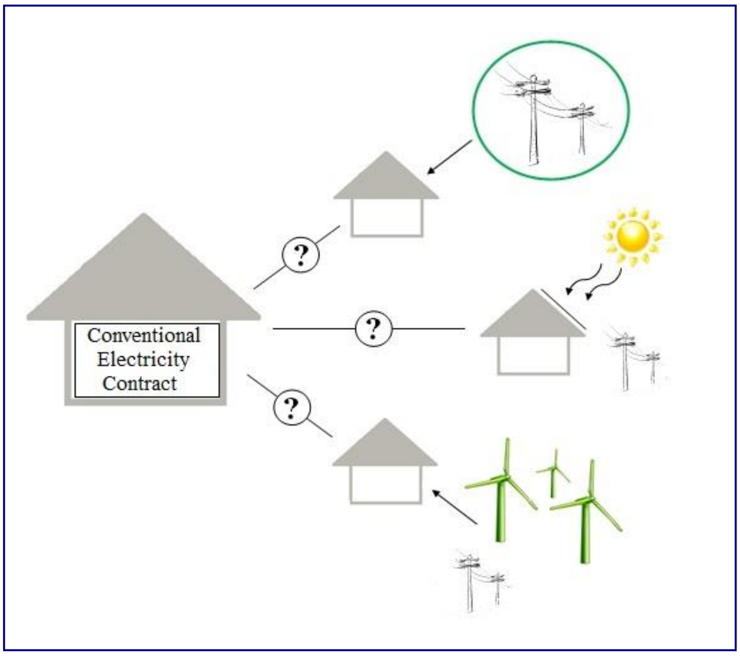

Economics of Renewable Electricity Supply

A Study Applicable for Private Householders in Sweden

Master's Thesis within the Sustainable Energy Systems programme

IDA WERNSTRÖM

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Department of Energy and Environment
Division of Energy Technology
CHALMERS UNIVERSITY OF TECHNOLOGY
Göteborg, Sweden 2014

MASTER'S THESIS

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Cover:
Illustration of the comparison between the conventional electricity contract and the three modelled renewable electricity supply scenarios; green electricity contracts, investment in solar PV and wind farm shares.

Chalmers Reproservice
Göteborg, Sweden 2014

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ABSTRACT

This thesis serves as an investment guideline for companies and actors contracted by Swedish private householders who consider replacing their conventional electricity contract with a renewable electricity supply.

An investigation of the financial implications of three renewable electricity supplies is conducted; green electricity contracts, installation of photovoltaic panels and investments in wind farm shares. A comparison between the three options and the conventional electricity contract reflects the current market situation.

The financial decisions are reached by models and economic optimizations, with the objective of minimizing the total net present cost, using *HOMER* (Hybrid Optimization of Multiple Energy Resources) and *Excel.* The investigations are realized for each energy system scenario separately. By compiling the main results from these studies the guideline is formed.

The study concludes that photovoltaic electricity supply can be the most economically competitive alternative. With the 35% investment subsidy (administrated by *Länsstyrelsen*) an installation of solar photovoltaic is the most profitable electricity supply. The investment cost will be paid back within 15 years. If the subsidy is discarded, a 10% reduction in investment cost is required to make the investment profitable. Depending on installation costs, this reduction may be achieved with the renovation subsidy (the so called ROT-tax deduction). Otherwise this thesis indicates that electricity supplied through the conventional electricity grid will be the most cost effective solution. Sensitivity analyses of the models show that the results are highly affected by changes in investment cost and electricity price, but also of the real interest rates. The importance for a private customer to select an electricity retailer with favourable agreements is particularly highlighted.

The study is conducted for a family household with the prerequisites and market conditions corresponding to bidding area 3 in the Swedish electricity system in year 2014. Yet, the methodology and the overall results are applicable for other regions and system loads.

Key words: Renewable electricity, solar PV, wind farm shares, green electricity contract, household electricity consumption, energy simulation, HOMER.

Lönsamheten av Förnybar Elförsörjning
En studie tillämpbar för svenska hushåll
Examensarbete inom masterprogrammet *Sustainable Energy Systems*
IDA WERNSTRÖM, ANNA WILLHAMMAR
Institutionen för Energi och Miljö
Avdelningen för Energiteknik
Chalmers tekniska högskola

SAMMANFATTNING

Uppsatsen utgör en riktlinje för företag och aktörer anlitade av privata hushåll som överväger att ersätta sitt konventionella elavtal mot förnybar elförsörjning.

De ekonomiska konsekvenserna av följande tre förnybara elförsörjningsalternativ studeras: gröna elavtal, installering av solceller samt investering av andelar i en vindpark. I jämförelsen mellan de tre alternativen och det konventionella elkontraktet påvisas det nuvarande marknadsläget för investering i förnybar elförsörjning.

De ekonomiska besluten grundar sig på modeller och ekonomisk optimering, med syftet att minimera den totala nuvärdeskostnaden, i *HOMER* (Hybrid Optimization of Multiple Energy Resources) och *Excel*. Varje energisystemscenario undersöks först separat. Genom att sammanställa de viktigaste resultaten från dessa studier formas de ekonomiska riktlinjerna.

Studien påvisar att solceller kan vara den mest ekonomiskt konkurrenskraftiga elförsörjningen. Med det av *Länsstyrelsen* administrerade investeringsstödet för solceller är en investering av solceller den sammantaget mest lönsamma elförsörjningen. Investeringskostnaden kommer vara återbetalad inom 15 år. Utan investeringssubventionen, fordras en minskning i investeringskostnad med 10 % för att solcellsinvesteringen ska vara ekonomiskt lönsam. Beroende på installeringskostnad kan denna reduktion uppnås genom skatteavdraget för renovering, ombyggnad och tillbyggnad (ROT-avdraget). I känslighetsanalyserna framkommer resultatens beroende av investeringskostnad och elpris, men även av kalkylränta. Små differenser i indata kan innebära stora skillnader i resultat. Vikten att som privatperson välja ett elhandelsbolag med gynnsamma avtal påvisas också.

Studien är genomförd för ett familjehushåll med förutsättningar och marknadsvillkor motsvarande elprisområde 3 i det svenska elsystemet år 2014. Metodiken och de övergripande resultaten är dock tillämpbara i ett bredare perspektiv, både för andra regioner och laster.

Nyckelord: Förnyelsebar elektricitet, solceller, vindparksandelar, gröna elavtal, elförbrukning för hushåll, energisimulering, HOMER.

Contents

Preface

This master's thesis has been performed by Ida Wernström and Anna Willhammar at the *Department of Energy and Environment* at *Chalmers University of Technology*, Göteborg 2014. The study has been conducted with supervision from M.Sc. Willy Adamsson and M.Sc. Monir Mikati at *ÅF*. Examiner and supervisor at *Chalmers* has been Prof. Filip Johnsson.

First and foremost we would like thank Willy Adamsson and Monir Mikati for their excellent support and guidance. Thanks also to Filip Johnsson who contributed with comments and valuable advice during the work.

Thanks Dr. Zack Norwood, *Chalmers*, and Mrs. Zinaida Kadic, *Energimyndigheten*, for helping us gather important data sets. We would also like to extend our gratitude to other organizations providing us with data. Further, we would like to thank B.Sc. Elin Elmehag for valuable inputs concerning solar PV systems.

Finally, we would like to thank *ÅF* for giving us the opportunity of conducting this master's thesis and for lending us a workplace in their new office building.

Ida Wernström and Anna Willhammar
Göteborg 2014-05-30

Terminology

Bidding area: An area with a uniform electricity price. The area is formed by limitations in power transfer on the transmission grids.

Decision variable: A variable in the *HOMER* simulation process, which the user has control of and for which the software can consider multiple values in its optimization process.

Derating factor: A scaling factor in the *HOMER* software. The factor scales the rated PV array power output to account for outer conditions of dirt, shading, snow cover, temperature effects, wiring losses and aging of the installation in the real-world operation.

Global solar radiation: The sum of the beam radiation that comes directly from the sun and the diffuse radiation from the firmament.

HOMER: Hybrid Optimization of Multiple Energy Resources. Software specifically designed for simulations, optimizations and sensitivity analysis of renewable hybrid systems. The software determines the optimal production mix in order to minimize the system's total net present cost.

Network concessionaire: Power transmission company which distributes electricity in a given geographical area.

PVs: Photovoltaic solar panels.

Quota obligation: The obligation for electricity producers and energy-intensive industries to purchase a certain share of electricity certificates in relation to their sales of electricity or usage.

Real interest rate: The rate an investor expects to receive for an investment. It constitutes of the nominal interest rate minus the inflation.

ROT-deduction: Swedish tax deduction for services including renovation, reconstruction and extension.

SE3: Bidding area three in Sweden.

Sellback: The price the utility company pays for the excess power produced in the customer's electricity system.

Sustainable Energy Systems: A master's programme at the mechanical engineering department at *Chalmers University of Technology*.

Typical Meteorological Year: Hourly averages of weather data. Collected for a specific location, for a long period of time.

ÅF: A technical consulting company. (http://www.afconsult.com/)

1 Introduction

The global sustainability issue is an important concern which has received increased attention from the society. This, together with the deregulated electricity market has formed willingness for small players to affect their electricity consumption. As an example, one out of five Swedish households considers to install self-produced electricity within five years. The main reasons for such an investment are possible monetary savings and reduced environmental impacts. (Svensk Energi, 2014)

Previous studies and articles within the field of renewable energy are often conducted with a focus on a single technology on a societal level. This thesis highlights the comparison between different electricity supplies and has a focus on profitability for the private consumer.

In an energy market containing several future options for the interplay of production and consumption *ÅF*, the company supervising the thesis, sees great potential in developing viable options with a focus on renewable electricity production. Through this master's thesis *ÅF* obtains deeper insights of the current market situation for renewables in a Swedish scenario.

1.1 Purpose

The purpose of the project is to investigate the financial implications of using available renewable electricity supplies for Swedish households. By revealing the economical differences in comparison to a conventional electricity contract, the most profitable supply for a household is presented.

The following three renewable electricity supplies are studied:

- Continuous billing from renewable electricity contract
- Installation in solar PV modules
- Investment in a cooperatively owned wind farm

The study results in a financial decision support and a discussion regarding the use of renewable electricity for private stakeholders. The decision support is through companies and sectorial actors intended to reach and benefit the public.

1.2 Boundaries

This master's thesis is a future outlook; a time dependent prospective study that simulates the present perspective with a project lifetime of 25 years (from year 2013 to 2037).

As stated, the study is conducted with a focus on three renewable electricity supply alternatives: a renewable electricity contract, installation of solar PVs and investments in wind farm shares. All possible to install and administrate for a majority of the Swedish householders. Small-scale wind turbines are not included; they are currently far too inefficient. The deficiencies of small-scale wind power may be explained by the power equation of wind, equation (1).

$$P_{wind} = \frac{1}{2}\rho A v^3 \quad (1)$$

Were ρ [kg/m^3] is the density of wind, A [m^2] the sweeping area and v [m/s] the wind speed. The power output increases with a larger sweeping area and foremost high wind speeds. Since the wind speeds are increasing with the height above the ground wind power benefits with larger constructions (Västra Götalandsregionen, 2012). Due to limiting building permits such a construction is often difficult to erect for a private householder (Vindlov, 2011). This is why investments in a wind farm, and not small-scale wind turbines, is investigated in the study.

This study strictly focuses on electricity generation; heat generation is not included.

The investigation is strictly conducted for households connected to the electricity grid. Stand-alone systems or battery storage solutions are not included.

The study will be limited to Swedish circumstances; that is: present electricity system, regional laws, regulations, taxes and subsidies. Geographically, there is a focus on the Swedish bidding area 3.

The simulated electrical loads are representative for households with an electricity consumption corresponding to electricity usages for appliances and direct electrical heating. Additional simulations for a smaller load, representing a district heating connected house with only electricity usage for appliances, are presented in Appendix A.

1.3 Method

An essential part of this report is to explain and raise awareness of the economic importance behind the selection of electricity supply. Crucial concepts such as the composition of the electricity price, support schemes, green electricity contract, solar PV technology and investments in wind farm shares are also explained. The report is therefore initially supported by literature reviews.

To define the different energy system scenarios the data is collected and estimated by assistance from Swedish utility companies, Swedish Government institutions, interest groups and the division of *Energy Technology* at *Chalmers University of Technology*.

The financial decisions are supported by energy system simulations. The simulations are conducted in order to compare and evaluate the economics of the electricity supply alternatives. The green electricity contract and the PV systems are modelled in *HOMER*[1] (Hybrid Optimization of Multiple Energy Resources). A software specifically designed for simulations of hybrid energy systems and renewables. The total system cost for all scenarios are compared and evaluated through optimizations and sensitivity analyses.

The wind simulations and the overall comparison between the renewable electricity supplies and the conventional electricity contract are conducted in *Excel*.

---

[1] *HOMER* optimizes the systems' economically and technically feasibilities, performs sensitivity analyses which treats differences in electricity prices, technology costs and resource availability. *HOMER* will for each scenario determine the optimal production mix in order to minimize the total system cost. (Lambert & Gilman & Lilienthal, 2006a)

The simulations rank the systems by net present cost and accordingly form the decision support.

1.4 Disposition of the Report

This report is divided into nine chapters. The first chapter is an introductory to the master's thesis and describes the study's content and execution. To give basic facts and understanding for the study and its results, the second chapter briefly explains the current Swedish electricity system. Chapter two also gives a description of the components of the electricity price and current Swedish support schemes, which are important facts to keep in mind when planning for own production of electricity. In the third chapter, all the three investigated alternatives of electricity supply are described. All these alternatives are simulated either in *HOMER* or *Excel*. Since *HOMER* is relatively unknown in Sweden, chapter four gives a description of the software and how it simulates and optimizes energy systems. The fifth chapter explains the specific modelling work conducted in the study. It also defines the modelled scenarios and presents the modelling parameters. Chapter six and seven presents, respectively, discusses the modelling results and give a wider perspective of the study. The final conclusion and investment guideline is given in the eighth chapter. The last, ninth chapter, provides further recommendations on other aspects interesting to include in the study.

2 Swedish Electricity Conditions

In order to provide the reader with basic understanding of the conditions for the investigation, crucial topics and concepts are presented.

First, to give an overview of the Swedish power production and the limitations of power transfer, the Swedish electricity transmission system is briefly explained in section 2.1. Then, in section 2.2 the elements which determine the Swedish electricity price are described. Section 2.3 focuses on the monetary compensation available when a micro producer delivers electricity to the grid. This gives the reader a deeper understanding of what economic benefits a micro production might have. Finally, in section 2.4, current subsidies for renewable power production is specified.

2.1 Electricity Transmission

The Swedish electricity mix primarily consists of electricity produced from hydro and nuclear power. This can be seen in Figure 1, which displays the electricity mix distributed to the Swedish households. (Svensk Energi, 2013)

There is an imbalance in the Swedish electricity system. A large portion of the electricity is produced by hydro power in northern Sweden, whereas the consumption is concentrated to the urban regions in the southern parts. This forms a demand of transporting electricity, from the north to the south, where the transmission capacity of the lines defines the amount of energy that can be transferred. When the demand for energy transfer exceeds the capacity, the lines get congested and bottlenecks are formed. The bottlenecks often re-occur at the same locations, and these spots have been used to define Sweden’s four bidding areas, Figure 2. Within each of these areas the electricity price remains constant. Over a year area *SE1* and *SE2* produces a net excess of electricity whereas area *SE3* and *SE4* have a net deficit. (Svenska Kraftnät, 2013)

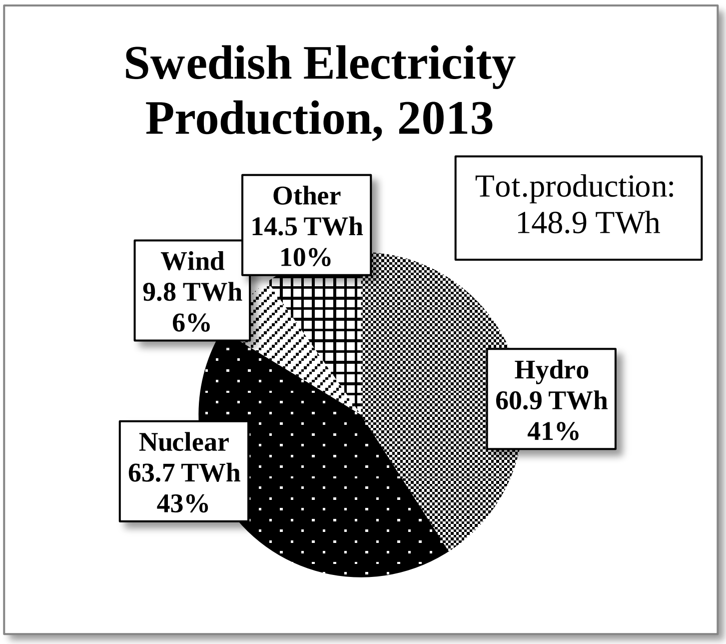

Figure 1: Swedish electricity production mix, year 2013 (Svensk Energi, 2013).

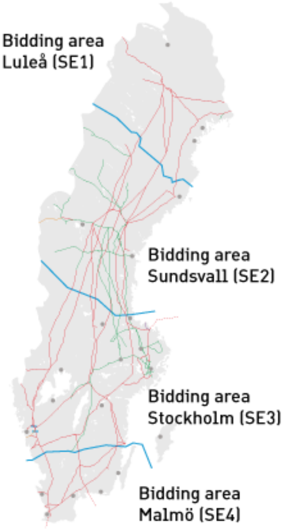

Figure 2: Illustration of the Swedish national grid and the four bidding areas (Svenska Kraftnät, 2013).

2.2 Electricity Price

The electricity price paid by the end consumer mainly consists of three parts; the electricity trading price, the transmission cost and fees & taxations (Svensk Energi, 2012a). All parts are explained in the sections below.

The electricity price is dependent on factors which vary over time. Typical factors are outdoor temperature, fuel prices and availability in water reservoirs. (SOU 2004:129) The price is equally, or even more, sensitive to policy decisions concerning energy fees and taxations which corresponds to an entire 50% of the total electricity price. All electricity price elements with their percentage contribution are displayed in Figure 3.

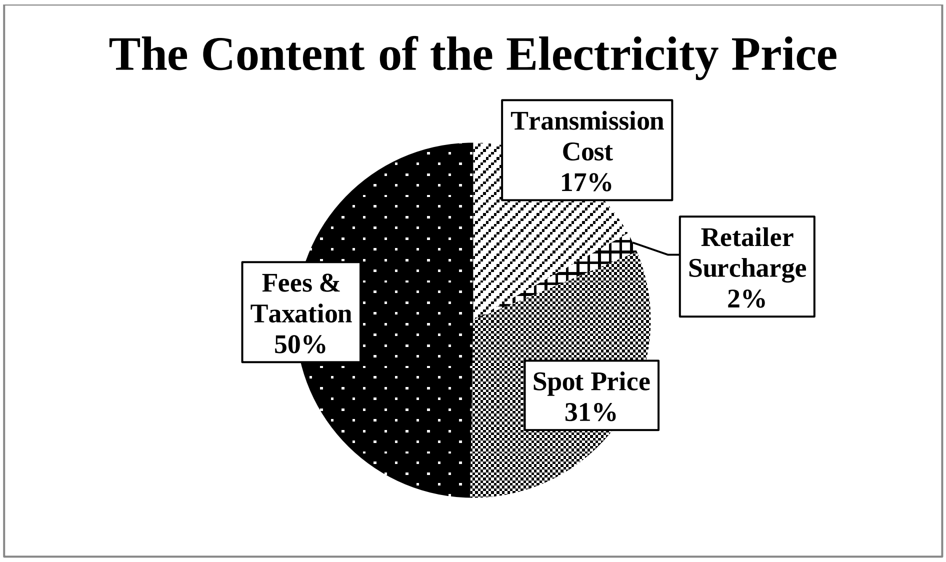

Figure 3: An overview of the elements of the total electricity price for consumers.

2.2.1 The Electricity Trading Price

The electricity trading price constitutes of the spot price and a retail company surcharge. The spot price is collected from the power market *Nord pool spot* and is settled within each of the bidding areas. With no congestion on the transmission lines, the price will be equal in Sweden's all bidding areas. In times of congestion, the spot price will differ. (Svenska Kraftnät, 2013)

The retail companies add a surcharge for handling the trades. This charge can be both variable and fixed. (Elskling, n.d) Since 1996 the Swedish electricity market is deregulated and customers can compare companies and make an active choice of electricity retailer. (Svensk Energi, 2012b)

2.2.2 Transmission Cost

The transmission cost is paid to the local electricity grid owner, which are responsible for the electricity transfer to the loads. The cost is divided in a variable and a fixed cost. The variable transmission cost, öre/kWh, is determined by the energy usage. The fixed transmission cost, SEK/year, consists of a subscription fee that also includes statutory charges; electrical safety fee, network monitoring fee and electrical preparedness fee. (Energimyndigheten, 2014a)

The distribution of electricity is monopolized. The transmission company is determined by geographical location and the cost of transmission can therefore not be affected by customer choice. (Swedish Energy Markets Inspectorate, n.d.)

2.2.3 Fees & Taxation

The fees and taxations in the electricity price consist of the energy taxation, the electricity certificate and the value-added tax, VAT. The VAT on electricity is 25% and is added to all costs, including the energy taxation. (Ekonomifakta, 2014)

The energy taxation is a mandatory charge paid by all electricity consumers. The size of the tax is determined by the parliament. A majority of Sweden's electricity consumers pay 29.3öre/kWh, although the residents in some of the northern municipalities pay 19.4öre/kWh due to tax reliefs. (Ekonomifakta, 2014)

The cost for the electricity certificate is paid by customers in order to form a subsidy that is handed out to the renewable energy producers. This policy is implemented in order to increase the share of renewable energy in the production mix. For a more detailed description see section 2.4.1, *The Electricity Certificate System*.

2.3 Price Received for Sold Electricity

When installing a micro production unit, the primary purpose is to cover as much as possible of the connected load. In times when the production from the unit exceeds the size of the load, excess electricity is distributed to the grid. For this electricity the micro producer receives monetary compensations, both from the electricity retailer and the electricity transmission company. To be defined as a micro producer the installed unit should be connected to the low voltage grid at 0.4kV, have a maximum inserted power average per hour of 43.5kW and a main fuse of a maximum 63A (Göteborgs Energi, n.d.).

2.3.1 Compensation from the Electricity Retailer Company

Electricity retailers offer a sellback for each kilowatt hour of electricity that the micro producer delivers to the grid. The size of this sellback varies with electricity retailer. The sellback conditions for the three large electricity retail companies, *E.ON*, *Fortum* and *Vattenfall* (Svenska Kraftnät, n.d.), and a number of small retailers are presented in Appendix B. To be eligible for the sellback the micro producer is obliged to be a yearly net consumer of electricity, this in accordance to Swedish legislation. ((Ellag, SFS 1997:857, ch4, 10§))

2.3.2 Compensation from the Electricity Transmission Company

The electricity transmission companies offer micro producers a compensation for delivered electricity. This compensation corresponds to the companies' reduced cost for electricity transfer due to a local electricity production. The reduced cost originates from reduced losses and reduced costs to superior networks. The compensation is therefore often higher in the southern parts of Sweden, where long transmission distances, hence high losses, otherwise are needed to cover the loads (which was explained in section 2.1 *Electricity Transmission*). The size of the compensation varies both with geographical location and company. As stated in section 2.2.2 *Transmission Cost,* the transmission company cannot be elected therefore neither the financial compensation. (Ellag, SFS 1997:857, ch3, 15§)

2.4 Support Schemes for Renewable Electricity Production

The Swedish parliament issues a variety of support schemes in order to increase the production of renewable energy. The main scheme is the electricity certificate system which aims to benefit production of renewable energy (Regeringskansliet, 2014). This scheme is foremost suitable for large scale producers. More suitable for micro producers is the investment support for solar PVs and the planned tax reduction (Regeringen, 2014).

2.4.1 The Electricity Certificate System

The Swedish Energy Agency, *Energimyndigheten*, states that the electricity certificate system "is a market-based support system for renewable electricity production". This system is an attempt to make renewable electricity production more profitable and thereby increase the share of renewable energy in Sweden. The system came in operation in May 2003 and has the goal of increasing the renewable electricity production with 25TWh by year 2020 (compared to year 2002). (Energimyndigheten, 2014b) In Sweden the certificate system is managed by *Energimyndigheten* and the Swedish national grid, *Svenska kraftnät*. (Energimyndigheten, 2012)

A power producer will receive one certificate from the government for each megawatt hour of renewable power produced[2]. The certificate can be sold on an open market where the buyers consist of players with quota obligations. The players are mainly electricity suppliers and electricity intensive industries or consumers that are required to purchase a certain number of certificates in relation to their electricity sale or usage.

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[2] Valid for wind-, solar-, wave-, hydro- and geothermal power, biofuels and peat (combined heat and power plants) (Energimyndigheten, 2013).

The price of an electricity certificate is determined by the seller and the buyer. (Energimyndigheten, 2013) The electricity supplier will then charge the cost through its customers' electricity bill. The cost was on average 2.7öre per kilowatt hour excluding VAT in year 2013. (Energimyndigheten, 2014b)

There are no costs associated with an application for electricity certificates, however the installation of measurement supplies and data management are related to additional costs. (Energimyndigheten, 2014c) For a small-scale producer these costs may exceed the profit of the certificates.

2.4.2 Solar Cell Investment Support

The solar cell investment support is an additional governmental support scheme formed in order to create a transition towards a more sustainable energy mix. The support covers a maximum of 35% of a solar PV system cost, including both material and installation, or a maximum of 1.2 million SEK per system. The PV installation investment support is available for all actors in the society, from households to large companies and organizations. (Energimyndigheten, 2014d)

Länsstyrelsen is the agency responsible for the investment support applications. The assigned sum for the support is limited; initially the support amounted to 210 million SEK for the period 2013-2016, in late 2013 another 45 million was added. (Länsstyrelsen, n.d.) The applications are addressed in the order they arrive at *Länsstyrelsen* and the money is distributed in the corresponding order. Due to a large amount of applications there is a considerable risk that all the money will be distributed before 2016 unless additional capital is added. (Gustafsson, A., 2014) It should be noted that the investment support cannot be combined with the Swedish ROT-deduction, a deduction for renovation, reconstruction and extension in a household. (Länsstyrelsen, n.d.)

2.4.3 Tax Reduction for Micro Production of Electricity

The primary purpose when producing electricity with a micro producing unit is to cover the household's load at the same point of grid connection. At times when the production exceeds the load, the excess electricity is delivered to the grid. With the new tax reduction, planned to be implemented the 1st of July 2014, the government will offer micro producers 60öre per kilowatt hour delivered to the grid. The 60öre-reduction corresponds to a double energy taxation. There are some boundaries to the proposed reduction; the micro producer cannot eject more electricity than it withdraws from the grid and the tax reduction is provided for a maximum of 30000kWh per producer and year. (Regeringen, 2014)

3 Investigated Renewable Electricity Supplies

The conventional electricity contract offers electricity originating from Sweden's electricity mix, displayed in Figure 1 in section 2.1. But there are options available. This chapter addresses the three investigated alternatives; green electricity contracts, installation in solar PVs and investment in wind farm shares, all possible investments for a majority of the Swedish householders.

3.1 Green Electricity Contracts

Green electricity contracts are offered by electricity retail companies, often as an alternative to the conventional, guaranteeing a "green" origin of the electricity. Still, the customer receives the Swedish electricity mix from the grid. The difference between the contracts is reflected in how the electricity is purchased. With a green electricity contract the electricity retailer undertakes a responsibility to buy electricity originating from green technologies in an amount corresponding to the consumption of the contract owner. The green electricity originates from renewable and sustainable energy sources: wind, solar, hydro and biomass (Energirådgivningen, 2012). This active choice often results in an additional cost per kilowatt hour or a monthly fee, giving an increased cost in the customer's electricity invoice.

E.ON is one of the major electricity retail companies on the Swedish electricity market. They claim that by buying one of their green electricity contracts the customer contributes to their work of improving the hydro power or the expansion and development of wind power (E.ON, 2013). But, the benefits of green electricity contracts are debated. Critical voices questions the fact that green electricity contracts lead to expansions of renewable electricity production, since Sweden already has large shares of renewables. (Broberg & Brännlund, 2010)

Since July 2013, there is a legal requirement in Sweden that the electricity on all customer invoices need to be origin labelled. *(Swedish Energy Market Inspectorate, 2014)* These documents, called *guarantees of origin*, are issued from the Swedish government for each megawatt hour of electricity produced and assure the used energy sources. (Energimyndigheten, 2014e) The labelling makes it easier for customers to compare different electricity traders when it comes to usage of green electricity and environmental impacts.

3.2 Installation in Solar PV

Currently there is a strong growth of solar PV investments in Sweden; in year 2013 19MW PV capacity was installed. As a reference, Sweden had 16.8MW grid connected PV capacity installed in the beginning of year 2013. The strong growth can mainly be derived from declining system costs and an increased public interest in PVs. (Svensk Solenergi, 2014) According to a SIFO survey, 80% of the Swedish householders is positive to install PVs on their houses (P1 Klotet, 2014).

An investment in solar PVs involves a physical product that is placed on the customer's property. Therefore, in order to connect the production to the electricity grid, the customer is responsible to report the installation to the network concessionaire. If required, the customer also needs to apply for building permits. The grounds for permits differ between municipalities, so it is important to take note of these regulations before installing a unit.

PV Technology

The production of electricity from a solar panel occurs when the solar PV is exposed to solar radiation. The procedure of transferring produced electricity from a solar PV to a household is illustrated in Figure 4. Initially direct current is produced in the solar PV. In order to utilize the generated electricity in the household the direct current is converted to alternating current in an inverter. The security of the system is established by two switches, one on the AC and one on the DC side, which can separate the components of the system. As the produced electricity is transferred through the electric cabinet and distributed to different parts of the house, an electrical meter measures the production from the installed solar PVs. If the production exceeds the household demand the electricity is delivered to the grid. Similarly, when the load exceeds the PV production rate, electricity is bought from the grid. (SolEl-programmet, 2010) In section 2.3, *Price received for sold electricity*, the monetary compensation for the electricity delivered to the grid is described.

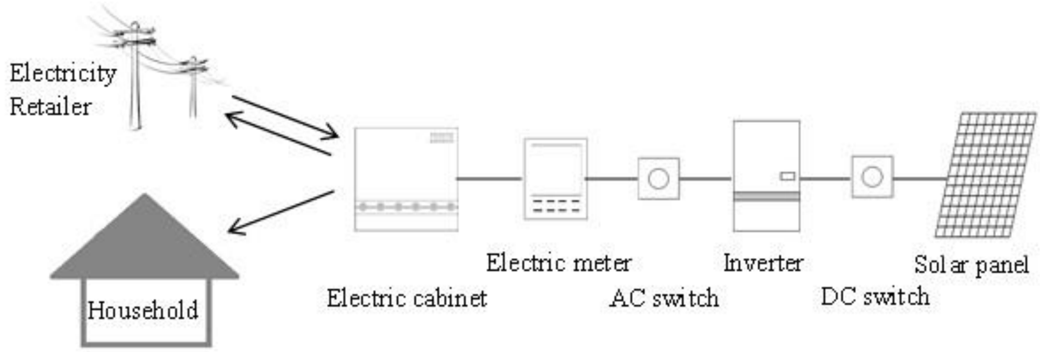

Figure 4: A schematic illustration of the electricity transfer from solar panel to household and grid.

To maximize the power output from installed panels, the placement in correlation with the sun is of great importance. For Swedish conditions a panel installation should be faced south with an angle of 30-40° to the horizontal plane in order to give an optimal output. (Arctus Nordic, 2012) The effect of the angle is presented in Figure 5. Further it is important to avoid shading of the installed panels. Shading of a small area affects the efficiency of the entire installation. The rooftop of a household often forms the most suitable placement for solar PVs. Shading from the chimneys are often a fact but small areas can be reconnected by by-pass diodes in order to minimize losses and keep the power effect. (SolEl-programmet, n.d.)

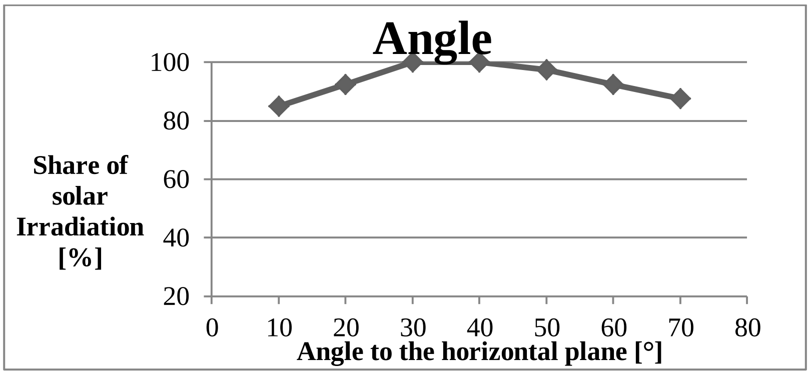

Figure 5: The share of the global solar irradiation reaching the solar panel surface for different angles to the horizontal plane for panels facing south in Sweden. The optimum is reached between 30-40°. (Arctus Nordic, 2012)

Prerequisites of Solar PV Installation

As stated in section 2.3 a micro producer's unit should be connected to the low voltage grid at 0.4kV, have a maximum inserted power average per hour of 43.5kW and a main fuse of a maximum 63A. For production plants up to this size, the electricity transmission grid owner conducts the installation of a new electricity meter. This new electricity meter manages the collection of dual series, consumption and production. To be classified as micro producer it is also mandatory to have a yearly net consumption; the household need to purchase more electricity from the grid than it delivers. (Göteborgs Energi, n.d.) Legislations stated in the *Ellag* highlight the importance of not becoming a net producer over a year. In the case of net production the consumer is obliged to pay for a feeding subscription and/or an exchange of electricity meter. (Ellag, SFS 1997:857, ch4, 10§) In order to secure a net consumption of grid electricity, it is often recommended to cover a maximum of 80% of a household's yearly electricity consumption with electricity produced from renewables. (VästanVind, n.d. a)

Characteristics

Figure 6 displays the characteristics related to a household with an installation of solar PVs for a Swedish summer day. The PV Power output is directly correlated to the global solar radiation; it is maximized during the middle of the day and non-existent during night time. At times when the PV Power output exceeds the load, between 10am and 6pm in this example, the micro producer receives a monetary compensation. Before 10am and after 6pm the load exceeds the power production and additional electricity needs to be purchased from the grid. It can also be seen that the price curve peaks at daytime, when the production from the solar PV peaks. Both the monetary compensation and the reduced demand of grid purchases is a positive aspect with PV installations.

A winter day displays similar characteristics, but the entries are scaled differently. The production from the solar PV is reduced and for a household with electric heating the load increases. The characteristics for a household during wintertime are attached in Appendix C.

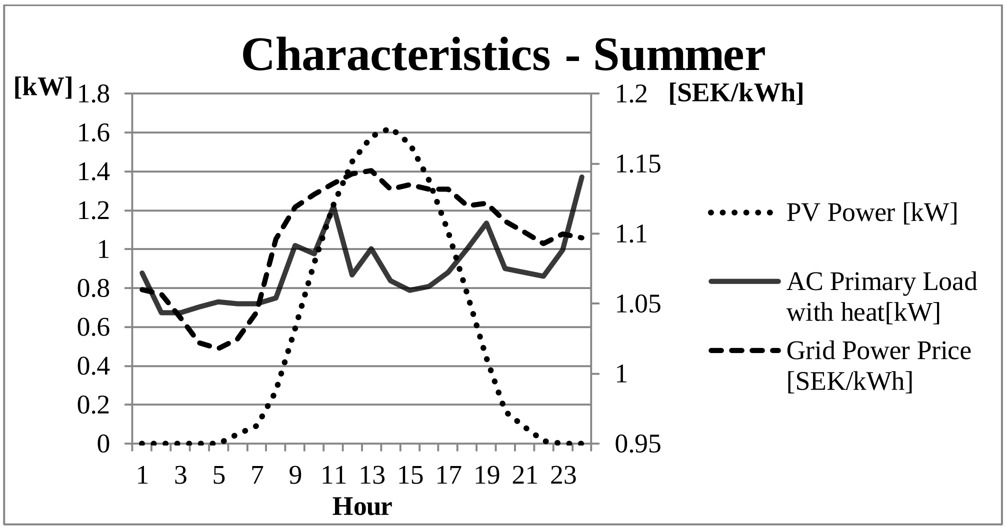

Figure 6: Displays the characteristics of solar PV production, load and electricity price a summer day in July in Sweden. The installed PV capacity is 2kW, and the PV power output curve is formed by simulations with solar data corresponding to a typical meteorological year. The load corresponds to a family household, including both electrical heating and usage of household appliances. The electricity price is compiled according to section 2.2 Electricity Price.

3.3 Investments in Wind Farm Shares

A wind farm consists of one or several large wind turbines which are collectively owned. By purchasing production shares the customer becomes a co-owner of the farm. The shares are paid initially as an investment cost. For each share the buyer can purchase electricity at a fixed cost per kilowatt hour. This cost, corresponds to the cost of the electricity production and electricity certificates. The money invested in the farm is used for maintenance and to invest in new wind turbines. (VästanVind, n.d. b)

A buyer can choose how many shares to purchase, but it should not exceed the household annual consumption. Due to load variations it is recommended not to cover the annual household load with more than 80% of wind shares. The yearly distribution of the wind shares is predefined according to a consumption pattern. Every month a customer receives electricity both from the shares and from the electricity grid. (VästanVind, n.d. a)

Share-owners always have the right and possibility to sell their shares. There are no specific regulations associated to these sales so the conditions are formed by the seller. The shares can be sold on the open market or sold back to the wind farm cooperative. *VästanVind*, a wind farm cooperative, offers to buy their shares back at the investment price, in case the sale occurs within five years from the time of purchase. (VästanVind, n.d. a)

An investment of shares in a wind farm is relatively easily conducted; it does not include any physical products. Therefore no specific surroundings, applications of contracts or any responsibility for maintenance is required. However, often when investing in a wind farm there is a requirement of switching electricity retailer.

4 The HOMER Software

The *HOMER* software is the primary simulation tool in the study. Since the software is relatively unknown in Sweden, a description of the software and the simulations of energy systems are described below. Note that this chapter is specifically about the *HOMER* software.

HOMER is an optimization tool developed by the U.S. National Renewable Energy Laboratory (NREL). With *HOMER* simulations, optimizations and sensitivity analysis of a micro power system can be performed. It is a tool where the user can model, investigate and develop electricity and/or heat generating micro systems each hour of the year. The modelling is based on the system's technical and economical specifications; hence the subsystems' physical behaviour and life-cycle cost including both installation and operation costs. (Lambert & Gilman & Lilienthal, 2006a)

The first step in *HOMER* is to perform a simulation of a particular energy system. Through this simulation the system's technical feasibility and costs are determined. In the optimization part, *HOMER* searches for the most optimal solution in terms of lowest life-cycle cost, still meeting the systems technical requirements. Then, a sensitivity analysis can be applied in order to investigate uncertainties and fluctuations in the inputs to the model. The result will describe how a specific configuration of components in the system design will operate over a long period of time. (Lambert & Gilman & Lilienthal, 2006a)

HOMER offers several options of design. The micro power systems can be both grid connected or isolated and various technologies of renewable power production can be evaluated and compared; photovoltaic (PV) modules, wind turbines, micro hydro power and biomass power. The software can serve micro systems demanding both dc and ac electric loads and also thermal loads. (Lambert & Gilman & Lilienthal, 2006a)

4.1 Simulation

The resolution in the *HOMER* simulation is hourly based. This provides a sufficient accuracy in the modelling of intermittent power sources; when the timing of power and load is important. Each hour the available renewable power is calculated and compared with the electric load. Hours of power excess, *HOMER* decides how to handle the surplus in order to minimize costs. Hours of power deficit, *HOMER* decides how to generate or purchase the additional power demand. When all the values for a year have been calculated, the conformance with the user requirements is evaluated. The key simulation, of how the system operates over the first year, is representative for all other years over the project lifetime. The simulation can therefore not consider changes over time. (Lambert & Gilman & Lilienthal, 2006a)

During the simulation *HOMER* calculates all costs related to the system's life-cycle cost; annual fuel consumption, annual generator operating hours, annual power purchase from the grid, initial component cost, replacement of components, etcetera. The sum of all these values is, by using equation (2) and (3), presented as the total Net Present Cost (NPC). Any electricity sold to the grid becomes an income, thus a reduction in the net present cost. (Lambert & Gilman & Lilienthal, 2006a)

$$C_{NPC} = \frac{C_{annual,tot}}{CRF(i, R_{proj})} \qquad (2)$$

$$CRF(i,N) = \frac{i(1+i)^N}{(1+i)^N - 1} \qquad (3)$$

Where $C_{annual,tot}$ is the system annual cost in SEK, CRF the capital recovery factor, i the real interest rate, R_{proj} project lifetime in years and N number of years. (Lambert & Gilman & Lilienthal, 2006b)

4.2 The Physical Modelling

In the modelling of a micro power system *HOMER* requires at least one source of electricity (or heat) and one electrical (or thermal) load, alternatively the possibility to sell electricity to the grid. The simulation of the system is optimized with a collection of components that together serves the system's loads. All loads are given in kilowatts for each hour of a year. This time resolution implies daily and seasonal variations. The information is either imported from a file or synthesized from a daily load profile. (Lambert & Gilman & Lilienthal, 2006c)

When having PVs in the system, a solar resource of global solar radiation in kilowatts per square meter needs to be specified. This resource provides hourly averaged values for that specific location during a typical year. A PV module's electricity production is in *HOMER* modelled in proportion to the global solar radiation. The power output is calculated with equation 4. (Lambert & Gilman & Lilienthal, 2006c)

$$P_{PV} = f_{PV} Y_{PV} \frac{I_T}{I_S} \qquad (4)$$

Where, f_{PV} is the derating factor of the PV, Y_{PV} the rated capacity in kilowatts (kW) for the PV module, I_T the global solar radiation (kW/m^2) and I_S the radiation of 1 kW/m^2 (which is the standard amount used to rate PV capacities). The derating factor is a scaling factor accounting for effects causing a different output than the rated. The effects can for instance be: dirt, wire losses, shading, snow cover, increased temperature and aging of the installation. The value of the rated capacity does already account for both the PV area and the efficiency of the PV module. (Lambert & Gilman & Lilienthal, 2006c)

Each hour *HOMER* uses a model called HDKR. This model calculates the global solar radiation incident on the PV module and accounts for current solar resource, the PV orientation, location of Earth's surface and the time of the year and day. (Lambert & Gilman & Lilienthal, 2006c)

The PV's initial capital cost (SEK), replacement cost (SEK) and operating and maintenance costs (SEK/year) are all specified by the user. (Lambert & Gilman & Lilienthal, 2006c)

A grid-connected system can receive electricity or sell a surplus of ac electricity to the grid. All electricity purchased from the grid has the grid power price in SEK/kWh and all electricity sold to the grid has the price called sellback price in SEK/kWh. (Lambert & Gilman & Lilienthal, 2006c)

4.3 System Dispatch

Fundamentally, *HOMER* dispatches all systems by the principle of minimizing cost. The cost of each dispatchable power is represented by both its marginal and its fixed cost. Considering these costs for all power sources in the system, *HOMER* searches for the combination of sources able to serve the loads at the lowest cost. Hour-by-hour decisions specify when and at what power level a specific technology shall run. The simulation also schedules when the system need to purchase electricity from or sell to the grid. *HOMER* assumes that all power generated at one bus first will serve the load at the same bus, secondly on opposite bus and then go to grid sales. (Lambert & Gilman & Lilienthal, 2006c)

The dispatch strategy is the most complex part of the *HOMER* simulation. Non dispatchable renewable power sources do not need any logic control in the simulation process; they simply produce in relation to available renewable recourses. Dispatchable power though, is more difficult to simulate. Each hour the dispatchable power needs to be controlled to match the supply and demand and to compensate for any renewable power intermittency in the system. To be able to compare different systems, *HOMER* uses the economic dispatch logic regardless of the system configuration. (Lambert & Gilman & Lilienthal, 2006c)

4.4 Economic Modelling

The objective is to minimize the system's total net present cost. The life cycle-cost is an appropriate metric when comparing renewables with non-renewable sources. The calculation then includes both investments and operational costs, which is of great importance due to the differences in cost characteristics for the sources. All costs and revenues during the project lifetime are discounted back to the present cost. When discounting to net present cost, the software assumes that all prices escalate at the same rate. The conclusion is then that inflation can be factored out by using the real interest rate instead of the nominal. (Lambert & Gilman & Lilienthal, 2006b)

When the project lifetime is reached *HOMER* calculates the salvage value, S, for each component by equation 5.

$$S = C_{rep} \frac{R_{rem}}{R_{comp}} \qquad (5)$$

Where C_{rep} represents the component replacement cost, R_{rem} the remaining component life of the component lifetime R_{comp}. (Lambert & Gilman & Lilienthal, 2006b)

For each component all costs, revenues and salvage values are combined in order to receive its annualized cost which hypothetical occurs all years during the project lifetime. The annualized costs for all components are summarized to receive the total annualized system cost. This value is then converted to net present cost. This system cost is the important value that is compared to other alternative system cost and will decide the economic order between them. *HOMER* will simply rank the systems by net present costs. (Lambert & Gilman & Lilienthal, 2006b)

4.5 Optimization

After the simulation, whereas a specific system configuration is modelled, the optimal configuration is determined in the optimization process. *HOMER* defines the optimal system configuration as the one that meets the user's requirements at the lowest total net present cost. The optimal system is a matter of size of components, combination of different components and the system's dispatch strategy. *HOMER* aims to find the optimal solution for each decision variable defined by the user. (Lambert & Gilman & Lilienthal, 2006d)

In the simulation process, *HOMER* allows the user to enter several values for each of the decision variables, such as sizes, models and number of components, etcetera. All these different options are represented in a search space; a set of all possible system configurations (Figure 7a). All configurations are simulated, but only the feasible ones are presented in an overall optimization summary table sorted by increased total net present cost (Figure 7b). (Lambert & Gilman & Lilienthal, 2006d)

a)

	PV Array (kW)	Grid (kW)
1	0.000	1,000.000
2	1.000	
3	2.000	
4	3.000	
5	4.000	

b)

	PV (kW)	Grid (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.
		1000	$ 0	6,221	$ 79,530	1.107	0.00
	1	1000	$ 20,962	5,158	$ 86,902	1.209	0.16
	2	1000	$ 41,924	4,027	$ 93,397	1.300	0.29
	3	1000	$ 62,886	2,867	$ 99,532	1.385	0.39
	4	1000	$ 83,848	1,696	$ 105,526	1.469	0.47

Figure 7: Tables from the HOMER *workspace.*
a) Search space table, showing the set of all possible system configurations defined by the user. This setup comprises five system configurations (5 x 1 = 5).
b) Overall optimization table, summarising all feasible system configurations specified in the search space. The first row is the optimal system configuration with the lowest total net present cost. (Homer Energy, 2009)

4.6 Sensitivity Analysis

The sensitivity analysis is performed after the optimization process and reveals the system's sensitivity to changes in the input data set. It investigates the robustness of the system configuration; how the behaviour, feasibility and economics of the system changes with variations in uncertain input variables. Almost all numerical inputs, except the decision variables, can be sensitivity variables. Even hourly data sets such as load and resources are possible to investigate. (Lambert & Gilman & Lilienthal, 2006e)

A sensitivity analysis can also incorporate several new optimizations of the system configuration, each with a different setup of input assumptions. (Lambert & Gilman & Lilienthal, 2006e)

5 Modelling Description & Definition

The underlying fact described in the previous chapters of *Swedish Electricity Conditions*, *Investigated Renewable Electricity Supplies* and *The HOMER Software* is the basics behind the study, i.e. which scenario definitions and assumptions are based on. The resulting financial decision support is reached by an economical simulation approach. A more detailed explanation of the simulation process, system scenarios and their underlying assumptions, limitations and modelling parameters, is presented in the following sections.

5.1 Scenario Definition

The study is conducted for a family household with a yearly load of 20743kWh, which covers electricity both for household appliances and heating. The household is modelled for three scenarios:

- Green electricity contracts
- Installation of solar PVs
- Investment in wind farm shares

All scenarios are compared with each other and the conventional electricity contract. In the comparison all scenarios' sensitivity towards an increase in electricity price is investigated. The scenarios are presented in the schematic illustration in Figure 8 and in the text below.

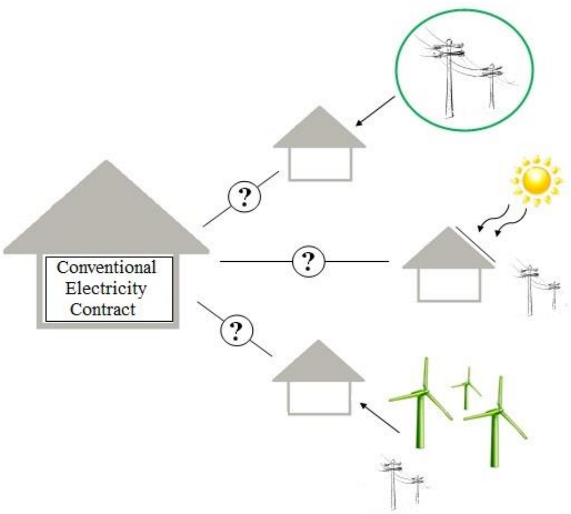

Figure 8: Illustration of the three modelled scenarios; green electricity contracts, investment in solar PV, wind farm shares. All scenarios are compared to the most common electricity supply, i.e. the conventional electricity contract.

Scenario - Green Electricity Contracts

As presented in section 3.1 *Green Electricity Contracts*, a majority of the electricity retail companies offer their customers the option of purchasing green electricity. These contracts are often charged with an additional fee per kilowatt hour. This scenario of electricity supply is defined by the average of *E.ON*, *Fortum* and *Vattenfall's* green electricity contracts.

Scenario - Installation in Solar PV

This scenario contains solar PV modules installed on the rooftop of the house. The produced electricity is primarily used to cover the household's load. Since the simulated house is grid connected and without possible energy storage, electricity is sold to the grid in times of net production and bought from the grid in times of power deficit, as stated in section 3.2 *Installation in Solar PV*.

Due to unfavourable regulations, net production from the micro producing unit should be avoided. Thereof it is recommended to cover a maximum of 80% of the household's annual electricity consumption with solar PVs. With the assumption of approximately 1000kWh produced electricity per installed kilowatt, 80% of the investigated household's load corresponds to an installation of 1-16kW. The remaining electricity is covered by electricity from the grid.

Sensitivity analyses are conducted for three parameters for the solar PV scenario:

- Sellback conditions
- Real interest rates
- Solar resources

In the study, four sellback conditions are investigated: two groups of electricity retailers, with or without a tax reduction. The conventional companies *E.ON*, *Fortum* and *Vattenfall* form one group whereas the second group is smaller companies with a sustainable branding, here represented by *Telge Energi*.

The interest rate is defined by the minimum return required for an investment. The size of this rate is set individually. It is dependent of the risk associated to the investment, the return on alternative investments and possible loan rates. (Skärvad & Olsson, 2011) This scenario's sensitivity towards the real interest rate is investigated for three options; 1.1%, 4% and 6%.

The solar resources vary over bidding area 3, which is the area of the interest for this study. The irradiance is higher along the coasts than the inland regions. The climate map in Appendix D displays that the main part of bidding area 3 is exposed to a global irradiance reaching between 900-1000kWh/m^2 per year. This range is representative for large parts of the country. In order to investigate the importance of geographical location the irradiances 900, 1000 and the base case of 960kWh/m^2 per year are modelled and compared.

Scenario - Wind Farm Shares

An alternative renewable investment is the purchase of wind farm shares. The conditions used in the modelling are collected from *VästanVind,* year 2014. The recommendation of 80% coverage of a household's annual electricity consumption is in this scenario, investment in wind farm shares, set as the maximum limit for the simulation. For the investigated household this corresponds to 166 shares á 100kWh. As a sensitivity analysis, the simulations are also conducted for investments in shares corresponding to 40 and 60% of the household's load.

5.2 Assumptions & Limitations

The study is conducted for Swedish households with the prerequisites and regulations of the Swedish electricity market. In occasion of regional differences, data applicable for bidding area 3 and the surroundings of Gothenburg is used.

For households and customers the following conditions are adapted throughout the simulations:

- The annual load is assumed to remain constant at 20743kWh during the project life time of 25 years.
- The household in the study is assumed to have good conditions for solar PV installations; i.e. a large rooftop area facing south with no shading.
- The base case scenarios are conducted with a real interest rate of 4%.
- It is assumed that all investments are conducted with capital already available by the purchaser. Cases including loans are not investigated.

For electricity grid and supply alternatives the following conditions are adapted throughout the simulations:

- The connected grid corresponds to an average of *E.ON*, *Fortum* and *Vattenfall's* variable electricity contracts, from year 2013/2014.
- A future electricity price is assumed with a 1.8 % increase of the spot price. The historical trend of the spot price is displayed in Appendix E.
- In scenarios of PV system installation and wind farm shares, where the entire load is not covered by the renewable electricity supply, the remaining demand is purchased from a conventional electricity contract.
- The residual value of the wind farm shares and solar PVs is assumed to be zero after the project's lifetime.

5.3 Modelling Parameters

The simulation conditions for the different scenarios are formed by inserting data for the grid, load, resources and economics. The household load remains equal in all main scenarios, whereas the electricity price, sellback conditions, real interest rate, resources and the number of shares differ. In this section the input data are specified and motivated.

A summary of all input data is displayed in the table in Appendix F.

Electricity Price

The customer electricity price, which is described in section 2.2, *Electricity Price*, constitutes of electricity trading costs, transmission cost and taxations & fees. In the scenarios, the simulated electricity price constitutes of the spot price collected from *Nord Pool Spot* year 2013 (Nord Pool Spot, n.d.), the average costs of transmission and the retail company fees from *E.ON*, *Fortum* and *Vattenfall* and present Swedish taxations year 2014. The annual distribution of the electricity price used in the simulations can be seen in Figure 9.

In the case of the green electricity contract an extra fee of average 2.2öre/kWh, including VAT, is added in order to receive green electricity.

The values of the electricity price elements and how they are derived is presented in Appendix G.

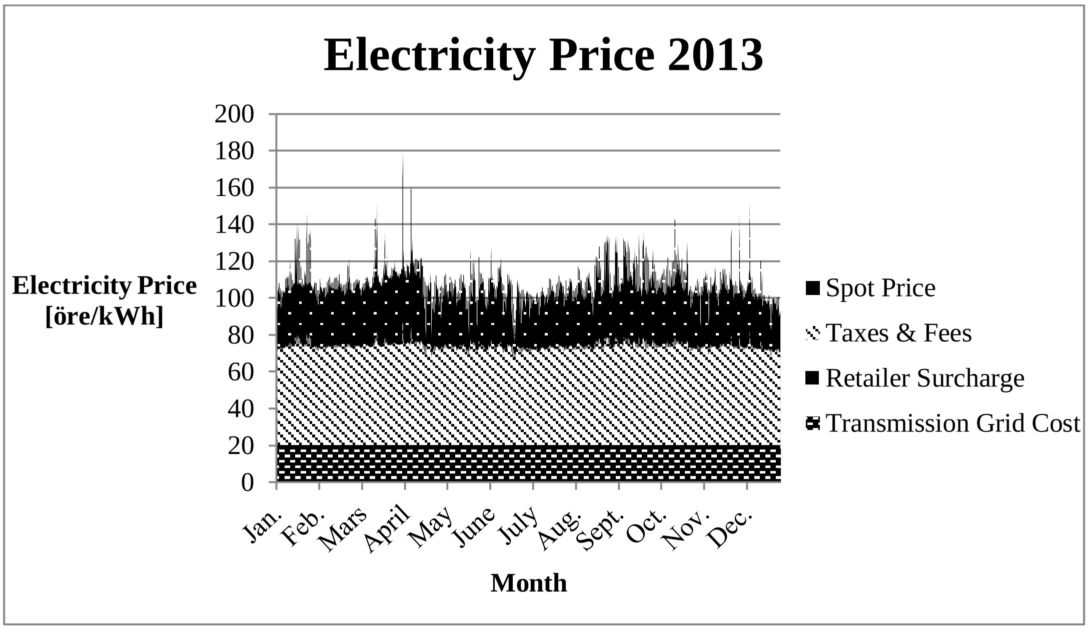

Figure 9: An overview of the hourly distributed annual electricity price for consumers 2013. The electricity price is divided in four price elements.

Sellback Conditions

The sellback price, received by customers (micro producers) for their excess electricity production, differs between electricity trading companies. In the spring of 2014 *E.ON*, *Fortum* and *Vattenfall* offer the spot price reduced with 4öre as their sellback condition. Small actors, with a sustainable branding, offer more than 1SEK per kilowatt hour. A comparison between a few small electricity retail companies showed that *Telge Energi* offers the most advantageous contract; a sellback price of 130öre per kilowatt hour. The whole comparison can be seen in Appendix B.

In the near future the new support scheme for electricity micro producers is planned to be implemented, as described in section 2.4.3, *Tax Reduction for Micro Production of Electricity*. In case of this implementation *E.ON*, *Fortum* and *Vattenfall* is said to keep their offers; the spot price reduced with 4öre. However, a majority of the smaller companies in the study will alter their offers. *Telge Energi* will offer the electricity price reduced by 60öre/kWh (which in combination with the tax reduction will end up as a version of net metering[3]). The compensations for sold electricity used in the modelling are displayed in Table 1.

In addition to the sellback price and the potential tax reduction, a customer receives a payment from the grid owners for each kilowatt hour distributed to the grid. In the model 7.2öre/kWh, including VAT, is used.

---

[3] Net metering: the customer receives the same price for the excess electricity as the cost of purchasing electricity from the grid.

Table 1: Differences in sellback price between electricity retail companies. For conditions with and without the tax reduction of 60öre/kWh.

	E.ON, Fortum, Vattenfall	Telge Energi
Without tax reduction [öre/kWh]	Spot price – 4	130
With tax reduction [öre/kWh]	Spot price – 4 + tax reduction	Net metering (incl. tax reduction)

Load

The simulated load represents the hourly electricity consumption for a family household during one year. The data is received from *Energimyndigheten* and is measured for a house situated in Mälardalen. Information of the household is presented in Appendix H. The household has an annual consumption of 20743kWh, which includes both direct electrical heating and household electricity for appliances. The hourly load distribution used in the simulations is displayed in Figure 10.

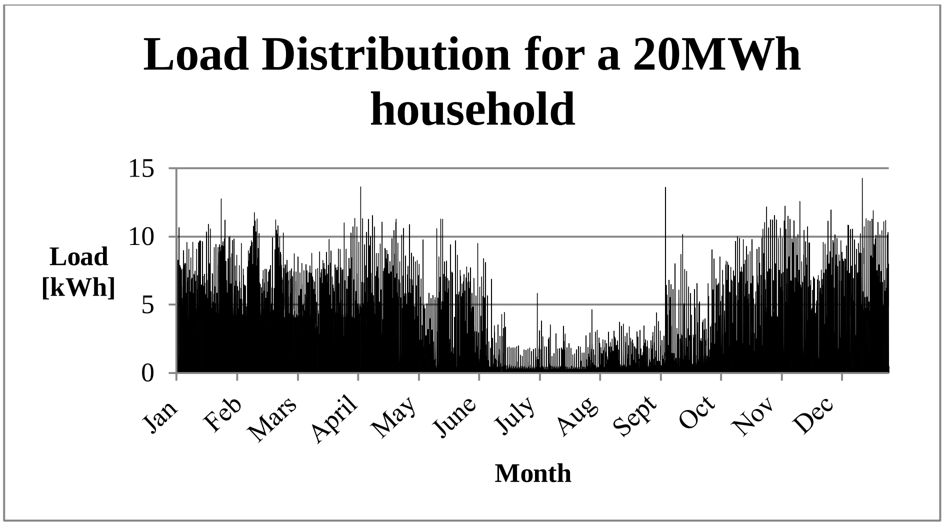

Figure 10: The hourly distribution of the annual load for the household of 20743kWh.

Solar radiation

Global horizontal irradiance, GHI, is a measure of the amount of shortwave radiation received by a horizontal surface, W/m^2. The short waves originate direct from the sun as well as from the diffuse radiation from the firmament. (SMHI, 2013) The solar data used in the model is collected from the database *Meteonorm* and represents a typical meteorological year (Remund, J., 2012). The hourly measurements simulating the chosen coordinates 57.875 11.875, just north of Gothenburg, is displayed in Figure 11.

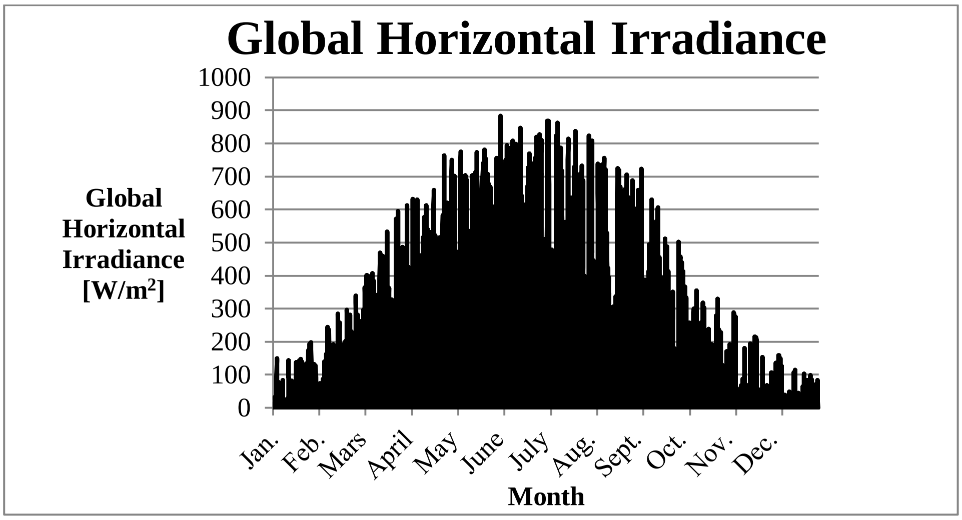

Figure 11: The hourly global horizontal irradiance for a location north of Gothenburg a normal year.

The Solar Panel

As stated in Figure 5 in section 3.2, optimal conditions for solar PV production are in Sweden received when the panels face south with a gradient of 30-40°. In the simulations 40° is used.

Further, a solar panel is affected by surrounding conditions. The difference between the rated and actual power output is accounted for in the derating factor, which in this study is set to be 0.9. (Homer Energy, 2010)

Today the majority of the manufacturers distribute their solar panels with a performance guarantee of around 80% after 25 years. This is what defines the technical lifetime. (Energimyndigheten, 2007) The project time used in the simulations is set by this solar technical lifetime, 25 years.

Economics

Solar PVs are often sold in package solutions including both the cost of panels and installation. The cost for solar PV packages has decreased over time. In 2013 the cost was 16000SEK/kW for the Swedish market (Appendix I), which is 20000SEK/kW with VAT included. (Energimyndigheten, 2014f)

A solar PV installation is almost maintenance free, the only component in need of replacement is the inverter. At a cost of 2000 SEK/kW the inverter is replaced after 15 years. By converting the cost to a present value, using equation 6, the replacement cost is added to the original investment and forms a total investment cost of 20962 SEK/kWh. This is the PV investment cost used in the simulation.

$$Net\ present\ value = Cost_{15yr} \times \frac{1}{(1+real\ interest\ rate)^n} \left[\frac{\text{SEK}}{\text{kWh}}\right] \quad (6)$$

The real interest rate is formed by individual settings and differs significantly between households. Dependent on the household's interests and financial assets, some household has extremely high real interest rates, whereas some has negative. The investigated household will be modelled for three different real interest rates, 1.1, 4 and 6%, Table 2. The base model is simulated for a real interest rate of 4%, an average interest rate used in several market studies. A real interest rate of 1.1 % represents a solar PV investment compared to a capital placement with savings rent. A real rate of 6% is suitable for individuals that compare a solar PV purchase with other investments.

Table 2: The real interest rates used in the sensitivity analyses in the models.

Case	Real interest rate [%]
"Capital placement"	1.1
Base case	4
"Other investments"	6

Wind

The conditions used in the modelling are collected from *VästanVind*. Each share of electricity measures 100kWh per year at a cost of 680SEK. The price for the electricity is set to 23öre/kWh excluding VAT. This gives a final cost of 90.61öre/kWh including the transmission grid cost, fees and the value added tax for the customer.

For the simulated scenarios the number of wind farm shares depends on how large part of the household's electricity load that should be covered. The remaining electricity is bought from a conventional contract. In case of 80% load coverage, 166 wind farm shares are needed resulting in an investment cost of 112880SEK. For the sensitivity analysis values of 60% and 40%, the number of shares is 124 and 83 with respectively costs of 84320 and 56440SEK.

5.4 Modelling Description

The financial decision support, which is the outcome of the study, is reached by an economical simulation and optimization model. Both *HOMER* and *Excel* are used to model the different energy system scenarios. The final comparison of all different energy systems is compiled in *Excel*.

Both in the *HOMER* and *Excel* modelling, each scenario needs its particular input data to be specified. The required data is similar in both programs but varies for the different alternatives of electricity supply. The input parameters were described in the *Modelling Parameters*, section 5.3.

Simulation Process

The *HOMER* software supports the models of the conventional electricity contract, the green electricity contract and all solar PV system scenarios. The PV electricity system scenarios, including PVs, primary load and the grid, is described in *HOMER*'s workspace and is schematised in Figure 12. The two different electricity contract alternatives are similarly described, but without the PV module.

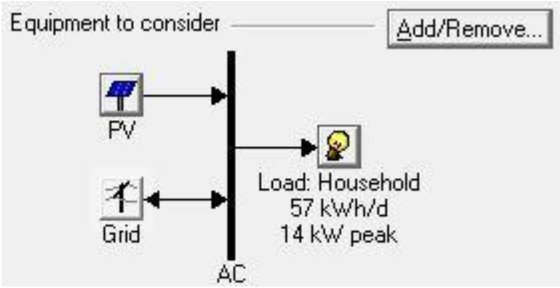

Figure 12: Schematic representation of the components, PVs, household load and electricity grid, simulated for all PV system scenarios –view from the HOMER *workspace.*

All the calculations are performed by *HOMER's* simulation and optimization process; the methodology described in chapter 4, *The HOMER Software*. Briefly explained, *HOMER* dispatches all systems by the principle of minimizing the system's net present cost. This is accomplished by calculating the technical feasibility and costs for all systems. In the modelling, the dispatchable power is hourly matched to the system's supply and demand of electricity. All costs related to the system's life-cycle are calculated and converted to net present cost, which is a suitable method as it includes the different system's cost characteristics of investments and operational costs. The objective is to find the combination of sources able to serve the household's load at the minimized total net present cost. As sensitivity, some variables of special interest are changed. This gives understanding of their sensitivity to fluctuations and their related impacts on the modelling result. The sensitivity parameters are presented in each scenario in the *Scenario Definition*, section 5.1.

The *Excel* software supports the modelling of the alternative of wind farm shares. These calculations also use the methodology of calculating the system's life cycle cost expressed in net present value. Although the methods are similar, the *Excel* calculations are more of step-by-step calculations. This is a necessity to be able to handle the specific cost characteristics related to wind farm shares and to simulate the annual distribution pattern of the usage of wind shares. Similarly to the *HOMER* modelling, a sensitivity analysis of parameters is performed.

As a final comparison of all different energy systems the cumulative system cost for all systems are determined in *Excel*. In these calculations a possible change of electricity price is included. Thus, all different electricity supplies have two results: one with and one without an annual cost increase of the spot price.

6 Results

Several scenarios of electricity supplies are simulated in the study. This chapter presents the results of the simulations. First, the most important overall results are presented. Then, particular results for each of the electricity supply alternatives, and their respective sensitivity analyses, are reported. Each renewable electricity supply is compared to a system with a conventional electricity contract.

As a complement, similar scenarios are simulated for an additional household of an annual load of approximately 5000kWh. These results are presented in Appendix A.

6.1 Most Important Result of the Simulations

The overall conclusion, when comparing all electricity supplies in Figure 13, is that the profitability of a system depends on the time perspective.

When considering the project time period of 25 years, the most profitable system is a grid connected 35%-subsidized PV system. This system will be paid off within 15 years.

The non-subsidized PV system requires an additional increase in electricity price or a reduction in investment cost in order to be profitable. In the time perspective of 25 years, a minor increase in electricity price will make the non-subsidized PV system profitable. This is seen in Figure 13. An electricity price increase results in that the non-subsidized PV system would end up with a lower cumulative cost than the conventional electricity contract; hence profitable for this time horizon.

The most expensive solution for this 25-year period is investments in wind farm shares. With a shorter time perspective of less than 7 years, wind farm shares will instead be more profitable than the subsidized PV system.

In case of no available PV investment subsidies, the least expensive renewable electricity supply is the green electricity contract. The PV system is the next best option.

Evidently, there are several factors influencing the profitability of a system: presence of subsidies, time perspective, choice of electricity retailer, real interest rates, fluctuation in electricity price and resource availability. The impact of these factors is further described in the sections below.

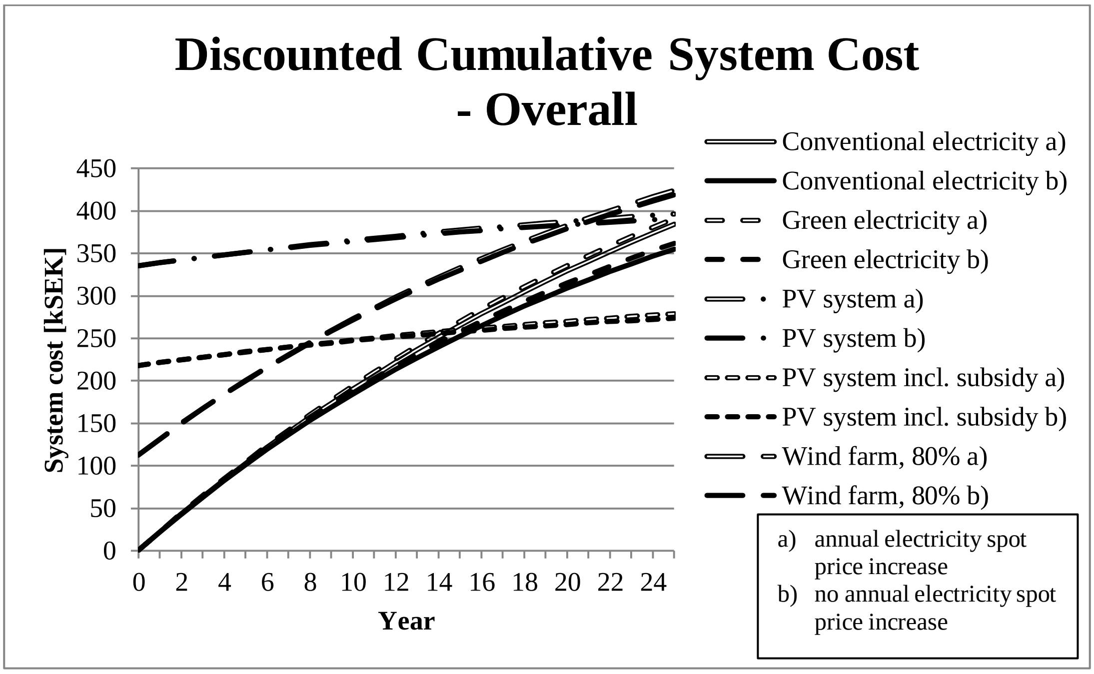

Figure 13: Presentation of the overall result of the discounted cumulative system costs for all electricity systems simulated; green electricity contract, PV system (with and without a 35% investment subsidy) and wind farm shares (covering 80% of the household's load). All scenarios are simulated and presented in the figure with a) an annual spotprice increase of 1.8% and b) no annual spotprice increase. All sytems are, in the figure, compared to the conventional electricity contract. Each curve represents the life cycle cost for respective energy system simulated, for the entire lifetime of 25 years.

6.2 Specific Results for the Electricity Supplies

In this section results for all the various electricity supplies, scenarios and sensitivity analyses are individually presented. These results offer a deeper understanding of the overall results. Also, by presenting each electricity system separately, system specific results and effects related to the sensitivity analysis are shown. Each electricity supply is modelled with and without an annual increase in spot price, denoted as *a)* and *b)* in the figures presenting the result.

First, the results for the conventional electricity contract are presented. This shows what costs a standard solution results in during the project lifetime of 25 years. Also it specifies what all other scenarios are compared to. Then, the most important results for each electricity system, the green electricity contract, solar PV installation and wind farm shares, are presented.

6.2.1 Conventional Electricity Contract

A conventional electricity contract is the standard electricity supply both for Swedish households and this study. The modelling of this system, consisting of a family household with the annual electricity usage of approximately 20MWh covered by conventional electricity, results in a total accumulated system cost of 355000SEK. Curve *a)* in Figure 14 shows the effect of an electricity price increase, in the form of an annual 1.8% increase in spot price. This increase leads to an approximately 30,000 SEK more expensive system.

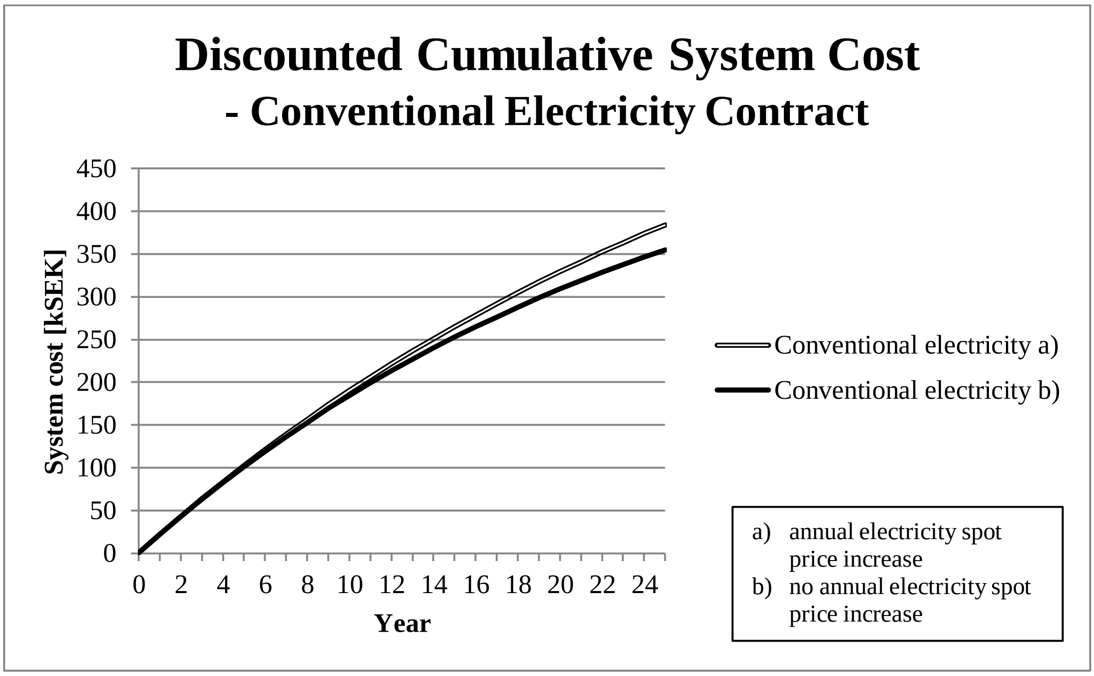

Figure 14: The discounted cumulative system cost for an electricity system with conventional electricity contract, with a) an annual spotprice increase of 1.8% and b) no annual spotprice increase. Each curve represents the life cycle cost for respective energy system simulated, for the entire lifetime of 25 years.

6.2.2 Green Electricity

The option of choosing a green electricity contract, a contract where the electricity retailer is paid 2.2öre extra per kilowatt hour, does not make any significant monetary difference for the consumer compared to the conventional electricity contract. The cumulative system cost after a 25-year period is 362000SEK with no electricity price increase and 391000SEK with an annual electricity price increase. In comparison to the conventional electricity contract an additional expense of using a green electricity amounts to 7000SEK scattered over 25 years.

Since the green electricity contract is based on the conventional electricity price they will have the same price trend. Their curves will never intersect (Figure 15); meaning that the choice of using green electricity contract will never be profitable in comparison with the conventional.

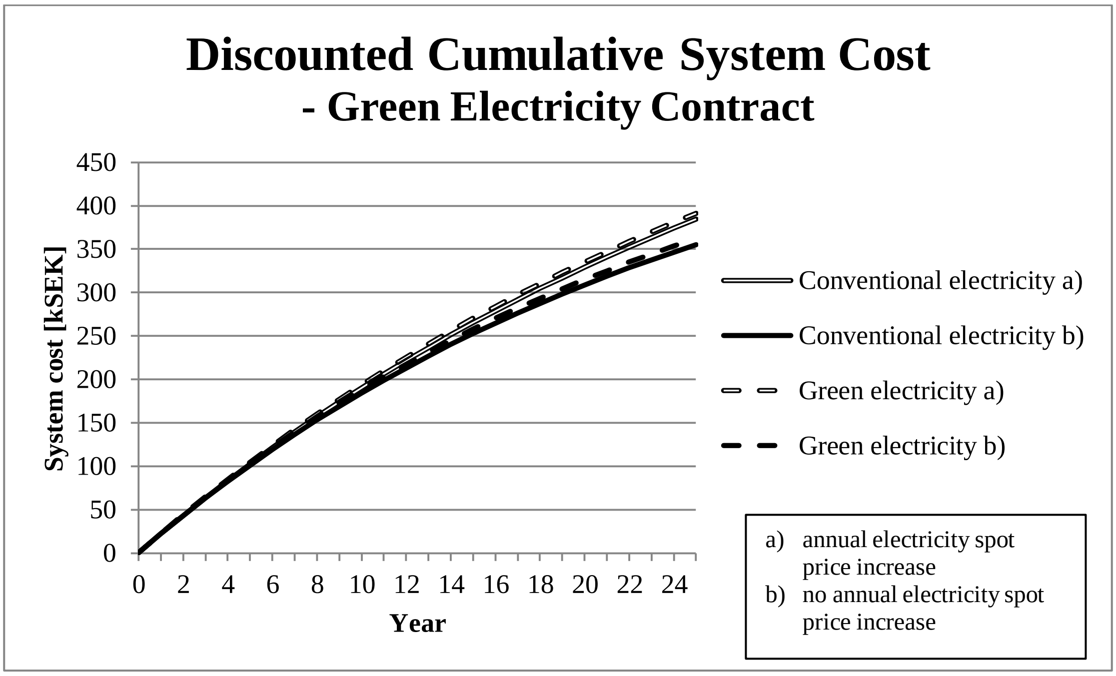

Figure 15: The discounted cumulative system cost for an electricity system with green electricity contract, with a) an annual spotprice increase of 1.8% and b) no annual spotprice increase. This sytem is, in the figure, compared to the conventional electricity contract. Each curve represents the life cycle cost for respective energy system simulated, for the entire lifetime of 25 years.

6.2.3 Solar PV Installation

The solar PV system comprises of a 1-16kW PV installation in combination with a connection to the electricity grid. As explained in the Scenario definition this study is focused on two groups of sellback conditions: group 1 includes the average sellback condition for the major Swedish electricity retailers *E.ON*, *Fortum* and *Vattenfall*, and group 2 includes the conditions for the company *Telge Energi*. For both groups the present sellback condition and a possible future sellback condition are investigated. For the possible future sellback condition a tax reduction of 60öre/kWh on all sold electricity is included.

The results of the PV sellback conditions, in comparison to electricity from a conventional electricity contract, are presented in Figure 16. The y-axis displays kilowatts of installed PV capacity. The x-axis displays an investment cost multiplier, where the value of 1 corresponds to 100% of the investment cost and similarly 0.65 refers to 65%. The figure explains at which sellback condition different sizes of PV investments become profitable. The results apply to a project period of the PV lifetime of 25 years, a real interest rate of 4% and no annual electricity price increase.

As seen Figure 16, none of the sellback conditions is profitable for 100% of the installation cost. But for a reduction of 1% in investment cost, the PV system with the *Telge Energi*-sellback condition becomes profitable. The guideline is then to invest in the maximum capacity of 16kW (80% of the load for the studied household).

An overall conclusion is that the sellback condition affects the PV installation profitability to a high extent. Another highly influencing factor of the profitability of the system is the PV investment cost. For a lower cost of the investment, all scenarios become more profitable compared to the conventional electricity from the grid. Lower costs can for example be achieved by subsidies or technical maturity with a following cost reduction of the PVs.

When considering an investment cost multiplier of 0.65, which corresponds to the present PV investment subsidy of 35%, all sellback-scenarios becomes profitable.

The breakpoint for investing in PVs occurs at different degrees of investment reduction for the different sellback conditions. A table summarizing the breakpoint figures is presented in Table 3.

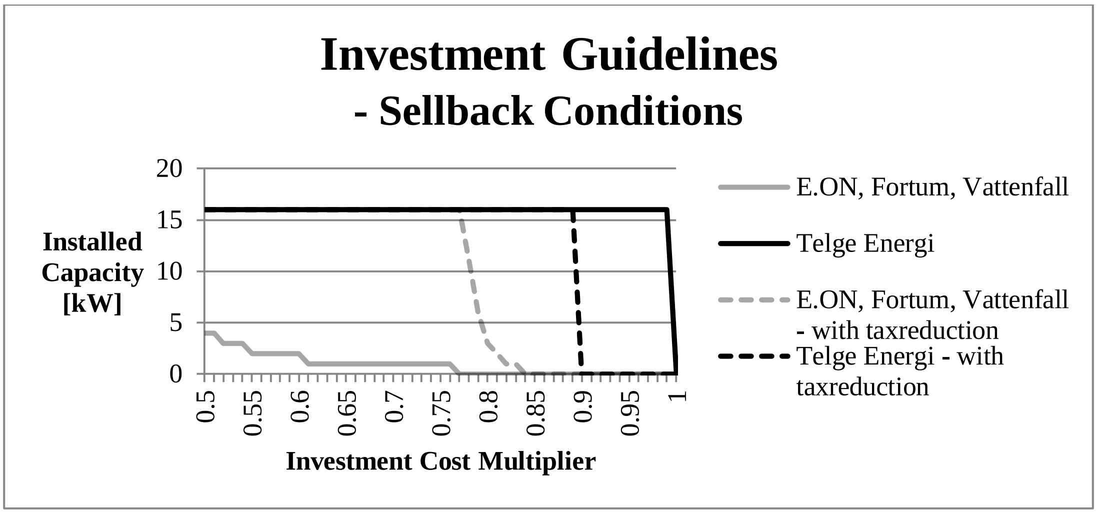

Figure 16: The figure presents the investment guidelines for a PV-system with two different sellback conditions for two groups of companies (presented in Tabel 1). Group 1: E.ON, Fortum and Vattenfall and Group 2: Telge Energi, both with the present- and future (including tax reduction) conditions. The x-axis displayes an investment cost multiplier; a factor that multiplied with the investment cost of 20962SEK/kW describes different levels of PV investment costs. The factor do represent values from 1 (100% investment cost) to 0.5 (50% of the investment cost), which symbolizes a future reduction in PV investment or investment subsidies. The y-axis displays installed PV capacity in kW.

Table 3: The breakpoints of when the different sellback conditions become profitable.

Sellback condition:	E.ON, Fortum, Vattenfall	Telge Energi	E.ON, Fortum, Vattenfall –with tax reduction	Telge Energi –With tax reduction
Investment breakpoint of investment cost multiplier:	0.76	0.99	0.83	0.89

Since *Telge Energi* offers advantageous sellback conditions (seen in Figure 16) and the tax reduction is a likely scenario of the near future, this forms a probable sellback condition for a micro producer. Hence, in the following sensitivity analysis the sellback condition for *Telge Energi* with tax reduction is modelled.

The sensitivity analysis indicates that the assessment of whether a PV system is profitable is strongly influenced by the real interest rate (Figure 17). For a 1.1% real interest rate the system is profitable for the full investment cost. The real interest rate value of 6% shows that the system becomes less profitable and a lower investment cost is needed to reach a profitable system.

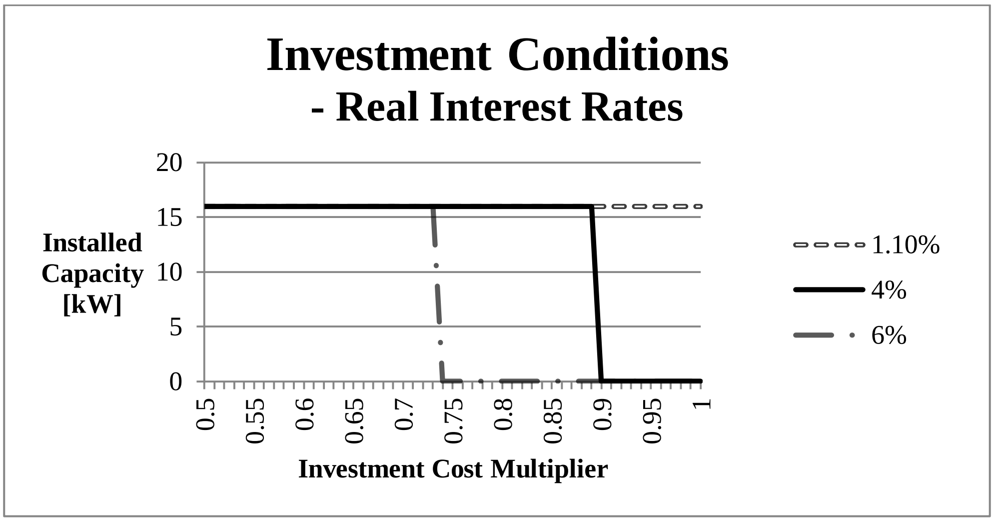

Figure 17: As a sensitivity analysis, the figure presents the investment guidelines for a PV-system with three different real interest rates for the calculations. The x-axis displayes an investment cost multiplier; a factor that multiplied with the investment cost of 20962SEK/kW describes different levels of PV investment costs. The factor do represent values from 1 (100% investment cost) to 0.5 (50% of the investment cost), which symbolizes a future reduction in PV investment or investment subsidies. The y-axis displays installed PV capacity in kW.

Moreover, the profitability of a PV system is influenced by variations in global solar irradiance. Compared to the simulated solar resource of 960kWh/m^2 the lower and higher irradiance investigated in Figure 18 shifts the breakpoint of profitability to lower respectively higher investment costs.

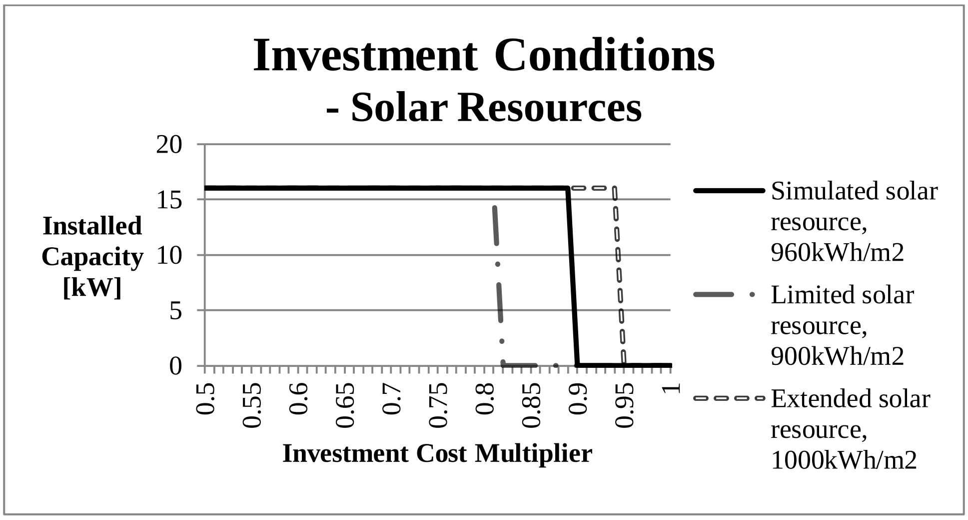

Figure 18: As a sensitivity analysis, the figure presents the investment guidelines for a PV-system with three different global solar irradinaces representing different parts of Sweden. The x-axis displayes an investment cost multiplier; a factor that multiplied with the investment cost of 20962SEK/kW describes different levels of PV investment costs. The factor do represent values from 1 (100% investment cost) to 0.5 (50% of the investment cost), which symbolizes a future reduction in PV investment or investment subsidies. The y-axis displays installed PV capacity in kW.

In Figure 19 the total discounted cumulative system cost for the project lifetime of 25 years is shown. The solar PV simulations presented in the figure are conducted with a real interest rate of 4%, a sellback for *Telge Energi* with tax reduction and a solar irradiance corresponding to 960kWh/m^2. The figure clearly shows that a 35% subsidized PV system is profitable in comparison to purchase electricity from a conventional contract. This investment will pay off in 15 years. However, a 100% investment cost scenario will not be profitable with assumed conditions in the time horizon of 25 years, although it is close.

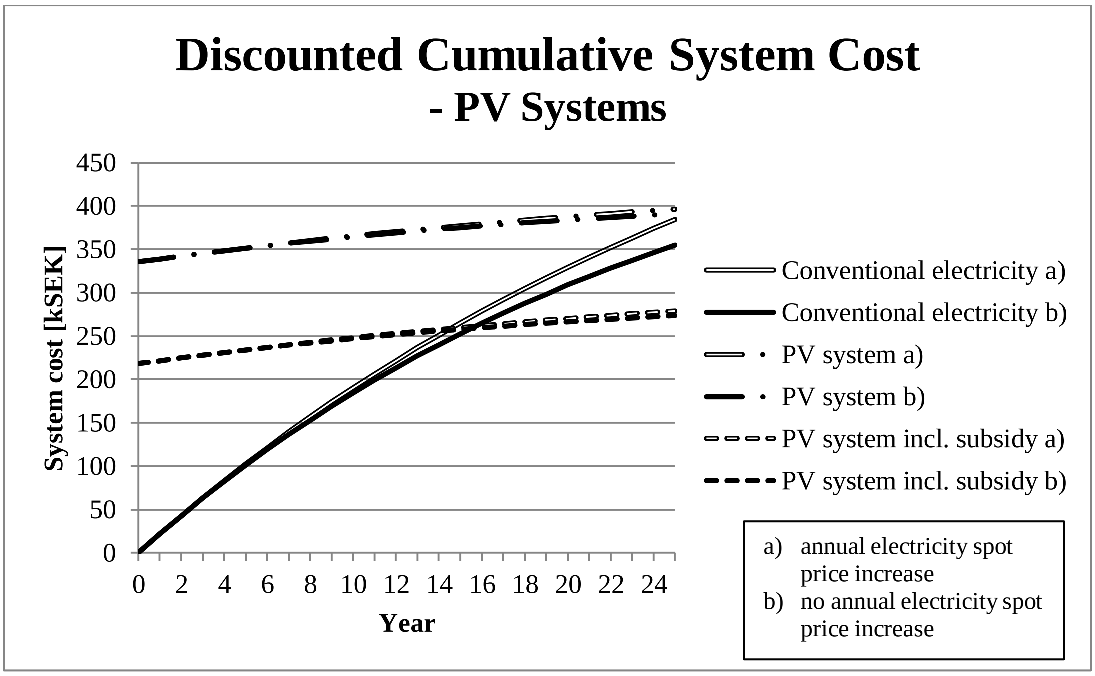

Figure 19: The discounted cumulative system cost for an electricity system with PVs, with a) an annual spotprice increase of 1.8% and b) no annual spotprice increase. In the figure both a 100% cost and 35%-subsidized PV system is modelled. These sytems are, in the figure, compared to the conventional electricity contract. Each curve represents the life cycle cost for respective energy system simulated, for the entire lifetime of 25 years.

6.2.4 Wind Farm Shares

The option of covering 80% of the household's load by wind farm shares is with prevailing conditions and assumptions, shown not to be profitable when compared to the conventional contract. Nor any of the smaller wind shares of 60 and 40% proves to be profitable. Figure 20 displays that none of the wind curves intersects the conventional electricity curve. The 80%-case will during the project period of 25 years reach a discounted cumulative cost of 416000SEK with no electricity price increase and 421000SEK with an annual electricity price increase.

Another result shown in Figure 20 is the sensitivity of electricity price; the smaller number of wind shares, the more sensitive to electricity price variations.

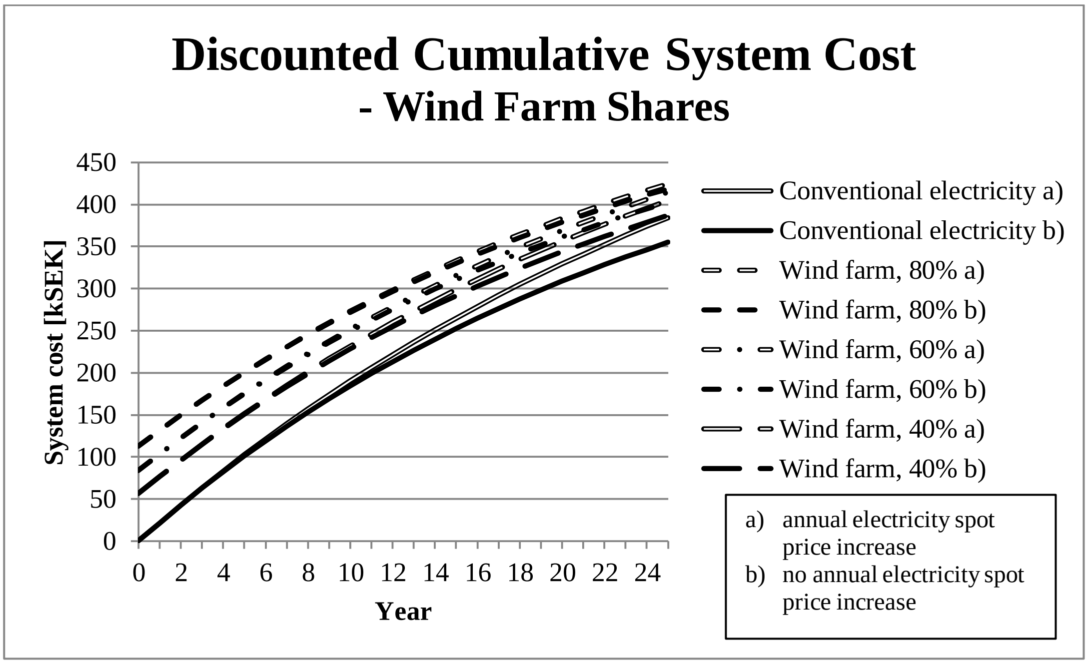

Figure 20: The discounted cumulative system cost for an electricity system with wind farm shares, with a) an annual spotprice increase of 1.8% and b) no annual spotprice increase. Wind shares covering three different load scenarios, 80, 60 and 40% of the houshold's annual load is modelled. These sytems are, in the figure, compared to the conventional electricity contract. Each curve represents the life cycle cost for respective energy system simulated, for the entire lifetime of 25 years.

7 Discussion

The outcome from the overall result is: if the current PV investment subsidy is available a customer should invest, otherwise keep using electricity from the conventional electricity contract. This will be the household’s most profitable electricity solution during the next 25 years. This result corresponds to the condition set in the scenario definition. For other conditions, if one or several parameters are varied, the result may differ.

For example in case of the PV system, the result from the model shows that the economic calculation is strongly dependent on the real interest rate. Thus, depending on the rate, a PV system can be proved both profitable and unprofitable. This rate is therefore important to decide individually for each customer in accordance to their specific conditions. As mentioned in section 5.3 *Modelling Parameters*, the real interest rate symbolizes what minimum return a customer need to receive from the investment in monetary terms in order to be profitable compared to alternative investments. For households, this real interest rate is highly affected by personal circumstances, interests and financial assets. Often the customer can base the real interest rate on the interest on a savings account at the bank or a loan rate received to cover the investment. In the case with a rate lower than the simulated 4% a more positive PV investment decision is formed and vice versa for rates above 4%.

Another factor that influences the result is the choice of electricity retailer and what sellback conditions they offer for electricity in times of excess production. Therefore the proved importance of making an active choice of an electricity retailer that offers advantageous sellback conditions can again be stressed. This will make the difference between if a PV system is profitable or not.

The market and technology of solar PVs is in a developing phase. Subsidization and regulatory changes are two interesting and relevant areas discussed at a governmental level. The outcome from these discussions will be of much interest for the calculations of profitable electricity sources. Thus it is important to keep up with the debate and the on-going governmental discussions in order to account for current conditions.

The outcome of the government discussion will especially affect the sellback conditions for excess electricity produced in a micro system. Several electricity retailers have claimed that they will change their sellback conditions after a possible regulatory introduction of the tax credits of 60öre/kWh for all excess production from micro systems. These changes will affect the profitability calculation which was shown in the PV result. In some cases the aggregated sellback and tax credit will give more profitable conditions (for example for *E.ON*, *Fortum* and *Vattenfall*), and in some cases in a slightly lowered total compensation (as in case of *Telge Energi*). This proves even more the importance of choosing a good electricity contract in terms of beneficial sales conditions, and to be informed and updated of the current conditions.

The sensitivity analysis for variations in global solar irradiance shows that this effect on profitability is relatively small in comparison to variations in PV investment cost or real interest rate. Large areas of Sweden will receive solar resources within the simulated range, i.e. 900-1000kWh/m^2. Therefore, as long as the PV modules face south, a majority of the Swedish households will have sufficient solar resources to take part of the result from this study.

Then there are the future aspects. What will happen with prices on electricity and installation costs, and how will they influence the overall result? In case of an electricity price increase all the investment calculations for the alternative systems would become more profitable. Also, the PV system will become more profitable if the PV investment cost continues to decrease (as the historical trend shown in Appendix I). This correlation was clearly shown in the modelling result. A reduced PV investment cost is not an unrealistic scenario, often it is a natural part in the development phase when a technology reaches a higher degree of technical maturity. The combination of increased electricity prices (which mostly affects the conventional system) and decrease of PV investment costs would create a more favourable situation for PV system.

As presented in section 5.3, *Modelling Parameters*, the PV manufacturers specify a solar PV lifetime of 25 years. This is probably an underestimation; the PV modules technical lifetime will most likely exceed 25 years, but at a somewhat lower performance. If that is the case, the PV module becomes more profitable since the investment will be spread over a longer period of time. The fact that PVs are expensive in investment cost but cheap in operation and maintenance forms a system favoured by long technical lifetimes. When the PV investment is paid back the system will generate free electricity for the household.

In case of the wind farm shares, the models show that it is not a profitable option to invest in compared to the other electricity systems. This is true for the project period of 25 years and with the assumption of no residual value of the acquired wind farm shares.

However, if the wind farm shares have a market value they can be sold on the open market. Also, if the project time is shorter, the wind farm investment can be profitable. For example, as stated in the description of the wind farm system in section 3.3 *Investments in Wind Farm Shares*, *VästanVind* offers to buy the shares back at the investment price, in case the sale occurs within five years from the time of purchase. This creates a totally different scenario where the total system cost only are dependent on the variable cost set by the wind farm cooperative and opportunity cost. This option would then probably be more profitable than purchasing electricity from a conventional electricity contract.

The option of a green electricity contract is in the simulation shown to be unprofitable. But when the primary reason to invest in renewable electricity supply instead is sustainable living, this contract would offer a relatively cheap solution with low financial risks. Then the question arises whether the money paid is used for renewable energy projects and investments in more renewables. An investment in solar PVs will cost more but in the same time offer an awareness of the electricity origin and its environmental benefit. Though, such an investment is related to high financial risks.

Finally, an interesting aspect of the results; are they applicable on other energy systems and scenarios? Yes, even though the exact figures and payback times are strictly valid for the modelled scenarios, the general results and the methodology are applicable on other similar households as well. The recommendation of if to invest or not, should be applicable for the majority of Swedish family households. As an example, a household with smaller load has been modelled and the results can be found in Appendix A. The way of modelling may be valid also for daycentres, industries and other buildings.

8 Conclusions

The overall result concludes that installing solar PVs may be a profitable alternative in comparison to a conventional electricity contract. With a PV investment subsidy, the recommendation is to invest in a grid connected PV system. This investment will be paid back after 15 years and thereafter continue to generate free electricity for the remaining lifetime. With a non-subsidized PV system a 10% reduction in investment cost is necessary to form profitability after 25 years. Depending on installation cost, this reduction may be achieved with a ROT-deduction. Otherwise the indication is that the conventional electricity grid will, for these models, be the most cost effective solution.

The sensitivity analysis conducted for the three alternative electricity supplies, shows the importance of proper input values. The profitability of the three modelled energy systems are greatly affected by changes in initial investment costs, presence of subsidies, sellback rates for the excess electricity and values in real interest rates. The values of these inputs made the difference between a profitable and an unprofitable system. Variations in solar resource availability in bidding area 3 did not, however, affect the systems' profitability to the same degree.

The time perspective of the investment is another highly affecting parameter. It is shown that the system with wind farm shares is, for a time perspective less than 7 years, more profitable than PV investments. Therefore the time perspective is of great importance when deciding which system to purchase.

An important aspect of the purchase guideline is how future changes in the Swedish energy system are affecting the modelled results. A future electricity price increase, is a factor with great impact on which system that becomes profitable over time. With an increase of electricity price, the renewable electricity supplies become more profitable than the conventional electricity contract. Therefore, there is a trade-off between calculated expected profitability of the systems and their respectively stability toward future potential changes. A household wants a profitable system independent of energy changes or political decisions.

In summary, the conclusion for the specific modelling conditions and the project lifetime of 25 years is that:

- Only the PV systems may be more profitability in comparison with a conventional electricity contract.
- For investments with shorter perspectives the profitability can appear completely different.
- The importance of reliable estimates of subsidies, sellback conditions and time perspective are always important in order to achieve a good and consistent purchase analysis.

The simulations have been performed according to the predefined conditions set by the input data in the modelling work; a family household with the prerequisites and market condition of bidding area 3, year 2014. The results are therefore representing the specific setups for the simulations, although the overall results and methodology are applicable for other regions and system loads.

9 Recommendations

To achieve a more comprehensive energy study, heat generation can be included. The combination of electricity supplies and heat generation provides new possibilities of feasible renewable energy supplies and would be an interesting investigation to perform.

Further interesting aspects would be to include different technologies of energy storage. This would give additional options of how to handle excess electricity and also how to supply electricity demand in times of electricity deficit in the household system.

To consider how the simulations and investment guidelines would be affected by greater loads, a simulation of for example a neighbourhood or a housing association would give broader perspectives to the study.

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Appendix A – Alternative Household, 5620kWh

A household without electric heating, hence a smaller load, is simulated with same input data and conditions as the household in the study. Data for the household is collected from *Energimyndigheten* and the characteristics are displayed in Table 4.

Table 4: Characteristics for alternative household (Kadic, Z., 2014)

Load	Without Direct Electric Heating
Consumption [kWh]	5620
Number of residents	3
Size (m^2)	129
Location	Southern Sweden

Most Important Result of the Simulations

In Figure 21 it can be seen that the overall results is similar for this household as for the larger investigated house with the load of 20743kWh.

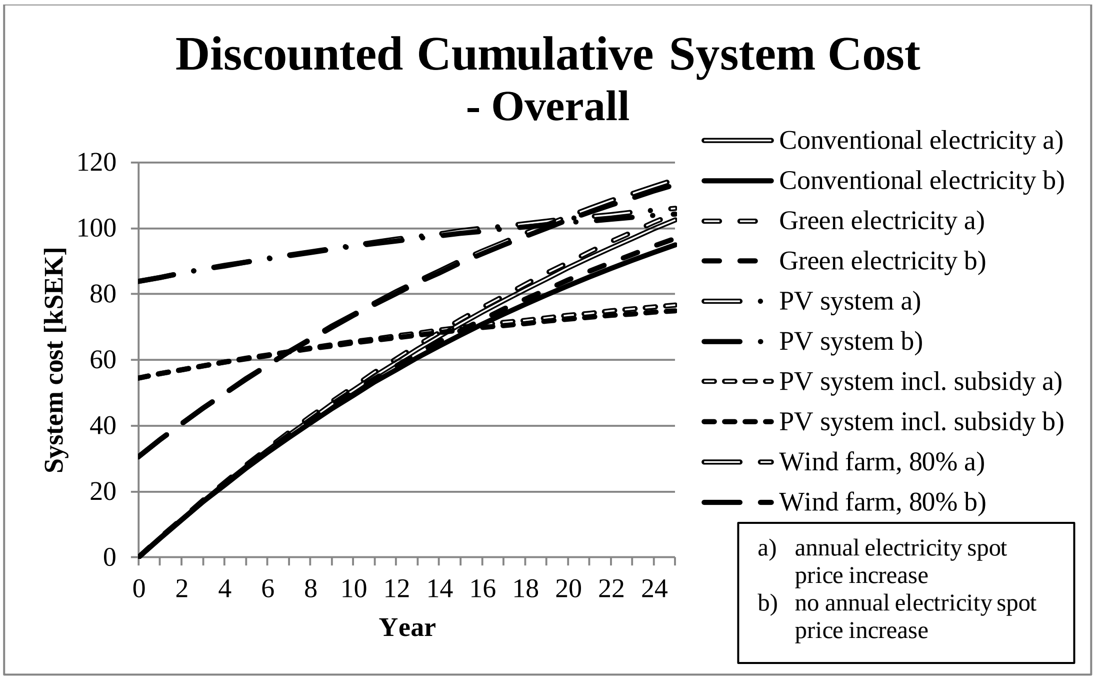

Figure 21: Presentation of the overall result of the discounted cumulative system costs for all electricity systems simulated; green electricity contract, PV system (with and without a 35% investment subsidy) and wind farm shares (covering 80% of the household's load). All scenarios are simulated and presented in the figure with a) an annual spotprice increase of 1.8% and b) no annual spotprice increase. All sytems are, in the figure, compared to the conventional electricity contract. Each curve represents the life cycle cost for respective energy system simulated, for the entire lifetime of 25 years.

Specific Results for the Alternative Power Systems

All the results for each alternative of electricity supply will be presented below. These results are smaller in value in comparison to the 20743kWh-house, but they do show similarities in profitable electricity supplies.

Conventional Electricity Contract

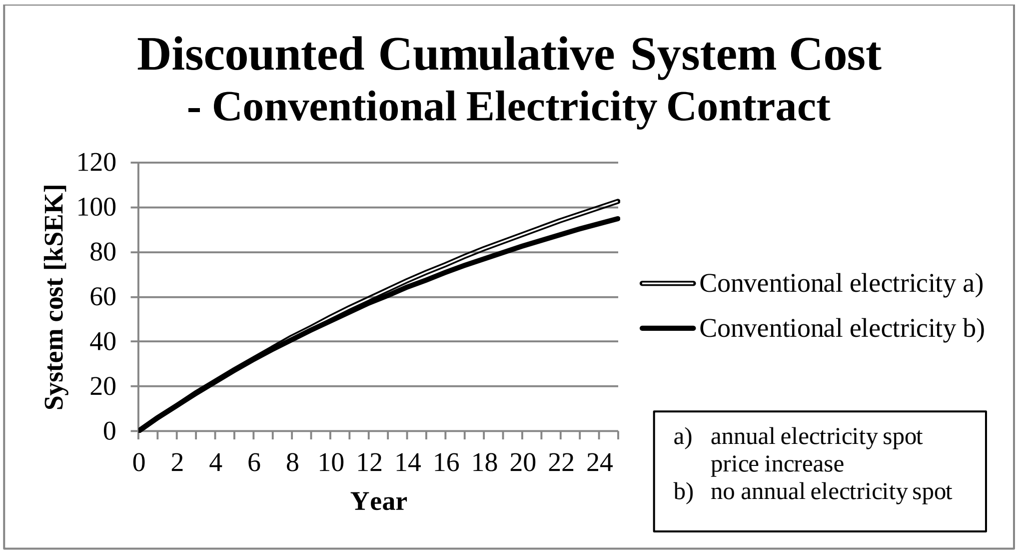

Figure 22: The discounted cumulative system cost for an electricity system with conventional electricity contract, with a) an annual spotprice increase of 1.8% and b) no annual spotprice increase. Each curve represents the life cycle cost for respective energy system simulated, for the entire lifetime of 25 years.

Green Electricity

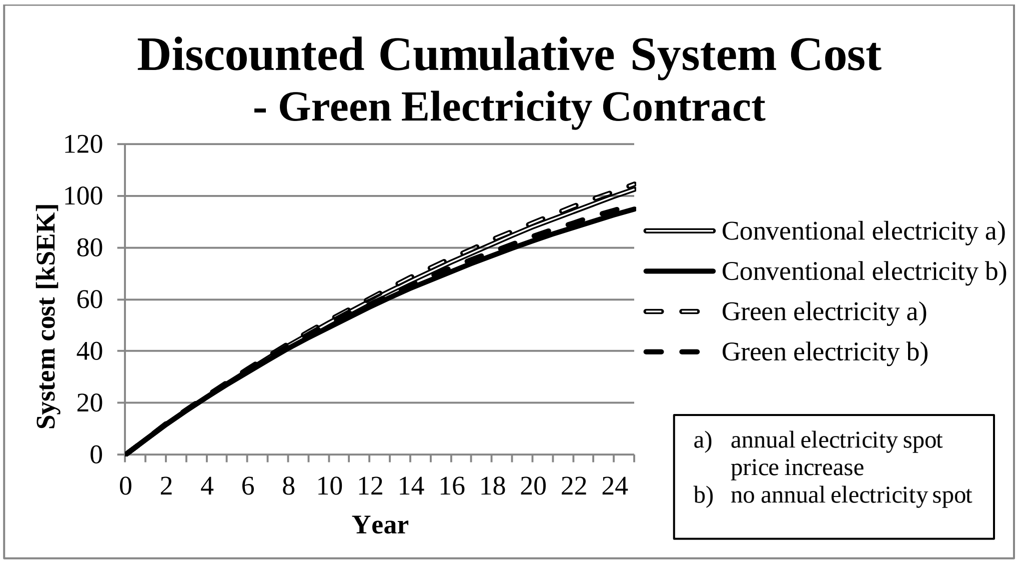

Figure 23: The discounted cumulative system cost for an electricity system with green electricity contract, with a) an annual spotprice increase of 1.8% and b) no annual spotprice increase. This sytem is, in the figure, compared to the conventional electricity contract. Each curve represents the life cycle cost for respective energy system simulated, for the entire lifetime of 25 years.

Solar PV Installation

Solar PV analyses

For a load of 5620 kWh, an investment between 1-4kW is suitable regarding the 80% installation recommendation. Figure 24-26 describes the recommended capacity installations for different investment costs regarding electricity retailer, annual interest rate and solar resources.

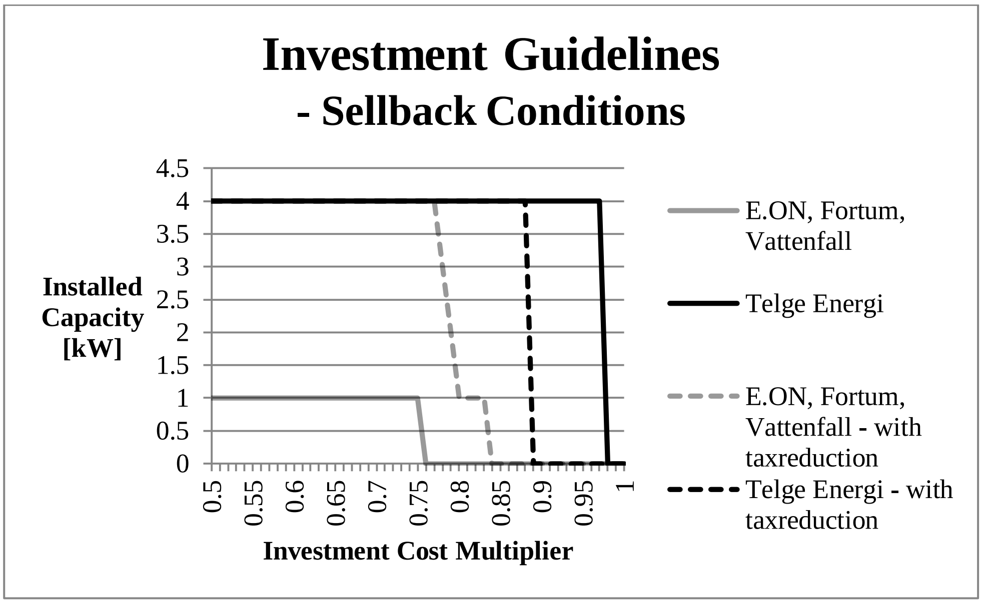

Figure 24: The figure presents the investment guidelines for a PV-system with two different sellback conditions for two groups of companies; Group 1: E.ON, Fortum *and* Vattenfall *and Group 2:* Telge Energi, *both with the present- and future (including tax reduction) conditions. The x-axis displayes an investment cost multiplier; a factor that multiplied with the investment cost of 20962SEK/kW describes different levels of PV investment costs. The factor do represent values from 1 (100% investment cost) to 0.5 (50% of the investment cost), which symbolizes a future reduction in PV investment or investment subsidies. The y-axis displays installed PV capacity in kW.*

Table 5: The breakpoints of when the different sellback conditions become profitable.

Sellback condition:	E.ON, Fortum, Vattenfall	Telge Energi	E.ON, Fortum, Vattenfall –with tax reduction	Telge Energi –With tax reduction
Investment breakpoint of investment cost multiplier:	0.75	0.97	0.83	0.88

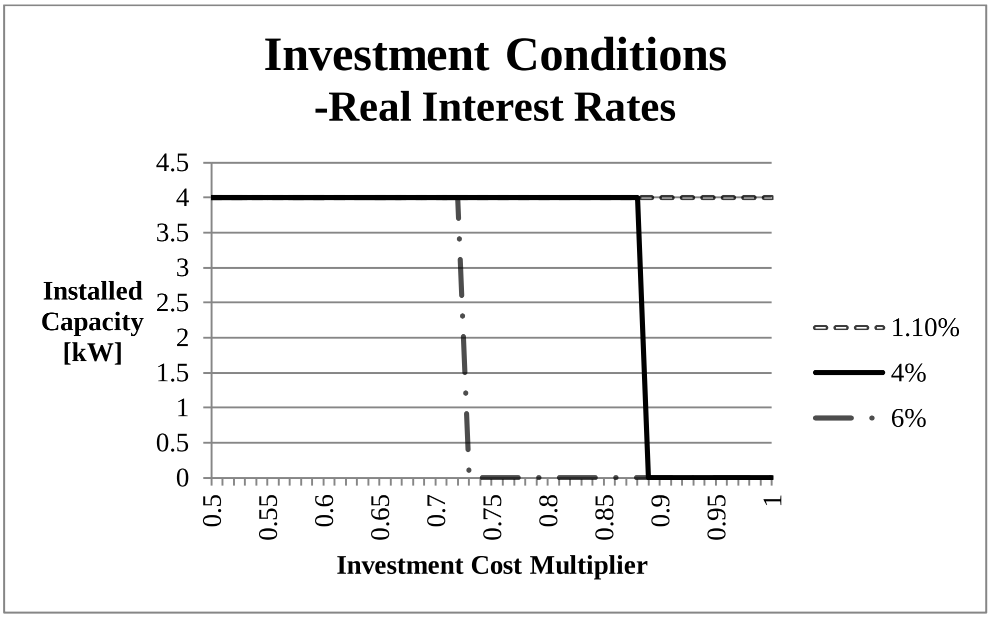

Figure 25: As a sensitivity analysis, the figure presents the investment guidelines for a PV-system with three different real interest rates for the calculations. The x-axis displayes an investment cost multiplier; a factor that multiplied with the investment cost of 20962SEK/kW describes different levels of PV investment costs. The factor do represent values from 1 (100% investment cost) to 0.5 (50% of the investment cost), which symbolizes a future reduction in PV investment or investment subsidies. The y-axis displays installed PV capacity in kW.

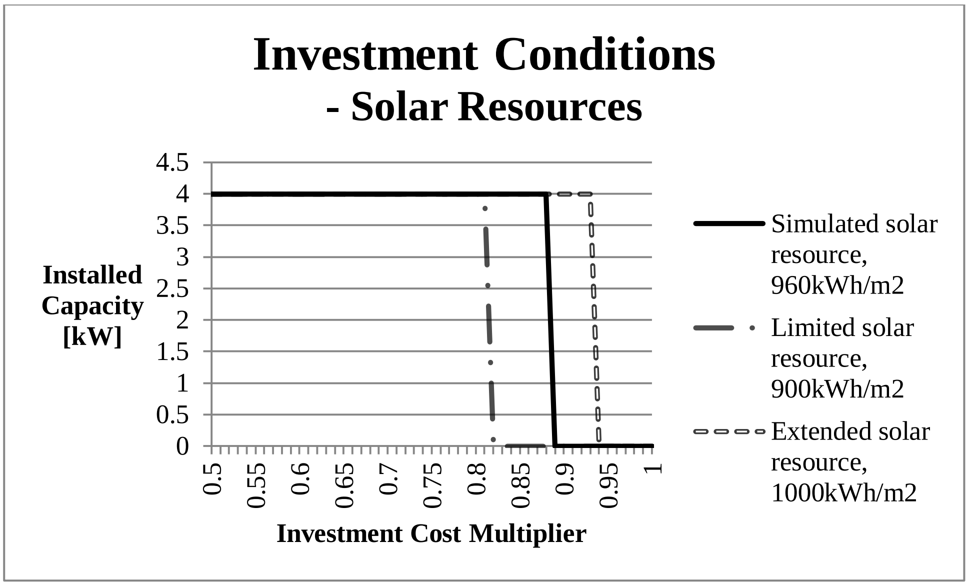

Figure 26: As a sensitivity analysis, the figure presents the investment guidelines for a PV-system with three different global solar irradinaces representing different parts of Sweden. The x-axis displayes an investment cost multiplier; a factor that multiplied with the investment cost of 20962SEK/kW describes different levels of PV investment costs. The factor do represent values from 1 (100% investment cost) to 0.5 (50% of the investment cost), which symbolizes a future reduction in PV investment or investment subsidies. The y-axis displays installed PV capacity in kW.

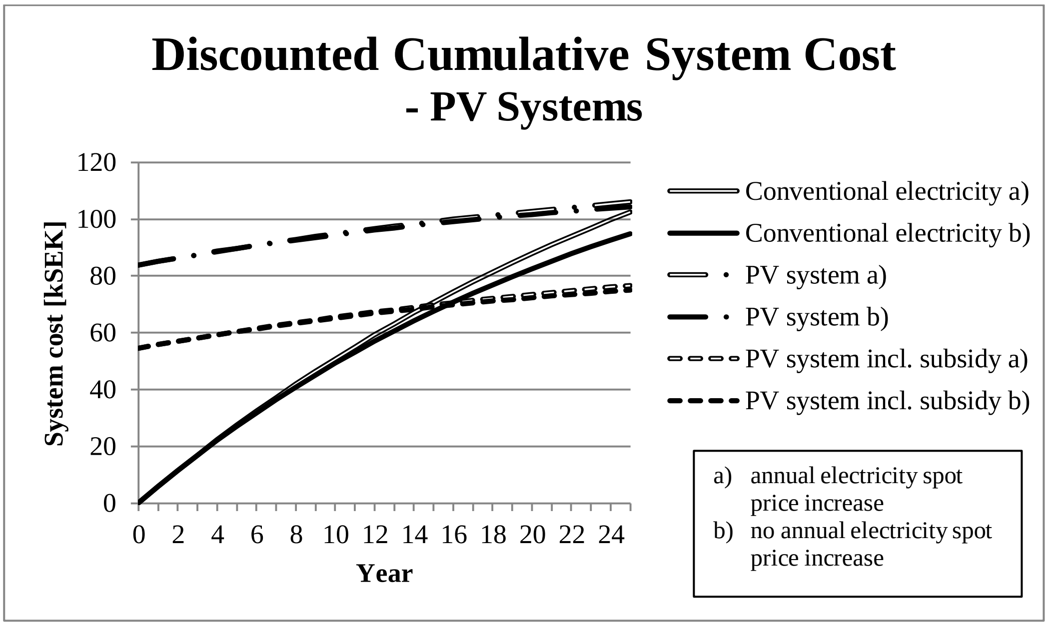

Figure 27: The discounted cumulative system cost for an electricity system with PVs, with a) an annual spotprice increase of 1.8% and b) no annual spotprice increase. In the figure both a 100% cost and 35%-subsidized PV system is modelled. These sytems are, in the figure, compared to the conventional electricity contract. Each curve represents the life cycle cost for respective energy system simulated, for the entire lifetime of 25 years.

Wind Farm Shares

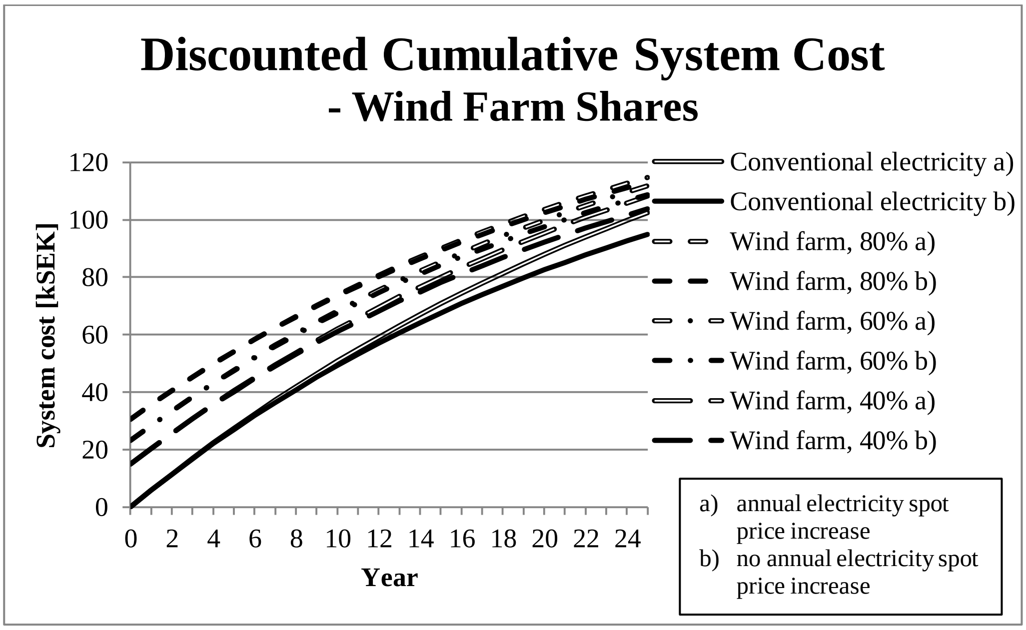

Figure 28: The discounted cumulative system cost for an electricity system with wind farm shares, with a) an annual spotprice increase of 1.8% and b) no annual spotprice increase. Wind shares covering three different load scenarios, 80, 60 and 40% of the houshold's annual load is modelled. These sytems are, in the figure, compared to the conventional electricity contract. Each curve represents the life cycle cost for respective energy system simulated, for the entire lifetime of 25 years.

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Appendix B - Sellback Conditions

During conditions when a micro production unit produces more electricity than the size of the load, the excess electricity is transferred out on the grid and the micro producer receives a monetary compensation. The compensation consists of a grid benefit, a sellback and a potential tax reduction. The size of the sellback varies with electricity retail company. In Table 6 the sellback from a number of electricity retail companies are displayed.

Table 6:Sellback conditions for different Swedish retail companies. The data is presented including the value added tax, VAT.

	Without tax reduction[öre/kWh]	**With tax reduction of 60 öre/kWh [öre/kWh]**	**Source**
E.ON	Spot price – 4öre	Spot price–4öre+60öre	(E.ON, 2014a), (Holm. A, 2014)
Fortum	Spot price – 4öre	Spot price–4öre+60öre	(Fortum,2013)
Vattenfall	Spot price – 4öre	Spot price–4öre+60öre	(Vattenfall, 2014), (Zackrisson.E, 2014)
Bixia	Average spot price	Average spot price+60 öre	(Bixia, 2014), (Fagerström.B, 2014)
Egen El (ETC El)	100	Spot price	(ETCel, 2014), (Ehrenberg.J, 2014)
Falkenberg Energi	100	X[4]	(Falkenberg Energi, 2014)
Göteborgs Energi	Net metering[5]	Spot price–2.9öre+60öre	(DinEl,2014), (Andersson.B.H,2014)
Telge Energi	130	El. Price - 60öre+60öre	(Sundelius.S, 2014)

Without tax reduction

The leading electricity retail companies *E.ON*, *Fortum* and *Vattenfall* offers the same sellback price: the spot price reduced with 4öre. This means that the sellback price differs with *Nord Pool Spot's* hourly data over a year.

Among the smaller retailers, the contracts are more beneficial. The most advantageous contract is offered by *Telge Energi* with 130öre/kWh.

[4] Classified
[5] For units up to 6kW (DinEl2014)

With tax reduction

The 1st of July a tax reduction scheme is planned to be set into effect. This scheme offers 60öre in tax reduction for each kilowatt hour electricity a micro producer delivers to the grid.

The leading electricity retailers keep their offers as is. So the tax reduction results in an increased compensation of 60öre/kWh for sold electricity.

A majority of the smaller retailers alters their offers in the case of a tax reduction. But still, *Telge Energi* will offer the highest return; the electricity price reduced with 60öre. In combination with the tax reduction a customer receives the full electricity price, similar to net metering.

Grid benefit

For all excess electricity delivered to the grid the micro producer receives 7.2öre/kWh (incl. VAT) from the electricity transmission company. In Table 7 the compensation from the major transmission companies are displayed.

Table 7: Displays the compensation a micro producer receives from its electricity transmission company for the electricity delivered to the grid.

Grid benefit [öre/kWh]		
E.ON	5.2	(EON, 2014b)
Fortum	6.15	(Fortum,2013)
Vattenfall	6	(Olsson.P, 2014)
Grid benefit (excl. VAT)	5.78	

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Appendix C - Solar Characteristics for the Household

The characteristics for a summer respectively a winter day is presented in Figure 29 and 30. There are visible differences in the size of the different elements between the seasons. During winter the load increases and the electricity production decreases. But still both characteristics show similar appearances. Monetary savings occur in the middle of the day, independently of season of the year.

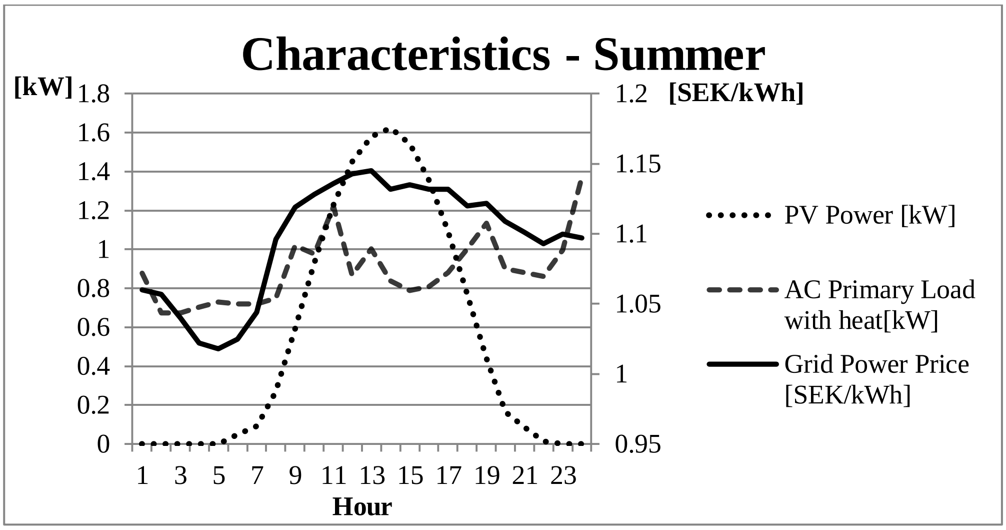

Figure 29: Displays the characteristics of solar production, load and electricity price a summer day in July in Sweden. The installed capacity is 2kW, and the PV power output curve is formed by simulations with solar data corresponding to a typical meteorological year. The load corresponds to a family household, including both electrical heating and usage of household appliances. The electricity price is compiled according to section 2.2 Electricity Price.

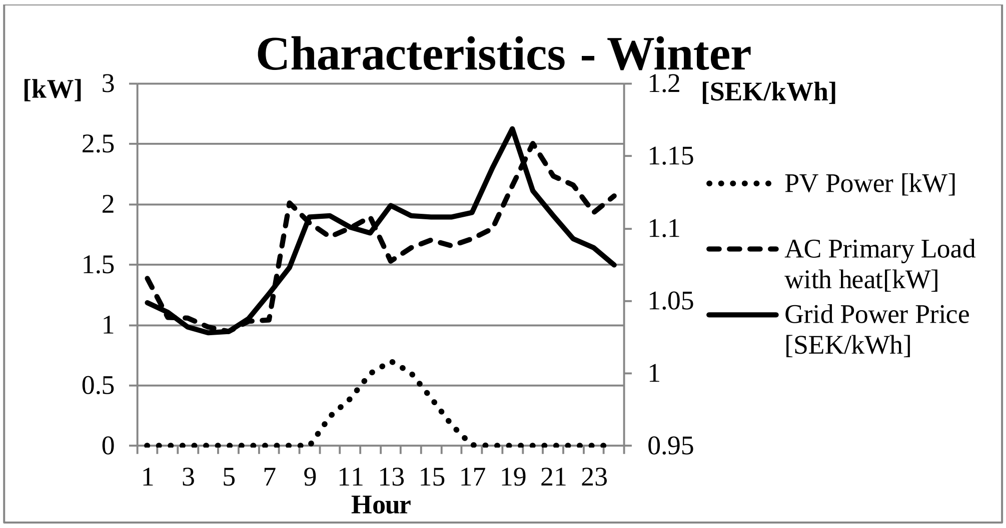

Figure 30: Displays the characteristics of solar production, load and electricity price a winter day in November in Sweden. The installed capacity is 2kW, and the PV power output curve is formed by simulations with solar data corresponding to a typical meteorological year. The load corresponds to a family household, including both electrical heating and usage of household appliances. The electricity price is compiled according to section 2.2 Electricity Price.

Appendix D – Solar Resources

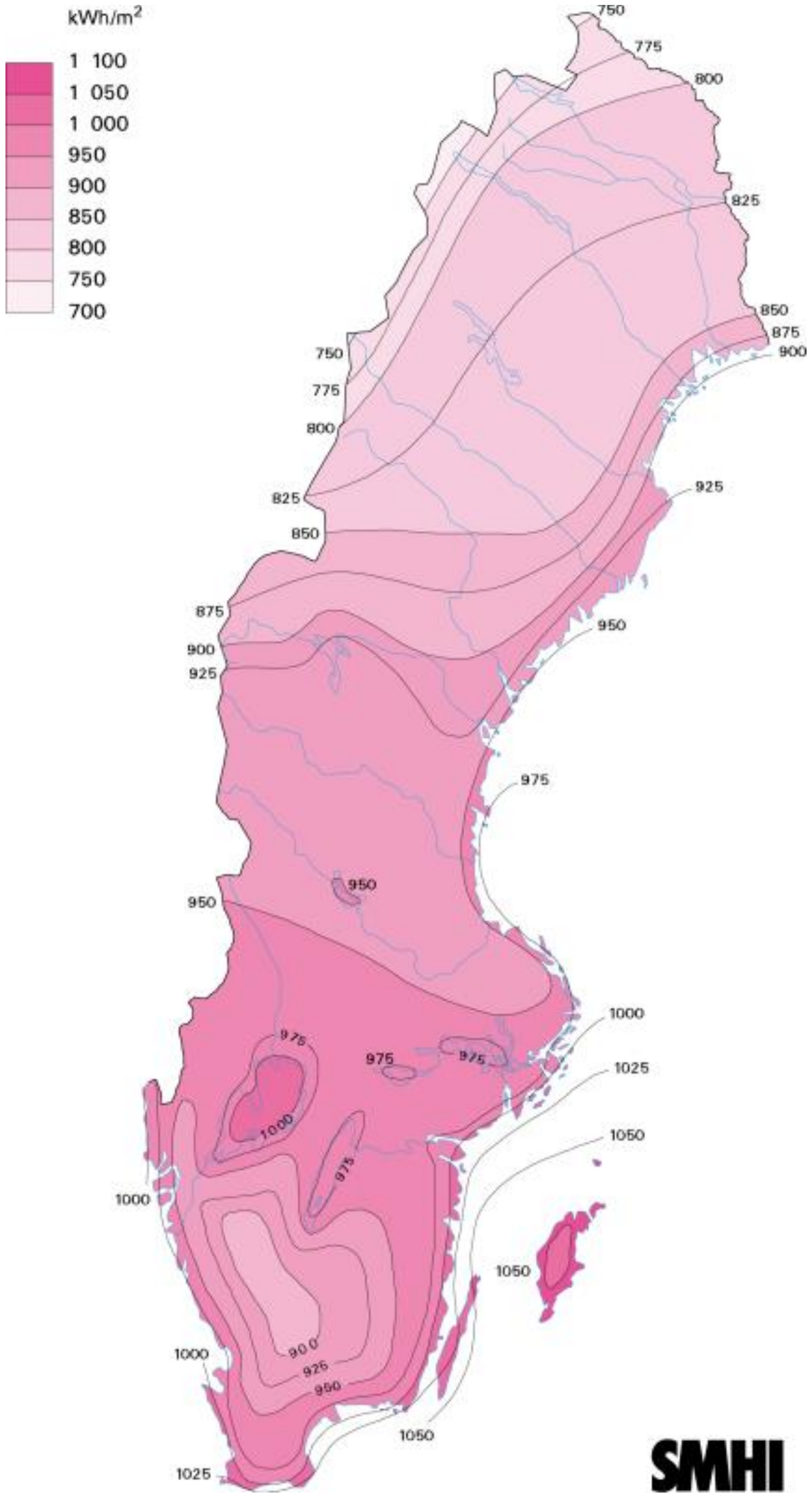

Figure 31: A climate map illustrating the global irradiance for Sweden during a normal year. (SMHI, 2009)

Reference:

SMHI. (2009) *Normal globalstrålning under ett år.* Retrieved April 14, 2014, from http://www.smhi.se/klimatdata/meteorologi/stralning/normal-globalstralning-under-ett-ar-1.2927

Appendix E - Trends for the Electricity Spot Price

A future electricity price is difficult to predict. It is dependent on a variety of factors, for example: regulations, inflation, weather and water availability in the hydro reservoirs. In this investigation the electricity price for 2013 is used as a base price. The future electricity price is formed by keeping all electricity price elements constant except for the spot price, which is given an annual increase of 1.8%. This increase is derived from the historical development of the spot price for bidding area 3, displayed in Figure 32.

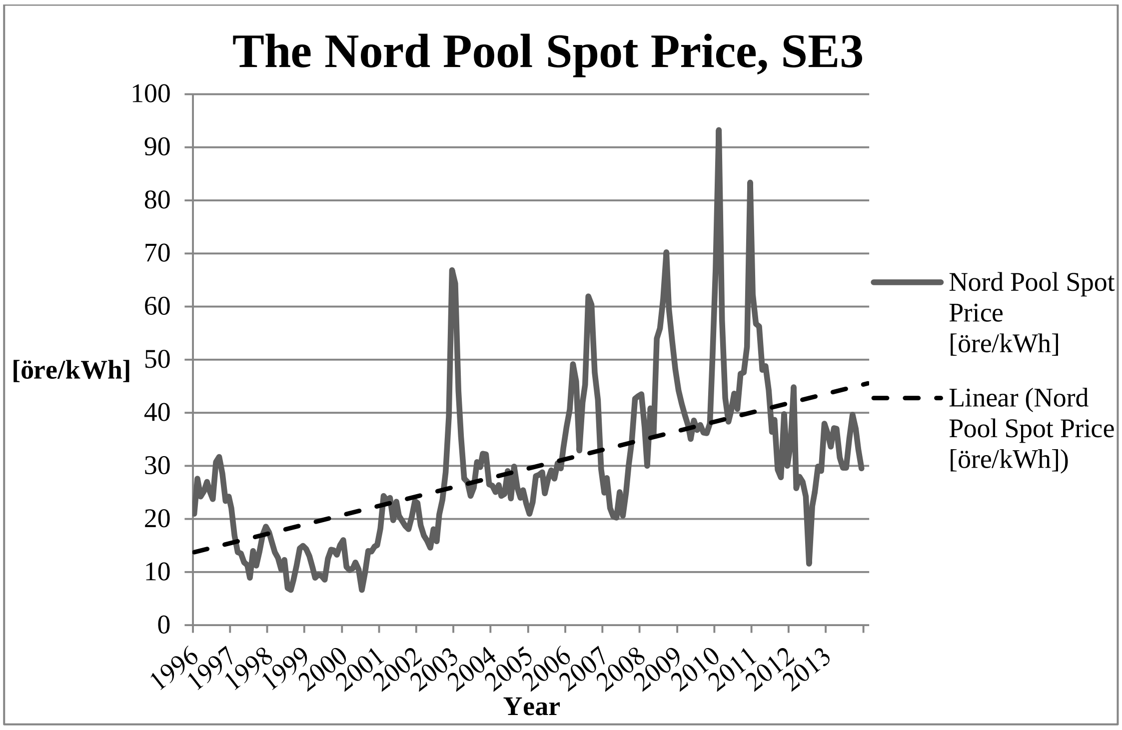

Figure 32: The historical development of the Nordpool spot-price for the years 1996-2013. (Nord Pool Spot, n.d)

Reference:

Nord Pool Spot (n.d). *Data download page.* Retrieved March 3, 2014, from http://www.nordpoolspot.com/Market-data1/Downloads/Historical-Data-Download1/Data-Download-Page/

Appendix F - Summary of Input Data

In Table 8 the input data for all scenarios are presented. Explanations and references of the values are given in section 5.3 *Modelling Parameters* and Appendix G.

*Table 8: A compilation of input data used in the models and calculations. *an average of 2013 years spot price.*

Input Data		
Electricity Price [öre/kWh]		
Spot Price*		34.08
Transmission Cost		18.19
Taxes & Fees	Energy Taxation	29.3
	Electricity Certificate	2.79
	Value-added Tax	22.03
Green Electricity		1.76
Retailer Surcharge		2
Total Price		110.15
Load [kWh]		
Size		20743
Hourly distribution		Figure 10
Solar		
Solar Radiation		
Longitude		11.875
Latitude		57.875
Hourly Distribution		Figure 11
The Solar Panel		
Investment cost		20962 SEK/kW
Azimuth (degrees West of South)		0° (South)
Slope		40°
Lifetime		25 years
Derating Factor		90%
The Sensitivity Analysis for Solar PV		
Sellback[öre/kWh]		
Without tax reduction	Vattenfall, E.ON, Fortum	Spot price – 4öre
	Telge Energi	130öre
With tax reduction	Vattenfall, E.ON, Fortum	Spot price – 4 + 60öre
	Telge Energi	Electricity price-60+60öre
Real Interest Rate [%]		
"Base case"		4%
"Compared to a capital placement"		1.1%

“Compared to other investments”	6%
Wind	
Size of shares	100 kWh
Cost per share	680 SEK
Price for electricity from wind farm, excl. VAT	23
Total paid price, incl. VAT	90.61

Appendix G - The Electricity Price

The electricity price used in the models is formulated by using 2013 years *Nord Pool Spot* price in combination with data from the leading electricity retail and transmission companies; *E.ON*, *Fortum* and *Vattenfall*. The final entries giving the average conventional electricity price is presented in Table 9. In the simulation the spot price varies hour by hour.

*Table 9: The average conventional electricity price that is used in the model. *an average of 2013 years spot price.*

<table>
<tr><th colspan="3">Conventional Electricity Price [öre/kWh]</th></tr>
<tr><td colspan="2">Average Spot Price*</td><td>34.08</td></tr>
<tr><td colspan="2">Transmission Cost</td><td>18.19</td></tr>
<tr><td rowspan="3">Taxes & Fees</td><td>Energy Taxation</td><td>29.3</td></tr>
<tr><td>Electricity Certificate</td><td>2.79</td></tr>
<tr><td>Value-added Tax</td><td>21.48</td></tr>
<tr><td colspan="2">Retailer Surcharge</td><td>2</td></tr>
<tr><td colspan="2">Total Electricity Price</td><td>107.84</td></tr>
</table>

A green electricity contract is often formulated with an additional fee, displayed in Table 10.

Table 10: Costs for the Green Electricity contracts.

Green Electricity Price [öre/kWh]	
Conventional Electricity Price	107.84
Green Electricity	1.76
Value-added tax	0.55
Total Green Electricity Price	110.15

The final entries in Table 9 and 10 are calculated from data originating from electricity retail companies and electricity market sites. The original data is displayed in Table 11.

Table 11: Formation of electricity price used in model. Note, all entries in the table are presented without the value added tax.

Electricity Price [öre/kWh]		
Electricity Grid		
Transmission Cost		
E.ON	16	(E.ON, 2013)
Fortum	19.36	(Fortum, 2014a)
Vattenfall AB	19.2	(Vattenfall AB, 2013)
Transmission Cost	**18.19**	
Electricity Retailer		
Surcharge		
E.ON	-	Fixed cost
Fortum	-	Fixed cost
Vattenfall	2	(Vattenfall, 2014a)
Surcharge	**2**	
Green Electricity		
E.ON (Wind)	2	(E.ON, 2014)
Fortum		Fixed cost
Vattenfall (Wind El.)	1.52	(Vattenfall,2014a)
Green Electricity	**1.76**	
Fees & Taxation		
Energy Taxation		
	29,3	(Ekonomifakta, 2014)
Electricity Certificate		
E.ON		
Fortum	2.76	(Fortum, 2014b)
Vattenfall	2.82	(Vattenfall, 2014b)
Electricity Certificate	**2.79**	
Value Added Tax		
	25%	(Ekonomifakta, 2014)

Reference

Ekonomifakta. (2014) *Konsumtionsskatter på el*. Retrieved February 24, 2014, from http://www.ekonomifakta.se/sv/Fakta/Energi/Styrmedel/Konsumtionsskatter-pa-el/

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Appendix H - Load Characteristics

The load in the study is represented by the electricity consumption for a family household. The household is situated in Mälardalen and the data is collected from *Energimyndigheten*. (Z, Kadic., 2014)The specifics of the household are presented in Table 12.

Table 12: Specific characteristics for the household used in the simulations. (Z. Kadic, 2014)

Load	Direct Electric Heating
Consumption [kWh]	20743
Number of residents	4
Size (m^2)	120(+60)
Location	Mälardalen

References

Email Correspondences:

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Appendix I- The Price Trend for Solar PVs in Sweden

The cost for installing solar PV-systems in Sweden is decreasing. A grid connected solar-PV installation for a household, 0-20kW, do today cost 16 SEK/W excluding the VAT. This cost includes both the material and the installation of the panels. Figure 33 presents the cost trend for four installation scenarios where the grid connected solar-PV installation is displayed by the orange line. (Energimyndigheten, 2014)

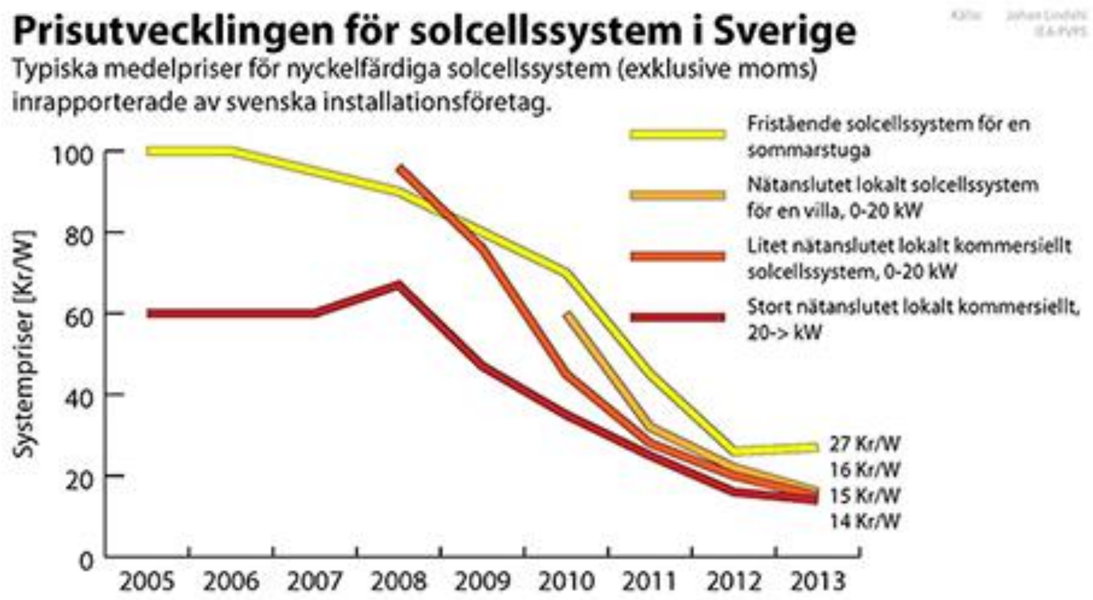

Figure 33: The cost trend for solar PVs.

Energimyndigheten. (2014) *Fortsatt starkt intresse för solceller gav solcellseffekt på 43,1 MW under 2013.* Retrieved April 12, 2014, from https://www.energimyndigheten.se/Press/Pressmeddelanden/Fortsatt-starkt-intresse-for-solceller-gav-solcellseffekt-pa-431-MW-under-2013/