Sveriges lantbruksuniversitet
Swedish University of Agricultural Sciences

Department of Economics

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- A sunny story?

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Master's thesis · 30 hec · Advanced level
Agricultural Programme – Economics and Management
Degree thesis No 881 · ISSN 1401-4084
Uppsala 2014

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Credits: 30 hec
Level: A2E
Course title: Independent project/Degree in Business Administration
Course code: EX0536
Programme/Education: Agricultural Programme – Economics and Management
Faculty: Faculty of Natural Resources and Agricultural Sciences

Place of publication: Uppsala
Year of publication: 2014
Cover picture: Louise Ekman and Emelie Jonsson
Name of Series: Degree project/SLU, Department of Economics
No: 881
ISSN 1401-4084
Online publication: http://stud.epsilon.slu.se

Key words: Photovoltaic, PV, pig production, linear programming, optimization, solar cells

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Acknowledgements

This thesis would not have been possible without the support from everyone who has helped with knowledge and expertise during the journey of writing. First and formal we would like to thank our supervisor Hans Andersson at the Department of Economics at the Swedish University of Agricultural Sciences. Then we would like to send a big thank you to David Larsson at Solkompaniet, Ida Norberg at JTI, Lars Neuman at LRF Konsult, Torsten Hörndahl at SLU Alnarp and Pathrik Herbertsson at EON for all of their knowledge and support.

We would also like to warmly thank our families and friends for believing in our capability and for cheering us on during the whole process. This has meant a lot for us. Last but not least we would like to thank the SLU Library at Ultuna for providing good material that made this thesis possible.

Uppsala, September 2014

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Abstract

In Sweden there is a large interest in renewable energy but the market for solar power is still small compared to other countries such as Germany. Here many farmers produce their own electricity. The Federation of Swedish farmers have acknowledged the potential for Swedish farmer to produce electricity and there is an interest among the farmers. The agricultural branches in Sweden most suitable for solar power are pig production and poultry due to the even electricity need throughout a year. Swedish pig farmers are going through a period of unsteady profitability which makes it interesting to see whether producing their own electricity can affect the economic situation. Earlier studies have shown that it is not profitable on farms to make such investments but due to market developments and rapid changes another study is highly relevant.

This thesis' aim is therefore to see with the help of mathematical modelling; if an investment in a photovoltaic system is economically feasible at a Swedish pig farm, if an investment can affect the profitability of the farm, how sensitive it is and what capacity of a photovoltaic system that is optimal. To reach the aim this study is conducted in a quantitative manner through the use of mathematical programing. A fictive farm has been created through statistics to use in an optimization model comparing eleven different investment options. A sensitivity analysis is also carried out in order to test how changes in different factors affect the outcome of the optimization.

Results show that in order for an investment in solar power to be economically feasible on a Swedish pig farm, with the conditions available at time of writing this thesis, there is a need for receiving investment grants and being able to trade electricity certificates. If these basic conditions are met an investment based on the electricity need of the farm is a part of the optimal solution. Another conclusion is that the optimal system size highly depends on the electricity need of the farm.

Sammanfattning

I Sverige finns det ett stort intresse för förnybar energi, men marknaden för solenergi är fortfarande liten jämfört med andra länder såsom Tyskland. Där producerar många lantbrukare sin egen el hemma på gården. Lantbrukarnas Riksförbund har lagt märke till potentialen för svenska lantbrukare att producera egen el och att det finns ett intresse bland dessa. De agrara produktionsinriktningarna i Sverige mest lämpliga för solenergi är gris- och fjäderfäproduktion på grund av det jämna elbehovet under året. Svenska grisproducenter går igenom en period av ostadig lönsamhet vilket gör det intressant att se om möjligheten att producera sin egen el kan påverka den ekonomiska situationen. Tidigare studier har visat att det inte är lönsamt att göra sådana investeringar på gårdsnivå, men på grund av marknadsutveckling med snabba förändringar är en ny studie mycket relevant.

Uppsatsens syfte är därför att med hjälp av matematisk modellering se; om en investering i ett solcellssystem är ekonomiskt möjlig på en svensk grisgård, om en investering kan påverka lönsamheten på gården, hur känslig investeringen är samt vilken storlek på ett solcellssystem som är optimalt. För att uppnå syftet utförs denna studie med ett kvantitativt perspektiv genom användning av matematisk programmering. En fiktiv gård har skapats genom statistik som används i en optimeringsmodell där elva olika investeringsalternativ jämförs. En känslighetsanalys görs även för att testa hur förändringar i olika faktorer påverkar resultatet av optimeringen.

Resultaten visar att en investering i solenergi är ekonomiskt möjlig på en svensk grisgård, med de villkor som finns i skrivande stund, om det finns en möjlighet att få investeringsbidrag samt möjligheten att kunna handla med elcertifikat. Om dessa grundläggande villkor är uppfyllda är en investering baserad på gårdens elbehov en del av den optimala lösningen. En annan slutsats är att vilket investeringsalternativ som är optimalt beror mycket på vilket elbehov gården har.

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1. Introduction

In the introduction the base of the study is presented. It begins with a short problem background and based on that the problem is formulated. Out of the problem the aim is then framed.

1.1 Problem background

The world, and especially the industrialized parts, is facing increasing demands of reducing the greenhouse gas emissions (Profu, 2013). Therefore, in Sweden today there is an interest in increasing the use of renewable energy (www, The Swedish Government, 2014), in order to meet the global targets. The government has since year 2009, (www, Swedish Energy Agency, 2013), tried to stimulate the development of renewable energy sources, by for example introducing grants and subsidies (www, The Swedish Government, 2014). Sweden is not the only country interested in renewable energy. In Europe both wind and sun are the two energy sources that are increasing the most (Corbetta & Miloradovic, 2014). For example, many winemakers in Germany have invested in solar panels due to beneficial economic incentives from their governments (Smyth, 2012). Germany has seen the potential for producing renewable energy within the agricultural sector (Wood, 2006). For instance solar energy has gone through a substantial development, where many farmers are interested in investing in energy production for their own consumption. In comparison, the solar energy market in Sweden is quite small. By the end of year 2012 the installed power from solar systems was 24,3 MW compared to 32,4 GW in world leading Germany (Stridh *et al.*, 2013).

The Federation of Swedish farmers, LRF, has acknowledged the potential of Swedish farmers being energy producers and have taken several initiatives to promote development (www, Federation of Swedish farmers, 2014). According to a survey made in year 2013 there is an interest among farmers for investing in solar energy (Innovatum Teknikpark, 2013). The reasons are many but one essential factor is large unused roofs and the rising cost of energy. The most interesting enterprises within the agricultural sector for investing in solar energy are pig and poultry production. The reason is that these animal production systems have an even need for energy throughout the year with small differences during seasons (*ibid.*).

In Swedish pig production today there is intensification in energy consumption due to new technology developments (Mattsson, 2010). Today's pig production consumes about 42 kWh per piglet and approximately 29,4 kWh per produced slaughter pig (Hörndahl & Neuman, 2012). About 50 % of the consumed energy in piglet production is strictly due to different ways of heating and 40 % of that amount is heat lamps in piglet boxes. In swine production ventilation and feeding systems consume the largest amount of energy and they account for about three quarters of the energy consumption. While the consumption of energy keeps increasing, so does the costs, making energy an increasing financial cost (Mattsson, 2010).

The farming sector in Sweden has been facing decreasing profitability at the same time as production costs have been increasing (www, Swedish Board of Agriculture, 2013). The pig sector alone has experienced profitability problems during several years (Swedish Board of Agriculture, 2013a). In the beginning of year 2013 the prices were fairly good but due to imported meat, prices dropped for the meat producers during the later parts of the year (www, LRF Konsult, 2013). Although the economic results for many pig farms were modestly positive 2013 there are poor chances for long-term profitability (*ibid.*).

According to the Swedish Pig Producer Organization's (Svenska Pig) international annual report for 2013, one of the major costs that needs to be lowered to create long-term profitability is the capital cost of buildings (Eriksson, 2013). The primary reason is the larger area per animal compared with the rest of EU (*ibid.*), that leads to less effective stables. A second factor is that pig stables in Sweden have to, compared to other pig producing countries in EU, be well isolated due to the cold climate and also have constructions that can carry large amount of snow.

Two studies have been conducted concerning Swedish farmers investing in solar panels, one from 2007 by Douhan and Rejstrand and one from 2009 by Nygren with a focus on an investment on dairy farms. The first study showed that an investment was not to recommend (Douhan & Rejstrand, 2007) and the second study showed that an investment was modestly positive on dairy farms, but under certain prerequisites (Nygren, 2009). Since these studies were conducted, the market and techniques for solar cells have developed (Bazilian *et al.*, 2013) and there is a high potential for solar cells to gain higher performance and lower production costs in the future (Othman *et al.*, 2013).

1.2 Problem

There seems to be a genuine interest from Swedish farmers to take the step towards becoming energy producers (Innovatum Teknikpark, 2013). However, after a period with decreasing economic viability it can seem as a hard step to take, with a lot of competition from the world market and increasing production costs. Normally when a business suffers from increasing costs, it is natural to seek possible ways for changing that trend. Producing own electricity instead of buying could be one way to reduce costs and making the farm less exposed to external factors. Energy plays an important role in pig production today, since maintaining good ventilation and a steady temperature in the stables may affect the health of the pigs in a positive way. For example in piglet production, energy in terms of heating lamps play a central part in keeping the piglets healthy, since they are sensitive to low temperatures (Puppe *et al.*, 2008). To keep the pigs healthy ultimately generates better financial results.

Farmers in for instance Germany show a large interest in producing their own energy (Wood, 2006). One of the sources is solar power where the German market is world leading. A reason for the Swedish market being small in comparison may be the result of two common myths. The first myth is that there is too little sunshine in Sweden for solar power to be beneficial (Stridh *et al.*, 2013). However, the south of Sweden has the same amount of sunshine and irradiation as northern Germany. The second myth is that it is too expensive to invest in solar power. According to Stridh *et al.* (2013) this myth has some truth but recently the market has shown a development towards lower production costs (Bazilian *et al.*, 2013; Stridh *et al.*, 2013). Although Stridh *et al.* (2013) argues that it is profitable with solar energy; the question that stands unanswered is if it is economically feasible to invest in solar power on a Swedish pig farm today.

1.3 Aim and research questions

The aim of this thesis is to examine based on mathematical modelling techniques; if an investment in a photovoltaic system is economically feasible at a Swedish pig farm. In addition it is of interest to examine if an investment may affect the profitability of the farm. Furthermore an important question is how sensitive these investments are and what the optimal capacity is. To reach the aim, the following research questions will be explored:

- Is an investment in solar cells on a farm with pigs economically feasible?
- Can an investment in solar cells affect the profitability on a farm with pigs?
- Which capacity of a solar cell investment would be the most economically optimal and how sensitive is such a solution to energy prices and capital cost of the system?

1.4 Delimitations

This thesis will be limited to examine solely Swedish conditions due to the fact that laws and investment regarding renewable energy may differ between countries. By choosing farrow-to-finish pig production farms, the authors of this thesis wish to explore an agricultural enterprise where the need for energy is quite large compared to other enterprises. This industry also have an energy need that is rather constant during the year (Hörndahl & Neuman, 2012); heating and feeding during winter and feeding and ventilation during the summer, which makes it interesting to examine this type of investment (Innovatum Teknikpark, 2013).

This thesis focuses on photovoltaic solar cell systems (mentioned as PV systems) for producing electricity and not solar panels for heating. In addition, energy supplied from the panels is not to be regarded as the only energy source, more as a complement to other sources at the farm. The panels are a grid connected system and the authors attempt only to examine rooftop systems, not ground based solar modules. The roof-tops at farms are usually an unexploited resource and they are well suited when it comes to tilt, size and positioning (Innovatum Teknikpark, 2013).

1.5 A basic photovoltaic system

A grid connected photovoltaic system (PV system) works according to the schematic figure (Figure 1) (Green *et al.*, 2002; Wenham *et al.*, 2007). When the sun shines at the panels (step 1), they start to produce electricity. This energy is transferred to the inverter (step 2), where the electricity is transformed from direct current (DC) electricity to alternating current (AC) electricity. The inverter is connected to the main electrical panel (step 3), which distributes the electricity in to the internal system for consumption (step 4). If there is an excess of electricity produced, the electrical panel pushes the electricity through the electrical meter (step 5) and out on to the grid. And vice versa, if there is a lack of electricity in the internal system, electricity can be bought from the grid. In Sweden net metering is not allowed, therefore two meters are installed (www, SunElectricityProgram, 2013).

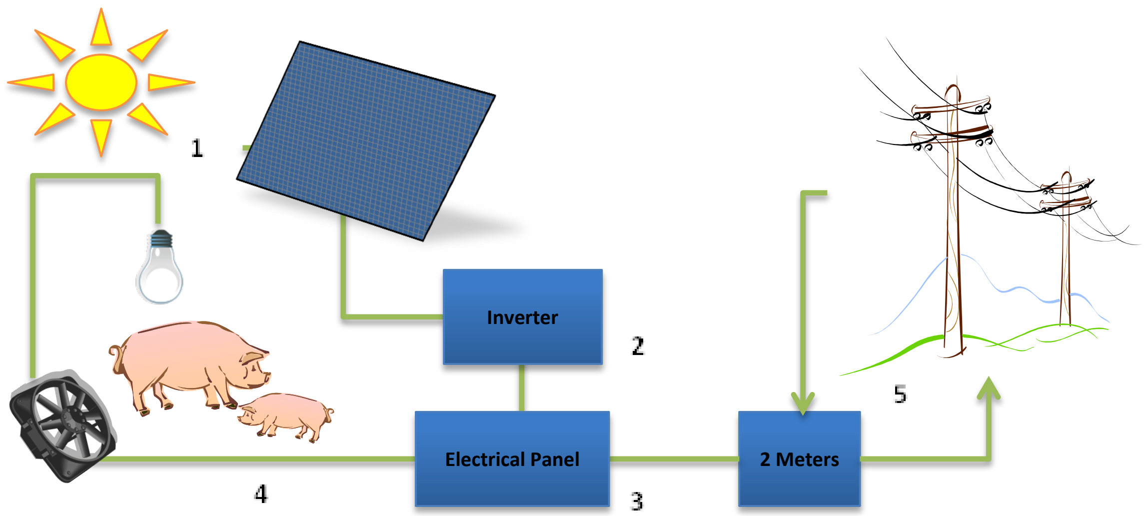

Figure 1. The basic PV system (own version based on Green *et al.*, 2002; Wenham *et al.*, 2007)

There are different types of solar cells in the market today. They differ in effect, type, size, amount of modules and cost (www, Swedish Energy Agency, 2014 b). There are four main types of photovoltaic panels (Wenham *et al.*, 2007); crystalline silicone, polycrystalline silicon, amorphous silicon and thin film crystalline silicon. In this study only crystalline silicone will be in focus, since this is the most common type of cells available on the market (pers. com., Larsson, 2014a).

The solar cell is made of a thin plate of silicon (Green *et al.*, 2002), that on the side that is exposed to the sun has a patterned metal layer, labelled the front connector. The back side of the solar cell is mainly covered by a metal coat, labelled the rear connector. When the sunlight hits the cell, the sunlight is absorbed in the silicon plate and this creates an electric tension between the two contacts. The cells are not sold one by one, but are often interconnected into a module, which generally consists of 36 cells. These are displayed on the front covered by a piece tempered glass, to protect the cells from the outdoor setting such as harsh weather and air particles. A photovoltaic system has during its life time low or non-existing costs for maintenance (www, Swedish Solar Energy, 2014). The only maintenance is the replacement of the inverter, which occurs about every fifteenth year.

1.6 The Politics of Photovoltaic Systems in Sweden

Photovoltaic systems in Sweden have followed a trend on the world market resulting in progressively lower prices. In the end of year 2013 the prices were around 14 SEK/watt for commercial systems larger than 20 kW, this compared with around 60 SEK/watt in year 2005 (Lindahl, 2014). Assuming an investment in late 2013 with a system size of 20 kW the investment cost would then have been around 280 000 SEK.

It is possible to receive investment grants from the Swedish government for installing solar cells. According to the Swedish Energy Agency (2014 a) the maximum possible grant is 35 % of the total investment costs. At the same time, these 35 % cannot exceed 1, 2 million SEK per solar cell system and 37 000 SEK per installed electrical maximum effect in kilowatts. The investment grants concern all sorts of solar systems, as well as hybrid systems where both wind and solar are used. For this session of investment grants, year 2013-2016, 210 million SEK are available and will be distributed as long as there are money available (*ibid.*). At the time of writing this report, the queue for this money is long and there is uncertainty when to receive the support (www, Swedish Energy Agency, 2013d).

The main fuse at the farm and the top production in a solar cell system are central factors concerning changes in installation fees and who has the responsibility. According to the law concerning electricity (www, Swedish Parliament, 2014), the grid company has the obligation not to charge any additional tariff for electricity that is brought out on to the grid from a producer with a fuse of maximum 63 amperes. If a producer has a larger fuse than 63 amperes and a system with an electricity production capacity between 43.5 kilowatts and 1 500 kilowatts the grid company are allowed to charge the producer with a fee for connecting to the grid and also a yearly fee for measurement, reporting and accounting.

There are also incentives provided by the government to stimulate small-scale production of electricity from renewable sources by using an electricity certificate system (www, Swedish National Grid, 2014). According to law, large-scale energy users and electricity suppliers have to buy a share of the certificates based on the amount they consume or sales, i.e. they have a quota obligation set by law. The producer of renewable energy is given a certificate for every megawatt-hour that the system produces, during a maximum of fifteen years. The certificates are tradable on a market consisting of both Swedish and Norwegian actors, where the price is determined by supply and demand. The possibility to sell certificates generates an additional income for the producers of renewable energy.

The assignment of certificates is not dependent on if the producer sells the electricity or uses it for their own needs. However, if the energy sources have an installed effect over 50 kilowatt and the producer uses more than 60 megawatt hours yearly, they become quota notifiable (www, Swedish Energy Agency, 2014 b). This means that they cannot sell all assigned certificates because some of these need to be used to meet the quota obligation. The level of the quota is determined for each year until year 2035 and is regulated by law concerning the electric certificates (www, Swedish Parliament, 2012). It is based on the future energy need and the supply of energy and differs over the years.

At the time of writing this report, a proposal from the government concerning a net billing system is discussed, i.e. the producer should be able to offset the electricity that is bought and the electricity that is sold according to SOU 2013:46 (2013). This would lead to a reduction in taxes and hopefully stimulate investments in renewable energy. The proposition concerns micro production from solar cells, but due to political uncertainty it will not be further discussed in this thesis.

3. Literature review

Chapter 3 provides a broader sense of what literature that can be found within the research area. The chapter is divided in three sectors, beginning with a presentation of literature found concerning investments in solar panels, then more specific literature concerning PV systems in an agrarian context. The chapter ends with a discussion and a summary about the findings.

3.1 Solar cells and investments

The development of the solar energy sector has up until year 2013 mostly been driven by policies or subsidies (Ball, 2012), or more specifically tariffs (Bazilian et al., 2013). The world market for solar cells has, during the last decade, gone through a dramatic shift where production cost and market prices have dropped dramatically. Even though there are highly motivating benefits with the energy source and the technological feasibility has been proven, many investors are sceptic. One of the major factors to why solar energy has not become a large commercial energy source is the invested cost. Even though, the European countries have gone through an economic recession and many of the generous subsidy policies have been reduced or even withdrawn (Ball, 2012). For example Germany has decreased the feed-in tariffs (a price guarantee from the government) and Spain has been withdrawing subsides retroactively.

The way that costs and prices generally have been examined and presented in literature, has caused some confusion among actors, according to Bazilian *et al.* (2013). The three most common metrics that are used; the peak price-per-watt capital cost of solar modules (SEK/Watt), the levelized cost of electricity (SEK/kWh, also known as LCOE) and grid parity (when alternative electricity production is less or equal the price of buying). The three variables can be calculated in different ways, depending of the assumptions that are based on data, technology and policies. This leads to a lack of transparency in the published studies. Since the metrics depend on geographic location and investors' demands the valuation of the investment does not always lead to solitary point valuation. The need for sensitivity analysis is therefore substantial, but not always presented in the studies about solar panels, according to the authors (*ibid.*).

While LCOE is more common among policy makers in order to evaluate the feasibility of technologies, the internal rate of return (IRR) and return on investment (ROI) are metrics that are more common to use to evaluate the economic feasibility (Bazilian *et al.*, 2013). In the paper by Talavera *et al.* (2010) a sensitivity analysis is conducted in a grid connected photovoltaic system. The IRR is estimated for scenarios based on the top geographic markets; Europe, USA and Japan. The authors choose IRR as a metric since this index is seen as one of the most meaningful for an investor (*ibid.*). The sensitivity analysis is then carried out, based on the different scenarios, in order to examine how possible changes in the variables affect IRR. The results show that in the Euro area the normalised initial investment is the one that affects the IRR the most, while the normalised initial investment subsidy affects the least. In the USA and Japanese market the results show that annual loan interest rate has the lowest effect, but the normalised initial investment has the highest.

In the calculation of IRR in Talavera *et al.* (2010) the tax is not included, due to the differences between the countries in the regions that are analysed. They clearly state that this might lead to a result that may be unrealistic, which led to an additional analysis where the tax was accounted for. In one of the three scenarios it had an effect on the results and a negative impact on the IRR (*ibid.*).

In Colmenar-Santos *et al.* (2012) the IRR and net present value (NPV) is used to evaluate the profitability of using grid connected photovoltaic panels for households self-sufficiency of electricity in Spain. In their model they also include storage of electricity, to examine whether a system like that can compete with an ordinary method, where the household is grid connected and electricity is applied when a shortage arises. The results show that it might be profitable if the price of surplus electricity is well below the current feed-in tariffs for PV systems connected to the grid. Another study concerning residential buildings, made by Ren *et al.* (2009), shows that adopting a PV system is beneficial for both households and the society. The approach of the study is to find the optimal size of a system by using a linear programming model in order to minimize the costs. A sensitivity analysis was also carried out in their study based on the LCOE and the simple payback period (*ibid*.).

A long term economic analysis of the installation of rooftop solar panel systems is presented by Spertino *et al.* (2013). The analysis is based on four case studies with data from the two main markets in Europe: Italy and Germany. The study reveals that in the Italian context the best profit margins are found in large sized solar plants, whereas in Germany the maximum profit is achieved for medium sized solar plants.

Compared with the European market, Sweden has few larger solar plants and the PV market is in general rather small. Stridh *et al.* (2013) argue in their conference paper from 2013 that there are two common myths about producing solar energy in Sweden. The first myth is that there is not enough sunshine and the second is that PV systems are too expensive. However, the authors claim that these statements are not entirely true. The reason is that southern Sweden has the same irradiation as northern Germany and although PV systems have been more expensive than other electricity alternatives, the system prices have dropped considerately during the last years. In the paper, Stridh *et al.* (2013) explore the production cost of Swedish PV electricity for a grid connected system. The aim of the study is to gain a better understanding of the competiveness of solar electricity on the Swedish market through analysing the LCOE in different scenarios. The results show that without subsidies, investing in PV electricity was still too expensive, year 2013, to make solar electricity competitive on a spot price market (*ibid.*).

3.2 Solar cells and agriculture

The application of solar cells in agriculture has a big potential. According to Chel & Kaushik (2011), who discuss potential energy sources for the sector it is common that farm operations use fossil fuels. They argue that the fossil fuels could be replaced by solar energy systems. The authors refer to a study by Resch *et al.* (2008) where solar energy is viewed as the most suitable renewable energy source in the agrarian sector. The main perspective in the article by Chel & Kaushik (2011) is wide, but they stress that the international community would gain from using renewable sources since the key factor is to reduce the carbon-dioxide in the atmosphere.

A study by Bardi *et al.* (2013) also discusses the role of renewable energy in the agrarian sector, where the they study if it is possible for the sector to become sustainable. They find that the power that the farm requires could be delivered from renewable sources, whereas the cost is not outside a sensible range. But due to the total energy requirements, including the power for producing fertilizers amongst others, it is hard to alter the entire agrarian processes and they need to be adopted towards more sustainable processes.

Borges Neto *et al.* (2010) present a study where power from solar panels is combined with bio gas from goat manure. The study is directed to the north-east area of Brazil, but the perspective is relevant for developing countries in general. The reason is that investments in energy systems that are less centralized can create job opportunities in these areas. Locally produced energy systems are also interesting since they are allocated close to where energy is consumed. Consequently the transmission losses when transporting the electricity to the user is minimized. This is due to the fact that the transmission losses are increased by the cable length (Borges Neto *et al.*, 2010).

In the United States the installations of renewable energy sources are extensive and particularly solar panels in the district of California (Beckman & Xiarchos, 2013). The authors build a heteroskedasticly ordered binary variable model, where the future investment was divided into four different sizes. If the expected utility from the new energy source is higher than the expected utility from the present source the farmer will adopt the new technology. The study evaluates what factor affects the farmers' interest in investing in solar energy, where they find that age and income see to have a negative effect. This is to be compared with internet connection, firm size and environmental practices among others that have a positive effect on adopting the new technology. They also investigate what size of operation the farmer chooses. The study shows that the current energy price did affect the decision whether to invest in a new energy source or not. However it did not affect the magnitude of the investment.

Among the Tennessee poultry producers a study was carried out in 2008 by Bazen & Brown (2009). According to the authors there have not been any studies on the use of solar cells in the industry. The study uses a simulation cost benefit model to examine whether an investment in solar energy is feasible. In the analysis investment grants that were available at the time of the study were included. The results showed that the investment could be beneficial if the investment cost declined or that there was a possibility for the farmer to retain all the possible investment grants. The case study did include an analysis of how the change of electricity price affected the investment. The authors define areas for future research on effects of the declining price on modules, in order to examine how it affects the profitability of the investment and how much governmental funding that is required.

3.3 Summary of the literature review

The literature review reveals that there is usually a need for governmental financial support, in one way or another, in order for an investment in PV systems to be profitable or viable (Bazen & Brown, 2009; Ball, 2012; Bazilian *et al.*, 2013; Stridh *et al.*, 2013). However, the market for PV systems has been subject to dramatic changes during the last decade (Bazilian *et al.*, 2013), which implicates that this is an ever-changing field of research. The literature also shows that there are substantial benefits for households, society and the agrarian sector by making investments in PV systems (Ren *et al.*, 2009; Borges Neto *et al.*, 2010; Chel & Kaushik, 2011; Colmenar-Santos *et al.*, 2012). Many of the results in the studies vary between positive and negative and there does not seem to be any general opinion within the literature concerning the profitability of PV systems. Bazilian *et al.* (2013) also points out that there is a lack of awareness among actors in the market concerning the economics of solar power. This implies that there is high relevance in conducting a study on the subject. There seem to be few studies conducted where interest lies with daily variations in electricity need and production, examining how this affects the feasibility.

The results also differ depending on the geographic location of the studies. One of the reasons for this is the fact that there are different policies in different countries. Where European countries like Germany, Spain and Italy have used different feed-in tariffs, Sweden has been using investment grants in order to stimulate an expansion of renewable energy sources. The studies conducted in European contexts may therefore be difficult to apply on Swedish conditions since the political prerequisites differ, a fact that further supports the relevance of this study. Stridh *et al.* (2013) also mention that few studies have been conducted in Sweden, which is a second factor that speaks for this study to be conducted.

The research methods within studies concerning PV display a wide range (see Table 1). Previous studies mostly consider only one investment option at a time. This makes it interesting to use a method that explores the possibility to compare several investment alternatives. The literature review also reveals a lack of studies made with the perspective chosen within this study, applying a PV system to a pig farm. The general approach when studying an investment is to examine whether it is viable or not. If the investment calculus deems positive the investment is chosen and conducted. A rather uncommon perception to consider is how the investment may affect the overall financial situation for the investor. This perception is considered within this study.

Table 1. Overview of studies, their main field of interest and their research method

Study/article	Field of interest	Research method
Bazen & Brown (2009)	Investment feasibility of solar energy at farms	Simulation
Ren *et al*. (2009)	Optimal size of grid connected PV systems for residential application	LP model and sensitivity analysis of LCOE and payback
Borges Neto *et al*. (2010)	Possible use of solar cells in rural areas	Literature review
Talavera *et al. (*2010)	Investment sensitivity of grid connected PV systems	Sensitivity analysis of IRR
Chel & Kaushik (2011)	Application of solar energy in farm operations	Literature review
Beckman & Xiarchos (2013)	Factors affecting solar energy investments at farms	Double-hurdle model
Colmenar-Santos *et al.*(2012)	Profitability evaluation of grid connected PV systems in households	Analysis of IRR and NPV
Bardi *et al. (*2013)	The possible use of renewable energy in the agrarian sector	Literature review
Bazilian *et al*. (2013)	World market of PV systems	Literature review
Spertino *et al.* (2013)	Long term feasibility of rooftop solar panels	Technical-economic analysis (IRR)
Stridh *et al.* (2013)	Production costs of Swedish PV electricity	Sensitivity analysis of LCOE

4. The theoretical framework

Given the results of the literature review, this chapter provides a brief introduction to the most commonly used investment evaluation methods and the parts in the calculation basis connected to these. The purpose of the theoretical framework is also to provide some knowledge about decision-making.

In economics there is a basic assumption that all firms strive to maximize their profits (Pindyck & Rubinfeld, 2009). This assumption can be used to explain how companies choose to combine different inputs and the amount of output to be produced. These choices are all the result of different decisions.

> *"Since the beginning of the history of mankind, man has been confronted with the problem of deciding a course of action that would be the best for him under the circumstances. This process of making optional judgement according to various criteria is known as the science of decision making."*
> (Sinha, 2006, p 1)

A decision can be described as a process involving a choice between two alternatives (Lee *et al.*, 1999). The types of decisions can be divided into subgroups, programmed decisions and non-programed decisions. The programmed decision is defined as a routine. It can for example be how a truck is loaded in a specific order for a specific round. The behaviour is repetitive and there are some guidelines that determine the way it is carried out. The non-programmed decision is a decision that only occurs once and can be less structured. The guidelines therefore do not exist, since the decision maker has not encountered the situation before. According to Lee *et al.* (1999) these types of decisions are noticeably more challenging and involves a higher grade of complexity for those concerned with making the decision.

An investment is a long-term project where capital is bound in order to gain future cash flows (Persson & Nilsson, 1999). When making an investment decision, the company chooses between using the spare cash as dividends to the firms shareholders or investing the funds in a project with the hope of receiving a higher amount of money in the future (Lumby & Jones, 2002). Hence the firm and the shareholders forego the chance for consumption now, with the aim of increasing the future consumption. The decision maker needs to have some sort of measurement tool when making an investment decision, to make it possible to judge whether an investment is worth the loss of consumption now or not (*ibid.*).

4.1 Investment appraisal

To support a good decision a mutual method of evaluation needs to be applied to the whole spectra of investment options, in order to determine which one of the investments that help maximizing the company's shareholder prosperity (Lumby & Jones, 2003). Many studies of capital investment decision-making practices exists (Alkaraan & Northcott, 2006; Carr *et al.*, 2010). The most common investment techniques that have been examined in the existing literature according to Alkaraan & Northcott (2006) is; payback, return on assets or investment, internal rate of return and net present value. These methods usually have been combined with some sort of risk approach; either a sensitivity analysis, adjustment of the payback period or discount rate adjustments (*ibid.).* Kayali (2006) also mentions payback, net present value and internal rate of return as the most common appraisals, but these are not always appropriate when the investment is somehow connected with insecurity. The net present value is the one that is the most advocated in the financial world according to Kayali (2006), but this may differ a lot depending on what industry according to Alkaraan & Northcott (2006). A short presentation of each calculation method will be followed.

4.1.1 Payback

The method of calculating the payback time for an investment is one of the simplest ways of evaluating one or multiple investment alternatives (Andersson, 2008). By using nominal cash flow values the period of time needed to recover an initial investment can easily be calculated (Lee *et al.*, 1999). The rule of the payback method is that the shorter lengths of time the better. The investment with the shortest payback time is always the best alternative. The rule does not account for any cash flows occurring after the investment is recovered and gives the same weight to each cash flow (Brealey *et al.*, 2014). An objection towards using the payback method is that the interest rate is usually not accounted and therefore the effect of moneys different values in time are ignored (Grubbström & Lundquist, 2005).

4.1.2 Net present value (NPV)

The method can be described as the different between the project's cost and the value of the project (Brealey *et al.*, 2014). Usually the investment's inflow is evaluated over a long time period (Grubbström & Lundquist, 2005). But, the value of money is reduced over time through inflation, and to summon an investment's all inflows, they need to be re-calculated to a common monetary value. The net present value is using a contemporary point, usually present time, where all the future inflows are discounted back through a selected hurdle rate. An investment according to NPV is profitable if the present value is larger than zero, and unprofitable if it is less than zero (*ibid.*).

The only real weakness of the method, according to Lee *et al.* (1999), is in the potentially false conclusions that can be drawn by the investor. The estimation of costs and revenues rely heavily on accurate expectations. But the strengths of that method is that it compared with alternative methods take all cash flows in the project into account, the timing of all the cash flows are considered and the method also takes risk and opportunity cost under consideration (*ibid.*).

4.1.3 Internal rate of return (IRR)

The evaluation method of internal rate of return (IRR) has a kind of kinship with NPV. The IRR is the interest rate that yields a zero NPV of an investment (Grubbström & Lundquist, 2005). According to the method of IRR any investment with an internal rate of return exceeding the cost of capital is a profitable investment (Brealey *et al.*, 2014).

Sometimes the equation determining the internal rate of return may have more than one solution. This usually happens when net cash flows change sign more than one time (Ljung & Högberg, 1999). One way of avoiding this problem is separating cash flows in and out and then discounting them with different rates adjusting for when and how they occur (Grubbström & Lundquist, 2005). This method is labelled the modified internal rate of return (MIRR).

4.1.4 Annuity

The word annuity stems from the phrase "yearly payment" and means that the investment is divided into equal pieces where the first payment is the one made in the end of period one (Grubbström & Lundquist, 2005). An annuity can also be described as an asset that results in fixed cash flows each year for a particular sum of years (Brealey *et al.*, 2014). The investor can use the annuity method if there is an awareness of a cash flow during the investment period or if the total sum is known, but not the cash flow. It is a quick way to calculate either a total sum or periodical cash flows with the recognition of an interest rate. Annuity is especially of interest if there are only costs occurring and no incoming cash flows (Olve & Samuelson, 2008).

4.1.5 Cash flow

When making an investment appraisal the users are faced with the problem of uncertainty of forecasts. This makes it hard to conduct an accurate accounting estimation. The cash flow in a business is always exposed to what happens in the surroundings. By being aware of the changes that can occur in the cash flow, the risk of making a wrong estimate is reduced (Brealey *et al.*, 2014). According to Brealey *et al.* (2014) there are four rules that are good to follow when estimating the future cash flow;

- Only cash flow is of relevance
- Estimations of cash flow should be on incremental basis
- Be consistent in treating inflation
- Investment and financing decisions should be separated

By taking these rules into account when making the calculations for the cash flow and try to predict all the unknown events that can take place, the decision maker becomes more prepared for the future and the assessment becomes more accurate (*ibid.*). It is also of importance to not ignore any variable or fixed cost, since these may have an impact on the cash flow.

4.1.6 Calculation period

When accounting for the time span for an investment there are two matters that need to be taken into interpretation; the economic life time and the technical life time (Persson & Nilsson, 1999). The economic life concerns the investment's economic durability. When it does not contribute any surplus any more or becomes too expensive to use, it is no longer economically beneficial to maintain it as a capital asset in production.

An investment may also become old, and not be functional any more. Then the technical life time is taken into account, which is how long the investment may technically function. This may be hard to estimate, since there might be possible to upgrade the investment during its life time (Olve & Samuelson, 2008). The economic life span can be shorter than the technical life time but it can never be the other way around. Before any calculations are conducted for the investment's profitability the economic life time has to be determined (Persson & Nilsson, 1999). The calculation period may either follow the economic life time or be determined by the decision maker (Olve & Samuelson, 2008).

4.1.7 Discount rate

The discount rate is the required return that a company demands on an investment. The common opinion is that capital is one of the scarce recourses in a company and the discount rate should take into account how the money could otherwise have been used (Persson & Nilsson, 1999). It can be viewed as the alternative cost, which reveals the alternative investments' rate of return in percentage (Brealey *et al.*, 2014). Factors affecting the discount rate may for example be risk, price changes and inflation (Persson & Nilsson, 1999). In the agricultural sector the required rate of return may also be affected by farm size and farm type

(Lagerkvist, 1999). However, according to Lagerkvist & Andersson (1996) fiscal allowances have a smaller impact on the cost of capital within this sector.

One can use a real or a nominal discount rate when creating an investment appraisal (Wålstedt, 1983). Using the real discount rate in the appraisal means that all amounts are expressed in the same monetary value. This is common in investment calculations due to the fact that there is uncertainty regarding future prices. When using a nominal discount rate, the amounts are expressed in current values instead and the rate has not been adjusted for inflation. Nominal values are common in costing calculations, since figures may be received directly from the accounting (*ibid.*).

It is of importance to select a discount rate that is as correct as possible. If it is incorrect an investment may be perceived as beneficial in the short-term and a long-term investment may be turned into a less profitable option (Olve & Samuelson, 2008).

4.3 Quantitative tools for decision making

One of the most commonly used quantitative methods for decision making is simulation (Anderson, 2000). It is a descriptive technique where one builds a model that represents a real system (Turban *et al.*, 2005). The model requires two types of inputs; probabilistic variables and controllable variables. Controlled variables are selected by the analyst while the probabilities are generated randomly. The model then uses the values of the inputs to calculate the output. By experimenting with the model, where the values of the controlled inputs are changed, one is able to gain an understanding of how changes in inputs can affect the output. This form of deeper knowledge makes it possible to predict how decisions could affect the real system (Anderson, 2000). It is a powerful tool when a decision maker wants to test and investigate the consequences of different decisions given different configurations of inputs and processes (Turban *et al.*, 2005). However since the technique is descriptive it cannot optimize the performance of the system. It can only show different "what if"-scenarios that may occur within the system.

Another common method is mathematical programming which has been of large interest to economists for a long period of time (Sinha, 2006). The technique is used in several areas, for example operational problems such as production scheduling but also planning problems such as capital budgeting (Nemhauser & Wolsey, 1999). When using mathematical programming as a tool for investment evaluation, one wants to find the most efficient way of using limited resources in order to maximize the desired objectives (Sinha, 2006).

Models used in mathematical programming all involve different kinds of optimization approaches, where the aim is to either minimize or maximize an objective function (Williams, 2013). The method requires the assumption that all values are known (Pidd, 2009). The most common types of mathematical models are linear, non-linear and integer programming models. The integer modelling techniques are combined with linear programming constraints. The method is normative, i.e. it attempts to find the alternative that is the best given all possible actions (Turban *et al.*, 2005). It is based on three assumptions according to Turban *et al.* (2005); that the decision maker is rational, that all alternatives and their consequences are known and that the decision maker has preferences and the ability to rank the possible consequences. The assumption of rationality among decision makers concerning the assumed economic and financial behaviour has been subject to discussion since in the real world any economic agent may behave in an irrational manner. Turban *et al*. (2005) point out that this could be a product of lack of information, misunderstandings, and incompetence.

4.4 Sensitivity analysis

A sensitivity analysis (SA) is a method to study how the uncertainty in a model's output can be distributed to the model's different inputs (Saltelli, 2002). The result of an optimization problem is only optimal given that the inputs are stable (Lundgren *et al.*, 2008). But if the inputs change there may be a new optimal solution and a new equilibrium. By changing the variables' values in the objective function the analysis can show how sensitive the investment is to different economic assumptions (Quiry & Vernimmen, 2011). The sensitivity analysis is therefore an important tool, since the uncertainty about the true value of the input, for example the price, cost or capacity, is usually substantial and hard to predict (Bertsimas & Tsitsiklis, 1997).

The analysis can be divided into three category's; factor screening, local SA and global SA (Saltelli *et al.*, 2000). The factor screening is a useful tool if the model is large, and one wishes to find subcategories of factors that affect the changeability of the outputs.

The local SA is regularly carried out by calculating partial derivatives of the output function with respect to the input factor (Saltelli *et al.*, 2000). The input is varied within a small range around a nominal value, where the range usually is the same for all the factors. The advantage of having the same range is that the relative importance of each input factor can be determined. The method is useful when the range around the nominal value is small and the relation between the output and input is presumed to be linear.

When uncertainty occurs in the input factors that are of importance, the linear sensitivities alone are not likely to provide a trustworthy estimator of the output uncertainty in the model (Saltelli *et al.*, 2000). Therefore, if the model is nonlinear and many variables are affected by uncertainty, the global SA is to be preferred. The global SA has the aim to allocate the uncertainty in the production variable to the uncertainty in each input factor. The distributions for each factor are utilized in the analysis, and these are valuable since they characterize our knowledge, or absence of it, with respect to the model. A global SA is usually conducted when all the factors are varied simultaneously and when the sensitivity is measured over the entire range for each input parameter.

When using SA in investment projects, the local SA is commonly used since the calculation is usually based on a point value of economic relevance (net present value, internal rate of return) (Borgonovo & Peccati, 2004). Due to a growing complexity of mathematical models the SA has been given a key role to evaluate the accuracy and validating the robustness of models in several disciplines (*ibid.*). Lumby and Jones (2003) stated two main advantages with using the SA where the first is that it gives the decision maker an idea of which factors that are the most sensitive. Secondly it brings light to whether or not the answers to the original models should be used as a basis for the investment decision. In addition it shows how sensitive the results are for changes. But the analyst tool has limitations, since it only take ones of the input factors in to account, while the others are held constant (*ibid.*). Therefore, if two variables or more changed at the same time the effect of this is ignored in the calculations.

5. Research method

How one conducts a study matters for the result and how reproducible the study is. This chapter gives an understanding of how the authors choose to carry out this study.

5.1 Scientific approach

The study is carried out using a quantitative methodological point of view, with a literature study and mathematical modelling. The orientation of the study is deductive, since it is built on known theories and principles (Bryman, 2011). Based on these theories the researchers attempt to draw conclusions from individual phenomena, in this case an investment of solar cells on a pig farm.

When choosing the design of the study, it is of importance to consider the research questions. Robson (2011) argues that this is a crucial part of the project, since it is really what turns the research questions into a specific project. The design used in this study is fixed, based on the fact that the mathematical modelling and the calculations for it are based on theories. Consequently, the method is based on the outcome of the literature review in chapter 3 and the theoretical framework developed in chapter 4. The flexible design offers a more open process where the research design evolves during the data collection and is usually used when collecting non-numerical information. It is therefore not so interesting in the context of this study.

5.2 Literature review

According to Robson (2011) there are several reasons for conducting a literate review before approaching the core of interest for the project. In this study a literature review is conducted to gain a broader understanding of the research area. There might be gaps in the awareness about the phenomena researched that a new study might be able to fill (*ibid*.). For the literature review in this study articles from academic journals are used. At the first step (see Figure 2) a screening of the solar energy area is conducted, in order to grasp the width of the research area. The search is conducted mainly in the search engine Primo, provided by the SLU Library.

The results are extensive and reveal a lot of research concerning the technology within the area, which is not relevant for this study. Some of the results use another term for solar cells, which is photovoltaic (PV) system. This term lays the ground for step two in the research. By using PV, the research in Primo provides a new spectrum of results, where more relevant material is found. To refine the search to suit the aim of the study, the terms investment, policy, EU (European Union) and market is added upon the term PV, to narrow down the number of articles and to highlight those of relevance. In the last step, the aspects of agriculture and Sweden are added to the term PV in the search. This yields some new articles, but not many. Finally the reference list of the most promising looking articles within the research are examined for further interesting articles within the topic (Robson, 2011).

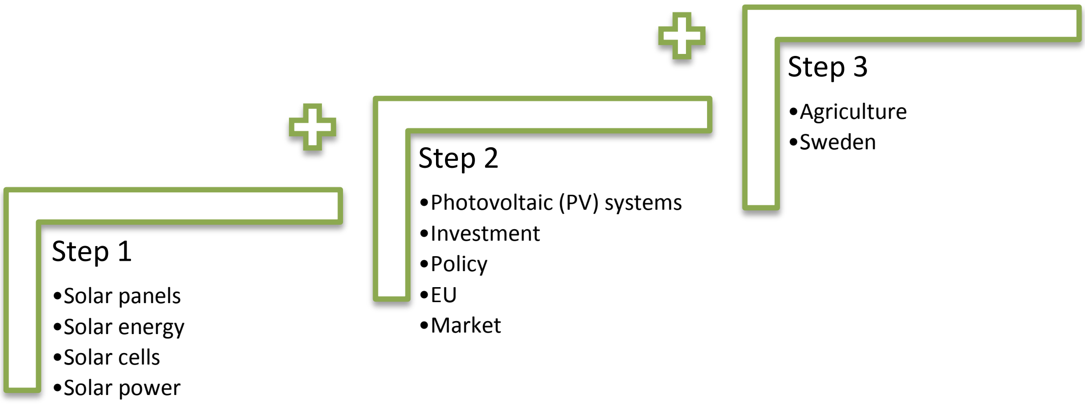

Figure 2. The process of searching literature

To be able to explore certain aspects more deeply, the authors choose to conduct extensive specialized research within the search engines Science Direct, Web of Science, Google Scholar, Scopus and ProQuest. The research is conducted in a more strategic manner using specific and combinations of the terms above. There may be some articles being overlooked, since the terminology within the research area is wide. Only articles in Swedish and English are examined in this study due to language limitations.

5.3 Applied theoretical framework

The principal model in this study can be displayed as seen in Figure 3. At T=0 an investment is conducted. The cost for this is C and the economic lifetime is 25 years. Each year has cash flows in and out generated by the investment. The outgoing flows are maintenance costs and the ingoing flows are yields from selling surplus electricity and electricity certificate trade. Trading electricity certificates is only available for 15 years. In order to examine the profitability of a PV investment the net present value of the cash flows is calculated according to equation (1).

$$Present\ value = \sum_{t=1}^{T} (S_t + CE_t - u_t)(1+r)^t - C \quad (1)$$

Where

u_t: Annual cost of maintenance
C: Cost of initial investment
CE_t: Annual revenue from trading electricity certificates
S_t: Annual value of electricity produced

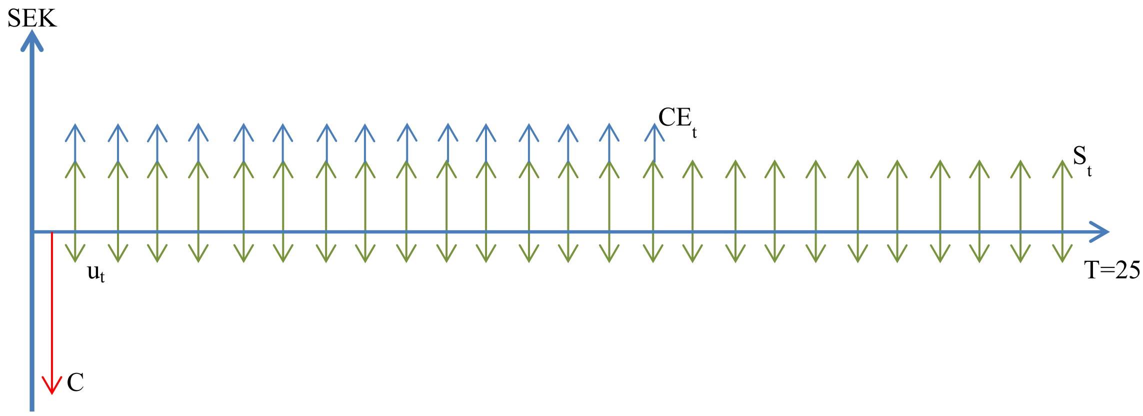

Figure 3. The principal model

By using a discounting method, such as the net present value, the change of the money value is calculated and a more correct picture is presented since the time perspective and discount rate are taken into account (Olve & Samuelson, 2008). In this study it is relevant to consider both time and discount rates, since the economic consequences of the investment extends over several years. Therefore the payback method is not considered suitable for this study. One commonly used method found in the literature review is the net present value. From a theoretical point of view the method is exactly the same as the annuity method (Olve & Samuelson, 2008), something that raises the question of which to use since they yield the same answer. Another method commonly used is IRR. This way of evaluating is strongly connected to the net present value.

In the case of this study the intention is to examine how an investment affects the profitability of a farm and what type of investment to choose. Therefore the principal model is modified by using the annuity method to calculate the annual result. However, given the complexity of the problem is the principal model not sufficient to achieve the purpose of this study and needs to be extended.

The literature review reveals that both simulation and optimization methods are used when examining PV investments, for example Bazen & Brown (2009) and Ren *et al.* (2009). Both models are of interest since the investment is a non-programmed decision, where the models may be seen as a decision support. Simulation has the benefit of showing how an intended investment could affect a business, given various changes in different parameters. This might be of interest since the investment in solar cells involves uncertain data such as prices of panels, discount rate and electricity price. However, when it comes to examine which alternative is more suitable to invest in given the fact that the investor is a rational decision maker, the optimization method is more appropriate. The rational is then the optimization method that yields an optimal result, considering both the farm operation and the different investment options that are available. This leads to an improved understanding of how profitability is affected by changes in the resource and factor use.

It is difficult to gather the information regarding future cash flow and the risk of mistakes exist (Olve & Samuelson, 2008). According to Abadie *et al.* (2013) a sensitivity analysis is a good way to observe the variables that are uncertain and they state that if there is no attention paid to uncertainty the wrong investment might be selected. In order to take this into account and prospective changes in parameter values during the investment's life span a sensitivity analysis is carried out. The analysis is a local sensitivity analysis, since the model is of linear character and no risk factors are included in the calculations. The factors studied in the sensitivity analysis are electricity price levels, electricity certificate price, calculation period and discount rate.

5.4 Applied Optimization model

In order to examine if an investment is of interest and which alternative to invest in given the electricity need for the pig operations a linear optimization model is built combining mixed integer programing and binary programing. This study uses a model of a pig farm where crop production, pig production and eleven different investment options are available.

5.4.1 Investment calculations

In this study eleven investment options are analysed by using a mathematical model, with systems varying from 15 kW to 300 kW. The possible sizes of a PV system are calculated based on available square meters of roof. Assuming that each stable has the dimensions of 30 x 70 meters with a roof slope of 15 ° (pers. com., Karlsson, 2014) the Pythagorean theorem yields each roof side the dimensions of 15,53 x 70 meters. The area of each roof side is then 1 087 square meters. Assuming that each stable has one roof side each, facing south, the total roof area available is 2 174 square meters. Furthermore, assuming that the stables' roofs have ventilation outlets and other details restricting the possibility to install solar cells the total available roof area is approximately 2 100 square meters. Costs for reinforcing the roof on the stable are not considered in this study. It is assumed that the roof is capable of carrying the extra weight of a PV system.

The total size of available roof is divided into eleven sizes by using the percentages defined in Table 2. To calculate the peak effect of each system size, the simple value of seven square meters per kW is used (pers. com., Larsson, 2014b). The effect for each investment option is found in Table 2.

Table 2. The sizes of the investment option

Option	Percentage	Square meter	kW
1	5 %	105	15
2	10 %	210	30
3	20 %	420	60
4	30 %	630	90
5	40 %	840	120
6	50 %	1 050	150
7	60 %	1 260	180
8	70 %	1 470	210
9	80 %	1 680	240
10	90 %	1 890	270
11	100 %	2 100	300

After defining the system sizes the average investment cost per watt is collected from several installation businesses and compared with literature regarding the Swedish market for solar cells 2013 (Lindahl, 2014). This result in an average installation cost of 12.50 SEK per watt used to calculate the total investment cost for each option. The investment calculation also includes the present values for electricity certificates and the cost for changing electricity meter. The range is between 0 and 90 200 SEK depending on system size (pers. com., Herbertsson, 2014). In the calculation no costs for electric wiring outside the buildings are considered.

In this study the calculation period is determined by the technical life span of the PV system (www, Swedish Energy Agency, 2007 c). Assuming a capital cost of 6 % (Lagerkvist, 1999) and a calculation period of 25 years makes it possible to calculate the annuity factor through equation (4) where *r* is the interest rate and *t* is the relevant time period (Brealey *et al.*, 2014).

$$Annuity\ factor = \frac{1}{r} - \frac{1}{r(1+r)^t} = \frac{1}{6\ \%} - \frac{1}{6\ \%(1+6\ \%)^{25}} \approx 12{,}78 \qquad (2)$$

The investments are to be seen as financed by the farms own capital and therefore no additional bank rate is added. The rate in the annuity factor calculations is real, and therefore the inflation is considered within the rate. In the calculation no reinvestments are considered after the 25 years, since the technical development is rapid and prices for such an investment are hard to predict and might give a misleading result. The expected lifetime is 25 years but the panels may last longer. After 25 years the effect from the panels has dropped (Innovatum Teknikpark, 2013) and do not produce electricity at the same level as before. This is also difficult to predict and therefore the model only stretches to 25 years.

A maintenance cost of 0.5 % of the initial investment cost is added to the annuity to cover the need for changing inverters after 15 years (Innovatum Teknikpark, 2013). No consideration is paid to the possibility that the exchange air from ventilation exhausts pipers may affect the performance and durability of the PV system.

The investment costs and annuities are calculated according to four scenarios: without consideration of investment subsidies, with consideration to certificate trading, with consideration of subsidies and with consideration to both subsidies and electricity certificates. All costs are summarized in Table 3.

Table 3. Investment costs and annuities for each option

Option	Without grants		With certificates		With grants		With grants and certificates	
	Investment	Annuity	Investment	Annuity	Investment	Annuity	Investment	Annuities
1	187 500	15 605	160 444	13 489	121 875	10 471	94 833	8 356
2	375 000	31 210	320 888	26 977	243 750	20 943	189 665	16 712
3	750 000	62 420	658 823	55 288	487 500	41 886	339 396	30 300
4	1 125 000	93 630	988 235	82 931	731 250	62 828	509 094	45 450
5	1 500 000	124 840	1 317 646	110 575	975 000	83 771	678 792	60 600
6	1 891 000	157 382	1 663 058	139 551	1 229 150	105 607	858 890	76 643
7	2 289 600	190 556	2 016 070	169 159	1 488 240	127 868	1 043 928	93 111
8	2 664 600	221 766	2 345 481	196 802	1 731 990	148 811	1 213 626	108 261
9	3 063 600	254 973	2 698 893	226 444	1 991 340	171 094	1 398 924	124 751
10	3 438 600	286 183	3 028 305	254 087	2 235 090	192 037	1 568 623	139 901
11	3 840 200	319 607	3 384 316	283 945	2 640 200	225 735	1 899 681	167 807

5.4.2 The objective function

Table 4. Key summarization to the objective function

	Notation		
	Coefficients (x_j-values)		*Subscripts*
A	Crop production	d	Total crop production
B	Bought electricity (kWh)	e	Winter wheat
C	Cost (SEK)	f	Rapeseed
D	All available land	g	Sugar beets
E	Electricity need (kWh)	h	Barley
F	Acres	k	Bought barley
G	Feed (kg)	l	Sold barley
I	Investment	m	Sow in production (SIP)
N	Number of animals	n	Pigs for slaughter
P	Pig production	o	Morning, quarter 1-4
R	Revenue (SEK)	p	Afternoon, quarter 1-4
S	Sold electricity (kWh)	q	Night, quarter 1-4
		s	Investment options 1-11

A starting point in any type of optimization problem is a problem formulation with control variables or coefficients that can be maximized or minimized to its most optimal values (Boehlje *et al.*, 1984; Lundgren *et al.*, 2008). The objective function for the model used in this study is defined based on the research aim to explore if an investment in solar cells is feasible and how it would affect the profitability of the farm. The function is formulated as the maximum net profit of farm activities and is defined by equation (3) where Table 4 is the key.

$$Max\ \pi = \sum_{d=1}^{7} R_d A_d + \sum_{n=1}^{1}\sum_{m=1}^{1} R_{mn} P_{mn} - \sum_{0=1}^{4}\sum_{p=1}^{4}\sum_{q=1}^{4} C_{opq} B_{opq} + \sum_{0=1}^{4}\sum_{p=1}^{4}\sum_{q=1}^{4} R_{opq} S_{opq} - \sum_{s=1}^{11} C_s I_s$$

$$\text{s.t} \qquad A_d,\ P_{mn},\ B_{opq},\ S_{opq},\ I_s \geq 0 \qquad (3)$$
$$I_s = \{0\ ,\ 1\}$$

Where the first part is the summation of seven crop-production-related activities and the second part summarizes sows in production and pigs for slaughter. The third and fourth part of the objective function summarizes the buying and selling of electricity during morning, afternoon and night in quarter one, two, three and four. Last but not least are the investment options, defined by alternatives 1-11. The control variables are of non-negative character and the investment coefficients are binary.

5.4.3 Constraints

The objective function is maximized given that certain constraints are satisfied. These constraints are expressed as:

$$\sum_{j=1}^{17} a_{ij} X_j \leq b_i \qquad (4)$$

Where a_{ij} expresses the quantity of resource i required to produce one unit of the farm activity j, X_j is the level of the control variable j and b_i is the available amount of resource i. How the constraints are expressed in the Excel model can be seen in appendix 1-4.

The constraints in this study can be divided into seven groups. The first group deals with acreage and these constraints express how to use the available land. As Table 5 indicates, the acres grown with each crop cannot exceed the total available acreage on the farm. There is also a maximum amount of available land for growing crops.

Table 5. Constraints concerning acreage

Name	Constraint
Available land	$\sum_{d=1}^{7} A_d \leq D$
Total arable land	$\sum_{d=1}^{7} A_d \leq F$

To secure a healthy crop rotation, the next group of constraints are created. As Table 6 displays, these constraints express how much of rapeseed and sugar beets to be grown and constraints relating to crops rotation.

Table 6. Constraints concerning crop rotation

Name	Constraint
Crops after wheat	$a_e A_e - a_f A_f - a_g A_g \leq F$
Rapeseed	$a_f A_f - D \leq F$
Sugar beets quota	$a_g A_g - D \leq F$
Rapeseed after Barley	$a_h A_h - a_f A_f \leq F$

Barley grown can be used in different ways. One of the main uses is feed for the pig. The constraint in Table 7 shows how the need for feed and any sold amount of barley is connected to the acreage grown and kilogram bought.

Table 7. Constraint concerning feed

Name	Constraint
Barley feed	$a_n P_n + a_l A_l - a_k A_k - a_h A_h \leq G$

In order to determine how much barley that is needed constraints concerning the farrow-to-finish pig production is necessary. The maximum number of pigs for slaughter is based on limited stable area, a determined number of sows and the relation of piglets per sow. The three constraints are defined in Table 8.

Table 8. Constraints concerning pig production

Name	Constraint
Number of piglets	$a_n P_n - a_m P_m = N_n$
Number of pigs	$a_n P_n \leq N_n$
Number of SIP	$a_m P_m = N_m$

There is a large need for electricity per livestock unit on a pig farm. The constraint of the farm's electricity production and consumption is divided into four subcategories. That makes it possible to explore the four quarters of a year separately. This is chosen so that the authors are able to illustrate and study the variations in electricity consumption and costs occurring over a year. Each constraint refers to a quarter of a year and is displayed in Table 9. The electricity need per livestock unit and amount sold needs to be connected by electricity bought and electricity production from any of the eleven investment options.

Table 9. Constraints concerning electricity concerning production and consumption

Name	Constraint
Electricity Q1	$\sum_{o}^{4}\sum_{p}^{4}\sum_{q}^{4}(E_m + E_n + S - B - I_s)$
Electricity Q2	$\sum_{o}^{4}\sum_{p}^{4}\sum_{q}^{4}(E_m + E_n + S - B - I_s)$
Electricity Q3	$\sum_{o}^{4}\sum_{p}^{4}\sum_{q}^{4}(E_m + E_n + S - B - I_s)$
Electricity Q4	$\sum_{o}^{4}\sum_{p}^{4}\sum_{q}^{4}(E_m + E_n + S - B - I_s)$

All investment options are of different sizes, ranging from rather small to rather large systems. There can only be one investment chosen and conducted at a time and therefore a constraint expressing this relation between the options is necessary. The constraint can be seen in Table 10.

Table 10. Constraint concerning the relation between investment options

Name	Constraint
Relation investments	$\sum_{s=1}^{11} I_s \leq 1$

The last constraint in the model is one of binary variables. Each variable for an investment option is binary. With other words, an investment can either be conducted (1) or not (0). This constraint is defined in Table 11.

Table 11. Constraint concerning binary variables

Name	Constraint
Binary investments	$I_s = \{0\,,1\}$

5.4.4 The fictive farm

The mathematical model in this study is based on a case farm with farrow-to-finished pig production system. The choice of a farrow-to-finish pig production system, as mentioned in the delimitations, is based on the fact that there is a relatively constant energy need within pig production (Hörndahl & Neuman, 2012) compared with other agrarian enterprises. The authors could have chosen to conduct the study within the poultry industry but Bazen & Brown (2009) have already conducted a study among poultry farmers in Tennessee, which makes pig production more relevant for further knowledge about applications of PV systems.

Another choice is to assume that the farm is located in the south of Sweden, Scania. This choice is based on statistics showing that the majority of Swedish pig industry is located in this area (www, SJV, 2014c). Other statistics, from the Swedish Board of Agriculture (2013b), reveals that the most common arable acreage on a farm in Scania is between 100 and 200 hectares. With this in mind, the authors have chosen a fictive farm that has a total acreage of 200 hectares available for farming.

The assumed crops for the fictive farm are winter wheat, winter rapeseed, sugar-beets and spring barley. The choice of crops is based on a basic crop rotation without ley for a farming system without animal production (Fogelfors, 2001). Pigs cannot fully digest the silage obtained from ley (Lärn-Nilsson *et al.*, 2005) and therefore it is not relevant to choose a crop rotation that contains ley.

The farrow-to-finish pig production system of the fictive farm consists of 200 sows, which is an average herd size (Swedish Board of Agriculture, 2013b). Each sow gives birth to about 25 piglets a year, according to Agriwise. Hence the farm produces about 5 000 pigs for slaughter each year. The data for the pig-production and the cropping system is based on data from Agriwise (www, Agriwise, 2014). Agriwise is a service provided by the Swedish University of Agricultural Sciences, where a software program uses known information to calculate gross margins for farm activities. By using Agriwise the opportunity is provided to alter costs and revenues and calculate the estimated gross margin per enterprise. For each crop, sow and pig for slaughter in this study the gross margin is calculated. The use of gross margin calculations is chosen because it can often be difficult to allocate common costs among specific farm activities. One input separated from the gross margin calculation of slaughter pigs is grain for feed. This aspect is illustrated separately in the mathematical model, since it depends on the optimal number of pigs produced. The authors express the relation between growing, buying and selling barley in order to obtain a deeper understanding how pig production affects crop production. In the model the authors have taken the agricultural direct income payment into account concerning the crop production. The value per hectare is 2 656 SEK, based on the exchange rate of one Euro to one SEK at the 13th May 2014 (www, SJV, 2014b; www, Forex, 2014).

In this study the costs for electricity has been separated from the gross margin calculations for the pig production in order to study the impact of investing in a PV system. The consumption, purchase and production of electricity have all been divided into four seasons and three time periods. This division is conducted in order to illustrate and explore the variations in production and consumption occurring during a year. In Table 12, the electricity need per pig is illustrated in kWh/season and time period of the day. To the right, the definition of each season and the time periods are presented.

Table 12. kWh/animal/quarter and time

	SIP	Pig for slaughter
Q1 am	82,58	3,99
Q1 pm	80,47	5,58
Q1 night	87,84	4,60
Q2 am	72,51	4,31
Q2 pm	70,66	6,03
Q2 night	77,12	4,96
Q3 am	65,35	4,93
Q3 pm	63,69	6,90
Q3 night	69,52	5,68
Q4 am	76,66	4,03
Q4 pm	74,71	5,63
Q4 night	81,54	4,64

The electricity requirement per pig is based on information from a farm in Scania, which has requested to stay anonymous. The choice of real farm data is motivated by the relevance of exploring how the energy use differs during the year, which might affect which investment that is undertaken. To distinguish any peaks or low periods of energy use during the year the authors have chosen to divide the energy use into periods, in this case quarters and time periods of the day. The data that is obtained extends over several years (2006-2013). Data are based on two stables, one for sows and one for slaughter pigs. An average per pig and per sow per quarter is calculated from this data. The electricity demand differs during day and night and is given through an estimated percentage distribution. The authors have assumed the distribution built on calculations after discussions with Lars Neuman (pers. com., 2014) due to lack of real data. Available literature concerning the energy use in the pig industry is available (Hörndahl & Neuman, 2012), but this data is based on a one year period and cannot be divided directly into sub periods.

5.4.5 Electricity prices and certificates

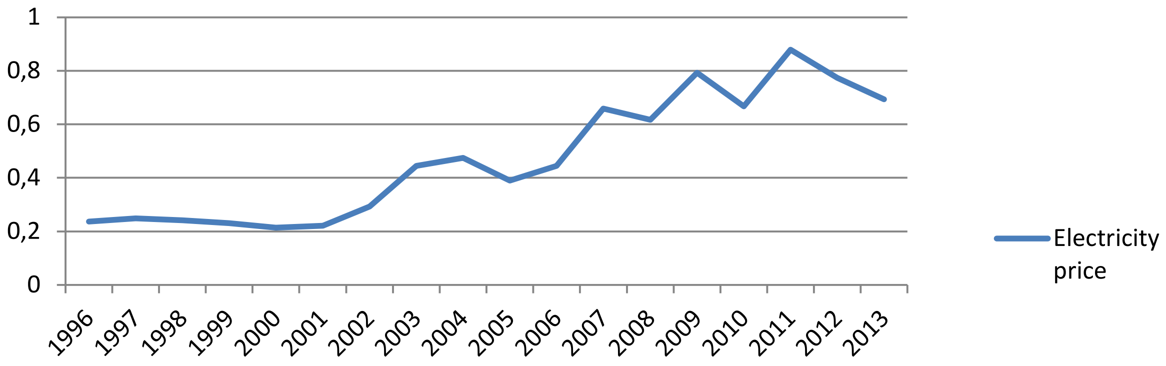

Figure 4. The electricity price 1996- 2013 (Own adoption based on figures from SCB, 2014b)

The electricity prices have during the last years fluctuated between 0.6 SEK/kWh up to almost 0.9 SEK/kWh, as can be seen in Figure 4. In this study, prices for buying electricity represent average prices for the last seven years, without taxes and tariffs, per quarter. These prices are calculated based on data from Statistics Sweden where the electricity trading companies' fee for electricity certificates are included (www, SCB, 2014a). The prices obtained for selling electricity are often negotiated with the electricity trading company. Selling prices for electricity are therefore based on average prices per quarter from Nord Pool spot prices, without considering taxes and tariffs. The prices are illustrated in Table 13. No consideration is paid to the possibility that the electricity prices may vary during the day.

Table 13. Electricity prices used in the analysis

	Buying price	Selling price
Q1	-0,72	0,32
Q2	-0,68	0,29
Q3	-0,67	0,27
Q4	-0,70	0,32

Electricity prices play a substantial role for the results of this study. A price level higher or lower than the initial level might have consequences for whether an investment is profitable or not. Due to the uncertainty of projections regarding future electricity price development, indicating an annual price change of 1-3 % (Hansson *et al.*, 2007; Profu, 2010; Energimyndigheten, 2011; Eriksson *et al.*, 2013), the authors conduct a sensitivity analysis where the price levels are raised with 10 %, 20 % and 30 % in order to examine the effects on the investment decision.

The electricity certificates need to be considered and their present value are included in the investment calculations. To calculate the present value of certificates a price has to be determined. In Figure 5, the average prices per month since year 2003 are presented. The authors assume an average price of around 200 SEK for the electricity certificates, which is a reasonable assumption (Eriksson *et al.*, 2013)(www, CESAR, 2014 a).

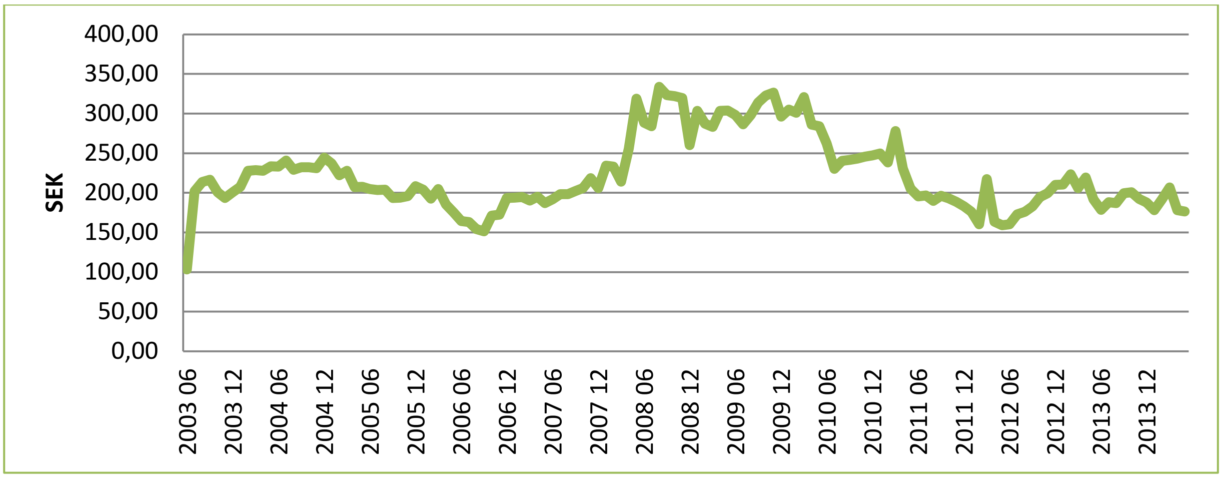

Figure 5. Average prices on electricity certificates (own adoption of CESAR, 2014 b)

When calculating the value of electricity certificates for the next 15 years the authors consider the quota rules relevant through law (see chapter 1.6 for more information). The present values are then included in the investment scenarios. The two smallest investment options do not qualify for the quota rules and therefore all certificates can be sold. Administration costs are not included when trading the certificates. The investment options are calculated both with and without taken into account the value of the certificates.

5.4.6 Taxes

Due to extensive regulations regarding taxes, no taxes are taken into account in the original model of this study. In Sweden farmers may receive tax refunds for electricity used within the farm activities (www, Skatteverket, 2014 a). The set tax rate for electricity during year 2014 is 0.293 SEK/kWh but farmers can apply for refunds, resulting in a real tax cost of 0.005 SEK/kWh if full refunds are received (www, Skatteverket, 2014 b). According to Talavera *et al*. (2010) taxes may affect the outcome of the investment and therefore the authors of this study examine in an additional sensitivity analysis the possible effects of the energy taxes on prices for bought electricity. Eventual taxes on sold electricity are not taken into account.

5.4.7 The sunlight

Another essential aspect in this study is the sunlight. To estimate the number of sun hours and kilowatts produced from the PV systems, the authors choose to use the PV estimator provided by the Institute for Environment and Sustainability at the European Commission Joint Research Centre (www, Europa, 2014). The estimator provides an estimated of the number of kilowatt hours produced, given the solar panels: orientation, slope, geographical location, peak production, type of material, estimated system loss and mounting. The assumed slope and PV system design is based on the use of stable roofs, which have a slope of 15 degrees. The location of the investment is assumed to be Scania, Sweden and the estimated system loss is determined to 5 % based on advice from David Larsson (pers. com., 2014a). The estimator has been used on all the eleven different investment options, to obtain data per month. This data is then used to calculate kilowatts produced during the four quarters. The PV performance calculator is a tool to give users an idea of the potential of PV as an energy source. The authors are aware that there are limits for the estimator and the estimate that have been used are to be viewed as proxies. Given this, it should be noticed that there are long distances between the measurement stations and that there are only 18 stations in Europe.

To divide the quarterly kilowatt hours produced into morning, afternoon and night, the PV estimator is also used. Given month and location, the estimator calculates the hourly watts of sunlight over an average day in the specific month. The watts for a specific time period during the day are divided with the total daily production, to determine a ratio. This ratio is then multiplied with the estimated kilowatt hours produced by the system, in order to examine how much of the total production that is produced during a specific period of time.

5.5 Validity and reliability

"Validation is impossible, but desirable" (Pidd, 2009, p 268)

The essence of validation according to Pidd (2009) is something ideal to strive towards if being dedicated to the idea that science relating to management aspires to provide support to the real world. To which extent models are "true" or "wrong" matters in the sense that they may mislead people to make decisions resulting in negative consequences. Therefore the designer of models has a responsibility to always aim for some type of validation, but it should be mentioned that it might not be completely achievable.

Assessing an investment project is a complex task and many aspects need to be considered (Persson & Nilsson, 1999). This thesis examines the economic aspects concerning whether an investment should be conducted or not and does not take strategic, market and environmental aspects into account. The consequences of an investment extend over a long period of time and they may therefore be complicated to estimate. This requires assumptions and theories based on available information and results from the model.

By comparing the electricity consumption data from the actual farm in southern Sweden with the consumption produced by Hörndahl and Neuman (2012) there is a credibility to the data used in the mathematical model. The only aspect that differs is the electricity consumption for slaughter pigs, which is rather high compared with the numbers in Hörndahl and Neuman (2012). Nevertheless, no farm is the other alike and they all face different preconditions. Hence, it is essential to adjust the model accordingly before using it outside the context of this study.

The results from the model cannot be generalized, but give an indication of a possible scenario. One reason for this may be the number of variables in the model and that it only illustrates one farm. Another reason may be the fact that the authors examine yesterday with the eyes of today. With other words, for example electricity prices are based on historical statistics, an aspect that may affect the results.

Future developments of electricity prices are plagued with a high level of uncertainty that may affect the results. This uncertainty concerns both prices for buying and selling electricity. There is also uncertainty concerning the development of electricity certificates in the future, which represent as difficult to estimate. In addition, basic linear programming models do not have the same possibilities as simulation models or quadratic programming models, such as MOTAD, to account for uncertainty and risk. In this study the effects of changes in prices are being taken into account through sensitivity analyses.

By designing a fictive farm based on statistics and literature instead of building the model based on data from a real farm, no Swedish pig farms need to display their economic situation. At the same time statistics may show a somewhat more positive or negative picture of the conditions and in that sense make the results slightly misleading.

5.6 Ethical aspects

It is important to consider the ethical aspects that can occur when conducting research within social sciences. The main categories are, according to Bryman (2005; 2011): no harm to participants, no lack of permission from participants, no intruding on participants' privacy and no kind of deception towards participants or readers.

This study is mainly based on information from published material and statistics. However, during some parts of the data collection process experts and companies are contacted. Each contacted person receives a short description of the study and how their knowledge and information may be of help. They are then provided the choice of being anonymous or if the authors may refer to them in the text. Each person referred to receive a copy of the finished report before the report is published, in order to avoid any misunderstandings or conflicts.

During the collection process of electricity consumption data a real farm in Scania is contacted. The farm has requested to stay anonymous. Although this may inflict problems with the credibility of the data the authors choose to keep the farm anonymous in order to follow Bryman's (2005; 2011) advice. The possible replication of the study may be affected, yet due to clear delimitations and a transparent process a replication should still be conceivable.

6. The Results from the Optimization

In this section the result of the study are presented. The results are divided into four scenarios. In each scenario a sensitivity analysis is conducted focusing on how four different factors affect the result.

The factors considered in the sensitivity analyses are price of electricity, price of electricity certificates, discount rate and calculation period. The sensitivity analysis of electricity certificates is not conducted in the scenarios where trading of certificates is not considered. The sensitivity analyses are conducted with pre-set intervals presented in each section. When a critical point is not found within the pre-set range the analysis is extended to find it.

An additional sensitivity analysis is carried out examining the effects of adding the energy tax rates of 2014 to the price of bought electricity for each scenario. Both the case where the farmer apply for full refund and in the end pay a real tax rate of 0.005 SEK/kWh and the full tax rate of 0.293 SEK/kWh is examined to see how they affect the outcome of the optimization.

6.1 The initial optimization

When examine the model with the basic data, considering no additional subsidies, the optimal solution revels that an investment is not interesting economically given these conditions. The profit of the farm given that all electricity is acquired is 242 710 SEK, as seen in Table 14 together with the other output values. The complete model is presented in Appendix 1.

Table 14. The result of the initial model with basic assumptions

Activity	Quantity	Price SEK	Return SEK
Winter wheat (hectare)	80	4 632	370 562
Rapeseed (hectare)	40	4 159	166 361
Sugar beets (hectare)	40	5 781	231 237
Barley (hectare)	40	-6 041	-241 622
Barely sold (kg)	0	1,21	0
Barley bought (kg)	845 000	-1,66	-1 402 700
Agriculture subsidies (hectare)	200	2 656	531 250
Sow	200	-5 501	-1 100 224
Swine	5 000	405	2 025 607
Total bought electricity (kWh)	486 916	-0,72	-350 927
Profit SEK		**242 710**	

Given the circumstances allowing the investor to sell certificates all the input data are set to the original values, no investment is made. The output is the same as in Table 14. A complete display of the model can be seen in Appendix 2.

An analysing considering investment grants but no trading with electricity certificates results in the same result as the starting points of the two earlier scenarios. This means that the total profit is 242 710 SEK and all electricity is bought, as no investment is made. Further results are displayed in Table 14 and the entire model is displayed in Appendix 3.

The optimal solution under the circumstances that the farmer both can sell certificates and receives investment grants, yields the same result as in Table 14, accept for the amount of electricity bought and profit. The reason for this is that in this scenario an investment is part of an optimal solution from the start as noted in the complete model in Appendix 4. The investment chosen is number 6 (150 kW), which results in a profit of 255 117 SEK and a total amount of 340 486 kWh electricity bought on a yearly basis. No electricity is sold during the year.

6.2 Change in electricity price level

In order to investigate how sensitive the investments are towards changes in the electricity market, a change in price levels is analysed. The analysis is conducted by examining the effects of if the price level would be 10 %, 20 % or 30 % higher than the initial levels. However this analysis reveals no effect on whether an investment is carried out in three out of four scenarios. Only the total profit of the farm is affected as seen in Figure 6.

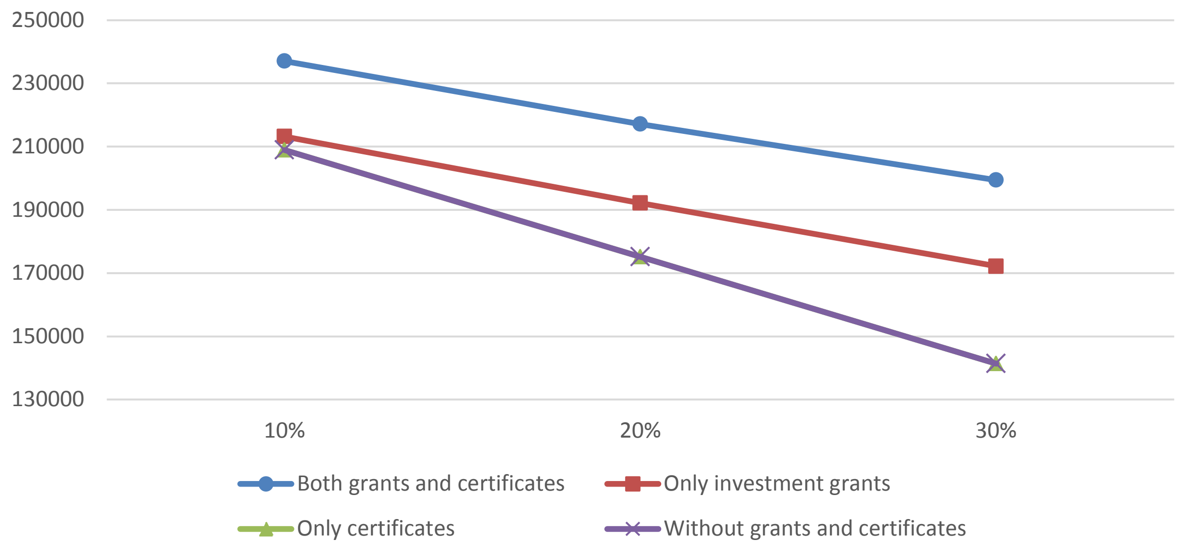

Figure 6. Effects on profit by changes in electricity price levels

To test where the critical point is for an investment to be made in the scenario with no grants and no certificates, the price level is increased in excess of 30 %. At the level of 56 % higher electricity price level than the initial, investment number 4 (90 kW) is conducted. This results in a total profit for the farm of 53 729 SEK and the amount of electricity bought is reduced to 399 043 kWh and no electricity is sold. Given the circumstances that certificates are traded but no investment grants are received, the critical point for conduction an investment occurs when the electricity price level is increased to 35 % higher than the initial level. In that case investment 2 (30 kW) is conducted and the profit of the farm, given the higher electricity price, is 124 553 SEK. The amount of electricity that is bought is 457 645 kWh per year.

In a scenario with investment grants the critical point for where the first investment is chosen is found when the electricity price level is increased with 5 %. In that point, investment option number 4 (90 kW) is chosen. The profit is 226 126 SEK and the electricity bought is 399 042 kWh. Before that no optimal solution involves an investment. At 10 % investment option number 5 (120 kW) is chosen, resulting in a profit of 213 166 SEK and no electricity is sold.

When testing 20 % and 30 % investment option number 8 (210 kW) is chosen. A small amount of electricity is sold and the profit is 192 156 SEK and 172 198 SEK accordingly.

When adding both investment grants and accounting trade of certificates the chosen investments differ between option 8 (210 kW) and option 10 (270 kW). The critical point for when no investment occurs at all, as a part of the optimal solution, is found when price levels are between -16 % and -17 % of the initial level. By 10 % and 20 % investment number 8 (210 kW) is chosen, resulting in profits of 237 066 SEK and 217 108 SEK accordingly. A small amount of electricity is sold during the second quarter. At 30 % investment option number 10 (270 kW) is chosen. In this case, the profits are 199 413 SEK and a quite large amount of 32 438 kWh are sold.

6.3 Change in discount rate

The discount rate in this sensitivity analysis varies within a range of 2-8 % (Lagerkvist, 1999) in order to examine how the discount rate might affect an investment decision. Varying discount rates yields a substantial change in the annuity factor affecting the costs of each investment option. As Figure 7 shows, the profit increases as the rate lowers for three out of four scenarios.

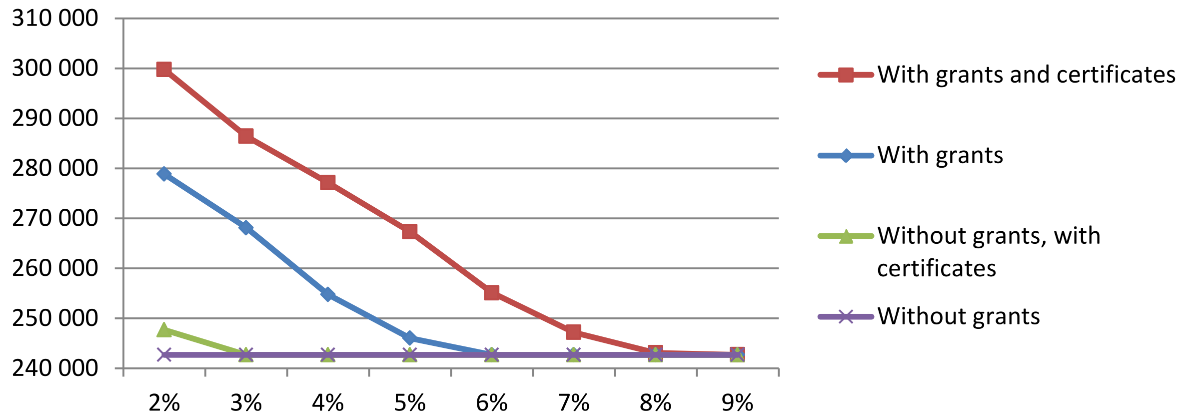

Figure 7. Effect on profit when changing the discount rate

In the scenario with no support systems the discount rate has no effect on whether an investment is made or not, as can be seen in Figure 7. Since no investment is made, there is no electricity sold and the electricity bought remains the same for all discount rates. The profit is not affected by the change, since the annuity factor and the discount rate are only connected to the capital cost of the investment options. When the discount rate is reduced to 1 %, investment 4 (90 kW) is made and the profit of the farm is 247 103 SEK. The bought electricity is set to 369 996 kWh and no electricity is sold.

With the conditions in the scenario where certificates are tradable, an investment takes place when the rate is set to 2 %. At any discount rate above that, it is not an optimal solution to conduct an investment. The chosen investment is number 5 (120 kW) which gives a total profit of 247 718 SEK. The bought amount of electricity reduces to 369 996 kWh and no electricity is sold during the year.

Given discount rates between 2 % and 5% investments are involved in the optimal solutions when investment grants are included. With a discount rate of 2 % or 3%, the result is an investment large enough to implement sales of electricity, option number 8 (210 kW). The critical point appears for a discount rate of 5-6%.

The critical discount rate in the case when the farmer both receives grants and trade certificates is between 8 % and 9%. With a discount rate of 5%t or less the model choses an investment option that opens up for selling electricity on to the national grid, option 8 (210 kW). At a discount rate of 2 %, the model finds investment number 10 (270 kW) optimal. Electricity is mainly sold, give investment option 10, during the mornings and afternoons in the second quarter. In addition, electricity is sold during mornings in the third quarter. As in earlier cases, given that investment option 8 (210 kW) is chosen, electricity is sold during mornings of the second quarter.

6.4 Change of calculation period

A change in the calculation period changes the annuity factors and thereby also the capital cost of the investment. The profit rises as the calculation period gets longer, as seen in Figure 8. When varying the calculation period between 10 and 50 years, the result still reveals that no investments are made in the two cases where no investment grants are included. This means that the profit does not differ. In these cases, even if the calculation period is extent beyond the time frame of the sensitivity analysis, no investment is enacted given these circumstances.

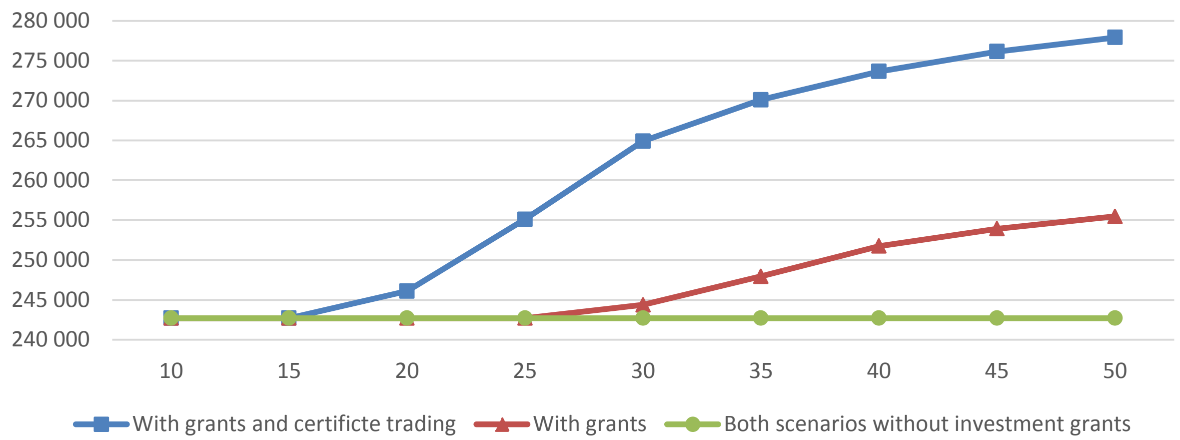

Figure 8. Effect on the profit when changing the calculation period

Given the conditions in the scenario where grants are received, changes in the calculation period affect the result as can be noted in Figure 8. The critical point where the calculation period results in an investment is between 25 and 30 years, where investment option 5 (120 kW) is chosen. A shorter period implicates no investment and at around 40 years, the model choses a larger investment option, number 6 (150 kW). No electricity is sold in any of the cases in this scenario.

For the last scenario, with both investment grants and certificates, a critical point can be found between 15 and 20 years, where the model choses its first investment, number 5 (120 kW). A second critical point is be found between 25 and 30 years, where the model choses the first investment, option 8 (210 kW). It is a system large enough for electricity to be sold in the second quarter.

6.5 Change in the price of electricity certificates

The certificate price is varied between 100 SEK and 300 SEK, where 200 SEK is the initial value. This change has no effect on the decision whether or not to invest in the case where only certificates and no grants are involved. As no investment is conducted, the critical point is beyond the sensitivity analysis interval. Once testing different prices, as can be noted in Figure 9, the critical point is found at 600 SEK per certificate. At that level investment 2 (30 kW) is conducted and the profit reaches 244 228 SEK where 457 645 kWh is bought.

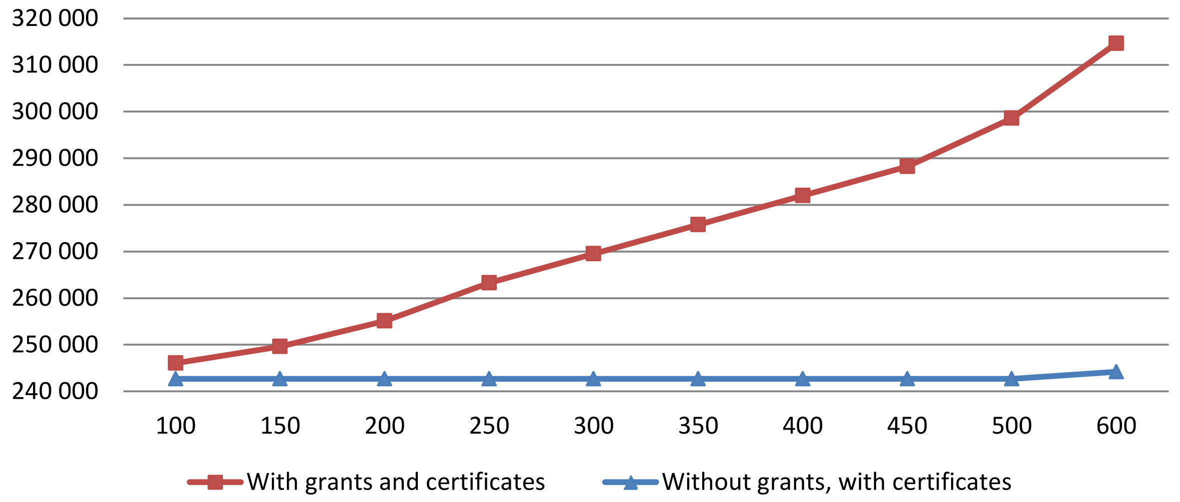

Figure 9. Effects on profit when changing the certificate price

When adding investment grants to the investment calculus, the optimal solution differs when the certificate prices change. When the price reaches 250 SEK, investment option number 8 (210 kW) is chosen which results in 5 040 kWh to be sold. The critical point where no investment occurs is found where the certificate price is between 40 and 45 SEK, which is not displayed in the figure above.

6.6 The effect of Energy taxes

The results from this sensitivity analysis are illustrated in Table 15. When adding energy taxes and accounting for the possibility for farmers to get tax refunds, a small effect is revealed in terms of conducted investments. As displayed in Table 15, an investment is chosen when grants are received.

Table 15. Results from analysis with energy tax

	Without grants		**With grants**	
	Without certificates	With certificates	Without certificates	With certificates
Reduced tax				
Profit (SEK)	218 365	218 365	220 443	242 678
Electricity bought (kWh)	486 916	486 916	369 996	287 186
Electricity sold (kWh)	0	0	0	5 040
Investment option	0	0	5 (120 kW)	8 (210 kW)
Full tax				
Profit (SEK)	100 044	103 730	147 929	175 485

Electricity bought (kWh)	486 916	369 996	287 186	255 863
Electricity sold (kWh)	0	0	5 040	32 438
Investment option	0	5 (120 kW)	8 (210 kW)	10 (270 kW)

Assuming that farmers pay full tax rate, with no refunds, yields the results displayed in Table 15. The first scenario with no investment grants or electricity certificates reveals no investment and a lower profit. Continuing with the next scenario, where electricity certificates are included, a drastic change can be noted. In this case investment option number 5 (120 kW) appear in the optimal solution, which results in less electricity being bought but no kWh are sold.

Considering full tax rates in the third and fourth scenarios, with investment grants included, even larger effects emerge. When no certificates are included investment number 8 (210 kW) appears in the optimal solution. Electricity is now sold during the second quarter. In the final scenario including both grants and certificates the optimal investment option changes from number 6 (150 kW), when no taxes are included, to number 10 (270 kW) when the full energy tax rate is taken into account. The farm sells a total amount of 32 438 kWh during the second and third quarters.

7. Analytical discussion

In this chapter the results will be analysed and discussed by being weighed against previous studies and the theoretical framework.

7.1 The Initial Optimization

The results show that in all of the scenarios, it is not always profitable to invest in solar cells. It is only optimal in the case where the farmer receives both investment grants and the possibility of trading electricity certificates. This is a result that is consisted with the results in a study by Bazen & Brown (2009). Their study showed that an investment in PV systems is feasibly if substantial governmental support is obtained. Although the study is a few years old, a more recent study among Californian wine makers showed that the probability of installing a PV system is higher if the chance of receiving financial support exists (Beckman & Xiarchos, 2013). This indicates that subsides offered by the government have a substantial impact on whether to invest or not. But the future for support mechanisms may be an uncertain factor. For example both Germany and Spain have made cut backs in their beneficial PV policies, which shows that these types of policies are sensitive to recessions and booms in the global economy.

Even though the market has developed and the prices of PV systems have decreased significantly the last decade, the results of this study show similar tendencies as previous studies made at SLU, that it is still rather expensive. Douhan & Rejstrand's results from 2007 showed that it is not realistic for a farmer to invest in a PV system.

In this study we have found that the optimal solution includes an investment of a PV system, given certain preconditions. The market was different at that time, and the financial support mechanisms were not as fully developed as of today. The initial assumptions of their study were different and gave a different result. One possible explanation for the different results of our study compared to Douhan & Rejstrand (2007) may be the developments in the market and support mechanisms.

The study by Nygren from 2009 revealed a modestly positive result, given that the farmer could receive all possible investment grants. This result is consistent with our study. Our study of different scenarios shows that an investment only occurs in the case where both investment grants and trade of certificates are possible. On the other hand, a study by Talavera *et al*. (2010) shows another picture where the results from the sensitivity analysis point out that the subsidy is a less important factor when it comes to PV investments. The investment was evaluated using IRR and the sensitivity analysis revealed that the factor that had a major impact on IRR was the initial investment cost. An explanation might be that the market during 2010 went through rapid changes and that the price of PV systems fell substantially until 2012 when the market started to stabilize.

A main caution with this study is the fact that it is based on a fictive farm. We have been forced to take certain decisions and make assumptions that may affect our analyses of the PV systems to some extent. For example the costs of strengthening the roof have not been included. This may be necessary if the building is older or has a construction that cannot carry the panels. This is a cost that is difficult to estimate since it differs from case to case. We would therefore need data from an actual building to be able to avoid such an assumption.

Another part of the study that may be perceived as a weakness is that we had to assume a distribution of electricity consumption during a 24-hour period. The data regarding electricity used per pig is based on one stable from one farm, which may give a narrow perspective. A better alternative would have been to conduct measures in several pig barns to obtain a more accurate picture. This would of course be time consuming in order to obtain results across the periods. On the other hand the question is if it is required, since the model can never be a perfect copy of the real world. To collect such data would also be costly. In a research context, as this study is, a larger data collection would enhance the validity of the results and perhaps provide a more correct picture and not only just a hint on major factors affecting PV investments.

7.2 The sensitivity analysis

Here follows a discussion about the outcome of the sensitivity analysis. The analysis is divided into the different examined factors. In section 7.2.1 and 7.2.4 two figures from chapter 6 are reused in order to make the analytical discussion easier to follow.

7.2.1 The electricity price level

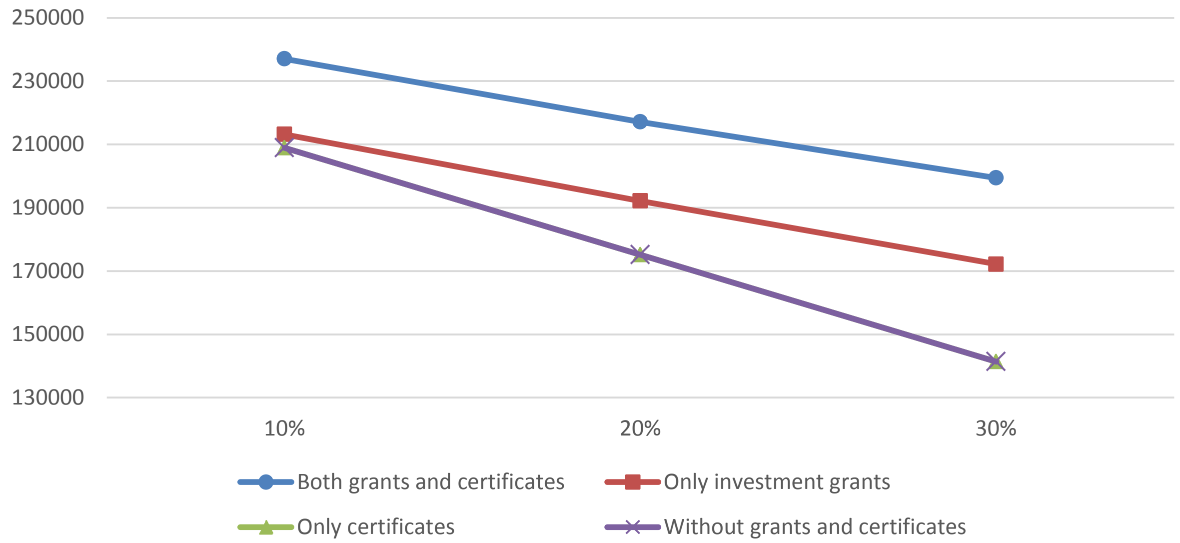

Figure 10. Effects on profit by changes in electricity price levels (same as in section 6.2)

The sensitivity analysis of the electricity price yields effects in profit that are quite different, as seen in Figure 10. Two of the scenarios show no differences in whether to invest or not. This because the price per kWh to buy electricity is less than the investments' annual cost divided per kWh produced. The green line with triangles (▲) and the purple line with crosses (×) in Figure 10 display how the profit in both scenarios without investment grants are decreasing as the electricity price increase. In order to choose an investment option the price level has to be increased by double-digit percentages. This implies that the price level of electricity is not the major factor that affects whether to invest or not in these scenarios. It seems to have a lesser effect on the decision.

The red line with boxes (■) reveals how profits are affected in the scenario with only investment grants. Compared to the basic assumptions and the two already mentioned scenarios, this scenario displays investments. The reason for this is that the price for electricity bought is less competitive than the price per kWh produced by a PV system and therefore the model chooses to invest. Since the firm may produce an amount of energy on their own, they become less affected by changes in the electricity market.

Given that the farmer may receive both investment grants and sell electricity certificates, as seen in the blue line with circles (●) in Figure 10, the profit is much higher compared to the three other presented scenarios. In this case an investment at 150 kW is chosen in accordance with the basic assumptions. Examining the differences in the profit, at initial price levels, between this scenario and a scenario where an investment is not conducted there is an estimated benefit of approximately 12 000 SEK a year. This value divided by the total investment cost for the entire system reveals a 1 % gain of conducting an investment.

Since the prices during the last decade have been characterized by substantial volatility, this might be a reasonable investment with less volatility. However, the pig industry has had a period of low profitability. Hence, an investment might be less interesting given that the benefits are quite low compared to the sacrifices of liquid assets for a long period of time. Therefore, it might perhaps be more interesting to buy electricity at a price fixed by a long-term contract.

7.2.2 Changes in prices of electricity certificates

Another sensitivity analysis examines the effects of changing the price of electricity certificates between 100 and 300 SEK. This interval represents the lowest and highest average prices since year 2003. The results of the scenarios that consider trade with certificates show a large difference. Under the circumstances that both investment grants are received and certificates are traded investments are chosen across the entire interval with investment option 5 (120 kW) to 8 (210 kW) depending on the price of the certificates. This compared with the scenario where only certificates are considered, where there is a need to go above 600 SEK before an investment is part of an optimal solution. Still, only investment option 2 (30 kW) is chosen. An examination of historical average prices of certificates indicates that it does not seem entirely realistic that the price would increase up to 600 SEK per certificate in a near future.

In our study we have included not only the possibility to trade certificates but also the quota rules (see section 1.6 for more information). If the quota rules are not included the results may be more positive. There seems to be a certain impact of being able to trade with electricity certificates when examining the different scenarios. This observation might be slightly more pronounced if the quota rules are not included and all certificates are available for trade. But on the other hand, if the quota rules are not included the results will not be realistic since the rules are applied through law.

The certificate system is a political instrument to stimulate renewable energy sources. This makes the future for certificate trading a rather uncertain business depending on future government. There may be more efficient systems or other ways to stimulate the market and this is therefore a factor that is hard to predict. The certificates in Sweden are received for a period of 15 years and predictions for this period are quite uncertain.

7.2.3 Changes in discount rate

As can be observed for the results of the two scenarios including investment grants, the choice of discount rate plays a substantial role to whether an investment is profitable or not. The importance of the discount rate is supported by theories (Persson & Nilsson, 1999; Olve & Samuelson, 2008; Brealey *et al.*, 2014) and it highly affects the economic value of the investment.

In the two scenarios without investment grants the importance of the discount rate seems minimal. This has been discussed previously given that the assumption regarding the different scenarios plays an important part. Since the discount rate is more important in the two scenarios with investment grants it is reasonable to conclude that the discount rate is important. Notice that in the scenario with no investment grants but certificate trade, an investment is a part of the optimal solution when the discount rate is 2 %. The discount rate does not only affect if an investment is made or not. As can be observed according to the results in section 6.3 the discount rate also affects which investment is the most profitable to choose. The largest effects are observed in the case where both investment grants and certificate trade are considered. Here five different investment options are optimal at different discount rates.

7.2.4 Changes in calculation period

The results show that the calculation period affects when to invest and which investment to conduct, given that all other factors remain the same. In Figure 11 the effects on the annual profits are illustrated. The largest effects can be noted for the last scenario with both subsidies and trade with electricity certificates considered. In this case, an investment is economically feasible already when the calculation period is 20 years. However, it should be noticed that the calculation period does not seem to affect the results for the two scenarios without subsidies. In this situation no investment is enacted irrespective of the economic life span.

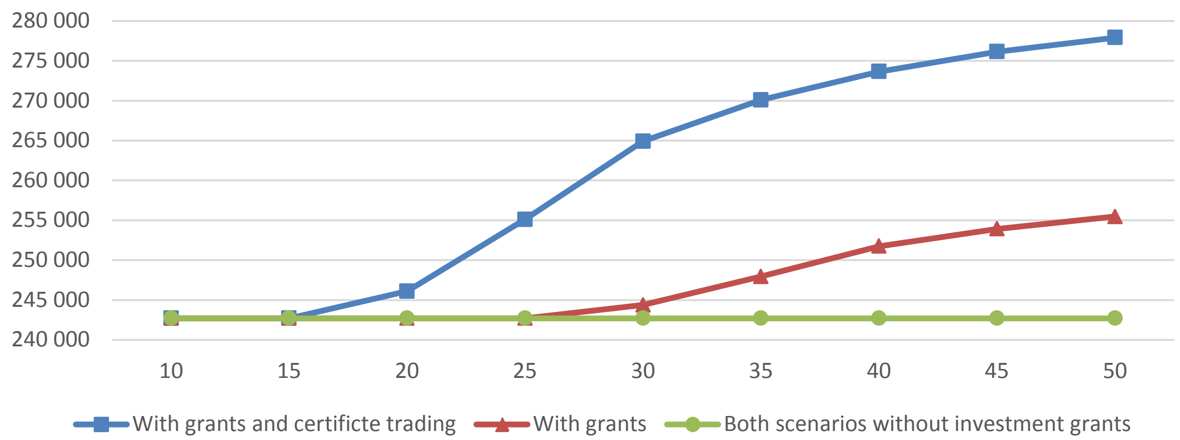

Figure 11. Effect on the profit when changing the calculation period (same as in section 6.4)

The trend indicated by Figure 11 suggests that investments may prove higher economic feasibility in the future, given further product development and innovations resulting in longer life span of PV systems. At the same time, there is a trend towards a lessen impact when the calculation period reaches the end of the sensitivity analysis interval. The annuity factor also reduces the impact of the calculation period. This indicates that the impact of the calculation period is decreasing when the economic life span increases.

In scenario three, with investment grants, the first investment is made when the calculation period is 30 years and investment number 5 (120 kW) is chosen. At a calculation period of 40 years investment number 6 (150 kW) is optimal instead. This option remains optimal through the analysis interval up to 50 years. In the fourth and last scenario, with both grants and certificate trading, the first investment appears already at a calculation period of 20 years and number 5 (120 kW) is optimal at this point. This scenario is substantially affected by the calculation period compared to the other three. Investment number 6 (150 kW) is included in the optimal solution at 25 years and option 8 (210 kW) at 30 years. In this case investment number 8 (210 kW) remains optimal through the rest of the analysis interval up to 50 years. This means that the calculation period substantially affects the costs of an investment but at a certain point the effect is mitigated.

7.2.5 Selling and buying electricity

A general observation during the study is that the farm's electricity need serves as a basis for seeking the optimal solution. In the initial analysis with basic values an investment that only covers as much as possible of the electricity needs is chosen, and no selling of electricity takes place. The same pattern is noticed in the sensitivity analysis, where it is always optimal to choose an investment where no or a small amount of electricity is sold. This indicates that the choice of investment is guided by the farm's own electricity consumption. The possibility to sell electricity into the grid seems to be of secondary importance. Our analysis indicates that a possible reason for this is the price picture of today's electricity market. The gap between the selling price and the buying price in today's market makes it more profitable to use the electricity on the farm. Only in those cases when there is a substantial increase in price of electricity and the price of certificates, the model chooses an investment that produces more electricity than the farm uses on its own. The same reason applies to the discount rate and the calculation period. When these reach certain values a small amount of electricity is sold.

Although selling electricity may be a more direct benefit from an investment, there might be other more indirect effects on the profitability of the farm. Solar modules placed on the roof of stables, or on other suitable farm buildings, use the same resource (the building) without conflicting with already existing production. Therefore the investment may be perceived as a good way to diversify the farm operation and a suitable method to become less sensitive to external factors. Given world-wide demands of reducing greenhouse gas emissions, electricity from renewable sources may play a huge role. A possible investment in solar power could therefore be perceived as an investment for the future.

7.2.6 Taxes

A factor not considered in the initial study is energy tax. Farmers in Sweden may receive tax reductions on energy used in the agricultural firm. Talavera *et al*. (2010) tested to include taxes in their sensitivity analysis on investments on residential buildings and the results showed a negative impact on IRR in one case out of three. This indicates that taxes may have a marginal effect on the investment outcome. In our case, the sensitivity analysis of energy taxes reveals substantial effects on the outcome if the farmers are faced with paying the full tax rate.

The first changes can be observed in the scenario including grants, but no certificates. This scenario displays an investment, which it did not show in the initial optimization. Here the model makes a rather interesting choice by shifting from no investment with the basic assumptions to investment number 8 (210 kW) when including full energy taxes. Another large change can be noted in the final scenario with both grants and certificates where the results shift from investment number 6 (150 kW), given that no taxes are included, to number 10 (270 kW). These changes indicate that the energy tax rate farmers are faced with may actually affect the outcome of the investment decision. At the same time it also indicates that as long as farmers are able to receive refunds on energy taxes they are not likely to substantially change the investment decision.

Although paying full energy taxes drastically reduces profits it still does not seem profitable to invest in solar power when a farmer does not receive any sort of financial support. However, when considering the possibility to trade electricity certificates we see a noteworthy difference compared to our earlier results when we do not consider taxes. It seems profitable to make an investment even without the financial support of grants. This finding is rather remarkable and indicates that future political instruments such as both taxes and certificate trading may play a large role in providing incentives for investments in solar electricity.

8. Concluding comments

The aim of this thesis is to examine with the help of mathematical programing; if an investment in a photovoltaic system is economically feasible at a Swedish pig farm, if an investment can affect the profitability of the farm, how sensitive it is and what capacity of a photovoltaic system that is optimal. Three research questions have been developed and in this chapter these will be answered based on the result and the discussion of this study.

Given the conditions defining this study it is economically feasible to invest in a solar cell system on a Swedish pig farm if one is granted investment subsidies and there is a possibility to trade electricity certificates.

An investment in a PV system may affect the profitability of a farm, mostly in the sense of making the farm less sensitive to price changes in the electricity market. However, the effects are marginal though and given the current state of the troubled Swedish pig industry, it is important to weigh the benefits of making an investment against the benefits of using the liquid assets in other projects and simply negotiating electricity prices with the electricity supplier.

The results show that the optimal system size depends highly on the electricity need at the farm. This implies that a farm should chose its investment size based on its electricity consumption. This also minimizes the cost of buying electricity from the national grid. Therefore, selling electricity is of secondary importance when choosing system. It is important to study the own need before making a decision concerning an investment in PV systems.

When testing the sensitivity of the solution in different scenarios it appears that basic factors, such as the availability of subsidies and trade with certificates, have a larger effect on whether to invest or not compared to other factors analysed; electricity price level, certificate price, discount rate and calculation period. In those scenarios where only certificate trading existed or nothing but the initial costs, no factors deem important enough to make investments. The scenario with subsidies displays a marginal sensitivity to the different factors, all within the pre-set ranges. But the scenario with consideration to both investment grants and certificate trading is the one where frequently different investment options are chosen depending on the values of other factors.

The results and the conclusions of this study are not entirely suited for generalization, since farms are heterogeneous. Nevertheless, this study gives an indication of how an investment affects the economic result of the farm. In addition the assumptions regarding political instruments that farms are faced with have a large impact on the outcome of the optimization. To obtain results more suited for generalization an extended study with multiple farms and long-term measurements of electricity consumption for various types of pig farms needs to be conducted.

Looking towards future research…

There is still a large need for further studies and research on applying PV on farms under Swedish conditions. Solar electricity is a growing and developing industry on a global scale and changes happen rapidly. Adding the political discussions in not only Sweden it is important to keep evaluating the economic feasibility for farmers to make investments in their own energy sources. Another relevant study to conduct in the future is to examine risks connected to PV systems and evaluate already conducted investments among farmers.

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Appendix 1: Initial Optimization Model, Scenario: No Investment Grants

										ELBQ1			ELBQ2			ELBQ3			ELBQ4	
	Xww	Xrs	Xsb	Xb	XbS	XbB	Xall	PSow	Pswine	AM	PM	Night	AM	PM	Night	AM	PM	Night	AM	PM	Night
quantity	80	40	40	40	0	845 000	200	200	5 000	36 487	44 012	40 545	36 055	44 261	40 223	37 735	47 215	42 281	35 488	43 116	39 498
revenue (cj)	4 632	4 159	5 781	-6 041	1,21	-1,66	2 656	-5 501	405	-0,72	-0,72	-0,72	-0,68	-0,68	-0,68	-0,67	-0,67	-0,67	-0,70	-0,70	-0,70
return	370 562	166 361	231 237	-241 622	0	-1 402 700	531 250	-1 100 224	2 025 607	-26 296	-31 720	-29 221	-24 419	-29 977	-27 242	-25 411	-31 794	-28 472	-25 003	-30 378	-27 829

Profit
242 710

				ai1	ai2	ai3	ai4	ai5	ai6	ai7	ai8	ai9	ai10	ai11	ai12	ai13	ai14	ai15	ai16	ai17	ai18	ai19	ai20	ai21
				Xww	Xrs	Xsb	Xb	XbS	XbB	Xall	PSow	Pswine	AM	PM	Night	AM	PM	Night	AM	PM	Night	AM	PM	Night
0	=	0	All land	1	1	1	1			-1														
200	<=	200	Total arable land	1	1	1	1																	
0	<=	0	Crop rotation	1	-1	-1																		
0	<=	0	Rape-seed		1					-0,2														
0	<=	0	Sugerbeats qvota			1				-0,2														
0	<=	0	Rape-seed after Bar		-1		1																	
0	<=	0	Barley feed				-5 000	1	-1			209												
0	=	0	Number of piglets								-25	1												
5 000	<=	5000	Number of swines									1												
200	=	200	Number of sowes								1													
0	=	0	Electricity Q1 AM								82,58	3,99	-1											
0	=	0	Electricity Q1 PM								80,47	5,58		-1										
0	=	0	Electricity Q1 Night								87,84	4,60			-1									
0	=	0	Electricity Q2 AM								72,51	4,31				-1								
0	=	0	Electricity Q2 PM								70,66	6,03					-1							
0	=	0	Electricity Q2 Night								77,12	4,96						-1						
0	=	0	Electricity Q3 AM								65,35	4,93							-1					
0	=	0	Electricity Q3 PM								63,69	6,90								-1				
0	=	0	Electricity Q3 Night								69,52	5,68									-1			
0	=	0	Electricity Q4 AM								76,66	4,03										-1		
0	=	0	Electricity Q4 PM								74,71	5,63											-1	
0	=	0	Electricity Q4 Night								81,54	4,64												-1
0	<=	1	Relation investments																					

.

ELSQ1			ELSQ2			ELSQ3			ELSQ4			(15kW)	(30 kW)	(60 kW)	(90 kW)	(120 kW)	(150 kW)	(180kW)	(210 kW)	(240 kW)	(270 kW)	(300 kW)
Am	Pm	Night	Am	Pm	Night	Am	Pm	Night	Am	Pm	Night	I1	I2	I3	I4	I5	I6	I7	I8	I9	I10	I11
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0,32	0,32	0,32	0,29	0,29	0,29	0,27	0,27	0,27	0,32	0,32	0,32	-15 605	-31 210	-62 420	-93 630	-124 840	-157 382	-190 556	-221 766	-254 973	-286 183	-319 607
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

ai22	ai23	ai24	ai25	ai26	ai27	ai28	ai29	ai30	ai31	ai32	ai33	ai34	ai35	ai36	ai37	ai38	ai39	ai40	ai41	ai42	ai43	ai44			
Am	Pm	Night	Am	Pm	Night	Am	Pm	Night	Am	Pm	Night	I1	I2	I3	I4	I5	I6	I7	I8	I9	I10	I11	Sum	<,=>	bi
																							3	=	0
																							4	<=	200
																							-1	<=	0
																							1	<=	0
																							1	<=	0
																							0	<=	0
																							-4791	<=	0
																							-24	=	0
																							1	<=	5000
																							1	=	200
1												-1 015	-2 030	-4 060	-6 087	-8 129	-10 152	-12 169	-14 192	-16 214	-18 281	-20 304	-112548	=	0
	1											-1 023	-2 046	-4 090	-6 133	-8 191	-10 228	-12 261	-14 298	-16 336	-18 419	-20 456	-113394	=	0
		1										0	0	0	0	0	0	0	0	0	0	0	92	=	0
			1									-2 935	-5 875	-11 746	-17 659	-23 435	-29 354	-35 272	-41 095	-47 013	-52 884	-58 754	-325946	=	0
				1								-2 935	-5 875	-11 746	-17 659	-23 435	-29 354	-35 272	-41 095	-47 013	-52 884	-58 754		=	0
					1							-329	-659	-1 318	-1 981	-2 629	-3 293	-3 957	-4 610	-5 274	-5 933	-6 591	-36492	=	0
						1						-2 491	-4 967	-9 940	-14 907	-19 860	-24 909	-29 814	-34 767	-39 768	-44 721	-49 674	-275750	=	0
							1					-2 491	-4 967	-9 940	-14 907	-19 860	-24 909	-29 814	-34 767	-39 768	-44 721	-49 674	-275749	=	0
								1				-198	-395	-791	-1 186	-1 580	-1 981	-2 372	-2 766	-3 163	-3 557	-3 951	-21865	=	0
									1			-609	-1 221	-2 410	-3 657	-4 874	-6 092	-7 316	-8 544	-9 763	-10 986	-12 209	-67600	=	0
										1		-616	-1 234	-2 435	-3 696	-4 926	-6 158	-7 394	-8 636	-9 867	-11 104	-12 341	-68327	=	0
											1	0	0	0	0	0	0	0	0	0	0	0	86	=	0
												1	1	1	1	1	1	1	1	1	1	1	11	<=	1

Appendix 2: Initial Optimization Model, Scenario: No Investment Grants, Certificate Trading

										ELBQ1			ELBQ2			ELBQ3			ELBQ4		
	Xww	Xrs	Xsb	Xb	XbS	XbB	Xall	PSow	Pswine	AM	PM	Night	AM	PM	Night	AM	PM	Night	AM	PM	Night
quantity	80	40	40	40	0	845 000	200	200	5 000	36 487	44 012	40 545	36 055	44 261	40 223	37 735	47 215	42 281	35 488	43 116	39 498
revenue (cj)	4 632	4 159	5 781	-6 041	1,21	-1,66	2 656	-5 501	405	-0,72	-0,72	-0,72	-0,68	-0,68	-0,68	-0,67	-0,67	-0,67	-0,70	-0,70	-0,70
return	370 562	166 361	231 237	-241 622	0	-1 402 700	531 250	-1 100 224	2 025 607	-26 296	-31 720	-29 221	-24 419	-29 977	-27 242	-25 411	-31 794	-28 472	-25 003	-30 378	-27 829

Profit
242 710

				ai1	ai2	ai3	ai4	ai5	ai6	ai7	ai8	ai9	ai10	ai11	ai12	ai13	ai14	ai15	ai16	ai17	ai18	ai19	ai20	ai21
				Xww	Xrs	Xsb	Xb	XbS	XbB	Xall	PSow	Pswine	AM	PM	Night	AM	PM	Night	AM	PM	Night	AM	PM	Night
0	=	0	All land	1	1	1	1			-1														
200	<=	200	Total arable land	1	1	1	1																	
0	<=	0	Crop rotation	1	-1	-1																		
0	<=	0	Rape-seed		1					-0,2														
0	<=	0	Sugerbeats qvota			1				-0,2														
0	<=	0	Rape-seed after Bar		-1		1																	
0	<=	0	Barley feed				-5 000	1	-1			209												
0	=	0	Number of piglets								-25	1												
5 000	<=	5000	Number of swines									1												
200	=	200	Number of sowes								1													
0	=	0	Electricity Q1 AM								82,58	3,99	-1											
0	=	0	Electricity Q1 PM								80,47	5,58		-1										
0	=	0	Electricity Q1 Night								87,84	4,60			-1									
0	=	0	Electricity Q2 AM								72,51	4,31				-1								
0	=	0	Electricity Q2 PM								70,66	6,03					-1							
0	=	0	Electricity Q2 Night								77,12	4,96						-1						
0	=	0	Electricity Q3 AM								65,35	4,93							-1					
0	=	0	Electricity Q3 PM								63,69	6,90								-1				
0	=	0	Electricity Q3 Night								69,52	5,68									-1			
0	=	0	Electricity Q4 AM								76,66	4,03										-1		
0	=	0	Electricity Q4 PM								74,71	5,63											-1	
0	=	0	Electricity Q4 Night								81,54	4,64												-1
0	<=	1	Relation investments																					

ELSQ1			ELSQ2			ELSQ3			ELSQ4			(15kW)	(30 kW)	(60 kW)	(90 kW)	(120 kW)	(150 kW)	(180kW)	(210 kW)	(240 kW)	(270 kW)	(300 kW)
AM	PM	Night	AM	PM	Night	AM	PM	Night	AM	PM	Night	I1	I2	I3	I4	I5	I6	I7	I8	I9	I10	I11
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0,32	0,32	0,32	0,29	0,29	0,29	0,27	0,27	0,27	0,32	0,32	0,32	-13 489	-26 977	-55 288	-82 931	-110 575	-139 551	-169 159	-196 802	-226 444	-254 087	-283 945
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

ai22	ai23	ai24	ai25	ai26	ai27	ai28	ai29	ai30	ai31	ai32	ai33	ai34	ai35	ai36	ai37	ai38	ai39	ai40	ai41	ai42	ai43	ai44			
AM	PM	Night	AM	PM	Night	AM	PM	Night	AM	PM	Night	I1	I2	I3	I4	I5	I6	I7	I8	I9	I10	I11	Summa	<,=>	bi
																							3	=	0
																							4	<=	200
																							-1	<=	0
																							1	<=	0
																							1	<=	0
																							0	<=	0
																							-4791	<=	0
																							-24	=	0
																							1	<=	5000
																							1	=	200
1												-1 015	-2 030	-4 060	-6 087	-8 129	-10 152	-12 169	-14 192	-16 214	-18 281	-20 304	-112548	=	0
	1											-1 023	-2 046	-4 090	-6 133	-8 191	-10 228	-12 261	-14 298	-16 336	-18 419	-20 456	-113394	=	0
		1										0	0	0	0	0	0	0	0	0	0	0	92	=	0
			1									-2 935	-5 875	-11 746	-17 659	-23 435	-29 354	-35 272	-41 095	-47 013	-52 884	-58 754	-325946	=	0
				1								-2 935	-5 875	-11 746	-17 659	-23 435	-29 354	-35 272	-41 095	-47 013	-52 884	-58 754		=	0
					1							-329	-659	-1 318	-1 981	-2 629	-3 293	-3 957	-4 610	-5 274	-5 933	-6 591	-36492	=	0
						1						-2 491	-4 967	-9 940	-14 907	-19 860	-24 909	-29 814	-34 767	-39 768	-44 721	-49 674	-275750	=	0
							1					-2 491	-4 967	-9 940	-14 907	-19 860	-24 909	-29 814	-34 767	-39 768	-44 721	-49 674	-275749	=	0
								1				-198	-395	-791	-1 186	-1 580	-1 981	-2 372	-2 766	-3 163	-3 557	-3 951	-21865	=	0
									1			-609	-1 221	-2 410	-3 657	-4 874	-6 092	-7 316	-8 544	-9 763	-10 986	-12 209	-67600	=	0
										1		-616	-1 234	-2 435	-3 696	-4 926	-6 158	-7 394	-8 636	-9 867	-11 104	-12 341	-68327	=	0
											1	0	0	0	0	0	0	0	0	0	0	0	86	=	0
												1	1	1	1	1	1	1	1	1	1	1	11	<=	1

Appendix 3: Initial Optimization Model, Scenario: Investment Grants

									ELBQ1			ELBQ2			ELBQ3			ELBQ4		
	Xww	Xrs	Xsb	Xb	XbS	XbB	Xall	PSow	Pswine	AM	PM	Night	AM	PM	Night	AM	PM	Night	AM	PM	Night
quantity	80	40	40	40	0	845 000	200	200	5 000	36 487	44 012	40 545	36 055	44 261	40 223	37 735	47 215	42 281	35 488	43 116	39 498
revenue (cj)	4 632	4 159	5 781	-6 041	1,21	-1,66	2 656	-5 501	405	-0,72	-0,72	-0,72	-0,68	-0,68	-0,68	-0,67	-0,67	-0,67	-0,70	-0,70	-0,70
return	370 562	166 361	231 237	-241 622	0	-1 402 700	531 250	-1 100 224	2 025 607	-26 296	-31 720	-29 221	-24 419	-29 977	-27 242	-25 411	-31 794	-28 472	-25 003	-30 378	-27 829

Profit
242 710

				ai1	ai2	ai3	ai4	ai5	ai6	ai7	ai8	ai9	ai10	ai11	ai12	ai13	ai14	ai15	ai16	ai17	ai18	ai19	ai20	ai21
				Xww	Xrs	Xsb	Xb	XbS	XbB	Xall	PSow	Pswine	AM	PM	Night	AM	PM	Night	AM	PM	Night	AM	PM	Night
0	=	0	All land	1	1	1	1			-1														
200	<=	200	Total arable land	1	1	1	1																	
0	<=	0	Crop rotation	1	-1	-1																		
0	<=	0	Rape-seed		1					-0,2														
0	<=	0	Sugerbeats qvota			1				-0,2														
0	<=	0	Rape-seed after Bar		-1		1																	
0	<=	0	Barley feed				-5 000	1	-1			209												
0	=	0	Number of piglets								-25	1												
5 000	<=	5000	Number of swines									1												
200	=	200	Number of sowes								1													
0	=	0	Electricity Q1 AM								82,58	3,99	-1											
0	=	0	Electricity Q1 PM								80,47	5,58		-1										
0	=	0	Electricity Q1 Night								87,84	4,60			-1									
0	=	0	Electricity Q2 AM								72,51	4,31				-1								
0	=	0	Electricity Q2 PM								70,66	6,03					-1							
0	=	0	Electricity Q2 Night								77,12	4,96						-1						
0	=	0	Electricity Q3 AM								65,35	4,93							-1					
0	=	0	Electricity Q3 PM								63,69	6,90								-1				
0	=	0	Electricity Q3 Night								69,52	5,68									-1			
0	=	0	Electricity Q4 AM								76,66	4,03										-1		
0	=	0	Electricity Q4 PM								74,71	5,63											-1	
0	=	0	Electricity Q4 Night								81,54	4,64												-1
0	<=	1	Relation investments																					

ELSQ1			ELSQ2			ELSQ3			ELSQ4			(15kW)	(30 kW)	(60 kW)	(90 kW)	(120 kW)	(150 kW)	(180kW)	(210 kW)	(240 kW)	(270 kW)	(300 kW)
AM	PM	Night	AM	PM	Night	AM	PM	Night	AM	PM	Night	I1	I2	I3	I4	I5	I6	I7	I8	I9	I10	I11
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0,32	0,32	0,32	0,29	0,29	0,29	0,27	0,27	0,27	0,32	0,32	0,32	-10 471	-20 943	-41 886	-62 828	-83 771	-105 607	-127 868	-148 811	-171 094	-192 037	-225 735
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

ai22	ai23	ai24	ai25	ai26	ai27	ai28	ai29	ai30	ai31	ai32	ai33	ai34	ai35	ai36	ai37	ai38	ai39	ai40	ai41	ai42	ai43	ai44			
AM	PM	Night	AM	PM	Night	AM	PM	Night	AM	PM	Night	I1	I2	I3	I4	I5	I6	I7	I8	I9	I10	I11	Sum	<,=,>	bi
																							3	=	0
																							4	<=	200
																							-1	<=	0
																							1	<=	0
																							1	<=	0
																							0	<=	0
																							-4791	<=	0
																							-24	=	0
																							1	<=	5000
																							1	=	200
1												-1 015	-2 030	-4 060	-6 087	-8 129	-10 152	-12 169	-14 192	-16 214	-18 281	-20 304	-112548	=	0
	1											-1 023	-2 046	-4 090	-6 133	-8 191	-10 228	-12 261	-14 298	-16 336	-18 419	-20 456	-113394	=	0
		1										0	0	0	0	0	0	0	0	0	0	0	92	=	0
			1									-2 935	-5 875	-11 746	-17 659	-23 435	-29 354	-35 272	-41 095	-47 013	-52 884	-58 754	-325946	=	0
				1								-2 935	-5 875	-11 746	-17 659	-23 435	-29 354	-35 272	-41 095	-47 013	-52 884	-58 754		=	0
					1							-329	-659	-1 318	-1 981	-2 629	-3 293	-3 957	-4 610	-5 274	-5 933	-6 591	-36492	=	0
						1						-2 491	-4 967	-9 940	-14 907	-19 860	-24 909	-29 814	-34 767	-39 768	-44 721	-49 674	-275750	=	0
							1					-2 491	-4 967	-9 940	-14 907	-19 860	-24 909	-29 814	-34 767	-39 768	-44 721	-49 674	-275749	=	0
								1				-198	-395	-791	-1 186	-1 580	-1 981	-2 372	-2 766	-3 163	-3 557	-3 951	-21865	=	0
									1			-609	-1 221	-2 410	-3 657	-4 874	-6 092	-7 316	-8 544	-9 763	-10 986	-12 209	-67600	=	0
										1		-616	-1 234	-2 435	-3 696	-4 926	-6 158	-7 394	-8 636	-9 867	-11 104	-12 341	-68327	=	0
											1	0	0	0	0	0	0	0	0	0	0	0	86	=	0
												1	1	1	1	1	1	1	1	1	1	1	11	<=	1

Appendix 4: Initial Optimization Model, Scenario: Investment Grants and Certificate Trading

										ELBQ1			ELBQ2			ELBQ3			ELBQ4		
	Xww	Xrs	Xsb	Xb	XbS	XbB	Xall	PSow	Pswine	AM	PM	Night	AM	PM	Night	AM	PM	Night	AM	PM	Night
quantity	80	40	40	40	0	845 000	200	200	5 000	26 335	33 783	40 545	6 701	14 907	36 930	12 826	22 306	40 300	29 395	36 958	39 498
revenue (cj)	4 632	4 159	5 781	-6 041	1,21	-1,66	2 656	-5 501	405	-0,72	-0,72	-0,72	-0,68	-0,68	-0,68	-0,67	-0,67	-0,67	-0,70	-0,70	-0,70
return	370 562	166 361	231 237	-241 622	0	-1 402 700	531 250	-1 100 224	2 025 607	-18 980	-24 348	-29 221	-4 539	-10 096	-25 012	-8 637	-15 021	-27 137	-20 711	-26 039	-27 829

Profit
255 126

				ai1	ai2	ai3	ai4	ai5	ai6	ai7	ai8	ai9	ai10	ai11	ai12	ai13	ai14	ai15	ai16	ai17	ai18	ai19	ai20	ai21
				Xww	Xrs	Xsb	Xb	XbS	XbB	Xall	PSow	Pswine	AM	PM	Night	AM	PM	Night	AM	PM	Night	AM	PM	Night
0	=	0	All land	1	1	1	1			-1														
200	<=	200	Total arable land	1	1	1	1																	
40	>=	1	Min barley				1																	
0	<=	0	Crop rotation	1	-1	-1																		
0	<=	0	Rape-seed		1					-0,2														
0	<=	0	Sugerbeats qvota			1				-0,2														
0	<=	0	Rape-seed after Bar		-1		1																	
0	<=	0	Barley feed				-5 000	1	-1			209												
0	=	0	Number of piglets								-25	1												
5 000	<=	5000	Number of swines									1												
200	=	200	Number of sowes								1													
0	=	0	Electricity Q1 AM								82,58	3,99	-1											
0	=	0	Electricity Q1 PM								80,47	5,58		-1										
0	=	0	Electricity Q1 Night								87,84	4,60			-1									
0	=	0	Electricity Q2 AM								72,51	4,31				-1								
0	=	0	Electricity Q2 PM								70,66	6,03					-1							
0	=	0	Electricity Q2 Night								77,12	4,96						-1						
0	=	0	Electricity Q3 AM								65,35	4,93							-1					
0	=	0	Electricity Q3 PM								63,69	6,90								-1				
0	=	0	Electricity Q3 Night								69,52	5,68									-1			
0	=	0	Electricity Q4 AM								76,66	4,03										-1		
0	=	0	Electricity Q4 PM								74,71	5,63											-1	
0	=	0	Electricity Q4 Night								81,54	4,64												-1
1	<=	1	Relation investments																					

ELSQ1			ELSQ2			ELSQ3			ELSQ4			(15kW)	(30 kW)	(60 kW)	(90 kW)	(120 kW)	(150 kW)	(180kW)	(210 kW)	(240 kW)	(270 kW)	(300 kW)
AM	PM	Night	AM	PM	Night	AM	PM	Night	AM	PM	Night	I1	I2	I3	I4	I5	I6	I7	I8	I9	I10	I11
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
0,32	0,32	0,32	0,29	0,29	0,29	0,27	0,27	0,27	0,32	0,32	0,32	-8 355	-16 710	-34 753	-52 130	-69 506	-87 776	-106 471	-123 847	-142 564	-159 941	-190 073
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-87 776	0	0	0	0	0

ai22	ai23	ai24	ai25	ai26	ai27	ai28	ai29	ai30	ai31	ai32	ai33	ai34	ai35	ai36	ai37	ai38	ai39	ai40	ai41	ai42	ai43	ai44			
AM	PM	Night	AM	PM	Night	AM	PM	Night	AM	PM	Night	I1	I2	I3	I4	I5	I6	I7	I8	I9	I10	I11	Sum	<,=,>	bi
																							3	=	0
																							4	<=	200
																							1	>=	1
																							-1	<=	0
																							1	<=	0
																							1	<=	0
																							0	<=	0
																							-4791	<=	0
																							-24	=	0
																							1	<=	5000
																							1	=	200
1												-1 015	-2 030	-4 060	-6 087	-8 129	-10 152	-12 169	-14 192	-16 214	-18 281	-20 304	-112548	=	0
	1											-1 023	-2 046	-4 090	-6 133	-8 191	-10 228	-12 261	-14 298	-16 336	-18 419	-20 456	-113394	=	0
		1										0	0	0	0	0	0	0	0	0	0	0	92	=	0
			1									-2 935	-5 875	-11 746	-17 659	-23 435	-29 354	-35 272	-41 095	-47 013	-52 884	-58 754	-325946	=	0
				1								-2 935	-5 875	-11 746	-17 659	-23 435	-29 354	-35 272	-41 095	-47 013	-52 884	-58 754		=	0
					1							-329	-659	-1 318	-1 981	-2 629	-3 293	-3 957	-4 610	-5 274	-5 933	-6 591	-36492	=	0
						1						-2 491	-4 967	-9 940	-14 907	-19 860	-24 909	-29 814	-34 767	-39 768	-44 721	-49 674	-275750	=	0
							1					-2 491	-4 967	-9 940	-14 907	-19 860	-24 909	-29 814	-34 767	-39 768	-44 721	-49 674	-275749	=	0
								1				-198	-395	-791	-1 186	-1 580	-1 981	-2 372	-2 766	-3 163	-3 557	-3 951	-21865	=	0
									1			-609	-1 221	-2 410	-3 657	-4 874	-6 092	-7 316	-8 544	-9 763	-10 986	-12 209	-67600	=	0
										1		-616	-1 234	-2 435	-3 696	-4 926	-6 158	-7 394	-8 636	-9 867	-11 104	-12 341	-68327	=	0
											1	0	0	0	0	0	0	0	0	0	0	0	86	=	0
												1	1	1	1	1	1	1	1	1	1	1	11	<=	1