

Het doel van deze exploratieve studie is om te kijken of biogas productie bij grote biogas fabrieken in Zweden economisch rendabel is in termen van operationele winstgevendheid voor de jaren 2004-2006. Tevens zijn verschillen in kosten of opbrengsten tussen biogas fabrieken geanalyseerd met een t-test. Met de resultaten uit de t-test konden indicaties gegeven worden welke kosten of opbrengsten de winst beïnvloedde tussen biogasfabrieken. Een winstfunctie model is gebruikt om kosten en opbrengsten te berekenen waarbij het niveau van emissies van CH₄, NO₂ en CO₂ berekend zijn als kostenpost in het model.

Resultaten binnen het kader van het winstmodel, aannames en empirische data van de acht biogas fabrieken waren als volgt. De biogasfabrieken in Uppsala, Kalmar, Vetlanda, Boden, Linköping en Borås bleken winstgevend te zijn voor de jaren 2004-2006². Winstgevendheid voor deze fabrieken werd veroorzaakt door hogere opbrengsten van behandelings vergoedingen (gate fees) en biogas opbrengsten voor brandstofgebruik behalve bij de biogas fabriek in Kalmar. Een hogere verwerking van afval lag ten grondslag aan de hogere opbrengsten van behandelings vergoedingen (gate fees) en biogas opbrengsten voor brandstof gebruik.

De biogas fabrieken in Huddinge en Göteborg maakte verlies voor de jaren 2004-2006. Met name was dit gerelateerd aan de hogere transportkosten. Bij de biogas fabriek in Huddinge lag ook relatief lagere opbrengsten van warmte ten grondslag.

Overige kosten naast transportkosten die de winst beïnvloedde tussen de biogas fabrieken in Uppsala, Kalmar en Göteborg werden veroorzaakt door arbeidskosten, energiekosten, waterkosten, emissiekosten en opwaarderingkosten van biogas. Aan de verschillen in kosten die de winst beïnvloedde lag ten grondslag dat er meer afval verwerkt werd per fabriek, het soort afval dat verwerkt werd, droge stof gehalte van het afval, de afstand tussen de biogas fabriek en de leverancier van afval, het soort transport, het voorverwerking traject van afval, anaerobische vergisting techniek, de hoeveelheid energieverbruik tijdens het proces en de prijs van energie.

²Alleen data voor de jaren 2005-2006 is verkregen van de biogasfabrieken in Vetlanda, Boden en Linköping. Desondanks waren deze biogas fabrieken winstgevend voor de jaren 2005-2006.

Sammanfattning på svenska

Syftet med denna explorativa studie har varit att undersöka om biogasproduktionen på svenska biogasanläggningar varit ekonomiskt lönsam under åren 2004-2006. En vinstmodell har använts för att beräkna avkastning och kostnader. Olika kostnader och inkomster är också analyserade med hjälp av ett statistiskt t-test. Resultatet från statistiskt t-testen gav indikationer vilka kostnader och inkomster påverkar vinsten. Utsläppsnivån av CH₄, NO₂ och CO₂ har beräknats som kostnader.

Resultatet inom ramen för vinstmodellen, beräkningsantagningar och empirisk data från åtta biogasanläggningar var följande; Biogasanläggningarna i Uppsala, Kalmar, Vetlanda, Boden, Linköping och Borås var vinstgivande åren 2004-2006³. Orsaken till vinsten för dessa anläggningar var den högre avkastningen för behandlingsinkomsten (gate fees) och biogasavkastningen för bilanvändning. En mer betydande avfallsbehandling är orsaken till den högre behandlingsavkastningen samt biogasintäkterna för bilanvändning. Biogasanläggningarna i Huddinge och Göteborg har ett negativt vinstresultat för åren 2004-2006. Orsakerna beror på högre transportkostnader och relativt låg värmeinkomst på biogasanläggningen i Huddinge.

Övriga kostnader näst transportkostnaderna som påverkar vinsten förefaller vara kostnaderna för arbete, energi, vatten, utsläpp och biogasuppgradering mellan biogasanläggningar i Uppsala, Kalmar och Göteborg. Orsakerna till de kostnadsskillnader som påverkat vinsten är mängden behandlat avfall, vilka typer av avfall som behandlats, torrhalt från avfall, avståndet mellan avfallskällan och biogasanläggningen, rötrestteknik, transportvägar, förbehandlingprocessen av avfallet, energimängden som behövs i de olika energianvändningsprocesserna och energipriset.

³ På biogasanläggningarna i Vetlanda, Boden och Linköping var bara data över åren 2005-2006 tillgängliga. De här åren var vinstgivande på dessa biogasanläggningar.

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List of abbreviations

Energy

KWh: Kilowatt hour
MWh: Megawatt hour
GWh: Gigawatt hour

MJ: Megajoule

Distance

Km: Kilometre

Volume

m³: Cubic metre
Nm³: Normal cubic metre of gas

Weight

Ton: Ton(1000 Kilograms)
Kg: Kilograms
g: Grams

Currency

€: Euro
SEK: Swedish Crones
DKK: Danish Crones

Chemicals

CO₂: Carbondioxide
CH₄: Methane
NO_x: Nitrogenoxide
SO₂: Sulfurdioxide
HC: Hydrocarbons

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1 General introduction

1.1 Introduction

Biogas is a renewable energy source produced by the biological breakdown of organic matter by micro-organisms in the absence of oxygen (IEA, 2005). Biogas is produced for multiple objectives. The objectives of the biogas system vary from issues such as improving waste management, the production of a renewable energy carrier and the improved management of plant nutrients (Berglund, 2006).

In order to improve waste treatment, the Swedish government put a ban on land filling in 2001 reducing in the near future the amounts of land filling plants. Reasons for this are to improve the living environment influencing the health of citizens and to use alternative waste management strategies as anaerobic digestion (SFS, 2001). Large-scale biogas plants were built since mid 1990 in order to improve the management of organic waste products from food processing plants or organic household waste (Bjurling & Svärd, 1998). In addition this treatment is nowadays preferable to combustion which can also treat organic waste. The preference of anaerobic digestion is related to the interim target 'A Good Built Environment' (SEOC, 2007); part of the national environmental quality objectives from the Swedish government. This implies that at least 35% of the food waste from households, restaurants, catering establishments and retail premises and 100% of the food waste of the food industry is treated biologically by the year 2010 (Swedish Government, 2005).

Several biogas plants are designed to produce renewable energy carriers (Berglund 2006). In the past, biogas was mostly used to produce heat and electricity. With increasing awareness of global warming and related policy incentives such as the reduction of 30% of greenhouse gases in the EU in 2020, biogas has potential as a green fuel carrier for energy production and transport purposes (Lantz et al, 2006). It can be used to replace fossil fuels, e.g. oil and gas. Biogas has many environmental benefits, such as reduced emissions of carbon dioxide, particles, hydrocarbons and sulphuric compounds compared to the primary energy sources (Berglund, 2006). In addition it can also be distributed in the existing infrastructure for gas, for example by injection into the natural gas grid (Berglund, 2006). Another objective for building biogas plants is the use of digestate as a fertilizer in agriculture. During anaerobic digestion digestate is produced as waste product in the bio-reactor. This waste product; digestate can be used to meet the demand for organic fertilizers or to reduce nitrogen leaching by digesting manure (Berglund, 2006). Also there are several nutrients preserved in the digestate especially nitrogen. Anaerobic digestion can therefore

allow for recirculation of plant nutrients and potentially reduce the demand for commercial chemical fertilizers (Berglund, 2006).

The current Swedish biogas production amounts to approximately 1.3 TWh/year (STEM, 2007a). Biogas is used as a main source for several multi-outputs. Twelve percent of the current biogas production is currently upgraded and used as vehicle fuel in buses, distribution trucks and passenger cars. The remaining current biogas production is mainly used for heat (33%), power (24%), flared (9%) or natural gas (2%) (STEM, 2007a).

Furthermore the waste product of biogas production is used as a fertilizer for agricultural land (Berglund, 2006).

For transport purposes the use of renewable fuels such as biogas and ethanol, is promoted within the EU, through national indicative targets on minimum proportions of renewable fuels on the market (EC, 2003). This is an important driver to increase the use of biofuels, e.g. biogas (EC, 2006). In 2005 the amount of biofuels used in Sweden was 3.1%. Biogas accounts for 0.17% out of the 3.1% of Swedish biofuels levels (EC, 2006). The target to reach in 2010 is that 5.75% of transport fuels used should be based on biofuels. According to forecasts for vehicle fuel purposes the demand of biogas is expected to rise in 2009 with, 45 million m³ compared to 31 million m³ in 2007 (STEM, 2007b). This implies more biogas fuel has to be produced. Furthermore, in 2003 an electricity certificate system came into force in Sweden. This aims to gradually increase the production of electricity from renewable sources by 10 TWh by the year 2010 compared with production levels from 2002. Bioenergy e.g. biogas based electricity production can be granted certificates and can be a potential renewable supplier complying with the target to increase 10 TWh production of electricity from renewable sources (SFS, 2003; EC, 2005).

Hence, to support to the expected future demand, a study estimated that biogas potential in Sweden indicates, that approximately 14 TWh/year can be technically produced from available mixed resources (Linne et al., 2005; Nordberg et al., 1998) This implies the possibility of a 10-fold increase of the present production of biogas. Available mixed resources contributing to the estimation of 14 TWh/year are household and restaurant waste (1 TWh), industrial and food production waste (1 TWh), sludge (1 TWh) and agricultural energy crops and waste residues (11 TWh) (Linne, 2005). Still the actual increase in biogas production does not necessarily matches the technical potential of 14 TWh. This is due to several barriers on the supply, process and demand side (Lantz et al, 2006).

From the supply level of organic waste the biggest potential accounts from agricultural energy crops and waste residues, such as ley crops, corn cereals and harvest residues. (11 TWh). However, the production of energy crops from the Swedish agriculture may depend significantly on the type of cultivated crops, land quality and geographical location (Börjesson, 2007). In addition it is important to note differences between various kinds of feedstock regarding economic feasibility of the production of agricultural energy crops. (Lantz et al, 2006). Another issue is the competition of waste between incineration and anaerobic digestion treatment. The gate fees charged for incineration of municipal waste are approximately 27–54 €/ton which can be compared with 43–80€/ton for municipal waste treated in centralised biogas plants (RVF, 2005). Since centralised biogas plants also require that municipal waste is separated at source, additional costs are made for this pre-treatment. These extra costs have the consequence not to encourage waste companies to deliver municipal organic waste to centralised biogas plants (Berglund, 2006).

Furthermore, the availability of biogas at petrol stations and economic factors such as the investments in biofuel vehicles could be a barrier for the utilisation of biogas as a vehicle fuel for private passenger cars (Lantz et al, 2006). However, local initiatives to promote the use of biogas as a vehicle fuel exist in Sweden. Some municipalities have, for instance, been granted with funds within the national climate investment programme in order to subsidise some of the extra costs for biofuel cars (NV, 2005) or offer free parking in the city (Fordonsgas, 2008). On a national level Swedish legislation insists that all large petrol filling stations (i.e. those selling more than 3 000 m³ petrol and diesel per year) must provide renewable vehicle fuels from April 2006 (Swedish Government, 2005a; 2005c). More filling stations will be subject to this eventually.

At the process level current expansion of biogas production is limited for land filling due to a ban by the Swedish government. In addition the municipal waste water treatment plants reaching their maximal treatment capacity as these plants main purposes are sludge treatment instead of biogas production (Lantz et al, 2006). Farm scale processing is promising, but only under specific conditions for scale, substrate and utilisation rate of resources financial feasible (Svensson, et al 2006). In order to facilitate the market development, large scale biogas plants further also described as biogas plants provide a promising treatment for increasing the potential supply and complying with expected biogas demands. Currently 0.13 TWh (STEM, 2007a) out maximum treatment capacity of 1-2 TWh of biogas plants is used (STEM, 2007b, RVF 2006). However to comply with the potential demand assuming barriers to resolve at this side, biogas production process capacity is limited to utilize the potential mixed resources. (Nordberg, 1998; Linne, 2004; RVF, 2006;

STEM, 2007a STEM 2007b; EC, 2005) Table 1 summarizes the overview of supply, process capacity, future demand and utilized biogas.

Table 1: Overview of supply, process capacity, future and utilized demand of biogas in 2008

Potential supply of biogas in Sweden (Nordberg, 1998, Linne, 2004)	14 TWh
Estimated process capacity of large scale biogas plants in Sweden (RVF, 2006; STEM, 2007a)	1-2 TWh
Estimated demand of biogas in Sweden (STEM 2007b; EC, 2005)	10,4 TWh
Current production biogas plants (large scale) in Sweden (STEM, 2007a)	0,13 TWh
Produced biogas all facilities in Sweden (STEM, 2007a)	1,6 TWh

According to studies from Lantz, et al (2006) and Börjesson (2007) on bioenergy systems, economical feasibility can be a barrier to increase production. In order to meet the expected demand of biogas and treat the potential supply of available mixed resources for biogas production, economical feasibility e.g. operational profitability of the production process at biogas plants is considered as a prerequisite to stimulate biogas production. Therefore this study analyses whether biogas production at biogas plants is economical feasible in terms of operational profitability. In addition specific costs or revenues are identified affecting different levels of profitability at the biogas plants. Another important issue to consider are externalities during the production of biogas for the plants with respect to emission levels of several greenhouse gases such as CH₄, NO₂ and CO₂ described in the list of abbreviations. Biogas energy systems consider to have social and environmental benefits, hence greenhouse gasses are emitted during biogas production at input-, process- and output level. Although it is known what the amount of emissions are per produced unit of a biogas system (Börjesson, 2006), it is unknown what the level of greenhouse gasses are at certain levels of production at large scale biogas plants. As biogas production could be expected to increase in the near future more insight is needed whether biogas plants can contribute with international objectives from the EU to reduce 30% of the greenhouse gases (Lantz et al, 2007) In addition the Swedish Government wants to reduce climate impact implying 4% lower level of emissions in 2012 compared to 1990 (SEOC, 2007). More taxes or legislation could be subject to this to reduce emissions for biogas plants. Therefore the levels of emissions of biogas production at large biogas plants are included as object of research.

1.2 Objective and methodology

Given the data collected from biogas plants the objective is to analyse the operational profitability further described as profitability for eight Swedish biogas plants during the period 2004-2006. Differences in revenues and cost items are identified for biogas plants and between biogas plants affecting the levels of profitability.

Methodology

A profit function model including emission costs is used to calculate the profitability for biogas plants for the years 2004-2006. Differences in revenue and cost items between plants are identified with a t-test. A t-test is providing evidence if revenue and cost times affect the differences of profit between the biogas plants. The outcome of the results are economically interpreted, explained and discussed based on the data and literature.

1.3 Limitations of study, focus and structure of the report

In contrast to many other energy production systems, anaerobic digestion is often applied to address more issues than the demand for energy carriers (Lantz, et al 2006). Anaerobic digestion can be used, to reduce the environmental impact of greenhouse gasses, to improve existing waste management strategies and to provide fertilizer for agriculture (Berglund, 2006). This complexity implies that many actors such as municipalities, farmers and energy companies influencing the system with their interests, acting as either incentives or barriers (Lantz, 2006). Figure 1 gives a scheme of a biogas energy system.

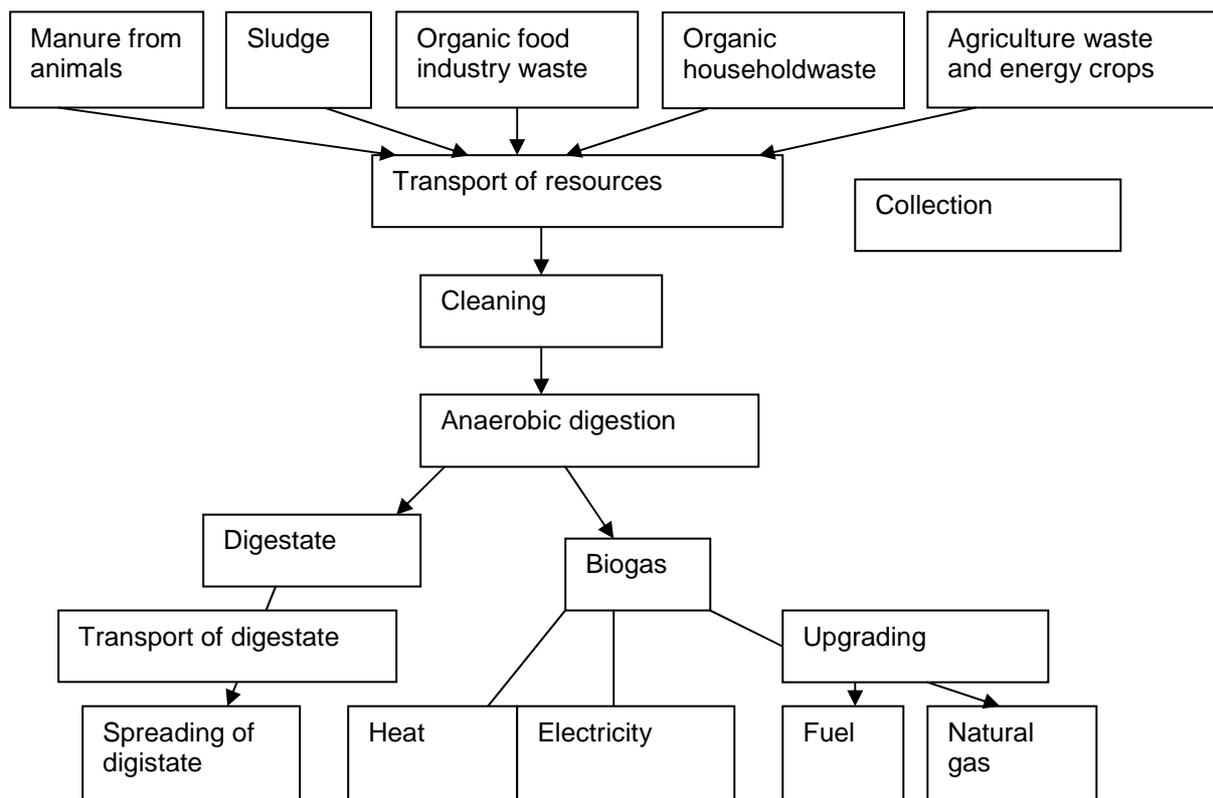


Figure 1: Overview of the biogas system to analyse in this study

Economical feasibility of biogas systems have been analysed from the perspective of incentives and barriers for the expansion of biogas systems mainly from energy political approach (Lantz et al, 2006). The main conclusion from this literature study is that biogas systems has a promising potential, but needs increased incentives and should reduce barriers by different kinds by policies to reach feasibility (Lantz et al, 2006).

Berglund (2006) highlights relevant economical indicators for biogas energy systems, about gate fees, production costs and prices of outputs based on information from plants and literature. Also economical feasibility studies by modelling have been done on farm scale biogas plants (Svensson, et al 2005). This study indicates that high-solid single-stage fed-batch reactors stand the best chances of being competitive, particularly in connection with organic farming. The methane yield, degree of gas utilisation, and operational costs were found to have the strongest impact on the financial success of the process. Another study from Svensson, et al (2006) indicates that scale choice of substrate and the utilisation rate of resources are the most important parameters for financial feasibility at farm-scale biogas plants.

In this study the economical feasibility of the biogas energy system is studied for biogas plants. A previous study focused on the economical feasibility of a large-scale biogas plant of 300 GWh (SGC, 2007) if build. This report has shown that biogas can be produced in a sizeable scale and that economics of scale makes biogas production feasible. Another study focuses more on the technical waste management aspects of large-scale biogas plants and ways to share this knowledge in a system between biogas plants. (Svård, Cour Janssen, 2003). However this study focuses on the simulation of economical results of current operating biogas plants for the years 2004-2006 in terms of profitability. Furthermore costs or revenues are identified affecting levels of profitability at biogas plants including emissions as costs. Previous studies in Sweden related to the environmental impact of biogas systems are done by Börjesson, (2006); Börjesson (2007); Berglund, (2006). These studies focused on the environmental impact of introducing biogas systems to replace various fuels and existing strategies for the handling of various raw materials. Main conclusions are that the environmental impact varies greatly between the biogas systems studied depending on the raw material digested and the reference system replaced. A study by Persson, (2003) analysed the emission level of different biogas upgrading technologies at biogas plant. Main conclusions were that losses of CH₄ during upgrading and pressurisation of the biogas have been reported to correspond to 0.2–2% up to 10-13% for different upgrading technologies. The focus of this study is to simulate the levels of emissions of the operational biogas plants based on the amount of waste treated and the type of waste. The emissions of the operation

of the biogas plant are taken as costs items affecting eventually the profitability of the biogas plant.

For the research an empirical dataset is collected on mixed resources (household waste, food industry waste, agricultural crops and waste residues, sludge and manure), inputs (labour, energy, transport, water, amount of biogas upgraded for vehicle use, outputs (heat, gas, electricity, biogas for vehicle use). The data is collected at eight large scale biogas plants in Sweden which cover the period from 2004 to 2006. The data will be used to calculate the revenues, costs and profit of the production process at biogas plants in a profit function model. The outcomes of this study are considered as explorative as the profit model is partly based on empirical data of the collected data sample and assumptions from literature or statistics on prices of revenues or costs described in chapter 4 and appendix C.

The report will contain the following structure. In chapter 2 a literature part is written about the biogas production process and related biogas production in Sweden. Chapter 3 shows a review of relevant biogas studies affecting the economics and environmental levels of biogas processes. In chapter 4 the profit function model is presented, collected data is described and methodology will be discussed. In chapter 5 results on profitability per biogas plant will be analyzed. Also different costs and revenues are identified explaining the differences in profit levels. In chapter 6 final conclusions are drawn including a discussion related to the data collected and literature.

2 Biogas production and related processes in Sweden

2.1 Overview of the production of biogas

Anaerobic digestion is a process by which organic waste can be biologically converted to biogas in the absence of oxygen (Lastella et al., 2002). This process requires specific environmental conditions and different bacterial populations. Mixed bacterial populations degrade organic compounds and produce as end-product a valuable high energy mixture of gases mainly methane (50-80%), carbon dioxide (20-50%) and hydro sulphide (0-0,4%) (SGC, 2005); (Lastella et al., 2002). The residue: digestate, that remains after the degradation process is used as plant nutrient which contains nitrogen and phosphor from the raw materials digested (Berglund, 2006).

Biogas is produced at several plants over Sweden (Table 2). In 2005 the production of biogas in Sweden was estimated at approximately 1.3 TWh (STEM, 2007a). The majority of biogas production facilities are municipal wastewater plants and landfill plants. The largest part of the 1,3 TWh is currently produced at municipal wastewater plants (0,58 TWh) and landfills (0,34 TWh). Other biogas production facilities are large-scale biogas plants, farm-scale biogas plants and industrial waste water treatments plants producing respectively 0,18 TWh, 0,01 TWh and 0,09 TWh (STEM, 2007a).

Table 2: Biogas production in Sweden (Stem, 2007a)

Production plant	Number of plants	Biogas production in TWh in 2005
Industrial waste water treatment plants	4	0,09
Farm-scale biogas plant	7	0,01
Large-scale biogas plant	13	0,18
Land fills	70	0,34
Municipal waste water plants ^a	139	0,58
Total	233	1,28

^aIncluding estimated numbers of 79 municipal waste water plants

In Sweden biogas is produced from different substrates at different treatment plants (Table 3). Sludge accounts for 78.6% of the biogas production. The other 21,4% is covered by household waste 0.8%, manure 2.8 %, food industry waste 15% and slaughterhouse waste 2.8%. The majority of waste besides sludge at large scale biogas plants comes from slaughterhouse waste. Secondly it is food waste from industry and manure (STEM, 2007a).

Table 3: Organic waste use for biogas production in wet ton weighted (STEM, 2007a)

Treatment plants	Household waste	Sludge	Manure	Food industry waste	Slaughterhouse waste
Industrial waste water plant				438 000	
Farm-scale biogas plants	400	600	30 430		3 500
Large-scale biogas plants	27 568	0	68 149	34 700	97 750
Municipal waste water plant	1 799	2 843 300	170	65 400	11
Total	29 767	2 824 900	98 749	538 100	101 261

The production process at large scale biogas plants can be divided in different processes.

These are described in Figure 2; it is a general process flow chart of biogas production.

Based on the flow chart next paragraphs describe the technical and biological processes of biogas production for the Swedish situation separately.

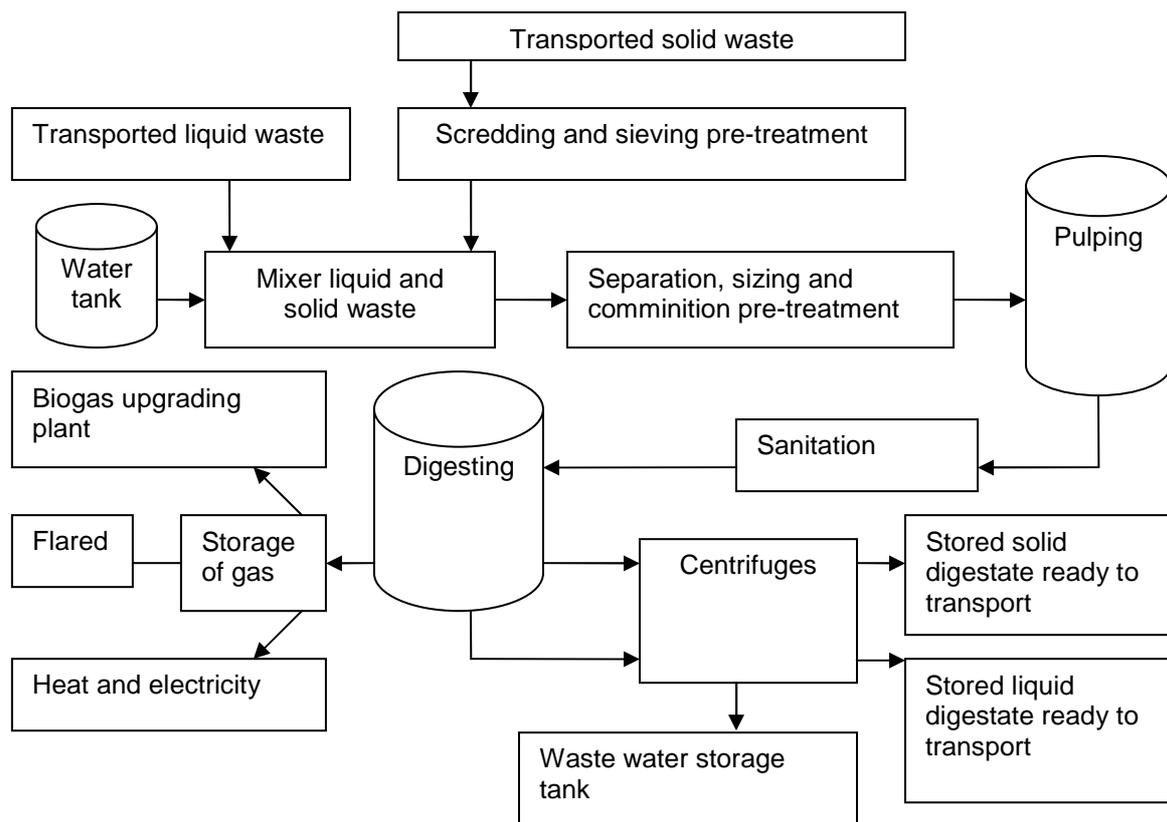


Figure 2: Process treatment flow for biogas production (Växkraft, 2006; Braun, 2002)

2.2 Transport, collection and pre-treatment

Available organic resources usually come from municipal organic waste collection, agriculture, or from agriculture related bio-industry (IAE, 2005). Storage at the plant can be done either in a silo's or a storage tank which has to contain bio filters to avoid emissions at a collection point in the municipality (Johansson and Nilsson, 2007).

The raw material is transported either by tractor, waste collection vehicles or trucks to the storage location or in the receiving hall of the biogas plant. The transport of raw materials to a large-scale, centralised biogas plant from the source such as food industry plants or households is on average 10 km (Sundqvist, 2002). However transport distances are reported to vary between approximately 3-15 kilometres (Börjesson, 2006). An alternative way of transporting organic material is pumping the waste through a pipeline. This way of transport is used for liquid organic waste such as manure. In Helsingborg a pipeline system was build in 2007 to move liquid waste (Johansson and Nilsson, 2007). Through the pipeline liquid waste is pumped from the source towards the plant.

Depending on the raw material and the dry matter content more energy and water is used. This affects the costs due to a comprehensive pre-treatment allowing a proper digesting operation (Braun, 2002, Börjesson, 2006). Hence many raw materials can be used as co-substrates without any pre-treatment. Among this are predominantly liquid waste or sludge's for instance (Braun, 2002). Food industry waste and restaurant waste require simple pre-treatment which usually includes removal of metals, glass, sand and stones. A few organic wastes require extended preconditioning for co-digestion. Among these is waste from separate collection, garden and yard waste, market waste, expired food as well as some industrial waste (Braun, 2002).

Several methods for pre-treatment exist. This encompass biological methods (e.g. pre-composting), mechanical methods (e.g. ball milling) and physical-chemical methods (e.g. thermal hydrolysis) reviewed by Mata-Alvarez, et al. (2000). In Sweden mainly mechanical methods are used for pre-treatment (RVF, 2005b). This includes technological methods as magnetic separation, comminution in a shredder, screening, sizing, gravity separation and pasteurization (Lissens, 2001); (Växtkraft, 2006).

The main aim of the pre-treatment is related to the principle of separation, sizing and comminution. Separation is occurring by the principle of magnetism of materials or gravity. The first method divides magnetic compounds from the non-magnetic ones, whereas the latter focus on the principle of the weight of materials which influences the specific gravity.

Sizing is based on the principle of separation of particles according to size. This can occur by mesh screens, rotating drum tromms, optical separation and sand traps. Comminution is particle size reduction of materials. It may be carried out on either dry materials or slurries. Crushing and grinding are the two primary comminution processes which can occur with a shredder (Wikipedia, 2008).

The first stage of the treatment process is occurring in the receiving hall where the waste enters. Here a shredder, comminution in a rotating drum, a sieve and optical scanning is used to separate the organic waste from plastic, stones and glass (Växtkraft, 2006), (RVF 2005b). Liquid waste such as manure is pumped from the truck or pipeline into storage tanks. Screws and pumps in the bunker are moving the liquid waste into the mixer.

After pre-treatment in the receiving hall the organic waste is transported to mixers and homogenised. The purpose of the mixers is to create a suspension suitable for the digestion process. The incoming waste is mixed with process water which creates a homogenous suspension with a dry matter content of 8 – 10 %. Afterwards it is following another intensified sizing and comminution pre-treatment process. To reduce the particle size in the suspension a separator device such as sand tanks and screen rakes are used. Afterwards the suspension is pumped to the suspension buffer tank for temporary storage. From the buffer tank the suspension is pumped to the sanitation mixer. Pathogenic micro-organisms are there removed in a sanitation/pasteurization step which heats the material to 70 °C for one hour or 55 °C for 10 hours if waste is treated in combination at thermophilic reactor temperatures (55 °C) before entering the reactor (Växtkraft, 2006); (Tafdrup, 1995). During this process laughing gas and sulphur compounds are formed (RVF, 2005b).

2.3 Anaerobic and co-anaerobic digestion technology

Currently co-digestion is implemented in Sweden at about 10 biogas plants (Lantz, 2006). Centralized biogas plants are treating manure from several farms, in combination with other organic waste, such as food and slaughterhouse waste and the organic fraction of source-sorted household waste. (Angelidaki, Boe, Ellegaard, 2005). Co-digestion can be realised in different reactors. In one-stage reactor systems digestion takes place in a single reactor, while in two- or multi-stage systems, the reactions take place sequentially in at least two stage reactors (Lissens et al, 2001). In two- and multi-stage systems the overall conversion process of organic substrate to biogas is mediated by a sequence of biochemical reactions which do not necessarily share the same optimal environmental conditions (Lissens et al, 2001). Optimizing these reactions separately in different stages or reactors may lead to a larger overall reaction rate and biogas yield (Ghosh et al., 2000). However, the main

advantage of a two-stage system is not the higher biogas yield or rate, but rather its increased biological stability for waste which causing unstable performance in one-stage systems (Lissens et al, 2001).

In Europe about 90% of the full-scale plants in use, rely on anaerobic digestion in a one-stage system. The domination of the one-stage systems is related to lower costs compared to two-stage system (Lissens et al, 2001). In “wet” complete mix systems the organic solid waste is diluted with water by pulping and slurry to less than 15% total solids. Consequently, digesters of the continuous stirred tank reactor type (CSTR) are mostly used in this type of application (Lissens et al, 2001). In Sweden the most frequent reactor technology is a one way continuous stirred based single-stage tank reactor (Lantz, 2006).

Other reactor technology enables higher rates of treatment for one step reactors. Improvements on the acceleration of the slurry digestion process can be realised by high-temperature digestion (thermophilic) and enhanced monitoring and control (Angelidaki et al., 2005; Bouskova et al.,2005; Liu et al., 2004; Steyer et al.,1999).

2.4 Biological processes in the digestion reactor

The anaerobic digestion in the digestion reactor is accomplished by series of biochemical transformations, which can be roughly separated into four metabolic stages. First, particulate organic materials like cellulose, hemi cellulose, pectin, and lignin, must undergo liquefaction by extracellular enzymes before being taken up by acidogenic bacteria. The rate of hydrolysis is a function of factors, such as pH, temperature, composition, particle size of the substrate and high concentrations of intermediate products. After that, soluble organic components including the products of hydrolysis are converted into organic acids, alcohols, hydrogen, and carbon dioxide by acidogens. The products of the acidogenesis are then converted into acetic acid, hydrogen, and carbon dioxide. Finally methane is produced by methanogenic bacteria from acetic acid, hydrogen, and carbon dioxide as well as directly from other substrates of which formic acid and methanol are the most important (Bouallagui et al., 2005).

Biogas reactors at large scale biogas plants can be operated at different temperatures, usually mesophilic (approximately 30–37 °C) or thermophilic (approximately 55–65 °C), but also under psychrophilic conditions (<20 °C). In general, the higher the temperature, the faster the degradation and the more waste can be treated (Berglund, 2006). Disadvantage of higher temperature treatment is that more energy is consumed to keep the temperature stable (BiogaS international, 2007). Energy can either come from primary energy sources for

electricity production or can be produced internally from combined heat and electricity production. In case of primary energy sources net amounts of emissions emitted can be increased. However electricity produced internally from combined heat and electricity production with a high overall conversion reducing emissions (Börjesson, 2006).

In Sweden the raw materials are typically treated for some 20–30 days in the case of mesophilic conditions, and for a shorter period of 10-20 days time under thermophilic conditions (Berglund, 2006). Optimal Ph rate of carbohydrates are PH 5,5 - 6,0 and for proteins 7,0 - 7,5. The optimal conditions for methane production is a PH 7,5 - 8,5 (Biogas international, 2007). In batch systems all the raw material is added simultaneously, it should be mixed well to get a homogenous equally slurry which increases the digestion (Berglund, 2006). In addition the proportion of carbon and nitrogen can influence the efficiency of the process in the reactor as micro-organism use this for their metabolism (BiogaS international, 2007). A consequence of excessive amounts of nitrogen results in a reduction of micro-organisms and so production. On the other hand a low content of nitrogen results that no carbon is produced and affect the growth of the micro-organisms (BiogaS international, 2007).

2.5 Digestate and transport of digestate from the biogas plant

The effluent from the digester tank is separated into a solid and a liquid fraction by centrifuges. The liquid fraction from the centrifuges is initially stored in a process water buffer tank where process water is either recycled to the mixers or discharged in a storage basin. In order to avoid loss of volatile compounds to the atmosphere mainly the basin is covered. The liquid digestate has a dry matter content of approximately 2-3 %, and is primarily used by the farmers as a nitrogen fertilizer after being transported to the farms by trucks (Växtkraft, 2006); (RVF, 2005). The solid digestate has a dry matter content of 25 – 30 %. Solid digestate can be stored without any coverage or with coverage with a seal. It is assumed that emissions are released by open storage method, although further research should provide more evidence of the amount of emissions emitted during this storing process (RVF, 2005). Solid digestate is directly loaded into containers to be transported by trucks to the farmers where it is used as a phosphorus rich fertiliser for crop production (Växtkraft, 2006).

2.6 Upgrading of biogas and transport upgraded gas

The biogas produced can be utilised for different energy services depending on the price and the quality of biogas. For natural gas or vehicle fuel purposes biogas has to be upgraded in order to enrich or purify the gas from water and CO₂ content of the methane (Lantz, 2006). This is primarily achieved by carbon dioxide removal which then enhances the energy value. Removal of carbon dioxide and hydro sulphate also provides a consistent gas quality with

respect to energy value. The latter is regarded to be of great importance from the vehicle manufacturers in order to reach lower emissions (IEA, 2007).

The most common technology for biogas upgrading in Sweden is the water scrubber technology (SGC, 2004). The second most used technology is the PSA technology in Sweden (SGC, 2004). Water scrubbing is used to remove carbon dioxide, but also to remove hydrogen sulphide from biogas. The separation of these gases are based on physical aspects on solubility. As carbon dioxide and hydrogen sulphide gas are more soluble in water than methane, blending the biogas within the water tank will adsorb carbon dioxide and hydrogen sulphur in the water and leaving the methane. For the adsorption processes two commonly water scrubbing technologies for upgrading of gas are used; single pass absorption and regenerative absorption. The major difference between the two processes is that the water in the single pass process is used only once (SGC, 2004).

Pressure Swing Adsorption, or PSA, is a method for the separation of carbon dioxide from methane by adsorption/desorption of carbon dioxide on zeolites or activated carbon at different pressure levels (IAE, 2007, SGC, 2004). The adsorption material adsorbs hydrogen sulphide irreversibly and is thus poisoned by hydrogen sulphide. For this reason a hydrogen sulphide removing step is often included in the PSA process. Other technologies used for biogas upgrading in Sweden is the membrane technology. The membrane technology has a potential to be energy efficient and is used to separate the gasses. However in Sweden this technology is limited used (SGC, 2004). Chemical adsorption technologies based on physical adsorption seem to be an attractive solution due to low methane losses and high selectivity. However the process requires rather high input of thermal energy in the regeneration of the chemical, but can on the other hand be operated on low pressure that reduces the electrical energy demand of the process (SGC, 2004).

Different upgrading technologies have several advantages among each other in terms of using resources as water and chemicals, level of emission and efficiency. For PSA it can be mentioned that it removes higher concentrates of the sulphide and water in the upgraded gas. In addition PSA does not imply any use of chemicals and it does not demand any access to water. The advantage with water wash with or without regeneration is that it does not imply any use of chemicals and there is great experience of the techniques in Sweden. Chemical adsorption technology including selexol implies the use of chemicals. The need for electricity to upgrade biogas with chemical reaction is less than for the other techniques, because gas that is separated is not compressed. Another advantage with chemical reaction is that it implies small losses of methane since the chemical selectively reacts with carbon

dioxide. Losses of CH₄ during upgrading and pressurisation of the biogas have been reported to correspond to 0.2–2% for PSA and water scrubbing. In some cases the losses are even up to 10-13% of the total amount of gas treated at the upgrading plant for selexol and regenerative absorption water scrubbing method. The degree of losses can be due to the upgrading technology, the required CH₄ content of the upgraded gas and occasional uncontrolled leakages (Persson, 2003).

After the gas is upgraded it is led to the gas storage where it either can be transported by tank trucks or pipelines depending on transport infrastructure available in Sweden (Johansson and Nilsson, 2007).

Biogas not upgraded is used for production of electricity and heat in a separate plant. In case of malfunctioning in the gas upgrading plant or fuel station, the excesses gas is flared in order to avoid any release of methane gas to the atmosphere (Växtkraft, 2006).

3 A review of economical and environmental variables affecting biogas systems

3.1 Economics of biogas systems

Literature on the economics of biogas systems is varied and based on different objects of research. This can be the scale of the plant, the country where the study has been done, the variables analysed and the perspective of modelling. A review of relevant studies about the economics of biogas plants is provided in this chapter following the structure of figure 3 which provide an overview on processes of biogas production. Shortly the aim, assumptions, variables, results and conclusions are discussed. The studies will be used partly to explain differences in profitability in this study. In addition the levels of profit are compared with international studies. Table 6 summarizes the studies at end of the chapter.

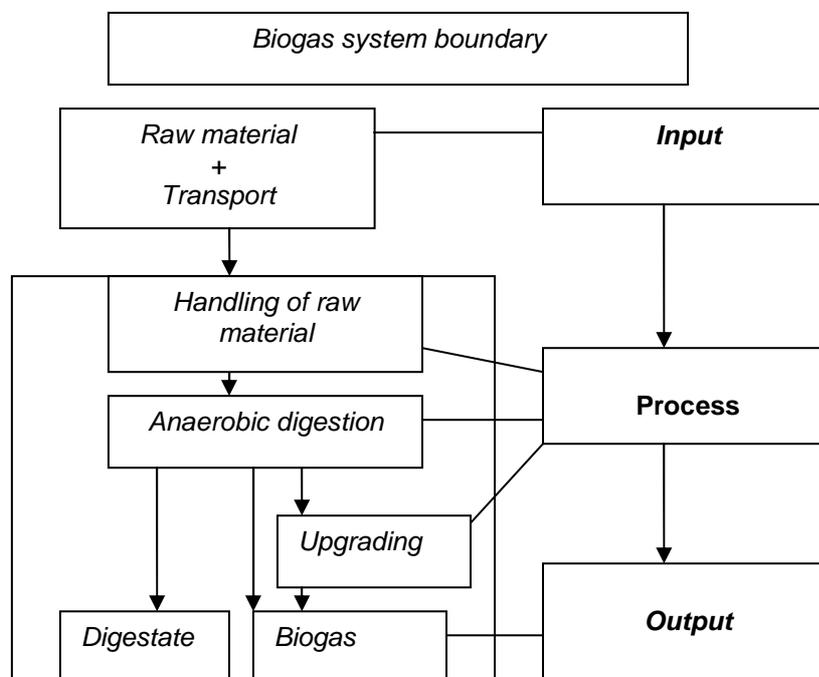


Figure 3: Processes of biogas production

3.2 Variables affecting differences in the economics of the biogas production process

The cost of transportation in the production of biogas at farm levels in Sweden was studied in a case study by Johansson and Nilsson, (2007). The method of study was to collect data about different transport alternatives through a combination of literature studies and several personal contacts. A program to calculate the costs including level of emissions was created and tested on a real case in Skeagård near Hässleholm in the south of Sweden.

Results on the mode of transporting of substrate had the lowest cost 0.05 SEK/KWh by lorry (load capacity 40 m³) when transporting the substrate to a larger biogas plant. A pipeline had the second lowest cost 0.14 SEK/KWh and transport by tractor was the mode of transport with the highest cost 0.15-1.0.20 SEK/KWh. On short distances large amounts of substrate favours the alternative with an own biogas plant on each farm, while long distances and smaller amounts of substrate favours a common biogas plant in the area.

For transporting the biogas towards the utilized source results are opposite compared to the transport of substrate. In this case the lowest cost 0.03 SEK/KWh with and without upgrading is a pipeline when biogas is transported. The second alternative is to use a lorry with high pressure tanks with a cost of 0.05 SEK/KWh. Transport distances are reported to vary between approximately 3 up to 15 kilometres between supplier and the biogas (km) and in some cases up to 25 km between the farm and biogas plant (Börjesson, 2006)

A study by Berglund, (2006) on biogas production from a systems analytical perspective highlights related issues to the economics of biogas production in general, instead of providing exact figures on the economical outcome of biogas production. Highlights are based on literature studies and the study elaborates on gate fees from plants, revenues, costs of digestate and costs of upgraded biogas. These highlights are shortly described.

The gate fees vary considerably between different categories of waste and between biogas plants in Sweden (NV, 2005). The gate fees for household waste at some biogas plants are reported to be approximately SEK500–750 per ton, and for various categories of slaughterhouse waste SEK50–300 per ton (NV, 2005). The gate fees are partly determined by the alternative cost of treatment of the waste; the cost associated with the delivery of waste to combustion plants in Sweden. Assuming a gate fee of SEK600 per ton of organic household waste and a biogas yield of approximately 1 MWh per ton, results in a revenue of SEK 0.60/kWh of biogas. Costs for upgrading the biogas, are reported to range from approximately SEK0.10–0.20, up to SEK0.40 per kWh of purified biogas for some Swedish upgrading plants (Persson, 2003). Most digestate intended for agriculture are delivered for free to the farmers. In cases when the farmers are charged, the price may be based on the content of plant nutrients and the price for chemical fertilizers (Berglund, 2006).

3.3 Economical feasibility of biogas production: a study review

A Danish study have been analysing the socio-economical results from centralised biogas plants on a corporate level. The study from Mæng, Lund and Hvelplund from 1999 is a review study of an empirical study from the Risø institute in 1991 and the Aarhus University in 1992. The focus of the study from the Risø institute is about the social-economical feasibility on a corporate level. The socio-economic calculations from the Risø institute are elaborated as present-value comparisons over a time horizon of 20 years for three different existing biogas plants: the Fangel, Davinde and Lintrup biogas plants. The prices used in the calculations are market prices exclusive of value added tax and energy taxes. The price prognoses, used for fossil fuels, are based upon the official prognoses from the Danish Ministry of Energy. The conclusion based on calculations were that the projects are not socio-economically feasible due to a negative present value including and excluding environmental costs of emission such as SO₂, NO₂ and CO₂ (Table 4). Reasons why the projects are not socio-economical feasible are not provided in the study review.

Table 4: Results on present value and annual surplus from the Risø study, 1991

Million DKK	Fangel	Davinde	Lintrup
Investment	26.7	4.3	45.2
Present value	-15.2	-5.1	-26.8
Annual surplus – environmental costs	-1.4	-0.5	-2.5
Annual surplus + environmental costs	-0.9	-0.4	-2.2

A study by Braun, (2002) highlighted the economical feasibility of centralised biogas plants by a Danish study by Hjort-Gregersen, (1999). The large scale biogas plant had a range of digester volume of 4,650 – 6,000 m³. It appeared that from a sample of 17 large-scale Danish centralized biogas plants 5 installations were classified acceptable, 5 balanced at “break-even”, 3 were qualified as “under pressure” and 4 as “economically unsatisfactory”. Further distribution of anaerobic digestion and co-digestion is adversely influenced by the currently restrictive legislation on allowable wastes and the restricted reuse of digestate. Unfavourable economics are further caused by reduced or missing gate fees obtainable for the wastes treated (Braun, 2002).

An Irish study on the economical feasibility of biogas production has been done by Murphy, and McCarthy (2005). Two different sizes of plants were analysed from a technical, economical and environmental perspective with the method of literature studies and sensitivity modelling. Two plants producing 3,200,000 m³ per year of CH₄-enriched biogas and a plant producing 1,600,000 m³ per annum of CH₄-enriched biogas were part of the

analyses. The larger plant of 3,200,000 m³ is assumed to correspond to the typical large centralised aerobic digestion plants in Denmark and Sweden in terms of capacity treatment.

Two technologies were assumed in this study, these are centralised aerobic digestion (CAD) and dry anaerobic combustion (DRANCO). Further on there was a distinguishing made which energy sources are used for either centralised anaerobic digestion (CAD) or dry anaerobic combustion process (DRANCO). Both digestion technologies are digesting pig slurry and organic fraction of municipal solid waste (OFMSW).

For the purpose of this analysis it is assumed that pig slurry generates 26 m³ biogas/ton and organic fraction of municipal solid waste generates 128 m³ biogas/ton. The biogas is assumed to have a 55.5% methane yield and an energy value of 21 MJ/Nm³; thus the destruction of 1 kg of volatile dry solids at an energy value of 21 MJ/kg generates 1 m³ of biogas. Slurry transportation is assumed to be by vacuum tanker. A gate fee of €150/ton organic fraction of municipal solid waste is utilised. The revenue from CH₄-enriched biogas utilised is assumed to be €0.65/Nm³. The amount of biomass used and biogas produced is 68.966 ton biomass and 3.008.000 m³ biogas is used. Results indicate that biogas production was profitable at centralised aerobic digestion plants (Table 5).

Table 5: Costs, revenues and profits of centralised anaerobic digestion plants in Ireland

CAD plant using different energy sources	Green energy use	CHP plant for energy use
Operating cost including capital costs	€1.67 Million	€1.50 Million
Revenues	€2.92 Million	€2.72 Million
Profit	€1.25 Million	€1.22 Million

Table 6: Summary of relevant economical indicators on economics of biogas plants

Scale and country	Method and data	Variable of study	Results	Author(s)
Transport to a large scale biogas plant Sweden	Literature, model calculation and interviews	<ul style="list-style-type: none"> • Transport mean • Average transport distances 	<ul style="list-style-type: none"> • Lowest cost by lorry (40m³), second lowest cost by pipeline and third lowest a tractor • 3-25 km. 	Johansson and Nilsson, 2007
Large biogas-Plant Sweden	Reviews of literature on Life Cycle Analysis(LCA)	<ul style="list-style-type: none"> • Input(gate fees) • Production costs • Cost of upgrading 	<ul style="list-style-type: none"> • Household waste SEK 500–750 per ton/kg, Slaughterhouse waste SEK50–300 per ton/kg (NV, 2005). • 0.60/kWh¹. • Biogas fuel SEK 0.10-0.40 per KWh of purified gas. 	Berglund, 2006a
Large scale biogas plants, Denmark	Empirical data from 20 biogas factories over the years 1984-1996 and the Danish energy institute. Present value method	<ul style="list-style-type: none"> • Investment cost, present value revenues and environmental costs 	Results of the Risø ⁴ socio-economic calculations showed that biogas was not feasible. Present value for three plants are between a range of -5.1 up to -26.6	Mæng, Lund, Hvelplund, 1999
Large scale biogas plants, Denmark	Survey data from biogas plants in Denmark. Level of economical feasibility for 17 biogas plants in Denmark	<ul style="list-style-type: none"> • Economical feasibility of biogas plants(profit) 	<ul style="list-style-type: none"> • 5 factories economical feasible • 4 factories break even • 3 under pressure • 4 economical not satisfactory 	Braun, 2002
Large scale biogas plants(3,200,000 m ³ and 1 600 000 m ³) Ireland	Literature Sensitivity modelling	<ul style="list-style-type: none"> • Operational costs including capital costs • Profit 	<ul style="list-style-type: none"> • Profit of €1.50-€1.67 Million (3 200 000 m³) • Profit €1.22-€1.25 Million (1 600 000m³) 	Murphy, McCarthy, 2005

¹ Assuming a gate fee of SEK 600 per ton/kg of organic household waste and a biogas yield of approximately 1 MWh per ton. (Berglund, 2006A).

3.4 Environmental impact of biogas systems

Several factors influence the environmental impact of biogas production. These are the raw materials available, the handling of raw material, the anaerobic digestion process the use of primary energy, upgrading and the use and disposal of the biogas and digestate. Figure 4 is based on a literature study from Berglund (2006) and shows an overview of a bounded biogas system for biogas production. During processes in the biogas system emissions are released. In this chapter studies are reviewed about factors affecting the different level of emissions and are used to explain some differences in levels of emission in this study. Previous studies have been analysing the environmental impact of different biogas systems on inputs, processes and outputs. Emissions which have been studied in the biogas system are: carbon dioxide (CO₂), carbon monoxide (CO), nitrogen oxides (NO_x), sulphur dioxide (SO₂), hydrocarbons (HC), methane (CH₄) and particles. Methods used for analysing are life cycle analysis Ishikawa et, al, (2006) model studies Sundqvist, (2002) and literature studies Börjesson, (2006). Table 8 will provide a summary on the described studies reviewed at the end of this paragraph.

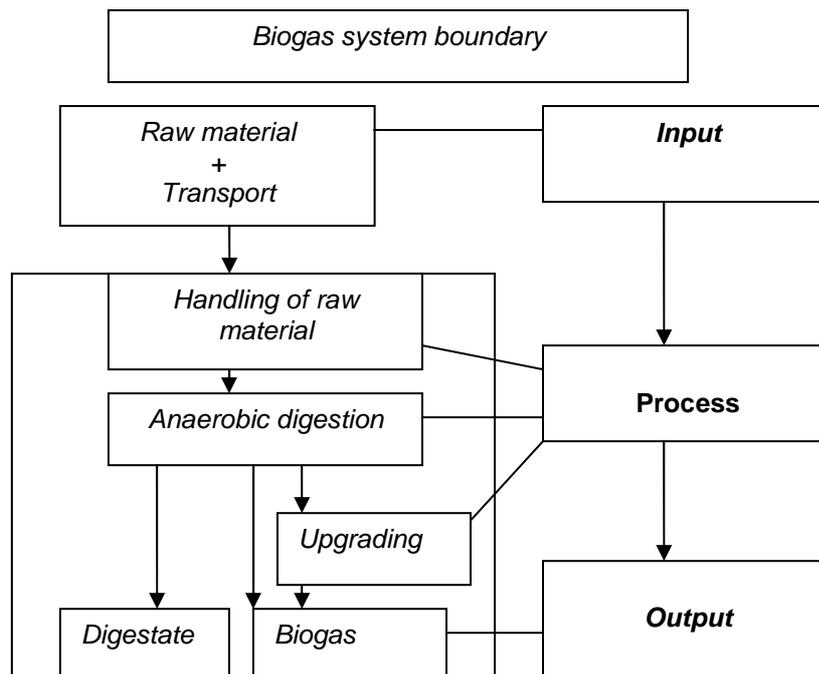


Figure 4: A bounded biogas emission analysis system for biogas production

Börjesson, 2006 evaluated the fuel-cycle emissions from a biogas system in Sweden. The fuel-cycle emissions include emissions from the production and the end use of the biogas. The calculations were done at large-scale and farm-scale biogas production level. The emissions studied included carbon dioxide of fossil origin, carbon monoxide (CO), nitrogen oxides (NO_x), sulphur dioxide (SO₂), hydrocarbons (HC), methane (CH₄) and particles. The

calculations included emissions from the production chain for energy carriers and chemical fertilizers.

Main conclusions for the large scale biogas plant were that emissions from the production of biogas can vary greatly. The contribution of various operations to the total emissions varies between emission categories. However, most CO₂ emissions normally originate from the operation of the biogas plants and the upgrading of the biogas. These emissions are mainly the result of the electricity production, assumed to be based on natural gas. If other primary energy sources are used in the electricity production, the net CO₂ emissions will be affected significantly. The need of extensive pre-treatment handling of the raw materials affects the level of CO₂ emissions. Household waste needs more pre-treatment than liquid waste. More energy use is subject to this. If energy is used from primary sources more emissions are released.

Production of fertilisers corresponds to 50% up to 70% of the net emissions of SO₂ and particles. This is related to a biogas system based on ley crops, of which the main part comes from the production of phosphorous fertiliser. If digestate can replace some of the chemical fertilisers, the emissions will decrease.

The end-use emissions accounts for the highest contribution to the fuel-cycle emissions concerning emissions of particles, or emission from biogas based on various waste products such as household waste. For example methane (CH₄) constitutes the energy-carrying component in biogas, but it is also a potent greenhouse gas. From a climate change perspective, the emission of one kilogram of CH₄ to the atmosphere is comparable to the emission of about 20 kilograms of CO₂ (Berglund, 2006). During the storing of digestate, un-combusted biogas to the air during occasional excess production and upgrading uncontrolled losses of methane can occur. Losses reported of methane during the upgrading and pressurisation normally correspond to less than 2% of the biogas purified, but may vary between 0.2% and 11–13%. (Persson, 2003). Differences depend on the upgrading technology used, the required methane content of the upgraded gas, and occasional uncontrolled leakages. To limit these losses, it is crucial to collect the biogas produced during storage, or to purify any excess gas in a compost filter (Börjesson, 2006).

Concerning the environmental impact of biogas transport the case study by Johansson and Nilsson, 2007 mention different levels of CO₂ equivalent emissions by means of transport. The method of study was to collect data about different transport alternatives through a combination of literature studies and several personal contacts. A program to calculate the

costs and level of emissions was created and tested on a real case in Skeagård near Hässleholm in the south of Sweden. The environmental impacts through emissions are lowest when the substrate and digestate is transported by pipeline. The second best alternative from this point of view is the lorry and the worst is the tractor.

In Japan a study was made to compare an on-farm biogas plant with a centralized biogas plant from the energetic point of view by Ishikawa, Hoshiba, Hinata, Hishinuma, Morita, (2006). The basic data for this evaluation were obtained from the centralized biogas plant in Betsukai, Hokkaido. Setting condition on the centralized biogas plant are described in table 7.

Table 7: Setting conditions of analysed centralized biogas plant

Organic waste	Manure of dairy cows with a dry matter content of 10%.
Quantity of raw slurry	50 m ³ /day
Temperature of digester	35 degrees (mesophilic)
Retention time	30 days
Rate of biogas production	30m ³ / m ³
Methane concentration	60%
Calorific value of methane	36MJ/ m ³

Life cycle assessment (LCA) was used to estimate the emissions of CO₂ released. The evaluation range of this study was based on energy inputs including processes as constructing, transport, product use and waste treatment. The amount of emissions released were about 2700 ton CO₂, however 80% of the CO₂ emissions were related by the energy investment of the biogas plant. The other 17% accounts for operating, maintaining the biogas plant. Carbon dioxide exhausted from the fuel by the collection of raw materials and transportation for digested manure was only 3%.

The production of CO₂ at the time of biogas combustion (1080t) was not included in emission because of the concept of carbon neutral.

Table 8: Summary of the factors affecting the level of emissions of different biogas systems

Scale and country	Method and data	Variables	Results	Author
Large biogas Plant Sweden	Review literature and life cycle analysis(LCA)	<ul style="list-style-type: none"> Emissions of biogas systems studied on inputs, process and output of a biogas system 	<ul style="list-style-type: none"> Emission from the production of biogas can vary greatly between biogas systems. Emissions are result of primary electricity production Household waste causing higher emissions due to higher energy use Losses reported of methane during the upgrading and pressurisation normally correspond to less than 2% of the biogas purified, but may vary between 0.2% and 11–13% 	Börjesson, 2006
Transport to a large scale biogas plant Sweden	Literature, model calculation and interviews	<ul style="list-style-type: none"> CO₂ equivalents 	<ul style="list-style-type: none"> The environmental impacts through emissions are lowest when the substrate and digestate is transported by pipeline. The second best alternative from this point of view is the lorry and the worst is tractor. 	Johansson and Nilsson, 2007
Large scale test biogas plant Japan	Life cycle analysis(LCA)	<ul style="list-style-type: none"> CO₂ 	<ul style="list-style-type: none"> Estimated emission of CO₂ was about 2700 ton/kg. 1080 ton/kg of CO₂ production related to biogas combustion was not included, due to the concept of carbon neutral. 	Ishikawa , Hoshiba, Hinata, Hishinuma, Morita, 2006

4 Materials and methods

Several studies exist to analyse the economical feasibility of biogas plants. Two common methods used in European studies described in chapter 3 are (1) sensitivity modelling based on scenarios and (2) the net present value method calculating the present value of future cash flows. This study does not use the method of sensitivity modelling or the net present value. However a simulation with a profit function model based on collected empirical data, statistical data and literature assumptions is done to analyse the profitability for biogas plants in Sweden for the years 2004-2006.

The profitability of biogas plants is calculated with the profit function $\pi = pq-wx-ev$ according to Nicholson (2004). The level of emissions in the profit function model are based on a literature study that describes per waste type the level of emissions of operational large-scale biogas plants in Sweden by Börjesson, (2006). Related prices of emissions are used from the study of Sundqvist et, al (2002). This study used the ORWARE model which is a simulation model for waste management. The simulation model is based on the life cycle analysis methodology and was applied to estimate the level of emissions and prices for anaerobic digestion treatment at operational plants.

The selected items to exemplify revenues and costs included in the profit function are based on the study of Braun (2002) and Hjort-Gregersen (2003). These studies analysed the economics of biogas plants in Denmark as similar profit studies on large biogas plants are not present for Sweden. These Danish studies describe essential costs and revenues of biogas production further described in table 9.

4.1 Profit function model

The biogas plant i produces with collected waste several outputs. The waste originated from households, food industry and farms. The output (q) is demanded by the heating sector, industry of biogas vehicles or energy producers. The prices of the final biogas product are market prices (p). Total revenues are the sum of revenues from gate fees, heat, gas and biogas. For converting a certain amount of waste, several inputs (x) are required. Inputs are transportation of substrate, transportation of digestate, labour, electricity, oil, gas, water and the amount of upgraded biogas. Costs are defined as input (x) multiplied with their price (w). The total costs are considered as the sum of all costs per plant. The emissions CO_2 , CH_4 and NO_x are used as cost items in the profit model. Emissions are simulated per ton of different type of waste digested per plant and year. These are defined as e_{co2} , e_{ch4} , e_{nox} and multiplied with the costs of the emission per waste type (v).

The profit function is described in figure 5 and table 9 provides an explanation of the variables of the profit function.

$$\pi_{it} = \sum_{i=1}^8 \sum_{t=1}^3 \left(p_{f,i} q_{w,itn} + p_{h,t} q_{h,it} + p_{g,t} q_{g,it} + p_{b,t} q_{b,it} \right) - \sum_{i=1}^8 \sum_{t=1}^3 \left(w_{ts,i} x_{ts,it} + w_{ds,i} x_{ds,it} + w_{lab,i} x_{lab,it} + w_{el,t} x_{el,it} + w_{oil,t} x_{oil,it} + w_{gas,t} x_{gas,it} + w_{wat,t} x_{wat,it} + w_t x_{upg,it} \right) - \sum_{i=1}^8 \sum_{t=3}^3 \left(e_{co2,it} v_{co2} + e_{ch4,it} v_{ch4} + e_{nox,it} v_{nox} \right)$$

$$e_{co2} = \sum_{n=1}^4 \left(co2_n q_{w,itn} \right)$$

$$e_{ch4} = \sum_{n=1}^4 \left(ch4_n q_{w,itn} \right)$$

$$e_{nox} = \sum_{n=1}^4 \left(nox_n q_{w,itn} \right)$$

Figure 5: Mathematical profit function

Table 9: Explanation of the variables of the profit function

$\sum_{i=1}^8$	Sum over plants 1-8
$\sum_{t=1}^3$	Years 1-3, year 1: 2004, year 2: 2005, year 3: 2006
$\sum_{n=1}^4$	Type of waste, waste 1: household, waste 2: organic industry waste 3: sludge 4: other waste
P_f	The price of gate fees per plant in SEK/ton
P_h	The market price of heat in SEK/MWh
P_g	The market price natural gas in SEK/MWh
P_b	The market price natural gas in SEK/MWh
Q_w	Quantities of total waste in ton
Q_h	Quantities of heat in MWh
Q_g	Quantities of gas in MWh
Q_b	Quantities of biogas in MWh
x_{ts}	The distance of substrate transport in ton/km
x_{ds}	The distance of digestate transport in ton/km
x_{lab}	The quantity of labour hours
x_{el}	The quantity of electricity used in MWh
x_{oil}	The quantity of oil used in MWh
x_{gas}	The quantity of gas used in MWh
x_{water}	The quantity of water in m3
$x_{upgrading}$	The amount of gas upgraded in Nm3
w_{ts}	The price of substrate transport in SEK/ton/km
w_{ds}	The price of digestate transport in SEK/ton/km

w_{lab}	The price of labour for a employee at a biogas plant in SEK per year
w_{el}	The market price of electricity in SEK/MWH
w_{oil}	The market price of oil in SEK/MWH
w_{gas}	The market price of gas in SEK/MWH
w_{water}	The market price of water in SEK/m ³
$w_{upgrading}$	The price of gas upgraded in SEK/KWH
E_{co2}	Level of emissions for CO ₂ in ton
E_{ch4}	Level of emissions for CH ₄ in kg
E_{nox}	Level of emissions for NO _x in kg
V_{co2}	Cost of emissions for CO ₂ in ton per SEK
V_{ch4}	Cost of emission for CH ₄ in kg per SEK
V_{nox}	Cost of emission for NO _x in kg per SEK

Figure 6 gives a graphical overview of the mathematical profit function. It shows how the profit is consisting of revenues and costs with it related quantities and prices.

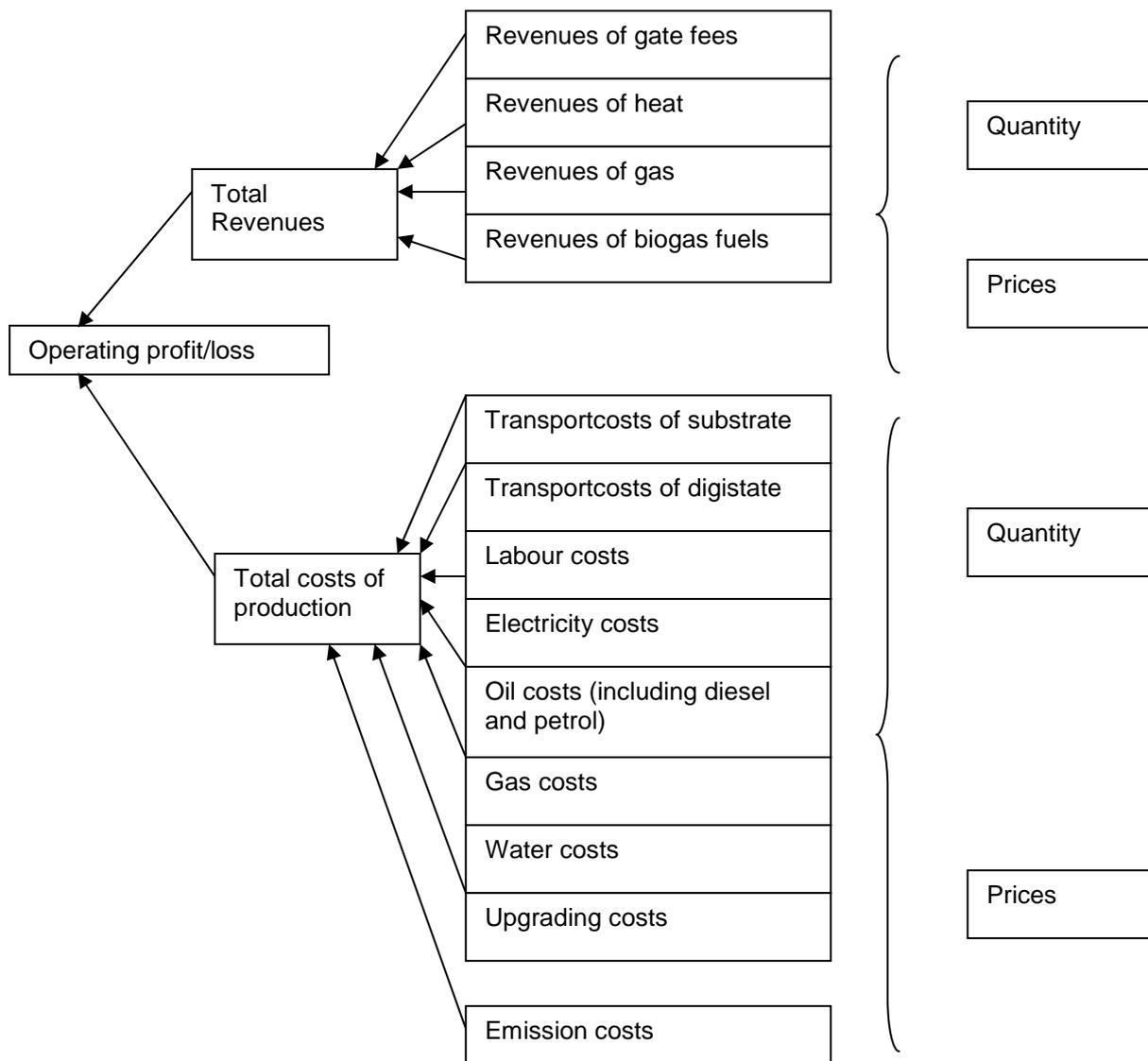


Figure 6: Overview of revenues and costs in the profit function model

4.2 Collection and description of data per biogas plant

Empirical data for the years 2004, 2005 and 2006 was collected at Swedish biogas plants during the months January and February of the year 2008. Seventeen biogas plants have been requested to cooperate. Reasons for not cooperating with the research were related to a lack of data due to malfunctions at the biogas plant, not available statistics or a lack of time to cooperate. Eight out of seventeen biogas plants provided eventually data. The plants of Uppsala, Kalmar, Göteborg, Huddinge and Borås provided their data for the years 2004-2006. The plants of Vetlanda, Boden and Linköping provided their data for the years 2005-2006.

The empirical dataset on amounts of waste quantities treated per year are based on the yearly environmental reports from the plants and figures on quantities of waste directly from the plants of Boden, Huddinge and Linköping. These empirical sources provided several figures on quantities of waste resources on household waste, food industry waste, slaughterhouse waste, manure, dry sludge and waste residues. It appeared that household waste is treated at every plant except the plants of Göteborg and Linköping. Industry waste is treated at all plants except the plant of Vetlanda. Only the plants of Göteborg and Boden are treating sludge. The total waste is calculated in ton as the sum of all waste per plant. The plants of Göteborg and Linköping are treating most of the waste on average. The plants of Boden, Kalmar and Borås are treating around 20.000 ton waste per year on average and the plants of Uppsala, Vetlanda and Huddinge plant are treating on average the smallest amounts of the sample.

Furthermore quantities of produced outputs of heat, gas and biogas for vehicle use are provided empirically based on the yearly environmental reports. In addition the gate fees per biogas plant are empirically provided. The prices of each revenue are based on commercial industry prices. Specific prices of revenues can be found in Appendix C. The average volumes for quantities on output per plant are described in Appendix C and D. It appeared that every plant have revenues from gate fees. Heat is produced and sold at every biogas plant except at the Göteborg plant. Gas for natural gas grid purposes is only produced at the Kalmar and Göteborg plant. Biogas for vehicle use is produced at the plants of Uppsala, Kalmar, Linköping and Borås. Total revenues are the sum of gate fees revenues, heat revenues, gas revenues and biogas for vehicle use revenues. On average the highest total revenues are from the Linköping plant. The lowest total revenues are present at the Vetlanda plant.

Data on quantities of inputs such as energy, labour and water have been empirically provided based on the yearly environmental reports. Data on upgrading costs, transport costs and emission costs are based on assumptions from literature. Appendix D provides an

overview of the exact average costs and related assumptions. Prices of water and energy are based on commercial industry prices. In appendix C prices of energy and water are described. The energy costs and water costs for the Linköping and Boden plant are simulated based on the plant of Kalmar. In addition the labour costs for the Boden plant are also simulated based on the plant of Kalmar. Simulation was needed as data on these costs were not provided. Upgrading costs have only been included at the plants where biogas is used as a vehicle fuel. These are the plants of Uppsala, Kalmar, Linköping and Borås. Total costs are the sum of transport, labour, energy, water, upgrading and emission costs. It appeared that the highest total average costs can be found at the Göteborg plant. The lowest average costs are present at the Vetlanda plant. In table 10 a summary of the data description is presented divided by 1000 SEK. Exact average costs and revenues including specific data are present in Appendix D.

Table 10: Summary data biogas plants

	Uppsala	Kalmar	Göteborg	Huddinge	Vetlanda	Boden	Linköping	Borås
Data years provided	2004-2006	2004-2006	2004-2006	2004-2006	2005-2006	2005-2006	2005-2006	2004-2006
Household waste	X	X		x	x	X		x
Industry waste	X	X	x	x		X	X	x
Sludge			x			X		
Total waste in ton	3.9	21.4	50.8	1.3	1.7	23.6	47.5	19.9
Gate fees	X	X	x	x	x	X	X	x
Heat	X	X		x	x	X	X	x
Gas		X	x					
Biogas	X	X					X	x
Total revenues in SEK	4 407	4 992	21 443	1 120	924	5 412	61 271	19 126
Transport	X	X	X	X	x	X	X	X
Labour	X	X	X	X	x		X	X
Energy	X	X	X	X	x			X
Water	X	X	X	X	x			X
Upgrading	X	X					X	X
Emission	X	X	X	X	x	X	X	X
Total costs in SEK	1 915	2 536	24 884	1 665	248	2 597	17 622	7 114

Table 11 provides the assumptions on gate fees, simulation, flaring, energy use of own produced biogas are used in the profit function model.

Table 11: Overview of assumptions in the profit functions

Variable	Assumptions
Gate fees	<ul style="list-style-type: none"> No different gate fees for different wastes have been calculated The average have been taken if gate fees are provided in a range
Natural gas upgrading	<ul style="list-style-type: none"> No upgrading costs for biogas used for natural gas purposes
Flaring	<ul style="list-style-type: none"> Costs of flaring are not calculated into the profit for all plants as flaring data was not provided by all plants
Energy use of own produced biogas	<ul style="list-style-type: none"> Own produced biogas used for electricity purposes of the plant are not calculated into the profit as this data was not provided by all plants.

4.3 Methodology

To explain which specific revenues or costs affecting the differences between plants and levels of profit between biogas plants independent t-tests are used. For each revenue or cost differences in means are tested between one plant compared to the other plants. Table 12 indicates which specific costs or revenues are tested between the plants.

Table 12: Specific revenues and costs tested between plants

Variables of costs	Transport costs	Energy costs Sum of oil, electricity and gas costs	Labour costs	Water costs	Upgrading costs	Emission costs
Variables of revenues	Gate fees	Heat revenues	Biogas revenues	Gas revenues		

Eight biogas plants are analyzed on each revenue and costs. The Uppsala is used as a reference plant to compare differences between the plants. This plant is chosen as their environmental reports provided most empirical information and is therefore most representative for the industry in this study.

1) The hypothesis to be tested is

H_0 : There is no difference in a revenue or a cost between plant A and B, $\bar{x}_A - \bar{x}_B = 0$

H_1 : There is a difference in a revenue or a cost between plant A and B, $\bar{x}_A - \bar{x}_B \neq 0$

2) The t-test significance level is $\alpha = 0.05\%$. However a two-tailed t-test is conducted and the significance level is $\alpha/2 = 0.025\%$.

Let n_A denote the years included for plant A (number of observations) and let \bar{x}_A and s_A denote the specific revenue or cost mean and the standard deviation specific of the revenue or cost for the provided years for plant A. Let n_B , \bar{x}_B and s_B denote the same definitions, but then for plant B. Furthermore the expected value of the difference on mean is $\bar{x}_A - \bar{x}_B$, $v = (n_A + n_B) - 2$ are the degrees of freedom and s is the pooled standard deviation of the sample. This is the estimate of a population's standard deviation σ obtained by combining or pooling standard deviation data from two or more samples in this case the plants.

3) The test statistic is defined as follows:

$$t = \frac{\bar{x}_A - \bar{x}_B}{s \sqrt{\frac{1}{n_A} + \frac{1}{n_B}}} \text{ where } s = \sqrt{\frac{(n_A - 1)s_A^2 + (n_B - 1)s_B^2}{(n_A + n_B) - 2}}$$

Assumptions: Independent samples from normal distributions with equal population variances.

4) The rejection area is

Reject H_0 if $|t| > t_{\alpha/2}$.

The $|t|$ is the absolute value of the t-statistic. The $t_{\alpha/2}$ is the value obtained from the t-student distribution based on the degrees of freedom v .

A higher t-statistic compared to the t-value leads to rejection of the null hypothesis. The interpretation of rejecting the null hypothesis is that there is evidence on differences in a revenue or a cost between biogas plants. Depending if the profit is explained at the revenue or cost side evidence on a difference in a revenue or a cost affecting also differences in profitability between plants. The acceptance of H_0 implies that there is no evidence on this revenue or cost and so not affecting a difference in profitability between plants.

5 Analyzing the differences between the biogas plants

In this chapter eight biogas plants will be described individually. The calculated profit costs and revenues per biogas plant year are given based on the profit function. Following sections analyse which specific costs or revenues are explaining the difference of profit between the years per biogas plant.

5.1 Results of the eight biogas plants.

The Uppsala plant

Table 13 provides an overview of the calculated revenues and costs for the years 2004-2006 based on the profit function model for the Uppsala plant.

Table 13: Calculated revenues and costs of the Uppsala plant

	2004	2005	2006	Average	Unit
Quantities of waste	4 551	4 642	2 712	3 968	Ton
Revenues					
Gate fees	2 730 600	2 785 200	1 627 200	2 381 000	SEK
Heat	21 276	63 981		42 629	SEK
Biogas	1 750 527	2 610 274	1 633 870	1 998 224	SEK
Total revenues	4 502 403	5 459 456	3 261 070	4 421 853	SEK
Costs					
Transport	91 871	112 253	86 672	96 932	SEK
Labour	984 000	1 008 000	1 032 000	1 008 000	SEK
Energy	287 877	367 184	492 835	382 632	SEK
Water	78 879	103 432	65 880	82 730	SEK
Upgrading	314 250	420 189	251 929	328 789	SEK
Emission	15 333	19 413	15 891	16 879	SEK
Total costs	1 772 210	2 030 471	1 945 207	1 915 963	SEK
Profit/Loss	2 730 193	3 428 985	1 315 863	2 491 681	SEK

The table shows that the Uppsala biogas plant is making a profit for all the years with the year 2005 as the highest profit year due to the higher biogas revenues for vehicle use. Gate fees and biogas for vehicle use appeared to be the highest revenues. Heat revenues are just a small part of the total revenues for the Uppsala plant. Labour and energy costs have the highest costs. Water and emission costs appeared to have the lowest costs.

The difference between the profit years is most probably related to the amount of waste treated. The difference of quantities treated has effect on the costs and the revenue side. For the revenue side the year 2006 shows a drop in the amount of total waste treated compared to the years 2004 and 2005. As gate fees revenues have been calculated as gate fees of waste multiplied with amount of total waste and it is assumed that gate fees stay constant for the years for this plant the difference are related to the amount of total waste treated. Also slightly lower revenues of biogas for vehicle use, no revenues of heat and

higher labour costs and energy costs explaining differences of the profit between the years 2004-2005 compared to the year 2006. Higher energy costs for the year 2006 compared to year 2004-2005 are related partly to the higher price of electricity described in appendix C as well as use of a higher use of electricity in 2006 (556 MWh) compare to 2005 (495 MWh). Higher demand for electricity was needed to construct a new part of the factory according to the environmental report of Uppsala in 2006⁴.

The Kalmar plant

Table 14 shows the calculated revenues and costs for the Kalmar plant. It appeared that all the years for the Kalmar plant are making a profit. Gate fees and heat are the highest revenues. The highest costs are labour costs and energy costs. Lower costs are for transport, water, biogas upgrading and emission costs. Differences in profit are related to the revenue side as the total costs are more similar between the years than the revenues. The higher gate fees and heat revenues are responsible for the highest profit in the year 2005 and are explaining the differences in the profit between the years. The costs are not fluctuating much between the years except for energy costs. These are increasing at least with 400.000 SEK in the year 2006 compared to the years 2004 and 2005. These are related to the higher prices of gas and electricity for the year 2006 present in appendix C as quantity units of these energy sources stay equal through the years according to the environmental reports of Kalmar⁵. The higher energy costs are slightly compensated with lower water costs for 2006 compared to the years 2004-2005.

Table 14: Calculated revenues and costs of the Kalmar plant

	2004	2005	2006	average	Unit
Quantities of waste	21 000	22 000	21 200	21 400	Ton
Revenues					
Gate fees	3 100 000	4 000 000	3 200 000	3 433 333	SEK
Heat	909 975	1 608 836	2 219 831	909 975	SEK
Gas	144 529	149 386		146 958	SEK
Biogas	299 541	241 469	1 322 619	621 210	SEK
Total revenues	4 454 045	5 999 691	4 522 619	4 992 118	SEK
Costs					
Transport	183 374	194 379	192 367	190 040	SEK
Labour	800 000	800 000	800 000	800 000	SEK
Energy	1 112 325	1 141 606	1 560 778	1 271 570	SEK
Water	172 000	164 850	144 315	160 388	SEK
Upgrading	50 188	38 871	203 936	97 665	SEK
Emission	42 890	44 933	43 291	43 705	SEK
Total costs	2 360 777	2 384 639	2 944 688	2 563 368	SEK
Profit/Loss	2 093 268	3 615 052	1 577 931	2 428 750	SEK

⁴ Miljörapporter 2004, 2005, 2006. Biogasanläggningen vid Kungsängens gård Uppsala

⁵ Miljörapporter 2004, 2005, 2006. Biogasanläggning Kalmar

The Boden plant

In table 15 calculated revenues, costs and profit of the Boden plant are described. The Boden plant is profitable for the years 2005 and 2006. Differences in the profit are related to the revenue side. Gate fees revenues have the highest revenue, although heat revenues increasing the profit between 2005 and 2006. The energy, labour and water costs have been assumed from the Kalmar plant as this information was not provided by the Boden plant. The costs of the Kalmar plant were chosen based on the nearest capacity treatment of the Boden plant. It appeared that the labour and energy costs had the highest costs between the years. Costs are increasing for energy and emissions between the years 2006 and 2005. The related increasement of cost for energy are related to the higher prices of gas and electricity for the year 2006 present in appendix C. Quantity units of these energy sources stay equal through the years according to the environmental reports of Kalmar⁶ and so prices are the influential factor. The higher level of emission is due to a higher amount of household waste treated in the year 2006 compared to the year 2005 according to collected data from the Boden plant. As household waste have the highest emission level according to appendix D and a higher quantity is used for household waste total costs of emissions increased.

Table 15: Calculated revenues and costs of the Boden plant

	2005	2006	average	Unit
Quantities of waste	24 140	23 100	23 620	Tons
Revenues				
Gate fees	3 621 000	3 465 000	3 543 000	SEK
Heat	1 305 417	2 433 162	1 869 289	SEK
<u>Total revenues</u>	4 926 417	5 898.162	5 412 289	SEK
Costs				
Transport	202 776	194 040	198 408	SEK
Labour	800 000	800 000	800 000	SEK
Energy	1 141 606	1.560 778	1 351 192	SEK
Water	164 850	144 315	154 583	SEK
Emission	77 837	117 261	97 549	SEK
<u>Total costs</u>	2 315 608	2 349 655	2 761 145	SEK
Profit/Loss	2 548 083	3 081 768	2 814 926	SEK

The Linköping plant

According to table16 the Linköping plant is making a profit and the main revenues are related to biogas revenues for vehicle fuel use. The energy, labour and water costs have been assumed from the Kalmar plant as this information was not provided by the Linköping plant. These costs are double calculated for the Linköping plant as the doubled amount of waste is

⁶ Miljörapporter, 2004, 2005, 2006. Biogasanläggning Kalmar

approximately treated at the Linköping plant. It appeared that labour and energy costs had the highest costs between the years. Besides water costs all other costs are increasing between the years 2005 and 2006. The highest costs are labour and energy costs for this plant. Lower costs are present with transport, water and emission. Higher costs for the year 2006 compared to the year 2005 are related to higher amount of waste treated. For energy costs it is related to the increasing energy prices between the year 2005 and 2006. The related increasement of costs for energy are related to the higher prices of gas and electricity for the year 2006 present in appendix C as quantity units of these energy sources stay equal through the years according to the environmental reports of Kalmar. The difference in profit is mostly related to the revenue side. The higher quantity of biogas revenues for vehicle use is the most influential factor increasing the profit.

Table 16: Calculated revenues and costs of the Linköping plant

	2005	2006	average	Unit
Quantities of waste	44 336	50 681	47 509	Ton
Revenues				
Gate fees	6 096 200	6 968 638	6 532 419	SEK
Heat	2 154 945		2 154 945	SEK
Biogas	47 276 941	60 045 593	53 661 267	SEK
Total revenues	55 528 086	67 014 230	61 271 158	SEK
Costs				
Transport	922 000	2 231 000	1 576 500	SEK
Labour	3 771 000	5 237 000	4 504 000	SEK
Energy	2 283 212	3 104 552	2 693 882	SEK
Water	329 700	288 630	309 165	SEK
Upgrading	7 610 407	9 258 511	8 434 459	SEK
Emission	88 051	121 700	104 876	SEK
Total costs	15 004 370	20 241 393	17 622 882	SEK
Profit/Loss	40 523 716	46 772 837	43 648 276	SEK

The Huddinge plant

Table 17 provides a calculation about revenues and costs of the Huddinge plant. The Huddinge plant is processing a small amount of waste compared to the other plants except the plant of Vetlanda. It appears that the profitability is negative for all years. Highest revenues are from gate fees revenues through the plant years. Highest costs are the transport and labour costs. The high transport costs are related to empirical data provided by the plant on transport costs. The plant mentioned 70 SEK/ton/km for truck costs. The assumption used for substrate transport costs in this study is 0.56 SEK/ton/km by Johansson and Nillsson, (2007). This assumption is certainly lower and explaining the main part of higher transport costs. In addition the distance of digestrate is 20 km for the Huddinge plant compared to 10 km assumed in this study. This also increases the transport costs.

Difference in losses are most likely related to higher transport costs. However higher amounts of waste and transport costs are compensated with a higher revenue from gate fees.

Table 17: Calculated revenues and costs of the Huddinge plant

	2004	2005	2006	average	Unit
Quantities of waste	665	534	2 745	1315	Ton
Revenues					
Gate fees	382 375	307 050	1 578 375	755 933	SEK
Heat	124 110	155 228	813 550	364 296	SEK
<u>Total revenues</u>	<u>506 485</u>	<u>462 278</u>	<u>2 391 925</u>	<u>1 120 229</u>	SEK
Costs					
Transport	638 344	507 942	2 472 232	1 206 173	SEK
Labour	295200	302 400	309600	302 400	SEK
Energy	90 250	105 300	176 475	124 008	SEK
Water	98 599	11 492	65 880	29 077	SEK
Emission	2 082	1 758	6 726	3 522	SEK
<u>Total costs</u>	<u>1 035 736</u>	<u>928 893</u>	<u>3 030 913</u>	<u>1.665 181</u>	SEK
Profit/Loss	-529 251	-466 615	-638 988	-544 952	SEK

The Göteborg plant

The plant of Göteborg works with a different transport system than the other biogas plants. It is a special biogas plant to produce biogas, as the sludge is derived from the municipal waste water treatment which is transported by tunnels. This sludge is dried and combined with a relatively small amount of organic waste. After treatment the biogas is stored in a gas silo and mainly sold to Göteborg energi.

Table 18 provides an overview about the profit calculation of the Göteborg plant. It appeared that the profitability of this plant is negative for all the biogas plant years. According to the factsheet of this plant for the year 2004 and 2005⁷ a negative profit i.e. a loss was also present. Highest revenues are related to gas and gate fees revenues. Highest costs are transport costs. As the length of the tunnel system at the Göteborg plant is 120 kilometres according to its environmental report⁸ the transport costs are high. Furthermore the energy costs are high and fluctuating between the years. This is due to the amount of quantities of electricity used according to the environmental report and the difference of electricity prices between the years present in Appendix C. Emission and water costs are also fluctuating between the years 2004-2005 compared to the year 2006, although no specific reason can be appointed.

⁷ Factsheet 2004, 2005 Gryaab (Göteborg plant)

⁸ Miljörapporter 2004, 2005, 2006 Gryaab (Göteborg plant)

Table 18: Calculated revenues and costs of the Göteborg plant

	2004	2005	2006	average	Unit
Quantities of waste	51 163	51 126	50 142	50 810	Ton
Revenues					
Gate fees	8 186 080	8 180 160	8 022 720	8 129 653	SEK
Gas	8 753 500	11 437 600	19 750 800	13 313 967	SEK
<u>Total revenues</u>	<u>16 939 580</u>	<u>19 617 760</u>	<u>27 773 520</u>	<u>21 443 620</u>	SEK
Costs					
Transport	3 900 000	3 700 000	6 100 000	4 566 667	SEK
Labour	864 000	864 000	864 000	864 000	SEK
Energy	17 480 000	12 425 400	18 591 042	16 165 481	SEK
Water	3 253 242	3 149 263	2 617 665	3 006 723	SEK
Emission	303 729	337 318	191 685	277 577	SEK
<u>Total costs</u>	<u>25 804 441</u>	<u>20 479 644</u>	<u>28 368 298</u>	<u>24 884 127</u>	SEK
Profit/Loss	<u>-8 864 861</u>	<u>-861 884</u>	<u>-594 778</u>	<u>-3 440 507</u>	SEK

The Vetlanda plant

Table 19 gives an overview of the calculated costs and revenues for the Vetlanda plant. Main revenues come from gate fees and explaining the difference in profit between the years. The change of gate fees revenues are related to quantities as the gate fees assumed to be constant through the years for this plant. Highest costs are found at the labour and water costs. Energy costs are relatively low compared to the other plants. The plant is making a profit for all the years.

Table 19: Calculated revenues and costs of the Vetlanda plant

	2005	2006	average	Unit
Quantities of waste	1 300	2 000	1 650	Ton
Revenues				
Gate fees	715 000	1 100 000	907 500	SEK
Heat	16308	17 438	16 873	SEK
<u>Total revenues</u>	<u>731 308</u>	<u>1 117 438</u>	<u>924 373</u>	SEK
Costs				
Transport	10 920	16 800	13 860	SEK
Labour	180 000	180 000	180 000	SEK
Energy	948	1 466	1 207	SEK
Water	25 858	52 704	39 281	SEK
Emission	11 073	17 035	14 054	SEK
<u>Total costs</u>	<u>228 798</u>	<u>268005</u>	<u>248 402</u>	SEK
Profit/Loss	<u>502 510</u>	<u>849 432</u>	<u>675 971</u>	SEK

The Borås plant

Table 20 gives an overview of the costs and revenues for the Borås plant. The plant is making a profit throughout the years. Gate fees and biogas appeared to have the highest revenues. Labour and energy have the highest costs. Furthermore the differences in profit between the years are related to the difference in revenues especially by biogas for vehicle fuel use and in a smaller proportion by heat revenues. This is related to higher amounts of biogas for vehicle fuel and heat produced every year according to its environmental report of the Borås plant⁹. In addition comparing the year 2004 with 2005 and 2006 the differences between transport costs play an influential role. This is due to a lower amount of transport fuel used in the year 2004 compared to the other years based on the environmental reports of the Borås plant. The energy costs are rising due to higher prices of electricity and oil especially for the year 2006. In addition the double amount of electricity is used for the year 2005 and 2006 compared to the year 2006 based on the environmental reports of the Borås plant¹⁰. Drop in emission costs should be related to less amount of waste treated as 2004 and 2006 are comparable in emission costs. Last point to stretch is that there was not a specific explanation found for the difference in output between the year 2004 compared to the years 2005-2006.

Table 20: Calculated revenues and costs of the Borås plant

	2004	2005	2006	Average	Unit
Quantities of waste	20 528	18 531	20 736	19 932	Ton
Revenues					
Gate fees	15 396 000	13 898 250	15 552 000	14 948 750	SEK
Heat	84 148	1 126 460	1 412 200	874 269	SEK
Biogas	1 473 218	3 444 012	4 993 795	3 303 675	SEK
Total revenues	16 953 366	18 468 722	21 957 995	19 126 694	SEK
Costs					
Transport	255 285	2 673 901	2 032 856	1 654 014	SEK
Labour	2 250 000	2 250 000	2 250 000	2 250 000	SEK
Energy	1 579 738	1 876 528	2 865 784	2 107 350	SEK
Water	295 444	565 938	648 420	503 267	SEK
Upgrading	246 837	516 600	770 000	511 146	SEK
Emission	92 490	76 867	96 235	88 530	SEK
Total costs	4 719 794	7 959 834	8 663 295	7 114 308	SEK
Profit/Loss	12 233 572	10 508 888	13 294 700	12 012 387	SEK

⁹ Miljörapporter 2004, 2005, 2006 Sobäckens biogasanläggning (Borås plant)

¹⁰ Miljörapporter 2004, 2005, 2006 Sobäckens biogasanläggning (Borås plant)

5.2 Difference in revenues items

Between plant A defined as Uppsala and B defined as all other plants hypothesis are tested with an independent t-test for differences in revenues. The hypothesis are tested with a two-tailed t-test at a significance level of $\alpha = 0.05\%$. The rejection region of the null hypothesis is $|t| > t_{\alpha/2, 4} = 2.78$ and $|t| > t_{\alpha/2, 2} = 4.30$ respectively according to the t-student distribution. If the t-statistic is less than the t-value, H_0 cannot be rejected. Outcomes of the test are provided in Appendix A. In this paragraph a summary of results are described.

Summary of results in difference of revenues

Revenues from gate fees, heat, and biogas for vehicle use have been tested with a t-test among hypotheses. An overview of results is provided in table 21. Not rejected in the table indicate that there is no evidence on differences in the tested revenue between the Uppsala plant and the other plant at a 5% statistical significance level. Rejected in the table indicate that there are differences in the tested revenue between the Uppsala plant and the other plant at a 5% statistical significance level. An asterisk "*" indicate that either a plant is not producing this output. No results mean that no test could be performed due to non degrees of freedom. Gas revenues have not been tested as the plant of Uppsala is not producing gas for natural gas purposes.

Table 21: Results of the t-tests on revenues: Rejecting the H_0

Plants	Gate fees	Heat	Biogas
Uppsala vs Kalmar	Not rejected	Not rejected	Rejected
Uppsala vs Göteborg	Rejected	*	*
Uppsala vs Huddinge	Rejected	Not rejected	*
Uppsala vs Vetlanda	Not Rejected	No results	*
Uppsala vs Boden	Not rejected	No results	*
Uppsala vs Linköping	Rejected	No results	Rejected
Uppsala vs Borås	Rejected	Not rejected	Not rejected

Differences between revenue items between the plants.

No differences in gate fees revenues appear to be present between the Uppsala plant and the plants of Kalmar and Boden. An explanation is that difference of gate fees revenues do not differ much between this plant for the t-test. Between the plant of Uppsala and the plants of Göteborg, Huddinge, Linköping and the Borås differences in gate fees revenues are related to the amount of quantities of waste processed as most of the gate fees are comparable and constant through the years. Uppsala is treating on average the double amount of waste compared to the Huddinge plant and therefore the Uppsala plant is gaining more revenues from gate fees revenues. The same explanation is valid when comparing the Linköping plant, Göteborg plant and Borås plant with the Uppsala plant. These plants are treating more waste compared to the Uppsala plant even with lower gate fees for the

Linköping plant and Göteborg plant. Therefore the amount of quantities treated explaining the difference in gate fees revenues.

For heat revenues no difference appeared to be identified between the Uppsala plant and the plants of Huddinge, Boden and Borås. Although on average higher heat revenues are present at the Huddinge, Boden and Borås plants compared to the Uppsala plant no differences appeared from the t-test. In addition heat revenues between the Uppsala plant and the plant of Linköping, the plant of Vetlanda and the plant of Boden can only be compared with the year 2005. The plant of Uppsala is producing heat in the year 2004 and 2005 and the plant of Vetlanda, plant of Boden and the plant of Linköping only provided their data on heat production for the years 2005 and 2006. Comparing the heat revenues for 2005 for the Uppsala plant with the plants of Vetlanda, Boden and Linköping was not possible as there are non degrees of freedom.

The revenues of biogas for vehicle use were only produced at the plant of Uppsala, the plant of Kalmar, Linköping and Borås. Although higher average biogas revenues for vehicle use purposes are present for the Borås plant compared to the Uppsala plant there are no differences in average biogas revenues between the Borås and Uppsala plant according to the t-test. However differences in average biogas revenues for vehicle use are present between the Kalmar and Linköping plant compared to the Uppsala plant. This is related to the quantities of biogas for vehicle use produced. According to appendix D, the plant of Kalmar is producing on average 72 141 Nm³ of biogas for vehicle fuel use compared to the 237 706 Nm³ of biogas for vehicle fuel use for the Uppsala plant on average. Linköping is producing 6 230 210 Nm³ of biogas for vehicle fuel use compared to the Uppsala plant and therefore explaining the differences of biogas revenues between these plants.

5.3 Difference in costs items

Between plant A defined as Uppsala and B defined as all other plants hypothesis are tested with an independent t-test for differences costs. The hypothesis are tested with a two-tailed t-test at a significance level of $\alpha = 0.05\%$. The rejection region of the null hypothesis is $|t| > t_{\alpha/2, 4} = 2.78$ and $|t| > t_{\alpha/2, 2} = 4.30$ respectively according to the t-student distribution. If the t-statistic is less than the t-value, H_0 cannot be rejected. Outcomes of the test are provided in Appendix B. In this paragraph a summary of results are described.

Summary of results for differences in costs

Costs of transport, labour, energy, water, emission and the upgrading of biogas for vehicle purposes have been tested among hypotheses. An overview of results is provided in table 22. Not rejected in the table indicate that there is no evidence on differences in the tested cost between the Uppsala plant and the other plant at a 5% statistical significance level. Rejected in the table indicate that there are differences in the tested cost between the Uppsala plant and the other plant at a 5% statistical significance level. An asterisk '*' indicate that either a plant is not producing this output.

Table 22: Results of the t-tests on costs; Rejection of H_0

Plants	Transport	Labour	Energy	Water	Emission	Upgrading
Uppsala vs Kalmar	Rejected	Rejected	Rejected	Rejected	Rejected	Rejected
Uppsala vs Göteborg	Rejected	Rejected	Rejected	Rejected	Rejected	*
Uppsala vs Huddinge	Not rejected	Rejected	Not rejected	Not rejected	Rejected	*
Uppsala vs Vetlanda	Rejected	Rejected	Rejected	Not rejected	Not rejected	*
Uppsala vs Boden	Not Rejected	Rejected	Not Rejected	Not rejected	Not rejected	*
Uppsala vs Linköping	Rejected	Rejected	Rejected	Rejected	Rejected	Rejected
Uppsala vs Borås	Not Rejected	Rejected	Rejected	Rejected	Rejected	Not rejected

Explaining differences in costs between plants

Evidence on differences in transport costs have been found between the Uppsala and the plants of Kalmar, Göteborg, Vetlanda and Linköping. Differences in transport costs are by differences in data provided, the mean of transport and related assumption and distances. The transport costs of the Uppsala plant was calculated with the assumption of 0.56 SEK/ton/km for a truck driven by diesel. For the distance the substrate of 15 kilometers is assumed and 10 km distance for digestate based on the studies of Börjesson, (2006).

The transport costs of the Kalmar plant are based on the environmental report¹¹. This report provided the amount of diesel used for transport costs and is used as indicator for the transport costs for this plant. This source could explain the difference between the plant of Kalmar and Uppsala. For the plant of Göteborg and the plant of Uppsala the mean of

¹¹ Miljörapporter, 2004, 2005, 2006. Biogasanläggning Kalmar

transport explain the difference. The Göteborg plant has a tunnel transport system of sludge substrate with a distance of 120 km. The long distance and this transport system explain the difference in transport costs between these plants.

Between the plants of Vetlanda and Uppsala there is a difference in amount of waste treated which affect the amount of waste to be transported. This has influence on the difference in transport costs. The plant of Linköping provided empirical distance on its transport costs. The transport costs of the plant of Uppsala are assumed as described. The difference in source explaining the difference.

No evidence on differences in transport costs have been found between the Uppsala and the plants of Huddinge, Boden and Borås according to the t-test.

For labour costs evidence on differences in labour costs has been found between the plant of Uppsala and all other plants. Difference in labour costs is directly based on the provided empirical data. Therefore no specific explanation can be given. More information is necessary to specify what is exactly causing the difference in labour costs between the plants.

Evidence on differences for energy costs between the plant of Uppsala and the plants of Kalmar, Göteborg, Vetlanda and Linköping and Borås are present. The amount of energy used explain the differences in energy costs. The plants of Kalmar, Göteborg, Linköping and Borås are treating more waste than the plant of Uppsala and therefore need more energy. A similar explanation can be mentioned between the plants of Vetlanda and the plant of Uppsala. The plant of Vetlanda is using less waste and therefore less energy. In addition the plant of Kalmar and the plant of Uppsala are using both oil and electricity as energy resources. However Kalmar is using also a high amount of gas. As gas prices rised proportionally from 2004-2006 according to appendix C this affected the gas costs for the Kalmar plant and could explain the difference in energy costs. No evidence on differences in energy costs have been found between the Uppsala and the plants of Huddinge and Boden according to the t-test.

For water costs evidence on differences in water costs have been found between the plant of Uppsala and the plants of Kalmar, Göteborg, Linköping and Borås. Differences in water costs are based on the provided empirical data are related to the use of more water for the production process. More water use could be affected by the dry water content of the waste. However more information is necessary to specify of this is exactly causing the difference water costs between the plants. No evidence on differences in water costs have been found

between the Uppsala and the plants of Huddinge, Boden and Vetlanda according to the t-test.

Evidence on difference of emission costs have been identified between the Uppsala plant and the plants of Kalmar, Göteborg, Huddinge, Linköping and Borås. Differences can be explained by the amount of waste and waste type treated and empirical data. For the plants of Kalmar, Göteborg, Linköping and Borås the higher costs of emission is related to more waste that is treated compared to the Uppsala plant. The difference between the Huddinge plant and the Uppsala plant is caused by the lower amount of waste treated for the Huddinge plant. In addition the plant of Göteborg provided empirical data of the amount of CO₂ and NO_x. These levels were relatively high compared to the simulated levels of emission of other plants. This could also be explained by the highest treatment of waste of this sample. No evidence on differences in emission costs have been found between the Uppsala and the plants of Vetlanda and Boden according to the t-test.

Evidence on difference of upgrading costs have been identified between the Uppsala plant and the Linköping and Kalmar plant. This was related to the amount of biogas upgraded. Between the plant of Uppsala and the plant of Borås there was no evidence of differences.

5.4 Differences in revenue items and costs items affecting profit levels

Difference in revenue-items and costs items have been identified by rejecting the H₀ and may affect different levels of profit between plants. In table 21 the profits, total costs and total revenues are given in averages between the plants for the years 2004-2006 divided with 1000 SEK. Based on table 23 it is decided if the revenue or cost side is responsible for a difference in a profit.

Table 23: Overview of average results for the period 2004-2006 on quantities, total revenue TR, total costs TC and profits per biogas plant

	Uppsala	Kalmar	Göteborg	Huddinge	Vetlanda 2005- 2006	Boden 2005- 2006	Linköping 2005- 2006	Borås
Quantity in ton	4	21.4	51	1.3	1.7	24	48	20
TR in SEK	4 407	4 992	21 443	1 120	924	5 412	61 271	19 126
TC in SEK	1 915	2 536	24 884	1 665	248	2 597	17 622	7 114
Profit in SEK	2 491	2 429	-3 440	-545	676	2 814	43 648	12 012

To decide what is affecting the difference in profit for plant A defined as Uppsala compared to plant B defined as the other plants the total average revenues and total average costs are analyzed. A difference of a higher or lower profit for plant A compared to plant B can either be caused by higher average revenues or lower average costs for plant A compared to plant B. It appeared that the Uppsala plant has a higher average profit compared to the Kalmar, Göteborg, Huddinge and Vetlanda plant. For the plant of Kalmar and the plant of Göteborg

this is related to the costs side as the average total revenues are higher for the Göteborg plant and the Kalmar plant compared to the Uppsala plant. For the plant of Huddinge and the plant of Vetlanda a lower profit compared to the Uppsala plant is related to the revenue side as the total average revenues are higher for the Uppsala plant and the average total costs are higher for the Uppsala plant compared to the Vetlanda and Huddinge plant. Furthermore the average total results of the plants of Boden, Linköping and Borås are responsible for a lower average profit for the Uppsala plant as the total costs of the Uppsala plant are lower compared with these plants.

Differences of profit explained by the revenue side

Evidence was found by the t-test that the difference of gate fees revenues between the plant of Uppsala and the plants of Huddinge, Vetlanda, Linköping and Borås was caused by a difference in gate fees. Furthermore differences of gate fees revenues were explained by the quantities of waste. As the revenue side is responsible for a difference in profit between the Uppsala plant and the plants of Huddinge, Vetlanda, Linköping and Borås, evidence in difference in gate fees revenues explained by different quantities of waste treated provides an explanation affecting the difference in a (higher) profit between these plants.

Biogas revenues for vehicle use is explaining a difference between the Uppsala plant and the Linköping plant. The difference in biogas revenues for vehicle use was explained by the high amount of biogas for vehicle use produced for the Linköping plant. As the profit of the plant of Linköping is higher than the plant of Uppsala and a higher profit is related to the revenue side, evidence in differences in biogas revenues for vehicle use is explained by a higher production of biogas for vehicle use affecting the difference in a (higher) profit between these plants.

Differences of profit explained by the costs side

The difference in a (lower) profit between the plant of Kalmar, the plant of Göteborg and the plant of Uppsala are related to the costs side. Evidence was found by the t-test that the transport costs, labour costs, energy costs, water costs, emission costs and biogas upgrading costs explaining differences in costs between the plant of Uppsala and the plants of Kalmar and Göteborg. These differences in costs between plants affecting the profit as the cost side is responsible for differences in profit.

The transport costs between the Uppsala plant and the plant of Kalmar could be influenced by a difference of empirical source. For the Uppsala plant an assumption was used of 0.56 SEK/km/ton for a truck driven by diesel. For the distance of substrate 15 kilometers is assumed and for digestate 10 km is assumed based on the study of Börjesson, (2006). The

transport costs of the Kalmar plant are based on the environmental report¹². This report provided the amount of diesel used for transport costs and is used as indicator for the transport costs for this plant. This source could explain the difference in profit between the plant of Kalmar and Uppsala. For the plant of Göteborg and the Uppsala plant the mean of transport explain the difference in profit. The Göteborg plant has a tunnel transport system of substrate with a distance of 120 km compared to the plant of Uppsala. Empirical data from their factsheets¹³ have been used to estimate the transport costs and were relatively high. The source and distance of the tunnel can in this case explain the difference in transport costs and so the difference in profit.

Evidence on differences in labour costs has been found between the plant of Uppsala and the plants of Kalmar, Göteborg. Differences in labour costs are based on empirical data. More information is necessary to specify what is exactly causing the difference in labour costs between the plants and therefore could explain exactly the differences in profit.

For energy costs evidence on differences between the plant of Uppsala and the plant of Kalmar and Göteborg are present. The plants of Kalmar, Göteborg, are treating more waste than the plant of Uppsala and therefore need more energy. This can explain the differences in profitability. In addition the Kalmar and Uppsala plant are using both oil and electricity as energy resources. However Kalmar is using also a high amount of gas. As prices rised proportionally from 2004-2006¹⁴ this affected the gas costs for the Kalmar plant and could explain the difference in energy costs and profit.

For water costs evidence on differences in water costs have been found between the plant of Uppsala and the plants of Kalmar, Göteborg. This was related to quantities of water used.

Evidence on difference of emission costs have been identified between the plants of Kalmar and Göteborg. Differences can be explained by the amount of waste treated and empirical data affecting the profit. For the plants of Kalmar and Göteborg the higher costs of emission is related to more waste treated compared to the Uppsala plant. In addition the plant of Göteborg provided empirical data of the amount of CO₂ and NO_x. These levels where relatively high compared to the other levels of emissions of other plants. Another explanation for the high emission cost could be the higher treatment of waste for this plant explaining the differences in costs and so affecting the profit.

¹² Miljörapport 2004, 2005, 2006 Kalmar biogasanläggning

¹³ Factsheets 2004, 2005, 2006 Gryaab (Göteborg plant)

¹⁴ See appendix C for prices of gas

6 Conclusions and discussion

This study is focusing on the levels of operational profitability for eight Swedish biogas plants during the period 2004-2006. Difference in level of profit through these years has been analyzed for each of the plant and between plants. Revenue and cost items have been identified and may explain the difference in profit. In this chapter main conclusions are provided including a discussion and recommendation for further research.

6.1 Conclusions

Within the current profit function the operational profitability for the period 2004-2006 was positive for the plant of Uppsala, Kalmar, Vetlanda, Boden, Linköping and Borås. The plants of Huddinge and Göteborg had a negative profit. e.g. loss. Positive results on profit are related to higher revenues of gate fees and higher biogas revenues for the Linköping plant. Differences in these revenues affecting the profit were explained by the treatment of more waste. Negative results on profitability for the plant of Huddinge and Göteborg were related to higher transport costs and relatively low revenues of heat for the Huddinge plant according to the results from this plant. Differences in transport costs affecting the profit were related by the mean of the transport and data provided on distances of transport between the plants. Other important costs factors were labour and energy costs for each plant. In addition costs factors affecting the profit between the plant of Uppsala and the plants of Göteborg and Kalmar appeared to be labour, transport, energy, water, upgrading and emissions further elaborated on in the discussion part.

6.2 Discussion

Conclusions in this study depend on the empirical data of the sample and assumptions from statistical data and literature to calculate the costs and revenues within the profit function model. In addition the plant of Uppsala was used as reference plant to indicate differences between plants. Therefore the outcomes and explanations from data and literature of this study are valid within the boundaries of the model and are discussed in the following section.

To verify the outcome of this study on the economical feasibility i.e. profitability, this study is compared with two other international studies on the economical feasibility of biogas plants. Economical feasibility of biogas plants was studied by a study of Braun, (2002). This study highlighted the economical feasibility of centralised biogas plants by a Danish study by Hjort-Gregersen, (1999). It appeared that from a sample of 17 large-scale Danish centralized biogas plants 5 installations were classified acceptable, 5 balanced at “break-even”, 3 were qualified as “under pressure” and 4 as “economically unsatisfactory. Another Danish study of Mæng, Lund, Hvelplund, (1999) using a net present value method including emission costs showed only a negative net present value at three biogas plants in Denmark. Both studies show similar results on the profitability of biogas plant compared to this study and therefore

the results of this study of profitability are not an exception. Furthermore an additional interesting result of the study of Mæng, Lund, Hvelplund, (1999) is the net present value including or excluding the emission costs. The difference between including and excluding the environmental costs with the net present value are 0.1-0.5 million Danish Crones equivalent to 0.12-0.6 million Swedish Crones.¹⁵ Referring to the emission costs of this study it appeared that emission costs has been a relative small proportion of the main costs for each plant. This would imply that the difference of profit would not change a lot whether emissions costs have been included or not. Therefore it can be argued that emissions are not an influential cost factor in the profit and the levels of emission are relatively low for operating biogas plants. However according to the analyses between the eight plants in this study, emission costs affects the difference in profitability. These results were seen between the Uppsala, Kalmar and Göteborg plant. Although the level of emissions are simulated and differences in the model could just be explained by the amount of waste treated, the type of waste treated and the source of empirical data following differences can be found. Differences of higher emission costs between the plants of Kalmar is related to more waste treated compared to the Uppsala plant. The plant of Göteborg provided empirical data of the amount of CO₂ and NO_x as one of the few plants. The level of emissions where relatively high compared to the other levels of emissions of other plants. This could have influenced differences as other emission levels were simulated. In addition the higher emission costs could furthermore be related to the high amount of treated waste for the Göteborg explaining the differences in costs and so affecting the profit. Furthermore level of emissions at biogas plants could also increase by other factors. This can be related to the upgrading process (Persson, 2003), differences in transport fuels (Johansson, Nilsson, 2007), storage methods (RVF, 2005) and energy use for the production process (Börjesson, 2006). Due to limitation of the model these factors where not taken into account

Besides emission costs also transport, labour, energy, water and upgrading costs have been reported to affect the level of profitability. The difference of costs for transport can be explained by the means of transport. The plant of Kalmar and Uppsala are using trucks for transport means and the plant of Göteborg is mainly using a tunnel system with a long distance of 120 kilometres. In this study transport costs are more expensive by tunnel than by truck. According to the outcome of this study and literature on transport costs by Johansson and Nilsson, (2007) it appeared that a tunnel system is more expensive than transport by trucks which is a similar result for this study. In addition data on tunnel cost was based on the empirical data from the factsheet¹⁶ of the Göteborg plant. This could also influence the difference in transport cost and so affected profit. Furthermore it is likely that

¹⁵ Using a conversion rate of 1 DKK = 1.24418 SEK (XE, 2008)

¹⁶ Factsheet 2004, 2005, 2006 Gryaab (Göteborg plant)

the transport distance is responsible for a difference in cost. The plant of Huddinge is transporting digestate on a long distance (70km) compared to the average assumption of 10 km for digestate transport for the plants of Kalmar or Uppsala. Assumed to have the same amount of transport costs for digestate of 0.74 SEK/km/ton, the distance has been influencing a lower profit according to the analyses between the plant of Huddinge and Uppsala. Data indicated the transport costs could eventually also explain differences of costs between the Kalmar and Uppsala plant. The transport data from the Kalmar plant on the amount of diesel used for transport purposes was based on the environmental report of the Kalmar plant¹⁷. For the Uppsala plant the distance was assumed to be 15 km between the plant and the supplier. The costs were 0.56 SEK/km/ton for substrate transport. The differences in data used as indicator for transport costs or different could explain additionally the difference in profit.

For energy costs differences of profit can be explained by amounts of energy used and prices of an energy source. The plant of Uppsala is using relatively a low amount of energy compared to the plants of Kalmar and Göteborg. The plant of Göteborg is using a higher amount of electricity for their production process compared to the plant of Uppsala. This is related to the fact that Göteborg is treating at least 12 times more waste compared to the Uppsala plant on average. In addition higher energy costs can also be an indication that there is a difference of pre-treatment process and digestion technology. Börjesson (2006) mentioned that the electricity demand can be affected by variations in pre-treatment demands and digestion technology, however further research should provide stronger evidence for a relation with these specific causes. In addition the Kalmar and Uppsala plant are using both oil and electricity as energy resources. However Kalmar is using also a high amount of gas. As gas prices rised proportionally from 2004-2006¹⁸ this affected the gas costs for the Kalmar plant and so could explain the difference besides the amount of waste treated.

For water costs higher amounts of water quantities affecting the difference in profit. Higher water quantities can be related to the dry water content of the waste according to Börjesson, (2006), but further research should provide stronger evidence. Furthermore differences in labour costs which affected profit and are based on empirical data from plants. Unfortunately the empirical data does not give specific indication what is affecting the labour costs. Therefore more data is needed. The upgrading costs assumed with a level of 0.14 SEK/KWh of biogas for vehicle purposes explain the difference in costs between the plants of Uppsala and the plants of Kalmar and Linköping. The difference in costs affecting profit is related to

¹⁷ Miljörapport 2004, 2005, 2006 Kalmar biogasanläggning

¹⁸ See appendix C for prices of gas

the amount of biogas for vehicle use produced. However different outcomes could appear if other upgrading technology or process capacity was used in the model.

Revenues are of vital importance influencing the different levels of profitability. A higher profit has been related to more revenues from gate fees and biogas in most cases. According to Braun, (2002) gate fees do make an enormous difference in profit or either making a loss at Danish plants. This study appears to show the same results. This could imply to raise the gate fees to increase income for plants. However the future level of gate fees should not be too high. Competition between incineration treatment with lower gate fees than biogas plants could affect the amount of quantities treated at biogas plant and therefore the general profit (Berglund, 2006). Furthermore using biogas as a resource made a difference affecting a higher profit. Higher profits were related to a higher amount of quantities produced for biogas. Therefore compared to the outputs of heat, gas and biogas for vehicle fuel use it appeared that biogas for vehicle fuel use is the best output incentive to stimulate the revenues for the biogas plant.

6.3 Recommendations for further research.

Within the profit model and assumptions made to perform this study it appeared that six out of eight biogas plants in Sweden showed an operational profitability using a profit model between the years 2004-2006. This is an indication the biogas production is economical feasible in Sweden. Different levels of profitability have been analysed. It appeared that waste quantities, type of waste, dry content of waste, transport distances, means of transport, pre-treatment, process, digestion technology and prices of energy could affect the profitability.

Originally this study was using an econometric model to analyse the economical feasibility and level of emissions if available organic material was produced at biogas plant in Sweden. However, due to a lack of empirical data this research was not possible. Still future levels of profit considering the availability of organic material available in Sweden to produce biogas is a relevant subject of research as demand for biogas will increase. This research can be a contribution to give an indication that there is operational profitability at biogas plants in Sweden and explaining some of the differences in profit and emission levels. Future research on levels of profitability and level of emissions at biogas plants could be extended by analysing in depth the factors which did not explain accurately the difference in profit between. Also the economical feasibility and level of emissions of the potential organic material produced at biogas plants in Sweden is still a relevant topic of research. More research can be supportive to verify the outcomes of this study and support the economical feasible and sustainable expansion of biogas production at biogas plants in Sweden.

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Appendix A: Outcome of t-tests revenues

Gate fees revenues

Between plant A defined as Uppsala and B defined as all other plants hypothesis are tested with an independent t-test for differences in gate fees revenues. The hypothesis to be tested is:

H_0 : There is no difference in gate fees revenues between plant A and B, $\bar{x}_A - \bar{x}_B = 0$

H_1 : There is a difference in gate fees revenues between plant A and B, $\bar{x}_A - \bar{x}_B \neq 0$

The hypothesis is tested with a two-tailed t-test at a significance level of $\alpha = 0.05\%$. The rejection region of the null hypothesis is $|t| > t_{\alpha/2, 4} = 2.78$ and $t_{\alpha/2, 2} = 4.30$ respectively according to the t-student distribution. If the t-statistica is less than the t-value, H_0 cannot be rejected.

Table A: Results of t-test for gate fees revenues

Plants	t-statistica	t-value	Degrees of Freedom	Mean Difference
Uppsala vs Kalmar	2.23	2.78	4	-1 052 233
Uppsala vs Göteborg	15.1	2.78	4	-5 748 653
Uppsala vs Huddinge	2.91	2.78	4	1 625 067
Uppsala vs Vetlanda	2.12	2.78	4	-1 298 700
Uppsala vs Boden	2.28	4.30	2	-1 336 800
Uppsala vs Linköping	5.98	4.30	2	-4 326 219
Uppsala vs Borås	19.39	2.78	4	-12 567 750

According to test results in table A there is no evidence on a difference in average gate fees between the Uppsala plant and the Kalmar plant, Vetlanda plant and the Boden plant at a 5% statistical significance level and the H_0 cannot be rejected. However there is a difference in average gate fees between the Uppsala plant and the Göteborg plant, Huddinge plant, Linköping plant and Borås plant at a 5% statistical significance level and the H_0 can be rejected.

Heat revenues

Between plant A defined as Uppsala and B defined as all other plants hypothesis are tested with an independent t-test for differences in heat revenues. The hypothesis to be tested is:

H_0 : There is no difference in heat revenues between plant A and B, $\bar{x}_A - \bar{x}_B = 0$

H_1 : There is a difference in heat revenues between plant A and B, $\bar{x}_A - \bar{x}_B \neq 0$

The hypothesis is tested with a two-tailed t-test at a significance level of $\alpha = 0.05\%$. The rejection region of the null hypothesis is $|t| > t_{\alpha/2, 4} = 2.78$ and $t_{\alpha/2, 2} = 4.30$ respectively according to the t-student distribution. If the t-statistica is less than the t-value, H_0 cannot be rejected.

Table B: Results of t-test for heat revenues

Plants	t-statistica	t-value	Degrees of Freedom	Mean Difference
Uppsala vs Kalmar	3.47	4.30	2	-1 216 776
Uppsala vs Göteborg	No results as the Göteborg plant is not producing sold heat.			
Uppsala vs Huddinge	3.67	4.30	2	97 040
Uppsala vs Vetlanda	No results due to 0 degrees of freedom			
Uppsala vs Boden	No results due to 0 degrees of freedom			
Uppsala vs Linköping	No results due to 0 degrees of freedom			
Uppsala vs Borås	1.08	4.30	2	-562 675

According to test results in table B there is no evidence on a difference in average heat revenues between the Uppsala plant and the Kalmar plant, the Huddinge plant and the Vetlanda plant at a 5% statistical significance level and the H_0 cannot be rejected.

Furthermore no results are present between the Uppsala plant, the Göteborg plant, the Vetlanda plant, the Boden plant and the Linköping plant. This is related to the fact that the Göteborg plant is not selling heat, but gas. At the Vetlanda plant, Boden plant and Linköping plant heat revenues can only be compared with the year 2005 as Uppsala is producing heat in the year 2004 and 2005 and the Vetlanda plant, Boden plant and Linköping plant only provided their data on heat production for the years 2005 and 2006. Comparing the heat revenues for 2005 for the Uppsala plant with the plants of Vetlanda, Boden and Linköping is not possible as the degrees of freedom are zero and this is not sufficient to run a test.

Gas revenues

The reference plant Uppsala is not producing biogas for the natural gas purposes according to their environmental report¹⁹. Therefore no comparison can be made of gas revenues between plants. However it known that the Kalmar plant and the Göteborg plant are producing gas.

¹⁹ Miljörapporter 2004, 2005, 2006. Biogasanläggningen vid Kungsängens gård Uppsala

Biogas revenues

Between plant A defined as Uppsala and B defined as the plant of Kalmar, the plant of Linköping and the plant of Borås hypothesis are tested with an independent t-test for differences in biogas revenues for vehicle use. The hypothesis to be tested is:

H₀: There is no difference in biogas revenues for vehicle use between plant A and B,

$$\bar{x}_A - \bar{x}_B = 0$$

H₁: There is a difference in biogas revenues for vehicle use between plant A and B,

$$\bar{x}_A - \bar{x}_B \neq 0$$

The hypothesis is tested with a two-tailed t-test at a significance level of $\alpha = 0.05\%$. The rejection region of the null hypothesis is $|t| > t_{\alpha/2, 4} = 2.78$ and $t_{\alpha/2, 2} = 4.30$ respectively according to the t-student distribution. If the t-statistica is less than the t-value, H₀ cannot be rejected. In addition the plants of Göteborg, Huddinge, Boden and Vetlanda are not tested as these plants don't produce biogas for vehicle use purposes.

Table C: Results of t-test for biogas revenues for vehicle use purposes

Plants	t-statistica	t-value	Degrees of Freedom	Mean Difference
Uppsala vs Kalmar	6.21	2.78	4	1 926 082
Uppsala vs Linköping	92.49	4.30	2	-45 154 869
Uppsala vs Borås	1.23	2.78	4	-963 320

According to test results in table C there is no evidence on a difference in average biogas revenues for vehicle use purposes between the Uppsala plant and the Borås plant at a 5% statistical significance level and the H₀ cannot be rejected. However there is a difference in average biogas revenues for vehicle use purposes between the Uppsala plant, the Kalmar plant and the Linköping plant at a 5% statistical significance level and the H₀ can be rejected.

Appendix B: Outcome of t-tests costs

Transport costs

Between plant A defined as Uppsala and B defined as all other plants hypothesis are tested with an independent t-test for differences in transport costs. The hypothesis to be tested is:

H_0 : There is no difference in transport costs between plant A and B, $\bar{x}_A - \bar{x}_B = 0$

H_1 : There is a difference in transport costs between plant A and B, $\bar{x}_A - \bar{x}_B \neq 0$

The hypothesis is tested with a two-tailed t-test at a significance level of $\alpha = 0.05\%$. The rejection region of the null hypothesis is $|t| > t_{\alpha/2, 4} = 2.78$ and $t_{\alpha/2, 2} = 4.30$ respectively according to the t-student distribution. If the t-statistica is less than the t-value H_0 cannot be rejected.

Table D: Results of t-test for transport costs

Plants	t-statistica	t-value	Degrees of Freedom	Mean Difference
Uppsala vs Kalmar	10.9	2.78	4	-93 108
Uppsala vs Göteborg	5.81	2.78	4	-4 469 735
Uppsala vs Huddinge	1.75	2.78	4	-1 109 241
Uppsala vs Vetlanda	6.52	4.30	2	85 602
Uppsala vs Boden	7.32	4.30	2	- 98 945
Uppsala vs Linköping	2.25	4.30	2	-1 477 038
Uppsala vs Borås	2.15	2.78	4	-1 557 082

According to test results in table D there is no evidence on a difference in average transport costs between the Uppsala plant and the Huddinge plant, Linköping plant and Borås plant at a 5% statistical significance level and the H_0 cannot be rejected. However there is a difference in average transport costs between the Uppsala plant and the Kalmar plant, Göteborg plant, Vetlanda plant and Boden plant at a 5% statistical significance level and the H_0 can be rejected.

Labour costs

Between plant A defined as Uppsala and B defined as all other plants hypothesis are tested with an independent t-test for differences in labour costs. The hypothesis to be tested is:

H_0 : There is no difference in labour costs between plant A and B, $\bar{x}_A - \bar{x}_B = 0$

H_1 : There is a difference in labour costs between plant A and B, $\bar{x}_A - \bar{x}_B \neq 0$

The hypothesis is tested with a two-tailed t-test at a significance level of $\alpha = 0.05\%$. The rejection region of the null hypothesis is $|t| > t_{\alpha/2, 4} = 2.78$ and $t_{\alpha/2, 2} = 4.30$ respectively according to the t-student distribution. If the t-statistica is less than the t-value H_0 cannot be rejected.

Table E: Results of t-test for labour costs

Plants	t-statistica	t-value	Degrees of Freedom	Mean Difference
Uppsala vs Kalmar	15.01	2.78	4	207 999
Uppsala vs Göteborg	10.39	2.78	4	-143 999
Uppsala vs Huddinge	48.77	2.78	4	705 600
Uppsala vs Vetlanda	70.00	4.30	2	840 000
Uppsala vs Boden	18.33	4.30	2	220 000
Uppsala vs Linköping	4.75	4.30	2	-3 484 000
Uppsala vs Borås	89.63	2.78	4	-1 242 000

According to test results in table E there are differences in average labour costs between the Uppsala plant and the Kalmar plant, Göteborg plant, Huddinge plant, Vetlanda plant and, Boden plant, Linköping plant and Borås plant at a 5% statistical significance level and the H_0 can be rejected.

Energy costs

Between plant A defined as Uppsala and B defined as all other plants hypothesis are tested with an independent t-test for differences in energy costs. The hypothesis to be tested is:

H_0 : There is no difference in energy costs between plant A and B, $\bar{x}_A - \bar{x}_B = 0$

H_1 : There is a difference in energy costs between plant A and B, $\bar{x}_A - \bar{x}_B \neq 0$

The hypothesis is tested with a two-tailed t-test at a significance level of $\alpha = 0.05\%$. The rejection region of the null hypothesis is $|t| > t_{\alpha/2, 4} = 2.78$ and $t_{\alpha/2, 2} = 4.30$ respectively according to the t-student distribution. If the t-statistica is less than the t-value H_0 cannot be rejected.

Table F: Results of t-test for energy costs

Plants	t-statistica	t-value	Degrees of Freedom	Mean Difference
Uppsala vs Kalmar	5.67	2.78	4	-888 938
Uppsala vs Göteborg	8.31	2.78	4	-15 782 849
Uppsala vs Huddinge	1.77	2.78	4	258 623
Uppsala vs Vetlanda	6.85	4.30	2	428 802
Uppsala vs Boden	4.21	4.30	2	-921 182
Uppsala vs Linköping	5.45	4.30	2	-2 263 873
Uppsala vs Borås	4.39	2.78	4	-1 724 718

According to test results in table F there is a difference in average energy costs between the Uppsala plant, the Huddinge plant and the Boden plant at a 5% statistical significance level and the H_0 cannot be rejected. However there is a difference in average energy costs between the Uppsala plant, the Kalmar plant, Göteborg plant, Vetlanda plant, Boden plant, Linköping plant and Borås plant at a 5% statistical significance level and the H_0 can be rejected.

Water costs

Between plant A defined as Uppsala and B defined as all other plants hypothesis are tested with an independent t-test for differences in water costs. The hypothesis to be tested is:

H_0 : There is no difference in water costs between plant A and B, $\bar{x}_A - \bar{x}_B = 0$

H_1 : There is a difference in water costs between plant A and B, $\bar{x}_A - \bar{x}_B \neq 0$

The hypothesis is tested with a two-tailed t-test at a significance level is $\alpha = 0.05\%$. The rejection region of the null hypothesis is $|t| > t_{\alpha/2, 4} = 2.78$ and $t_{\alpha/2, 2} = 4.30$ respectively according to the t-student distribution.

Table G: Results of t-test for water costs

Plants	t-statistica	t-value	Degrees of Freedom	Mean Difference
Uppsala vs Kalmar	5.63	2.78	4	-77 658
Uppsala vs Göteborg	14.83	2.78	4	-2 923 993
Uppsala vs Huddinge	2.50	2.78	4	53 653
Uppsala vs Vetlanda	1.97	4.30	2	45 375
Uppsala vs Boden	3.27	4.30	2	69 926
Uppsala vs Linköping	8.07	4.30	2	-224 509
Uppsala vs Borås	3.92	2.78	4	-420 537

According to test results in table G there is no evidence on differences in average water costs between the Uppsala plant, the Huddinge plant, the Vetlanda plant and Boden plant at a 5% statistical significance level and the H_0 cannot be rejected. However there is a difference in average water costs between the Uppsala plant, the Kalmar plant, Göteborg plant, Linköping plant and Borås plant at a 5% statistical significance level and the H_0 can be rejected.

Emission costs

Between plant A defined as Uppsala and B defined as all other plants hypothesis are tested with an independent t-test for differences in emission costs. The hypothesis to be tested is:

H₀: There is no difference in emission costs between plant A and B, $\bar{x}_A - \bar{x}_B = 0$

H₁: There is a difference in emission costs between plant A and B, $\bar{x}_A - \bar{x}_B \neq 0$

The hypothesis is tested with a two-tailed t-test at a significance level of $\alpha = 0.05\%$. The rejection region of the null hypothesis is $|t| > t_{\alpha/2, 4} = 2.78$ and $t_{\alpha/2, 2} = 4.30$ respectively according to the t-student distribution.

Table H : Results of t-test for emission costs

Plants	t-statistica	t-value	Degrees of Freedom	Mean Difference
Uppsala vs Kalmar	18.8	2.78	4	-26 825
Uppsala vs Göteborg	5.91	2.78	4	-260 698
Uppsala vs Huddinge	6.51	2.78	4	13 356
Uppsala vs Vetlanda	1.04	4.30	2	3 597
Uppsala vs Boden	4.04	4.30	2	-79 897
Uppsala vs Linköping	5.15	4.30	2	-87 223
Uppsala vs Borås	11.81	2.78	4	-71 651

According to test results in table H there is no evidence in a difference in average emission costs between the Uppsala plant, the Vetlanda plant and Boden plant at a 5% statistical significance level and the H₀ cannot be rejected. However there is a difference in average emission costs between the Uppsala plant and the plants in Kalmar, Göteborg, Huddinge, Linköping and Borås at a 5% statistical significance level and the H₀ can be rejected.

Biogas upgrading costs

Between plant A defined as Uppsala and B defined as the plant of Kalmar, the plant of Linköping and the plant of Borås, hypothesis are tested with an independent t-test for differences in biogas upgrading costs. The hypothesis to be tested is:

H₀: There is no difference in biogas upgrading costs between plant A and B, $\bar{x}_A - \bar{x}_B = 0$

H₁: There is a difference in biogas upgrading costs between plant A and B, $\bar{x}_A - \bar{x}_B \neq 0$

The hypothesis is tested with a two-tailed t-test at a significance level of $\alpha = 0.05\%$. The rejection region of the null hypothesis is $|t| > t_{\alpha/2, 4} = 2.78$ and $t_{\alpha/2, 2} = 4.30$ respectively according to the t-student distribution.

Table I : Results of t-test for biogas upgrading costs

Plants	t-statistica	t-value	Degrees of Freedom	Mean Difference
Uppsala vs Kalmar	3.19	2.78	4	231 224
Uppsala vs Linköping	4.31	4.30	2	-507 386
Uppsala vs Borås	1.14	2.78	4	182 356

According to test results in table I there is no evidence on a difference in biogas upgrading costs between the Uppsala plant and the Borås plant at a 5% statistical significance level and the H_0 cannot be rejected. However there is a differences in biogas upgrading costs between the Uppsala plant, the Kalmar plant and the Linköping plant at a 5% statistical significance level and the H_0 can be rejected.

Appendix C: Assumptions in the profit function model

Variable	Assumption	Source and explanation
Prices of electricity	2004: 475 SEK / MWh 2005: 351 SEK / MWh 2006: 543 SEK / MWh	Statens energimyndighet, 2007(STEM), Swedish Energy Agency
Prices of medium and heavy fuel oil	2004: 173 SEK / MWh 2005: 237 SEK / MWh 2006: 237 SEK / MWh	commercial energy prices excluding taxes
Prices of petrol	2006: 498 SEK / MWh	
Prices of diesel oil	2006: 522 SEK / MWh	
Costs of water	2004: 17.2 SEK / m ³ 2005: 15.7 SEK / m ³ 2006: 15 SEK / m ³	Svensk Vatten, 2008 <i>Based on the average water price of houses in the whole of Sweden</i>
Prices of heat	2004: 591 SEK / MWh 2005: 604 SEK / MWh 2006: 614 SEK / MWh	Statens energimyndighet, 2007(STEM), Swedish Energy Agency
Prices of gas(methane content of 67%)	2004: 205 SEK / MWh 2005: 232 SEK / MWh 2006: 327 SEK / MWh	commercial energy prices excluding taxes
Prices of vehicle fuel (methane content of 97%)	2004: 8.08 SEK / Nm ³ 2005: 8.41 SEK / Nm ³ 2006: 8.78 SEK / Nm ³ 2008: 9.41 SEK / Nm ³	http://www.sgc.se/go/vinstmedgas.jpg 2008 is used as reference year to calculate the prices with the producers price index
Producers price index February	2004: 121.5 2005: 124.9 2006: 131.0 2008: 143.2	Swedish Statistical Agency
Digestate	Delivered free of charge to farmers	Berglund, 2006
Transport costs for substrate by truck diesel, 40 tons	0.56 SEK/ton/km	Johansson, Nilsson, 2007
Transport costs for digestate by truck diesel, 40 tons	0.74 SEK/ton/km	Johansson, Nilsson, 2007
Upgrading of biogas	0.015 €/KWh = 0.14 SEK/KWh	IAE, 2007

Appendix D: Description of average data from the biogas plants

In this appendix average data from eight biogas plants are described based on the profit function model. Averages from the plants are described for the year 2004-2006 and 2004-2005 for each biogas plant. First a table describes the amount of average mixed resources treated per plant. The second table describes the output, prices and average revenues. Third a table about costs and inputs is given. The tables providing an overview about the quantities, revenues, costs and assumptions per plant. Open spaces in the table's means that no information was available.

To simplify the amount of waste treated three categories of waste are described. These are household waste, industry waste and sludge. Industry waste contains organic waste from the food industry, restaurants, slaughterhouse waste, manure and waste residues from parks or gardens. Table J provides an overview of the mixed resources treated per biogas plant in ton divided by 1000 ton. In general there is more industry waste and sludge treated than household waste between the plants.

Table J: Average quantities of waste per biogas plant

Resources	Uppsala	Kalmar	Göteborg	Huddinge	Vetlanda 2005- 2006	Boden 2005- 2006	Linköping 2005- 2006	Borås	Units
Household waste	1.38			0.47	1.65	0.82		5.98	Ton
Industry waste	2.58		0.43	0.83		1.60	47.50	13.95	Ton
(dry) sludge			50.37			22.0			Ton
Total waste	3.97	21.40	50.80	1.30	1.65	23.6	47.50	19.93	Ton

Table H is describing the average quantities of outputs, prices, gate fees and revenues per biogas plant divided per 1000 SEK. The data on the quantities of outputs is empirically based on the environmental reports. The amounts of gate fees are provided empirically from the plant. The prices of gas, heat and electricity are based on the commercial prices provided by the Swedish energy agency for the years 2004-2006. The biogas price is provided by the Swedish gas center. The exact prices used for calculating the revenues are provided in Appendix C.

Table H: Average revenues per biogas plant

Output per plant	Uppsala	Kalmar	Göteborg	Huddinge	Vetlanda 2005- 2006	Boden 2005- 2006	Linköping 2005-2006	Borås	Units
Total output per plant	2.8	9.5	50.8	0.597	0.54	4.5	45.9	6.5	MWh
Gas produced		0.674							MWh
Price of gas		0.22	0.26						SEK/MWh
Revenues from gas		147	13.31						SEK
Gate fees	0.6	0.15	0.16	0.575	0.550	0.150	0.138	0.500	SEK/ton

Revenues gatefees	2 381	3 433	8 129	756	908	3 543	6 532	14 949	SEK
Heat produced	0.071	2.6		0.597	0.028	3.1	3.6	1.4	MWh
Price of heat	0.598	0.603		0.603	0.609	0.609	0.604	0.603	SEK/Mwh
Revenues from heat	43	1.579		364	16	1 869	2 155	874	SEK
Biogas produced	238	72					6 230	387	nm3
Price of biogas	8	8					9	8	SEK/nm3
Revenues biogas	1 998	621					53 661	3.304	SEK
Digestrate	8.6	22	n.a.	0.830	n.a.	n.a.	49.6	n.a.	Ton
Total revenues	4 408	4 992	21 444	1 120	924	5 412	61 271	19 127	SEK

The emissions have been calculated based on outcomes of a literature study of Börjesson, (2006). The quantities of waste per year are calculated with the mentioned level of type of emissions related to the type of waste. The amount of emission per type of waste is provided in table K.

Table K: Amount of emission per waste type

	CO₂(kg)	NO_x(g)	CH₄ (g)	Source
Liquid manure *	3.6	11	1	Börjesson, 2006
Food industry waste **	3.6	11	1	
Municipal organic waste	15	46	4	
Tops and leaves residues	10	31	2.7	

* Emission related to the quantity of sludge are assumed as liquid manure

** Emissions related to the quantity of slaughterhouse waste are assumed as food industry waste

The levels of CO₂, NO_x and CH₄ have been summed per quantity of waste type per year. The costs of emissions are based on a study of Sundqvist et al, (2002). It is using the ORWARE model to calculate the price of emissions. This is a tool for environmental systems to analyse waste management. Prices of emissions are following. The prices for CO₂ are 400 SEK per ton, for NO_x 54 SEK/kg of CH₄ are 8.4 SEK/ton. Table K describes the inputs and costs for the eight plants. The total costs for example transport costs are divided in 1000 SEK and highlighted in black. Other costs are just given in their original amount. The data is based on different sources. The quantities of electricity, oil, gas and water are based on the environmental reports of the biogas plants. The averages per year of the labour costs have been requested at the biogas plants. Transport costs per unit have been based on a literature study of Börjesson, (2006).

Table K: Average costs per biogas plant

Input and costs	Uppsala	Kalmar	Göteborg	Huddinge	Vetlanda 2005- 2006	Boden 2005- 2006	Linköping 2005- 2006	Borås	Units
Transportcosts per unit	0.56	453		0.56	0.56	0.56		453	SEK/ton/km
Distance substrate	15		120	60	15	15			km
Substrate amount	3.97	428	50 810	1.315	1.650	23.620		3.406	ton
Total substrate transport costs	33	190	4 566	44.2	13.9	198		1 654	SEK
Transportcosts per unit digestate	0.74		0.56 ²⁰	20					SEK/ton/km
Distance digestate	10		15	70					km
Digestate amount	8 594		438	830					ton
Total digestate transport costs	63		3.7	1 162					SEK
Total transport costs	96	190	4 570	1 206	13.9	198	1 577	1 654	SEK
Total labour costs	1 008	800	864	302	180	800	4 504	2 250	SEK
Electricity volume	479	250	35 467	272	3	250	500	4 142	MWh
Kost of electricity	456	456	456	456	447	447	447	456	SEK/MWh
Total electricity costs	220	114	16 159	124	1.2	112	224	1 876	SEK
Oil volume	742	114	18			105	211	1 226	MWh
Costs of oil	216	216	498			237	237	216	SEK/MWh
Total costs of oil	163	24	9			25	50	232	SEK
Gas volume		4 474	22			4 343	8 660		MWh
Costs of gas		255	522			280	280		SEK/MWh
Total costs of gas		1 133	11			1 214	2 420		SEK
Total energy costs	383	1 272	16 165	124	1.2	1 351	2 694	2 107	SEK
Water	5.1	10	188	1.9	2.6	10	20	32.2	m3
Costs of water	16	16	16	16	15	15	15	16	SEK/m3
Total cost of water	83	160	3 007	29	39	155	309	503	SEK
Total cost of upgrading biogas	329	98					8 434	511	SEK
CO ₂	3	77	694	19	25	213	237	156	ton
Costs of CO ₂	400	400	400	400	400	400	400	400	SEK/ton
Total costs of Co2	1.2	32	277	7.5	9.9	85.2	94.8	62.3	SEK
NOx	92	235	1	58	76	225	177	478	kg
Costs of NOx	54	54	54	54	54	54	54	54	SEK/kg
Total costs of Nox	4.9	12.7	68	3.1	4.1	12.2	9.5	25.8	SEK
CH ₄	8	21	43	2	7	24	65	42	SEK
Costs of CH ₄	8	8	8	8	8	8	8	8	SEK/kg
Total costs of CH₄	0.068	0.180	0.358	0.016	0.055	0.199	0.545	0.354	SEK
Total emissions costs	16.9	44	278	3.5	14	98	105	89	SEK
Total costs	1 915	2 536	24 884	1 665	248	2 597	17 623	7 114	SEK

²⁰ Are the substrate transport costs of organic waste instead of digestate for the Göteborg plant