Profitability of optimizing biogas production in dairy farms

An experimental case study of a Swedish dairy farm´s usage of nitrogen in digestate as a nutrient resource for crop production

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Abstract

Biogas has the potential to be a contributor to sustainable energy for electricity, fuel, and heating. Because of that, there are different alternatives for biogas plants. In this study, a farm-based biogas plant for electricity production has been of interest. The related earnings and costs have been compared in eight different case farm alternatives to determine whether investing in a farm-based biogas plant is profitable. All case farm alternatives have had their base in milk production. Four of the case farm alternatives have had conventional agriculture, where two have had 200 dairy cows and 280 hectares of arable land, and two have had 400 dairy cows with 560 hectares of arable land. Each production size has compared one alternative without biogas production and one alternative with biogas production. The same structure has been used for the remaining four case farm alternatives with an organic agriculture focus.

The findings have been found using linear optimization models for each of the eight case farm alternatives. The results showed that the alternatives with 200 dairy cows with 280 hectares of arable land and biogas production were marginally profitable regardless of agricultural focus compared to the alternative with the same number of dairy cows, hectares of arable land, and agricultural focus. In the conventional alternative, the case farm with biogas production increased their overall profit with approximately 30 000 SEK compared to the alternative without biogas production. In the organic alternative the profit from biogas production increased more, as the difference was approximately 150 000 SEK.

When alternatives with 400 dairy cows and 560 hectares of arable land was investigated, a farm-based biogas plant proved profitable and contributed significantly to the overall result. In the conventional alternative, the biogas plant contributed with roughly 600 000 SEK to the overall profit, compared with approximately 830 000 SEK. When comparing all the eight case farm alternatives, the conventional agricultural focus proved more profitable than their organic counterparts. It could be explained by higher yield per hectare, the cheaper cost for feed ration inputs, the higher price for sales of calves and less cost per additional nitrogen needed.

The main difference between the case farm alternatives without biogas production compared to those with it is that the cost for nitrogen is much higher when not having biogas production. That is because the digestate from the biogas production, given the study's substrate mixture, contains a higher percentage of nitrogen per tonne.

Keywords: Biogas, Optimization, Profitability, Economic effects, Organic, Conventional, Agriculture, Dairy farms, Digestate, Nitrogen

Sammanfattning

Biogas har potential att bidra till hållbar energi för el, bränsle och värme. Till följd av det finns det olika alternativ för biogasanläggningar. I denna studie har en gårdsbaserad biogasanläggning för elproduktion varit av intresse. De relaterade intäkterna och kostnaderna har jämförts i åtta olika fallgårdsalternativ för att avgöra om det är lönsamt att investera i en gårdsbaserad biogasanläggning. Alla fallgårdsalternativ har haft sin bas i mjölkproduktion. Fyra av fallgårdsalternativen har haft konventionellt jordbruk, där två har haft 200 mjölkkor och 280 hektar åker och två har haft 400 mjölkkor med 560 hektar åker. Varje produktionsstorlek har jämfört ett alternativ utan biogasproduktion och ett alternativ med biogasproduktion. Samma struktur har använts för de återstående fyra fallgårdsalternativen med inriktning på ekologiskt jordbruk.

Fynden har hittats med hjälp av linjära optimeringsmodeller för vart och ett av de åtta fallgårdsalternativen. Resultaten visade att alternativen med 200 mjölkkor med 280 hektar åker och biogasproduktion var marginellt lönsamma oavsett jordbruksinriktning jämfört med alternativet med samma antal mjölkkor, hektar åker och jordbruksinriktning. I det konventionella alternativet ökade fallgården med biogasproduktion sin totala vinst med cirka 30 000 SEK jämfört med alternativet utan biogasproduktion. I det ekologiska alternativet ökade vinsten från biogasproduktion mer, då skillnaden var cirka 150 000 kr.

När alternativ med 400 mjölkkor och 560 hektar åkermark undersöktes visade sig en gårdsbaserad biogasanläggning vara lönsam och bidrog väsentligt till det totala resultatet. I det konventionella alternativet bidrog biogasanläggningen med cirka 600 000 SEK till den totala vinsten, jämfört med cirka 830 000 SEK. När man jämförde alla de åtta fallgårdsalternativen visade det sig att fokus på konventionellt jordbruk var mer lönsamt än deras ekologiska motsvarigheter. Det kan förklaras av högre avkastning per hektar, den billigare kostnaden för foderransoner, det högre priset för försäljning av kalvar och lägre kostnad per ytterligare kväve som behövs.

Den största skillnaden mellan fallgårdsalternativen utan biogasproduktion jämfört med de med den är att kostnaden för kväve är mycket högre när man inte har biogasproduktion. Det beror på att rötresterna från biogasproduktionen, givet studiens substratblandning, innehåller en högre andel kväve per ton.

Nyckelord: Biogas, Optimering, Lönsamhet, Ekonomiska effekter, Ekologiskt, Konventionellt, Lantbruk, Mjölkgårdar, Rötrester, Kväve

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Abbreviations

FONC	First order necessary condition
GNS	Götalands Norra Slättbygder
LCH4/kg	Liquid methane per kg
REA	renewable energy ac
PEMFC	Proton Exchange Membrane Fuel Cell
SLU	Swedish University of Agricultural Sciences
VS	Volatile solids
SEK	Swedish krona, the currency of Sweden
ECM	Energy Corrected Milk
DM	Dry matter
EU	European Union

1. Introduction

The background of the study's subject is discussed in this chapter, forming the foundation for the problem statement. The study's aim and research questions are developed in response to the problem background. The thesis delimitations and outline are then explained to help the reader understand the structure and methodology of the study.

1.1 Problem background

The synergistic effect of climate change and the long-term, continuous price rise of fossil fuels compel the production and use of renewable energy globally and nationally (Meggyes & Nagy. 2012; FRED. 2023).

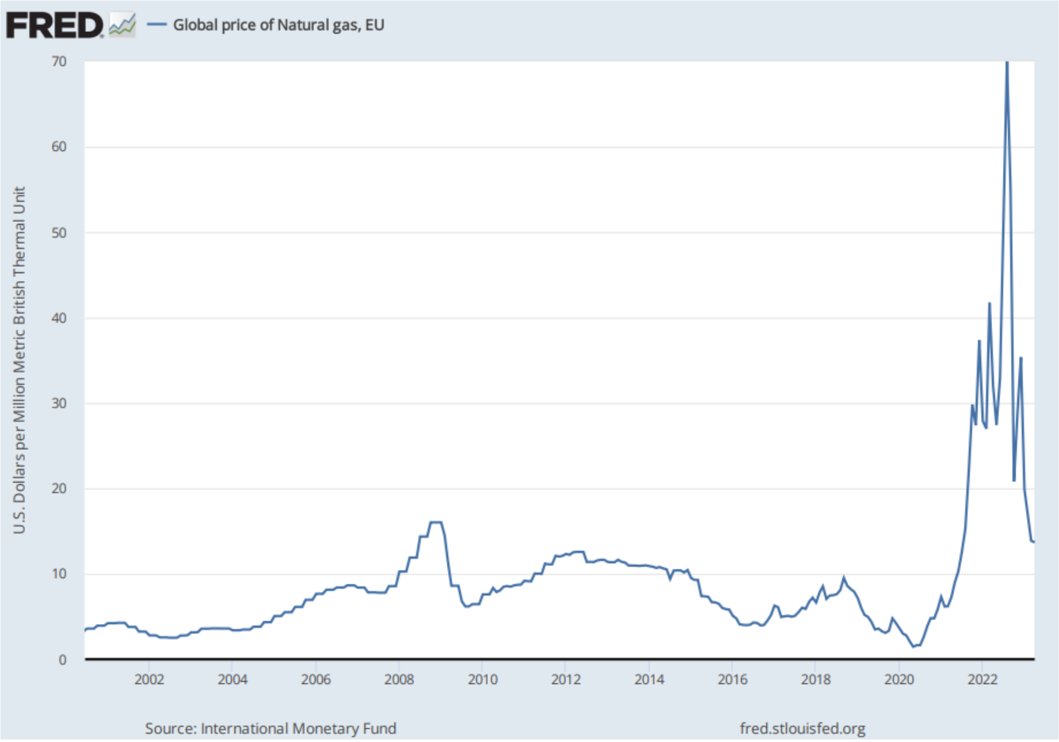


Figure 1. Global price of Natural gas in EU 2000-2023 (FRED. 2023).

The demand for fossil free energy globally is continually increasing and one way of producing more sustainable energy for electricity, heating and fuel is trough biogas production (Weiland. 2009). The primary goals of expanding renewable energy sources are to improve energy supply security or, in the best-case scenario, to achieve complete energy independence (Meggyes and Nagy. 2012). To achieve this, there is more to develop in exploiting existing waste that is not fully utilized to whatever value is contained in that waste. Meggyes and Nagy (2012) further explain that in addition to its energy benefits, biogas is essential for environmental, economic, and regulatory reasons since it may help meet energy needs while protecting the environment. This is possible by utilizing traditional and renewable energy sources in a coordinated manner. Although the focus is on the environment and waste disposal, developing a sophisticated biogas generation and utilization system for energy is vital for meeting the future demand of renewable energy. Waste management and environmental energy use must be linked at the system's core (ibid.). Feiz et al. (2022) mention that there are 97 biogas plants in Sweden, 54 of which are located on farms, excluding those that are a part of wastewater treatment facilities or collect biogas from landfills.

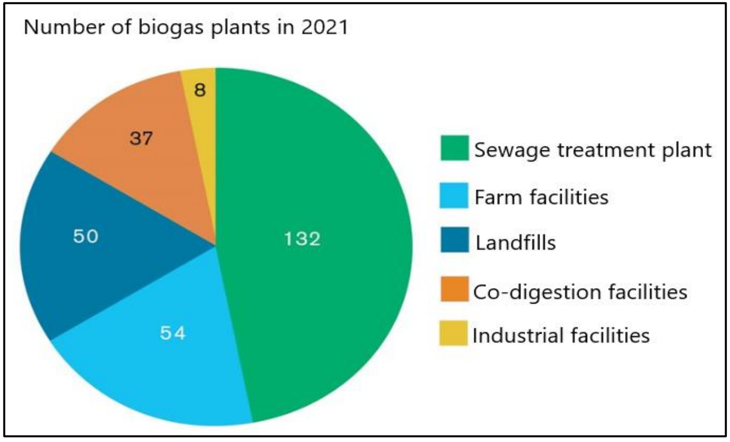


Figure 2. Number of biogas plants in Sweden 2021 (Energigas, 2023) (own rendering).

Ahlberg-Eliasson et al. (2017) mention that an effective method for producing fossil-free energy, allowing nutrient recycling, and lowering emissions of greenhouse gases is the production of biogas from agricultural waste streams. However, biogas production from agricultural substrates is far from its full potential (ibid.). However, how could this production be optimized and meet the new demands for fossil-free energy? Energigas (2023), a member-financed industry organization that works for increased use of energy gases, explains that the farm facilities combined production of biogas in 2021 was 78 GWh, almost exclusively from manure. The development between 2005-2021 shows a steady incline in the farm's total capacity to produce biogas, but how could this capacity be even more effective?

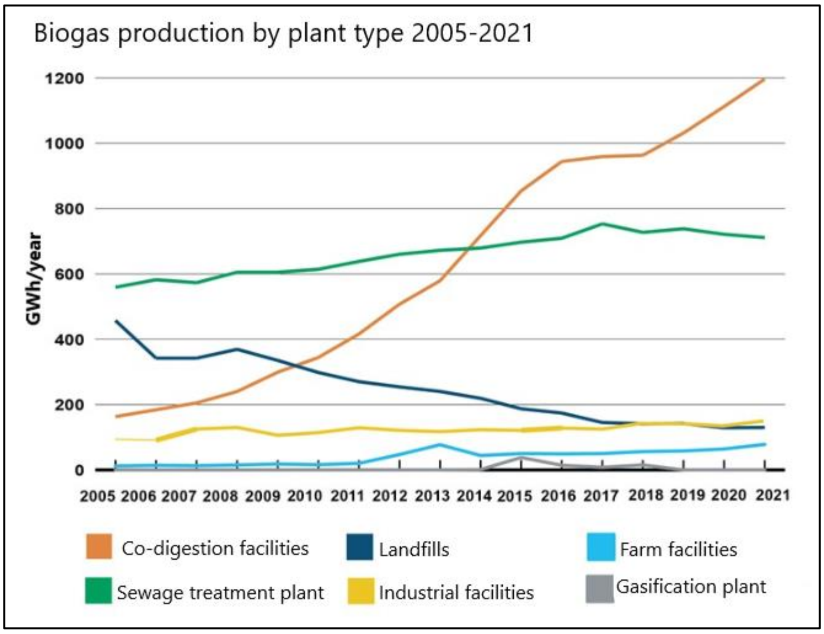


Figure 3. Biogas production by plant type in Sweden 2005-2021 (Energigas, 2023) (own rendering).

Waste and residual items from homes, businesses and agriculture create biogas (Energigas. 2023). The biogas yield varies substantially depending on the substrate and its Dry Matter. The biogas production can be divided among various substrates by dividing it based on reported substrate amounts and then utilizing assumed biogas yields. According to estimates, manure, food waste and sewage sludge together account for 31% of all biogas generation (manure stands for 11%). Energigas (2023) mentions that it is essential to remember that there is much ambiguity surrounding this distribution.

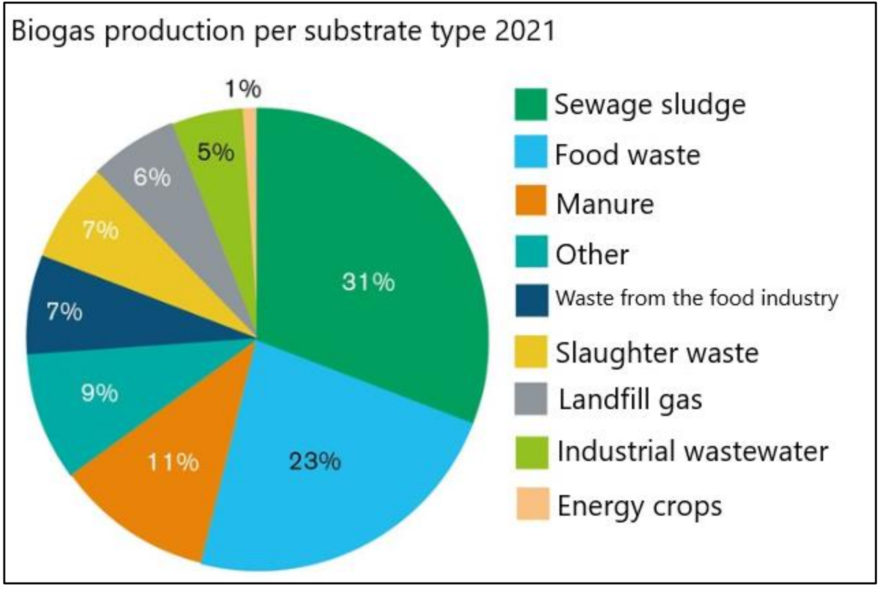


Figure 4. Biogas production per substrate type in Sweden 2021 (Energigas, 2023) (own rendering).

The digestion facilities also create a nutrient-rich digestate that can be utilized as fertilizer in addition to biogas (Schnürer. 2016). This way, essential nutrients are returned to crops, and the cycle is completed. It decreases the requirement for imported mineral fertilizers and lowers agricultural CO2 emissions (Energigas. 2023). 87 percent of the 3 million tonnes of digestate (wet weight) produced in 2021 were used as fertilizer for farming. Almost all the digestate (biofertilizer) from agricultural and co-digestion facilities was utilized as fertilizer, and 39% of the digestate (digestion sludge) from sewage treatment plants was used similarly. The remainder was primarily used as building dirt or for final landfill covering. A small volume of the industrial facilities' digestate was used as fertilizer (ibid.).

It´s also noticed that the development of biogas facilities in Sweden could be greatly affected by the judgment of the Court of Justice of the European Union in the case T-626/20 of Landwärme GmbH v. The kingdom of Sweden (2022). It was decided that Sweden´s tax exemptions which compensates for additional costs during production would be repealed. If this would be implemented, it would result in a price increase of approximately SEK 4.7-5/kg biogas including VAT (SvenskBiogas. 2023). This would greatly affect the profitability of biogas production on farms in Sweden, which will be further discussed in chapter 6.

This shows the importance of digestate for agriculture and how politics greatly affect future biogas production. But how could the optimal production of manure be implemented in biogas production, resulting in an excellent value digestate for agricultural farming to show its future worth?

1.2 Problem statement

Previous studies that mention biogas production at farms could be expressed by the work of Svensson et al. (2006). The author's study discussed the most critical parameters for financial feasibility when producing biogas from crop residues. This study could be a leading example of how to go forward with biogas production on a farm-scale level, but to make a more transparent view of the issue, we need to include all parts of a farm's production. To achieve even more transparency, how could biogas production be affected by which type of farming (conventional or organic) is implemented? In the literature, there are few studies comparing the impact of the conventional and organic dairy cow production systems on biogas output. One of these unique studies was conducted by Vedrenne et al. (2008), who compared the impact of various feeding schedules under conventional and organic dairy cow management on biogas production. Dairy cows fed a conventional diet produced 296 liquid methane per kg (LCH4/kg) of volatile solids (VS). Observed production for the cows fed organically was 234 LCH4/kg of VS. These outcomes are consistent with the results of Matos et al. (2017), who found that treatments in which cows were fed conventionally resulted in higher methane generation. This shows some differences between conventional and organic dairy cow production. Still, it is also important to showcase the effects of these two different options in crop cultivation and biogas production when all parts are integrated.

By developing an optimization model from a quantitative perspective would make it simpler to comprehend the relationship between these types of agriculture and how it is significant for other farms in this context by quantitatively studying manure from cows in the dairy farm sector and how the digestate could be used at an optimal level for conventional and organic farming. This would also help to benefit creating a whole farm system model. Whole farm system modelling, according to Crosson et al. (2011), was developed to describe and quantify the internal cycling of materials (e.g., fertilizers, animal feed, chemicals) and their constituents, as well as material and nutrient exchange between the farming system and its environment. A whole farm approach has the potential to be a powerful tool for predicting the effects of management changes. Ekman (1995) used whole farm system when conducting research about similar subjects being brought up in this research, for example feed ration, acreage for feed production, and dairy cows, and found whole farm system modelling to be useful to analyse the overall result.

This study could be helpful from an empirical and theoretical standpoint by shedding more light on how manure from dairy cows could impact the biogas-industry if the farm-scale bioproduction would be enlarged concerning the sustainability of producing more fossil-free fuels. The work may theoretically be pertinent to studying biogas at a farm level and developing insights into biogas importance and dynamic capabilities in the agricultural sector.

1.3 Aim and research questions

This study compares the economic conditions for conventional and organic agriculture´s utilization of manure and nitrogen levels in digestate when considering milk production, crop cultivation and biogas production. These three types of production will be investigated independently and then integrated. The following research questions are addressed to answer the aim:

1. *How can the nitrogen levels in digestate be used in the most profitable way in both organic and conventional farming based on milk production?*

2. *How can the profitability of biogas production from the dairy farm be affected by the produced manure and purchased poultry manure?*

3. *How is the profitability affected by cropping system and plant size the dairy farm dispose?*

To answer the research questions, two optimization models are constructed to explore the optimization of milk production, crop cultivation and biogas production. A conventional and organic alternative system will be implemented in the models to compare how the economic result differs between two types of agricultural systems.

1.4 Delimitations

To develop a Swedish viewpoint on the issue, it is only natural to examine Swedish farmers because the study intends to develop the issue from a Swedish context. As the study aims to investigate biogas production potential at dairy farms, the study is narrowed down to areas in Sweden with many dairy cows. As most dairy cows in Sweden are found in Västra Götaland County (Juverportalen. 2023), this study consequently chose to adapt a fictional farm from this area. More specifically, as figure 5 shows, the production area in which the dairy farm is situated is Götalands norra slättbygder (GNS). The motivation behind this choice is further elaborated in chapter 5.1. Investigating the environmentally optimal value of manure usage is another problem not covered in this master's thesis. The rations per cow will focus mainly on the produced fodder crops rather than all the extra supplements that must be included. This is motivated by this study's frames that focus mainly on significant aspects that can be significant for biogas production at a farm level.

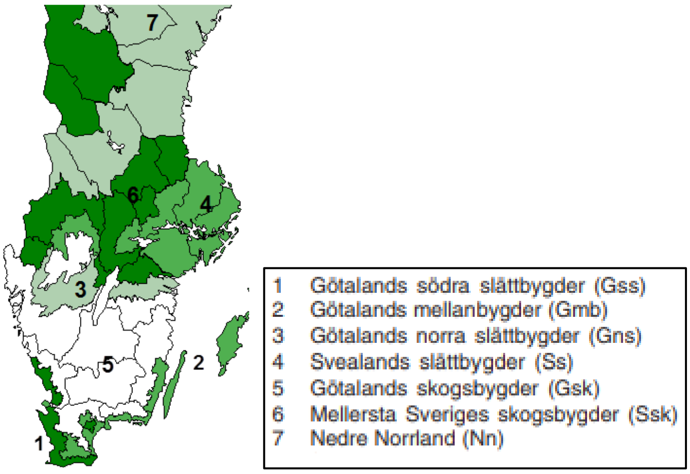
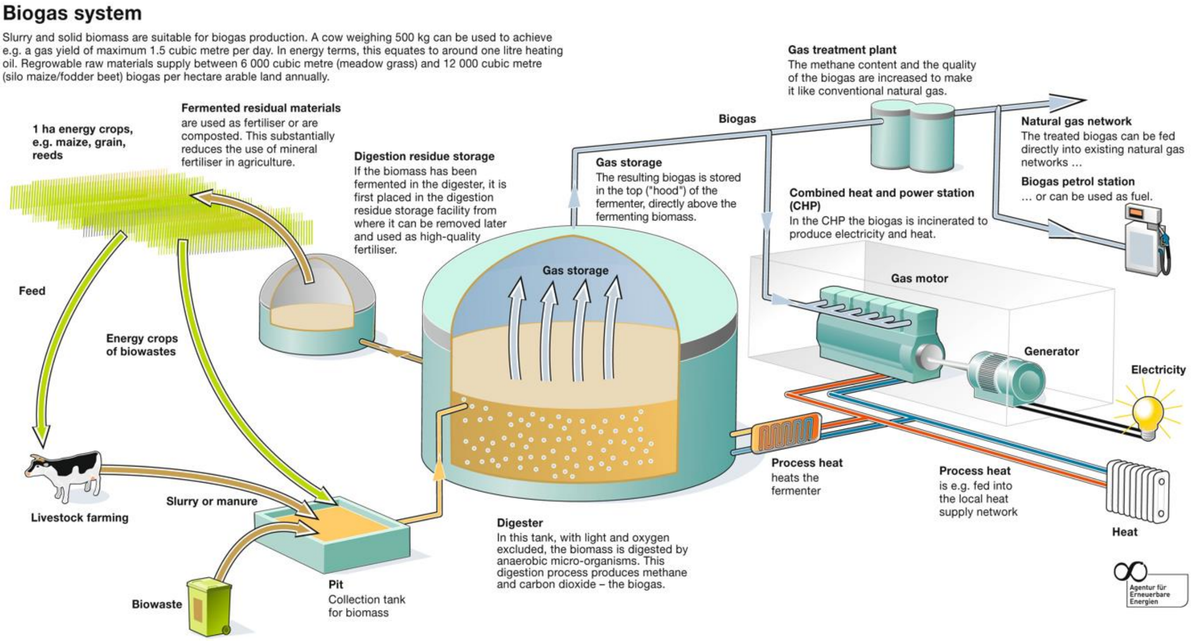


Figure 5. Production areas of southern Sweden (Jordbruksverket. n.d.) (own rendering).

As the data collection of this thesis is restricted to only one farm, it excludes the most recent data since it is not yet available to access for this thesis.

This thesis will only cover the production stage to the point where the biogas is produced and sold when the residues are used for fertilization. As a result, we will not focus on where the biogas is delivered in the production chain. The biogas mixture will consist of only manure from dairy cows and poultry manure, this is due to raise the nitrogen levels in the digestate, as poultry manure consist of higher concentrations of nitrogen. No residues from the arable land will be digested. The study will investigate how manure and digestate can be used to cover the farms nitrogen need for the crops grown. Eventual left-over manure or digestate is not covered to be sold. The study is also limited to only concern nitrogen levels of the digestate as it´s the most influential for the digestate and manure in terms of nutritional values.

Another delimitation is that the authors of the study does not intend to study how differences in feed rations will affect the manure production. Although there are differences in the feed rations, the produced amount of manure from dairy cows will in this study be the same.



Biogas system

Slurry and solid biomass are suitable for biogas production. A cow weighing 500 kg can be used to achieve e.g. a gas yield of maximum 1.5 cubic metre per day. In energy terms, this equates to around one litre heating oil. Regrowable raw materials supply between 6 000 cubic metre (meadow grass) and 12 000 cubic metre (silo maize/fodder beet) biogas per hectare arable land annually.

Fermented residual materials are used as fertiliser or are composted. This substantially reduces the use of mineral fertiliser in agriculture.

Digestion residue storage If the biomass has been fermented in the digester, it is first placed in the digestion residue storage facility from where it can be removed later and used as high-quality fertiliser.

Gas storage The resulting biogas is stored in the top ("hood") of the fermenter, directly above the fermenting biomass.

Gas treatment plant The methane content and the quality of the biogas are increased to make it like conventional natural gas.

Natural gas network The treated biogas can be fed directly into existing natural gas networks …

Biogas petrol station … or can be used as fuel.

Combined heat and power station (CHP) In the CHP the biogas is incinerated to produce electricity and heat.

Process heat heats the fermenter

Process heat is e.g. fed into the local heat supply network

Digester In this tank, with light and oxygen excluded, the biomass is digested by anaerobic micro-organisms. This digestion process produces methane and carbon dioxide – the biogas.

Pit Collection tank for biomass

Figure 6. Functions of a biogas plant (PlanET. n.d.).

1.5 Structure of the report

This section will present the report's structure, as shown in Figure 7. The second chapter presents a literature review that covers relevant articles that will provide a deeper understanding of the research field. In chapter three, the theoretical framework that was used in this investigation will be described. The methods used in this paper are described in chapter four. The results and empirical findings are presented in the fifth chapter. The findings are analysed and discussed in chapter six. The conclusions are presented in chapter seven.

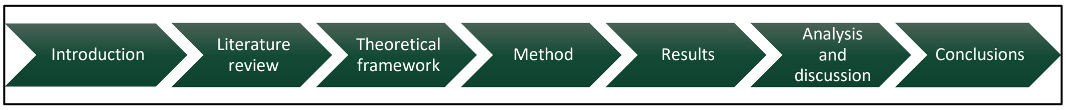


Figure 7. The structure of the report (Own illustration).

2. Literature review

This chapter will give a critical and in-depth review of the existing research on agricultural biogas production, emphasizing studies that have looked at Swedish and international agricultural biogas optimization. This chapter covers several optimization methodologies, where economic models are discussed. Studies concerning the market for biogas from farms will also be presented. The goal is to identify the strategies best suited to this thesis. The conclusion of this chapter provides an overview of the chapter's discussed literature. Before beginning any new research, it is critical to know prior research in the studied area (Bryman & Bell. 2017). Any literature review is carried out before a study to find the most recent publications in a field of interest to establish a solid theoretical foundation, advance knowledge, and improve understanding (ibid.). The peer-reviewed articles and books from which data has been gathered are collected from several databases, including the Swedish University of Agriculture´s search engine Primo, Google scholar & Web of Science.

2.1 Optimizing biogas at farms

To understand the optimization of biogas at farms, it is essential to review previous relevant research that has been gathered. The mixtures of which biogas is produced can significantly impact the end-product, as Uranga-Soto et al. (2018) investigated. The authors found that through co-digestion, various blends of maize stover, rumen content, and feedlot manure were used to produce biogas that contained a significant amount of methane. Gas chromatography was used to identify and quantify the biogas components in each mixture. For 15 days, total biogas and methane output were assessed for ten combinations. Using the response surface approach, the ideal mixture was discovered. The mixture, including 75% feedlot manure, 12.5% ruminal content, and 12.5% maize stover, produced the highest biogas and methane yields, with a 126 ml CH4g1 VS and a 7.5% VS content (ibid.). These results demonstrate the potential of co-digestion of livestock farming wastes as a sustainable energy source. When discussing biogas optimization, some research reveals that maize silage could be an excellent substrate to consider when producing biogas (Bilandžija et al. 2013). The optimization could also be beneficial for the farm itself. Guan et al. (2014) mention in their research that integrated

Proton Exchange Membrane Fuel Cells (PEMFC) could significantly impact how to achieve self-sufficiency. According to the findings, a dairy farm with 300 milking cows can produce enough wet manure to support a biogas plant producing 1280 MWh of biogas annually. Based on biogas production, a PEMFC-CHP with a 40% electrical efficiency stack generates 360 MWh of electricity and 680 MWh of heat annually, sufficient to meet the system's energy needs (ibid.). The PEMFC-CHP system's overall efficiency is 82%. If the PEMFC-CHP has the aforementioned electrical efficiency, the integrated PEMFC-CHP, dairy farm, and biogas plant could make the dairy farm and the biogas plant sustainably self-sufficient (ibid.). This research shows the potential of investing in biogas for self-sufficiency, which connects to chapter 2.2, which treats some different economic models for biogas production at a farm level.

2.2 Economically linked models for agricultural biogas production

Karlsson et al. (2019) mention that farm-based biogas production has the potential to impact the environment, society and the economy positively since it is a promising renewable energy technology. However, due to high investment costs and intense price competition with fossil fuels, Swedish farmers who engage in this business find it difficult to profit. Reorganizing the activity through developing the business model (BM) in the direction of sustainability is one way to deal with this issue, accordingly to the authors (ibid.). A research team used an action research methodology in this study to suggest solutions for the financial issues at a farm cooperative that intended to expand its farm-based biogas production. The authors (ibid.) emphasize the network idea's value for sustainable BM development in general. An efficient strategy to boost long-term financial profit and encourage the expansion of a company, a network, or an industry is through collaborative business modelling to develop network-level BMs that address environmental and social challenges for and with stakeholders.

Rivza & Rivza (2012) developed a dynamic model which was constructed for a farm that generates biogas from agricultural biomass. A complete cycle of agricultural production is included in the dynamic model, which is made up of several interconnected building blocks: production (grain, biomass, milk, meat, biogas, heat, electricity), finances (investments, income, outcomes, subsidies, loans), resources (arable land, farms, bioreactors, technical equipment, workforce), and risks. This model helps display renewable production's sustainable and economic efficiency in a specific time frame (ibid.).

Wu et al. (2016) provide a spreadsheet calculator for UK-based farm-fed anaerobic digesters to predict biogas production, operational revenue and costs. Although complex biogas production models can be applied to farm-fed anaerobic digesters, this is frequently not practicable, according to the authors. This is because few measuring tools are available, there are financial limitations, and the operators lack anaerobic digesting expertise.

Putmai et al. (2020) mention that the typical all-in/all-out batch management method used in most small- to medium-sized swine farms frequently results in an imbalance between the farm's power needs and its ability to generate electricity through biogas systems. Putmai et al. (ibid.) have developed models to prevent an unneeded lengthy lag period in the digester. This allows for more consistent anaerobic digestion performance and more uniformly distributed biogas output. The authors made a sensitivity analysis demonstrating how variations in several essential criteria, such as the energy repurchase price, may affect the profitability of biogas facilities. According to the authors, shifted farm management may substantially decrease operating expenses without calling for further investment.

2.3 Market for biogas agriculture

Torrijos (2016) describes a mixed future market for biogas in Europe. In some countries, Germany, and Italy, for example, changes and cuts of support schemes have led to fewer investors and decreased the market advance for biogas. These changes and cuts were recently implemented at the time of Torrijos's study, which meant that an increase in the market appeared unlikely in those countries. However, in France and Great Britain, the biogas market is described as better, with both countries having biogas-friendly policies in place (ibid.)

Piwowar et al. (2016) provided insight from the Polish biogas market. Even though the potential is great, the legal, economic, institutional, and technological barriers hinder the biogas market from reaching its full potential. At the time of the study, the market situation reached a standstill. Sobczak et al. (2022) also researched biogas production in Poland and described a similar market in 2022. They describe the market as slowly developing, meaning low incentive provided by the government is the reason.

From a Swedish perspective, Mårtensson (2007) has provided some insight. At the time of his study, the biogas market was described as bright due to its environmental benefits as a substitute for energy in heating, fuel, and electricity. However, as Piwowar et al. (2016) described, Mårtensson (2007) also saw a lack of interest from the government. This was demonstrated in a lack of far-reaching support packages, which could have created a less risky market situation for the investors. Mårtensson (ibid.) meant that the risky market situation created a lack of interest from investors.

Insight into how to implement a sustainable market for biogas was noticed by Thrän et al. (2020), who means that the biogas market can only reach its potential if governed appropriately. Based on that belief, they investigated the governance and sustainability of the biggest agricultural biogas market in the world, the German national biogas market. They mean that without regulations on the market, it could lead to unwanted changes in land use, which can affect agriculture, grasslands, forests, and water availability and quality (ibid.). For the German biogas market, the legalization of named renewable energy act (REA) is named as an important one. It is legislation governed by both the agricultural and energy sector. REA has created favourable conditions for biogas for electricity markets and has conducted measures to fund biogas investors through remuneration (ibid.). This has made it easier for new actors to enter the biogas market. The effects of REA have been positive for the German biogas market, as it has successfully promoted developments in the market of renewable energy sources. An explanation is that rules and legislations are periodically adjusted and updated to the current market situation (ibid.).

2.4 Summary of literature

The literature that has been determined to be the most relevant to the development of this study is presented in Table 1. The review of the literature has influenced the theoretical and methodological approach. However, there is a lack of relevant studies addressing the research questions. Although the literature did not specifically deal with a linear problem with profit maximization, earlier studies were able to shed light on how the economic aspects of biogas modelling on agricultural farms could function (Rivza & Rivza. 2012). The authors made an optimization model that showed some aspects of biogas production (ibid.), but not how the digestate could have a significant impact on the farms crop production as this study aims to answer. This demonstrates the significance of this study's objectives and research questions since it broadens a new path for research about the profitability of producing biogas and using the digestate on dairy farms in Sweden.

Table 1. Alphabetical summary of the literature that concerns biogas production at farms, economic models for agricultural biogas and economical measures.

Author	**Subject**	**Region**	**Method**
Bilandžija et al. (2013)	Biogas production on Croatian dairy farms	Croatia	Quantitative
Guan et al. (2014)	Performance of an integrated PEMFC at a dairy farm and biogas plant system	Sweden	Quantitative modelling
Karlsson et al. (2019)	Business modelling in farm-based biogas production	Sweden	Qualitative
Mårtensson (2007)	Handbook of biogas	Sweden	Qualitative
Piwowar et al. (2016)	Agricultural biogas plant in Poland	Poland	Qualitative
Putmai et al. (2020)	Economic Analysis of Swine Farm Management with focus on biogas production	Asia	Quantitative modelling
Rivza & Rivza (2012)	Farm optimization and biogas production	Latvia	Quantitative modelling
Sobczak et al. (2022)	Economic conditions of using biodegradable waste for biogas	EU	Qualitative
Thrän et al. (2020)	Governance of sustainability in the German biogas sector	Germany	Qualitative
Torrijos (2016)	State development of biogas production in Europe	EU	Qualitative
Wu et al. (2016)	Biogas production and economic measures for UK-based farm-fed anaerobic digesters	United Kingdom	Quantitative
Uranga-Soto et al. (2018)	Optimizing feedstock mixtures	North America	Quantitative

3. Theoretical framework

This chapter presents theories that are the foundation for developing the study's empirical model. The research examines theories of production economics, profit maximization, and profit maximization of dairy farms.

Classical microeconomic theory is the study's theoretical foundation (Pindyck & Rubinfeld. 2009). The behaviour of individual economic entities is the focus of microeconomics. It is more specifically concerned with the economic decisions made by market participants. Actors strive to maximize utility, which is frequently synonymous with profit maximization (Debertin. 2012). The constant challenge for any firm manager is to allocate scarce resources profitably. The commodity's production function and input and output prices influence the manager's behaviour. Other theoretical perspectives are then offered, along with arguments for and against the validity of the theoretical framework used in this research.

3.1 Production function

The concept of the production function, which describes how inputs are consumed concerning the commodity produced, is an important management tool (Debertin. 2012). The information provided by the production function is required to maximize profit. The production function has information about each input's contribution to the product's assembly. In conjunction with input and commodity prices, this relationship provides information on allocating resources to specific manufacturing activities. The equation represents the general expression for the production function (1).

$$Y = f(x) \tag{1}$$

The output level, y, is expressed as a product of the input amount, x, by the production function. This expression is valid for any x value equal to or greater than zero, which provides a value for y. However, the most simplified expression of a production function is equation (1) (Debertin. 2012). The equation represents another general expression for a more comprehensive illustration of the production function (2). Few firms have a production function in which a commodity uses only one resource in production. However, the theoretical implications of the general expression remain valid for far more complex production functions.

$$y = f(x_i|u_i) \qquad (2)$$

This function distinguishes between variable input, x_i, and fixed input, u_i. Feed is an example of a variable input in dairy production (Flaten. 2001). On the other hand, buildings and land are frequently classified as fixed inputs. The ability to change employed amounts determines the distinction between variable and fixed inputs (Pindyck & Rubinfeld. 2009). A variable input is traditionally defined as an input that can be managed in volume when market conditions change.
Conversely, the manager usually cannot change the number of fixed resources employed. However, the distinction also has a time component. After a certain amount of time, all resources become variable. Nonetheless, dairy farmers operate in a market with highly volatile prices (ibid.). This environment limits the possibilities for proactive planning. As a result, a large portion of the cost of a dairy farm is traditionally regarded as fixed costs.

3.2 Profit maximization

Profit maximization is divided into two distinct dimensions: cost minimization and revenue maximization. To achieve the goal, a production level that meets both the profit maximization and cost minimization dimensions must be identified (Debertin. 2012). Equation (3) depicts a generalized maximization problem.

$$max\ \Pi = P_y * Y - P_x * x_i - FC \qquad s.t. Y \leq f(X_i|U_i) \qquad (3)$$

$$Y \leq 0 X_i \leq 0 U_i \leq 0$$

In this instance, the total revenues and total costs determine the profit, which is shown by the symbol (Π). The quantity produced (Y) and the commodity price (P_y) are the two factors that determine total revenues. Two factors, fixed and variable, influence total cost (Debertin. 2012). The fixed cost is indicated by the letter (FC) and is independent of the production level. The input price (P_x), and the quantity of allocated input (X_i), affect the variable cost. Debertin (2012) asserts that a more all-encompassing strategy might be profit maximization by ensuring that output from applied input is maximized. This strategy could be expressed similarly to the equation (3) display.

$$max\ \Pi = P_y * f x_i - P_x * x_i - FC \qquad (4)$$

Three criteria must be met to create a theoretical model for the profit maximization of a typical dairy producer (Flaten. 2001): First, the problem must have a continuous and recognizable production function. Second, there is divisibility in the link between inputs and outputs. Third, the relationship described in the production function may be homogeneous to the degree of one. To sustain long-term successful production, the profits of an employed input must be more than the cost. $P_y * fx_i - P_x * x_i + FC$. The expression can also be written as:

$$P_y > \frac{P_x x + FC}{f(x)} \tag{5}$$

The general expression for production's long-term profitability is shown in Equation (5). (Flaten. 2001). The goal is accomplished when the commodity price exceeds AC's average unit production cost. If the output price covers the variable costs, AVC; $P_y > \frac{P_x x+FC}{f(x)}$, production would still be economically viable in a time of financial hardship. In this case, a portion of the fixed costs, which are present whether or not production is running, are covered by the production surplus (Flaten. 2001). Therefore, even if revenues decline, this action limits the losses.

To determine the profit-maximizing production level, the derivative from equation (5) must be calculated (Debertin. 2012). The FONC, or first-order necessary condition, is calculated by partially differentiating equation (5) subject to x_i. The FONC contains information about how to use an input best. Furthermore, it expresses how profit changes when one more input unit is. x_i is added. The FONC is typically written as:

$$\frac{\partial \Pi}{\partial_{x_i}} = P_y f'(x_i) - P_{x_i} = 0 \tag{6}$$

The optimal input use is not constrained by FC, as shown in Equation (6) (Flaten, 2001). The relationship can be expressed simply as:

$$P_y MPP_x = P_x \tag{7}$$

Equation (7) illustrates the prerequisite for resource allocation when attempting to maximize profits or minimize costs (Debertin. 2012). The extreme that the production level leads to is not revealed by meeting the condition.

3.3 Profit maximization dairy farmer

So far, the fundamental theory of profit maximization in firms has been explained. However, the profit-maximizing equation (4) must be more detailed in order to highlight the unique circumstances that a dairy farmer face (Debertin. 2012). Equation (8) depicts a typical dairy firm's revenue and cost streams, albeit in a simplified form, to cover the study's theoretical foundation. Profit as a concept is determined by a summary of revenues and fewer cost items (Pindyck & Rubinfeld. 2009). Most of a dairy farm's revenue comes from milk sales (Debertin. 2012). Equation (8) illustrates this. Still, some revenue comes from grain production, which relies on feed requirements that are already met. The farmer has the option of purchasing grain from crop growers. The trade balance is visible indirectly in the second entity of equation (8) and is an essential component if the farmer grows and purchases grain. This thesis does not cover other marketable commodities produced on a dairy farm because feed strategies do not affect them. The primary cost item is feed acquisition, which can be accomplished in two ways. The feed can be produced on the farm or purchased commercially. Available land in crop production can be used to grow forage or grain (Flaten. 2001). While grain harvests can be sold as commodities, due to a lack of a functional market, cultivated forage is solely used as feed. From both Flaten (2001) and mainly Johansson & Persson (2015), the following profit function (8) was developed.

$$\underset{N, X_k, X_g, A_k}{Max}\ \Pi = P_y f\left(X_k, X_g\right) N + P_b BN - C_b BN + P_k\left(A_k Y_k - N X_k\right) - C_k A_k - C_g A_g - N X_a - FC \tag{8}$$

$$\text{s.t.} \qquad A_k + A_g \leq \overline{A} \qquad\qquad N X_g = A_g Y_g$$

$$N\left(e_k X_k + e_g X_g\right) \geq \overline{E}$$

Because using limited resources governs the farmer's business style, the profit function (8) is likewise constrained by some constraints. A dairy farmer's two critical limits are available acreage and nutritional needs for milk production. These two limits are essential for the optimization model presented in Chapter 4.

N =Number of cows in production
P_b =Price of produced biogas
B =Total amount of biogas produced
C_b =Cost of biogas
$f(K_i)$ =Production function for milk production
P_k =Price of feed grain per Kg DM
A_k =Land for grain production

A_g =Land for forage or silage production
Y_k =Yield of grain production, kg per ha
Y_g =Yield of forage or silage production, kg per ha
X_k =Kg of feed grain per cow
X_g =Kg of forage or silage per cow
FC =Total fixed costs
$\overline{A}$ =Total land
e_k =Nutritional supply of one Kg DM of feed grain
e_g =Nutritional supply of one Kg DM of forage or silage
$\overline{E}$ =Total nutritional requirement
λ_1 =Shadow price of land
λ_2 =Shadow price of nutritional requirements

3.4 Lagrange function

The Lagrange function is a helpful tool to enable the mathematical programming approach of this study, as it embraces the complexity of a profit maximization problem when having scant resources (Debertin. 1986). As noted by Johansson and Persson (2015. p15) *“the Lagrange function includes mathematical expressions for implications of fixed volume for key resources”*. The impact of the farm’s restrictions is expressed by λ, which is the Lagrange multiplier or shadow price. Furthermore, this is used to state the marginal cost, MC, at a specific level of production on the farm (Debertin. 1986). A basic rule within the Lagrange function is that if the shadow price equals zero, it means that the restricted amount of the resource is sufficient. That means that the profit is not affected negatively by the restricted amount. The opposite can be concluded if the constraint is binding, and the shadow price then express how the profit is affected by one more or one less of the binding resource (Johansson & Persson. 2015).

$$\begin{aligned} Max\ L = {} & P_y f\left(X_k, X_g\right)N + P_b BN - C_b BN + P_k(A_k Y_k - NX_k) - C_k A_k - \\ & Cg\frac{NX_g}{Y_g} - N - FC + \lambda_1\left(\bar{A} - \frac{NX_g}{Y_g} - A_k\right) - \lambda_2[\overline{E} - N\left(e_k X_k + e_g X_g\right)] \\ & {\scriptstyle N, X_k, X_g, A_k, \lambda_1, \lambda_2} \end{aligned} \tag{9}$$

Equation (9) is a further development of equation (8). In equation (9), A_g is replaced by $\frac{NX_g}{A_g}$ as the conditions mentioned in the mathematical scheme that was presented beside equation (8). When transformed to a Lagrange function, the total amount available is added as well as the nutritional requirement aspect. Following Johansson and Persson’s (2015) example, equation (9) is maximized with different variables that determines the profit, in this study’s case $N, X_k, X_g, A_k, \lambda_1, \lambda_2$. A big difference from their study is that this one involved biogas production, but apart from that the logic and calculations are similar. The Lagrange function formulated above allows for calculations of the first order necessary conditions (FONC). These calculations reveal the sensitivity of the variables exposed to the restrained resources (ibid.). Equation (10-15) show the FONC for the case farm.

$$\frac{\partial L}{\partial N} = P_y f(.)+P_b B - C_b B - P_k X_k - \frac{C_g X_g}{Y_g} - \frac{\lambda_1 X_g}{Y_g} \qquad =0 \qquad (10)$$

$$\frac{\partial L}{\partial X_k} = P_y f' X_k(.)N - P_k N + \lambda_2 N e_k \qquad =0 \qquad (11)$$

$$\frac{\partial L}{\partial X_g} = P_y f' X_g(.)N - \frac{C_g N}{Y_g} - \frac{\lambda_1 N}{Y_g} + \lambda_2 N e_g \qquad =0 \qquad (12)$$

$$\frac{\partial L}{\partial A_k} = P_k Y_k - C_k - \lambda_1 \qquad =0 \qquad (13)$$

$$\frac{\partial L}{\partial \lambda_1} = \bar{A} - \frac{N X_g}{Y_g} - A_k \qquad =0 \qquad (14)$$

$$\frac{\partial L}{\partial \lambda_2} = -\left[\overline{E} - N\left(e_k X_k - e_g X_g\right)\right] \qquad =0 \qquad (15)$$

Equation (11) and (12) can be rewritten:

$$P_y f'\, x_k(.) - P_k + \lambda_2 e_k = P_y f'^{x_g}(.) - \frac{C_g}{Y_g} - \frac{\lambda_1}{Y_g} + \lambda_2 e_g \qquad (16)$$

Equation (16) can also be rewritten and thereby simplified:

$$\frac{P_y MPPx_g}{P_y MPPx_k} = \frac{\frac{C_g+\lambda_1}{Y_g} - \lambda_2 e_g}{P_k - \lambda_2 e_k} \qquad (17)$$

Observe that equation (16) and (17) is not affected by B, P_b or C_b. X_k and X_g is not affected by biogas production. This shows that a vital assumption is made that the volume of biogas produced per cow (B) does not depend upon the specific feed ration, given biogas production. The optimal feed rations are determined by equation (17). The feed ration for a simulation with conventional an organic dairy is determined and discussed in section *5.1.4. Feed rations for cows.*

4. Method

The research strategy for the study is described and discussed in this chapter. The research design and its consequences for selecting methodologies are described at the beginning of the chapter. The fictional farm that has been developed will be presented. The collection of data is presented, along with how it was gathered. Also, the empirical model and the model's construction are shown. Finally, the research's validity, reliability, and ethical issues are discussed.

4.1 Research strategy

When designing a study and selecting a research strategy, the researcher typically has two options: qualitative or quantitative (Saunders. 2007). According to Robson and McCartan (2016), a balance is essential for continued study. The study's findings may differ depending on the research strategy used. This happens because there are differences in how data is collected and analyzed. The purpose of this study is to examine how the optimal solution to a dairy farm that produces biogas differs when implementing conventional or organic agriculture. A quantitative method with a deductive approach and an experimental design is used to achieve the goal. The deductive approach is used because this study aims to answer questions rather than generate new theories (Bryman & Bell. 2017). A quantitative researcher will typically encounter two types of modeling designs: experimental and descriptive. An experimental study establishes the causality of variables, whereas a descriptive study establishes the relationship (ibid.). When applying the profit maximization theory to numerical data, the variables' relationship and causality are determined (Debertin. 2012).

When conducting research, it is crucial to mention the ontological and epistemological standpoints, according to Bryman and Bell (2017). The ontological perspective used in this study is objectivism, which is the philosophical view that there is an objective reality and that events occur independently of social actors. The biological characteristics of the variables introduced into the production of biogas have an impact on how the end-result will be. As a result, we believe that the social actor's role has been somewhat diminished. By selecting the variables to use and the purpose of the biogas, the social actor affects the biogas production.

The social actor has no other impact on the system's sustainability once the choice has been made. This paper adopts a positivistic epistemological stance, which holds that knowledge is based on natural phenomena (Saunders. 2007). The positivistic viewpoint is appropriate for the study because it is grounded in empirical data and uses theory to examine the problem. According to the positivist viewpoint, the researcher's impact on the data is negligible (ibid.). For instance, the researcher cannot alter the characteristics of the biogas. This fact cannot be changed (Bryman & Bell. 2017). One could contend that the researcher has some influence over data gathering and research methodology selection (Saunders. 2007). This study employs a structured methodology to make it replicable so that another researcher can produce comparable findings (Gill & Johnson. 2002).

4.2 Research design

Yin (2009) asserts that the choice of research design might impact the generalizability of the findings. The data for the study are gathered in this study using a case study research approach. As the inquiry presents results from two different forms of one fictional farm, examining two fictitious farm types may alter the study's generalizability. The results are probably hard to generalize because this farm is only based in one production region of Sweden. However, compared to a study with only one example, utilizing two cases of the farm might increase generalizability (Yin. 2009). Compared to a study with only two examples, the findings from a multiple-case study with more than two cases may become more generalizable. It is possible that different forms of a farm with comparable production conditions would produce similar results since they are made to mimic a dairy farm in different forms.

The case study is designed as an experimental study to determine what happens to the biogas generation of the case farm when organic or conventional agriculture is used (Stake. 1995). To achieve the goal of this work, an experimental model in the form of an optimization model is developed. The two forms of the case farm are used to assess various scenarios. These are the two types of fictional dairy farms: organic and conventional. The experimental design aims to find out what happens with the indicators. These indicators are computed for two scenarios, one with organic agriculture and one with conventional agriculture.

Case studies are not without criticism. According to Yin (2009), case study researchers may have a biased view of data gathering and reporting, influencing the results. When conducting case study research, it is essential to attempt not to affect the outcomes (Bryman & Bell. 2017). To reduce the possibility of bias in data reporting, it is critical that the researcher be careful to describe data and findings fairly and appropriately (Yin. 2009).

4.3 Data collection

Essentially, two main sorts of data sources referred to as primary and secondary data, can be used to support an empirical study (Bryman & Bell, 2015). Primary data is information that the researcher personally gathers, such as through interviews and surveys, and is frequently thought of as requiring much time and financial resources. Secondary data is the opposite of primary data (ibid.).

Secondary data in the form of agriculture-related statistics from the Swedish Board of Agriculture's statistical database and the Swedish Board of Agriculture's calculation tool Agriwise is used in this study (Agriwise. 2023; Jordbruksverket. 2023). This approach assures that the study's data is of good quality. Secondary data from the Swedish Board of Agriculture is required to discover the necessary information for the optimization models, increasing the study's credibility. There are calculations in Agriwise that contain the necessary information for the production area of crops where data on measures are accessible, such as costs for tillage, crop establishment, plant protection, plant nutrition, maintenance costs and harvesting.

4.4 Empirical model

The optimization method is explained in this chapter, followed by an introduction to the empirical model.

4.4.1 Applied optimization

Optimization aims to use applied mathematics to identify the best decision alternative in various decision-making contexts (Lundgren. 2008). Investigating how a farmer can allocate resources most effectively in a specific situation is possible by using the profit maximization theory and applying a linear optimization model. The best possible solution for the situation can be found by developing an objective function subject to several constraints. The indicators mentioned in chapters 3.2 and 3.3 can be derived from the optimization model.

A series of steps are required to analyze a problem using linear optimization, as shown in Figure 6. The first step is to identify the actual problem; the problem is identified in this step (Lundgren. 2008). The real issue is complicated, and numerous factors influence it. As a result, the problem must be defined and simplified. In this case, it could be the limitation of the optimal biogas production that turns into profit for the farmer. The optimization model is created as a mathematical problem after the problem has been simplified (Lundgren. 2008). When developing a mathematical problem, it is necessary to consider what data is available. The optimization model is created from the mathematical problem. This optimization model includes an objective function as well as problem-related constraints. These constraints in this study are crop rotational constraints and acreage constraints. The profit maximization function is the objective function. Once the optimization model has been developed, Excel is used to solve the optimization problem. The outcomes are derived from this solution. Before using these results as information in a decision-making process, they must be validated and verified.

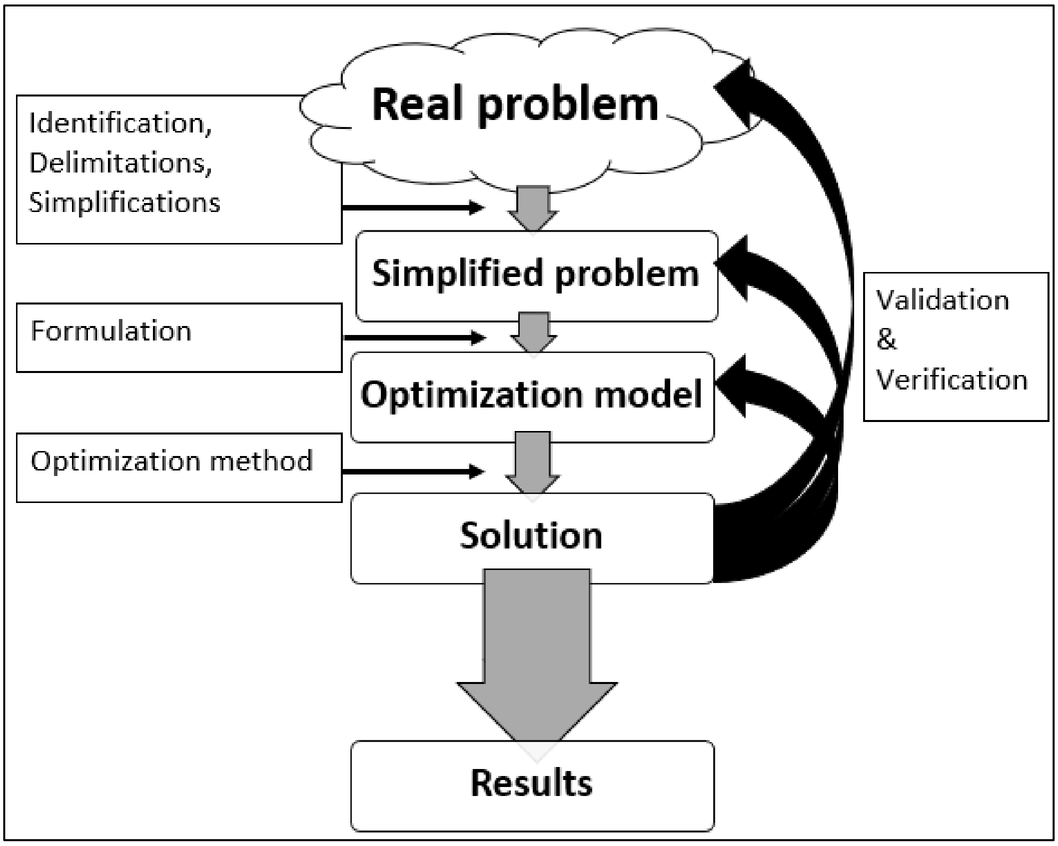


Figure 8. Workflow for solving optimization problems (Lundgren, 2008) (Own rendering).

The linear problem in this study is solved using a Simplex LP algorithm. This algorithm is appropriate for linear optimization because it finds corner solutions to a linear problem (Lundgren. 2008). The algorithm maximizes the objective function and finds the optimal solution among possible solutions.

4.4.2 Background of the empirical model

Concerning the constraints, linear programming is a technique for calculating the maximum profit from a combination of potential activities (Hazell & Norton. 1986). To use a linear programming model in a particular situation, three conditions must be met:

1. It is necessary to be aware of all potential activities on the farm and how they use resources. A particular activity must have specific limitations, such as manure production being limited to a certain amount.

2. The farm's fixed resources, such as the maximum amount of arable land or storage capacity, must be specified.

3. Accurate gross margin calculations are required to get a reliable result.

By meeting these three requirements, it is possible to develop an objective function and constraints that can be optimized. Equation (18) shows the general expression of an objective function in a farm model:

$$\Pi = \sum_{j=1}^{n} C_j X_j \tag{18}$$

In this study, the objective function represents the profit (Π) of the fictitious farm. The control variable (X) represents the units of activity j, such as hectares. C_j Represents the gross margin of farm activities. The sum extends from the lower bound *m/j* to the upper bound *n*.

Some restrictions must be met to maximize the objective function. Equation (19) gives the general expression for constraints:

$$\begin{aligned} &\sum_{j=1}^{n} A_{ij} X_j \le B_i && i = 1, \dots m. \\ &x_j \ge 0, && j = 1, \dots, n \end{aligned} \tag{19}$$

In short, the mathematical expression in equation (19) states that resource consumption cannot exceed the amount available (Hazell & Norton. 1986). A_{ij} denotes the resource consumption of resource i by activity j for employing one unit of X_j. B_i represents the amount of resource i that is available. i represents the various resources consumed by activity j, which can be numerous. The relationships hold if resource consumption is nonnegative and the amount employed, x_j, is also nonnegative.

The objective function of the study, which is the mathematical interpretation of the problem formulated based on the conditions for the fictitious case farms, is presented in equation (20). The objective function is the sum of the contributions of the fictitious agricultural company’s activities. Equation (20) describes the different profit maximization models that examines the optimal allocation of resources and produced goods on the farm. The model is an mathematical interpretation of the optimization of various alternatives of the fictitious case farm. The inspiration to the model comes from the empirical model given by Johansson & Persson (2015).

Following scenario is given in the model:

- Equation (20) depicts the choice of using biogas in a conventional or organic dairy farm with either 200 cows and 280 hectares of arable land or 400 cows and 560 hectares of arable land. Equations (21)-(30) displays the restrictions.

4.4.3 Empirical model

$$\begin{aligned} Max\ \pi = {} & X_c(AGM_c) + (P_{bio}B - C_bBd) + P_w(X_wY_w - X_cf_w) \\ & + P_b(X_bY_b - X_cf_b) - c_wX_w - c_bX_b - P_NG_N^wX_w - P_NG_N^bX_b \\ & - P_NG_N^{gl}X_{gl} - P_NG_N^{pa}X_{pa} - c_{gl}X_{gl} + c_{pa}X_{pa} - P_pXP_s \end{aligned} \tag{20}$$

s.t.

$$X_wY_w \geq X_cf_w \tag{21}$$
$$X_bY_b \geq X_cf_b \tag{22}$$
$$X_{gl}Y_{gl} \geq X_cf_{gl} \tag{23}$$
$$X_{pa}Y_{pa} \geq X_cf_{pa} \tag{24}$$

$$T_s = X_cC_m + XP_s \tag{25}$$

$$X_wG_w = G_N^wX_w + dT_s^wX_w \tag{26}$$
$$X_bG_b = G_N^bX_b + dT_s^bX_b \tag{27}$$
$$X_{gl}G_{gl} = G_N^{gl}X_{gl} + dT_s^{gl}X_{gl} \tag{28}$$
$$X_{pa}G_{pa} = G_N^{pa}X_{pa} + dT_s^{pa}X_{pa} \tag{29}$$

$$X_w + X_b + X_{gl} + X_{pa} \leq \bar{L} \qquad (30)$$

Abbreviations in the model (some are also included in the restrictions):
X_c =Number of cows in production
AGM_c =Adjusted gross margin per dairy cow
B =Biogas that is produced from one cow at the farm
P_{bio} =Price per unit of biogas produced
C_b =Variable cost of producing one unit of biogas
d =Amount of nitrogen made available by one tonne of substrate
P_w =Price of wheat produced
X_w =Hectares of wheat
Y_w =Yield of wheat in kg per hectare
f_w =Feed ration of wheat per cow
P_b =Price of barley produced
X_b =Hectares of barley
Y_b =Yield of barley in kg per hectare
f_b =Feed ration of barley per cow
c_w =Variable cost for wheat per hectare
c_b =Variable cost for barley per hectare
P_N =Price of nitrogen
G_N^w =Purchased amount of nitrogen per hectare of wheat
G_N^b =Purchased amount of nitrogen per hectare of barley
c_{gl} =Variable cost for grassland per hectare
c_{pa} =Variable cost for pasture on tillable land per hectare
G_N^{gl} =Purchased amount of nitrogen per hectare of grass land
X_{gl} =Hectares of grassland
G_N^{pa} =Purchased amount of nitrogen per hectare of pasture on tillable land
X_{pa} =Hectares of pasture on tillable land
P_p =Price per one tonne of poultry manure

Abbreviations in the restrictions:
Y_{gl} =Yield of grassland in kg per hectare
Y_{pa} =Yield of pasture on tillable land in kg per hectare
f_{gl} =Feed ration of grassland per cow
f_{pa} =Feed ration of pasture on tillable land per cow
T_s =Total volume of substrate in tonne
C_m =Cow manure in tonne per cow
XP_s =Tonne of poultry manure
G_w =Total nitrogen per hectare for wheat

T_s^w =Substrate allocated to one hectare of wheat
G_b =Total nitrogen per hectare for barley
T_s^b =Substrate allocated to one hectare of barley
G_{gl} =Total nitrogen per hectare for grassland
T_s^{gl} =Substrate allocated to one hectare of grassland
G_{pa} =Total nitrogen per hectare for pasture on tillable land
T_s^{pa} =Substrate allocated to one hectare of pasture on tillable land
$\bar{L}$ =Total amount of land

The explanation for restrictions (21)-(30) are as followed:

Restrictions (21)-(24) are the expressions for the feed ration where the quantity that is produced of wheat, barley, grassland and pasture is more than or equal to the amount of feed per wheat, barley, grassland or pasture that the cow needs.

Restriction (25) is the expression for the total amount of substrate needed which is equal to the produced manure per cow + purchased poultry substrate.

Restrictions (26)-(29) are the expressions for the need of fertilizer to each crop which is equal to the amount of bought nitrogen per hectare that meet´s the nitrogen need for each crop + additional digestate and total substrate that is given to each crop per hectare that meet´s the nitrogen need for each crop.

Restriction (30) is the expression of area for all growing crops which is less than or equal to the total amount of land available.

Chapter 5 presents and explains how the various values were calculated and the background to the restrictions. The restrictions specify conditions such as cultivation area, number of producing dairy cows, and feed requirements. The model (Equation 20 and restrictions 21-30) can also be viewed in appendix 7.

4.5 Quality assurance

To ensure the quality of this study, two quality concepts, validity, and reliability, must be considered. Based on these two concepts, it is discussed which measures have been taken to ensure the quality of this study.

4.5.1 Validity

Validity is explained by Bell et al. (2019) as the issue regarding if indicators that are meant to be measuring a concept measure that exact concept. To exemplify, if the concept is measured accurately, it has high validity (Heale & Twycross. 2015). It can be measured in several different ways. According to Bell et al. (2019) a minimum requirement is that the research should have *face validity*, which is about if the right thing is being measured. This is an essential intuitive process and can be tested by asking people with experience in the field if the measures seem to target the concept of attention for the study (ibid.). The authors of this study have achieved this by having an experienced supervisor who repeatedly overlooked the process of creating the excel-model and the solutions from it.

4.5.2 Reliability

Reliability is described as *"the consistency of a measure of a concept"* (Bell et al. 2019. p172; Heale & Twycross. 2015; Golafshani. 2003). Reliability consists of three different prominent factors: stability, internal reliability, and inter-rater stability. Stability is about if the results show the same thing even when tested at different times (ibid.). The easiest way to test if the result is consistent is through the test-retest method, which is where the results from at least two different tests are compared. The test should show the same result for the research to have good reliability (ibid.). The retests the authors of this study have done have all shown the same results, giving the findings good reliability. That is because this research measures something stable over time (ibid.) and the only thing that can change is the price for different inputs, but this must be changed manually. If not, the retest will always show the same result as the first test from the optimization.

4.6 Ethical issues

Ethical considerations in research must be worked on continuously throughout the research process (Bell et al. 2019). The most crucial consideration for this study is ethical concerns related to data handling. These are *"the impact of data protection legislation, copyright and the sharing of data, and the need to declare sources of funding and support that may cause a conflict of interest for the researcher"* (ibid. p124).

Data management focuses on concerns over ethical considerations and data confidentiality. Questions arising in this section are who owns the data and what guidelines have been given regarding sharing and usage of the data (ibid.). It is commonly encouraged that researchers share their findings so that the outcome of their research can benefit others as well. This is particularly important if the data involves personal information (ibid.). In events like this, it can raise concerns over data security and the protection the data might need to stop it from being shared to unauthorized access and usage.

Copyright is also an important ethical aspect. Most things published are protected by copyright, including books, research publications, reports, and interview transcripts. To share any of this data, it is therefore essential to get an allowance from the ones owning the copyright beforehand (ibid.).

Finally, Bell et al. (2019) writes about affiliation and conflicts of interest. This is important when the researcher has received an assignment to do research for a company or if funding is involved somehow (ibid.).

5. Empirical data and results

In this chapter, the choices of the case farm´s different forms and inputs will be motivated, and the empirical model's findings will be presented. The empirical data about the fictional case farms will be presented in chapter 5.1.

5.1 The case farm´s different forms and inputs

The fictional case farm that forms the basis of the optimization model in this study is described in the following chapter, along with the included parameters that form the basis of the optimization model in this study.

The fictitious farm has been defined to reflect today's Swedish production system and contain parts that, when combined, represent a larger reality-related case farm with crop cultivation and milk production. The farm is situated in GNS (Götalands Norra Slättbygder), first presented in chapter 1.4. Why this choice has been made is presented below.

5.1.1 The general structure of the case farm

Figure 8 depicts the case farm's general structure and the various options in the production decision process based on the conditions. To generalize the farm, it was built using the same basic model but with different data, depending on the chosen production area, which is taken from Agriwise (2023). In Agriwise (2023), calculations for a production size of 200 and 400 dairy cows have been applied. This is motivated by the fact that the biogas plant size should correspond to the size of the dairy herd, considering the given substrates that the biogas plant will mainly use. Given the number of dairy cows, the conventional dairy cow produces approximately 10 800 liters of milk per year, and the organic dairy cow produces approximately 9 900 liters of milk (ibid.). On the case farm in various forms, there is also crop cultivation that solely aims to distribute feed rations to the cows. The model is developed on the condition that both the conventional and organic alternatives cultivate either 280 hectares (if 200 dairy cows) or 560 hectares (if 400 cows). This excludes the grazing requirement that the cows need, which is handled separately in the optimization model.

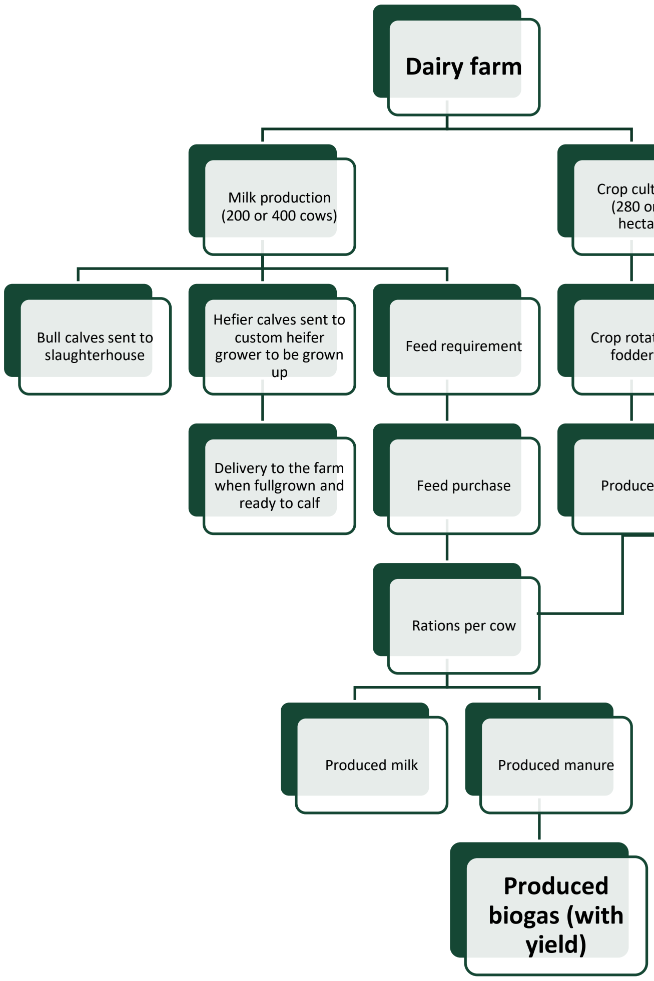


Figure 9. A schematic figure describes the fictitious farms' decision-making process (own illustration).

Figure 9 depicts the choices that define the mathematical optimization problem. Figure 9 also depicts the logic for the given choice independent of constraints. Milk production and crop cultivation will be part of the production. Winter wheat, spring barley, grass silage, semi-natural pasture and grazing on arable land are grown as feed in plant cultivation to supplement the needs of feed. There is a requirement in milk production logic to sell bull calves, send the heifer calves to a custom heifer grower and that the cows require feed. Given the two paths that lead to feed needs per cow, the model calculates whether you buy feed and produce everything yourself. Given the rations per cow, this will lead to two given choices: Produced milk and produced manure. The manure will then be transferred into the biogas production, and biogas will be the product. In the event of no biogas production manure is used for fertilizing the crops.

The following chapters will present how the empirical data for the optimization has been gathered.

5.1.2 Cows for milk production

Appendix 2 shows that while the number of companies has decreased by just under 17 200 since 2000, the number of cattle has decreased by roughly 234 500 animals (Jordbruksverket, 2022).

The Swedish Board of Agriculture (Jordbruksverket. 2022) states that the number of cows for milk production in June 2022 was 296 500. This represents a 1.8% decrease since 2021 and a roughly 30% decrease since 2000, as represented by appendix 2. The amount of milk weighed in the spring of 2022 was slightly less than in the spring of 2021. The number of dairy farms has steadily declined. The number of farms with dairy cows has decreased by 5.4%, or 160 farms, since 2021. There were 12 700 farms with dairy cows in 2000, but there will be fewer than 2 800 by June 2022. At the same time, the average herd is growing, rising from 33.7 dairy cows in 2000 to 106.1 in 2022. Figure 10 demonstrates that in June 2022, 21.9% of dairy cow farms had between 25 and 49 dairy cows, and 7.2% of all dairy cows were located on these farms. About 36% of the dairy cows were found in the 11.3% of the dairy farms with more than 200 dairy cows.

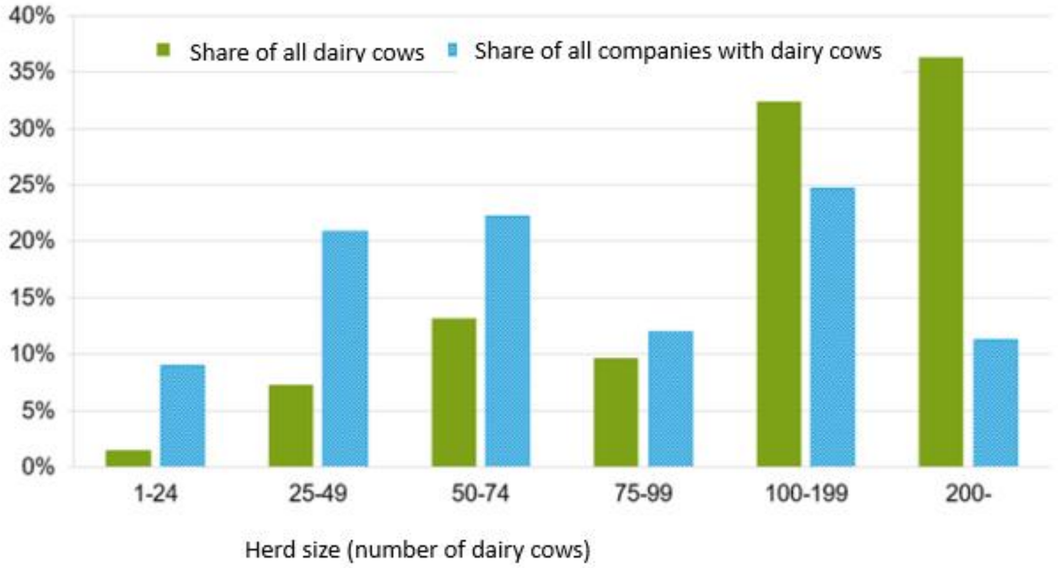


Figure 10. Share of cows for milk production and companies with cows for milk production by herd size in 2022 in Sweden (Jordbruksverket. 2022) (own rendering).

This connects to why this study has chosen to adapt two different sizes of dairy farms, where there are either 200 cows or 400. The study aims to address the profitable choices for the dairy farm if choosing to invest in a biogas facility. As appendix 2 and figure 10 depict, there are needs to meet the declining numbers of dairy cow companies and make a sustainable profit to survive at a market with a declining share of cows for milk production. To meet these questions, the study has chosen to have 200 and 400 cows to show how the majority share of all producing dairy cows impacts the choices of introducing complements to contribute to increased profitability to survive. Therefore, the entrance of a biogas facility seems logical, as Torquati et al. (2014) mention that energy production from biogas on a dairy farm can provide a good opportunity for sustainable rural development, supplementing the farm's traditional income and help to reduce the overall environmental impact of the energy sector.

The choice of comparing both conventional and organic dairy farm production in GNS stems from the fact that Västra Götaland, as mentioned below in figure 10 and figure 11, has the highest amount of producing dairy cows of all counties in Sweden with 100-199 dairy cows and over 199 dairy cows (figure 11). Furthermore, Västra Götaland also maintains the highest number of dairy farms in Sweden, with farms with 100-199 dairy cows and over 199 dairy cows (figure 12).

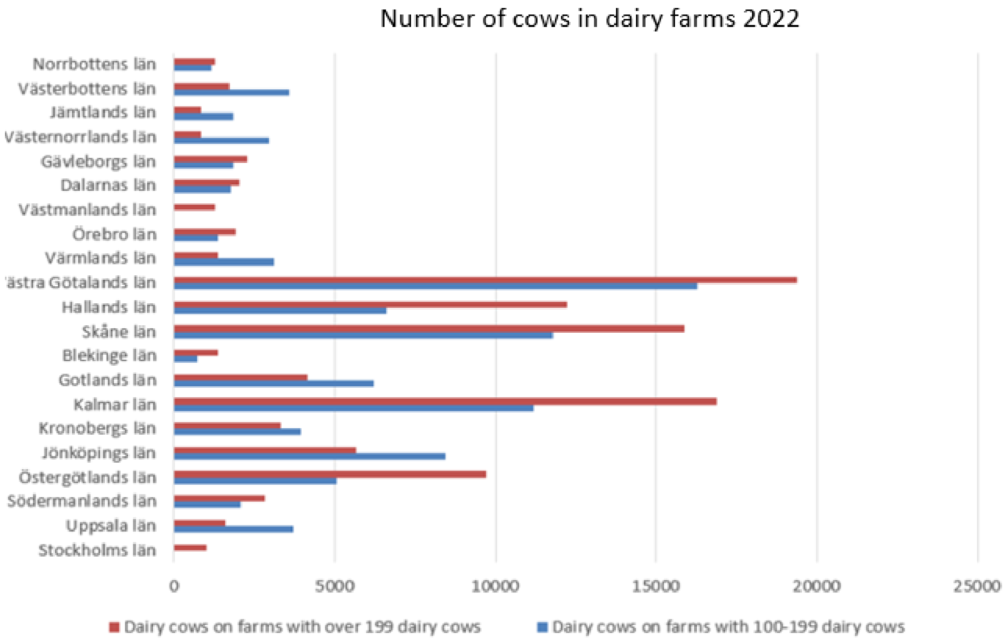


Figure 11. Number of dairy cows that exceeds 100-199 dairy cows or over 199 dairy cows in dairy farms (Jordbruksverket. 2022) (own rendering).

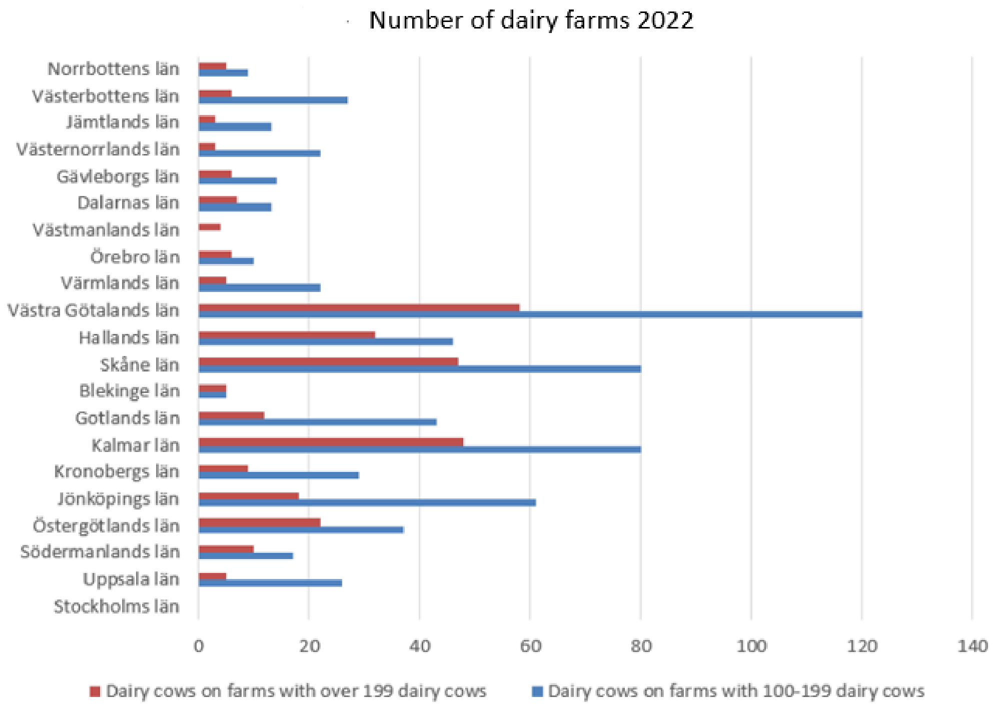


Figure 12. Number of dairy farms with 100-199 dairy cows and over 199 dairy cows (Jordbruksverket. 2022) (Own rendering).

The percentage share of cows for organic milk production per county is also the largest in Västra Götaland, as shown in figure 13.

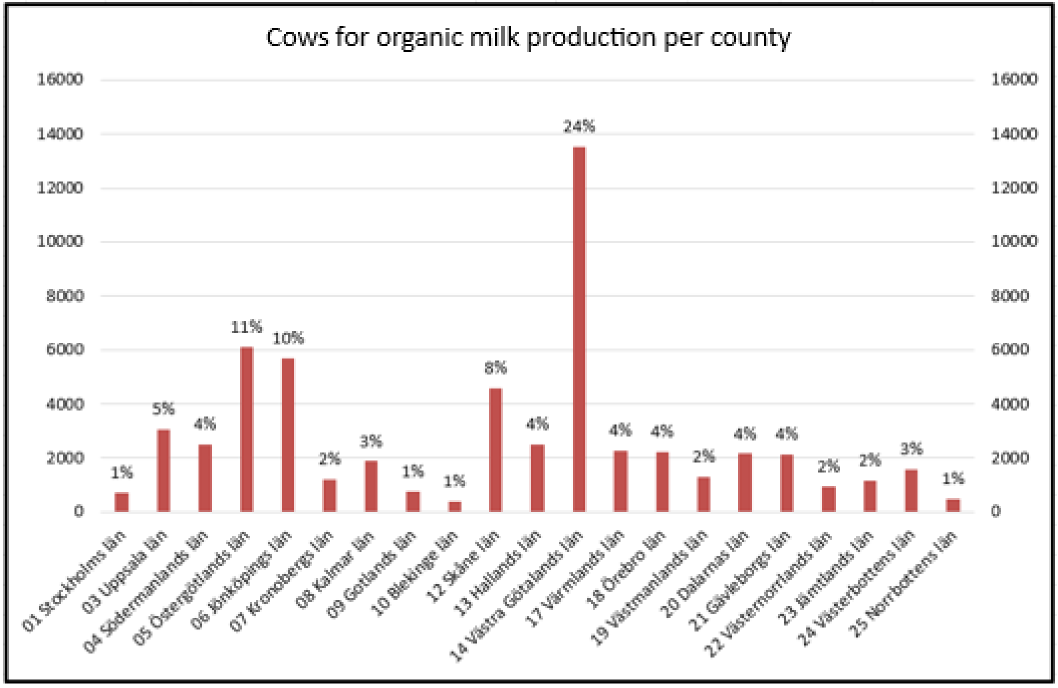


Figure 13. The Swedish Board of Agriculture's statistical reports for organic animal husbandry in 2021 (Jordbruksverket. 2021) (own rendering).

Figures 11, 12, and 13 all show that Västra Götaland is the most suitable county for this study since it has the highest share of cows.

The chosen race for the producing dairy cows is SLB and chosen return of ECM that the model calculates from is a total of 9 900 ECM for an organic alternative and 10 800 ECM for a conventional alternative as motivated by Agriwise (2023).

5.1.3 Government- and EU supports received

The supports are based upon several factors, for such that organic dairy farmers receive a support payment for organic milk production. These supports that are received is summarized in table 2 and are based upon Agriwise (2023):

Table 2. Various support received for dairy production (Agriwise. 2023).

Alternative	**Name**	**Value of the support in SEK**
Conventional	Cattle support	910 SEK
Alternative	**Name**	**Value of the support in SEK**
Organic	Cattle support	910 SEK
Organic	Support organic milk production	1770 SEK
Organic	Environmental compensation for organic farming (wheat)	1500 SEK per hectare
Organic	Environmental compensation for organic farming (barley)	1500 SEK per hectare

5.1.2 Sale of calves

In the optimization model of the case farm, the calves are assumed to be sold. The price for calves differs depending on production focus and is higher in the conventional alternative. The price for heifer calves is 1 540 SEK, and for bull calves, the price is 2 480 SEK (Agriwise. 2023). In the optimization with 200 conventional cows, the combined income from sales of calves is therefore 402 000 SEK, and in the optimization with 400 conventional cows, the income is 804 000 SEK.

In the organic alternative, the price per heifer calf is 524 SEK, and the price per bull calf is 1 125 SEK. In the optimization with 200 organic dairy cows, the income from selling calves, therefore, is 164 900 SEK, and in the optimization with 400 organic dairy cows, the income is 329 800 SEK.

Selling the calves can be done by having a contract with a heifer grower as this has many benefits for the dairy farmer. Bieler (2000) explains three as less need for space, less work, and fewer resources needed. Since the case farm only has dairy cows, there is no need to invest in a recruitment stable, and by having fewer livestock on the farm, the workload lessens, as well as the need for grazing and feed ration (ibid.). When dairy cows are needed, they will be bought from the heifer grower.

Andersson (2010) provided valuable information about the relation between calve producers and heifer growers and saw a differentiation in payment contracts among the research participants. Three research participants sold the heifer back to the dairy milk production farm for 10 500 SEK after buying them for 1500 SEK (two companies) and 12 SEK/kg, respectively (one company). Two of the other heifer breeder companies in the study had a contract with a payment per day of 16.5 SEK. Andersson (ibid.) also compiled pricing amongst the research participants in what they paid daily for heifer hotels. On average, that price was 15.29 SEK/day. Anderson’s study was conducted in 2010, and the prices have increased since then. In talks with the same Andersson (2023), who now is a heifer grower, a figure of 25-27 SEK per day was named more updated. In talks with another heifer grower, Wejdmark (2023), the figure was mentioned as updated and likely. In the case farm, the cost for a heifer grower will be 26 SEK per day. The heifers will stay at the heifer grower for 24 months, and per heifer, this will result in a cost of 18 980 SEK when repurchasing them to the case farm. Each year some dairy cows must be replaced to keep a good consistent number of productive dairy cows and to cover for the cows who die for different reasons. Those reasons could be that they are sent to slaughter due to high age or that some cows die within 90 days after giving birth to their first calf (Växa. 2021). A standard recruitment percentage from the last ten years has been 35% (ibid.) which for 200 dairy cows will be 70 heifers, resulting in a cost of 1 328 600 SEK. For the alternatives with 400 dairy cows, the number of recruitment heifers will be 140, resulting in a 2 657 200 SEK cost.

5.1.4 Feed rations for cows

To value the amount of manure produced, it is necessary to express what the feed ration contains regarding nutrient limits and what feed values the cows need.

Table 3 and 4 describes both the abbreviations for the feed ration (table 3) and the Swedish nutritional recommendations (table 4). The recommendations are based upon the programs Nibstat (Nibstat. 2023) and Freefarm (Freefarm. 2023), which are programs that calculates the optimal value for the feed ration based on for example weight (kg) of the cow and the amount of ECM (kg). In the case of tables 5 & 6, the parameters are based on the premise that the cow weighs 600 kg and produces 30 ECM (kg) per day. The data for minimum and maximum per parameter is based on Spörndly´s (2003) feeding tables for ruminants. This will lead to a feed ration that suits conventional and organic alternatives.

Table 3. Abbreviations and their explanations (NibStat 2023; Freefarm 2023).

Abbreviations	**Explanation**
Roughage, % & kg	Roughage in percent and kilograms (e.g. hay, straw, silage)
Concentration, MJ/DM	The concentration of Metabolisable energy per Dry Matter
Energy, MJ	Metabolizable energy, MJ
CP, %	Percent of Crude Protein
AAT, g/MJ	Amino acids absorbed in the small intestine, g. / MJ
PBV, g	Protein balance in the rumen, gram
e.e., %	Percent of Ether Extract (Fat), gram
Starch, %	Percent of starch
NDF, g	Neutral Detergent Fibre, gram
NDF, %	Percent of Neutral Detergent Fibre
Ca, g	Calcium, gram
P, g	Phosphorus, gram
Mg, g/DM	Magnesium, gram per Dry Matter
K, g/DM	Potassium (kalium), gram per Dry Matter
Na, g/DM	Sodium (natrium), gram per Dry Matter
Weight, kg DM	Weight per kilogram Dry Matter

Table 4. Limits on nutrients and parameters (Based upon Spörndly. 2003).

Limits on nutrients: Weight (kg) = 600 kg ECM (kg) = 30		
Parameter	**Min**	**Max**
Roughage, %	35.0	
Concentration, MJ/DM		
Energy, MJ	221.1	
CP, %	17.0	19.0
AAT, g/MJ	7.6	8.4
PBV, g	100	600

e.e., %	2	5
Starch, %		22.0
NDF, g		9000
NDF, %	30	
Ca, g	109.0	125.3
P, g	75.0	86.3
Mg, g/DM	2.5	3.0
K, g/DM	9.0	22.0
Na, g/DM	1.8	3.6

Table 5 & 6 display a suggested feed plan for both conventional and organic alternative, given the data and programs mentioned earlier, and Agriwise (2023), given the limits on feeds (Spörndly. 2003; Freefarm. 2023; NibStat. 2023; Agriwise. 2023). Cost per day, year, and size of cows are also included. The numbers are round off in the tables (5 & 6).

Table 5. Feed ration conventional alternative (based on prices from Agriwise. 2023).

Feed	**Ration per year (in kg and kg DM)**	**Cost per unit per kg or kg DM**
Pasture	118 kg DM	1.36 SEK
Grass silage	4 465 kg DM	2.79 SEK
Wheat	1 259 kg	1.90 SEK
Barley	1 272 kg	3.20 SEK
Concentrate	1 033 kg	5.03 SEK
Minerals	59 kg	16.84 SEK
Premix	379 kg	7.01 SEK

Table 6. Feed ration organic alternative (based on prices from Agriwise. 2023).

Feed	**Ration per year (in kg and kg DM)**	**Cost per unit per kg or kg DM**
Pasture	815 kg DM	1.58 SEK
Grass silage	3 820 kg DM	3.23 SEK
Wheat	838 kg	2.52 SEK
Barley	838 kg	2.47 SEK
Concentrate	1012 kg	9.68 SEK
Minerals	64 kg	18.56 SEK

5.1.5 Crop rotation and produced feed

For the case farm, it is essential to grow as much of its feed ration needs on the farm as possible. Spring barley and winter wheat are usual components of dairy cow feed ration (Agriwise. 2023); therefore, the case farm will grow enough to cover the needs. Nourishing crops is also necessary to maintain a good crop rotation (ibid.). Therefore, the case farm will also grow grassland. The crop rotation will be the same for conventional and organic case farm optimization. This is because the crop rotation is based on fitting the need for the dairy cows, and simultaneously offer a mixture of crops planted in spring and autumn to make the farmer's workload more evenly spread.

The crop rotation is as follows: spring barley will be sown and harvested in year one. The grassland will be reseeded into spring barley, then grow for two years, and harvested three times yearly (year two and three). After those two years, the soil will accumulate some nitrogen for winter wheat to grow (year four).

Table 7. Crop rotation on case farm.

Harvest	**Year 1**	**Year 2**	**Year 3**	**Year 4**
Crop	Spring barley	Grassland year 1	Grassland year 2	Winter wheat

The reason for having grassland in a two-year period is because of three main reasons: the farm needs much grassland for silage, a two-year rotation has many benefits for organic farming since it collects nitrogen from the air which means that less nitrogen needs to be bought (Jordbruksverket. 2010). The case farm needs to get good harvests to produce enough grain for the feed ration; in organic farming, this has much to do with crop rotation. The best results can be found when mixing nourishing and consuming crops, annual and perennial crops, and crops sawed in the spring and the autumn (ibid.). A challenge with having two-year grassland is that weeds can be grown and later affect the productivity of the land (Växa. 2019). For each percentage of weed presence, the productivity of the grassland reduces with one percentage, due to the weed competing with the grassland species in terms of water and nutrient. The case farms can prohibit the presence of weeds through weed control. By seeding the grassland together with spring barley, the grassland gets a cover crop the first year, and if the grasslands get harvested intensively year two and three, it will have good effect for prevent thistles to compete. Another important procedure could be to mowing the field edges to prevent cough grass and docks to be spread in the field (ibid.). In organic farming, intensive tillage is a successful procedure to minimize the weed in the fields, as it affects the nutrient supply in rot grass.

As mentioned earlier, spring barley and winter wheat are usual components of a feed ration for dairy cows. For the conventional alternative, the need of spring barley for 200 dairy cows with the feed ration the case farm uses is 244 000 kg which is a cost of 780 000 SEK, and for 400 dairy cows, the need is 488 000 kg with a cost of 1 560 000 SEK. The need for winter wheat is 250 000 kg for 200 dairy cows, resulting in a cost of 460 000 SEK, and winter wheat for 400 dairy cows is 500 000 kg with a cost of 940 000 SEK (see table 5 above).

The need for spring barley and winter wheat and its price differs in the organic feed ration. The need for 200 dairy cows in the organic alternative is 167 000 kg and a cost of 630 000 SEK for both crops respectively, and for 400 organic dairy cows, the need is 334 000 kg which results in a cost of 1 260 000 SEK for both crops respectively (see table 6 above).

5.1.6 Rules for grazing

Regardless of whether the farm is conventional or organic, the farmer needs to have enough grazing area available for the dairy cows close to the farm. The rules for conventional and organic production differ and will be explained below. Starting with the conventional alternative, the rules state that dairy cows in the chosen area GNS need to have access to grazing at least six hours per day for a minimum of 90 days between April 1st and October 31st. Of these 90 days, 60 days should be between May 1st and September 15th (Greppa Näringen. 2017). During the rest of the year, the dairy cows need access to an area where their natural grazing behaviour can be fulfilled. This area does not have to contain enough grazing or nutritional needs to meet the dairy cow’s grazing needs. Research has shown that even areas with little grazing are enough for dairy cows to fulfil their natural behaviour (Jordbruksverket. 2023). The grazing area must be vegetated to at least 80%. If it is less than that, there are too many cows in the same area (Svensk mjölk. 2008). It must also be large enough not to make fertilizer regulations a problem. The fertilizer values for the manure from the dairy cows is 3.1 kg of nitrogen and 0.6 kg of phosphorus per tonne of manure (Salomon & Wivstad. 2013). The farmer is not allowed to spread over 22 kg of phosphorus per hectare and year on average (Jordbruksverket. 2022).

Grazing in the chosen area, GNS, needs to be divided into grazing on arable land and grazing on semi-natural pastures. This is because available semi-natural pastures is limited in the area (Larsson et al. 2020). It is common for cattle (which dairy cows are a part of) to get their feed from semi-natural pastures during the grazing season. In GNS, the grazing animals on semi-natural pastures consist of 73% cattle (Spörndly & Glimskär. 2018). In Västra Götaland, which is the county

GNS is in, the need for additional grazing is the greatest in the country (Larsson et al. 2020). This is calculated using the land available for semi-natural pastures compared to the number of livestock in need of grazing in that area (ibid.). In the optimization, the authors of the study have put 20 hectares of semi-natural pastures as maximal hectares of semi-natural pasture possible, due to the case farm being in an area where access to semi-natural pastures is limited. The assumption is made that the dairy cow stable is located in the middle of the combined area of semi-natural pastures and grazing on arable land.

Using the mathematical formula for calculating radius, it can be calculated how far the dairy cows need to walk the furthest based on the assumption that the cow stable is in the middle of the combined grazing area with an equal distance to the outskirts. The mathematical calculation for radius is:

$$A = r^2 * 3.14 \tag{31}$$

Which means that:

$$\frac{A}{3.14} = r^2 \tag{32}$$

and that:

$$r = \frac{\sqrt{A}}{3.14} \tag{33}$$

In the model with 200 conventional dairy cows, 13.11 hectares of semi-natural pastures and zero hectares of grazing on arable land was the optimal solution. The hectares will be multiplied with 10 000 to get square meters for the total hectares (SCB. n.d.). Using the calculations explained above, the maximum distance the dairy cows need to walk is 204.33 meters away from the dairy cow stable.

The same rules and logic are used for 400 conventional dairy milk cows. The optimization showed us that the optimal number of hectares for semi-natural pastures is 20 and the need for arable grazing is 2.22 hectares. Using the same mathematical model as above, this shows that the dairy cows must go 266 meters to reach the fence of the grazing area.

To examine if the result from the optimization is reasonable, it is important to know how much surface is needed to stay within the fertilizers regulations. Each dairy cow produces 0.6 kg of phosphorus per tonne of manure (Jordbruksverket. 2005). Per year, each dairy cow produces 19 670 kg of manure (Agriwise. 2023), which equals 53.89 kg daily. During the grazing period, the conventional dairy cows need access to a minimum of six hours per day (Greppa Näringen. 2017). With the assumption that the cows are out for six hours each day, the sum of daily manure production from the dairy cows is divided by 24 and then multiplied with six, which results in 13.47 kg of manure per dairy cow and day. This time 200 dairy cows results in 2 694 kg of manure on the grazing area daily. Since the cows need to have access to grazing for a minimum of 90 days (ibid.), the sum is multiplied by 90 to get that the total amount of manure from the dairy cows equals 232.460 tonne. This multiplied with the amount of phosphorus per tonne manure (0.6 kg), gives the total amount of phosphorus the dairy cows fertilize the grazing area with, which is 145.476 kg. Since no more than 22 kg of phosphorus per hectare is allowed on average, it is interesting to know how many hectares are needed to meet the regulations. Therefore, the sum is divided by 22 kg, showing that the minimum hectares required is 6.61. The same calculations are made for the alternative with 400 dairy cows, and the minimum hectares required is 22.04 hectares. The optimization revealed a higher value for both alternatives which means that the result is reasonable, and that eutrophication does not become a problem.

The grazing period for organic dairy cow production is the same as the conventional alternative, from April 1st to October 31st. The difference is that the organic cows need to have access to grazing for a minimum of 12.5 hours per day during 90 days in GNS (Greppa Näringen. 2017). Out of those 90 days, a minimum of 60 days should be from May 1st to September 15th. Apart from 90 days of grazing, organic dairy cows need access to the outdoors for another two months. During those two extra months, there are no requirements for grazing (ibid). As for conventional dairy cows, the limit for organic agriculture for phosphorus is 22 kg/hectare and year (ibid.). The fertilizers value of the dairy cow manure content is 3.1 kg of nitrogen and 0.6 kg of phosphorus per tonne of manure (Salomon & Wivstad. 2013).

From the optimization, the optimal hectare for arable grazing for 200 organic dairy cows is 20 hectares of semi-natural pastures and 29.6 hectares of grazing on arable land. By using the mathematical formula for radius explained earlier, the result showed that the dairy cows need to walk 397.44 meters to reach the outer fence of the gracing area.

The same rules, logic, and mathematical model are used for 400 organic dairy milk cows, which results in 20 hectares of semi-natural pastures and 66.82 hectares of grazing on arable land needed. With the calculations above used, the dairy cows need to go furthest 525.82 meters away from the dairy cow stable.

To see if our result from the optimization is reasonable, the same logic as in the conventional alternative is used. Each dairy cow produces 0.6 kg of phosphorus per tonne manure (Jordbruksverket. 2005). Per year, each dairy cow produces 19 670 kg of manure (Agriwise. 2023), which equals 53.89 kg daily. During the grazing period, the organic dairy cows need access to a minimum of 12.5 hours per day (Greppa Näringen. 2017). With the assumption that the cows are out for 13 hours each day, the sum of daily manure production from the dairy cows is divided by 24 and then multiplied by 13, which results in 29.19 kg of manure per dairy cow and day. This time 200 dairy cows resulted in 5 838 kg of manure daily. Since the cows need to have access to grazing for a minimum of 90 days (ibid.), the sum is multiplied by 90 to get that the total amount of manure from the dairy cows equals 525.427 tonne. This, multiplied with the amount of phosphorus per tonne manure (0.6 kg), gives the total amount of phosphorus the dairy cows fertilize the grazing area with, which is 315.256 kg. Since no more than 22 kg of phosphorus per hectare is allowed on average, it is interesting to know how many hectares are needed to meet the regulations. Therefore, the sum is divided by 22 kg, showing that the minimum hectares required is 14.32. The optimization for 200 organic dairy cows showed 49.6 hectares of grazing as the optimal solution. In the alternative with 400 organic dairy cows, the result was 86.82 hectares. Both solutions ensure that eutrophication does not become a problem.

5.1.7 Arable seed mixture

For the above reasons, a predominant part of the grazing must be on arable land. In this section, an explanation of the seed mixture in the arable grazing will be explained. The chosen alternative mixture is based on the mixtures that Jordbruksverket (2004) proposed. The chosen mixture is adapted to benefit the conditions in GNS and is suitable for grazing. The mixture consists of shamrock (20%), meadow fescue (25%), English ryegrass (20%), red fescue (20%), and meadow grass (15%). Shamrock is a first-hand choice for grazing on arable land (Greppa Näringen. 2019). Its benefits are that the dairy cows think it is palatable, has good feed value, is hardy and grazing resistant, and fills gaps effectively (ibid). Meadow fescue has been chosen due to its grazing resistance benefits and because it offers good regrowth. English ryegrass is the base in an energy-rich and high-yielding mixture, making it suitable for grazing and mowing (ibid.). Red fescue benefits grazing since it is durable and resistant to grazing, drought, and tramp. The same thing can be said about meadow grass, although it does not handle drought or red fescue (ibid.). This mixture is a good choice for intensive grazing systems (Jordbruksverket. 2004).

5.1.8 The biogas plant with budget and value of residues

Table 8 shows a suggested budget for investing in a biogas plant. The budget is formed based on both production alternatives' farm sizes (200 or 400 cows) (Agriwise. 2023).

Table 8. Budget for investing in a biogas plant (Agriwise. 2023).

Production size farm	**Investment in a biogas plant**	**Investment in an electricity production facility**	**Total cost/year** **(incl. operation, tax, and capital costs)**
50 kWel	4 000 000 SEK	700 000 SEK	525 000 SEK

For the case farm, the substrate mixture will consist of 86% produced manure from dairy cows and 14% bought poultry manure. Poultry manure is a collective term for both chicken manure and hen manure. The price for dairy cow manure will be zero since the farm produces it, and the price for poultry manure is 380 SEK per tonne (Hushållningssällskapet. 2016). The reason for choosing poultry manure as a substrate mixture is because the gas production will be significantly higher when combining the two animal manures compared to only using manure from dairy cows (Edström et al. 2018). Adding energy-rich manure (which poultry manure is) to biogas production is one of the most effective non-technological solutions to reach a better economic value (ibid.). Per wet weight unit, poultry manure has ten times higher biogas production than liquid manure and is an interesting substrate for biogas (ibid.). The number of companies with hens older than 20 weeks is highest in Västra Götaland, (in where GNS is located) with a total of 837 companies, which is close to four times as much as the county with the second most hen companies (Jordbruksverket. 2018). The number of broiler companies in the area is 31 (Jordbruksverket 2020). Therefore, the case farm should not have trouble purchasing poultry manure.

The mixture in the biogas plant must have a DM percentage of 10-15% to run smoothly throughout the process (Bahonjic. 2016). Dairy cow manure has a DM percentage of 9%. Poultry manure usually has a 25-50% DM percentage if it is day fresh and up to 70% if stored (Magelryd et al. 2002). This means that the poultry manure needs to be diluted, which can be done using a material with a DM percentage of less than 10% (Bahonjic. 2016), which the dairy cow manure produced on the example farm is.

As can be seen in table 8, the biogas plant will produce biogas for electricity. To calculate how much kWh of electricity the biogas mixture can produce, some calculations are needed. The calculations are the same for both conventional and organic alternative. The difference is between 200 and 400 dairy cows, where the sum of biogas mixture is the double compared to the one used for 200 dairy cows.

To eventually know how much electricity the biogas plant can produce, it is first necessary to know how much kg VS it is per tonne of biogas mixture—starting with the dairy cow manure, which will contribute to 86% of the biogas mixture. First, it is necessary to know the VS percentage in TS, calculated by dividing VS in TS. The TS percentage in manure is different depending on, for example, the feed ration, but in this calculation, a percentage of 7.45% TS will be used for dairy cow manure and a VS percentage of 6.18% (Edström. 2023). Using the calculation model described earlier, the following is made:

$$\frac{6.18VS}{7.45TS} = 83\% \qquad (34)$$

This shows that it is 0.83 kg VS per kg TS. The same reasoning is used to calculate the percentage of VS in TS for chicken manure. This calculation uses a TS-percentage of 65.3% (Salomon & Wivstad. 2013) and a VS-percentage of 56.1% (Edström. 2023).

$$\frac{56.1VS}{65.3TS} = 86\% \qquad (35)$$

These percentages are then used to calculate how much kg methane a tonne of biogas mixture consists of, which is interesting for calculations for total biogas production. As mentioned, the biogas mixture will comprise 86% dairy cow manure, which will be multiplied by its TS percentage, 8.9% (Salomon & Wivstad. 2013). After that, the sum is multiplied with 83% to get the amount of VS.

$$860\ kg * 0.089TS = 76.54kgVS \qquad (36)$$

$$74.56kgTS * 0.083 = 63.5kgVS \qquad (37)$$

According to Edström (2023), the multiplication factor for cubic methane production per kg VS is 0.2. By multiplying with 0.2, it will show how much kg of methane the dairy cow manure produces per tonne of biogas mixture.

$$63.5kgVS * 0{,}2 = 12.7kg\ methane \qquad (38)$$

The same reasoning is used to calculate methane per tonne biogas mixture from chicken manure. The following calculations are made:

$$140kg * 65.8\%TS = 92.12kgTS \tag{39}$$

$$92.12kgTS * 0.086 = 79.2kgVS \tag{40}$$

$$79.2kgVS * 0.2 = 15.84kg\ methane \tag{41}$$

Therefore, the total amount of methane per tonne of biogas mixture is 28.54kg. The density of methane (CH_4) is 0.72kg per Nm^3CH_4 (Edström. 2023). By multiplying the amount of methane per tonne biogas mixture by the density of methane, the answer shows the amount of kg methane produced in the biogas plant per tonne mixture.

$$28.54 * 0.72 = 20.54 \tag{42}$$

The effectual heating output for methane is 9.97kWh per Nm^3CH_4 (ibid.), and if that is calculated with the amount of kg methane produced per tonne of biogas, the answers show how much kWh is produced by one tonne biogas mixture. The sum multiplied by the total amount of manure in the biogas mixture, which is 4574 tonnes for the alternative with 200 dairy cows, shows the total kWh produced from the biogas mixture.

$$20.54 * 9.97 = 204.7838 \tag{43}$$

$$204.7838 * 4574 = 936681 \tag{44}$$

The price for electricity produced by biogas is 0.63 SEK per kWh (Energiföretagen. 2021), which results in 590 109 SEK from the produced electricity.

Since the sum of produced manure and bought substrate is the double in the alternative with 400 dairy cows, the sum of produced biogas is 1 873 363 kWh which multiplied with 0.63 brings an income of 1 180 218.69 SEK.

When biogas is produced, some of the weight from the mixture ends up in methane and carbon dioxide. Therefore, the number of tonnes in the biogas as a biogas mixture does not equal the amount of digestate. To calculate the biogas volume, methane volume (28.54) needs to be calculated with methane content (60%) (Edström 2023).

$$\frac{28.54}{0.6} = 47.56\text{m}^3 \text{ biogas} \tag{45}$$

The m^3CO_2 volume of the m^3 biogas is the sum minus the amount of methane, and the weight of CO_2 is 1.94kg/m^3 (ibid.).

$$47.56 - 28.54 = 19.02 \tag{46}$$

$$19.02 * 1.94 = 36.9 \tag{47}$$

The weight of gas in the biogas mixture is the sum of methane in kg/tonne biogas mixture (28.54) and the sum of carbon dioxide per tonne biogas mixture (36.9), which is 57.44 kg. When calculating the amount of digestate, 57.44 kg per tonne of biogas mixture needs to be removed. This is done by dividing the sum without kg biogas with the total biogas mixture.

$$1000 - 57.44 = 942.56 \tag{48}$$

$$\frac{942.56}{1000} = 0.94256 \tag{49}$$

$$0.94256 * 4574 = 4311.27\ tonnes\ of\ digestate \tag{50}$$

This shows that the total amount of digestate the case farm can spread on their arable land or sell to other farmers is 4311.27 tonnes. How much the case farm will use is described below later headings.

5.1.9 Contents of digestate and need of N-P-K

When the manure has been digested in the biogas plant the ammonium nitrogen becomes easier accessible for plants, which gives the manure a higher value once spread on the fields (Salomon & Wivstad. 2013). However, the difference between dairy cow slurry that has been digested and not is not that big in terms of ammonium nitrogen content. The more significant effects can be seen when digestating solid manure with liquid manure (ibid.). The content of manure after the digestate can be seen in the table below. In the table, cattle manure (which dairy cow manure is a part of) has been digested with chicken manure (a part of poultry manure). By co-digesting, it is possible to convert solid heterogeneous fertilizers into liquid homogenized fertilizers, which affects the possibilities of adapting the right amount of nutrition the crop needs in a positive way (ibid.).

Table 9. Description of digestate and manure values (Salomon & Wivstad. 2013) (own rendering).

Parameters	**Solely cattle manure (before digestion)**	**Solely chicken manure (before digestion)**	**Cattle manure (86%) and chicken manure (14%) after digestion**
Dry matter content %	8.9	65.8	9.1
pH	-	-	8.0
Charcoal kg/tonne	31	280	37
Total nitrogen kg/tonne	3.1	29.7	6.4
Ammonium nitrogen kg/tonne	1.3	4.0	4.3
Phosphorus kg/tonne	0.6	9.7	1,7
Potassium kg/tonne	3.5	19.1	5.4
Sulfur kg/tonne	0.3	4.2	0.6
Magnesium kg/tonne	-	-	0.9
Calcium kg/tonne	-	-	2.3

As mentioned earlier, grassland can collect some of the nitrogen in the soil. However, fertilizers are still needed for the crops to reach the maximum harvest level. In the table below, the need for nitrogen per hectare for different crops is shown.

Table 10. Nitrogen needs for the crops in the crop rotation, conventional alternative.

Crop	**Spring barley**	**Grassland year 1**	**Grassland year 2**	**Winter wheat**
Nitrogen need/hectare in kg conventional alternative	94	180	180	165
Nitrogen need/hectare in kg organic alternative	45	69	69	103

5.2 Findings conventional alternative

The conventional alternative of the fictional case farm that forms the basis of the optimization model in this study is described in the following chapter.

5.2.1 Optimal solution from optimization

The optimal profit from the four optimizations with conventional case farm alternatives are shown in table 11. The difference between the scenarios without and with biogas production is small when comparing the alternatives with 200 dairy cows. However, when the dairy cows are doubled the biogas production becomes profitable and adds approximately 590 000 SEK to the overall result.

Table 11. Optimal profit from four different conventional case farm scenarios.

Case farm alternatives	**Total profit**
200 conventional dairy cows without biogas production	2 402 126 SEK
200 conventional dairy cows with biogas production	2 430 465 SEK
400 conventional dairy cows without biogas production	4 784 225 SEK
400 conventional dairy cows with biogas production	5 373 320 SEK

One of the reasons for why biogas production reaches a higher difference in the alternative with 400 dairy cows is because the biogas mixture is doubled compared to the alternative with 200 dairy cows, which thereby results in doubled biogas production earnings. The operation cost for the biogas production is a fixed cost and therefore the same for both alternatives. For the case farm scenarios with biogas, the need for additional nitrogen is lower which results in a lower overall cost for artificial fertilizers. Lower costs lead to a higher result, which is why the alternative with biogas production for 200 dairy cows shows a higher optimal profit than the alternative based on the same number of cows but without biogas production.

Table 12. Parameters that differ from scenarios with and without biogas production.

Case farm alternative	**Operating cost of biogas plant**	**Purchase of poultry manure**	**Biogas production earnings**	**Total need for additional nitrogen (tonne)**
200 cows, without biogas	0	0	0	181.6
200 cows, with biogas	-530 000	-243 359	590 109	85.9
400 cows, without biogas	0	0	0	363.39
400 cows, with biogas	-530 000	-486 718	1 180 218	170.47

The biogas production reduces the need for additional fertilizers, since the digestate contains more nitrogen per tonne digestate (6.4%) than dairy cow manure does (3.1%). All other parameters are the same for the alternatives with the same number of cows and agricultural focus. That means that the difference between the optimal profit scenarios with no biogas production and a biogas production can be connected the costs and income related to biogas production and the reduce of cost for artificial fertilizer.

5.2.2 How dairy cows manure and digestate can cover the nitrogen need for the crops

For the case farm, it is interesting to know how the fertilizer need in form of nitrogen can be fulfilled with or without biogas production. The nitrogen need for conventional farming is 165 kg/hectare winter wheat, 94 kg/hectare spring barley, 180 kg/hectare grassland and 50 kg/hectare grazing on arable land (Agriwise. 2023). In the table below, the four different conventional case farm alternatives is shown in terms of how far the dairy cow manure or digestate can fulfill the overall nitrogen needs for each crop. Total dairy cow manure available in the scenarios with 200 dairy cows is 3934 tonne and total amount of available digestate is 4311 tonnes. For the alternatives with 400 dairy cows the sum is double, 7868 tonnes dairy cow manure and 8622 tonne of digestate. In the optimization, an artificial nitrogen content of 180 kg nitrogen per tonne is used with a cost of 12.5 SEK/kg nitrogen, resulting in 2250 SEK per tonne of artificial fertilizer.

In the alternative with 200 dairy cows without biogas production the fertilizer need cannot be fulfilled with solely manure from the dairy cows which means that artificial fertilizers need to be bought to cover the nitrogen need on the farm. All the dairy cow manure gets spread on the winter wheat and the other crops gets fertilized with artificial nitrogen. By spreading the manure on winter wheat, the case farm can spread some of the manure during the autumn and the rest during the spring. The storage place for manure is allowed to be smaller when spreading the manure on both the autumn and the spring compared to when only spreading in the spring, as would have been the case if the manure were spread on any other of the farm’s crops since they don’t enter their growing stage during the autumn. Winter wheat is at a growing stage on the autumn and can absorb the nitrogen better that way. By dividing the spreading of nitrogen in both autumn and spring, the nitrogen loss is limited, and since the nitrogen is expensive no farmer wants to lose any of it. Another benefit is that by spreading nitrogen on the fields before the crop has started to grow, the harvest can increase by 15-30% (Western Winter Wheat Initiative. 2018).

When comparing with the same fame size but with biogas production clear differences in manure spreading can be seen. The digestate is more nitrogen rich per tonne than solely dairy cow manure, leading to fewer tonne per crop needed and therefore the possibility to cover more crops nitrogen need. The need for additional artificial nitrogen is therefore also lower, which results in less cost for the case farm. Compared to the alternative without biogas production, the need for artificial fertilizers in approximately 100 tonne less. The cost for artificial fertilizers decreases a lot when the case farm has biogas production, in this alternative the with 215 000 SEK. That can be explained by more own manure, since 14% of the biogas mixture is bought poultry manure. Another explanation is that the nitrogen content (6.8 kg/tonne) in the digestate from biogas production is higher than the one in solely dairy cow manure (3.1 kg/tonne). These two factors result in less additional nitrogen needed, which in turn leads to less cost of artificial nitrogen.

As the result showed in the alternative with 200 dairy cows and no biogas production, the result in the alternative with double productional size also assigns all dairy cow manure to the winter wheat. To cover the nitrogen need, the manure from dairy cows needs to be supplemented when the case farm has 400 dairy cows as well. That is because both number of dairy cows and hectares of arable land has been doubled, which leads to the same ratio between fertilizer and hectares of arable land as in the alternative before. In this alternative, an additional 363.39 tonnes of artificial nitrogen need to be bought, resulting in a cost of approximately 817 000 SEK.

However, when the case farm has a biogas production along with 400 dairy cows and 560 hectares of arable land, the manure can be spread more even. The digestate can cover the full nitrogen need for grassland and some of the nitrogen need for spring barley. As described earlier, the nitrogen content is bigger in the digestate than in solely dairy cow manure, leading to less artificial nitrogen needed to be bought to cover the case farm’s total nitrogen need. Compared with the alternative without biogas, approximately 190 tonnes less is needed, resulting in a reduced cost of artificial fertilizer of approximately 435 000 SEK.

Table 13. Manure or digestate and artificial fertilizer need per hectare and crop for all conventional case farm alternatives.

200 conventional dairy cows without biogas production	**Hectares per crop**	**Total amount of dairy cow manure or digestate per hectare (tonne)**	**Total need for artificial fertilizers per hectare (tonne)**
Winter wheat	92.46	42.55	0.184
Spring barley	48	0	0.522
Grassland	139.53	0	1
Grazing on arable land	0	0	0
200 conventional dairy cows with biogas production			
Winter wheat	92.46	24.17	0
Spring barley	48	13.77	0
Grassland	139.53	10.14	0.615
Grazing on arable land	0	0	0
400 conventional dairy cows without biogas production			
Winter wheat	182.71	43.06	0.175

Spring barley	96	0	0.522
Grassland	279.06	0	1
Grazing on arable land	2.22	0	1
400 conventional dairy cows with biogas production			
Winter wheat	182.71	0	0.916
Spring barley	96	13.15	0.023
Grassland	279.06	26.37	0
Grazing on arable land	2,22	0	0.274

Appendix 5 shows the total need of manure or digestate per crop as well as the total need for artificial nitrogen per crop, and the total cost for it. The total cost for artificial fertilizer per hectare without biogas production is approximately 1460 SEK/hectare for both productional sizes and approximately 690 SEK/hectare for both productional sizes when having biogas production.

5.3 Findings organic alternative

The organic alternative of the fictional case farm that forms the basis of the optimization model in this study is described in the following chapter.

5.3.1 Optimal solution from optimization

The optimal profit given the restrictions in the optimization for organic case farm alternatives are shown in table 14 below. As can be seen, having biogas production does not increase the overall profit when having 200 dairy cows. An increase in profit can be seen when having 400 dairy cows, where the profit increase by approximately 831 000 SEK.

Table 14. Optimization result of optimal profit for different organic case farm scenarios.

Case farm alternatives	**Total profit**
200 organic dairy cows without biogas production	1 269 323 SEK
200 organic dairy cows with biogas production	1 419 004 SEK
400 organic dairy cows without biogas production	2 183 164 SEK
400 organic dairy cows with biogas production	3 312 738 SEK

The difference in the results depends on factors connected to biogas production and reduced amount of additional nitrogen in form of biofers needed. All other variables in the optimization have been the same. In table 15 below, the differences are shown. The need for additional fertilizer in form of biofer is needed in scenarios without the biogas. This is because the digestate contains more nitrogen per tonne and therefore can fulfil the farms total nitrogen need. As an effect, the cost of additional fertilizers equals zero in the scenarios with biogas production. In the alternatives without biogas, additional fertilizers are needed which affects the result to show a lower optimal profit.

Table 15. Optimal division of dairy cow manure and biofers to cover the total nitrogen need for 280 hectares organic farming.

Case farm alternative	**Operating cost of biogas plant (SEK)**	**Purchase of poultry manure (SEK)**	**Biogas production earnings (SEK)**	**Total need for additional nitrogen (tonne)**
200 cows, without biogas	0	0	0	107.58
200 cows, with biogas	-530 000	-243 359	590 109	0
400 cows, without biogas	0	0	0	215.86
400 cows, with biogas	-530 000	-486 718	1 180 218	0

5.3.2 How dairy cow manure and digestate can cover the nitrogen need for the crops.

For the different alternatives in the organic case farm, it is also interesting to know how the fertilizer need in form of nitrogen can be fulfilled with or without biogas production. The nitrogen need for organic farming is 103 kg/hectare winter wheat, 45 kg/hectare spring barley, 69 kg/hectare grassland and 50 kg/hectare grazing on arable land. In the tables below, the four different organic case farm alternatives will be shown in terms of how far the dairy cow manure or digestate can fulfill the overall nitrogen needs for each crop. Total dairy cow manure available in the scenarios with 200 dairy cows is 3934 tonne and total amount of available digestate is 4311 tonnes. For the alternatives with 400 dairy cows the sum is double, 7868 tonnes dairy cow manure and 8622 tonnes of digestate. The nitrogen content in the biofer is 60kg nitrogen per tonne biofer with a cost of 52,18 SEK per kg nitrogen (Agriwise. 2023).

When the organic case farm with 200 dairy cows and no biogas production uses its manure to cover the nitrogen need, it can bs seen in the table below that the manure can cover the total nitrogen need for grassland and some of the nitrogen need for winter wheat. An additional 107.58 tonnes of biofer are needed to cover the farms total nitrogen need, resulting in a cost of approximately 337 000 SEK.

When comparing the alternative above with the same case farm but with biogas production, a clear difference in need for additional nitrogen can be seen, since there is no need for additional fertilizer when using digestate. The optimization considers if additional fertilizers are needed and does not consider digestate to be sold. Therefore, when the need has been fulfilled for all crops, one of the crops will receive the surplus available until all digestate has been used. As mentioned in the delimitations, selling the left-over manure has not been considered in this optimization. The digestate contains enough nitrogen to exceed the farms total need of nitrogen, which results that the need for buying biofer for additional nitrogen disappears in this alternative.

When production size is doubled it is once again clear that additional nitrogen is needed when the case farm does not have biogas production. As in the corresponding alternative with 200 dairy cows, the manure is enough to meet the full nitrogen need for grassland and partly the nitrogen needs for winter wheat. 215.86 tonnes of biofer are needed as a complement to meet the farms total nitrogen need, resulting in a cost of approximately 676 000 SEK. However, when the organic case farm with 400 dairy cows has biogas production, the digestate contains enough nitrogen to cover the farms total need and no additional nitrogen are therefore needed.

Table 16. Manure or digestate and biofer needed per hectare and crop on each organic case farm alternative.

200 organic dairy cows without biogas production	**Hectares per crop**	**Total amount of dairy cow manure or digestate per hectare (tonne)**	**Total need for additional biofers per hectare (tonne)**
Winter wheat	48.87	13.44	0.741
Spring barley	62.62	0	0.750
Grassland	147.23	22.25	0
Grazing on arable land	29.26	0	0.833
200 organic dairy cows with biogas production			
Winter wheat	48.87	12.62	0
Spring barley	62.62	31.79	0
Grassland	147.23	10.11	0
Grazing on arable land	29.26	7.32	0
400 organic dairy cows without biogas production			
Winter wheat	81.75	16.06	0.886
Spring barley	116.95	0	0.749
Grassland	294.46	22.25	0
Grazing on arable land	66.82	0	0.833

400 organic dairy cows with biogas production			
Winter wheat	81.75	15.09	0
Spring barley	116.95	33.53	0
Grassland	294.46	10.11	0
Grazing on arable land	66.82	7.32	0

Appendix 6 shows the total need of manure or digestate per crop as well as the total need for biofers per crop, and the total cost for it. The total cost for biofer per hectare without biogas production is approximately 1200 SEK/hectare in both productional size, and when having biogas production, the need for buying biofer is zero for both productional sizes.

5.4 Difference in findings between conventional and organic alternative.

Table 17 shows a summary of the eight different case farm alternatives. All alternatives with conventional dairy cow production showed a greater result than their organic counterpart.

Table 17. Optimization result from all eight different case farm scenarios.

Case farm scenario	Profit conventional alternative (SEK)	Profit organic alternative (SEK)	Difference (SEK)
200 dairy cows, without biogas production	2 402 126	1 269 323	1 132 803
200 dairy cows, with biogas production	2 430 465	1 419 004	1 011 461
400 dairy vows, without biogas production	4 784 225	2 481 214	2 303 011
400 dairy cows, with biogas production	5 373 320	3 312 738	2 060 582

The difference in optimal result from the optimization between the conventional and organic alternative depends on many things. Appendix 4 shows that the inputs are the same for each case farm scenario regardless of if it has biogas production or not, which is the reason for only one scenario from each case farm alternative is represented in appendix 4. The difference in the parameters in appendix 4 can be explained by several different reasons. One difference is the income from sale of grains. The reason for the sum being higher in the conventional alternative is because the yield per hectare is bigger in conventional farming, which leaves more room for sale of grain after the need for feed ration has been fulfilled. The higher yield is an effect of more fertilizers being allowed per hectare which effects the production per hectare to be bigger than in conventional farming. Another factor is the parameters connected to dairy cows, which is milk production and sales of calves. The conventional dairy cows get a higher feed ration and can therefore produce more milk, which reflects in value per dairy cow and later in total value. The reason for sale of calves being higher in conventional farming is because the calves is older when being sold compared to organic farming. The price for inputs in feed rations is more expensive in the organic alternative compared to the conventional alternative. Although the dairy cows have approximately the same need for minerals and concentrate in conventional and organic farming, the price difference per kg equals to a big difference in the end-result.

Other parameters that affect the result negatively is the cost for grass-silage and heifer grower which combined costs approximately 2 500 000 SEK for the conventional alternative with 200 dairy cows, and approximately 5 000 000 SEK for 400 conventional dairy cows. In the organic alternative, the cost for grass-silage and heifer grower is approximately 2 580 000 SEK for 200 dairy cows and approximately 5 167 000 SEK for 400 dairy cows. The cost for additional nitrogen in form of artificial fertilizer or biofer fertilizer also affects the result negatively.

Table 18. Cost of buying additional nitrogen for all case farm alternatives.

Case farm alternatives	Conventional alternative	Organic alternative
200 dairy cows, without biogas production	408 600 SEK	336 811 SEK
200 dairy cows, with biogas production	193 275 SEK	0 SEK
400 dairy cows, without biogas production	817 627 SEK	675 814 SEK
400 dairy cows, with biogas production	383 332 SEK	0 SEK

A similarity regardless of agricultural focus in the production of biogas. When producing biogas, both new costs and new incomes arise compared to when not producing biogas. The costs are operational cost for biogas plant and purchase of poultry manure, while the income is produced biogas. When having 200 dairy cows, the case farm’s production of biogas given the mixture explained earlier is 936 681,5 kWh and the selling price for externally sold electricity is 0,63 SEK/kWh (Energiföretagen. 2021). The operational cost of the chosen biogas plant is 525 000 SEK (Agriwise. 2023) and the cost for poultry manure is approximately 243 000 SEK. This means that the production of biogas is not profitable when having 200 dairy cows. However, the improved nitrogen content in the digestate makes the need for additional nitrogen much less, which leads to lower costs in that department. However, when having 400 dairy cows the income from produced biogas exceeds the costs and makes the investment profitable. The explanation for it can be found in the operational cost for the biogas plant being the same for both alternatives.

Table 19. Income and costs related to biogas production for different farm sizes.

Income and costs related to biogas production	**200 dairy cows**	**400 dairy cows**
Income produced biogas (SEK)	590 109	1 180 218
Operational cost of biogas plant (SEK)	525 000	525 000
Purchase of poultry manure (SEK)	243 359	486 718
Overall profit from biogas production (SEK)	-178 250	168 500

6. Analysis and discussion

In this chapter the gathered findings from the previous chapter will be analysed. The findings are discussed and critically analysed in this chapter, along with their relevance to previous research. The research questions serve as the focal point for the conversation.

6.1 The factors for profitability in biogas production on a dairy farm

Table 20 summarizes factors for profitability in biogas production on a dairy farm.

Table 20. Summary of the factors for profitability for the biogas production on a dairy farm

Factors:	**Does it affect the incitements to begin with biogas?**	**Does it seem profitable to use?**	**Does the increase of natural gas prices affect?**	**Would a repeal of the tax exemption affect?**
The value of digestate	Yes, since it has a high value of nitrogen that will meet the demand of buying fertilizer. If overproduced, you could sell it for market prices.	Yes, it has high values for the crops as well for economic aspects.	No, it will further elevate the value of digestate since it becomes more profitable.	Yes, the digestate would lose in value if the price of production is being raised.
Value of the manure production	No, rather than the value of manure, the amount has a great impact if it´s profitable to begin with biogas production.	If you have larger productional sizes it gets more profitable to use the manure for biogas production.	Yes, manure would be more attractive for biogas production.	Yes and no, biogas would be more expensive to produce, but the manure would be a more depending part to the farm.

Impact on sustainability	For the sustainability aspect of converting from fossil fuels to fossil-free fuels it would be a big factor.	Economical sustainability would be impacted on a positive note since biogas is yet another production option for the farm. With exception of the investing costs.	The raise of natural gas prices affect sustainability in the manner of the need for more production of biogas that can meet future demand of fuel.	The repeal of tax exemption for biogas would decrease the incitements to begin producing biogas if it´s not profitable. Thus, economical sustainability would be affected.

6.2 How the repealed tax exemption would affect the case farms

As mentioned in chapter 1.1, it is noticed that biogas facilities in Sweden would be greatly affected by the repeal of tax exemption that has been decided by the Court of Justice of the European Union. This will lead to a tax based on kg biogas produced, this gives for our case farms a tax (if 4.7 SEK) of approximately 338 000 SEK for the biogas production based on 200 dairy cows, and 677 000 SEK for the alternatives with 400 dairy cows. This impact is presented in table 21.

Table 21. Earnings of biogas with or without tax reduction for biogas.

Alternative	**Earnings without tax**	**Earnings with tax**
200 conventional dairy cows	2 430 465 SEK	2 091 819 SEK
400 conventional dairy cows	5 373 320 SEK	4 696 027 SEK
200 organic dairy cows	1 419 004 SEK	1 080 358 SEK
400 organic dairy cows	3 312 738 SEK	2 635 445 SEK

This shows the significance of how the tax will affect the total profit from the biogas production. Most noticeable is the tax for organic alternative with 200 cows, where the profit just barely surpasses 1 000 000 SEK in an already tough scenario for profitability. The given differences in table 21 shows the impact of a repealed tax exemption would affect farmers. With regards to Karlsson et al. (2019) who mentions that Swedish farmers who engage in this business will find it difficult to profit due to high investment costs and intense price competition with fossil fuels, this tax will further strengthen Karlsson et al.´s (2019) statement.

6.3 Discussion

With the results presented in this study, it has been clear that having a farm-based biogas plant is profitable enough only when having a certain number of animals. The farm alternatives with 200 dairy cows were not profitable enough for the farmer to invest. However, when having 400 dairy cows, the biogas production profit greatly contributes to the overall result. One of the reasons for it is that the operating cost for the biogas plant is the same for both 200 and 400 dairy cows. Other reasons for it are because the need for additional nitrogen in either artificial fertilizer or biofer reduces, leading to lower costs and a higher result.

This research also noted that the conventional case farm alternatives with conventional dairy cows show a higher result than their organic counterparts. This is because the inputs for organic farming are more expensive, and the crops produce a lower yield per hectare. Furthermore, the options for organic fertilizers are more expensive than the conventional alternatives. The farmers then decide to use all digestate in both alternatives since the costs of fertilizers significantly impact the profit.

As seen in previous research, it has also been clear that co-digesting dairy cow manure with another type of manure leads to a higher nitrogen level than when digesting only dairy cow manure. The exact fertilizer content based on the feed ration has not been calculated, which could affect the result somehow.

Comparing the findings of this study to the previous work regarding optimization models for biogas at dairy farms could be best described by the work of Rivza & Rivza (2012). While Rivza & Rivza´s (2012) model displays renewable production's sustainable and economic efficiency in a specific time frame, the model of this study displays if farms would be able to afford investing in biogas. The model of this study also shows how the digestate could be used to support crop production for the dairy farm, which is a vital part of dairy farms. This shows the importance of further elevating new models of biogas profitability for dairy farms as fossil fuels are phased out and rising prices for natural gas increase the demand for renewable fuels.

Karlsson et al. (2019) mention that farm-based biogas production has potential to impact the environment, society and the economy positively. However, as Karlsson et al. (2019) also mention, Swedish farmers who engage in this business will find it difficult to profit due to high investment costs and intense price competition with fossil fuels. Karlsson et al. (2019) stated this in 2019 and did not consider how the tax exemption of biogas would further support their statement of how biogas production in Sweden is non-attractive for farmers to invest in if the taxes were to be reinstated. As found by this study, the tax impacts further incentives to invest in biogas significantly, which further displays the importance of conducting research to develop economic optimization models for biogas at dairy farms to aid sustainable goals, whether economical or environmental.

As a result of the gathered findings, the authors agree that biogas would be optimal for larger-scale farms, and smaller ones should combine their productional sizes and cooperate. Having a biogas facility demands much of the farmers, and logically it needs to be supervised frequently during the day to prevent productional stalls. It is also even more crucial to cooperate between farms if the taxes for biogas are being brought back to Sweden since it is decreasing the profit significantly.

Finally, it can be concluded that the optimization model used shows a close reflection of the reality. For example, the cost per kg grass silage is in the conventional feed ration 2,79 SEK, and the shadow price in the optimization model showed 2,53 SEK while the price for wheat was 1,9 in the feed ration and 2,01 in the optimization model.

7. Conclusions

This chapter presents the study´s conclusions by answering the research questions. Suggestions for future research will also be presented.

This study aimed to investigate:

1. *How can the nitrogen levels in digestate be used in the most profitable way in both organic and conventional farming based on milk production?*

2. *How can the profitability of biogas production from the dairy farm be affected by the produced manure and purchased poultry manure?*

3. *How is the profitability affected by cropping system and plant size the dairy farm dispose?*

With the gathered findings and previous discussion considered, it is evident that the specific mixture in the digestate can fulfil the farm's nitrogen needs better than solely dairy cow manure in the conventional alternatives and entirely in the organic alternatives. Therefore, the most profitable way is to use the digestate on the farm's hectare since less additional nitrogen must be bought.

The profitability of biogas is affected by the inputs from the farm level because most of the substrate comes from the farm’s dairy cows. If the farm could not produce the substrate, it would need to be bought, which would affect the profitability of the biogas.

The productional size has proven to be an essential factor in deciding whether investing in a biogas plant is profitable enough. Regardless of agricultural focus, investing in a biogas plant when having 200 dairy cows is not profitable enough since workload has not been included in this study. The difference in overall profit from conventional alternative with and without biogas production was approximately 30 000 SEK, and approximately 140 000 SEK for organic alternative within the same productional size. However, when having 400 dairy cows, it was proved to be profitable, as it increased the overall profit with approximately 590 000 SEK in the conventional alternative and 830 000 SEK in the organic alternative. The difference the biogas production brings is mostly made up of less cost of additional nitrogen, which is more costly in organic farming than in conventional farming. This leads to biogas production having a bigger impact on the organic case farms optimal profit. It can be concluded that the biogas production per se is not profitable when having 200 dairy cows, but the reduced need of buying additional nitrogen makes the investment and its contributing consequences reach a higher overall result than when not having biogas production. An important aspect though is that cost for workload has been delimitated.

Many similarities can be drawn between this research and the literature mentioned in literature review, for example that the fields finances, resources and production are all included. The contribution this study does and what differs it from the others is that the aim in this study has been to compare the economic conditions for conventional and organic agriculture´s utilization of manure and nitrogen levels in digestate when considering milk production, crop cultivation and biogas production. None of the previous studies had that research aim and therefore were not able to provide information in that field, which the authors of this study believe that this research contributes to. To the best of the authors knowledge, research in that area has not been done before and therefore it is the authors belief that this research contributes greatly to provide insight in differences between agricultural focus with and without biogas production on two different farm sizes and four different comparisons.

7.2 Suggestions for future research

Previous research on the matter has not attempted to see the issue from a business perspective. It would be of great interest to see primary data being optimized to give the research a higher value and impact on a more global academic level.

As for further suggestions, it would be interesting to see all parts of N-P-K in an optimization model to see how the farm utilizes them in crop production.

Another suggestion, concerning a more qualitative approach, would be to carry out a study where farmers' attitudes towards investing in biogas is analyzed.

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Popular science summary

Biogas is a promising renewable energy source that can contribute to sustainable electricity, fuel, and heating systems. To assess the profitability of farm-based biogas plants for electricity production, a study compared the earnings and costs of eight different case farm alternatives. All of these alternatives were based on milk production, with variations in conventional and organic agriculture approaches, herd sizes, and arable land areas.

Using mathematical optimization models, the study found that the case farm alternatives with 200 dairy cows and 280 hectares of arable land, combined with biogas production, were marginally profitable regardless of the agricultural focus. In the conventional alternative, incorporating biogas production increased the overall profit by approximately 30,000 SEK compared to the alternative without biogas. In the organic alternative, the profit from biogas production showed a more significant increase, reaching approximately 150,000 SEK.

When analyzing alternatives with 400 dairy cows and 560 hectares of arable land, it was found that a farm-based biogas plant proved to be profitable and significantly contributed to the overall profit. In the conventional alternative, the biogas plant contributed roughly 600,000 SEK to the overall profit, compared to approximately 830,000 SEK. Across all eight case farm alternatives, the conventional agricultural focus proved to be more profitable than the organic counterparts. This difference could be attributed to higher yield per hectare, lower costs for feed inputs, higher prices for calf sales, and reduced costs per additional nitrogen required.

The main disparity between the case farm alternatives with and without biogas production lies in the cost of nitrogen. When biogas production is absent, the cost of nitrogen is considerably higher. This is because the digestate produced from biogas production, due to the study's substrate mixture, contains a higher percentage of nitrogen per tonne.

In conclusion, the study highlights the potential profitability of farm-based biogas plants for electricity generation. Depending on factors such as farm size and agricultural approach, incorporating biogas production can lead to increased profits and contribute positively to sustainable energy production.

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Uppsala, June 2023

Nils Hermansson & Albin Åkerblom

Appendix 1 return and contribution margin

Table 22. Contribution margin calculations for organic farming (2022) in crop growing area 1. (Agriwise. 2022)

Crop	**Winter wheat, feed**	**Spring barley, feed**
Return in kg	4 100	3 000
Price/kg	2,52	2,47
Nitrogen need, kg	103	50
Phosphorus need, kg	12	9
Potassium need, kg	6	0
Special income	11 832	8 910
Special cost 1	8 991	4 930
Special cost 2	711	595
Contribution margin 1	2 481	3 980
Contribution margin 2	2 130	3 384

Table 23. Contribution margin calculations for conventional farming (2022) in crop growing area 1..(Agriwise. 2022)

Crop	**Winter wheat, feed**	**Spring barley, feed**
Return in kg	7 600	5 300
Price SEK/kg	2,01	1,91
Nitrogen need, kg	165	94
Phosphorus need, kg	23	16
Potassium need, kg	23	12
Special income	15 276	10 123
Special cost 1	7 707	5 157
Special cost 2	807	678
Contribution margin 1	7 569	4 966
Contribution margin 2	6 762	4 288

Table 24. Contribution margin calculations for organic farming (2022) in crop growing area 1.(Agriwise. 2022)

Crop	**Grassland**	**Grazing on arable land**
Return in kg	5189	4 340
Price SEK/kg	2,34	1,14
Nitrogen need, kg	69	50
Phosphorus need, kg	10	0
Potassium need, kg	69	0
Special income	12 142	4 948
Special cost 1	8 525	3 614
Special cost 2	2 185	916
Contribution margin 1	3 618	1 334
Contribution margin 2	1 433	418

Table 25. Contribution margin calculations for conventional farming (2022) in crop growing area 1.(Agriwise. 2022)

Crop	**Grassland**	**Grazing on arable land**
Return in kg	6 400	5 040
Price SEK/kg	1,81	0,88
Nitrogen need, kg	180	150
Phosphorus need, kg	16	0
Potassium need, kg	107	0
Special income	11 584	4 435
Special cost 1	8 486	2 871
Special cost 2	2 309	915
Contribution margin 1	3 098	1 565
Contribution margin 2	789	650

Appendix 2 Number of cattle distributed by category 2000-2022

Table 26. Number of cattle distributed by category 2000-2022. (Jordbruksverket. 2022)

Number of animals	**2000**	**2010**	**2013**	**2016**	**2020**	**2021**	**2022**
Cows for milk production	427 621	348 095	344 021	330 833	303 390	301 850	296 543
Cows for rearing calves	167 277	197 053	188 810	193 657	206 950	209 745	213 102
Cows – total	594 898	545 148	532 831	524 490	510 340	511 595	509 645
Heifers, bulls & steers	588 686	512 566	496 919	489 217	480 493	476 497	481 973
Calves, under one year	500 183	478 944	466 776	475 917	462 149	465 211	457 698
Cattle – total	1 683 767	1 536 658	1 496 526	1 488 904	1 452 982	1 453 303	1 449 316
Number of companies with animals	**2000**	**2010**	**2013**	**2016**	**2020**	**2021**	**2022**
Cows for milk production	12 676	5 619	4 669	3 872	3 087	2 955	2 795
Cows for rearing calves	13 861	12 190	11 092	10 379	10 063	9 974	9 909
Cows – total	25 500	17 775	15 712	14 221	13 150	12 929	12 704
Heifers, bulls & steers	30 457	20 295	17 824	16 060	14 444	14 266	13 957
Calves, under one year	27 733	18 494	16 306	14 839	13 266	13 022	12 674
Cattle – total	32 063	21 586	18 962	17 046	15 426	15 227	14 895

Appendix 3 Separable costs for grain production

Table 27. Separable costs for grain (Agriwise. 2022)

Type of grain	**Separable cost Conventional alternative**	**Separable cost Organic alternative**
Winter Wheat	7 707 SEK	8 991 SEK
Spring barley	5 157 SEK	4 930 SEK
Grass Silage	8 486 SEK	8 525 SEK
Grazing on arable land	2 871 SEK	3 614 SEK

Appendix 4 Costs and incomes that explains the difference in the different case farm alternatives

Table 28. Costs and incomes that explains the difference in the different case farm alternatives.

All units in SEK	**200 conventional dairy cows**	**200 organic dairy cows**	**Difference**	**400 conventional dairy cows**	**400 organic dairy cows**	**Difference**
Sale of wheat or barley	906 434	50 077	856 357	1 778 922	38 689	1 740 233
Purchase of minerals	-198 712	-237 568	38 856	-397 424	-457 136	59 712
Purchase of concentrate	-1 039 198	-1 959 232	920 034	-2 078 396	-3 918 464	1 840 068
Purchase of premix	-531 358	0	-531 358	-1 062 716	0	-1 062 716
Production of dairy cow	5 912 400	5 615 000	297 400	11 824 800	11 230 000	594 800
Sale of heifer calf	154 000	52 400	101 600	308 000	104 800	203 200
Sale of bull calf	240 000	112 500	127 500	496 000	225 000	271 000
Support for organic dairy production	0	354 000	354 000	0	708 000	708 000
Result	5 443 566	3 987 177	1 456 389	10 869 186	7 930 089	2 939 097

Appendix 5 Total amount of manure or digestate per crop, total need, and cost for artificial fertilizer per crop for all conventional case farm alternatives.

Table 29. Optimal division of dairy cow manure and artificial fertilizers to cover the total nitrogen need for 280 hectares conventional farming.

200 conventional dairy cows without biogas production	**Hectares per crop**	**Total amount of dairy cow manure per crop (tonne)**	**Total need for artificial fertilizers per crop (tonne)**	**Cost of artificial fertilizers per crop (SEK)**
Winter wheat	92.46	3934	17.01	38 272.5
Spring barley	48	0	25.06	56 385
Grassland	139.53	0	139.53	313 942.5
Grazing on arable land	0	0	0	0
Total	280	3934	181.6	408 600

Table 30. Optimal division of digestate and artificial fertilizers to cover the total nitrogen need for 280 hectares conventional farming.

200 conventional dairy cows with biogas production	**Hectares per crop**	**Total amount of digestate per crop (tonnes)**	**Total need for artificial fertilizers per crop (tonnes)**	**Cost of artificial fertilizers per crop (SEK)**
Winter wheat	92.46	2235.16	0	0
Spring barley	48	661.19	0	0
Grassland	139.53	1414.63	85.9	193 275
Grazing on arable land	0	0	0	0
Total	280	4311	85.9	193 275

Table 31. Optimal division of dairy cow manure and artificial fertilizers to cover the total nitrogen need for 560 hectares conventional farming.

400 conventional dairy cows without biogas production	**Hectares per crop**	**Total amount of dairy cow manure per crop (tonne)**	**Total need for artificial fertilizers per crop (tonne)**	**Cost of artificial fertilizers per crop (SEK)**

Winter wheat	182.71	7868	31.98	71 955
Spring barley	96	0	50.13	112 792
Grassland	279.06	0	279.06	627 885
Grazing on arable land	2.22	0	2.22	4 995
Total	560	7868	363.39	817 627

Table 32. Optimal division of digestate and artificial fertilizers to cover the total nitrogen need for 560 hectares conventional farming.

400 conventional dairy cows with biogas production	**Hectares per crop**	**Total amount of digestate per crop (tonne)**	**Total need for artificial fertilizers per crop (tonne)**	**Cost of artificial fertilizers per crop (SEK)**
Winter wheat	182.71	0	167.49	376 852.5
Spring barley	96	1262.35	2.27	5 107
Grassland	279.06	7360.96	0	0
Grazing on arable land	2,22	0	0.61	1 372.5
Total	560	8623	170.37	383 332

Appendix 6 Total amount of manure or digestate per crop, total need, and cost for biofer per crop for all organic case farm alternatives.

Table 33. Optimal division of dairy cow manure and biofers to cover the total nitrogen need for 280 hectares organic farming.

200 organic dairy cows without biogas production	**Hectares per crop**	**Total amount of dairy cow manure per crop (tonne)**	**Total need for additional biofers per crop (tonne)**	**Cost of biofer fertilizers per crop (SEK)**
Winter wheat	48.87	656.84	36.23	113 429
Spring barley	62.62	0	46.97	147 053
Grassland	147.23	3277.15	0	0
Grazing on arable land	29.26	0	24.38	76 329
Total	280	3934	107.58	336 811

Table 34. Optimal division of digestate and biofers to cover the total nitrogen need for 280 hectares organic farming.

200 organic dairy cows with biogas production	**Hectares per crop**	**Total amount of digestate per crop (tonne)**	**Total need for additional biofers per crop (tonne)**
Winter wheat	48.87	617	0
Spring barley	62.62	1991.19	0
Grassland	147.23	1488.74	0
Grazing on arable land	29.26	214.4	0
Total	280	4311	0

Table 35. Optimal division of dairy cow manure and biofers to cover the total nitrogen need for 560 hectares organic farming.

400 organic dairy cows without biogas production	**Hectares per crop**	**Total amount of dairy cow manure per crop (tonne)**	**Total need for additional biofers per crop (tonne)**	**Cost of biofer fertilizers per crop (SEK)**
Winter wheat	81.75	1313.68	72.47	226 889
Spring barley	116.95	0	87.71	274 602
Grassland	294.46	6554.31	0	0

Grazing on arable land	66.82	0	55.68	174 323
Total	560	7868	215.86	675 814

Table 36. Optimal division of digestate and biofers to cover the total nitrogen need for 560 hectares organic farming.

400 organic dairy cows with biogas production	**Hectares per crop**	**Total amount of digestate per crop (tonne)**	**Total need for additional biofers per crop (tonne)**
Winter wheat	81.75	1234	0
Spring barley	116.95	3921.6	0
Grassland	294.46	2977	0
Grazing on arable land	66.82	489.59	
Total	560	8623	0

Appendix 7 The optimization model

Optimering <u>konventionell</u> modell										
	XHV		XKORN					XVALL		
	Höstvete foder	Höstvete sälj	Vårkorn foder	Vårkorn sälj	Inköp mineral	Inköp koncentrat	Inköp premix	Vall	Naturbete	Bete på åker
antal XJ	92,46875	450962,5	48	0	11800	206600	75800	139,53125	13,111111	0
pris CJ	-7707	2,01	-5157	1,91	-16,84	-5,03	-7,01	-8486	-385	-2871
return	-712656,6563	906434,625	-247536	0	-198712	-1039198	-531358	-1184062,188	-5047,7778	0
vinst	2430465,109									

Restriktioner	Höstvete foder	Höstvete sälj	Vårkorn foder	Vårkorn sälj	Inköp mineral	Inköp koncentrat	Inköp premix	Vall	Bete	
Return										
Åker	1		1					1		1
Insådd vall			-1					0,5		
Växtföljd	1		-1					-0,5		
Grovfoder ensilage								-6400		
Behov fodervete	-7600	1								
Behov foderkorn			-5300	1						
Behov mineraler					-1					
Behov koncentrat						-1				
Behov foderhalm	-4560		-1961							
Behov bete									-1800	-5040
Behov strömedel										
Försäljning livkalv kviga										
Försäljning livkalv tjur										
Antal kor										
Nötkreaturstöd										
Stöd ekologisk mjölkproduktion										
Produktion gödsel										
Biogasanläggning										
Total energiproduktion kWh										
B.produktion										
Proportioner biogas										
Total biogasblandning										
Behov av gödsel										
Inköp slaktavfall										
Biogasblandning										
Max naturbete									1	
Inköp kvigor										
Behov av gödsel kommer från prod gödsel										
Rötrester										
Rötrester till höstvete										
Kväve till höstvete	165									
Rötrester till korn										
Kväve till korn			94							
Rötrester till vall										
Kväve till vall								180		
Rötrester till åkerbete										
Kväve till åkerbete										150
Flytgödsel till åker										
Rötrestor till grödor										
Behov premix							-1			

							Xprod G	
Strömdedel	Producerande Mjölkko	Livkalv kviga	Livkalv tjur	Nötkreaturstöd	Kostnad kvighotell	Stöd ekologisk mjölkproduktion	Produktion gödsel	Biogasanläggning
80000	200	100	100	200	70	0	3934	1
-1,3	29562	1540	2480	910	-18980	0	192	-530000
-104000	5912400	154000	248000	182000	-1328600	0	755328	-530000

Strömedel	Producerande Mjölkko	Livkalv kviga	Livkalv tjur	Nötkreaturstöd	Kostnad kvighotell	Stöd ekologisk mjölkproduktion	Produktion gödsel	Biogasanläggning
-1,3		524	1125	910		1770	192	-530000
	4465							
	1259							
	1272							
	59							
	1033							
	134							
	118							
-1	400							
		1						
			1					
	1							
	-1			1				
	-1					1		
	-19,67						1	
								1
								-936681,5
	0							
	0,35				-1			
							-1	
							0	
	379							

	XBIGBL	XBG	XFGC		XHVRR	XHVFG	XHVKonst	XKRR
B.produktion KWh	Biogasblandning	Behov av gödsel	Flytgödsel till åker	Behov fjäderfägödsel	Rötrest till höstvete	Flytgödel till höstvete	Inköp konstgödsel till höstvete	Rötrest till korn
936681,5	4574,418605	3934	0	640,4186047	2235,835837	0	0	661,1957796
0,63	0	0	10	-380	0	0	-2250	0
590109,345	0	0	0	-243359,0698	0	0	0	0

B.produktion KWh	Biogasblandning	Behov av gödsel	Flutgödsel till åker	Inköp slaktavfall	Rötrest till höstvete	Flytgödel till höstvete	Inköp konstgödsel till höstvete	Rötrest till korn
329	0	0		0				
1	-204,78							
1								
	0,14			-1				
	-1	1		1				
0		0						
0	0			0				
	0							
		1	1					
	0,94256							
					1			
					-6,824	0	-180	
								1
								-6,824
						0		
					1			1

XKFG	XKKonst	XVALLRR	XVALLFG	XVALLKonst	XÅKERBETERR	XÅKERBETEFG	XÅKERBETEKonst
flytgödsel till korn	Inköp konstgödsel till korn	Rötrest till vall	Flytgödsel till vall	Inköp konstgödsel till vall	Rötrest till åkerbete	Flytgödsel till åkerbete	Inköp konstgödsel till åkerbete
0	0	1414,632384	0	85,90096452	0	0	0
0	-2250	0	0	-2250	0	0	-2250
0	0	0	0	-193277,1702	0	0	0

flytgödsel till korn	Inköp konstgödsel till korn	Rötrest till vall	Flytgödsel till vall	Inköp konstgödsel till vall	Rötrest till åkerbete	Flytgödsel till åkerbete	Inköp konstgödsel till åkerbete
0	-180						
		1					
		-6,824	0	-180			
					1		
					-6,824	0	-180
0			0			0	
		1			1		

XRÖT	XFLYTGÖDSEL
Rötrester tot	Flytgödsel tot
4311,664	0
0	0
0	0

Rötrester tot	Flytgödsel tot		Bivillkor
		<=	280
		>=	0
		<=	0
		<=	0
		<=	0
		<=	0
		<=	0
		<=	0
		<=	0
		<=	0
		<=	0
		<=	100
		<=	100
		<=	200
		<=	0
		<=	0
		<=	0
		=	1
		<=	0
		<=	0
		=	0
		=	0
		<=	0
		<=	0
		<=	0
		<=	20
		=	0
		<=	0
-1		=	0
-1		<=	0
		<=	0
-1		<=	0
		<=	0
-1		<=	0
		<=	0
-1		<=	0
		<=	0
0		=	0
-1		=	0
		<=	0

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