CALCULATION MODEL FOR LCC-ANALYSES OF PHOTOVOLTAIC SYSTEMS IN SWEDEN

The introduction of tax reduction as a subsidy

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Master Thesis in Energy-efficient and Environmental Buildings
Faculty of Engineering | Lund University

Lund University

Lund University, with eight faculties and a number of research centers and specialized institutes, is the largest establishment for research and higher education in Scandinavia. The main part of the University is situated in the small city of Lund which has about 112 000 inhabitants. A number of departments for research and education are, however, located in Malmö and Helsingborg. Lund University was founded in 1666 and has today a total staff of 6 000 employees and 47 000 students attending 280 degree programs and 2 300 subject courses offered by 63 departments.

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The degree project is the final part of the master program leading to a Master of Science (120 credits) in Energy-efficient and Environmental Buildings.

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Abstract

It is quite complicated to make a detailed and reliable economic analysis of a photovoltaic system. The electricity consumption and production of the specific building and system should be considered with at least hourly measurements in order to analyze how the production is allocated. In combination with a number of factors such as the development of electricity price, initial investments costs and policies during the lifespan, turns the choice of system into a complex equation that have to be performed and updated carefully and frequently.

Sweden is about to introduce a new subsidy system, with the goal of supporting small-scaled PV produced electricity enough to increase the interest in renewable energy sources.

The aim with this research was to develop a tool that can make detailed economic analyses of PV systems and use this tool to evaluate how the upcoming changes to the subsidy system will affect the design phase of PV systems.

With the current selling price, one unit of self-consumed electricity is worth twice as much as exported, and it is therefore important to maximize the self-consumption. It is in some cases possible to slightly increase the level of self-consumption by orientating the array away from its maximum production, but this cannot be done in a way that is economically supportable. However, orientations that are relatively close to optimal, presents economical results that is almost as good. With this in mind, there is no point in spending extra money on optimizing the available building surfaces in terms of orientation in order to achieve better results.

With the added tax reduction, the price of sold electricity is comparable to the price of bought and it improves the economical results of all PV systems with some kind of over-production. With the assumed price development in this report, the buying price will increase and get higher than the selling price as the years go by, and the importance of self-consuming the produced electricity will get bigger for every year to come.

A wider range of buildings will be able to install systems with a positive result than before, but buildings that today can install economically supportable systems will benefit the most from the tax reduction and will be able to install even larger systems than before. Buildings with a high base load should dimension the systems for maximum production without over-producing more than the limitations of the tax reduction. However, single family houses that already have problems with dimensioning profitable PV systems, will not benefit significantly.

Even though the upcoming subsidy will be a step in the right direction, it is not good enough to support small-scaled PV production, at least not from a single family house owner's perspective.

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// Martin & Hannes
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Abbreviation

A-Si	Amorphous and micromorph Silicon,
BIPV	Building Integrated PV systems.
CIGS	Copper-Indium-Gallium-(di)Selenide,
DSM	Demand Side Management
FIT	Feed- in Tariff
IPCC	The Intergovernmental Panel on Climate Change
LCC	Life Cycle Costs
LCOE	Levelized Cost of Electricity
MC-Si	Multi Crystal Silicon
NPV	Net Present Value
O&M	Operation and Maintenance
PV	Photovoltaics, i.e. electric power generation with solar cells.
SC-Si	Single Crystal Silicon
UNEP	United Nations Environment Programme
VAT	Value-Added Tax
WMO	World Meteorological Organization

1 Background

1.1 Energy and environmental issues

The Intergovernmental Panel on Climate Change, IPCC, established by the United Nations Environment Programme, UNEP, and the World Meteorological Organization, WMO, is constantly working on presenting clear and robust conclusions in a global assessment of climate change science. Thousands of scientists across the world contribute to the work of the IPCC and the fifth assessment report shows, with a summarized opinion, a clear-cut picture that the climate is getting warmer. Warming of the atmosphere and the ocean, diminishing snow and ice, rising sea levels and increasing concentrations of greenhouse gases are all indicated climate changes with tremendous consequences (IPCC, 2013).

A well debated question is whether the global warming is a caused by humans' with our resource consuming lifestyle in modern society or if this is something that simply is out of our hands. Regarding this, IPCC now also concludes that the evidence for human influence has grown since the forth assessment report in 2007 and it is now extremely likely that human influence has been the dominant cause of the observed warming since the mid-20th century. This is evident from the increasing greenhouse gas concentrations in the atmosphere which primarily is due to fossil fuel use.

Today, fossil fuels are the dominant primary energy source on earth and in order to limit the emissions of greenhouse gases, it is crucial that the usage of this energy source is reduced. However, with a steady growth in population this is easier said than done.

Fossil fuels is not a renewable energy source and even if we're quite far from there yet, our recourses will eventually run out and whether it being for environmental reasons or not, we will have to find a different solution.

1.2 Alternative energy sources

There are a lot of different alternative energy sources that can and already are replacing fossil fuels and that emit none or at least very small proportions of greenhouse gases.

Wind energy allows generation of electricity from wind. Geothermal energy can use the earth's internal heat to heat water for heating buildings or generating electricity. Biofuel and ethanol are plant-derived substitutes for gasoline that can fuel vehicles. Hydroelectric energy allows generation of electricity from water in motion. Solar energy can with solar thermal technologies capture heat and more complex technologies can also convert the sunlight to electricity.

1.3 EU directives

The European commission is regularly implementing new targets and demands on how to limit emissions and reduce the energy consumption on our planet. Meetings on 7-8th of March 2007, Member states committed to fulfil four goals before 2020, commonly known as the "20-20-20" target (Council of the European Union, 2007).

- 20% reduction of greenhouse gas emissions compared to levels from 1990.
- 20% of the energy consumption should come from renewable energy sources.
- 20% reduction in total primary energy use, achieved by improving energy efficiency.
- Increase the proportion of biofuels used for vehicles to 10%.

Energy consumption in residential and commercial buildings represents around 40% of the total primary energy use of the European Union's member states and is also responsible for 36% of the total CO_2 emissions. The buildings sector is also increasing which is bound to increase its energy consumption. Therefore, it is essential that the sector reduce its energy consumption and increase its energy from renewable sources, to be able to apply with the "20-20-20" target by the end of 2020.

In consequence of the "20-20-20" target, on 19 May 2010, a recast of the Energy Performance of Buildings Directive, EPBD, was adopted by the European Commission. According to the directive, member states should ensure that:

- By 31 December 2018, new buildings occupied and owned by public authorities are nearly zero-energy buildings.
- As of 31 December 2020, all new buildings are nearly zero-energy buildings and the energy will be 'to a very large extent' from renewable sources.

To achieve this, national roadmaps towards nearly zero- energy buildings are needed for all member states with plans for increasing the number of nearly zero- energy buildings. The plans should include the member state's detailed application in practise of the definition of the nearly zero-energy buildings, reflecting their national, regional or local conditions, and including a numerical indicator of primary energy use expressed in kWh/m^2 per year. Primary energy factors used for the determination of the primary energy use may be based on national or regional annual average values and may take into account relevant European standards. The plans should also include, inter alia, intermediate targets for improving the energy performance of new buildings, by 2015. (European Commision, 2010)

A nearly zero-energy building is defined in the EPBD recast as "*a building that has a very high energy performance. The nearly zero or very low amount of energy required should be covered to a very significant extent by energy from renewable sources, including energy from renewable sources produced on-site or nearby*".

This means that by 2020, all our new buildings do not only need to be very low energy consuming, but they also need to self-produce all or at least close to all the remaining energy in order to fulfil the requirements of being a nearly zero-energy building. This means that we will see a big upswing in on-site production of renewable energy sources in the near future. For this, solar energy is an possible choice since it can be well integrated into the building and is one of the most promising renewable energy technologies with a rapidly expanding market.

1.4 Solar energy

As mentioned in chapter 1.2, solar energy can either be captured as heat with solar thermal technologies or as electricity with PV technologies. The solar thermal technology can in a simplified way be described as the procedure when heat from the sun is captured and stored in a liquid or gas. The technology behind solar electricity is however completely different.

1.4.1 Solar spectrum & Radiation

Solar radiation is caused by fusion of hydrogen in the sun that transforms hydrogen into helium which is a more stable gas, and the extra energy is emitted as radiation (Miljöportalen, 2010). The irradiance level outside the atmosphere is about 1370 W/m2, but the maximum level on earth is about 1000 W/m2. The difference have been absorbed or scattered by molecules in the atmosphere.

The emitted radiation is as a mix of photons with different wavelengths. This can be presented as a spectrum that differs from ultra violet radiation to infrared radiation. Different wavelengths are measures of how much energy the photons have; more energy gives a higher frequency which results in shorter wavelengths.

The human eye can see wavelengths between 400 and 700 nm. Figure 1.1 shows the distribution and intensity over the spectrum and as seen, the radiation is most intense at wavelengths of about 500 nm. The visible and near infrared radiation is responsible for 53% and 44% of the total energy content respectively (Fieber, 2005).

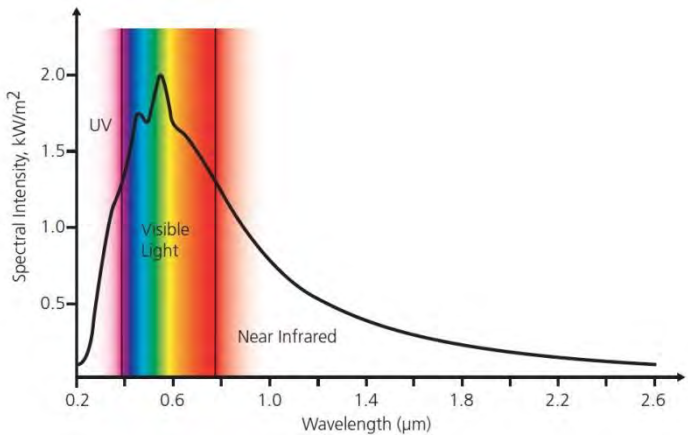

Figure 1.1 - Spectral intensity of solar radiation between 200 and 2600 nm (Fieber, 2005).

Solar radiation can be divided into four parts, seen in Figure 1.2. Direct radiation is the radiation that not in any way is blocked by objects like clouds etc. Radiation that is blocked by clouds or reflected by other objects is called diffuse radiation. Diffuse radiation reflected from the ground is usually in its own category and called ground reflected radiation. The reflection varies with the albedo of the object. Snow is a material with high albedo and thus has a high reflectance while asphalt has a low albedo and thus a low reflectance. The last part is the circumsolar radiation which is radiation that comes from angles close to the sun but still outside the solid angle of the sun. The total solar radiation measured on a horizontal surface including direct, diffuse, circumsolar and ground reflected radiation is called the global radiation.

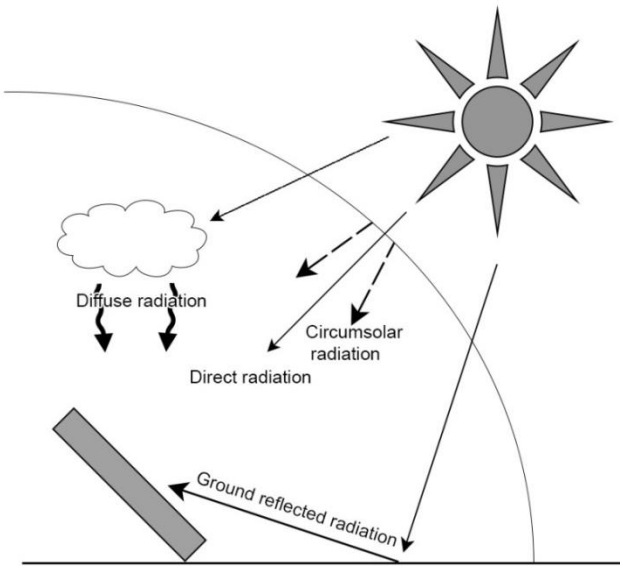

Figure 1.2 - Different types of radiation: direct, diffuse, circumsolar and ground reflected.

1.4.2 PV technology

1.4.2.1 Cells, modules & arrays

The smallest part in a PV-system is normally represented by the photovoltaic cells. They are typically square sized from 12.5 cm up to 20 cm and can in general be classified as either wafer-based crystalline (single crystal and multicrystalline silicon, compound semi-conductor), thin film or organic. As of right now, crystalline silicon technologies is without a doubt the most common one with roughly 80% of the total cell production in the IEA PVPSs 28 participating countries.

Single crystal silicon cells, SC-Si, have commercial efficiencies between 16 and 24%. At the same time, multicrystalline silicon cells, MC-Si, are becoming more popular as they are less expensive to produce but are less efficient with average conversion efficiency around 14-17%. Thin film cells are even less efficient, currently with a range from 7% of the amorphous and micromorph silicon cells, A-Si, to 13% of the copper-indium-gallium-diselenide cells, CIGS, but they are also potentially even less expensive to manufacture.

The disadvantage of having a low efficiency of the PV cells is that the system requires a bigger surface area to produce the same amount of electricity. Organic thin film PV cells have recently created interest which has led to the takeoff of a lot of research, development and demonstration activities.

One single PV cell is very small and cannot produce particularly much electricity, in order to produce more electricity they are put together as a module. A PV module's structure depends on which kind of PV cells it is based on. Crystalline silicon modules consists of individual PV cells connected together and encapsulated between a transparent front, typically glass, and a backing material, usually of glass or plastic. Thin film modules on the other hand, encapsulate PV cells formed into a single substrate, in a flexible or fixed module with transparent plastic or glass as the front material.

To produce a required amount of power, a number of modules are usually needed. Then a number of modules are connected in series, forming strings and then coupled in parallel, forming PV arrays (IEA, 2013).

1.4.2.2 PV-systems & components

A PV system can either be grid-connected or work independently off the grid. An off-grid system requires a storage battery to provide electricity when the sunlight is not sufficient. The most commonly used batteries in PV systems are of the deep discharge lead-acid type but there are also more expensive alternatives of batteries that are less sensitive for over-charging or deep-discharging.

An important parameter is that a battery's lifetime typically is between 5 to 10 years so during the lifetime of a complete PV system, the battery might have to be changed multiple times, making it a rather big factor in an economical evaluation. To protect a battery from deep discharge or overcharging, maintaining it at the highest possible state of charge and provide the user with the required amount of electricity, a charge controller is used.

Grid-connected PV systems work differently. The PV array produces electricity in direct current, DC, and the electricity grid can only be supplied with alternating current, AC. Therefore a grid-connected PV system needs something that can convert the electricity from DC to AC. This problem is taken care of with an inverter. An inverter is nowadays very efficient but there are still some small losses that are important to keep in mind. Efficiencies of 95% to 97% are typical, with peak efficiencies reaching 98%. Off-grid systems can also be equipped with a stand-alone inverter if there is a need for AC electricity (IEA, 2013).

This is only some of the many important components included in a complete PV system.

1.4.2.3 PV-Physics

A photovoltaic cell is basically a semiconductor that works like a diode. A current in a photovoltaic cell is produced when a high energy photon excites an electron within the material. The photon transfers its energy to the electron which makes a jump from the valance band. If the transferred energy is lower than the band gaps the electron will remain at the valance band. The band gap is the energy difference between the valance and the conduction band, which in PV-cells are purposely rather small to get the wanted properties of the cell. If the electron receives the same amount energy as the band gap or more it will

get excited to the conduction band and transferred throughout the circuit and a current occurs. The band gap is directly connected to the maximum voltage that the PV-cell can produce, while the current is dependent of the amount of radiation. With more sunlight, there are more photons and higher currents are possible (Bernardo, 2013).

A common way to present the characteristics of a PV-cell is by plotting the current-voltage curve (IV-curve) of the cell. The IV-curve shows how the specific cell behaves during different resistance-levels at a certain condition. Figure 1.3 shows a typical IV-curve.

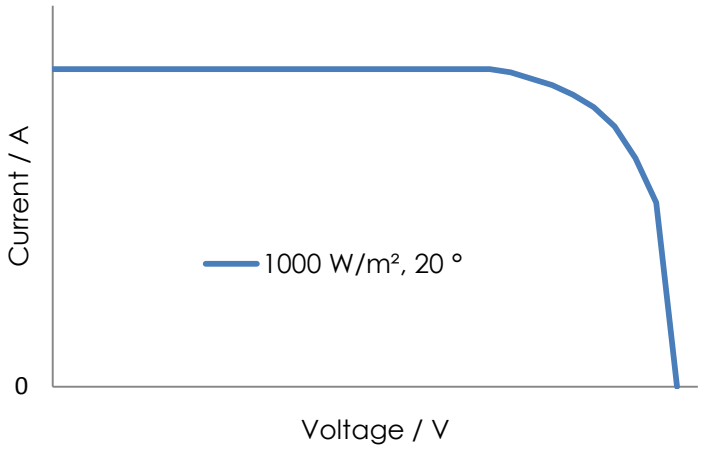

Figure 1.3 - Example of a typical IV-curve at a certain condition.

The max point on the y-axis is called short circuit current, I_{sc}, and the maximum point on the x-axis is called open circuit voltage, V_{oc}, and together they are two of the most important characteristics of the PV-cell.

It can be seen that the current drops when the voltage gets too high. The knee where this drop occurs is usually the point where another very important factor, the maximum power point, MPP of the PV-cell is found. This is where the combination of current and voltage is at its highest and where the system works as efficient as possible. Most of the inverters on the market today have an integrated maximum power point tracker, MPPT, built in that actively forces the PV-cells to work at this point to maximize the efficiency and get a stable and continuous output.

As mentioned previously photovoltaic cells have efficiencies up to 24%. This is mainly because the efficiency is calculated as a ratio between the output of the PV-cell and incoming radiation on a surface outside the cell, and not in the cell. A lot of the incoming radiation is reflected on the surface of the PVs and of the radiation that reaches the PV-cell, not all of the photons have enough energy to excite an electron, and furthermore a lot of the photons have too much energy. A basic but important fact to notice when discussing the efficiency of solar energy systems is that a photon only can be used once. A high energy photon can transfer all of its energy to an electron, but the electron will jump to a level

higher than the conduction band and then fall back down to the conduction band, and emit the extra energy as heat.

The efficiency of a PV cell is strongly dependent on the temperature of the cell. With a higher temperature, the band gap is reduced. With a reduced band gap, the photons need to transfer less energy to excite the electrons to the conduction band. This increases the current slightly since more photons have enough energy and makes it through the circuit, but the main effect is that the voltage of the system is reduced drastically. Figure 1.4 shows an illustration of how the IV-curve is affected by a change in either irradiation or temperature (Bernardo, 2013).

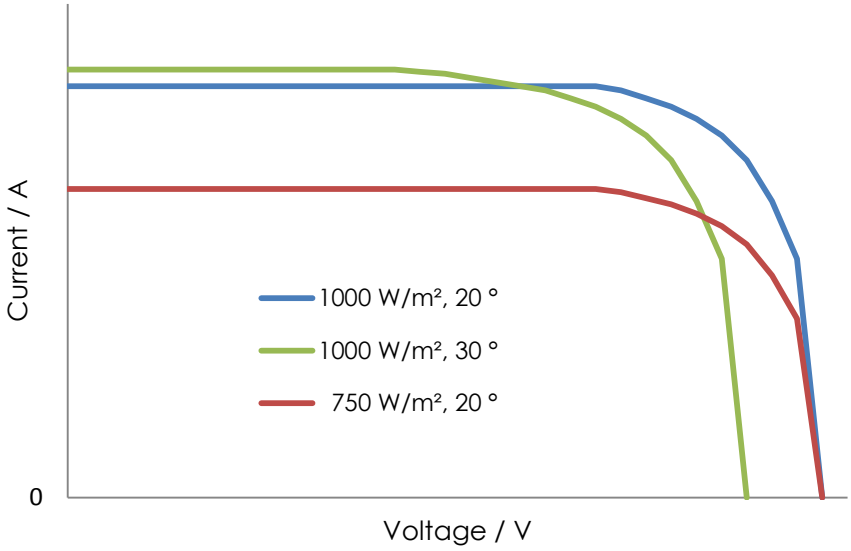

Figure 1.4 - Example of how temperature and different radiation levels affects an IV-curve.

1.4.3 Past and present situation for photovoltaics

1.4.3.1 Worldwide

Even during difficult economic times, PV technology has over the past decade grown at a spectacular rate and is on the way to becoming a major source of power generation in the world.

Noticed in Figure 1.5, we were approaching the 10 GW mark of total installed PV capacity in the world at the end of 2007. Since then, the evolution of the global PV capacity really has been remarkable, to the point that at the end of 2012, only five years later, the capacity had grown with 1000% and broke into 100 GW mark. This is an amount that is capable of producing at least 110 TWh of electricity each year, which is enough to cover the annual power supply need of over 30 million European households. Europe represents the world's leading region in terms of PV capacity with about 70%, as of 2012.

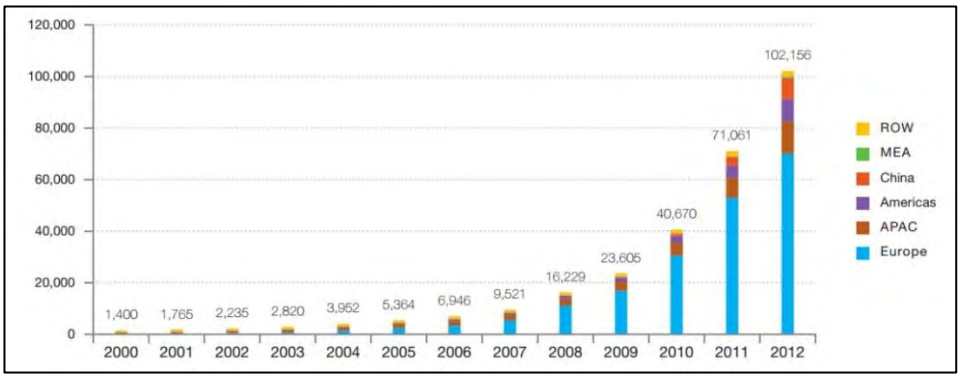

Figure 1.5 - Evolution of global PV cumulative installed capacity 2000-2012 (MW) (ROW: rest of world, MEA: Middle East and Africa, APAC: Asia Pacific) (EPIA, 2013)

From Figure 1.6 it is noticeable that 2012 might be a turning point for the PV market evolution, in different aspects. The last couple of year's strong growth seems to be stabilized in 2012, in fact the amount of installations in Europe was smaller in 2012 compared to 2011. However, in some countries the PV market continues to grow and areas like Asia will likely continue to grow over the upcoming years (EPIA, 2013).

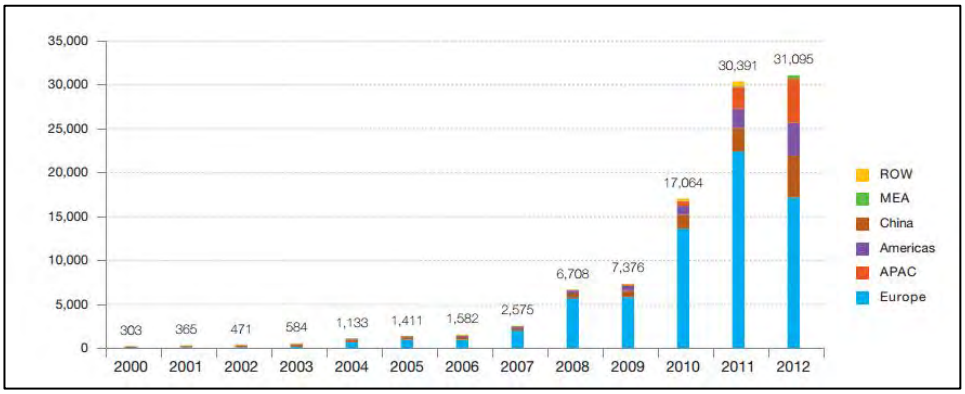

Figure 1.6 - Evolution of global PV annual installations 2000-2012 (MW) (ROW: rest of world, MEA: Middle East and Africa, APAC: Asia Pacific) (EPIA, 2013)

1.4.3.2 Sweden

Even though the global PV market has stabilized in 2012, the interest continues to grow rapidly in Sweden. Recent statistic updates is saying that during 2013, new PV systems were installed with a capacity of 19 MW, compared to 8.3 MW during 2012. The total PV capacity in Sweden at the end of 2013 was 43.1 MW. One of the contributed reasons to the increased popularity in Sweden is the price development of PVs. Separate PV modules as well as complete systems continued to get cheaper during 2013 in Sweden, simply being a consequence of the international price development during recent years. It is however not very likely that the PV prices in Sweden continues to drop this rapidly in the upcoming years since the module prices on the international market stabilized during 2012 (Lindahl, 2014).

1.4.4 Future potential and market evolution

When discussing the future market evolution of PVs there is mainly four key questions that will be a determining factor:

- Policy: PV is a policy-driven market where political decisions have a huge impact of in which way the market will evolve. With the right decision making, creating sustainable and smart support schemes, the PV market can continue to grow.

- Competitiveness: PV is in terms of LCOE rapidly becoming competitive with other power sources. However, challenges with grid and market integration will get more serious as the PV deployment gets bigger.

- Industry consolidation: In the last few years, the module production capacity has been a lot higher than the annual global installations. This is having a big impact on companies involved, making it hard for them to survive.

- Trade: Trade disputes in parts of the PV industry are creating uncertainty that may affect markets forecasts in the next few years.

Unquestionable is however, the enormous potential and benefits PV can and already is bringing to the power system and the promise it holds for supporting the achievement of vital energy, environmental and economic goals. PV will continue to influence the energy situation around the world and is becoming a reliable source of clean, safe and renewable energy for everyone (EPIA, 2013).

1.5 Objectives

With the tools publicly available today, it is rather easy to calculate and simulate the peak power and annual electricity production of a PV system, even for someone who do not have knowledge in the field. This output is often the only data used for an economic analysis of a PV system, and in some cases the results are quite good, at least when all the electricity produced is used directly in the building.

It is however more complicated to make a complete and more reliable analysis. The electricity consumption data of the specific building must be considered with measurements not only on a yearly or monthly basis but with at precision of at least hourly values. The same measurement frequency is needed for the simulated PV produced electricity and additionally, economical aspects of how to value self-consumption, over-production and under-production are needed.

This complexity makes it harder to find the most economical solution for a specific building. On top of this, electricity prices, investment costs, policies and subsidies are constantly changing which makes it important that these analyses are done frequently to be updated with most beneficial solutions.

Sweden is on the way of introducing a new subsidy system, with the goal of supporting small-scaled PV produced electricity enough to increase the interest in renewable energy sources.

The aim with this research is to develop a tool that can make complete economic analyses of PV systems and use this tool to evaluate how the upcoming changes to the subsidy will affect the design phase of PV systems.

The reasoning above has led to the following questions, which this research will focus on:

- What are the economic influences of using electricity internally versus exporting it to the grid?
    - Could it be beneficial to turn the PV array away from the orientation that presents its annual maximum production, in order to match the internal electric load better?
- On which type of building is it most beneficial to place a PV system?
    - Will more buildings be able to install a PV system that is economically supportable with the upcoming subsidy system?
    - Will the subsidy system also affect the most optimal system size?

1.6 Limitations

This thesis has limited its research field to only investigate grid connected PV systems which means that the calculation model that is developed will not be able to handle off-grid systems where batteries are included.

The results are based on the geographical location of Lund in Sweden and the presented conclusions can therefore not with certainty be representative for different locations.

The PV production simulations are based on theoretic calculations with no consideration of snow and/or dirt potentially covering the PV array. Additionally no shades from potential surrounding object are analyzed or possible increases in radiation from reflective surfaces such as snow etc.

The results in this research are based on case-studies. Four different cases were investigated regarding each building type. It cannot however be guaranteed that these are representative for similar buildings.

The layout and shape of the buildings investigated in the case studies is unknown. This means that it is not sure that all the PV systems evaluated would actually fit on all of the specific buildings available surfaces.

1.7 Method

To develop a complete tool for the evaluation of PV systems and to be able to answer the questions presented in Chapter 1.5, a lot of different segments have to be included. In Figure 1.7, a schematic is showing all the segments included in the tool and their relationship to each other. The different segments will be discussed separately throughout the research report and concluded in the end through the economic analyses.

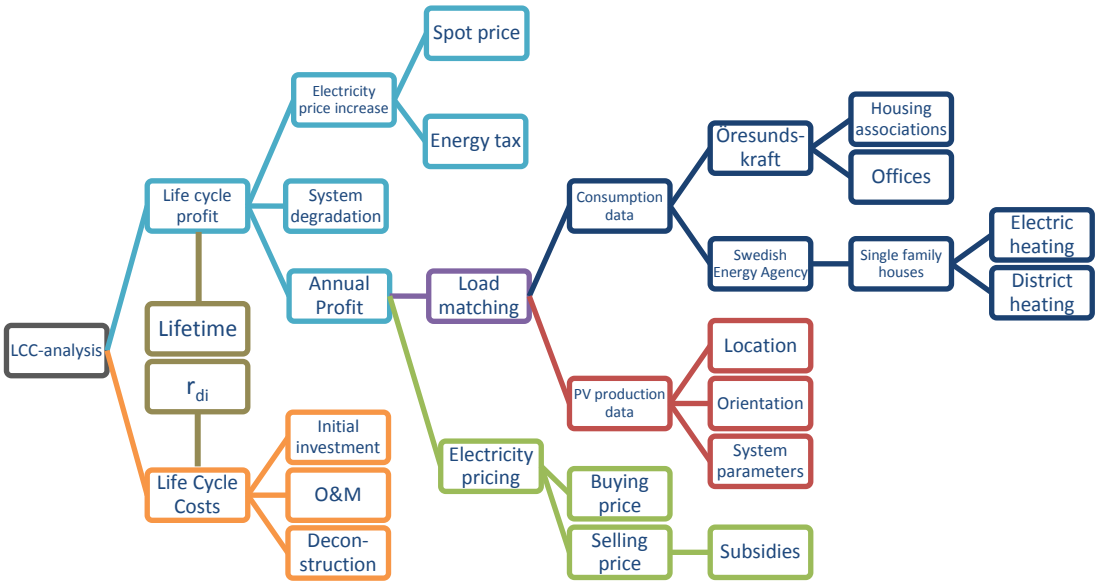

Figure 1.7 - Model segments and their relationships to each other.

This tool have been developed in excel and have later been used to be able to draw conclusions and answer the questions presented in the objectives chapter, 1.5.

2 Electricity profiles

2.1 Consumption data

An electricity consumption profile of a building is a graph showing the electric load at specific times, based on measured data. Every building has its own unique consumption profile that will vary dependent on, for example:

- Heating - What kind of heating system is used? District heating, gas, heat pumps, electric heating? How is the heating controlled? Timers with specific heating patterns or is it just random? Different settings for weekends and holidays? What is the climate like, outside the building?

- Ventilation and air conditioning – Is it a mechanical ventilation system with fans? Heat recovery? Is there air conditioning? If so, is it used all year around to achieve a good indoor environment? At certain times to keep some equipment cool? Or is it used only during summer to limit potential overheating problems?

- Lighting – Is there an efficient lighting system, both in terms of power need of single lights and selection of control device. When do the lights come on and off, automatic sensor detection or on/off switch? Is light on even when it's not needed, due to sufficient daylight or even when there is no occupancy in the zone?

- Electric equipment – Is the electric equipment energy efficient? Is it turned off when not in use? Stand-by losses?

This thesis will look at a couple of different building types where the consumption profile can differ quite a lot with different electricity sources and occupancy patterns. All the consumption data used is measured with a time frequency of one hour. Data with lower time resolution than this was considered too vague to be used in this research and would limit the reliability of the results.

The building types that will be evaluated are:

- Single family houses with district heating.

- Single family houses with electric heating.

- Apartment blocks with district heating.

- Offices with district heating.

2.1.1 Swedish Energy Agency

Consumption data was partly collected from the Swedish Energy Agency and their report "End-use metering campaign in 400 households in Sweden – Assessment of the potential electricity savings" by Jean Paul Zimmermann in 2009 (Zimmermann, 2009).

2.1.1.1 Single family houses with district and electric heating

Consumption data from four different houses have been evaluated during this research. Information regarding the houses can be seen in Table 2.1. House 1-2 were heated with electric heating and house 3-4 used district heating. The differences in heating system have a huge impact of the total electricity demand, which is why the two different alternatives have been evaluated separately.

The amount of occupants in the houses should have an impact of the consumption profiles and this research looks at typical households of 3-4 family members. To be able to compare the results and draw conclusions, houses of roughly the same size have been looked at.

The location of the houses will have a big impact on the consumption demand in an electric heated house while it probably has a smaller impact in houses heated with district heating since the occupancy patterns inside a house probably does not change very much dependent on the outdoor climate.

Table 2.1 - Specifications of evaluated houses.

	Electric heating		District heating	
House number	1	2	3	4
Occupants	4	4	3	3
Living space / m^2	130	120	129	90
Additional space / m^2	-	60	-	20
Location	Central Sweden	Central Sweden	Southern Sweden	Northern Sweden
Annual electricity demand / kWh	15 633	20 957	5 538	4 006

Figure 2.1 to Figure 2.3 shows typical daily consumption profiles of the evaluated single family houses. Figure 2.1 shows that the occupancy patterns in a district heating house, generally, don't change depending on the heating season. The total electricity consumption however, is normally lower during the summer months since more time is spend outside.

These graphs also show that the house investigated have an idle consumption that can include electricity needed for the running of refrigerators, freezers, digital clocks on microwaves, stand-by losses and many other things. During weekdays, the consumption is

quite low and stable during the night when the occupants are sleeping and also low during the day when occupants are at work or in school. The consumption goes up during the mornings and also mainly during late afternoons and evenings when the house is occupied.

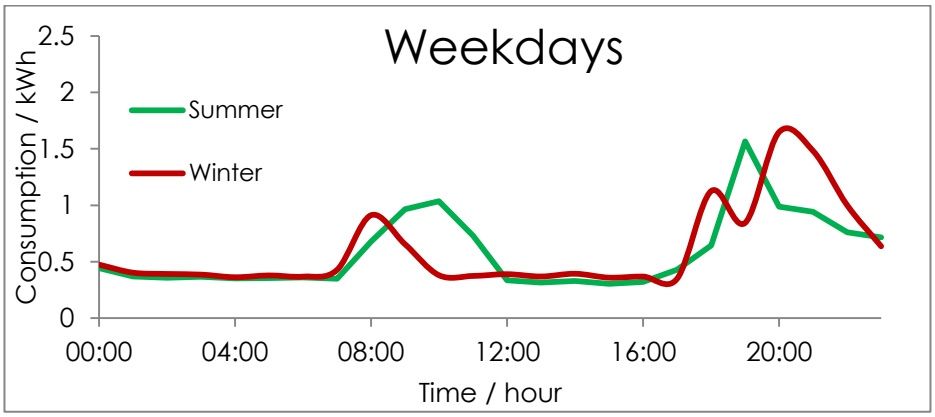

Figure 2.1 - Typical weekday consumption profile of single family houses with district heating. Graphs formed from consumption data received from the Swedish Energy Agency (Swedish Energy Agency, 2014).

During weekends, seen in Figure 2.2, the consumption profile is a bit different in single family houses. People usually sleep a little bit longer, but they are also home more during the day which leads to a higher consumption during more hours of the day.

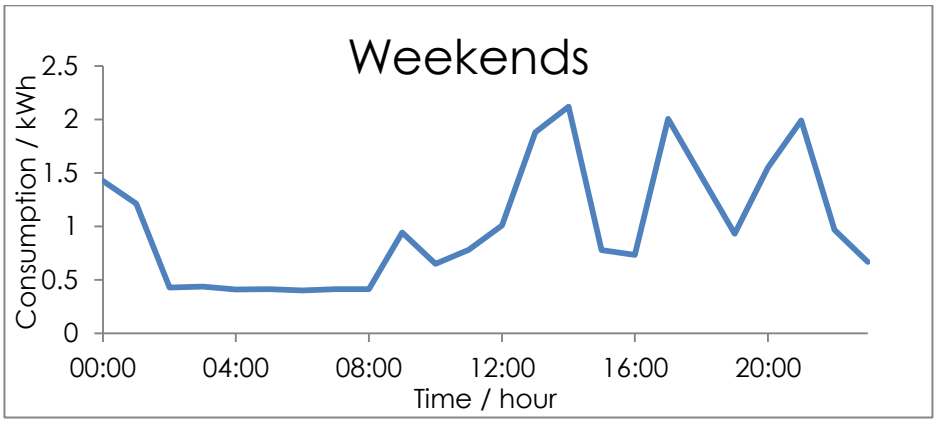

Figure 2.2 - Typical weekend consumption profile of single family houses with district heating. Graph formed from consumption data received from the Swedish Energy Agency (Swedish Energy Agency, 2014).

Figure 2.3 shows the electricity consumption profiles for a single family house using electric heating. One graph represents a summer day and one represents a winter day. The difference in the graphs shows that during summer, when there is no, or limited heating need, the consumption profile is quite similar to the district heated house. But during winter when there is a heating need for the house, the consumption profile for the electrically heated house is on another level with a higher base of consumption. The occupancy patterns however, are the same, with peaks during mornings and evenings.

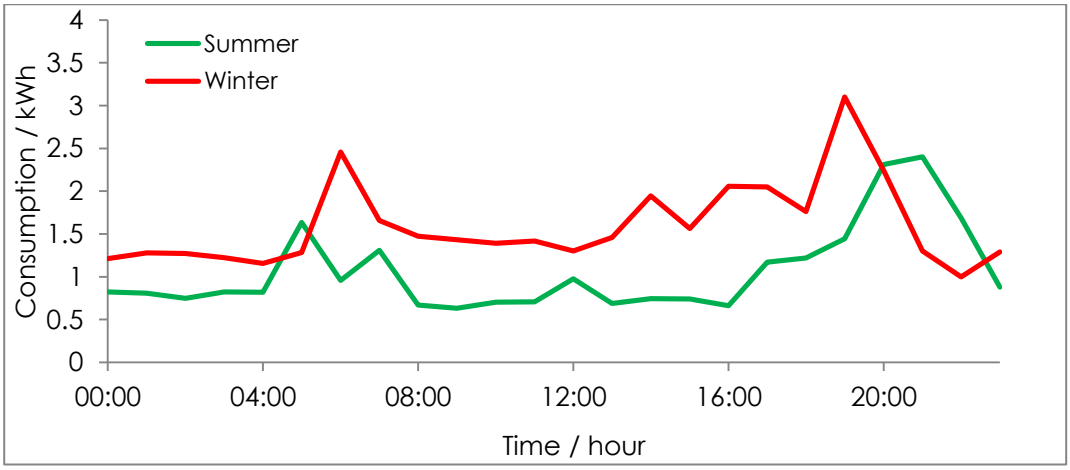

Figure 2.3 - Typical weekday consumption profiles of a single family house with electric heating. Graph formed from consumption data received from the Swedish Energy Agency (Swedish Energy Agency, 2014).

Summarized on a monthly basis, these seasonal changes have a big impact of the total electricity consumption, seen in Figure 2.4. Noticeable is the electricity consumption in a district heated house which is more or less constant, compared to the electric heated house where the monthly variations are significant.

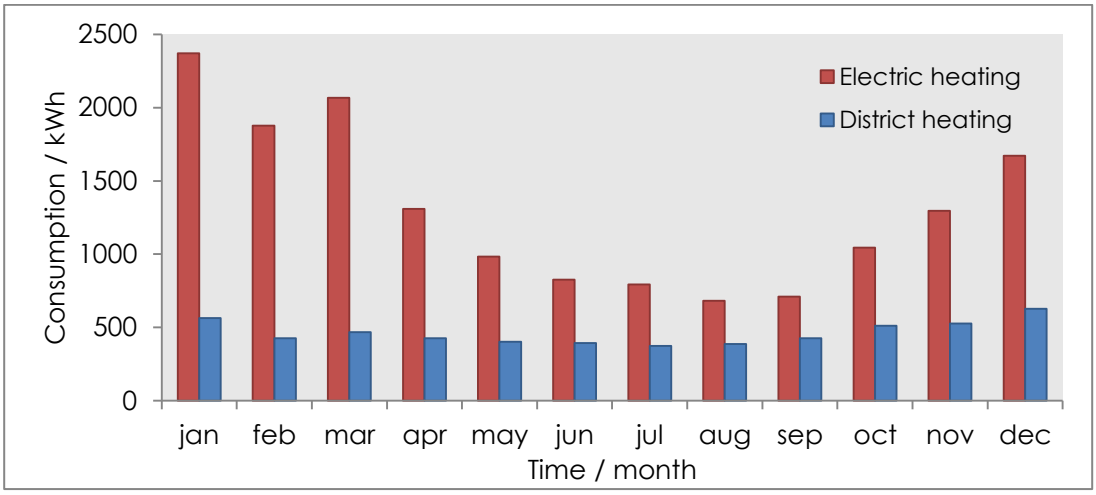

Figure 2.4 - Monthly electricity consumption data from house 1 and house 3 of the evaluated cases. Graph formed from consumption data received from the Swedish Energy Agency (Swedish Energy Agency, 2014).

2.1.2 Öresundskraft

Öresundskraft is an energy company in Sweden that produces and sells energy in different forms, mainly electricity and district heating, but also gas and district cooling. Öresundskraft have supported this research by giving access to electricity consumption data from some of their customers. Electricity consumption data that was asked for was from apartment blocks and offices with district heating. Öresundskraft did not have the rights to present too many specifications about the buildings, only the main characteristics were received.

2.1.2.1 Apartment blocks with district heating

In an apartment block with a various number of apartments, the total electricity consumption is much larger than the single family houses described earlier. A housing association cannot force the tenants to buy electricity from a potential on-site producing PV system. Tenants have their own rights to pick and choose an electricity distributer by themselves. Due to this, it is not necessary or even logical to dimension a PV system for a housing association according to its total electricity consumption. The electricity consumption of interest is instead the operational electricity of the building. This is the electricity that is used by the equipment that is running the building, for example, electricity for lighting in collective areas, washing rooms, mechanical ventilation fans, pumps for the distribution system of heat, elevators, etc. Therefore, it is the consumption data for operating electricity that is received from Öresundskraft with data from four different housing associations. This data can be seen in Table 2.2.

Table 2.2 - Specifications of the evaluated Apartment blocks.

House number	1	2	3	4
Location	Southern Sweden	Southern Sweden	Southern Sweden	Southern Sweden
Building status	New	Old	Old	New
Heating system	District	District	District	District
Annual electricity demand / kWh	144 145	42 128	59 114	52 114

Consumption profiles for housing associations have similar patterns as single family houses since they generally are occupied during the same hours over the day. One often occurring difference though is that the housing associations, especially newer build ones, have a higher base load in electricity consumption with continuous running fans for ventilation systems etc.

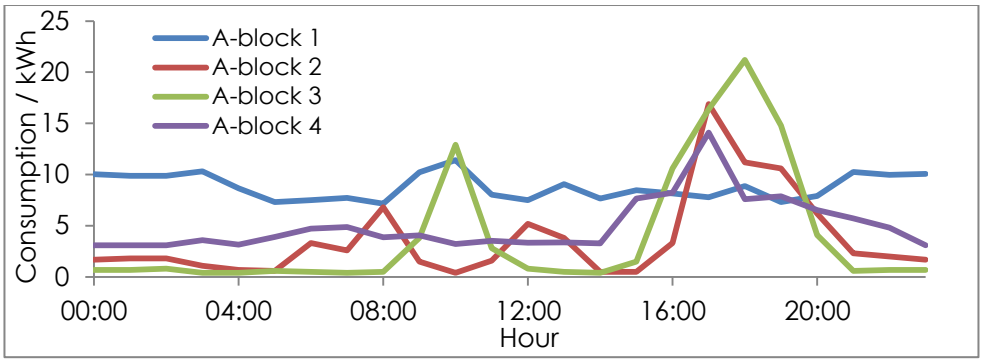

Figure 2.5 - Typical weekday consumption profiles of electricity in the four different housing associations investigated. Data received from Öresundskraft (Öresundskraft, 2014).

Older houses with less energy efficient equipment can however have higher peaks of electricity consumption even though they have a lower idle consumption without fans for mechanical ventilation systems. This can be seen in Figure 2.5, where house 1 and 4 is newer buildings than 2 and 3.

2.1.2.2 Offices with district heating

Offices are another type of building that has been evaluated. Offices generally have a different consumption profile compared to a regular single family house or a housing association. Offices are generally used during working hours, with occupancy from around 08.00 to 17.00, which is when the electricity consumption normally is the highest. Other differences are that during weekend and holidays, offices are normally empty which leaves them with a constant idle consumption with various levels depending on the equipment in the office.

One often occurring problem in offices is overheating during working hours, especially in newer offices that tend to use a lot of glazing in the facades. This is solved with cooling systems. These cooling systems generally use a lot of electricity which increases the electricity consumption even more during working hours when the sun is shining, Figure 2.6.

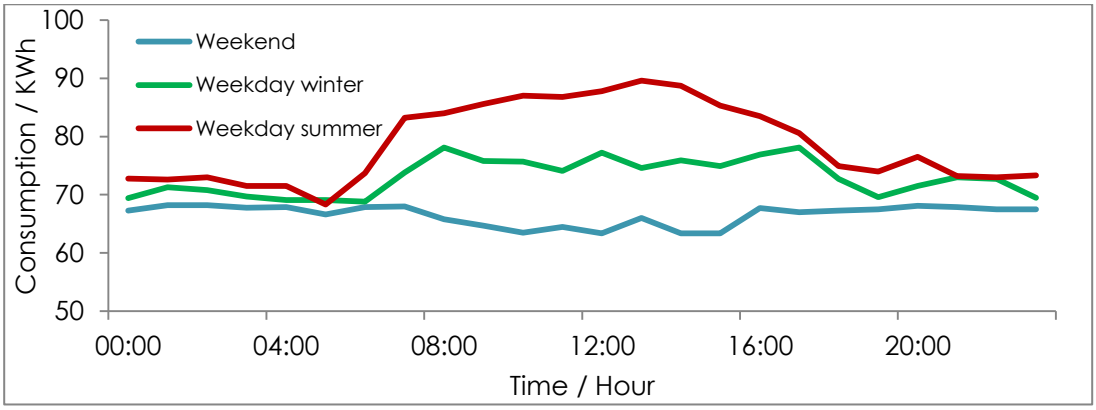

Figure 2.6 - Typical daily consumption profiles of electricity in an office. The graphs were obtained with data from office 3 from Öresundskraft (Öresundskraft, 2014).

Consumption data from four different offices were obtained from Öresundskraft. As seen in Table 2.3 the offices are quite different.

Table 2.3- Specifications of the evaluated offices.

Office number	1	2	3	4
Location	Southern Sweden	Southern Sweden	Southern Sweden	Southern Sweden
Building status	New	Old	New	Old
Heating system	District	District	District	District
Annual electricity demand / kWh	56 633	174 717	643 949	907 537

The annual electricity demand presents the biggest differences. These differences have been explained with the information received about the buildings from Öresundskraft together with an evaluation of the consumption profiles, with examples shown in Figure 2.7, of the different cases, ending up with the following conclusions:

- Office 1: New office with district heating. Mechanical ventilation system with a quite high base load consumption but a limited office space and efficient equipment resulting in a small annual electricity demand and small variations in consumption levels throughout the day.

- Office 2: Old office with district heating. Higher base load consumption than office 1, probably due to mechanical ventilation system in combination with less efficient equipment or simply because the office being bigger. This is also resulting in higher annual electricity consumption than office 1.

- Office 3: New office with district heating. A high base load consumption that includes a mechanical ventilation system but also other unexplainable sources. This results in a very big annual electricity demand. See graphs in Figure 2.6 for typical daily consumption profiles.

- Office 4: Very large and old office with district heating. Very high base load consumption and a huge unexplainable increase in consumption roughly between 04.00 and 20.00. This is probably a combination of inefficient equipment and a flushing mechanical ventilation system that is very electricity consuming. This is resulting in the highest electricity consumption of the investigated offices.

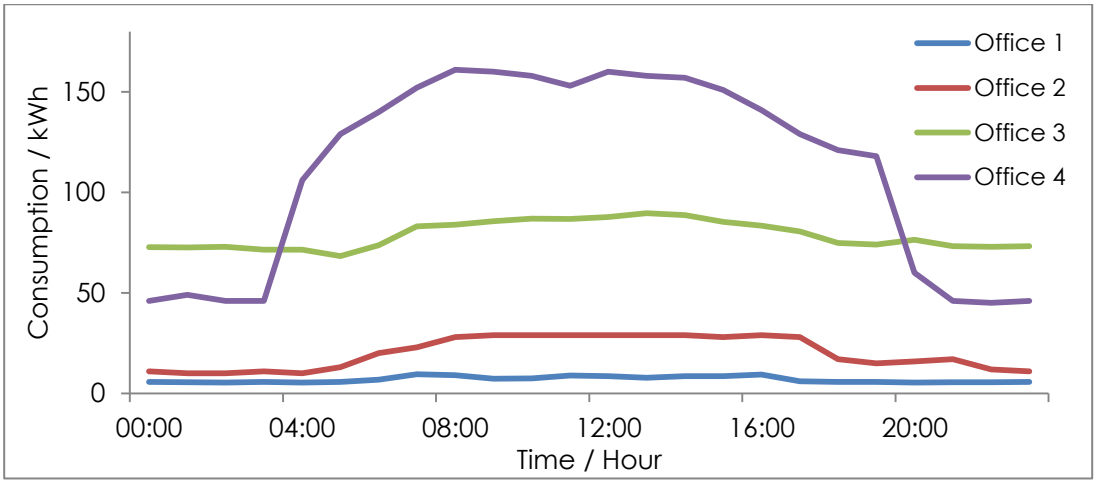

Figure 2.7 - Typical weekday consumption profiles of electricity in the four different offices investigated. Data received from Öresundskraft (Öresundskraft, 2014).

2.2 PV electricity production output

Production data from PV systems can be obtained in different ways. It is getting more common that output from existing systems is presented and publicly available through monitoring websites such as Sunny Portal (Sunny Portal, 2014) etc.

But production data from PV systems is also easily obtained through computer simulation programs. There are a lot of different simulation programs on the market today, of course with varying complexity, precision and user friendliness. Using a computer simulation program compared to output from existing buildings has its advantages during research projects since it enables all the input parameters to be changed. Output from existing systems is however always good to have and can be used as an indication and validation that simulated production is accurate.

2.2.1 PVSYST

This research used PVSYST V6.0 which is a computer software package for the study, sizing and data analysis of complete PV systems. The software is designed to be used by architects, engineers, researchers as well as for educational training and it offers three different levels of studies, corresponding to the different stages in the development of real projects. (PVSYST, 2014)

PVSYST will be used to simulate the annual production, with output from every hour of the year. The three main categories specified in PVSYST to obtain an accurate PV production are location, orientation and system specifications, seen in Figure 2.8.

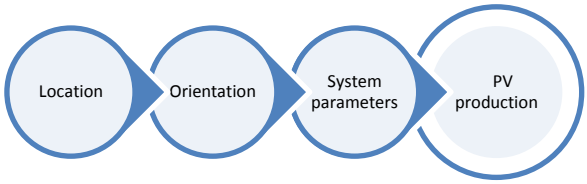

Figure 2.8 - Input categories in the production simulating program PVSYST.

The chosen power output from PVSYST is the AC power production. This means that it is the power output after the inverter which is important since the inverter doesn't have 100% efficiency.

2.2.2 Location

Based on Chapter 1.4.1, the location has a huge impact of the PV production due to varying radiation levels on earth. It is therefore also important to have a corresponding weather data file with instant weather conditions since the hourly production will be calculated. For all simulations, meteorological data from Meteonorm 6.1 (Meteonorm, 2014) for Lund were used. Meteonorm is a program that with spatial interpolation methods and measurement data from weather stations around the world generates a meteorological typical year for the chosen location. The same data is used during the whole lifecycle of the PV system and future potential climate changes are not taken into account.

2.2.3 Orientation

As seen in Figure 2.9, the orientation of a PV systems array in terms of azimuth angles (horizontal axis) and tilt angles (vertical axis) is critical for its total annual electricity production. The green area indicates roughly 90% of the maximum total annual production where the maximum production corresponds to south direction with a tilt of 40-45°, in Lund.

	90	80	70	60	50	40	30	20	10	0	10	20	30	40	50	60	70	80	90
Tilt°	W									S									E
90	56	60	64	67	69	72	73	74	74	75	74	74	73	72	70	67	64	60	56
85	59	63	67	71	74	76	77	78	79	79	79	79	78	76	74	71	67	64	59
80	62	67	71	74	77	80	82	83	83	84	83	83	82	80	78	75	71	67	62
75	65	70	74	77	81	83	85	86	87	87	87	87	85	84	81	78	74	70	65
70	68	72	77	80	84	86	88	90	91	91	91	90	89	87	84	81	77	73	68
65	70	75	79	83	86	89	91	93	93	94	94	93	91	89	86	83	79	75	70
60	72	77	81	85	89	91	93	95	96	96	96	95	94	92	89	85	81	77	72
55	74	79	83	87	90	93	95	97	97	98	98	97	95	93	90	87	83	79	74
50	76	80	84	88	91	94	96	98	99	99	99	98	97	94	92	88	84	80	76
45	77	81	85	89	92	95	97	99	100	100	100	99	97	95	93	89	86	81	77
40	78	82	86	89	93	95	97	99	100	100	100	99	97	95	93	90	86	82	78
35	79	83	86	90	93	95	97	98	99	99	99	98	97	95	93	90	86	83	79
30	79	83	86	89	92	94	96	97	98	98	98	97	96	94	92	90	87	83	79
25	80	83	86	89	91	93	95	96	96	97	96	96	95	93	91	89	86	83	80
20	80	83	86	88	90	91	93	94	94	95	94	94	93	91	90	88	86	83	80
15	81	83	85	86	88	89	90	91	92	92	92	91	90	89	88	86	85	83	81
10	81	82	84	85	86	87	88	88	88	89	88	88	88	87	86	85	84	82	81
5	81	82	82	83	83	84	84	85	85	85	85	85	84	84	84	83	82	82	81
0	81	81	81	81	81	81	81	81	81	81	81	81	81	81	81	81	81	81	81

Figure 2.9 - The way tilt and azimuth angles affect the total annual electricity production of a PV system in Lund, Sweden, presented as percentage. The table was set up by simulation results from PVSYST.

This research has performed simulations of the analyzed PV systems in multiple orientations from west to east with tilts from flat to completely vertical.

2.2.4 System parameters

PVSYST also allows the users to design the PV systems on their own. By selecting the amount and type of modules and inverters, the whole PV array is designed according to a planned power, available area or as a consideration of both.

This research have used three different turn-key PV systems packages offered by the Swedish electricity company Vattenfall (Vattenfall, 2014) since they presented fitting systems for this research. These systems are described in Table 2.4.

Table 2.4 - Description of the PV systems used during the research.

Installed power / kWp	3.3	7.7	11.1
Amount of modules	12	28	40
Required area / m^2	20	48	68
Module type	Yingli Panda YL275c-30b	Yingli Panda YL275c-30b	Yingli Panda YL275c-30b
Inverter type	Sunny Boy 3000HF	Sunny Tripower 7000TL	Sunny Tripower 10000TL
Simulated annual production with optimal orientation / kWh	3 247	7 781	11 717

When necessary, these packages have been combined to achieve a higher installed power. This has been done in some cases where the electricity consumption in the buildings is significantly higher than the production of the biggest system.

2.3 Load matching

A commonly used term when speaking about PV systems is solar fraction, which is the amount of electricity that is provided by the PV system, divided by the total electricity demand. When the whole electricity demand is provided by the PV system over a certain time period, the solar fraction is 1.0 and when no PV production is utilized, the solar fraction is 0. As mentioned before, the Energy Performance of Buildings Directive (EPBD) states that at the end of 2020 all new buildings should be nearly net-zero energy buildings and the needed energy should to a large extent be produced with renewable resources. In this case only the solar fraction is of importance. An solar fraction does however, not at all, indicate how much of the produced electricity that actually is self-consumed in the building. A PV production that matches the total consumption on a annual basis does not mean that they match every month, day, hour, minute or specific moment. Consequently, it is harder to achieve a high level of self-consumption the more into detail you go with a more frequent consumption reading.

Figure 2.10 shows how a consumption and production profile presents over-production, self-consumption and electricity that are needed from the grid.

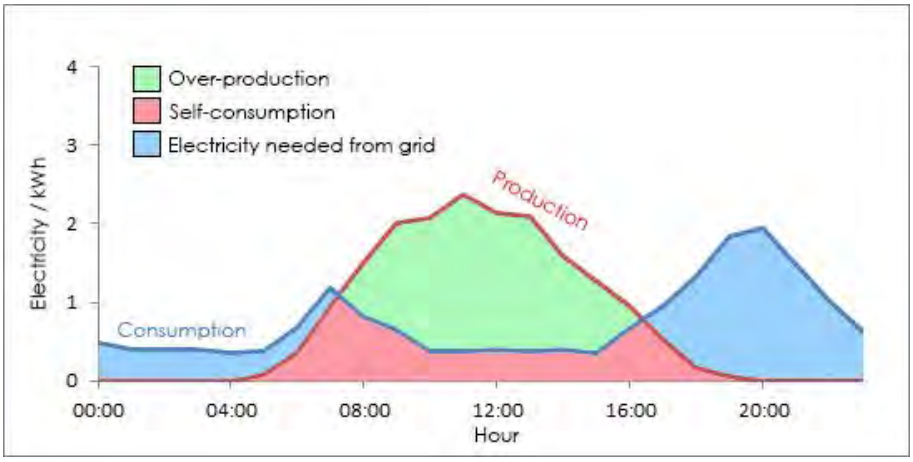

Figure 2.10 - How the production can be divided between over-production, self-consumption and the extra electricity needed from the grid during a typical day.

There are a couple of reasons to why a high level of self-consumption and a good match of consumption and production are good:

- It limits the amount of electricity that needs to be bought from the grid.
- It limits the amount of electricity submitted to the grid.

This does not only affect the consumer from an economical point but also the net owner since the mismatch between consumption and production can cause overvoltage, reverse power flow and other problems at high levels of power, generated to the distribution grid. A high level of PV penetration to the distribution grid can also affect the supply/demand balance on the electricity market as a whole. (Joakim Widén, Ewa Wäckelgård, Peter D. Lund, 2009)

2.3.1 Alternatives for improving load matching

There are a couple of different methods that can be applied in order to increase the self-consumption and limit the amount of over- and underproduction. Three different methods will be presented but this thesis will limit its research and focus on one of them.

2.3.1.1 Demand side management

DSM is a method where the focus is on the consumption profile. The goal is to reduce or shift the power demand to periods when it matches the production of the installed PV-system. To do this in a successful way, the comfort of the occupants can be influenced since it would mean that they might have to make changes to their daily routines and habits. Therefore, this procedure is questioned and it was not analyzed in this research.

As of October 2012, electricity consumers in Sweden have the rights to achieve data on their electricity consumption on an hourly basis, without having to pay additional costs. It is

easier to change the consumption patterns when there is clean information about what they look like and this can possibly lead to better consumption profiles and potentially also a lowered electricity demand as a whole (Regeringen, 2013).

2.3.1.2 Electricity storage on batteries

Batteries can extend the amount of time when a building is independent on the grid. The batteries store the overproduced electricity, which later can be utilized when the PV production is not sufficient, for example during nights and mornings. Since the cost is significantly increased and previous studies have showed that this is not cost-efficient today, this study did not investigate the use of batteries (Lindahl, 2014).

2.3.1.3 System orientation

As mention in Figure 2.9 the orientation of a PV system array is critical in terms of total annual electricity production, however, it is important to understand that the angles also affect the daily profile of the electricity production. With this in mind, a different PV orientation could possibly, in certain cases, increase the match between the production and the consumption profiles, increasing the self-consumption and limit the over- and underproduction. The effect of this is noticeable in Figure 2.11.

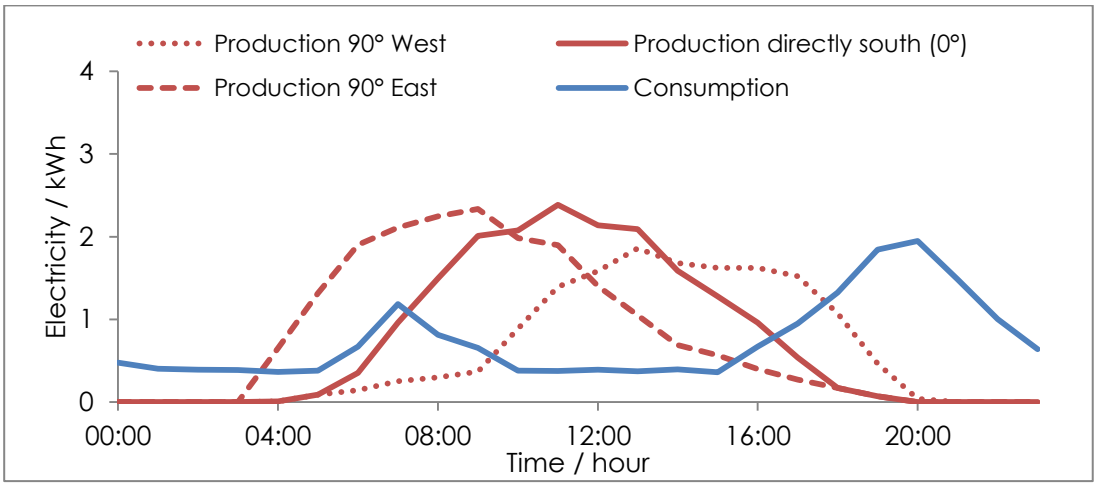

Figure 2.11 – Electricity production for three different azimuth angles is shown in red. The blue graph shows the electricity consumption. All graphs represent values from one typical day.

3 Electricity pricing evaluation

3.1 Contracting

The complexity of the electricity pricing is big in many different ways. First off, the customers are allowed to select their electricity company and negotiate the best possible deal. In Sweden there are about 120 different companies to choose from with their own kinds of offers and contract opportunities.

The four most common contracting types in Sweden are:

- Fixed price, with different binding periods: In this case you pay the same SEK/kWh during the whole binding period.
- Variable pricing, following the development of the electricity market: A variable price can vary significantly over the year according to the development of the Nordic electricity market.
- Mixed contracts with both set and variable parts: This means that you pay a part of your electricity to a set price and another part of the price is variable.
- "Until further notice" price: If you do not actively choose a contract yourself, the power distribution grid will choose an electricity provider for you. In this case you will pay a "until further notice" price for the electricity, which normally is significantly higher than what one pays if one actively makes a own choice in contracting.

Recent studies have showed that during 2013, a variable electricity price was cheaper than a set price in Sweden. (Elpriskollen, 2014).

3.2 Containing parts of the electricity price

The price for electricity in a household consists of one fixed part and one variable part. The fixed part is not dependent of the amount of electricity the user need each year. A fixed subscription fee is paid to the grid company and most commonly also to the electricity company.

The variable part is dependent on how much electricity the user consumes and is charged per kWh of electricity. The variable part itself consists of five parts, shown in Figure 3.1.

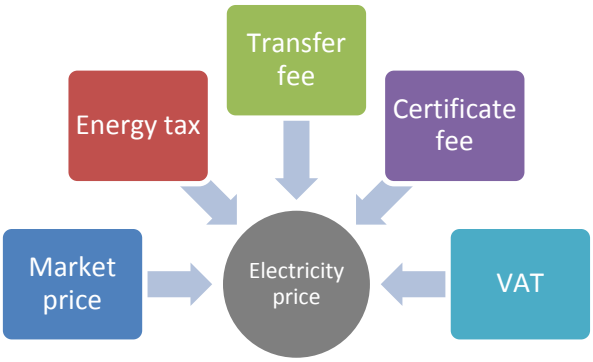

Figure 3.1 – The containing parts of the electricity price.

3.2.1 Electricity market price

The electricity market price is based on the Nordic electricity markets hourly spot prices. The hourly electricity price is determined by the balance between supply and demand. This can be influenced by factors such as the weather or power plants not producing to their full capacity etc. This leads to seasonal, daily and even hourly variations of the electricity price, noticeable in Figure 3.2 (Nord Pool Spot, 2014a). The market price and fluctuations from 2013 were used in the calculations in this research.

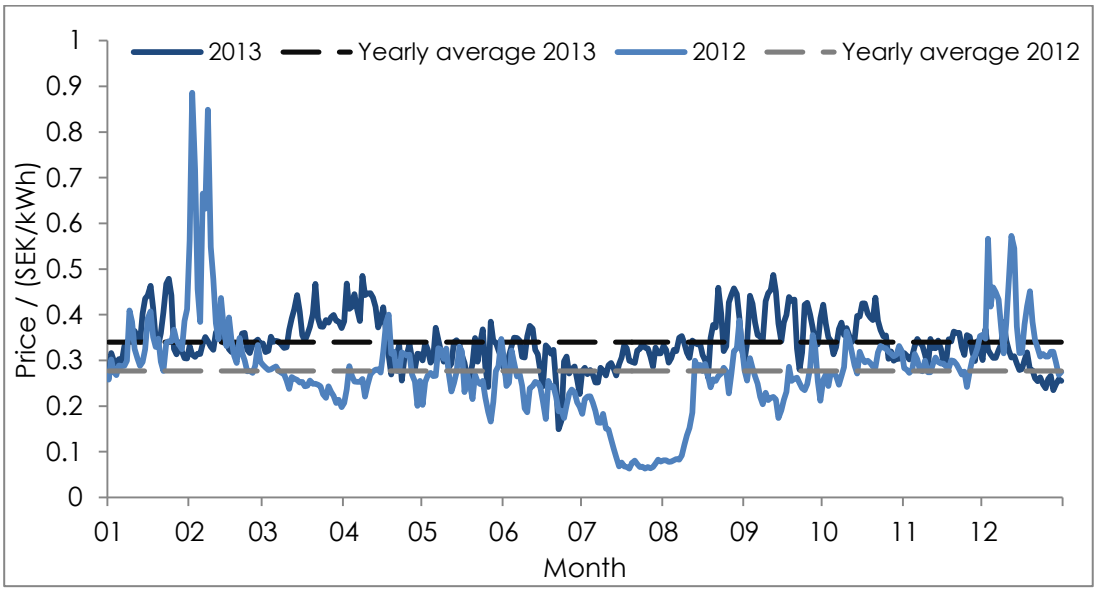

Figure 3.2 - Daily spot price variations and yearly average spot price of 2012 and 2013 (Nord Pool Spot, 2014b).

3.2.2 Energy tax

All consumed electricity in Sweden is liable to tax, according to the law (1994:1776) about energy tax. The tax rate is different depending on the location in Sweden where some parts

in northern Sweden have a lower energy tax of 0.194 SEK/kWh compared to the 0.293 SEK/kWh that the rest of Sweden has (Skatteverket , 2014a).

3.2.3 Electricity transfer fee

The owner of the distribution grid takes a fee for the transfer and the usage of the grid. One part of this fee is as mentioned before, a fixed subscription fee, independent on how much electricity that is used. The second part of the transfer fee is directly dependent on the electricity consumption. On-site generated electricity would benefit the most from having the electricity dependent part as big as possible since this is the only part that can be reduced with self-produced electricity. The grid companies all have their own specific electricity transfer fees but they are all similar, around 14-17 öre/kWh. 16.25 öre/kWh will be used during this research (Kraftringen, 2014).

3.2.4 Electricity certificate fee

The law regarding energy certificates was introduced in 2003 and states that everybody should pay for and be involved in the development of electricity generated from renewable energy sources. This means that there is a fee for electricity certificates on all bought electricity which is credited to the producers of clean electricity (Energimyndigheten, 2014a).

At first, this fee was specified separately in the electricity bill but nowadays it is often included in the spot price. Some electricity companies do still specify it though, and during the last five years it has varied between 4 and 8 öre/kWh, which makes it a rather small portion of the total electricity price (Stridh, 2013a). In this research 5 öre/kWh have been used which is the current fee of the electricity certificates.

3.2.5 Value-added tax

The value-added tax, VAT, is 25% and is applied to all of the containing parts above, even the energy tax.

3.3 Buying price vs. selling price

The containing parts of the electricity price mentioned above are specific for the bought electricity. When solar electricity instead is sold to the grid from an on-site electricity producing PV-system, some of these parts are not included. The energy tax is not included, as well as the fees for electricity transfer and electricity certificates. On top of this, the VAT applied to all the containing parts, is also removed. The only containing part that is left and which the producer can be credited with in the case of overproduction is the Nordic electricity markets hourly spot price.

But apart from the electricity market price, there is also two other containing parts included in the selling price, shown in Figure 3.3.

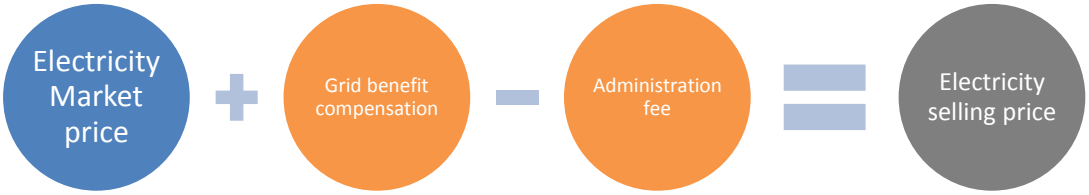

Figure 3.3 - Current situation of the selling price for a PV electricity producer.

The administration fee is the fee that the electricity companies charges for taking care of the overproduced electricity that is stored in the grid. This is typically a very small fee per kWh but it can vary a bit between the electricity companies. The common value is 4 öre/kWh of the electricity companies in Sweden and will therefore be used in this research (Öresundskraft, 2013)

According to the Swedish electricity law (1997:857) 15 §, electricity producers have the rights to achieve compensation for the electricity delivered to the grid since it limits the electricity losses in the grid caused by long transportation routes. The value of this is normally around 6 öre/kWh which will be used in this research (Öresundskraft, 2013).

The difference between buying and selling price and its containing parts can be seen in Figure 3.4.

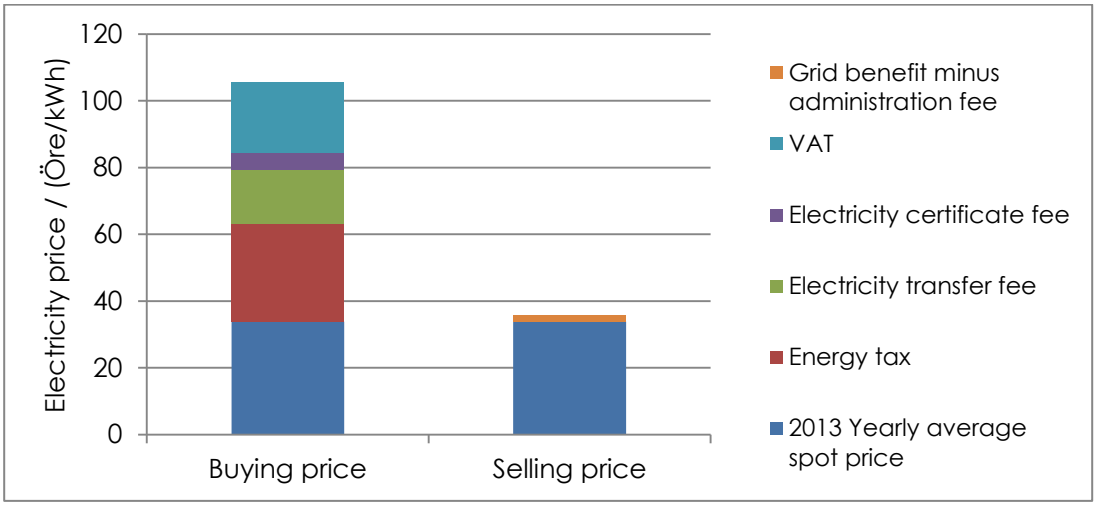

Figure 3.4 - Current situation of the differences between buying and selling price for a PV electricity producer.

3.4 Political decisions and subsidy options

Every country has their own way to support the expansion and development of renewable energy usage. It is political decisions that decide what kind of subsidies that will be available, some are more favorable for the integration of PV systems than others.

3.4.1 Investment subsidies

With an investment subsidy you get supported economically with the investment of the system. In Sweden one can get two different investment subsidies, but they cannot be combined.

Since 2009 there is a governmental subsidy for installations of PVs and it's available for all kinds of actors like private persons, companies and public organizations. During the period of 2013 – 2016, the government has reserved 210 million SEK that will be available for investors to apply for. The subsidy size for each case is maximum 35% of the total investment costs and not higher than 1.2 million SEK (Energimyndigheten, 2014b). Of the reserved 210 million SEK, 150 million SEK was used only during 2013. The application queue is also very long which means that it is very unlikely that a system that is installed today will be able to take credit of this subsidy (Stridh, 2014).

A different alternative is available if the PV system is to be placed on an existing building that is more than 5 years old and an investment subsidy have not been applied for. This subsidy is in Sweden called "ROT-avdrag" and gives you the right for tax reduction of the labor costs of a reparation, maintenance act, extension or reconstruction. As for PVs this gives you the option to receive tax reduction for the labor costs of the installation or change of PV panels (Skatteverket, 2014b).

3.4.2 Feed- in tariff

In many countries a Feed- in tariff system, FIT, is a way of supporting renewable energy technologies. FIT offers long-term purchase agreements for the sale of renewable energy, typically within contracts ranging from 10-25 years and are given for every kWh of electricity produced. The size of the payment per kWh varies dependent on renewable energy technology type, project size, resource quality and project location to better reflect actual project costs. Payment levels can be adjusted by the policy makers to decline from year to year in order to track and encourage technological costs reductions. Summarized, the feed- in tariff approach typically includes three key benefits, if applied successfully (NREL, 2010):

- Guaranteed access to the grid.
- Stable, long-term purchase agreements (typically 10-25 years).
- Payment levels based on the costs of renewable energy production.

This method is however not used in Sweden and will therefore not be included in this research.

3.4.3 Renewable energy certificates

In Sweden, as mentioned before, producers of electricity generated from renewable energy sources have the rights to be granted with renewable energy certificates on all the produced electricity. This is therefore a subsidy that is variable and directly dependent on how much electricity that is produced and credits are given for every MWh electricity produced.

Credits can however only be awarded for 15 years which normally is a shorter period than a lifetime of a system.

As mentioned, renewable energy certificates can be awarded for all the produced electricity. This however, requires the building to have a measuring device for the hourly production of the PV system, as well as a specific measuring subscription, with a total cost of 1000-1500 SEK/year (Öresundskraft, 2013). For a small-scale producer this seldom gets profitable and the most common approach is getting paid only for the overproduction that is delivered to the grid, since this can be done without additional costs.

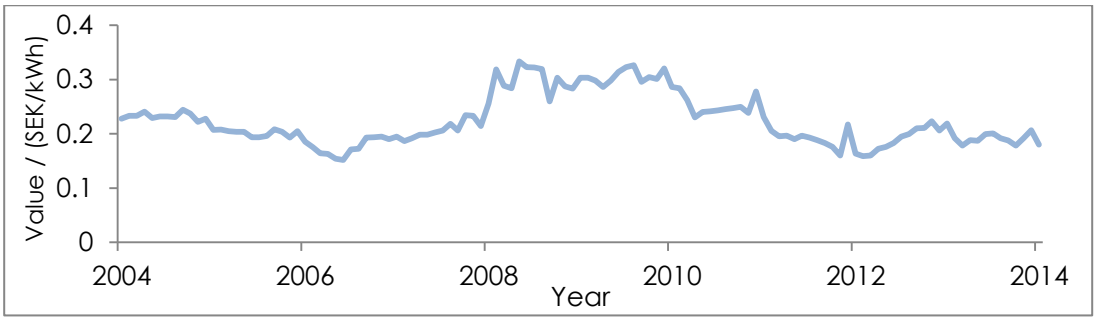

Figure 3.5 - Values of the electricity certificates during the last 10 years (Cesar, 2014).

The value of the certificates is set by the supply and demand balance which makes it vary with time. As presented in Figure 3.5 the value of the electricity certificates have varied during the last 10 years with values roughly between 0.15 and 0.35 SEK/kWh. During the last year the average value have been 0.2 SEK/kWh which will be used in this research. Yearly fluctuations and development of the electricity certificates have not been included and the value is set to 0.2 SEK/kWh during the first 15 years of the PV systems lifetime.

The way renewable energy certificates affect the selling price can be seen in Figure 3.6.

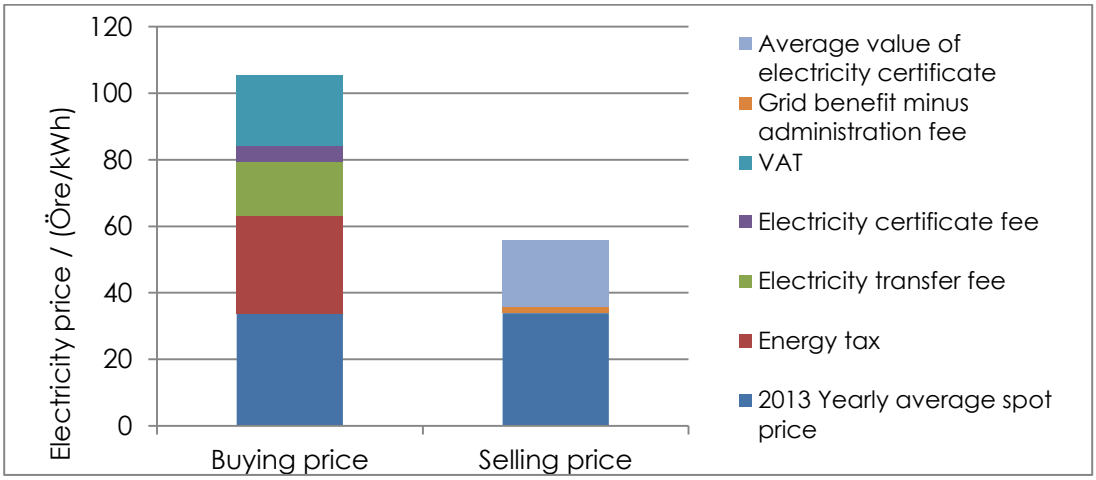

Figure 3.6 - Differences between buying and selling price for a PV electricity producer if the producer has applied to receive electricity certificates.

3.4.4 Net-metering

Net metering is a way to set off the electricity balance and could be described as the electricity meter going backwards when overproducing, and the bill for the consumer will only show the difference in consumption and production after a specific time period. In this case 1 kWh exported electricity gets the same value as 1 kWh bought, Figure 3.7. Net metering on a larger scale is not allowed in Sweden due to tax issues with the fact that the consumer only pays taxes for the amount that differs in the end on the time-period and not for the total amount of bought electricity during the period.

Net metering on a "larger scale" is in this case referring to net metering on a monthly or yearly basis since this leads to rather big set offs. Net metering is however used to a certain scale, but only on an hourly basis. The electricity consumption during one specific hour can be covered with the PV produced electricity during the same hour. This is good for the consumer since it takes away the risk of mismatches between consumption and production at specific moments during that hour. This might change in the future when measuring devices get more accurate with a shorter measurement time interval.

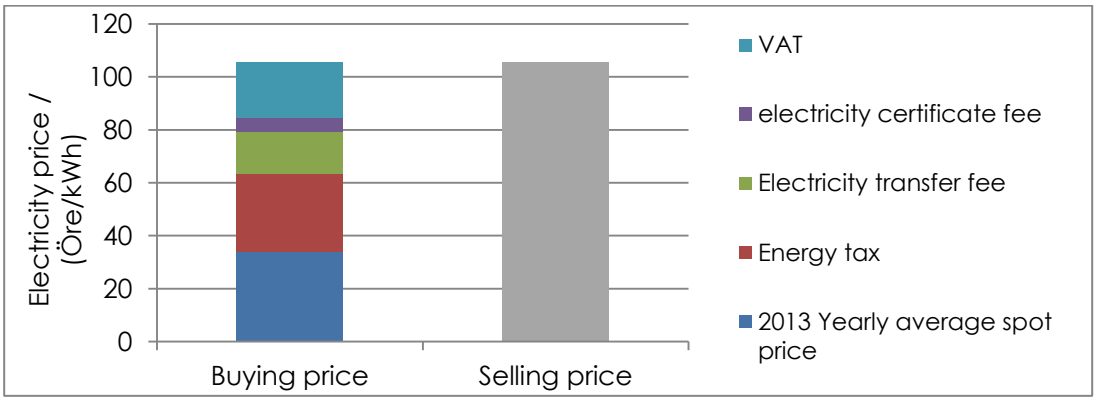

Figure 3.7 - Differences between buying and selling price for a PV electricity producer with Net-metering.

3.4.5 Tax reduction – new subsidy possibility

The Swedish government has recently, in a submission for comments to the law council proposed that tax reduction for small-scale renewable electricity production should be introduced in order to increase the fraction of renewable electricity and to strengthen the consumers position on the electricity market.

The tax reduction will be available for systems with a safety-fuse of maximum 100 Ampere and can only be accounted for up to 30 000 kWh per year and as long as the amount of electricity delivered to the grid equals the amount of electricity that have to be bought from the grid, on a yearly basis (Regeringen, 2014)

The size of the tax reduction was first thought to be introduced as the energy tax multiplied with two. This would mean that it would differ depending on where in the country the electricity production is made. This proposal was later changed to 0.6 SEK/kWh for the whole country which almost corresponds to the most common case of energy tax in Sweden of 0.294 SEK/kWh multiplied with two.

The way the introduction of tax reduction would impact the selling price of electricity can be seen in Figure 3.8.

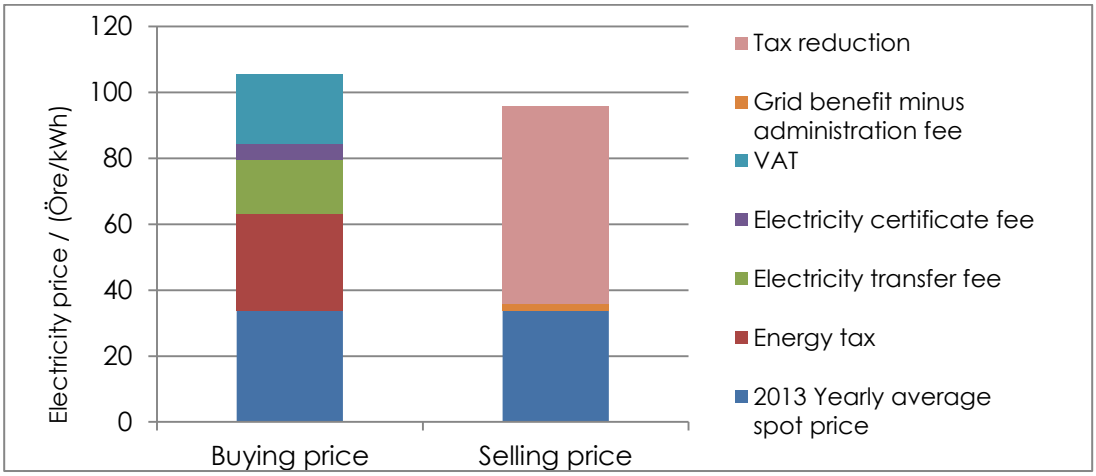

Figure 3.8 - Future situation of the differences between buying and selling price for a PV electricity producer when tax reduction will be implemented.

According to the referral to the Council on Legislation, the tax reduction will be given to private persons and companies (Regeringen, 2014).

With the proposal of tax reduction, a number of changes to the income tax law (1999:1229) are also proposed. Except making renewable micro produced electricity tax-deductible it is also proposed to rephrase "1§ Kap 67" in order to allow legal entities to receive tax reduction (Regeringen, 2014).

Housing associations are legal entities accordingly to the Swedish companies' registration office, Bolagsverket, and are therefore entitled to tax-deduction of the governmental real estate tax and municipal real estate fee if the proposal is implemented (Bolagsverket, 2012). Accordingly to the Swedish tax agency a housing association pays municipal real estate fee for the residential parts and governmental real estate tax for rest of the spaces in a multi-family building (Skatteverket, 2014c).

This indicates that a housing association does have a tax that can be deducted and can therefor also benefit from the proposed tax-reduction if they meet the other requirements that are stated in the proposal.

With the statements above, it is clear that tax reduction will be available for all the building types that this research is investigating.

The new regulations are proposed to come into effect as of 1 July 2014 (Regeringen, 2014).

3.5 Different scenarios for buying and selling price

As mentioned before, PV-system matched with a consumption profile presents three different situations: over-production, self-consumption and remaining electricity need form the grid, that all gets handled separately also from an economic point of view. The first situation is the part that is produced and consumed directly in the building. This electricity gets valued to the same price as the bought electricity would cost in that specific hour. The second situation is when there is a consumption need but there is no production, or the consumption need is bigger than the production output. In this case, extra electricity has to be bought from the grid from a specific price that hour. The third situation is when there is an electricity production without a consumption need, or when the production is higher than the consumption need. This overproduction gets sold to the grid to a different price than the buying price as have been shown above.

The most common case of selling price in Sweden right now is that the electricity companies offer the Nordic electricity market hourly spot price, plus a small grid benefit substitution minus a small administration fee, Figure 3.3. Since all the producers of renewable energy have the rights to apply for electricity certificates, this certificate can also be applied to the selling price, at least for all the overproduced electricity. If tax reduction is introduced, it can be added on top of this, Figure 3.9, resulting in a favorable selling price compared to the current situation.

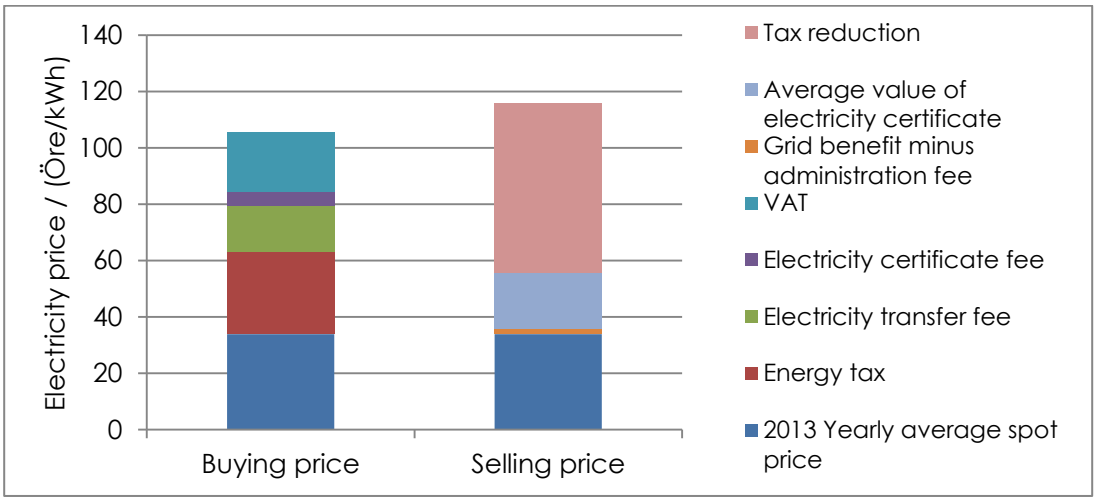

Figure 3.9 - Future situation of the differences between buying and selling price for a PV electricity producer if both electricity certificates and tax reduction is added to the selling price.

In order to increase the amount of renewable electricity in the grid, many electricity companies also offers a set selling price of around 1 SEK/kWh. These kinds of deals varies a lot and in some cases the electricity companies gets credited with the electricity certificates and in some cases the certificates can still be awarded to the producer on top of the 1 SEK/kWh. However, this deal will probably disappear if and when the law of tax reduction is introduced, preventing the producers to achieve 1.6-1.8 SEK/kWh when selling electricity. A fixed selling price of 1 SEK/kWh can be either better or worse than the

upcoming changes with tax reduction depending on the current hourly spot price, as shown in Figure 3.10.

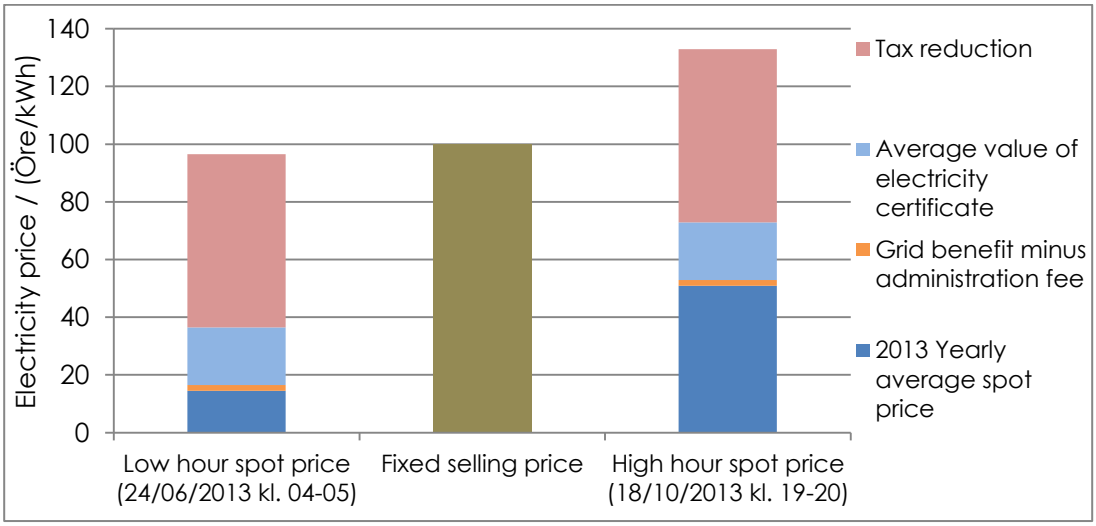

Figure 3.10 - The figure is showing how the differences in the value of the hourly spot prices can affect the benefits of having a fixed price versus the upcoming situation with tax reduction.

During hours when the spot price is high, tax reduction would be very beneficial compared to a fixed price, but during hours when the spot price is very low, a fixed selling price of 1 SEK/kWh can be better for the consumer.

The different alternatives above are presented in Figure 3.11. This figure shows the current and potential future situation regarding the buying vs. selling aspects of electricity for small-scale producers in Sweden.

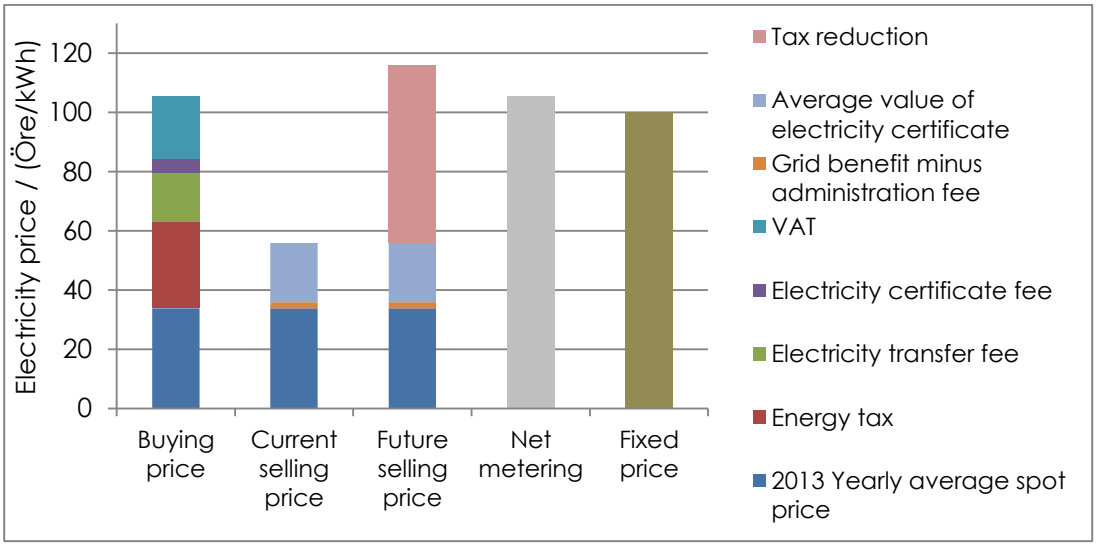

Figure 3.11 - The way different deals and subsidies affects the situation of buying versus selling price of PV produces electricity.

4 Economic analysis

Economic analyses can be done it many different ways, Levelized cost of electricity, LCOE, is a common way of expressing the cost-effectiveness of different electricity generating technologies. The LCOE is the average cost of the electricity that a system is producing during its lifetime when all the costs of the investment are included. To be able to compare different generating technologies with the same economic analysis, LCOE is generalized in a way that it does not include different taxes, subsidies etc. which might be added to the price of electricity generated by the source. (K. Branker, M.J.M. Pathak, J.M. Pearce, 2011). To make a complete and correct analysis of PV systems from a small scaled producer's point of view, directly consumed and overproduced electricity has to be handled separately with different values, which means that LCOE does not have the depth that is needed for this research. Instead a LCC-analysis will be used where both the profits and the costs during the systems whole lifetime are estimated and presented in a net present value, this is discussed further in 4.4.2.

4.1 Annual profit

The profit a PV system makes every year consists of two parts. First, all the self-consumed electricity used directly in the building is valued with the same price as bought electricity since it is a cost that is avoided. Secondly, a potential overproduction is sold to the grid. As mentioned in Chapter 3.5 there are a lot of different scenarios for this.

To decide how much electricity that is self-consumed and how much that potentially is overproduced, the electricity consumption, every hour of the year, is compared with the simulated hourly PV electricity produced. To decide its economic value, this is also compared with the hourly fluctuating spot price at the Nord Pool spot market.

The annual profit, A, of a PV system is calculated with equation 4.1 – 4.2.

$$\boldsymbol{A} = \sum_{\boldsymbol{h=1}}^{\boldsymbol{8760}} \boldsymbol{D_h\, B_h + O_h S_h} \qquad (4:1)$$

- A is the annual profit of the PV system in, SEK
- D_h is the directly self-consumed electricity in hour h, kWh
- B_h is the buying price of electricity in hour h, SEK/kWh
- O_h is the overproduced electricity in hour h, kWh
- S_h is the selling price of electricity in hour h, SEK/kWh

In cases when net metering is analyzed the formula changes to:

$$\boldsymbol{A} = \sum_{\boldsymbol{h=1}}^{\boldsymbol{8760}} \boldsymbol{D_h\, B_h + O_h B_h} \qquad (4:2)$$

However, this is only applicable as long as the total production is less or equal to the total consumption need.

4.2 Life cycle profit

4.2.1 Predictions of the electricity price development

To be able to analyze a PV systems economical profitability during its whole lifetime, the current situation of electricity pricing, both from a buying and from a selling point of view, is not enough since the PV system have a lifetime of at least 25 years. Therefore, aiming at increasing the accurateness of the evaluation, predictions have also been made regarding the upcoming electricity price development. These predictions are difficult to do since, and as mentioned before, the electricity price consists of many different parts that are independent from one another. It is not only the current containing parts that can change, but more containing parts can even be added during the following 25 years. Looking back 25 years, there were no electricity certificates or even VAT added to the electricity price, so it is difficult to predict the future price for electricity.

Common ways of trying to predict the future electricity price is by looking at the past and try to find patterns in the development. This can be done either for the electricity as a whole or for each containing part individually.

When performing an LCC-analysis it is common that the electricity price increase is a part of the discount interest rate which means that it only affects the electricity price increase as a whole, and both the buying and selling price equally much. There is a couple of different reasons why this "simplification" isn't good enough and why it is a lot better to evaluate the different containing parts of the electricity individually.

First of all, adding a price increase rate to the electricity as a whole means that all its containing parts increases equally. By looking at the historic development of the electricity price's two biggest parts; the electricity market price and the energy tax, it is very noticeable that they haven't developed equally. This can be seen in Figure 4.1 and Figure 4.2.

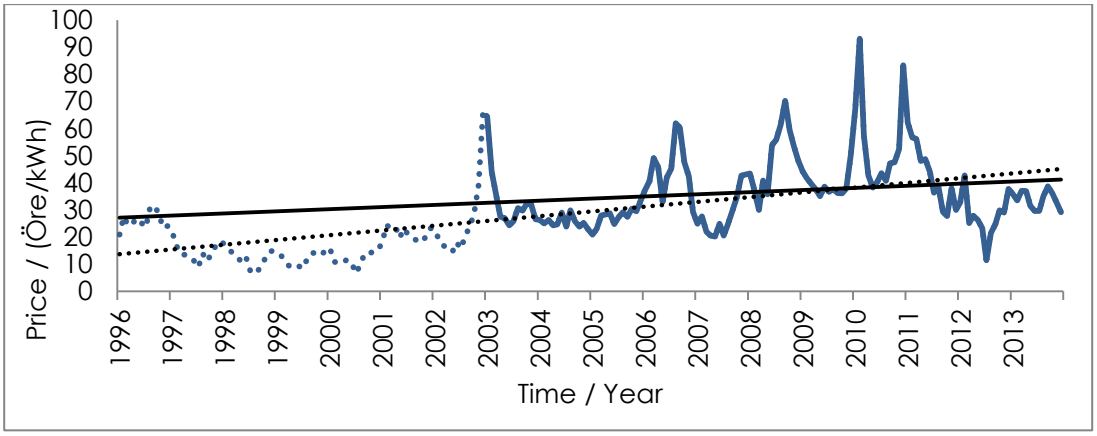

Figure 4.1 - Monthly average spot price fluctuation and average increase of the spot price during the last 18 (dotted lines) years and during the last 10 years (continuous lines) (Nord Pool Spot, 2014).

The monthly average spot price development during the last 18 years has been irregular, but the dotted trend line in Figure 4.1 shows a yearly increase in 6.7%, the development of the electricity market price has however been more stable during the last 10 years and the trend line in Figure 4.1 shows an increase that is slightly smaller of 2.5%. The price increase of 2.5% during the last 10 years is chosen for the evaluation of the PV systems in this research.

The development of the energy tax looks different. When the energy tax on electricity was implemented back in 1951, it was limited to 1 öre/kWh. It has grown significantly since then, especially during the last 20 years. During the last 20 years the average tax increase has been 9%, but during the last 10 years it has started to settle down and has instead been 3.5%, which also have been used in this research. (Skatteverket, 2014d). This is noticeable, looking at the trend curves in Figure 4.2:

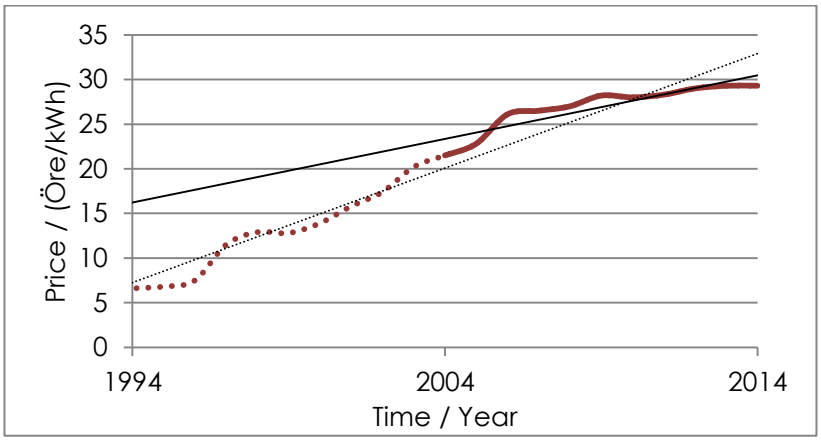

Figure 4.2 - Yearly average energy tax fluctuation and average tax increase during the last 20 years (dotted lines) and during the last 10 years (continuous lines) (Skatteverket, 2014d).

Another important note about increasing the electricity price as part of the discount interest rate in the LCC-analysis is that it also would make the selling price of overproduced electricity to increase equally. This means that if for example the electricity price increase rate would be 2% yearly, then all the containing parts of the selling price would increase by 2%, resulting in a price increase of also the tax reduction, which supposedly should be fixed at 60 öre/kWh. Otherwise the tax reduction would be worth 0.98 öre/kWh after 25 years.

With these arguments in mind, the electricity price increase rate in this research has been applied to both the electricity market price and the energy tax, separately. Consequently this means that the results of this research will vary depending on this and how much these parameters change.

This also means that the differences between the buying and selling price of the electricity will vary, depending on which parameter that is changed the most. This impact is explained in Figure 4.3.

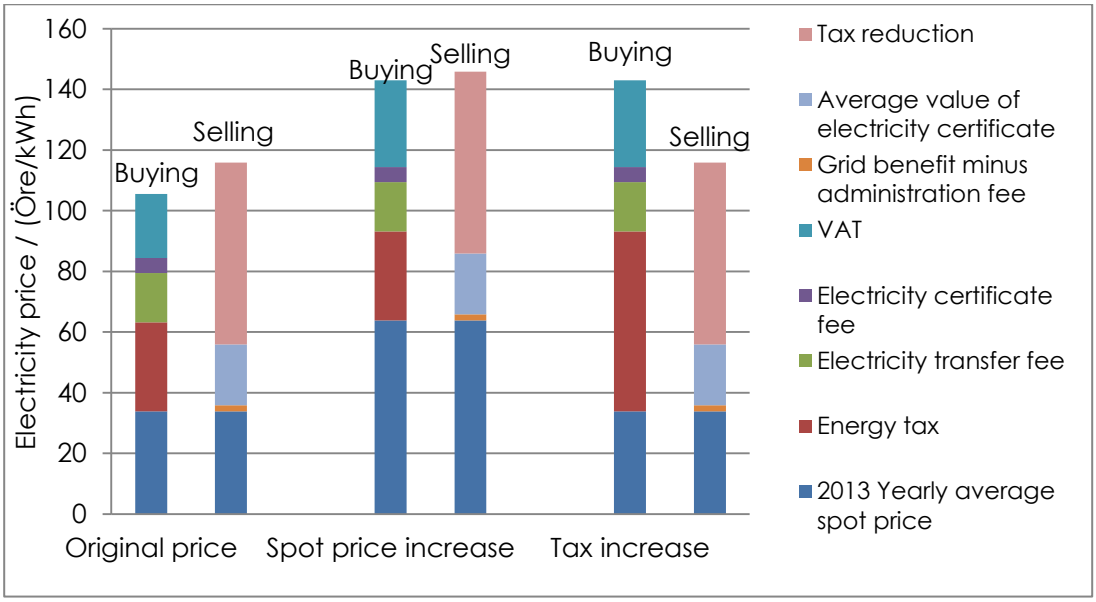

Figure 4.3 - Showing the impact on the buying and selling price of an increase in electricity market price versus an increase in energy tax.

Figure 4.3 shows that the electricity market price is as explained in chapter 3.3 included both in the buying and the selling price of electricity but the energy tax on the other hand is only a parameter in the buying electricity price. This means that an increase in the electricity market price would result in an increase of both the buying and selling price. Since VATs is added on the buying price which partly is based on the spot price, the buying price will increase slightly more than the selling price. But an increase in energy tax would result in a price increase of only the buying price, which would be less beneficial from a PV electricity producer's point of view.

However, as a side note, one should keep in mind that the tax reduction is actually based on the energy tax and is today valued approximately to the energy tax times two, which is 60 öre/kWh. Would it not be realistic to think that the tax reduction also would increase as the energy tax rise? This is highly uncertain and since tax reduction will be introduced as a subsidy to make PV systems more profitable, it is instead more realistic that the tax reduction will be reduced when other parameters have made the systems more economically supportable on their own. This is however only speculations and during this research, the tax reduction is set to 60 öre/kWh throughout the whole lifetime of the system.

The fixed price is set to 1 SEK/kWh and is an independent value, not including the different containing parts of the regular price. This means that it has a separate price development and this research have estimated the fixed price's development to be increased with 2.5% of the total price annually, relating to the spot price increase.

With these assumptions in mind, Figure 4.4 shows the potential buying and selling price with tax reduction and the fixed selling price, at the end of year 25.

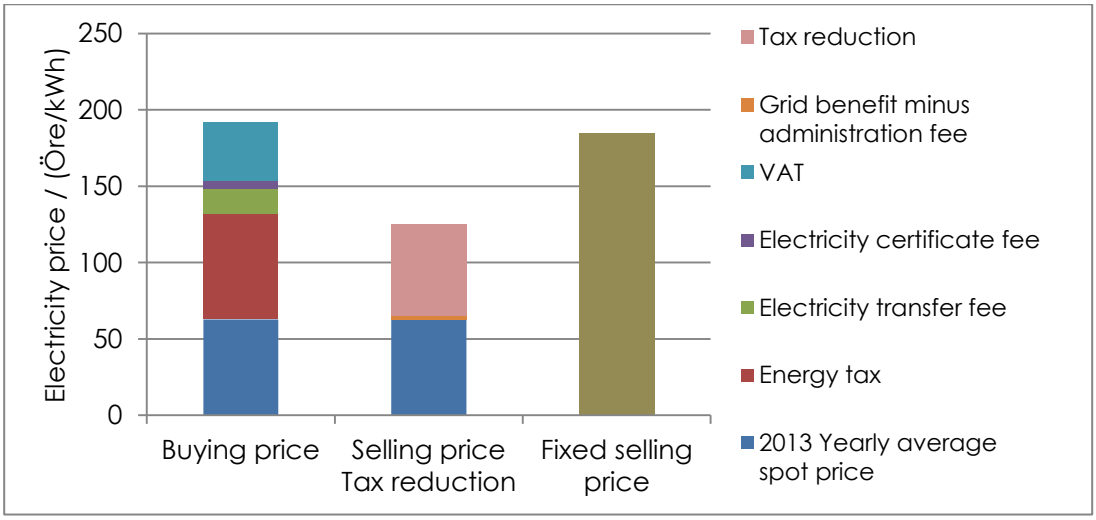

Figure 4.4- Buying vs selling price after 25 years according to the assumptions presented in this research.

4.2.2 System degradation

PV systems have a yearly degradation of the efficiency that should be considered. Studies have shown that 0.5% yearly degradation is a reasonable annual performance loss in efficiency and will therefore be used throughout this research (Dirk C. Jordan, Sarah R. Kurtz, 2012).

4.3 Life cycle costs

The life cycle costs of a PV system are including all the costs a PV system has during its whole lifetime. These costs consist of initial investment costs, operation and maintenance costs and deconstruction costs.

4.3.1 Initial investment costs

Initial investment costs for PV systems are a very important parameter in an economic analysis of a system. The development today is advancing so quick that information with one year old references can be completely unreliable today. The initial investment costs are influenced and dependent on many different factors, including:

- System size – Generally a lower price per kW_p can be reached with a larger system.
- Connection to an electricity grid - The lowest system prices for off-grid systems are roughly twice as big as the grid-connected systems. This is simply because the off-grid systems require storage batteries and corresponding equipment that is very costly (Lindahl, 2014). Small systems do not have to pay a fee to be connected to the grid, but for a bigger facility this could possibly be the case.
- Technical specifications – Higher module efficiencies leads to higher costs, the same goes for inverters.

- Optional components selection – Certain components can be added to the system that necessarily does not have to be included. For example, measurement devices for detailed electricity production, solar radiation, temperatures etc.

- The difficulty level of the installations – Roof construction, angles and heights are factors that can influence the difficulty and potentially the separate structure needed to install the system.

- Building integration, degree of innovation, aesthetics, custom-made modules etc.

- Quality and lifespan of the components and labor.

- Warranty clauses.

The initial investment costs also vary a lot depending on where the installation takes place since some countries have been able to lower the costs more than others. It is therefore important that these costs are analyzed from a local rather than a global perspective to get more accurate values.

From a global perspective, prices of both PV modules and complete PV systems stabilized during 2013 after many years of steady price decreases. In Sweden however, the prices kept going down during 2013, simply because Sweden is lagging behind. If the market continues to grow, the competition between companies can force the costs to go down even further.

Current costs and the recent development of turn-key systems in Sweden can be seen in Figure 4.5. The system costs are presented without VAT. VAT will be included in the life cycle costs of the systems, resulting in costs of 20 SEK/W for grid-connected systems 20 kW and 17.5 SEK/W for systems above 20 kW.

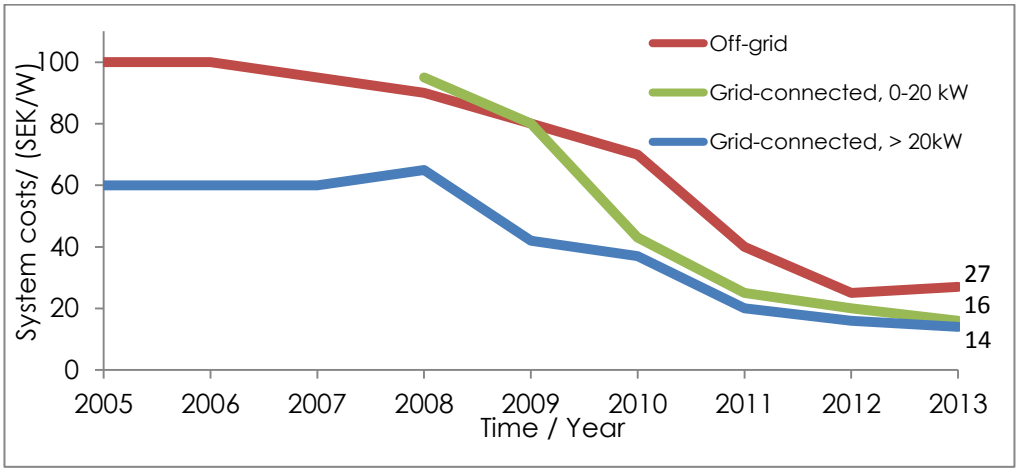

Figure 4.5 - Price development of typical turn-key PV systems (no VAT included) in Sweden (Lindahl, 2014).

During recent years, it is the module makers that have experienced the most price pressure, much more than the inverter suppliers. Consequences being that the inverters are responsible for an increasingly big portion of the total system price of the PV systems,

together with the rest of the balance of systems-costs including wiring, switches and support racks.

Forecasts are saying that the inverter prices will go down, how fast and how much is however hard to say. As of right now, the warranty period of most inverters are shorter than it is for the rest of the components in a PV system, which means that the inverters in a system might have to be replaced within the lifetime of the system. This is another factor that the inverter suppliers need to work on (IHS, 2013).

4.3.2 Operation and maintenance costs

In general PV systems have relatively low operation and maintenance costs. The system works independently and even cleaning costs can be neglected since this gets handled by rain and snow melting. Studies have shown that the production loss caused by snow and dust is very low, at least on an annual basis since the potential snow covering period often occur when the solar radiation is rather low. Of course the impact of this varies depending on the module tilt but generally speaking it is not economically supportable to regularly clean the modules from snow or dust.

Repair costs that are caused by production errors should be covered by warranties. When it is repair costs caused by human errors or other outstanding sources it is however different.

It is realistic that the O&M costs increase with the age of the system, however, during this research the O&M costs are set to 1% of the installation costs on a yearly basis, which is a commonly used assumption in economic analyses of PV systems. With this assumption, the O&M costs that probably is overestimated during some of the first years after installation, covers up for the underestimation during some of the years when the system is older and requires more maintenance (Heinz Ossenbrink, Arnulf Jäger-Waldau, Thomas Huld, Nigel Taylor, 2012).

As mentioned in the previous chapter, the inverter in the system might have to be replaced within the lifetime of the PV system since it has a shorter warranty period than the system as a whole. This could be considered as an O&M cost but will be handled separately and is therefore not included in the yearly 1% O&M costs.

Typical warranty periods of inverters today are 15 years. Some systems will need an inverter change by this time, some will need it later and some systems might not have to replace the inverter within the lifetime of the whole PV system. This research will include an inverter change in the economic analyses at the end of the 15th year for all the systems analyzed. This is probably a conservative analysis.

Average inverter prices today, from a global perspective is roughly 2700 SEK/kWp (PVinsights, 2014). As mentioned earlier, the Swedish market is lagging behind a bit in the PV market, resulting in slightly higher costs than the global average. However, in 15 years when an inverter change is of interest, the prices of inverters in Sweden should at least be matching today's global average, and potentially be a lot lower than that. The forecasts in price development of inverters are so unclear that this research has decided to use today's global average of 2700 SEK/kWp in the calculations to prevent a potential assumption from being exaggerated.

4.3.3 Deconstruction costs

It is rather hard to estimate the deconstruction costs of a PV system at the end of its lifetime. A PV system, or at least parts of it, potentially also have a value at the end of its lifetime. This research made a simplification considering that the end of life value of the PV system equals out the costs for tearing down the system, allowing them to be neglected in the economic analyses.

4.4 Life cycle cost analysis

The life cycle profits and the life cycle costs are considered, when put together a life cycle cost analysis.

4.4.1 Yearly economical results

To perform a life cycle cost analysis, the yearly economical results have to be calculated separately, since they may differ from year to year. The yearly economical results can be calculated with the equations presented below:

$$\boldsymbol{R_n} = \sum_{\boldsymbol{h=1}}^{\boldsymbol{8760}} (\boldsymbol{D_{n,h}\, B_{n,h} + O_{n,h} S_{n,h}}) - (\boldsymbol{I_0 C_m}) \tag{4:3}$$

- R_n is the economical result of year n, SEK
- $D_{n,h}$ is the directly self-consumed electricity in year n and hour h, kWh
- $B_{n,h}$ is the buying price of electricity in year n and hour h, SEK/kWh
- $O_{n,h}$ is the overproduced electricity in year n and hour h, kWh
- $S_{n,h}$ is the selling price of electricity in year n and hour h, SEK/kWh
- I_0 is the initial investment costs of the complete PV system, SEK
- C_m is the constant yearly O&M costs as a percentage of the initial investment costs, SEK

With a yearly system degradation δ, the PV electricity production changes, resulting in value changes from year to year for the following parameters: $P_{n,h}$, $D_{n,h}$, $O_{n,h}$. These values are calculated with the following equations:

$$\boldsymbol{P_{n,h} = P_{1,h}(1-\delta)^{n-1}} \tag{4:4}$$

$$\boldsymbol{D_{n,h}} = \begin{cases} \boldsymbol{E_h} & \forall \boldsymbol{h};\ \boldsymbol{P_{n,h} > E_h} \\ \boldsymbol{P_{n,h}} & \forall \boldsymbol{h};\ \boldsymbol{P_{n,h} \leq E_h} \end{cases} \tag{4:5}$$

$$\boldsymbol{O_{n,h}} = \begin{cases} \boldsymbol{P_{n,h} - E_h} & \forall \boldsymbol{h};\ \boldsymbol{P_{n,h} > E_h} \\ \boldsymbol{0} & \forall \boldsymbol{h};\ \boldsymbol{P_{n,h} \leq E_h} \end{cases} \tag{4:6}$$

- $P_{n,h}$ is the PV production in year n and hour h, kWh
- E_h is the electricity demand in hour h, kWh
- δ is the yearly system degradation, %

The buying price and the selling price of electricity for a specific year and hour is calculated from the specified historical values, $B_{0,h}$ and $S_{0,h}$.

$$\boldsymbol{N_{n,h} = N_{0,h}(1+p)^{n-1}} \tag{4:7}$$

$$\boldsymbol{T_n = T_0(1+t)^{n-1}} \tag{4:8}$$

$$\boldsymbol{B_{n,h} = \left(N_{n,h} + T_n + C_f\right) \cdot (1 + C_v)} \tag{4:9}$$

$$\boldsymbol{S_{n,h} = N_{n,h} + C_c + C_g - C_a + C_r} \tag{4:10}$$

- $N_{n,h}$ is the Nordic market spot price of electricity in year n and hour h, SEK/kWh
- *p* is the yearly electricity spot price increase, %
- T_n is the energy tax in year n, SEK/kWh
- *t* is the yearly energy tax increase, %
- C_f is the constant fees for electricity transfer and certificates, SEK/kWh
- C_v is the constant VAT added to the buying price, SEK/kWh
- C_c is the constant assumed value of credited electricity certificates, SEK/kWh
- C_g is the constant value of grid benefit compensation, SEK/kWh
- C_a is the constant value of administration fees, SEK/kWh
- C_r is the constant value of tax reduction, SEK/kWh

C_c is only credited for the first 15 years of the calculations, after that C_c is set to zero. C_r is zero if and when $O_n \geq 30\ 000$ kWh and/or when $P_n \geq E_n$.

In cases of a fixed selling price, $B_{n,h}$ is the same as in equation 4:9 but $S_{n,h} = F_n$.

$$\boldsymbol{F_n = F_0(1+f)^{n-1}} \tag{4:11}$$

- F_0 is the fixed price of 1 SEK/kWh
- f is the yearly fixed price increase, %

In cases of net metering, $B_{n,h}$ is the same as in equation 4:9 but $S_{n,h} = B_{n,h}$. As long as $E_n \geq P_n$

4.4.2 Net Present Value

The NPV is the value of a specific stream of future cash flows presented in today's value. The reason for this being that a certain amount of money today is more valuable than the same amount of money in a couple of years, due to price inflation.

NPV should include initial investment costs but also all future costs and revenues. A positive NPV at the end of a systems lifetime means that it is an investment that is worth doing, while a negative value means that it would be a bad investment, at least from an economical point of view.

In this case, when analyzing PV systems with the NPV method, the following parameters have to be included and presented in its NPV:

- Initial investment costs.
- The yearly economical result with both profit and O&M costs during the systems total lifetime.
- Inverter replacement cost after 15 years.

The introduction of NPV presents two new parameters that have to be considered and that has not been mentioned before. These are the lifetime of the system and discount interest rate.

The formula for the calculation of NPV for a PV system is presented with equation 4.12:

$$\boldsymbol{NPV} = (-\boldsymbol{I_0}) + \frac{\boldsymbol{R_1}}{(\boldsymbol{1}+\boldsymbol{r_{di}})^{\boldsymbol{1}}} + \frac{\boldsymbol{R_2}}{(\boldsymbol{1}+\boldsymbol{r_{di}})^{\boldsymbol{2}}} + \cdots + \frac{\boldsymbol{R_L}}{(\boldsymbol{1}+\boldsymbol{r_{di}})^{\boldsymbol{L}}} - \frac{\boldsymbol{X}}{(\boldsymbol{1}+\boldsymbol{r_{di}})^{\boldsymbol{15}}} \qquad (4:12)$$

- I_0 is the initial investment costs
- R_n is the yearly economical results
- r_{di} is the discount interest rate
- L is the lifetime of the system
- X is the inverter replacement cost

4.4.2.1 Lifetime

Determining the lifetime of a PV system is quite difficult since there generally is no single disastrous event ending its functionality, but more gradual aging and degradation. As long as the system output still satisfies the user, the systems end of life state have not been reached. For economic analysis, the lifetime for a PV system is usually considered to be the manufacturer's guarantee period which most commonly is 20-25 years. However, research have shown that the actual lifetime of a PV system is far more than that, up to 30-40 years, even for older technologies and the current technologies are supposedly going to improve the lifetimes even further (Dunlop E, Halton D, Ossenbrink H., 2005)

With the manufacturer's guarantee period in mind, which in this case with Vattenfalls PV system packages is 25 years, the lifetime of the PV systems is set to 25 years for the economic analyses performed. With the lifetime set to 25 years, the calculations are made on the safe side, without having to rely on unnecessary predictions in potential longer lifetimes. But it is important to know that the results achieved, can be far more economical beneficial if the calculations are based on a longer lifetime.

4.4.2.2 Discount interest rate

The second parameter is the discount interest rate. When investing in a PV system, the most common situation is that a bank loan is taking care of the lifetime investment costs. Due to this, a loan rate has to be included in the interest rate. Average loan rates today with the longest binding period is 4.22% (Compricer, 2014).

Apart from this, a tax deduction can be applied to 30% of the loan rate as well as the inflation. The average inflation during the last 10 years has been 1.24% as seen in Figure 4.6.

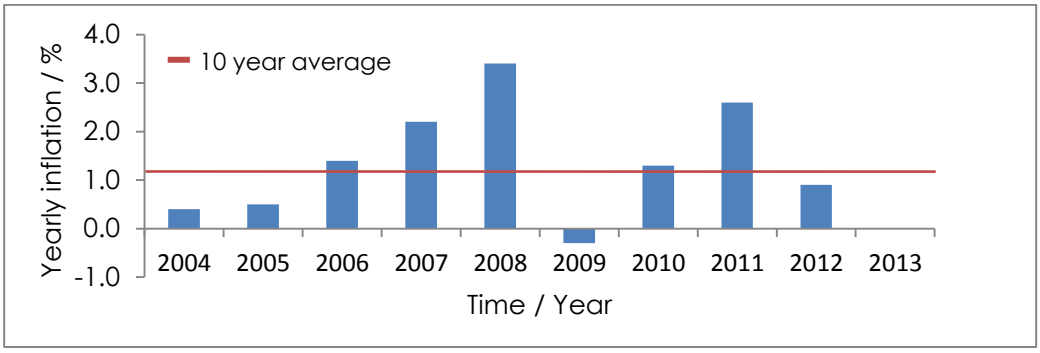

Figure 4.6 - Yearly inflation rate during the last 10 years and its average value . Graph based on data from Statistiska centralbyrån (SCB, 2014).

Based on these assumptions the discount interest rate is calculated to 1.71%, equation 4:12. During the analyses, the discount interest rate was set to 2% (Stridh, 2013b) (Johansson, 2014).

$$\boldsymbol{r_{di} = 4.22 \cdot 0.7 - 1.24 = 1.71\%} \qquad (4:13)$$

5 Calculation model

Using excel, a calculation model was developed to analyze PV-systems from an LCC perspective, presented as NPV. The calculation model can be divided into three parts and will be described separately.

5.1 Model description

In this description of the model, figurative numbers will be used in order to show how the calculations are done but only for an example of six hours of operation.

5.1.1 Energy

The first part of the model, Figure 5.1, handles the electricity balance between consumption and production. In the first two columns hourly data for both load and production for a specific angle and tilt should be entered for the wanted time interval. First of all the load (1) is subtracted from the production (2) to display the system balance with the grid (3), with positive numbers corresponding to electricity export to the grid. The data is then analyzed regarding load, production and balance and divided into three different parts for each hour.

	1	2	3	4	5	6	
				Energy			
	Load	PV Production	Grid Balance	Used Internally	Over Produced	Need with solar	
Sum	9.00	8.00	-1.00	6.00	2.00	3.00	kWh
Date/Time							
01/01/2013 09:00	1.00	0.00	-1.00	0.00	0.00	1.00	kWh
01/01/2013 10:00	2.00	1.00	-1.00	1.00	0.00	1.00	kWh
01/01/2013 11:00	3.00	2.00	-1.00	2.00	0.00	1.00	kWh
01/01/2013 12:00	2.00	2.00	0.00	2.00	0.00	0.00	kWh
01/01/2013 13:00	1.00	2.00	1.00	1.00	1.00	0.00	kWh
01/01/2013 14:00	0.00	1.00	1.00	0.00	1.00	0.00	kWh

Figure 5.1 - Energy flows and balance based on Load and PV-production on hourly basis.

The first priority is to use the produced electricity within the building prior to exporting it to the grid. This means that if there is an electricity need in the building, the PV produced electricity will be used (4) to cover it. In case there is more electricity than needed, produced, the difference will be exported to the grid (5), and imported (6) if an electricity deficit occurs. Examples of different cases are presented in Figure 5.1.

The columns are then summarized and presented as different fractions. As described in 2.3 the produced electricity can be divided by the load and presented as solar fraction. The solar fraction (9) can be separated into two parts, one which represents the amount of electricity that is being used internally directly after production (7) and one part that have been over produced and exported to the grid (8). The example in Figure 5.1 would result in the following fractions, presented in Figure 5.2.

	Fractions			
7	Direct use	Used Internally/Load	66.67	%
8	Missmatched	Over Produced/Load	22.22	%
9	Solar Fraction	PV Production/Load	88.89	%

Figure 5.2- The balance between load and PV-production divided into fractions dependent of match.

5.1.2 Economical

Solar fractions are a good way to show how much of the total energy need that is covered by solar electricity, but it do not consider the economical parts with price variations over the day, week and year for selling and buying electricity. If not considering net metering, exported and imported electricity does not have equal value, even if they are of equal amount. Therefore, a value needs to be assigned for the balance of every hour.

The first column (1) in the economical part (Figure 5.3) contains the specific electricity price from the Scandinavian electricity market Nord Pool, for every hour of a year. The actual price that a customer both receives and pays are affected by a number of parameters that are added to the spot price as described in Chapter 3.2. The parameters that affect the prices can be changed in separate fields, shown in Figure 5.4.

	1	2	3	4	5	
	Economy					
	Spot Price	Real Spot Price	Real Spot Reduction	Fixed Price	Buy Price	
Average	21.81	43.81	103.81	100.00	90.44	öre/kWh
Date/Time						
01/01/2013 09:00	26.60	48.60	108.60	100.00	96.44	öre/kWh
01/01/2013 10:00	23.57	45.57	105.57	100.00	92.65	öre/kWh
01/01/2013 11:00	20.94	42.94	102.94	100.00	89.37	öre/kWh
01/01/2013 12:00	18.69	40.69	100.69	100.00	86.55	öre/kWh
01/01/2013 13:00	19.17	41.17	101.17	100.00	87.15	öre/kWh
01/01/2013 14:00	21.86	43.86	103.86	100.00	90.51	öre/kWh

Figure 5.3 – Different prices for the specific hours in the calculation.

The spot price (1) and adjustments (a) for the sell value are combined into a second column (2), as well as a third column with the tax reduction (b) included (3). Since some electricity companies offer a fixed price a fourth column with this option is added with a total value of 1kr/kWh (4). The adjustment values of bought electricity (c) are added to the spot price into a fifth column (5).

	Sell	
b	Tax Reduction	60.00 öre/kWh
a	Elcert	20.00 öre/kWh
	Grid benefit	6.00 öre/kWh
	Administration	-4.00 öre/kWh

	Buy	
c	Tax	29.30 öre/kWh
	Elcert	5.00 öre/kWh
	Transfer	16.25 öre/kWh
	VAT	25 %

Figure 5.4 - Calculation parameters that affect the prices of selling and buying electricity.

When both the different prices and the energy flows are known, the values of these can be calculated. Figure 5.5 shows the economical values of the energy flows in Figure 5.1 and prices in Figure 5.3.

	6			7		8	
	Value Sold	Sold with Reduction	Sold with Fixed price	Cost Bought	Used Internally	Cost No Solar	
Average	0.85	2.05	2.00	2.78	5.32	8.10	kr
Date/Time							
01/01/2013 09:00	0.00	0.00	0.00	96.44	0.00	96.44	öre
01/01/2013 10:00	0.00	0.00	0.00	92.65	92.65	185.31	öre
01/01/2013 11:00	0.00	0.00	0.00	89.37	178.73	268.10	öre
01/01/2013 12:00	0.00	0.00	0.00	0.00	173.10	173.10	öre
01/01/2013 13:00	41.17	101.17	100.00	0.00	87.15	87.15	öre
01/01/2013 14:00	43.86	103.86	100.00	0.00	0.00	0.00	öre

Figure 5.5 – Values and costs of the energy flows.

The value of sold electricity (6) is the sum of overproduction and the different prices for selling. The value of bought and internally used electricity (7) is the price of buying multiplied with the amount of electricity imported from the grid, and internally used PV electricity. The cost of having no solar electricity (8) is what it would cost to buy the whole electricity need from the grid.

All parts described above are then merged into a complete model making it possible to see all combinations of flows and costs regarding a specific hour, Figure 5.6.

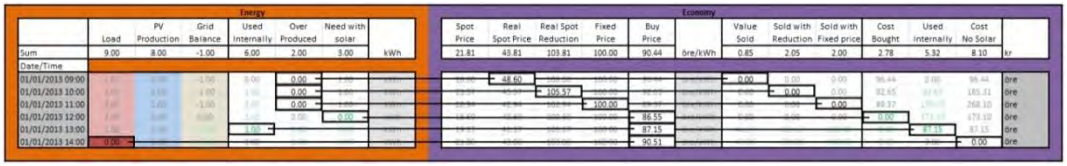

Figure 5.6 – The economical and energy-part combined to allow all information at a specific hour to be seen on the same row.

Every hour is then summarized and the economical result over the chosen time is presented separately for the four different price-options above, this is shown in Figure 5.6. The first row (9) in Figure 5.7 represent the cost of buying all electricity from the grid, then the value of the internally used PV-electricity (10) is subtracted which results in the cost of the electricity still needed to be imported from the grid (11). If some overproduction occurs the value of it (12) is subtracted and the final cost of the bought electricity is found (13). The difference between this and the initial cost of having no solar is presented as "saved" (14) and is how much money the solar installation have reduced electricity bill with during the calculated time (1 year in the model, 6 hours in this example).

Figure 5.7 - Costs and profits for the four different price-options

5.1.2.1 Life cycle cost analysis

As described in Chapter 4.3 a LCC-analysis is a combination of the Lifecycle Costs, Lifecycle Profits and a number of parameters. The parameters used are presented in Figure 5.8 and have been explained earlier in this report.

System Parameters	
Lifespan	25 years
System Size	0.1 kWp
System Price	20 000 kr/kWp
Inverter Price in 15 years	2 700 kr/kWp
Degradation	0.50% / year
Spot price Increase	2.50% / year
Tax Increase	3.50% / year
Yearly maintenance	1.00% of investment
Real interest rate	2.00%

Figure 5.8 – System parameters

The main input to the calculation in Figure 5.9 is the value called "Saved" in Figure 5.7. This is the value of the saved energy in the first year. Due to system degradation, electricity price increase and other parameters the energy balance and annual savings will change over the systems lifespan and the present value of these need to be calculated individually (1). The annual savings made from the solar installation are then summarized into a total present value of the saved energy during the lifespan (2). During the lifespan the system has certain expenses that are necessary for maintaining a high level of operation.
The system requires maintenance every year, and a replacement of the inverter after 15 years, as described in Chapter 4.3.2. Since maintenance and replacement occur on different time basis they are calculated to today's value separately and summarized as "Expenses" (3) in the calculation chart. The profitability of the system is analyzed by calculating the net present value (4) and simply subtracting the present value of the future expenses (3) from the present value of the savings (2) made during the lifespan. A positive number indicates a profit and a viable investment and a negative number like the once in the example in Figure 5.9 indicates that the invested money did not pay back during the calculated time.

Example	Spot	Fixed	Tax	Netto	
Initial cost	2 000	kr			
Yearly maintenance	20	kr/y			
Saved					
Year 0	6.167	7.316	7.392	7.236	kr
Annual change	0.141	0.179	0.134	0.175	kr/y
NPV					
Saved - year:					
1	6.046	7.173	7.247	7.094	kr
2	6.063	7.204	7.234	7.123	kr
3	6.077	7.231	7.218	7.148	kr
4	6.089	7.254	7.200	7.169	kr
5	6.098	7.274	7.180	7.187	kr
6	6.104	7.290	7.158	7.201	kr
7	6.107	7.302	7.134	7.213	kr
8	6.108	7.311	7.108	7.220	kr
9	6.107	7.317	7.081	7.225	kr
10	6.103	7.320	7.052	7.227	kr
11	6.097	7.320	7.021	7.226	kr
12	6.089	7.318	6.989	7.222	kr
13	6.079	7.312	6.955	7.216	kr
14	6.067	7.304	6.920	7.207	kr
15	6.053	7.294	6.884	7.195	kr
Inverter change	*-201*	*-201*	*-201*	*-201*	*kr*
16	5.196	6.439	6.005	6.340	kr
17	5.146	6.391	5.933	6.292	kr
18	5.096	6.343	5.862	6.243	kr
19	5.046	6.294	5.792	6.193	kr
20	4.996	6.245	5.722	6.143	kr
21	4.946	6.195	5.653	6.093	kr
22	4.896	6.144	5.584	6.042	kr
23	4.846	6.094	5.516	5.991	kr
24	4.797	6.042	5.448	5.940	kr
25	4.747	5.991	5.381	5.888	kr
Sum NPVs					
Saved	0 141	0 171	0 163	0 169	kr
Expenses	**2 591**	**2 591**	**2 591**	**2 591**	kr
Investment	*2 000*	*2 000*	*2 000*	*2 000*	*kr*
Replacement	*201*	*201*	*201*	*201*	*kr*
Maintanance	*0 390*	*0 390*	*0 390*	*0 390*	*kr*
Diff	-2 450	-2 420	-2 428	-2 422	kr

Figure 5.9 - The calculation model for the LCC, with the figurative numbers used in the six hour example above.

6 Results

When performing any kind of economic analysis it is always important to clearly state which parameters that have been included and what they are specified to. If there is no information about the input data for the reader, the results lose their value. With clearly stated input data, the reader can draw their own conclusions of whether the results are realistic or not and if they think some parameters might be valued wrong.

The input data used in this research have been presented and discussed throughout the report but for the sake of convenience and to have them presented close to the results, they are summarized in Table 6.1:

Table 6.1 - Input data

Consumption data	Hourly values of electricity consumption [kWh]
Production data	Hourly values of AC power production [kWh]
Weather data	Lund
Electricity pricing	Hourly fluctuations from Nordic spot price market [SEK/kWh]
Yearly Nordic spot price increase	2.5 [%]
Yearly Energy tax increase	3.5 [%]
Electricity certificates on selling price	200 SEK per overproducuced MWh and only during. the first 15 years
System price 0-20 kWp	20 000 [SEK/kWp]
System price >20 kWp	17 500 [SEK/kWp]
Inverter replacement	2700 [SEK/kWp] after 15 years
Yearly maintenance	1 [%] of initial investment
System degradation	0.5 % per year
Discount interest rate	2%
Lifetime of system	25 years

6.1 Single family houses

Single family houses most commonly have pitched roofs. This means that unless a PV-system is part of the plans when designing a house, the choices for installing a system is usually limited to a specific tilt angle with two different azimuth angles that is decided by the cardinal direction of the house. When analyzing the PV-system potential on a specific existing house, this limits the research to two different orientations. These two orientations might even be far from the optimal solutions.

In this research however, the layout of the houses is unknown, which means that the most optimal solutions can be searched for. As mentioned in chapter 2.2.3 the most optimal orientation in terms of total annual production in Lund is directly to south with a tilt of 40-45°.

Simulations were performed in multiple orientations to see if an alternative orientation potentially could be more optimal in terms of NPV with a production that matches the consumption profiles better. The three different PV systems of 3.3 kW_p, 7.7 kW_p and 11.1 kW_p offered by Vattenfall were analyzed.

6.1.1 Current selling price

From a NPV perspective Figure 6.1 presents the most optimal orientations and system sizes for the four different houses investigated and their corresponding NPV, with the current selling price situation without tax reduction.

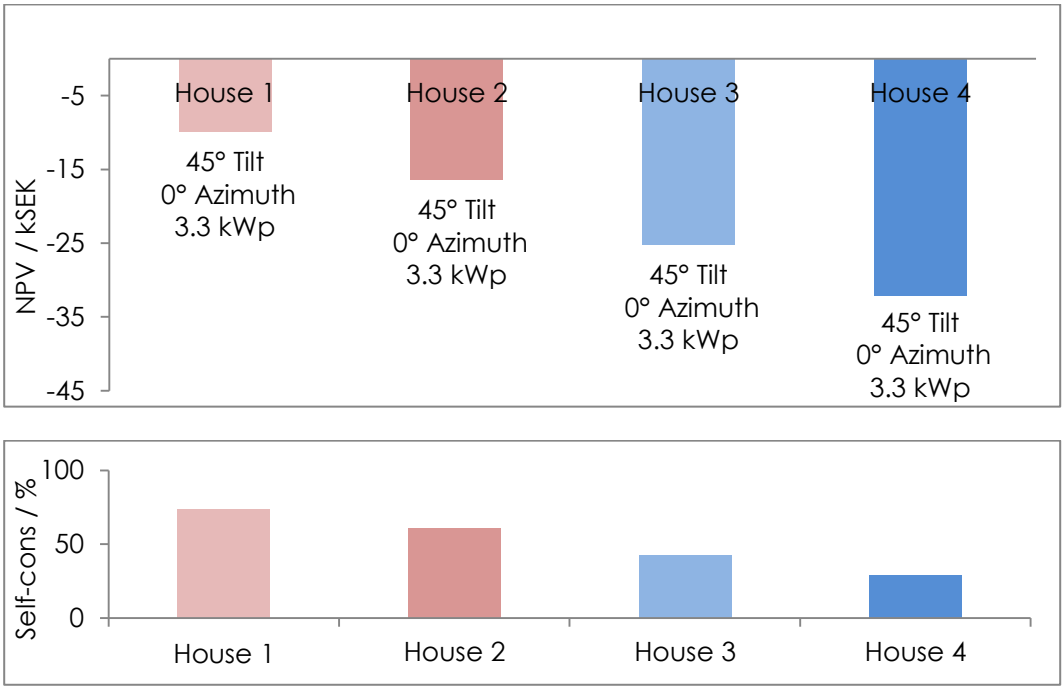

Figure 6.1 – Best NPV case for the four different houses, regarding system size and orientation (upper graph). Percentage of Self-consumed electricity in relation to the total PV production (lower graph).

Worth mentioning is that all the houses presents systems that is not economical supportable after 25 years. House 1 and 2 are heated with electric heating and presents slightly better values than the district heated houses.

Figure 6.1 also shows that the level of self-consumed electricity in relation to the total PV production of the most economic system is highest in house 1 and gets lower for house 2, house 3 and house 4 respectively.

Figure 6.2 on the other hand shows that the level of self-consumed electricity in relation to the total electricity demand of the house is lower in an electrically heated compared to a district heated house with 15.3% compared to 23.4%.

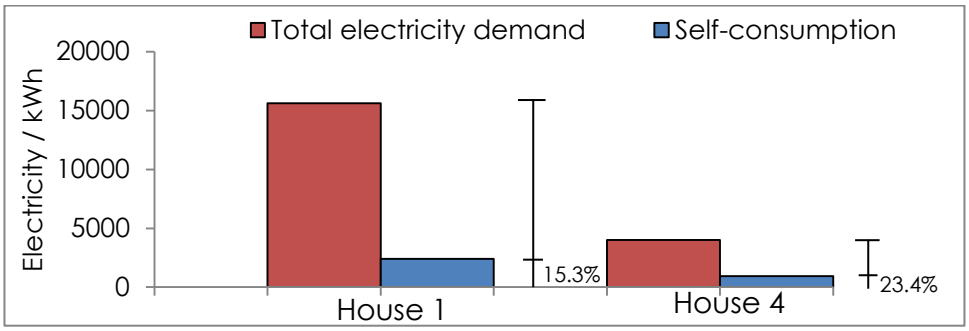

Figure 6.2 – Self-consumed electricity in relation to the total electricity demand of house 1 and house 4.

From a solar fraction point of view, a system of 3.3 kW_p in optimal orientation produces, as presented in Chapter 2.2.4, roughly 3250 kWh. This production covers a larger fraction of the total electricity demand in a district heated house than what it does in an electrically heated house.

6.1.1.1 Sensitivity analysis

A sensitivity analysis was performed in order to identify critical parameters and how the assumed input values can affect the NPV. Figure 6.3 shows the results of the analysis regarding the best case in Figure 6.1, i.e. house 1 with the 3.3 kW_p system towards south with a 45 degree tilt.

All the values are presented in relation to the initial NPV value and the red line is marking the limit for when the NPV of the system would be 0, when the system would have paid itself back within 25 years.

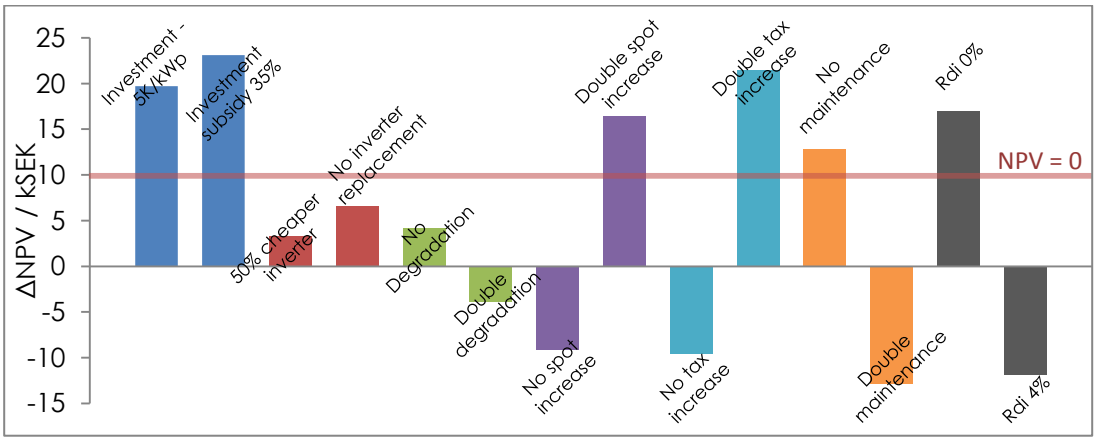

Figure 6.3 Sensitivity analysis of the different parameters affecting the 3.3 kW_p system with the current selling price situation. The red line represents a NPV of zero.

If the investment costs would have been 5000 SEK / kW_p less or if an investment subsidy of 35% would have been achieved, the system would have been economically beneficial.

If the inverter would last for the whole system lifetime or if the inverter in 15 years is 50% cheaper, the system would still not be economically supportable. The level of system degradation does not affect the results significantly. Both the containing parts of the electricity price development on the other hand have a large impact separately, the spot price increase as well as the energy tax increase.

The maintenance costs also have a significant impact even though they only represent 1% of the investment costs per year. The discount interest rate is also a very sensitive parameter.

6.1.1.2 Alternative orientations

The previously presented results have showed the NPV for the optimal orientations. Now the focus is to analyze how alternative orientations can affect the results. The results are presented as the difference in NPV compared to each house best result.

Figure 6.4 shows on the left axis the variation in NPV compared to the optimal solution for each house. The horizontal axis shows the variation in azimuth angles. The right axis shows the production of a 3.3 kW_p system and is representing the green graph.

In the figure it is noticeable that if it is not possible to have an optimal azimuth angle, it is slightly better to have the array orientated towards east than towards west both from a NPV perspective and from a total production perspective.

Figure 6.4 shows the results from a 3.3 kW_p system, similar patterns can be seen in the results for the larger systems, presented in Appendix A.

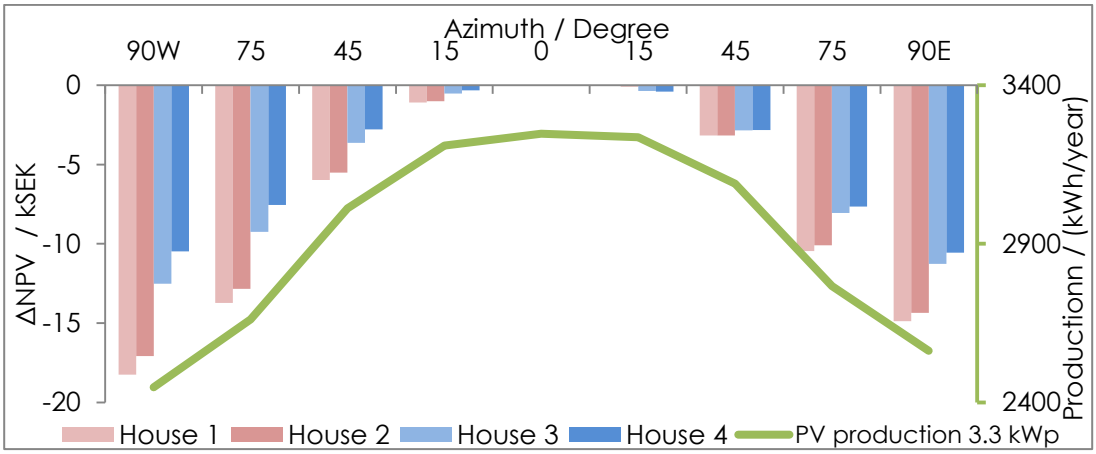

Figure 6.4 – Variation in NPV due to azimuth angles compared to the best 3.3 kW_p cases presented in Figure 6.1 and the total PV production of the 3.3 kW_p at specific angles.

Stepping away from actual economic results in terms of NPV, Figure 6.5 shows that in general it is also best from a load matching perspective to stay close to 0° azimuth angle, but there are cases when an alternative orientation potentially could be better. The graphs show the fraction of self-consumption in relation to the maximum production a system could produce with optimal conditions.

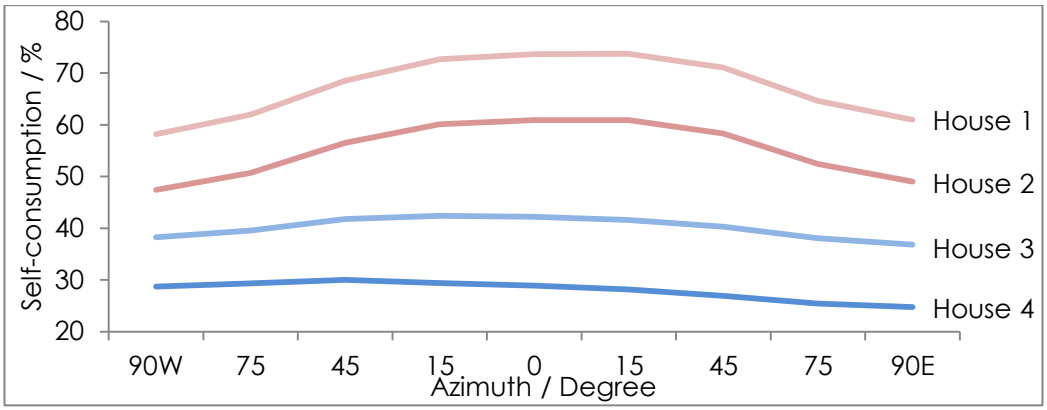

Figure 6.5 - Fraction of self-consumption with alternative orientations, in relation to the maximum output of a 3.3 kW_p system.

Noticeable in Figure 6.5 is that house 3 and 4 has a slightly higher amount of self-consumption in relation to the maximum output of the system in an alternative orientation.

Figure 6.6 explains how both production and self-consumption varies with alternative azimuth angles. The left axis represent the electricity in kWh and the right axis and its corresponding line shows the fraction of self-consumption. The fraction of self-consumption is in relation to the maximum production for a system with optimal orientation.

It can be seen that even with a loss in production, the self-consumption can still slightly increase with azimuth angles towards west, for the investigated house.

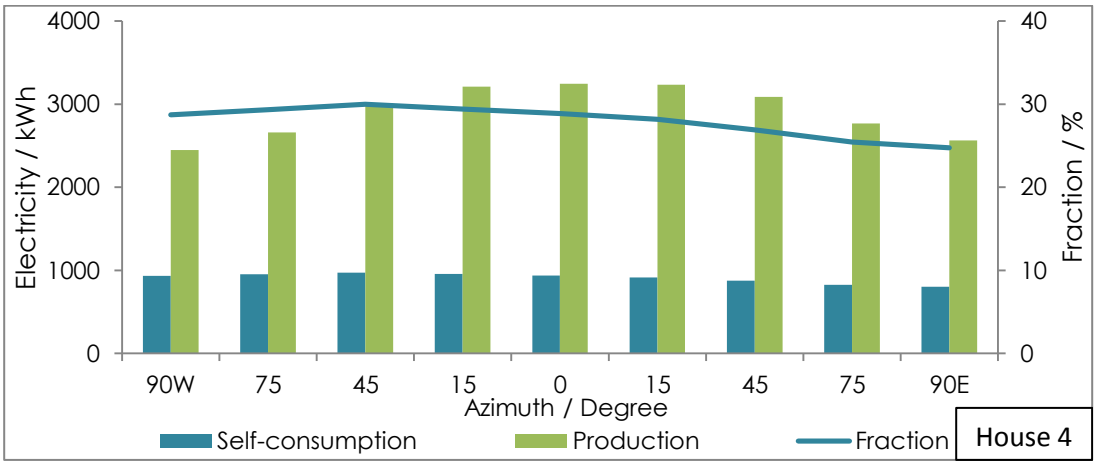

Figure 6.6 – Electricity produced and self-consumed (bars) and the fraction of self-consumption in relation to a specific angles production and in relation to the optimal production, with different azimuth angles for House 4.

By dividing the self-consumed electricity for a specific angle, with the production of a system with optimal conditions, the fraction for different angles can be compared with each other and act as an indication of whether it is good or not to change the orientation.

Figure 6.7 is similar to Figure 6.4 with the difference that the tilt angle is varied instead and presented on the horizontal axis. Noticeable is that it is better to decrease the tilt angles towards horizontal than it is to increase them towards vertical both from an NPV and a total production perspective. The same patterns are noticeable also for the bigger systems evaluated, presented in Appendix A.

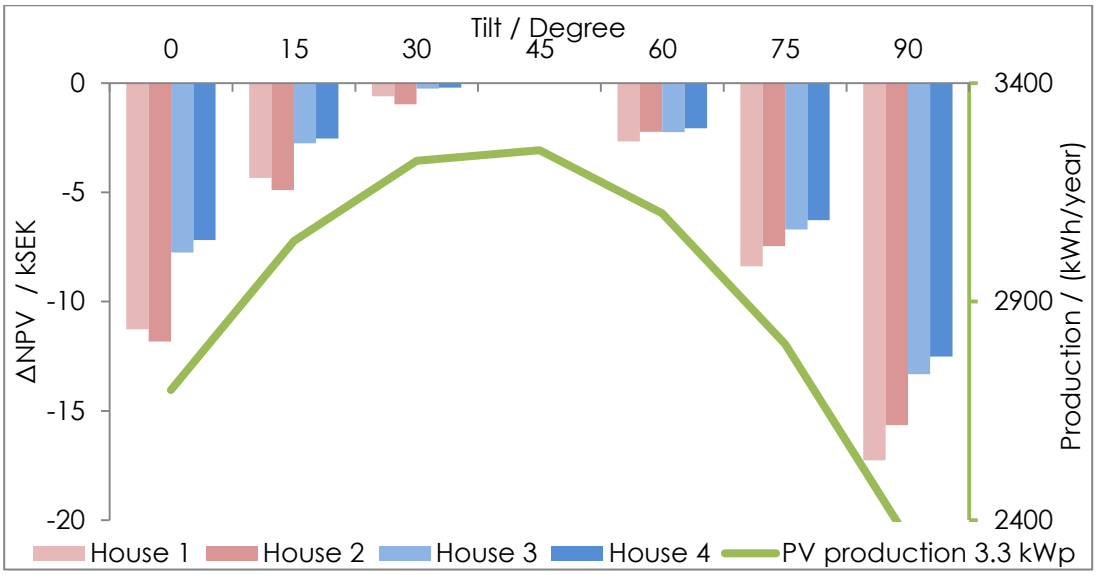

Figure 6.7 – Variation in NPV due to tilt angles compared to best 3.3 kWp case presented in Figure 6.1 and the total PV production at specific tilts.

Figure 6.8 shows how the variation in tilt angles also affects the level of self-consumption.

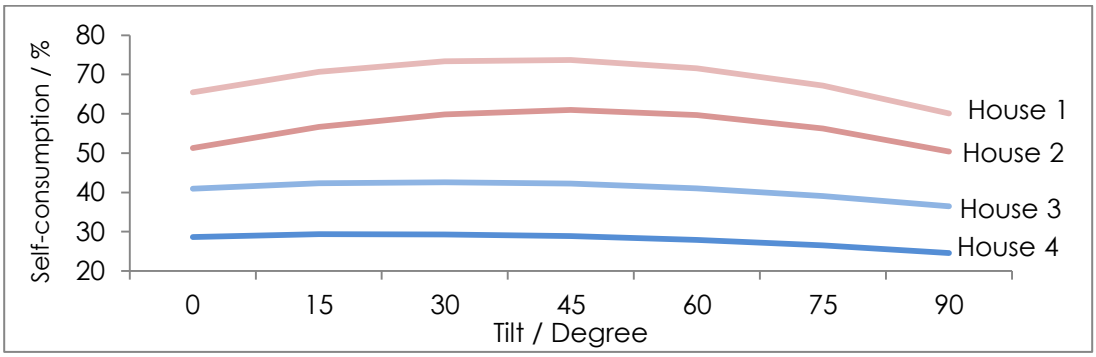

Figure 6.8 - Fraction of self-consumption with alternative tilts, in relation to the maximum output of a 3.3 kW_p system.

Noticeable is that it is better to decrease the tilt towards horizontal than it is to increase the tilt towards vertical in terms of self-consumption. Same patterns as presented regarding azimuth variations can be seen, with a higher self-consumption in an alternative orientation in some cases.

Figure 6.9 and Figure 6.10 shows all system sizes and angles compared to the most beneficial solution presented in Figure 6.1. The presented results represent house 1 and the results for the remaining three houses can be seen in Appendix A and shows similar results.

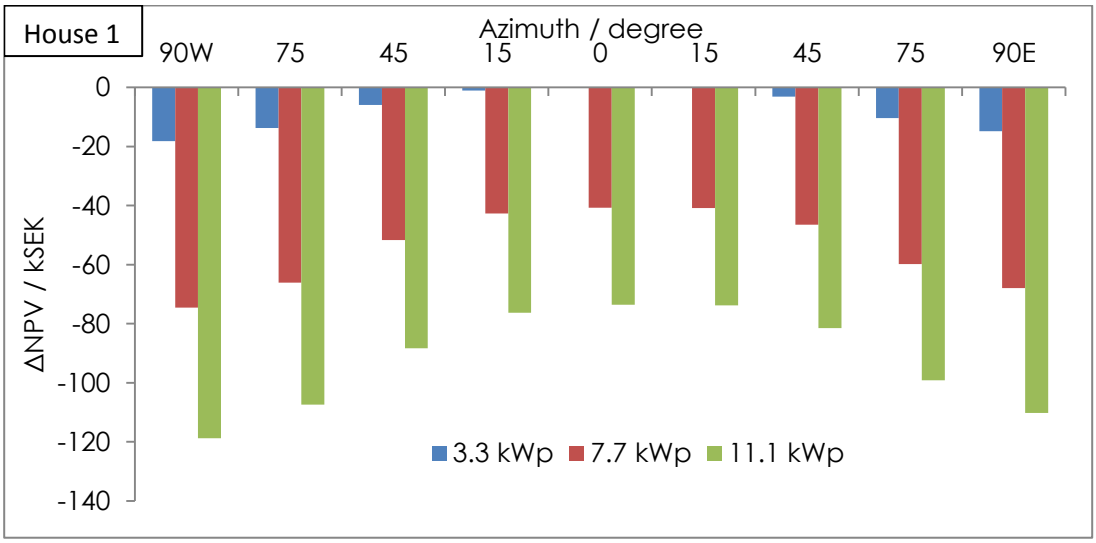

Figure 6.9 – Variation in NPV for different system sizes compared to the most beneficial option for house 1 with varying azimuth angles.

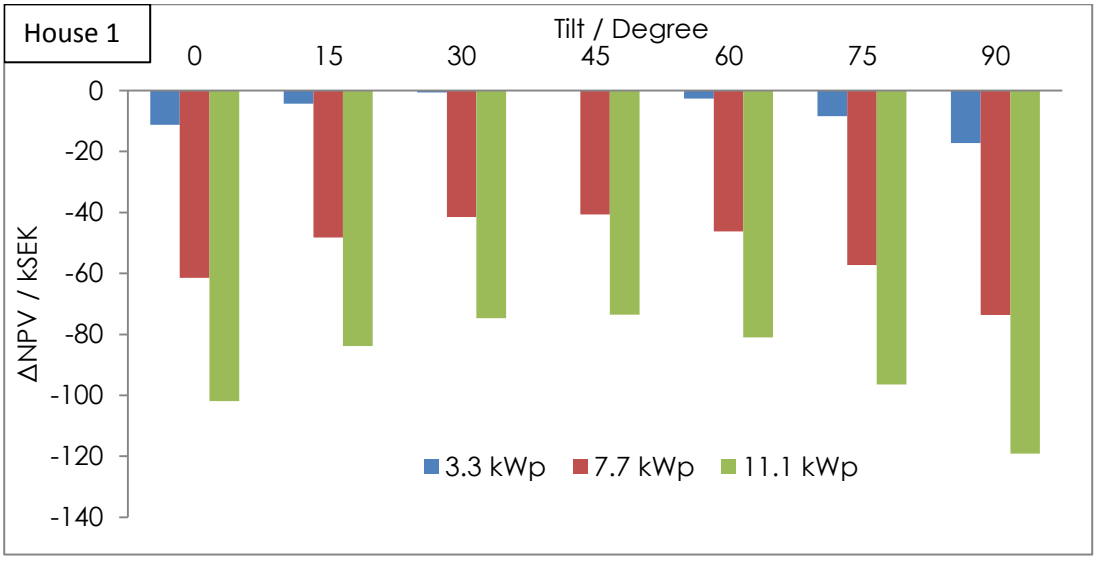

Figure 6.10 – Variation in NPV for different system sizes compared to the most beneficial option for house 1 with varying tilt angles.

Noticeable is that increasing the system sizes have a significant negative impact on the economical results, but shows the same patterns regarding azimuth and tilt angles as presented in Figure 6.4 and Figure 6.7.

6.1.2 Future selling price

In Figure 6.11 a comparison for each house's best option is made between the current and the future selling price with tax reduction. The added tax reduction improves the NPV of all system sizes and orientations but the optimal systems are the same as before, 3.3 kW_p with a 45° tilt directly to the south. However, the added tax reduction is not beneficial enough to make the systems economically supportable in 25 years.

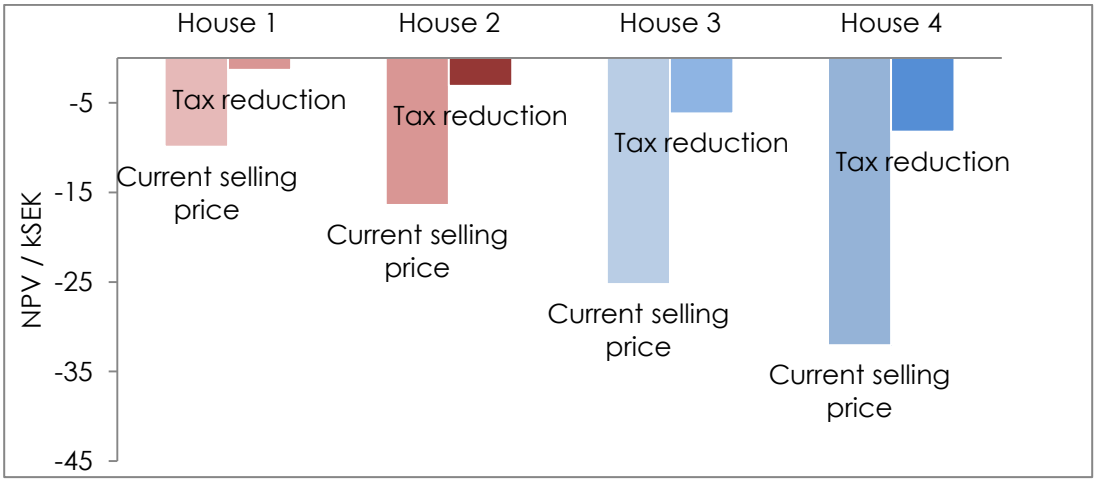

Figure 6.11 – Comparison of the best NPV result for the four different houses, regarding system size and orientation for both the current and the future selling price.

6.1.2.1 Alternative orientations

Now the focus is to analyze how alternative orientations can affect the results with the future selling price. The results are presented as the difference in NPV compared to each house best result.

Figure 6.12 and Figure 6.13 shows the variation in NPV with varying tilt angles and system sizes, compared to the optimal system and angle, for one district heated (house 4) and one electric heated house (house 1). The results for the other two houses are similar to their corresponding heating system and can be seen in Appendix A.

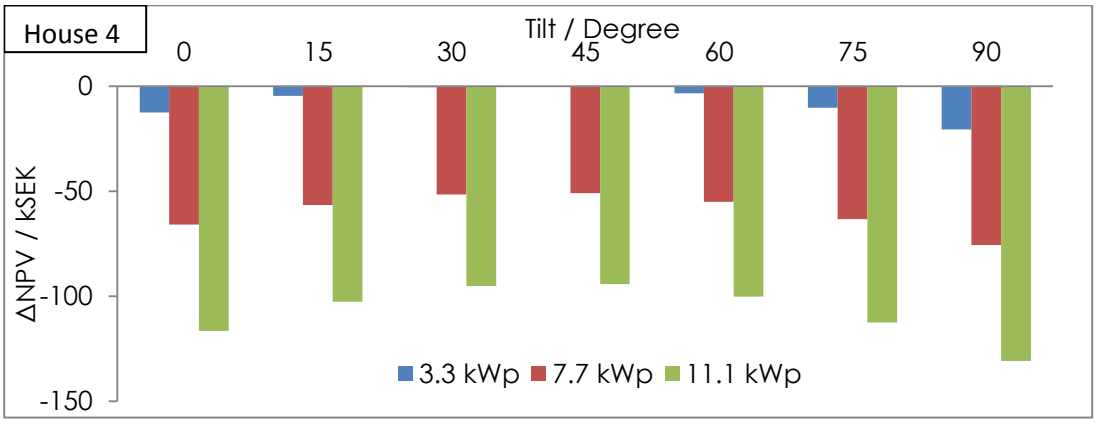

Figure 6.12 – Variation in NPV with tax reduction added, for different system sizes compared to the most beneficial option for house 4 with varying tilt angles.

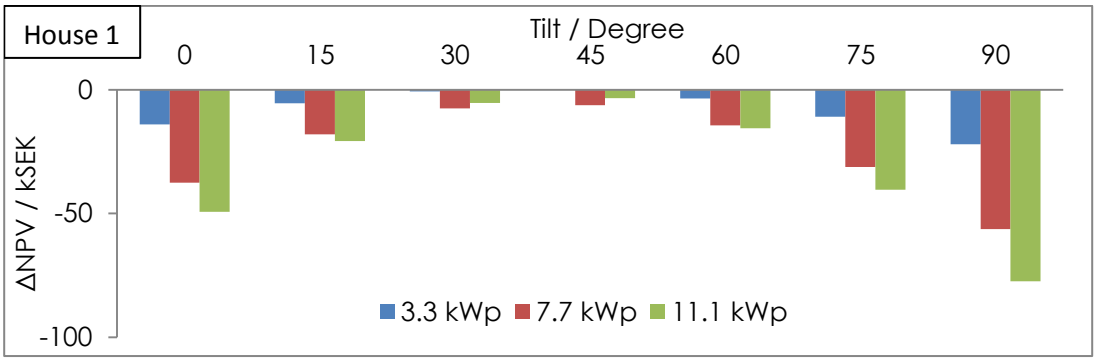

Figure 6.13 – Variation in NPV with tax reduction added, for different system sizes compared to the most beneficial option for house 1 with varying tilt angles.

Generally, the added tax reduction improves the NPV for all the houses and systems. The improvement is however not equally big between the two different heating systems. Figure 6.13 shows that if the tilt angles are relatively optimal, it could be almost as beneficial to install a bigger system size for the electric heated houses.

The continuous lines in Figure 6.14 and Figure 6.15 show the NPV of the different system sizes with the current selling price. The dotted lines present the corresponding results with the added tax reduction.

For the district heated house in Figure 6.14, variable azimuth angles affect the NPV with and without tax reduction equally much.

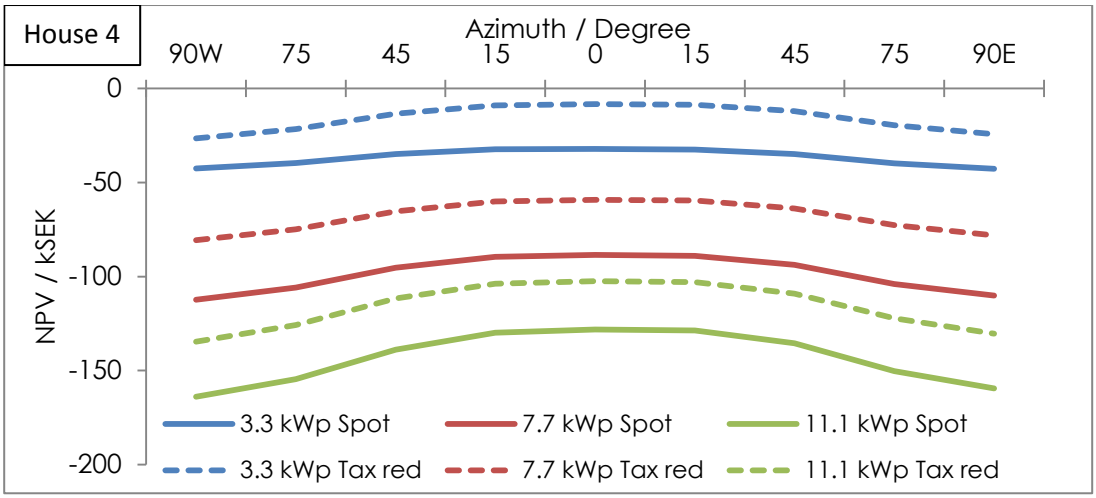

Figure 6.14 – How tax reduction affects the NPV for different system sizes and azimuth angles for house 4.

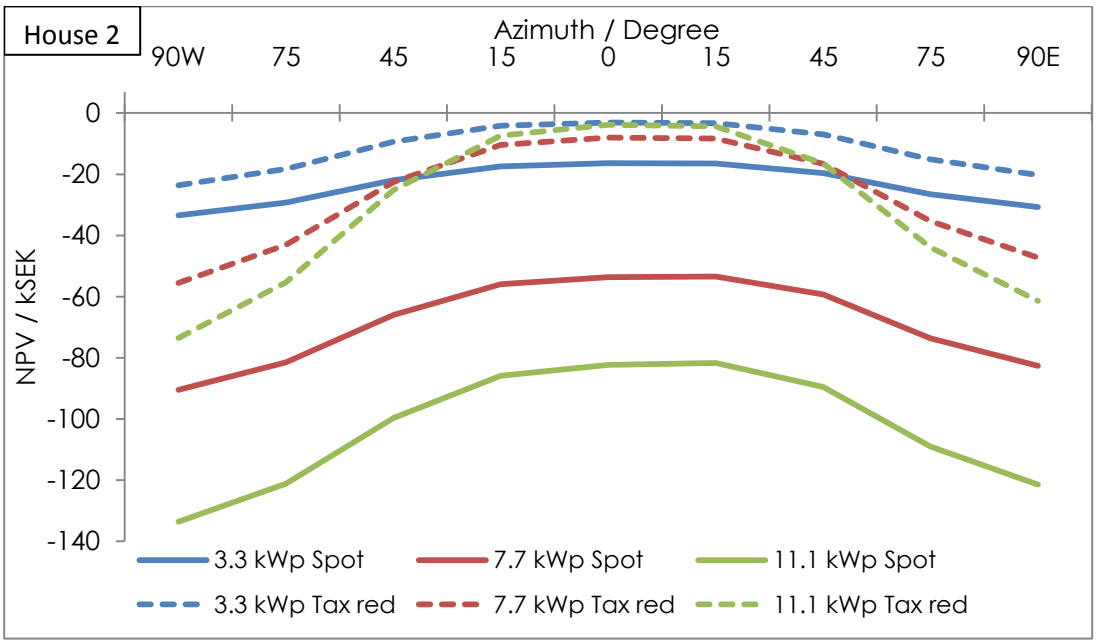

Figure 6.15 - How tax reduction affects the NPV for different system sizes and azimuth angles for house 2.

For the electrically heated house (house 2) in Figure 6.15 it is noticeable that with the current price, the patterns are similar to the district heated house. However, with the future selling price, it is a large difference. The larger systems improve the results significantly and

represent a value similar to the best solution. Noticeable is also that since the dotted lines cross each other, a varying azimuth angle can present different system sizes as the optimal solution.

Figure 6.16 and Figure 6.17 shows how the remaining electricity need affect the opportunity to receive tax reduction for the overproduction. One district heated house (house 4) and one electrically heated house (house 2) are presented.

In the figures, the amount of self-consumed electricity, over-produced electricity and remaining electricity need is presented. The over-production is divided into two different parts. One part represents the over-production that can obtain a full price with added tax reduction and the other part represents the part when the tax reduction is lost.

The vertical axis represents the amount of electricity in kWh and the horizontal axis presents the three different system sizes.

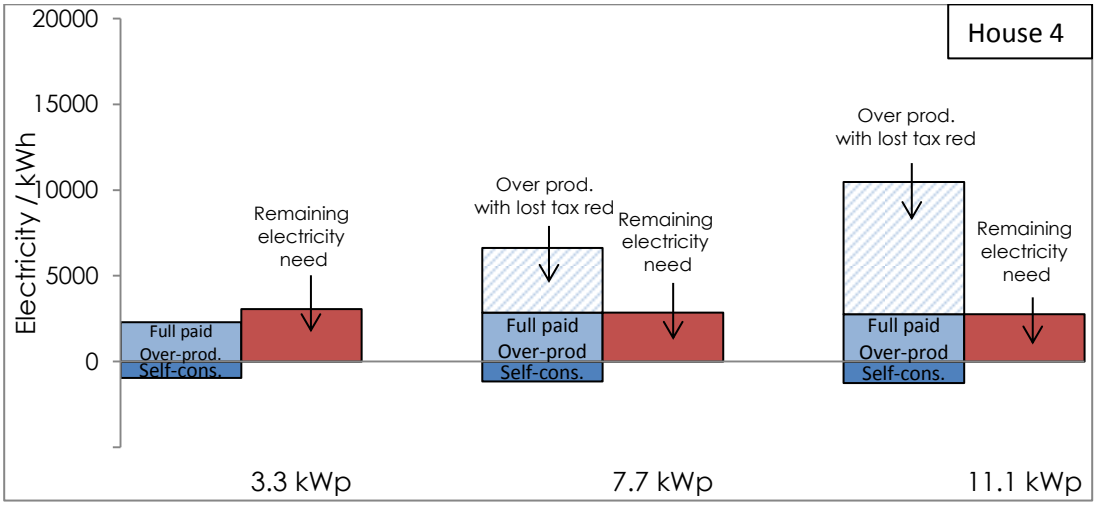

Figure 6.16 - How the remaining electricity need affects the opportunity to receive tax reduction for the over-production for house 4.

Figure 6.16 shows that the district heated houses with an increasing system size, quickly over-produce more than the remaining electricity need, which results in a lost tax reduction for the remaining over-production.

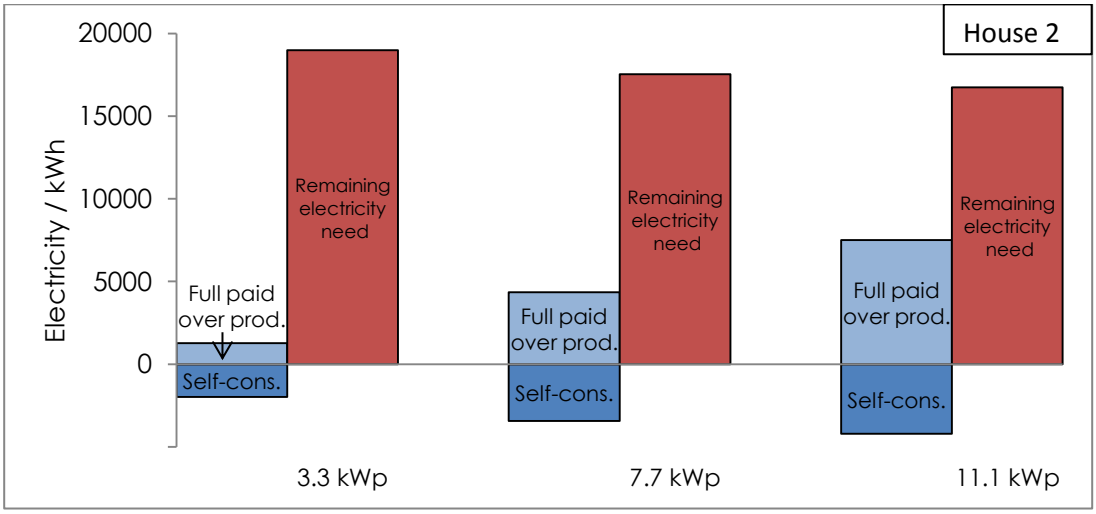

Figure 6.17 - How the remaining electricity need affects the opportunity to receive tax reduction for the over-production for house 2.

Figure 6.17 show that the electrically heated houses on the other hand have a larger potential to receive full price for the over-production, even with bigger systems. The limitations of the tax reduction were discussed previously in Chapter 3.4.5.

Figure 6.18 is comparing the future selling price, with the fixed price that some electricity companies offers today, for house 2.

It can be seen that the two different options, presents similar results in terms of NPV. However, as the system sizes gets larger, the fixed price tends to present better results.

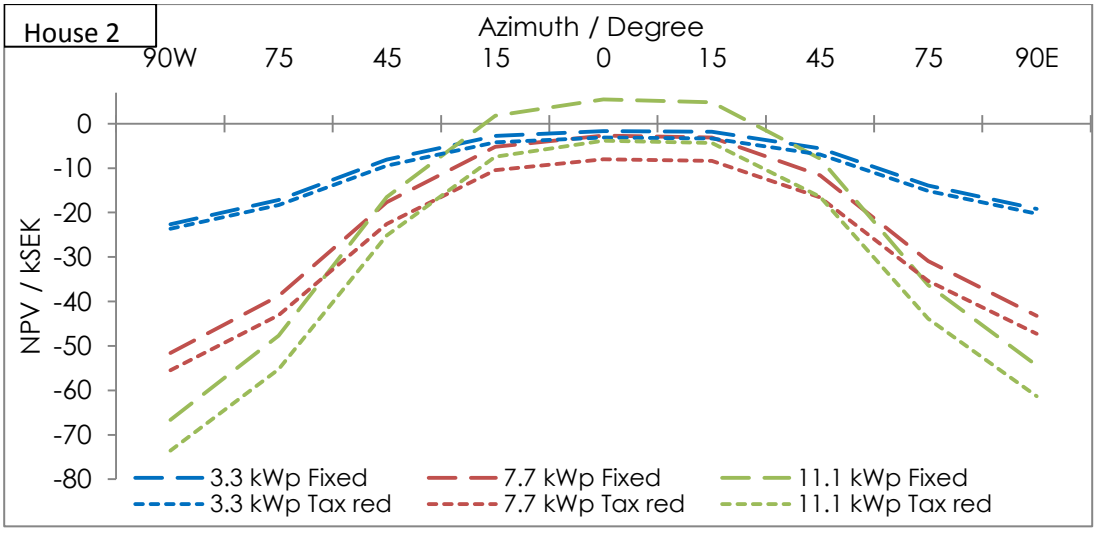

Figure 6.18 - Comparing tax reduction to a fixed price in terms of NPV with alternating azimuth angles and system sizes for house 2.

6.2 Apartment block

A similar analysis was done on the apartment blocks with simulations of three different system sizes in multiple orientations.

6.2.1 Current selling price

In terms of NPV with the current selling price, Figure 6.19 shows that two of the apartment blocks present results that are economically supportable after 25 years with the 3.3 kW_p systems. These two houses can furthermore increase the system size from 3.3 kW_p to 11.1 kW_p and get even better economical results.

The system size of 3.3 kW_p will be used as a reference in the upcoming graphs when investigating how alternative orientations will affect the NPV.

45º tilt directly to the south is still the best solution in terms of NPV for all the evaluated apartment blocks.

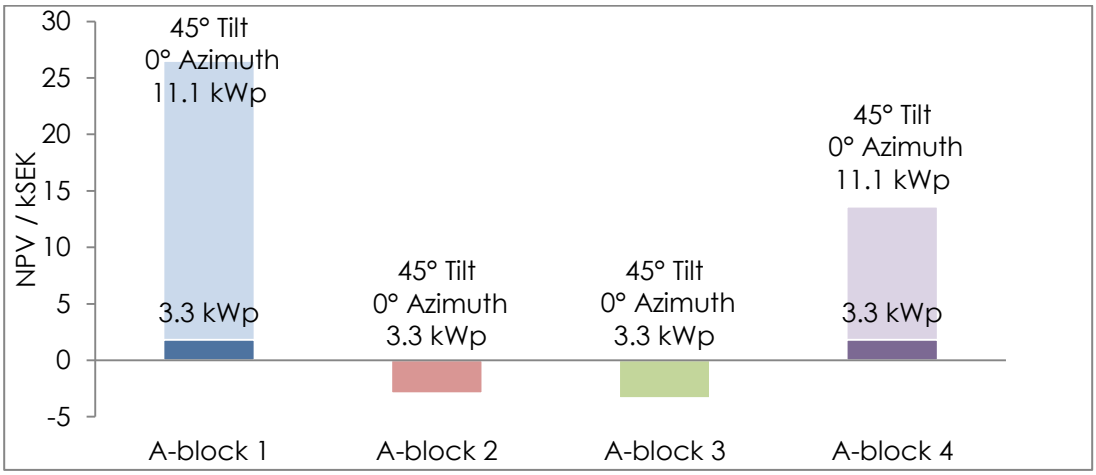

Figure 6.19 - Best NPV option for the four different apartment blocks, regarding system size and orientation and the reference cases of 3.3 kW_p.

Figure 6.20 shows how much of the produced PV electricity that is self-consumed in the buildings and how this varies with increased system sizes, for the four different apartment blocks.

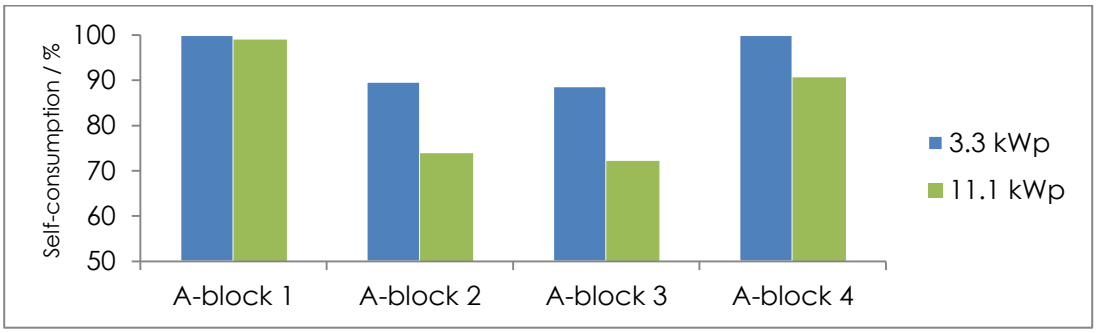

Figure 6.20 - Percentage of Self-consumed electricity in relation to the total PV production

Noticeable in Figure 6.20 is that the percentage of self-consumption with a larger system is relatively high for apartment block 1 and 4, but 2 and 3 lose a rather high level of self-consumption with the increasing system sizes.

6.2.1.1 Sensitivity analysis

A sensitivity analysis was performed for one of the apartment blocks in order to investigate if the same parameters are sensitive for an apartment block as for a single family house. Apartment block 1 was chosen and since it presented positive values in terms of NPV, the red line in Figure 6.21 shows which parameters that possibly could affect the NPV enough to make the system loose its positive results. The biggest system size of 11.1 kW_p was selected since it presented the best NPV values for this specific apartment block.

The sensitivity analysis of the apartment blocks shows similar results as the results presented in Figure 6.3 for house 1.

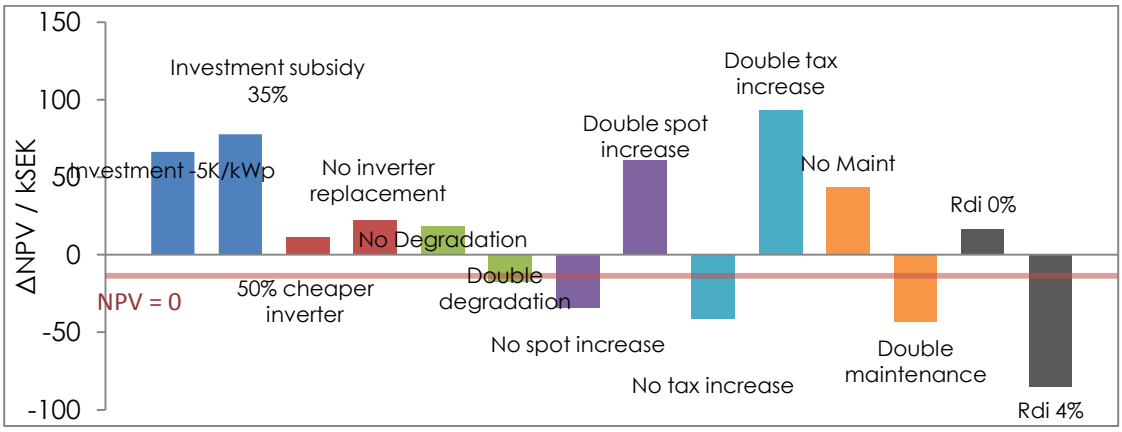

Figure 6.21 – Sensitivity analysis of the different parameters affecting the 11.1 kW_p system with the current selling price situation. The red line represents a NPV of zero.

6.2.1.2 Alternative orientations

The same approach of analysis regarding alternative orientations as for the single family houses were applied to the apartment blocks.

The system size of 3.3 kW_p was used as a reference for all the investigated buildings and the difference in NPV according to the optimal orientation are presented on the vertical axes. In appendix B the same results can be seen for the larger systems, both in terms of azimuth and tilt variations.

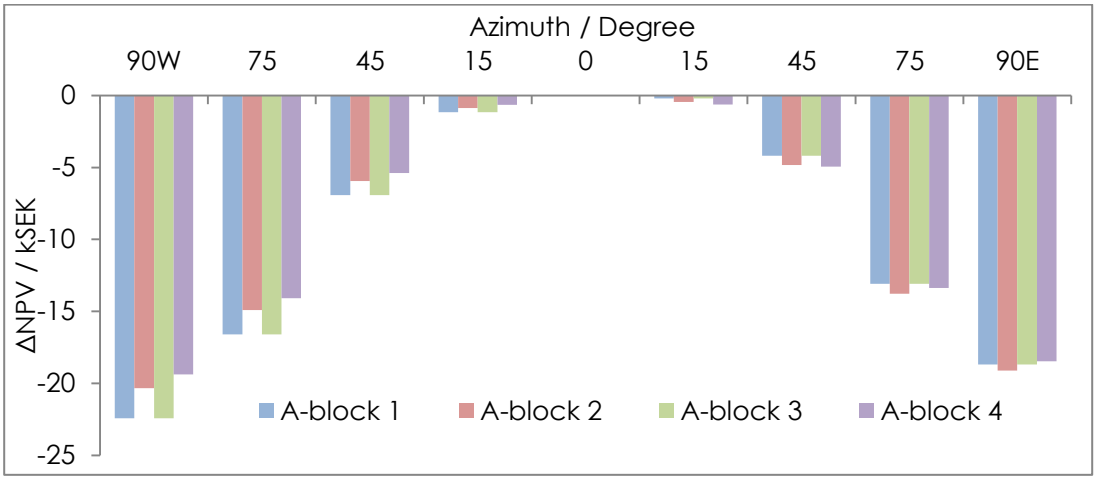

Figure 6.22 - Variation in NPV due to azimuth angles compared to the best 3.3 kWp cases presented in Figure 6.19.

Figure 6.22 shows that the same patterns regarding differences in NPV due to alternative azimuth angles are noticeable for the apartment blocks. Directly to the south is the best option, but small variations with 15º towards east or west is almost as beneficial.

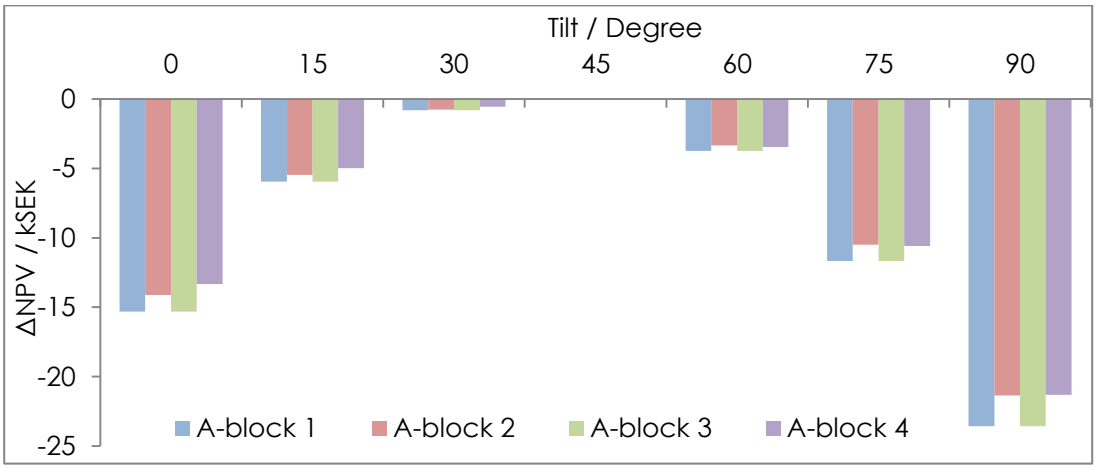

Figure 6.23 - Variation in NPV due to tilt angles compared to best 3.3 kWp cases presented in Figure 6.19.

Regarding tilt angles, Figure 6.23, it is still more beneficial to tilt the system down towards horizontal than up towards vertical as the results for the single family houses also showed, but 45º is still the optimal solution.

Figure 6.24 and Figure 6.25 shows how apartment block 1 and 2 is affected by alternative orientations and system sizes compared to their corresponding reference case.

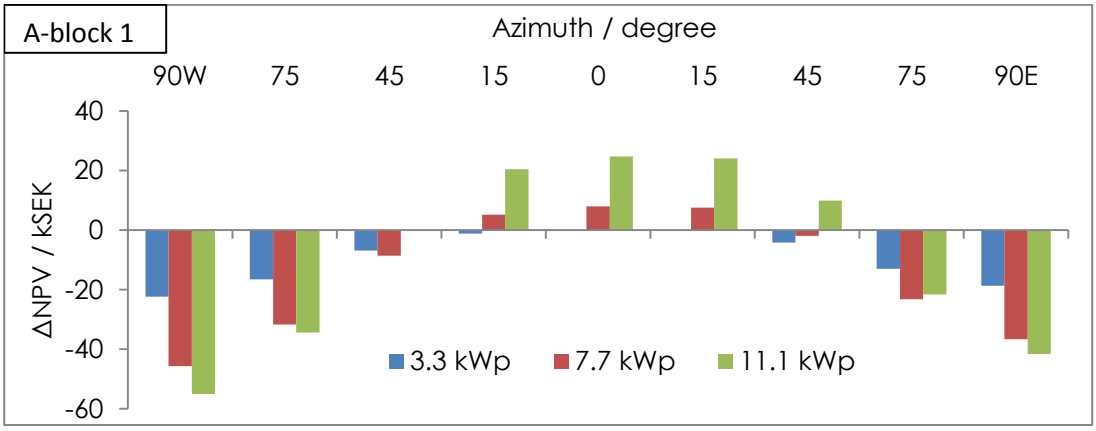

Figure 6.24 – Variation in NPV for different system sizes compared to the most beneficial option for apartment block 1 with varying azimuth angles.

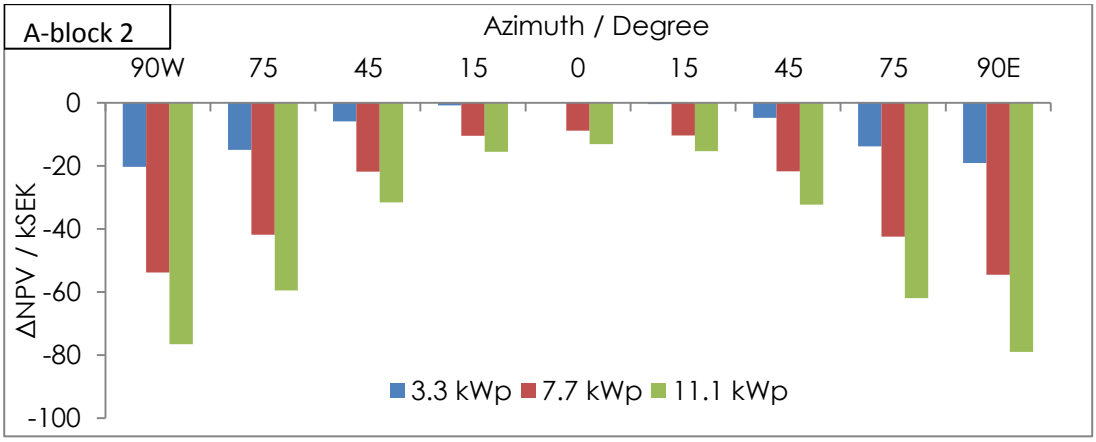

Figure 6.25 – Variation in NPV for different system sizes compared to the most beneficial option for apartment block 2 with varying azimuth angles.

Figure 6.24 shows that it is possible to increase the system size for apartment block 1 and get better economical results, for certain azimuth angles.

On the other hand, apartment block 2, presented in Figure 6.25 shows that the smallest system with optimal orientations still is the best solution, a bigger system could not be more beneficial in any orientation.

The results for apartment block 3 and 4 can be found in Appendix B. Similar results regarding tilt angles for the four different apartment blocks can be seen in Appendix B.

6.3 Future selling price

With added tax reduction, all the apartment blocks can present economic supportable solutions. Apartment block 2 and 3 that previously could not achieve a positive NPV even with the smallest system can with added tax reduction invest in a bigger system and present better and positive economic results. Apartment block 1 and 4 had beneficial results even without the added tax reduction but the subsidy will make the results even better and potentially even bigger systems could have been beneficial if they were investigated, Figure 6.26.

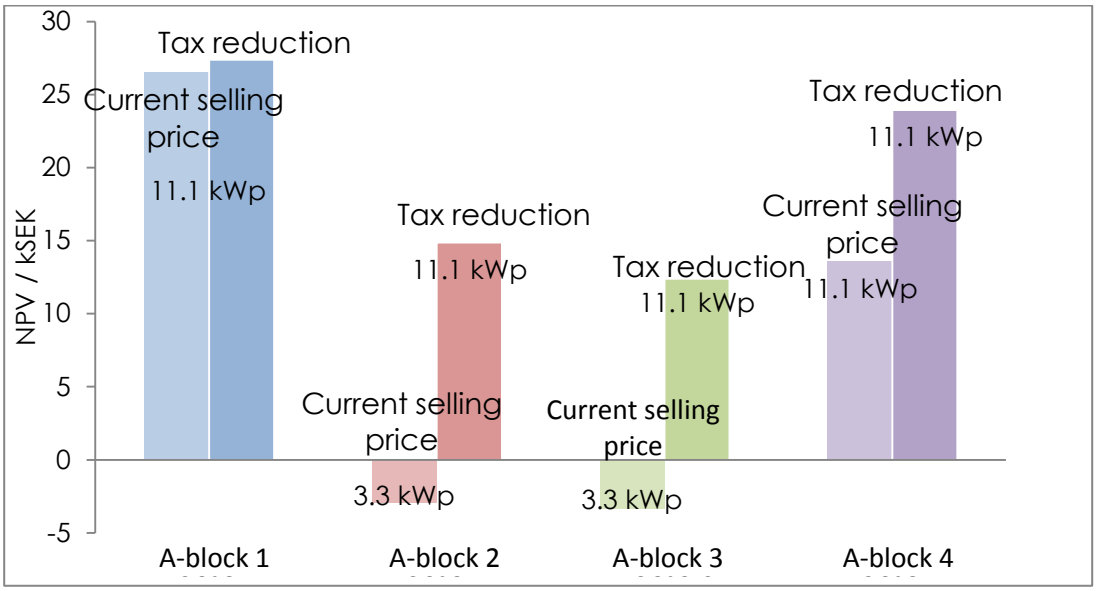

Figure 6.26 – The best NPV result for the four different apartment blocks both regarding system size and orientation. The brighter bar to the left, represent the current selling price and the darker bar to the right represent the future selling price with added tax reduction.

The future selling price will support larger systems economically. Figure 6.27 shows how solar fraction and self-consumption in relation to the total load, is affected by this.

The bars to the left in darker colors show the solar fraction.
The dashed bars to the right, shows the self-consumption in relation to the total load.
If the added tax reduction supports a larger system, these parameters will be increased, noticed as brighter bars on top of the previous ones.

If all the produced electricity is self-consumed, it is equal to the solar fraction. But it can never be larger than the solar fraction that only is the percentage of total production in relation to total consumption.

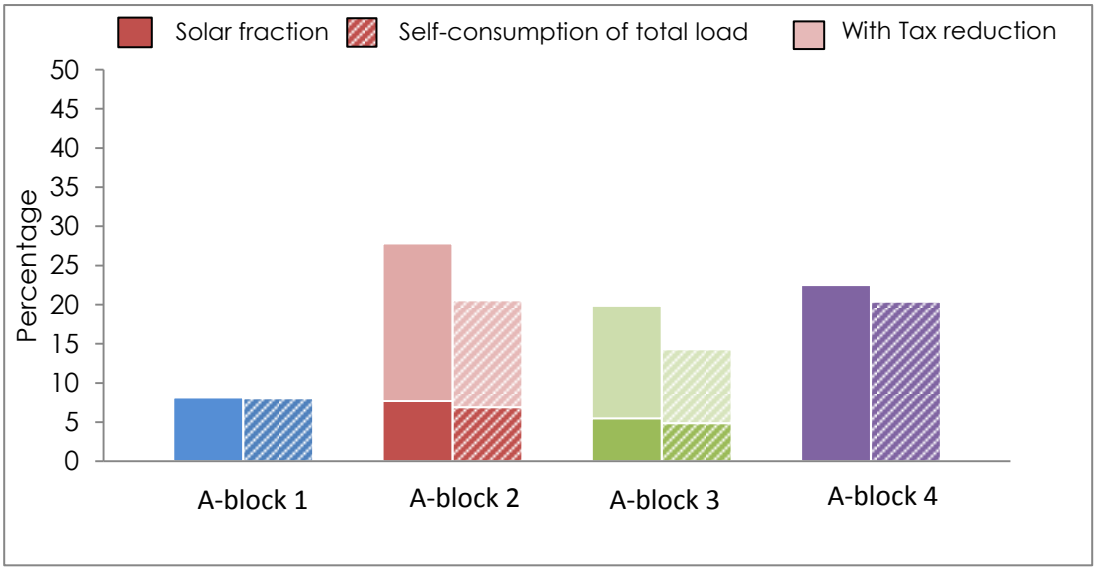

Figure 6.27 – Solar fraction and self-consumption of the total load (dashed), with the current selling price and with added tax reduction (brighter colours), for the four different apartment blocks.

Figure 6.27 shows that since apartment block 2 and 3 can increase the optimal system size with the added tax reduction, the solar fraction and level of self-consumption can be increased. It is also noticeable that since apartment block 1 and 4 will not increase their system sizes, these factors will remain the same.

6.3.1 Alternative orientations

With the added tax reduction, the alternative tilts and different system sizes in Figure 6.28 shows that bigger systems could be beneficial for apartment block 2 if the tilts are relatively close to the optimal. The results for the three other cases can be seen in Appendix B.

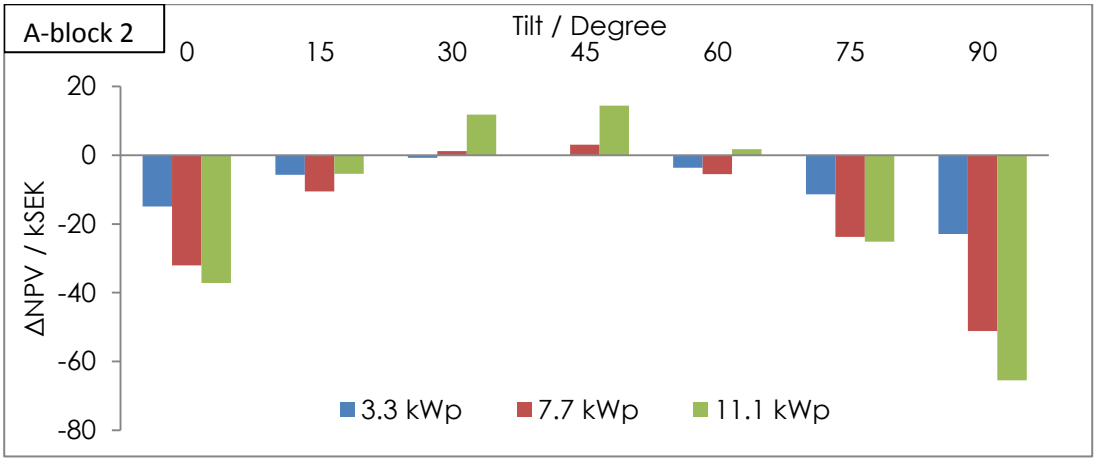

Figure 6.28 – Variation in NPV with tax reduction added, for different system sizes compared to the most beneficial option with the current selling price for apartment block 2 with varying tilt angles.

Figure 6.29 and Figure 6.30 shows the current and future selling price affects the NPV for different system sizes and azimuth angles.

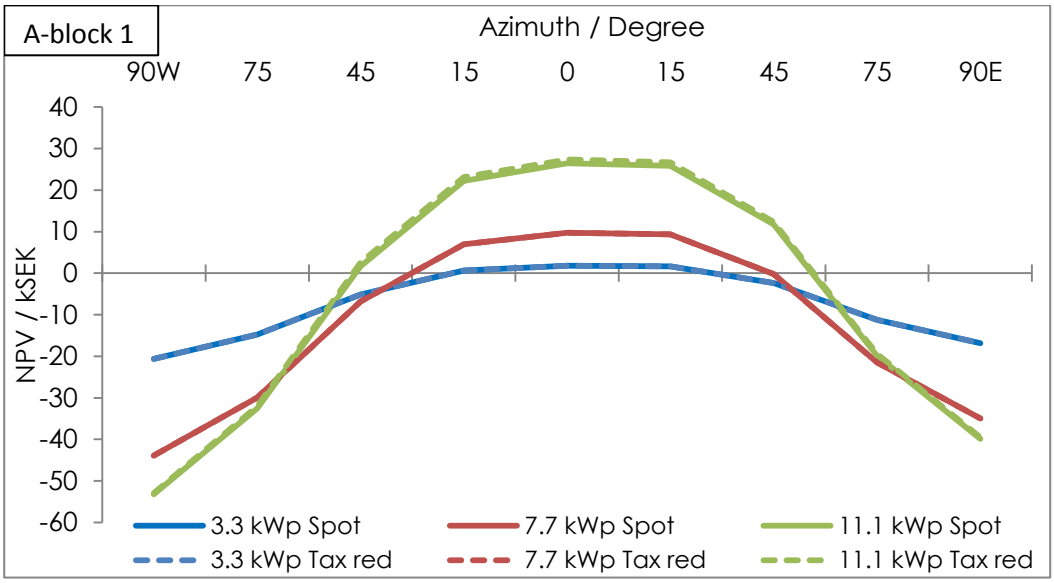

Figure 6.29 - How tax reduction affects the NPV for different system sizes and azimuth angles for apartment block 1.

Figure 6.29 shows the results for apartment block 1. The economical differences between the current and the future selling price are almost none existing for all system sizes and azimuth angles evaluated. This can be related to previous results in Figure 6.20, showing that almost all the production in self-consumed in apartment block 1, regardless of the system size. Self-consumed electricity is not affected by the tax reduction.

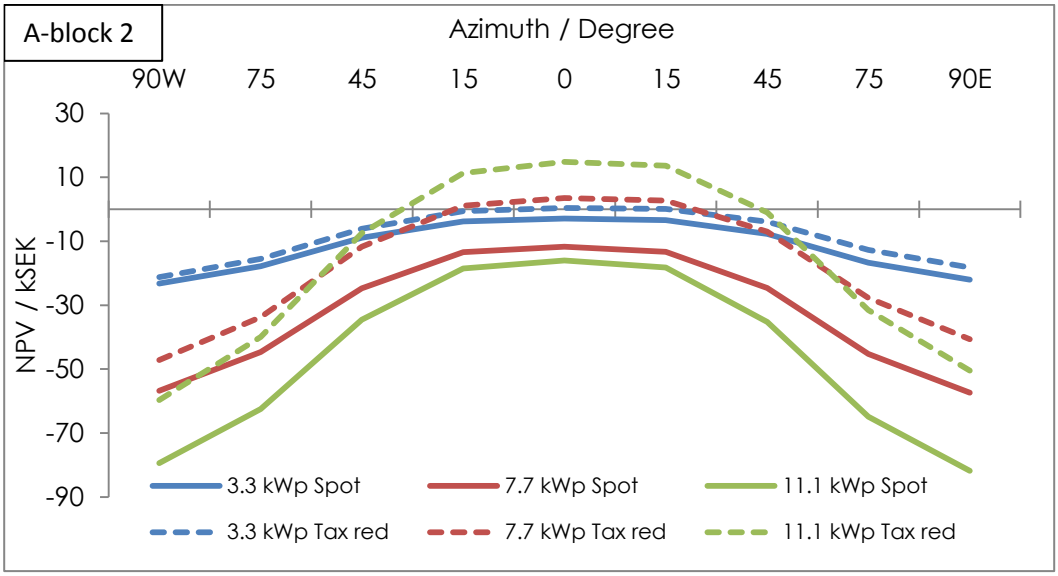

Figure 6.30- How tax reduction affects the NPV for different system sizes and azimuth angles for apartment block 2.

Figure 6.30 shows the results for apartment block 2. These results are completely different whereas tax reduction improves all the results significantly, at least as the system gets bigger. This can also be explained in Figure 6.20 where it is noticeable that even with the smallest system roughly 10% will be over-produced, which is affected by the tax reduction.

It can also be seen that lines corresponding to larger systems with the added tax reduction crosses the lines of smaller systems with added tax reduction, indicating that the optimal system size varies with the azimuth.

6.4 Offices

The offices evaluated presented larger electric loads. In order to analyze systems that were more suitable for these consumption profiles, the system sizes were increased significantly from the previous evaluations of the single family houses and apartment blocks.

Initially an evaluation was done for office 1 for alterative orientations. This research presented similar same results as for the single family houses and apartment blocks. These results can be seen in Appendix C.

With the elimination of alternative orientations in terms of NPV, the continued research investigated a potential system resizing in order to get a more economically supportable system. The results are presented both with and without the added tax reduction.

6.4.1 System size selection

Figure 6.31, Figure 6.33, Figure 6.35 and Figure 6.37 shows how a variation in system sizing affects the economical results of the different offices. The blue bars represent the current selling price and the pink bars represent the future selling price. The vertical axis presents the NPV and the horizontal axis shows the different system sizes.

Figure 6.32, Figure 6.34, Figure 6.36 and Figure 6.38 shows the amount of self-consumed electricity, over-produced electricity and the remaining electricity need from the grid, for one year.

The over-production is divided into two different parts. One part represents the over-production that can obtain a full price with added tax reduction and the other part represents the part when the tax reduction is lost. The black line marks an over-production of 30 000 kWh, which is one of the two limiting factors for the tax reduction, explained in Chapter 3.4.5.

The green line represents the NPV of the different system sized with the added tax reduction. Noticeable is that the tipping point in the graph is strongly related to the system size that starts to have an over-production with a lost tax reduction.

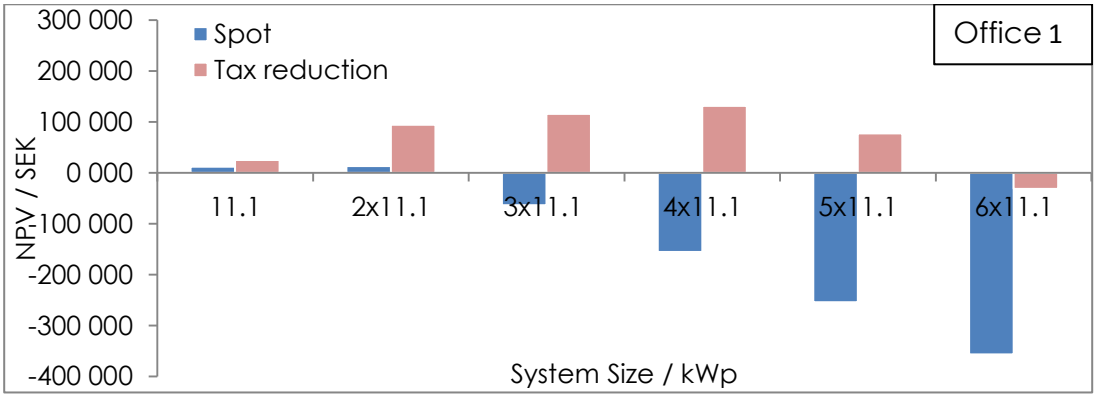

Figure 6.31 – NPV with the current and future selling price and its variation with a varying system size for office 1.

Figure 6.31 shows that 22.2 kW_p is the most optimal system size for office 1with the current selling price. With added tax reduction, the system size can be increased to 44.4 kW_p and still present better results.

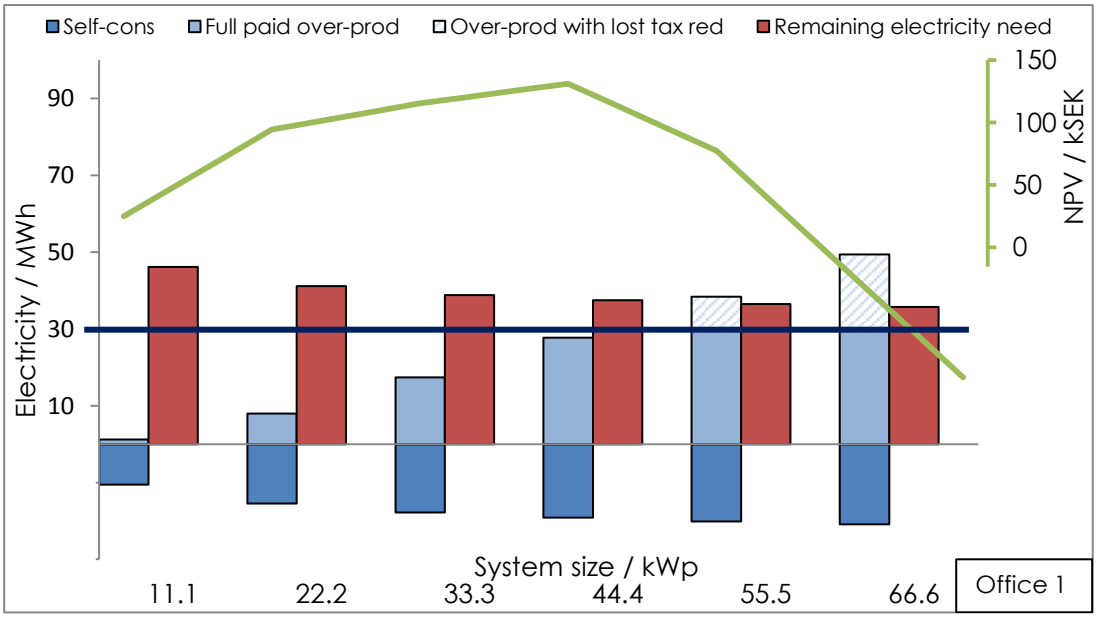

Figure 6.32 – Relationship between the NPV and limited amount of full paid over-production for office 1.

Figure 6.32 shows the situation with future selling price. The green line representing the NPV shows that the maximum NPV is achieved at 44.4 kW_p for office 1, which is the same result as Figure 6.31 indicated.

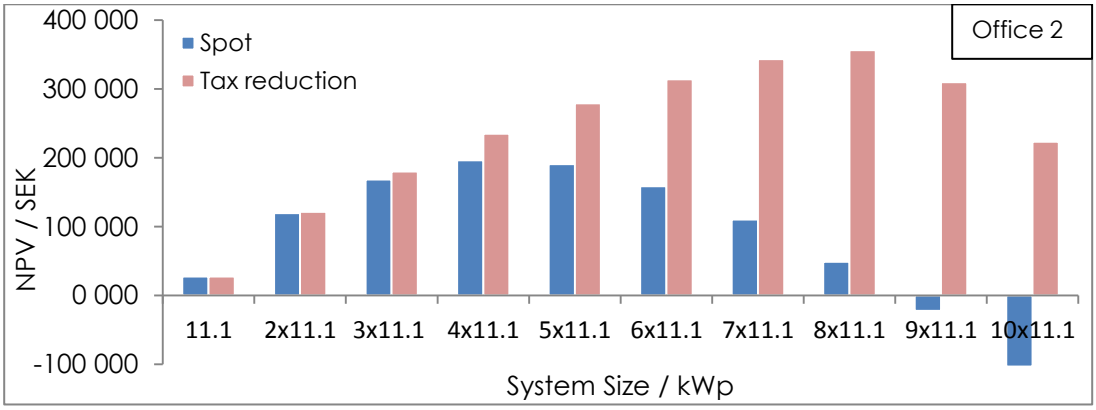

Figure 6.33 - NPV with the current and future selling price and its variation with a varying system size for office 2.

Figure 6.33 shows that 44.4 kW_p is the most optimal system size for office 2 with the current selling price. With added tax reduction, the system size can be increased to 88.8 kW_p and still present better results.

Smaller system sizes means that a larger amount of the production is self-consumed. Noticeable in Figure 6.33 is that the NPV for the current and future selling price in these cases are similar. When an over-production occurs with a larger system, the bars start to develop differently. The NPV with the current selling price quickly starts to decrease, while the future selling price continues to grow until the limitations of the tax reduction is reached.

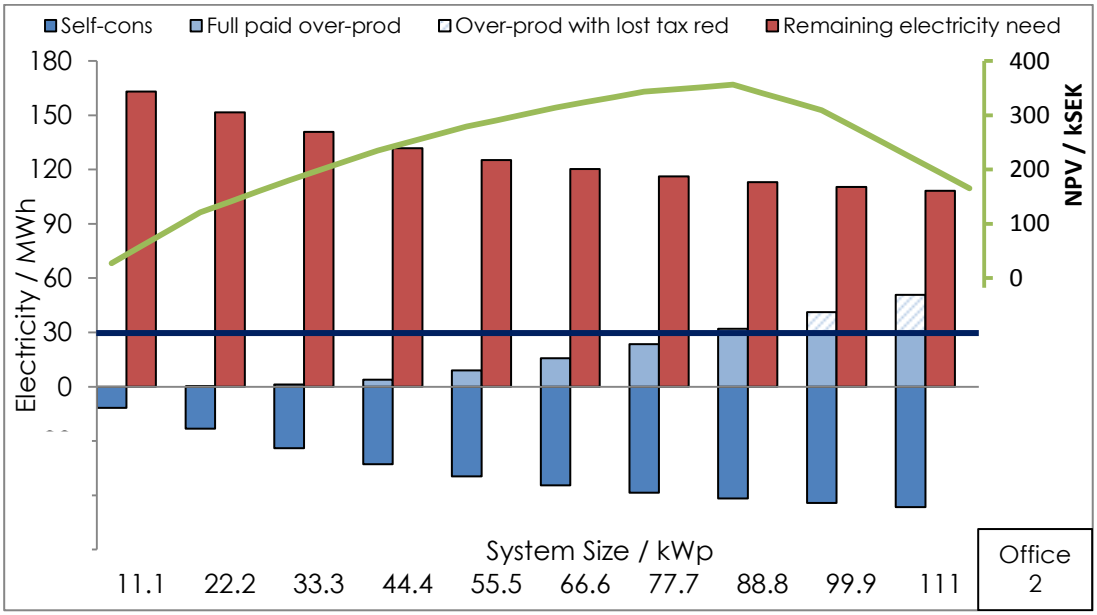

Figure 6.34 - Relationship between the NPV and limited amount of full paid over-production for office 2.

Figure 6.34 shows the situation with future selling price. The green line representing the NPV shows that the maximum NPV is achieved at 88.8 kW_p for office 2, which is the same result as Figure 6.33 indicated.

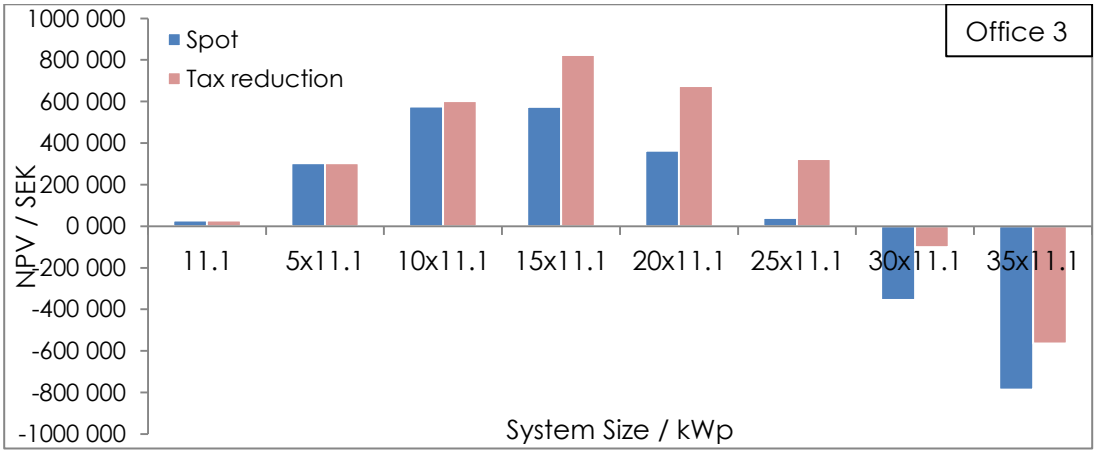

Figure 6.35 - NPV with the current and future selling price and its variation with a varying system size for office 3.

Figure 6.35 shows that 111 kW_p is the most optimal system size for office 3 with the current selling price. With added tax reduction, the system size can be increased to 166.5 kW_p and still present better results.

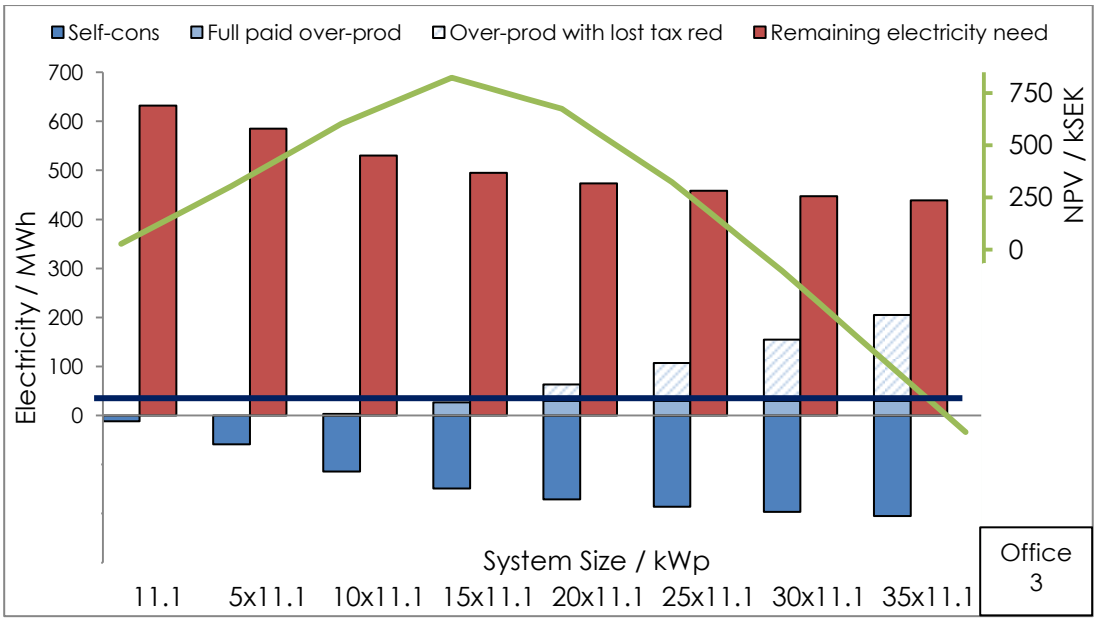

Figure 6.36 - Relationship between the NPV and limited amount of full paid over-production for office 3.

Figure 6.36 shows the situation with future selling price. The green line representing the NPV shows that the maximum NPV is achieved at 166.5kW_p for office 3, which is the same result as Figure 6.35 indicated.

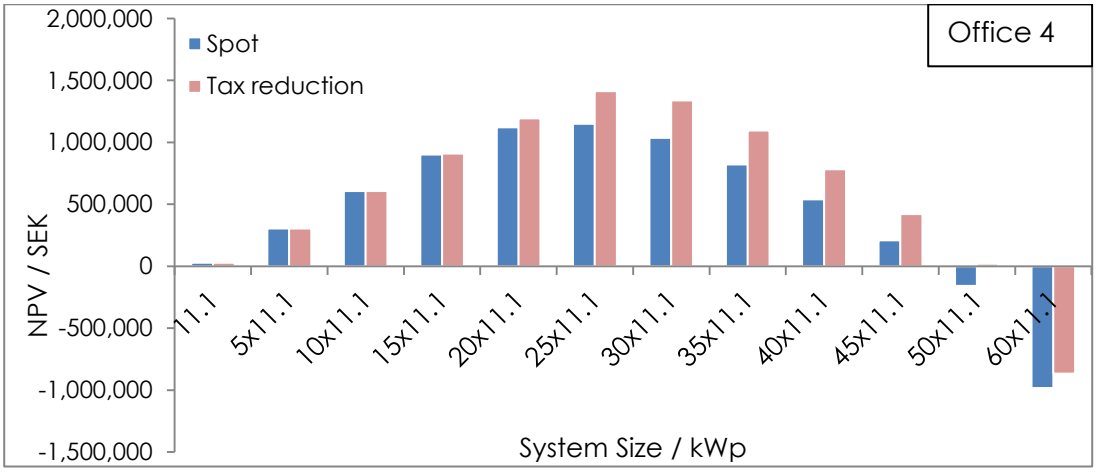

Figure 6.37 - NPV with the current and future selling price and its variation with a varying system size for office 4.

Figure 6.37 shows that 277.5 kW_p is the most optimal system size for office 4 with the current selling price. With added tax reduction, the optimal system size is still to 277.5 kW_p but presents a better NPV.

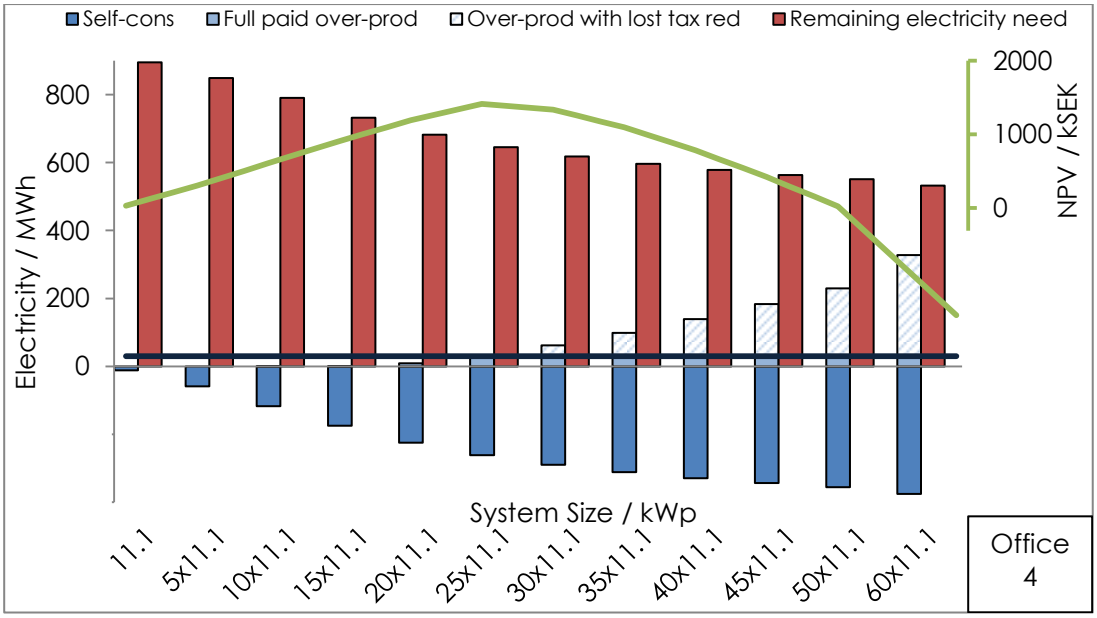

Figure 6.38 - Relationship between the NPV and limited amount of full paid over-production for office 4.

Figure 6.38 shows the situation with future selling price. The green line representing the NPV shows that the maximum NPV is achieved at 277.5kW_p for office 4, which is the same result as Figure 6.38 indicated.

Figure 6.39 summarizes the four different offices with the current selling price in dark colours and future selling price in brighter colours, and their corresponding system size.

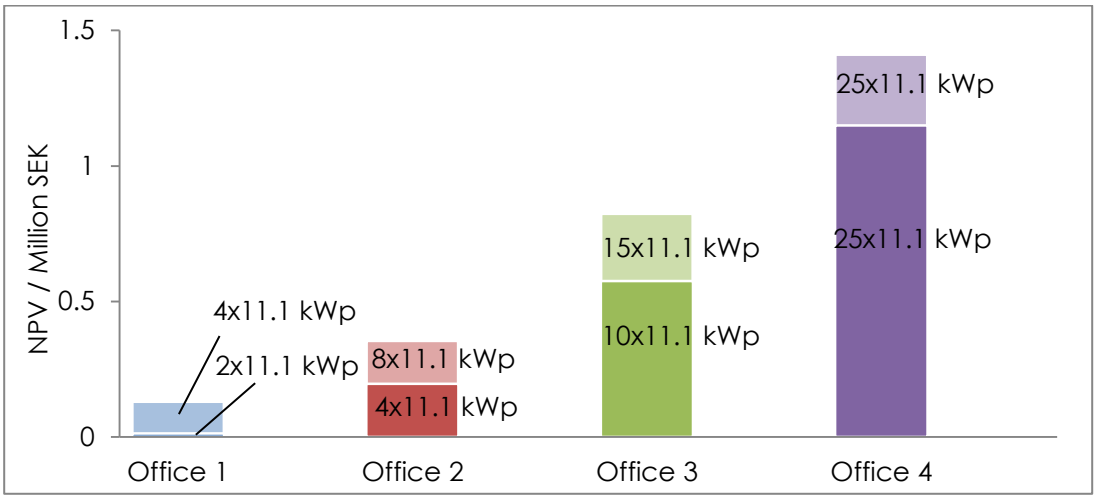

Figure 6.39 - The best NPV result for the four different offices regarding system size for both the current and the future selling price.

All the offices investigated can present positive NPV with an optimally sized PV system with the current selling price. There is a large difference in optimal system size, relating to the large difference in electricity consumption, Table 2.3.

With the future selling price, the NPV can be significantly increased and all the offices except office 4 can install a bigger system. Office 1 and 2 can even double the system size, office 3 can increase the system size with 50%. Office 4 presents the same optimal system with the current and future selling price, however the system sizes between 20x11.1 kW_p and 30x11.1 kW_p could change these results if they were investigated.

Figure 6.40 shows how solar fraction and self-consumption in relation to the total load, is affected by the system sizes of the different offices.

The bars to the left in darker colors show the solar fraction.
The dashed bars to the right, shows the self-consumption in relation to the total load.
If the added tax reduction supports a larger system, these parameters will be increased, noticed as brighter bars on top of the previous ones.

If all the produced electricity is self-consumed, it is equal to the solar fraction. But it can never be larger than the solar fraction that only is the percentage of total production in relation to total consumption.

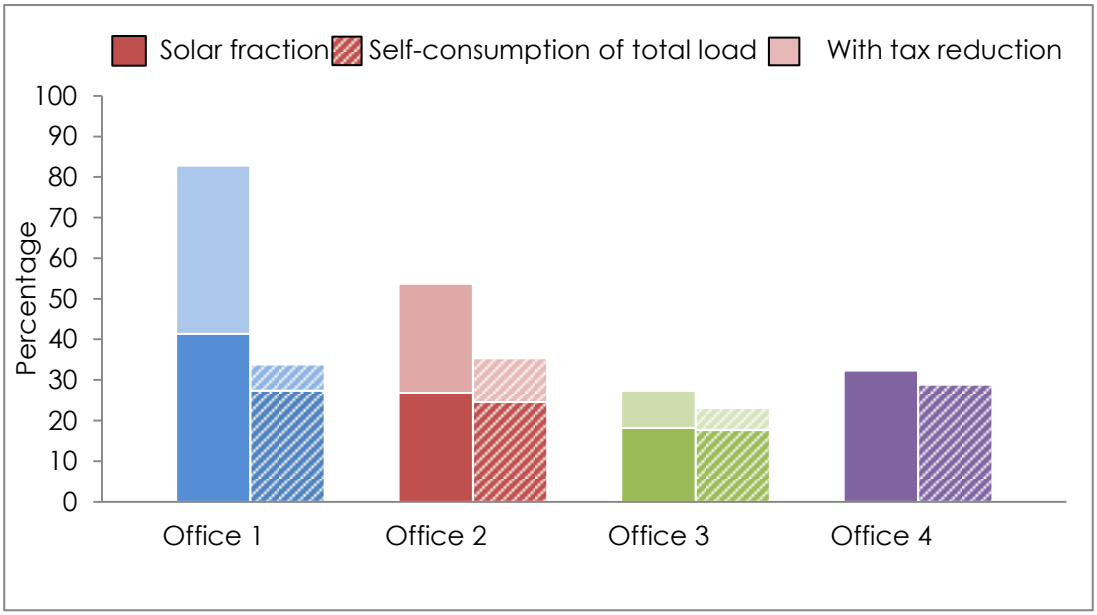

Figure 6.40 - Solar fraction and self-consumption of the total load (dashed), with the current selling price and with added tax reduction (brighter colours), for the four different offices.

With an increased supportable system size with the added tax reduction, some of the offices can cover a large solar fraction and even a relatively high level of self-consumption of the total load. This can be seen in Figure 6.40. With the tax reduction office 1 can cover 80% of its consumption with the production, and 30% of the total load can be used directly internally. The other offices presents relatively good values as well, at least compared to the previously investigated building types.

6.4.2 Sensitivity analysis

Previously a sensitivity analysis has been performed on two different, quite small PV systems. Since the offices presents a lot bigger systems, a new sensitivity analysis was done on office 4 with a system size of 277.5 kW_p to see if the same parameters are sensitive for a very big PV system, Figure 6.41.

The vertical axis shows the variation in NPV compared to the optimal results of office 4. The red horizontal line represents a NPV value of zero.

The analysis presents similar results as Figure 6.3 and Figure 6.21, but since the system analysed for office 4 already is very economically supportable, it is only an increased discount interest rate that on its own, potentially could put the NPV in a negative result, Figure 6.41.

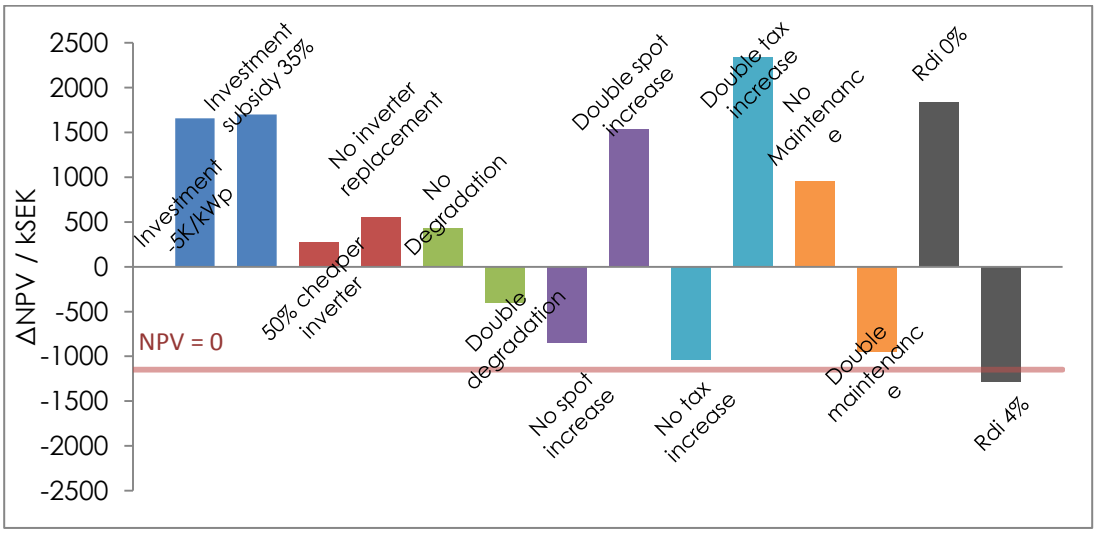

Figure 6.41 – Sensitivity analysis of the different parameters affecting a 277.5 kW_p system with the current selling price situation for office 4. The red line represents a NPV of zero.

7 Discussion

This research is based on a lot of assumptions. The general idea was to always value parameters in a way that would result in conservative results.

The lifetime of a system is a critical parameter. As mentioned in Chapter 4.4.2.1, the lifetime of the PV systems in this research was assumed to 25 years since it represents the manufacturer's guarantee period even though research have shown that the actual lifetime could be up to 40 years. This could have improved the results significantly.

An inverter replacement is predicted after 15 years of system operation, Chapter 4.3.2. The development of inverter prices is highly uncertain, and today's inverter costs were assumed. Not all systems will have to replace the inverter after 15 years and it is possible that the inverter costs at that time will be lower than what they are today.

The electricity price development was assumed with separate values for energy tax and spot price in Chapter 4.2.1. A higher estimation of electricity price increase presents better economical results for a PV system since the electricity that is self-consumed is valued higher. Historical values presented a spot price increase of 6.7% during the last 18 years, however a value of 2.5% was assumed which represents the development during the last 10 years. The energy tax increase during the last 20 years has been 9% but the assumed increase in this research was limited to 3.5% since it also represents the development during the last 10 years.

The discount interest rate was in Chapter 4.4.2.2 calculated to 1.71% but assumed to 2%. A higher value represents a negative outcome in terms of NPV for a PV system.

The initial investment costs are based on Swedish prices which are slightly higher than the global markets, Chapter 4.3.1.

Both O&M costs and system degradation are included which is parameters that often are neglected in economic analyses of PV systems.

The analyses of the systems with the current selling price are not including the current investment subsidy of 35% in the calculations. As mentioned in Chapter 3.4.1, the application queue is very long and almost all of the money reserved for the subsidies until 2016 is already used.

Regarding the new subsidy possibility with tax reduction, the initial state places the buying price and selling price in a comparable value. The estimation of a fixed tax reduction for the upcoming 25 years, presented in Chapter 3.4.5, will continuously increase the difference between buying and selling price as the years go by. If the tax reduction was estimated to increase with the electricity price, the economic results of the PV systems would become a lot better.

With all this in mind it could be said that the presented results are representing a conservative NPV and it is important to know that the results can possibly be significantly better.

7.1 Sensitivity analysis

One sensitivity analysis was performed for each building type and they presented similar results regarding sensitive parameters.

One of the most sensitive parameters is the investment costs and it was analyzed in two different ways. The current investment subsidy of 35% reduces the initial cost of a PV system with 7000 SEK/kW_p. The other option investigated in the analysis assumed a decreased investment cost of 5000 SEK/kW_p. Even though they can be seen as similar parameters, they affect the calculations differently. The O&M costs in this report are calculated as one percent of the initial investment costs. With this way of calculating O&M costs, a lower initial investment cost also reduces the O&M costs, however, with an investment subsidy the actual component costs are still the same and the O&M costs should not be reduced.

Even though one percent is a small fraction of the initial cost, the maintenance occurs annually and during the calculated lifespan of 25 years it accumulates to an important factor in the calculations.

Apart from the initial investment costs, the second most important factors are the electricity price parameters. Neither the inverter replacement nor the system degradation has as big impact as could be expected. However, the inverter cost is based on the system size and with bigger systems the relative impact are still similar, but the difference in actual money is a lot larger and could make a nonprofit installation to a good one.

It is also noticeable that the discount interest rate has a big impact of the results and is also a sensitive parameter.

7.2 Single family houses

An electrically heated house would supposedly not go very well in hand with a PV system, at least not from a load matching perspective since the electricity heating demand usually take place during hours when the sun is not heating the house, which also happens to be when there would be no PV production. However, the results in Figure 6.1 show the complete opposite. This is simply because the electrically heated houses generally have both a higher total and electric base load. This means that more of the produced electricity can be used internally, which is worth more than the electricity that is sold to the grid.

Due to the higher load, an electrically heated house has a lower fraction of its electricity demand covered by PV electricity than a district heated house with a PV-system of the same size. This fact does not however make the PV system less economically supportable, since the important fraction is how much of the production that is used internally and valued high.

7.2.1 Alternative orientations

7.2.1.1 Current selling price

Multiple calculation results have shown that an azimuth directly towards south is the best option, but that a difference of about ± 15 degrees around south does not have a critical effect of the NPV. The fact that multiple graphs in Chapter 6.1.1.2 are asymmetric around south is explained by a higher electricity production at easterly orientations than at westerly orientations. Easterly orientations support a production during mornings, which usually is higher due to clearer weather, lower cell temperatures and higher efficiencies (Stridh, 2013c).

Even though the maximum production occurs towards south, it can be seen that a higher level of self-consumption can be found at alternative orientations, Figure 6.5. In Figure 6.6 the relation between production, orientation and internally used electricity is shown for house 4. It can be seen that a small increase in self-consumption requires a big change in orientation and a much bigger decrease of production. With a decreased level of production in combination with increased self-consumption, the overproduction is reduced significantly and less electricity can be sold to the grid. This difference is simply too big for the limited increase of self-consumption to make up for lost overproduction, which is why the best NPV can be found at orientations towards south.

The same phenomena can be found when alternating the tilt instead of the azimuth. Figure 6.7 shows that the peak production occurs at the same angle as the best NPV and when the fractions of self-consumed electricity are analyzed, Figure 6.8, both results correspond to the previous analyses and the same conclusions as before can be drawn.

To ensure that the observation above not is a coincident for small systems, both tilt and azimuth were controlled with larger systems in terms of NPV. The results were similar and followed the same pattern. The only difference was that the bigger systems had worse values and were simply offset from the small system, due to higher investment costs.

7.2.1.2 Future selling price

By adding the tax reduction to the calculations on the houses with district heating and comparing it with the results with the current selling price, there is not much of a difference in terms of NPV, as seen in Figure 6.14. The graphs for both azimuth and tilt have the same pattern as before and only a small change of actual values.

However, the impacts on the electrically heated houses are much larger. This can especially be seen in Figure 6.15, where both the current and future selling price are shown for all systems. Accordingly to the results, electrically heated houses with a close to optimal orientation can install a more than three times larger system and have the same economical result after 25 years. The potential for a larger system is much greater than a small, only a small change in electricity price or another parameter could transform a non-profitable system into a positive investment. However, a small change in the opposite direction could affect the NPV even more due to the high initial investment costs a larger system requires.

The reason for the tax reduction to affect the different building types differently is connected to the definition of the reduction, and the load of buildings. Since the tax reduction only can be obtained for as much exported electricity as imported, the electrically heated houses have a much larger threshold and can receive the reduction for a larger over-production, this can be seen in Figure 6.16 and Figure 6.17.

The tax reduction is as most beneficial in the beginning of the calculated 25 years. This is due to the assumptions made earlier in this report. It is assumed that the tax reduction itself will not increase. This means that after a number of years, the price of bought electricity will rise above the one of sold, and overproduction will not be as beneficial. The fixed price of 1 SEK/kWh is initially similar to the tax reduction but since a continuous price increase of 2.5% is assumed during the whole lifetime of the system, it is becoming more beneficial than tax reduction as the years go by.

With systems and results like these it could be discussed if the current investment subsidy or the future tax reduction is most favorable. The investment subsidy reduces the initial investment costs and risk of the system, but the tax reduction increases the economic potential during the lifespan. It could also be discussed if it potentially is better to postpone the investment a couple of years in hope of buying a system with reduced initial investment costs due to the price development of the market , and still be able to receive the tax reduction.

A side note is that when a person or family produces their own electricity with a local PV system, the awareness of the electricity consumption might increase. This can potentially lead to a decreased consumption, at least during the hours when they know that the PV production is limited. An increased awareness of electricity consumption is a good thing, not only for the economic aspects of a PV system, but from a holistic perspective of sustainability.

7.3 Apartment blocks

Regarding the apartment blocks, they can be divided in to groups regarding load and economic results. The occupancy patterns of all the apartment blocks are similar to the single family houses, but have higher values. Apartment block 1 and 4 have higher base loads, but lower peaks than apartment block 2 and 3. Apartment block 1and 4 are as well the two apartment blocks that are economically feasible after 25 years, even with the 3.3 kW_p system. This can be explained by looking at the level of self-consumption for the different apartment blocks and systems. Apartment block 1and 4 uses most of the production internally regardless the size of the system. Apartment block 2 and 3 has a lower percentage of self-consumption with their best system, than 1 and 4 have with their worst, Figure 6.20.

When adding the tax reduction, all apartment blocks present some combination of size and orientation with a positive NPV after 25 years. Apartment block 1and 4 had positive results even without the reduction, but the numbers are even better with it.

7.3.1 Alternative orientations

7.3.1.1 Current selling price

When alternating the orientation of the small 3.3 kW_p PV system the same result as previous occurs, Figure 6.22 and Figure 6.23**Error! Reference source not found.**. The best rientation is directly towards south and a tilt of 45 degrees, and that a lower tilt is better than a higher.

When analyzing bigger system sizes, they differ from the single family houses. An increased size improves the NPV for all angles. Apartment block 1and 4 can even achieve both positive values for angles and tilts other than optimal and better values with larger systems than with a smaller.

7.3.1.2 Future selling price

With tax reduction, it is not only Apartment block 1and 4 that present results with a positive number. Also apartment block 2 and 3 produces positive numbers, and not only for the optimal tilt. With the tax reduction it can be seen that a bigger system is more beneficial than a small, with both a tilt and azimuth within 15 degrees from the optimum. This is because the increased overproduction with the bigger systems makes up for the lost production caused by tilting the arrays. This has been shown before with single family houses in 6.1.1.2.

With the increased system sizes, the production and the use of electricity will change compared to the smaller systems. This is shown in Figure 6.27 and it can be seen that the biggest systems that are economically supportable both with and without the tax reduction still have a limited fraction of the load covered.

With a high fraction of the produced electricity self-consumed as in apartment block 1, Figure 6.27 and Figure 6.29, the tax reduction does not affect the NPV much. This is because almost all produced electricity is used within the system and simply not exported to the grid. In cases like this, it is only the system sizes that affect the NPV until the system gets so big that overproduction occurs, which is the case for the other three apartment blocks.

7.4 Offices

The initial thought was that offices should have a rather big potential in terms of PV produced electricity utilization. This is expected since the offices are occupied and have their main consumption during working hours when the PV production with optimal tilt and orientation, is peaking. This was confirmed by Figure 6.40.

Figure 6.39 show that offices in fact have good potential to invest in PV systems that will be economically supportable over a 25 years period. This is true both with the current selling price and the future situation with added tax reduction. The tax reduction will however make it possible to invest in larger systems, in some cases even twice as big.

As mentioned in Chapter 6.4, the system sizes for the evaluation of the offices were increased in order to match the consumption better. This also means that the system sizes would be above 20 kW_p. These systems have their initial investment costs reduced by 2500 SEK/kW_p which makes the difference compared to an 11.1 kW_p more noticeable and improves the chances of having an economically supportable system.

The offices investigated do not only have a big total electricity consumption but also a big base load, this means that a lot of the electricity, even with large systems can be used internally. This also opens up the opportunity to make it profitable to receive electricity certificates for all the production and not only the overproduction. As mentioned in Chapter 3.4.3, this requires an electricity meter that counts all the electricity produced which have an annual fee of roughly 1500 SEK. With the electricity certificates valued to 0.2 SEK/kWh this means that an internal use of 7500 kWh needs to be utilized internally every year to cover up this fee. With some of the big systems presented in the evaluation of the offices, this internal use is easily covered, which means that even better economical results could have been achieved, but this have not been considered in this research.

As experienced in the analysis of the apartment blocks, the tax reduction in some cases were restricted by the fact that the less electricity was exported to the grid than overproduced. For the offices, the tax reduction was instead limited to the maximum output point of 30 000 kWh over-production per year, which also is stated in the new regulation proposal.

With this in mind, the added tax reduction makes it possible to increase the system size to the point when the overproduction reaches the value of 30 000 kWh. By increasing the system size even further, the over-production loses the tax reduction which means that all the remaining over-production will be sold for the spot price. Since this over-production has such a limited selling price, the profits will not cover up for the extra added life cycle costs of a bigger system. This is representative for all the offices. Figure 7.1 is with situation two and three describing the two different ways to lose the tax reduction. Situation two is when the over-production exceeds the remaining electricity need and situation three is when the over-production is larger than the 30 000 kWh limit.

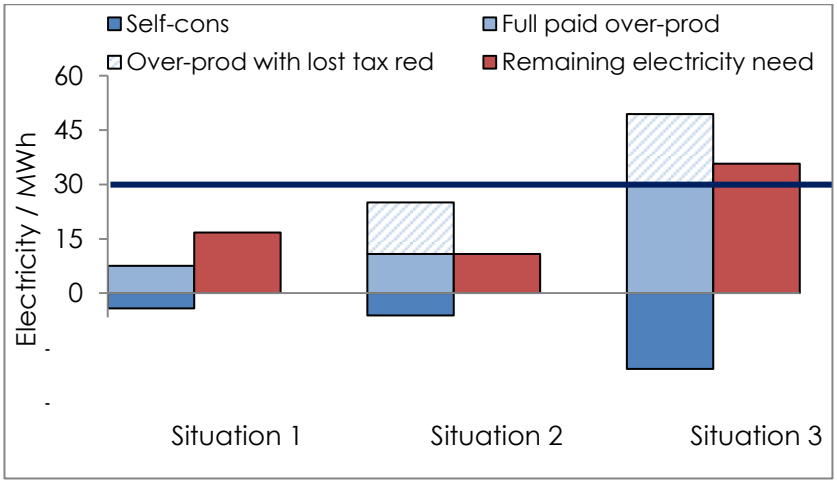

Figure 7.1 Three different situations of overproduction in relation to remaining electricity need. Situation two and three are resulting in a partly lost tax reduction.

Figure 6.40 show that offices do not only present good economical results for the PV system itself. The consumption profile of an office, especially with cooling systems, is allowing a PV installation that also can cover a large solar fraction and high level of self-consumption in relation to the demand of the office.

A lot of old, existing buildings have significantly high electricity demands, which is suitable for a PV system. But buildings with very high electricity demands do also most commonly have large potential in energy-efficient measures. If major improvements regarding energy-efficiency also can be done, this should be prioritized before dimensioning a new PV-installation. This is because, if a PV system is dimensioned according to a high electric load that later is reduced due to energy-efficiency measures, the PV system could end up being too big. This will affect both the life cycle costs and payback time of the system and can result in a system that is not economically supportable.

Modern and more efficient buildings tend to have a higher base load than an older, but with less and smaller peaks in the demand, Figure 2.5. This is also a very suitable consumption profile for a PV system which means that buildings with performed energy-efficient measures still will be able to get a supportable PV system, only with a smaller size.

As seen throughout the chapter some of the offices can utilize and make profit of large system sizes. With systems of these sizes both funding of the investment and enough space to install the systems can be limiting factors. The 277,5 kWp system that is the best option for office four requires an area of roughly 1 700 m² and 5 million SEK. This should also be taken into account when designing a system.

8 Conclusions

It is in some cases possible to slightly increase the level of self-consumption with orientations that are not optimal from a maximum production point of view, but this cannot be done in a way that is economically supportable for the investigated cases. The change of orientation causes a large decrease of production that cannot be economically compensated by the minor increase of self-consumption.

From an economical perspective, the optimal orientation is closely related to the one for maximum production. However, orientations which are relatively close to the optimal solution present similar economical results. With this in mind, there is no point in spending extra money on optimizing the available building surfaces in terms of orientation if it already is quite good. This money can instead be spent on a larger system.

With the current investment costs and selling price situation, it is only economically supportable to install a system in buildings that self-consume a large fraction of all the electricity since the over-production is sold to a very limited price. This means that it is only realistic to install a system on buildings with a base load covering the production, if the economy is an essential factor.

The introduction of tax reduction as a subsidy added to the selling price, places the selling price in a comparable value as the current buying price, Figure 3.9. This opens up the opportunity for systems that do not self-consume all of the electricity since the over-production can get sold with the same value. But, with the assumed price development in this research and the estimation that the tax reduction will remain the same for the upcoming 25 years, the buying price will grow further apart from and get a higher value than the selling price as the years go by, Figure 4.4. This means that the importance of using the produced electricity internally will get bigger for every year to come.

The tax reduction will improve the economical results of all PV systems with some kind of over-production, but with the statement above, buildings with a consumption profile that is poorly optimized for a high level of self-consumption and instead have a big portion of over-production will quickly loose a big potential in savings. With this in mind it is important, even with the upcoming subsidy, to have a system with high self-consumption and systems that have a hard time to be beneficial today will not have it much easier with the added tax reduction.

Buildings that already can get systems with a high level of self-consumption and already are economically supportable are the ones that also can benefit the most from the tax reduction and it will allow them to pick an even bigger system that still is profitable.

With the added tax reduction and its restrictions, buildings with a high base load are recommended to dimension the system for maximum production without over-producing more than what they have to buy from the grid and no more than 30 000 kWh annually.

Taking a look into the future, plus energy houses will become more common. In order to be called a plus energy house, the building must produce more energy than what it consumes. This means that it will be impossible for these buildings to even obtain a tax reduction since

one of its limitations is that a building is not allowed to produce more electricity than it is consuming to benefit from it. If one wants to support the development of energy efficient buildings for the future, the subsidies have to be more favorable.

If two different system sizes present the same net present value after 25 years in the process of selecting a system, choosing the bigger can be a better decision for a number of reasons. A bigger system has a bigger economical potential after the calculated lifespan. A bigger system also leads to a lower net energy consumption of the building as a whole which is a step in the right direction towards low energy buildings. The way the regulations are written today, to achieve a net-zero or plus energy house, it is only a large solar fraction that is considered. If the produced electricity is self-consumed or not, do not matter.

It could be discussed whether these regulations are logic or not, since they force some buildings to choose between a low energy classified building and an economically supportable PV system. However, even if the increased production of a bigger system is not self-consumed, it can be good from an environmental perspective since the over-production increases the level of renewable energy in the society.

Even though the upcoming subsidy will be a step in the right direction, it is clearly not good enough to support small-scaled PV production, at least not from a single family house owner's perspective, with the assumed price development. In order to develop the market even further, something else have to be introduced as support or the existing investment subsidy could potentially be revised.

In order to limit the effects of political decisions, policy changes, the electricity price development and other parameters, a system should be dimensioned for as high level of self-consumption as possible and minimize the interaction with the grid. For this, single family houses needs economically supportable electricity storage possibilities and this is something that should be focused on in the future.

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Appendix A – Single family houses

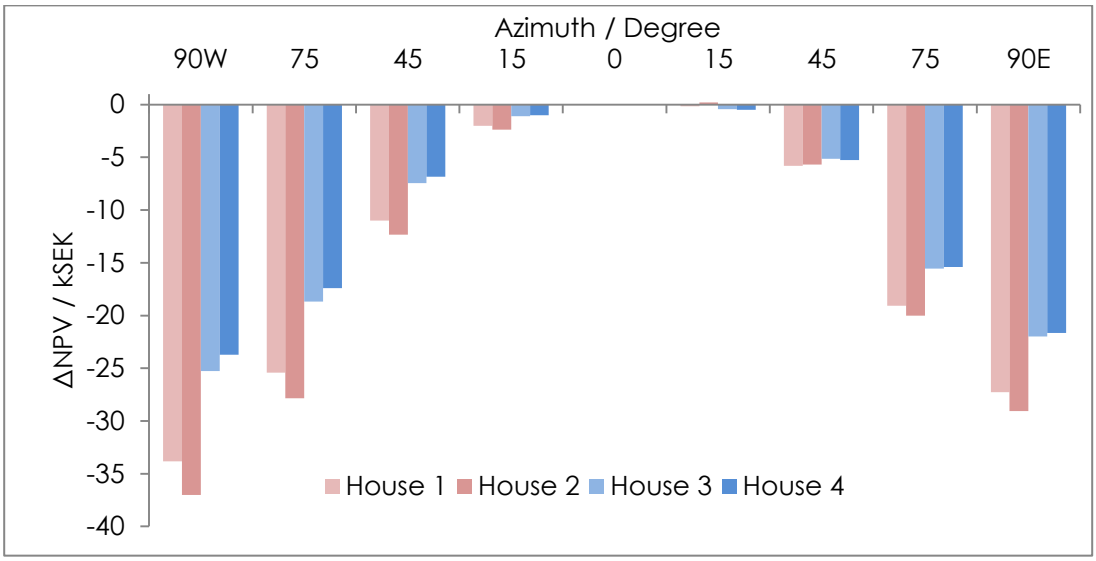

Figure A. 1 – Variation in NPV due to azimuth angles compared to the best 7.7 kW_p cases.

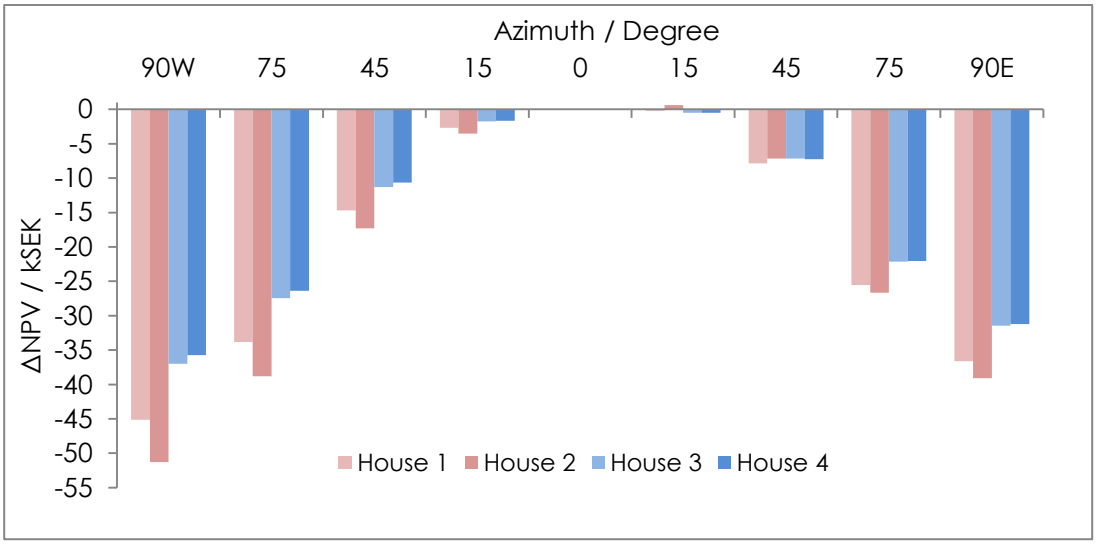

Figure A. 2 – Variation in NPV due to azimuth angles compared to the best 11.1 kW_p cases.

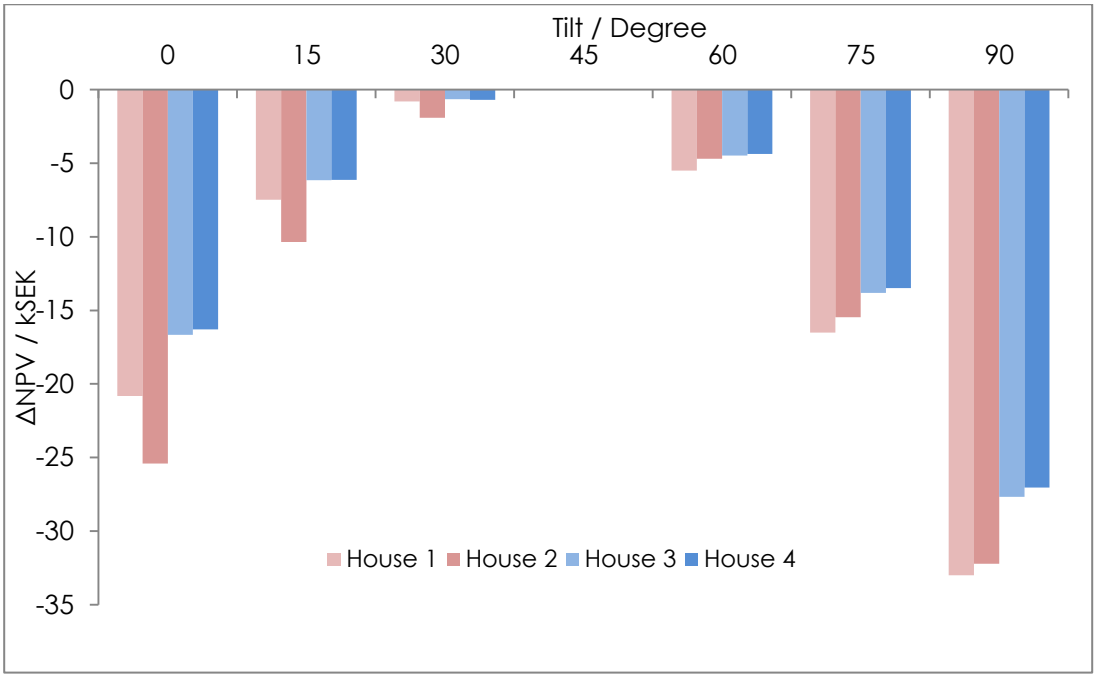

Figure A. 3 - Variation in NPV due to tilt angles compared to the best 7.7 kW_p cases.

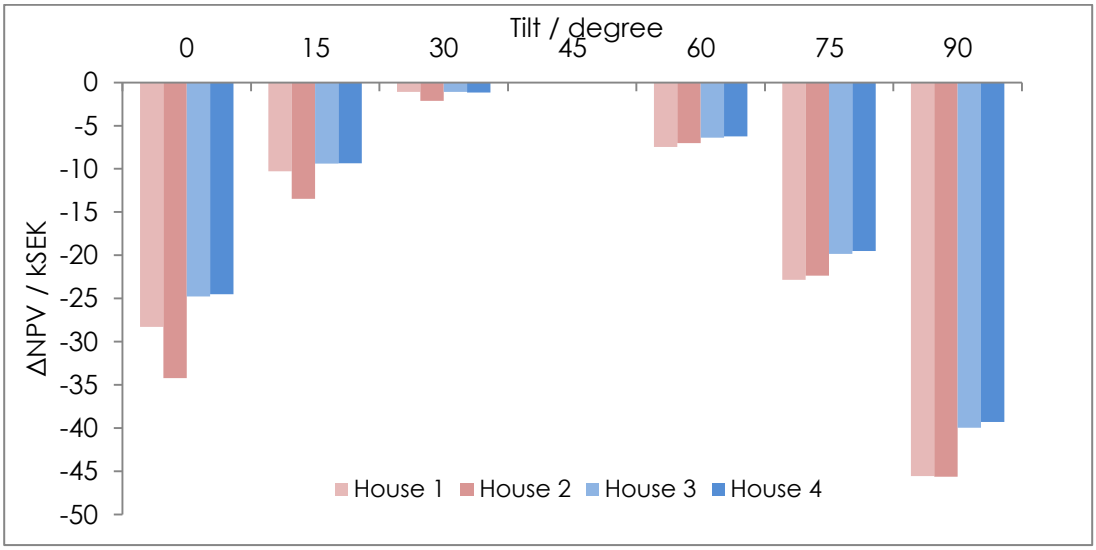

Figure A. 4 - Variation in NPV due to tilt angles compared to the best 11.1 kW_p cases

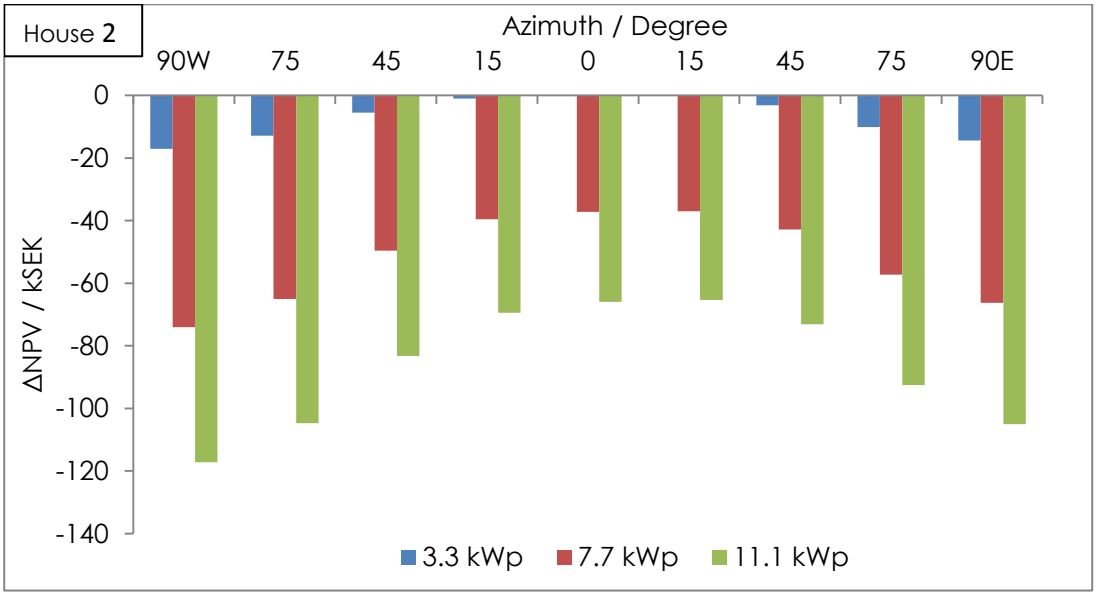

Figure A. 5 – Variation in NPV for different system sizes compared to the most beneficial option for house 2 with varying azimuth angles.

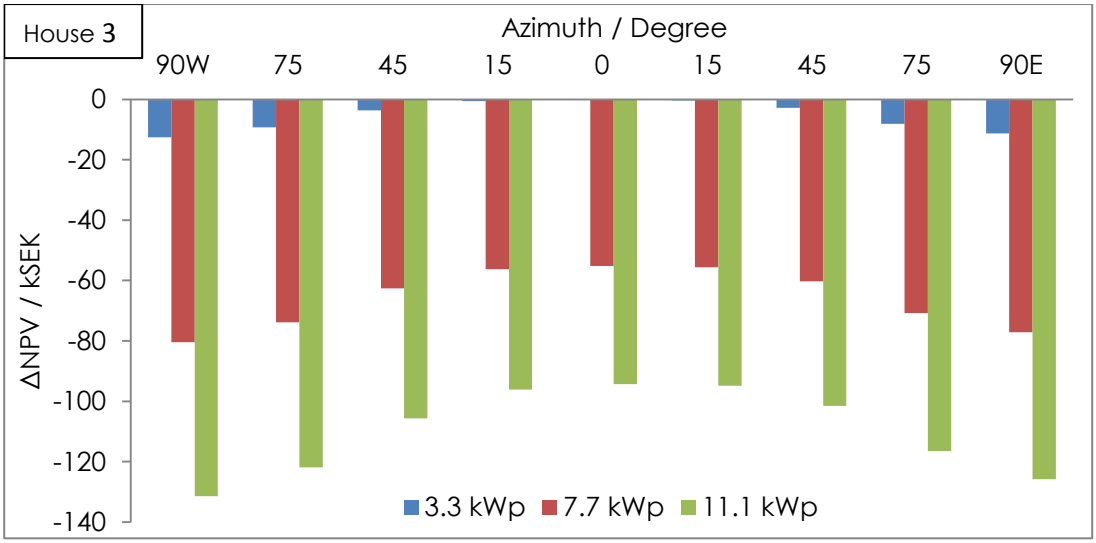

Figure A. 6 – Variation in NPV for different system sizes compared to the most beneficial option for house 3 with varying azimuth angles.

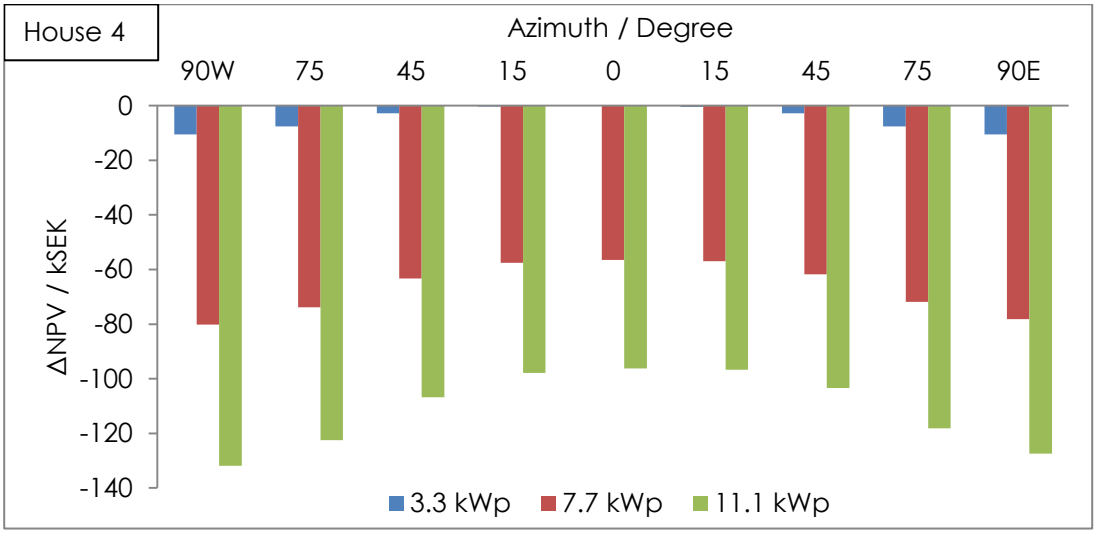

Figure A. 7 – Variation in NPV for different system sizes compared to the most beneficial option for house 4 with varying azimuth angles.

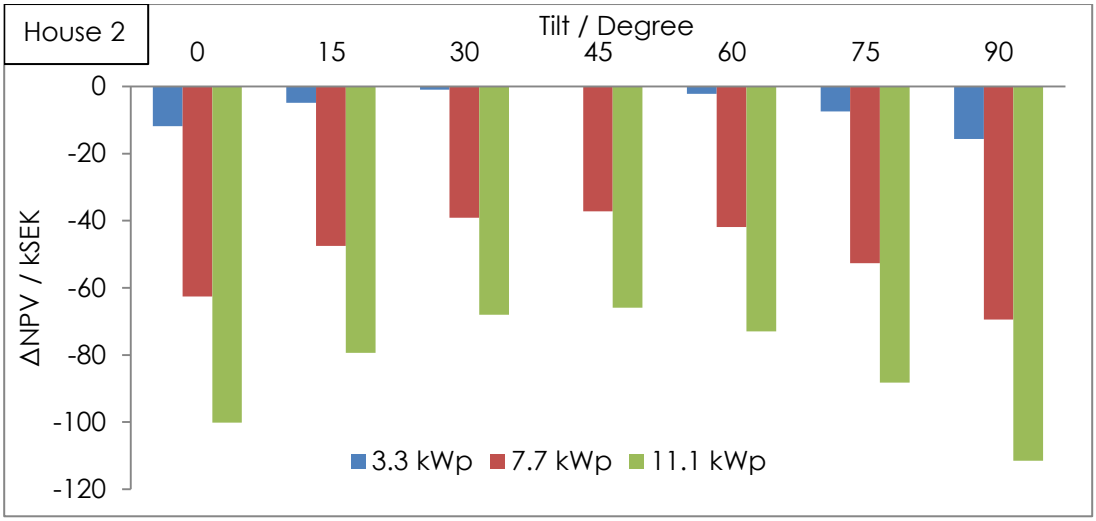

Figure A. 8 – Variation in NPV for different system sizes compared to the most beneficial option for house 2 with varying tilt angles.

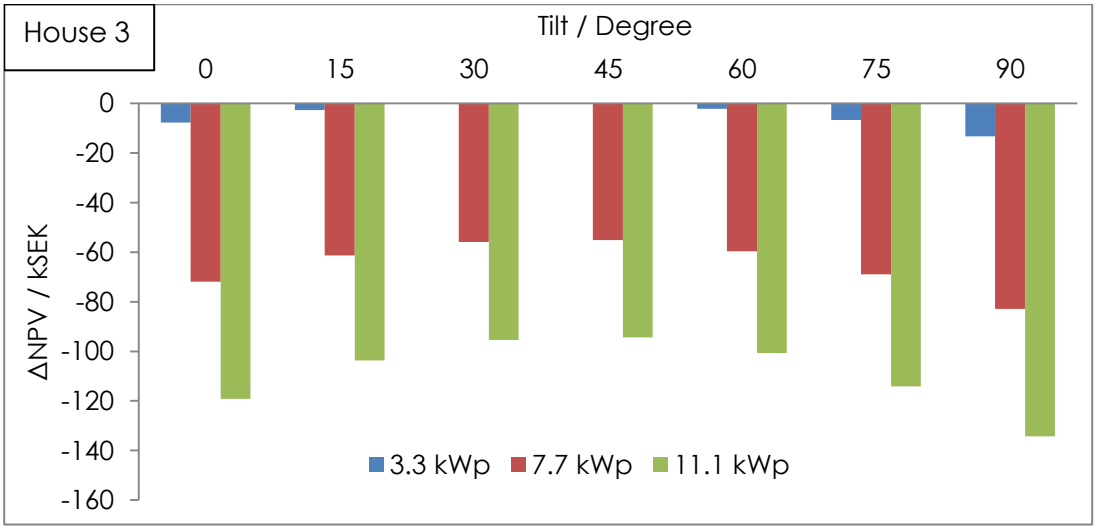

Figure A. 9 – Variation in NPV for different system sizes compared to the most beneficial option for house 3 with varying tilt angles.

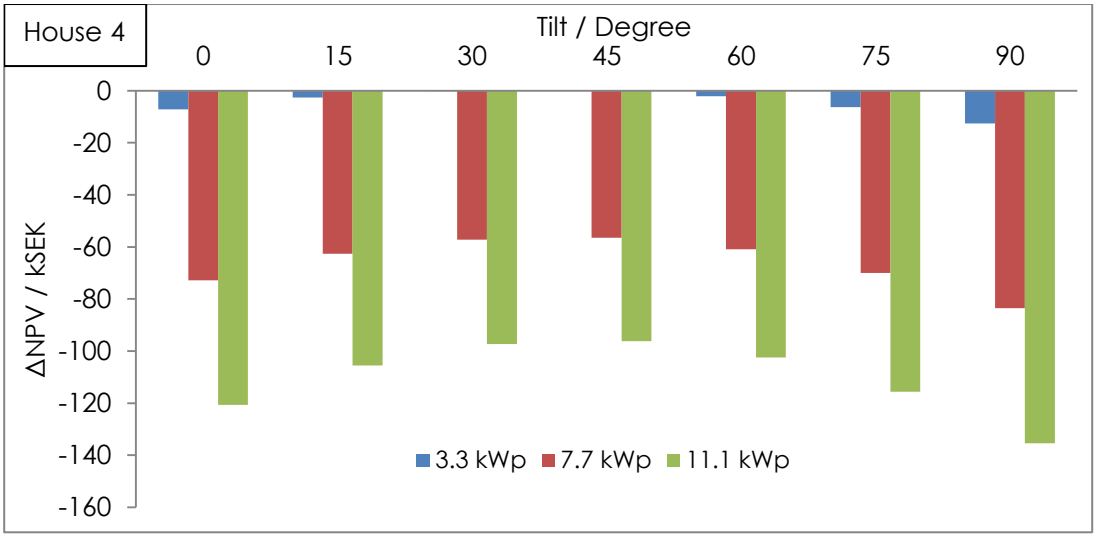

Figure A. 10 – Variation in NPV for different system sizes compared to the most beneficial option for house 4 with varying tilt angles.

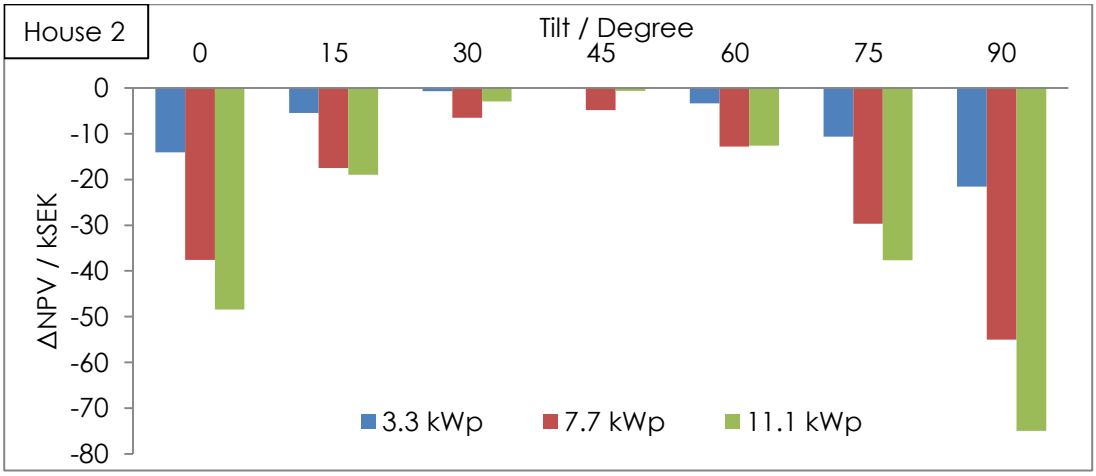

Figure A. 11 – Variation in NPV with tax reduction added, for different system sizes compared to the most beneficial option for house 2 with varying tilt angles.

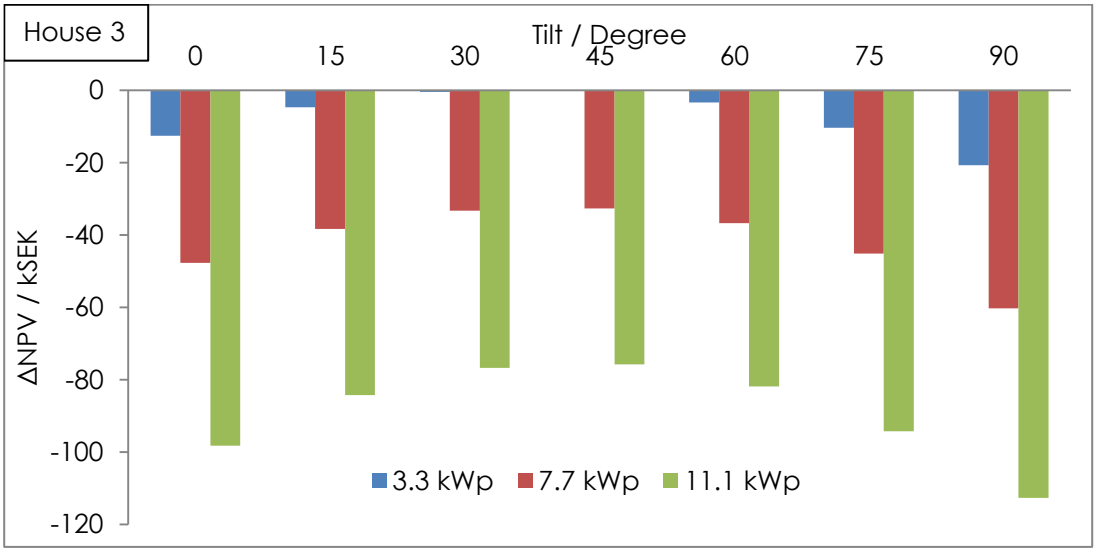

Figure A. 12 – Variation in NPV with tax reduction added, for different system sizes compared to the most beneficial option for house 3 with varying tilt angles.

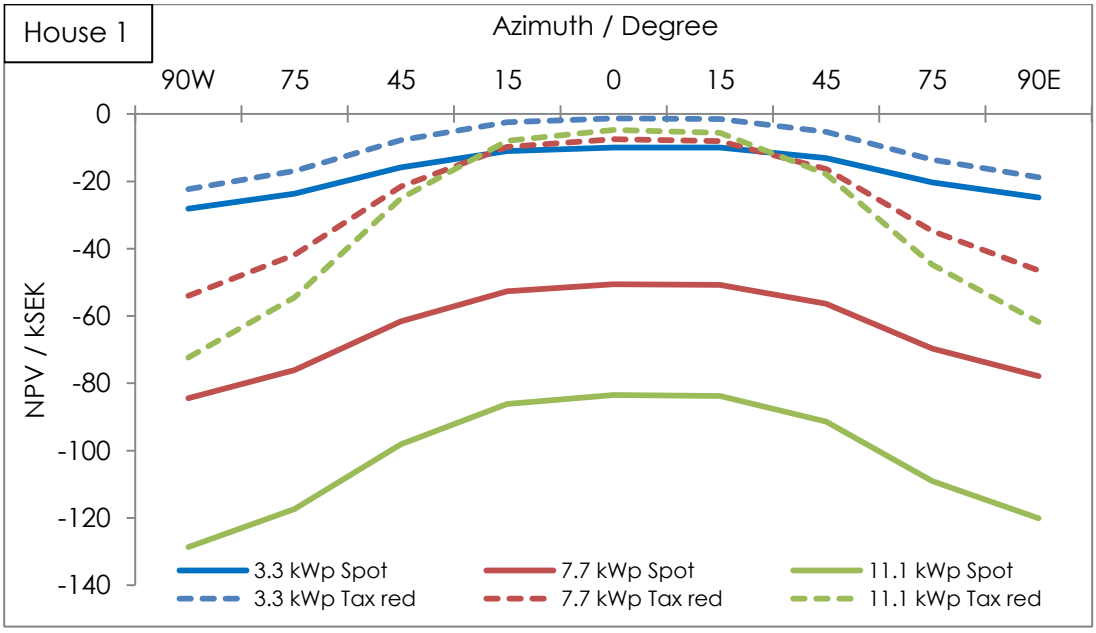

Figure A. 13 - How tax reduction affects the NPV for different system sizes and azimuth angles for house 1.

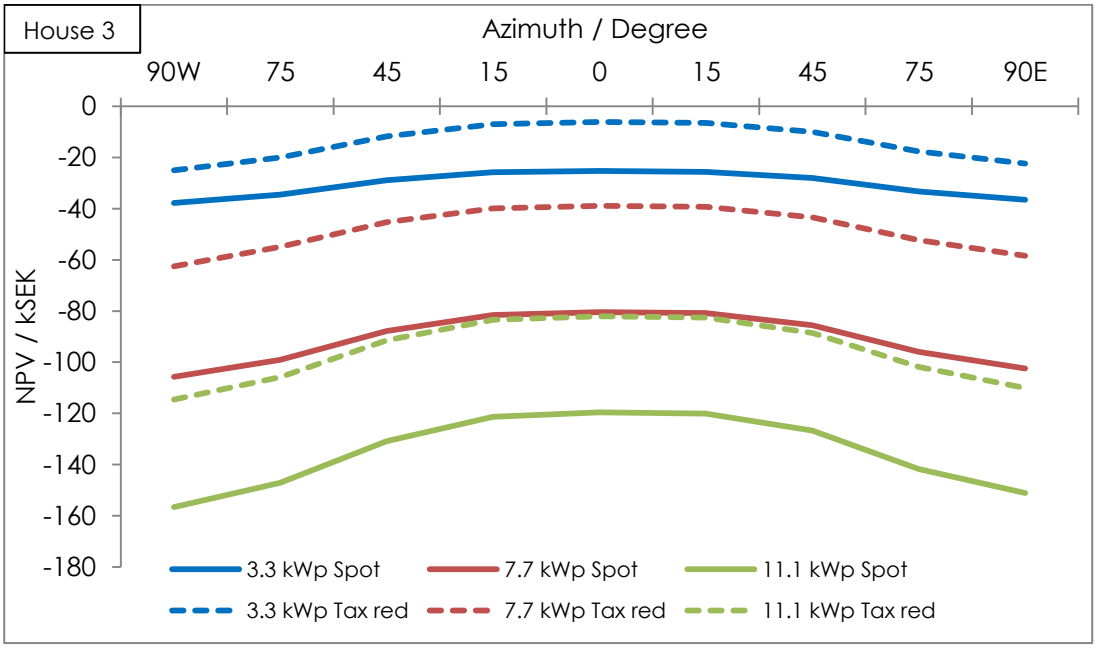

Figure A. 14 - How tax reduction affects the NPV for different system sizes and azimuth angles for house 3.

Appendix B – Apartment blocks

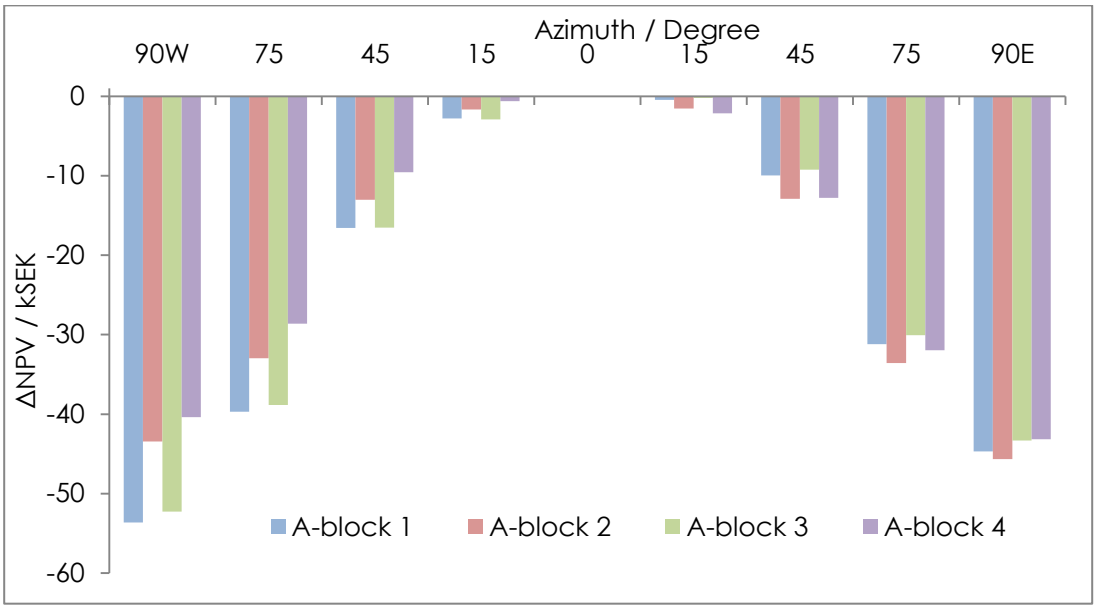

Figure B. 9.1 - Variation in NPV due to azimuth angles compared to the best 7.7 kWp cases.

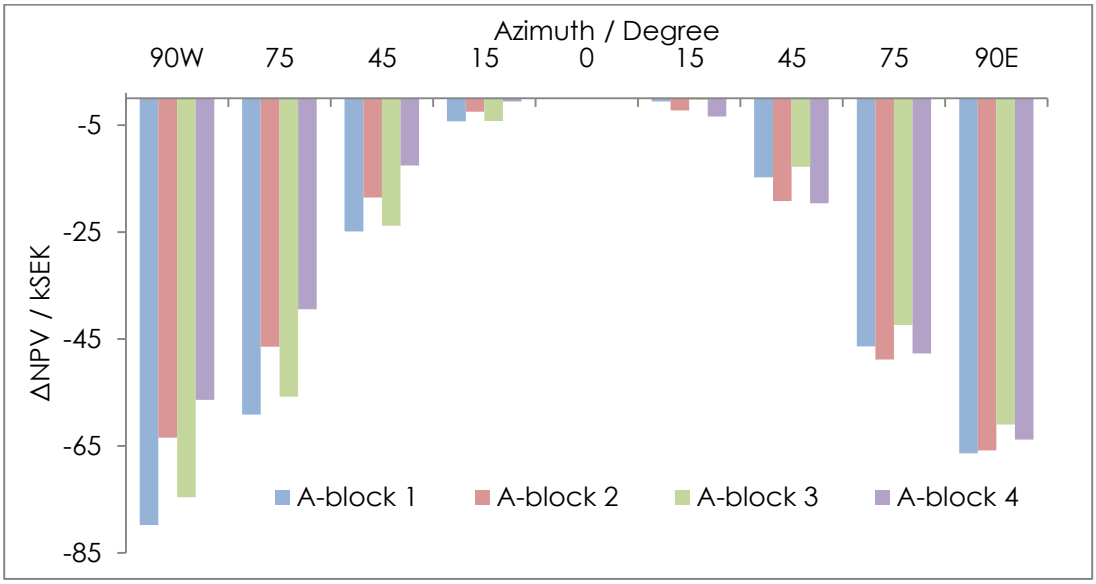

Figure B. 9.2 - Variation in NPV due to azimuth angles compared to the best 11.1 kWp cases.

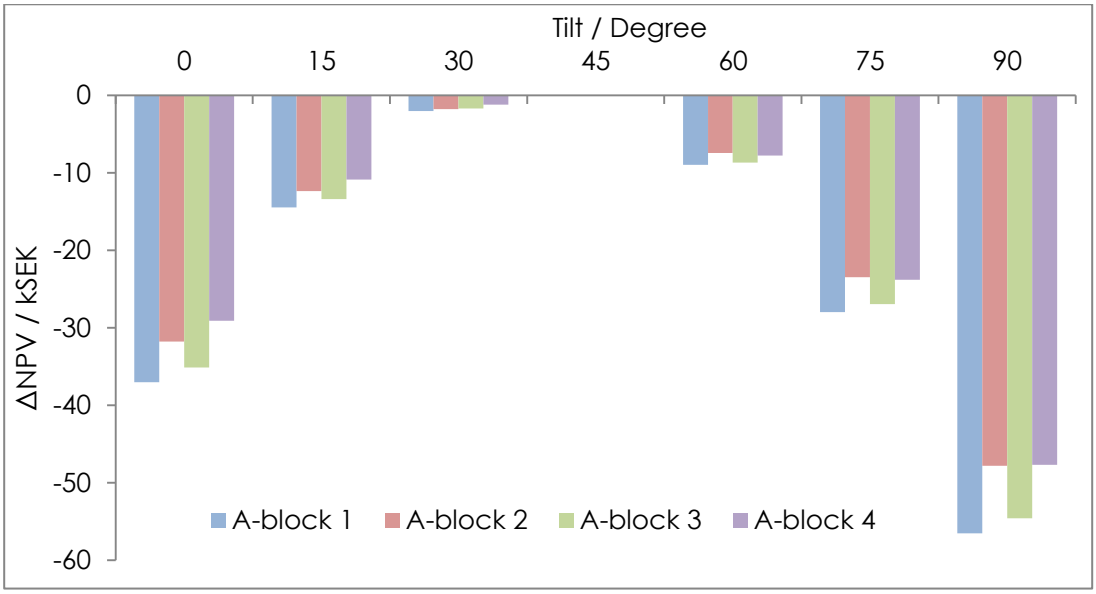

Figure B. 9.3 - Variation in NPV due to azimuth angles compared to the best 7.7 kWp cases.

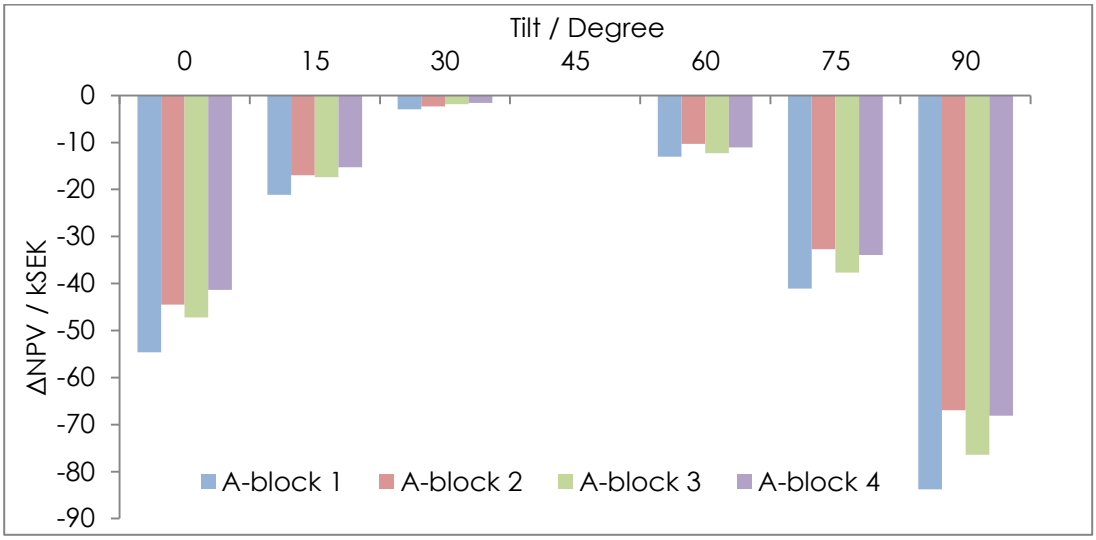

Figure B. 9.4 - Variation in NPV due to tilt angles compared to the best 11.1 kWp cases.

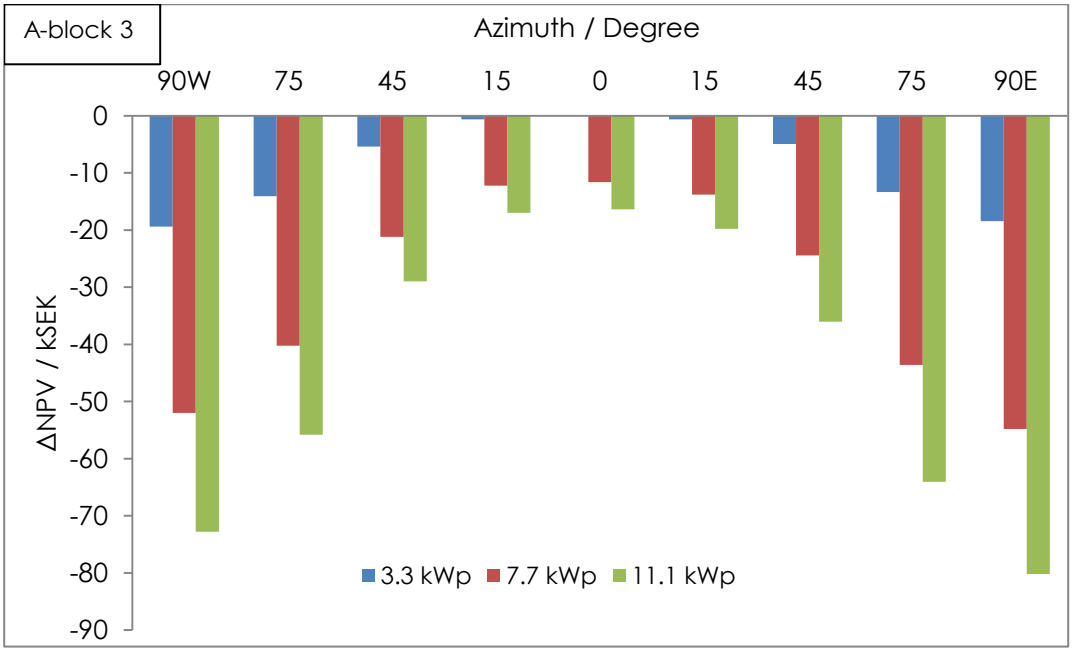

Figure B. 9.5 – Variation in NPV for different system sizes compared to the most beneficial option for apartment block 3 with varying azimuth angles.

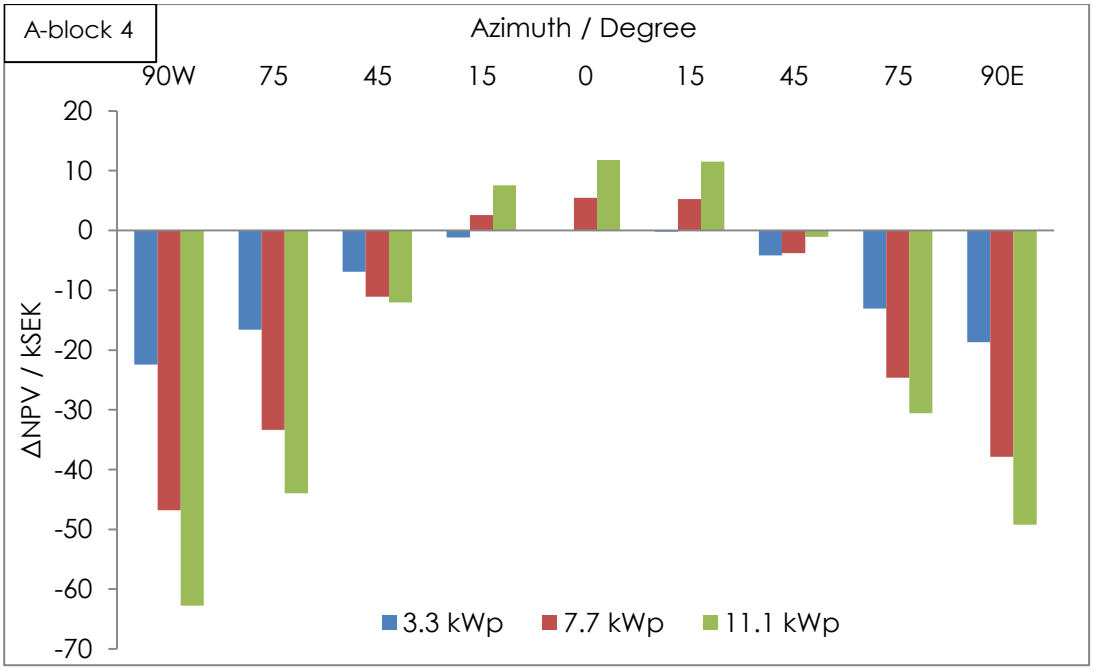

Figure B. 9.6 – Variation in NPV for different system sizes compared to the most beneficial option for apartment block 4 with varying azimuth angles.

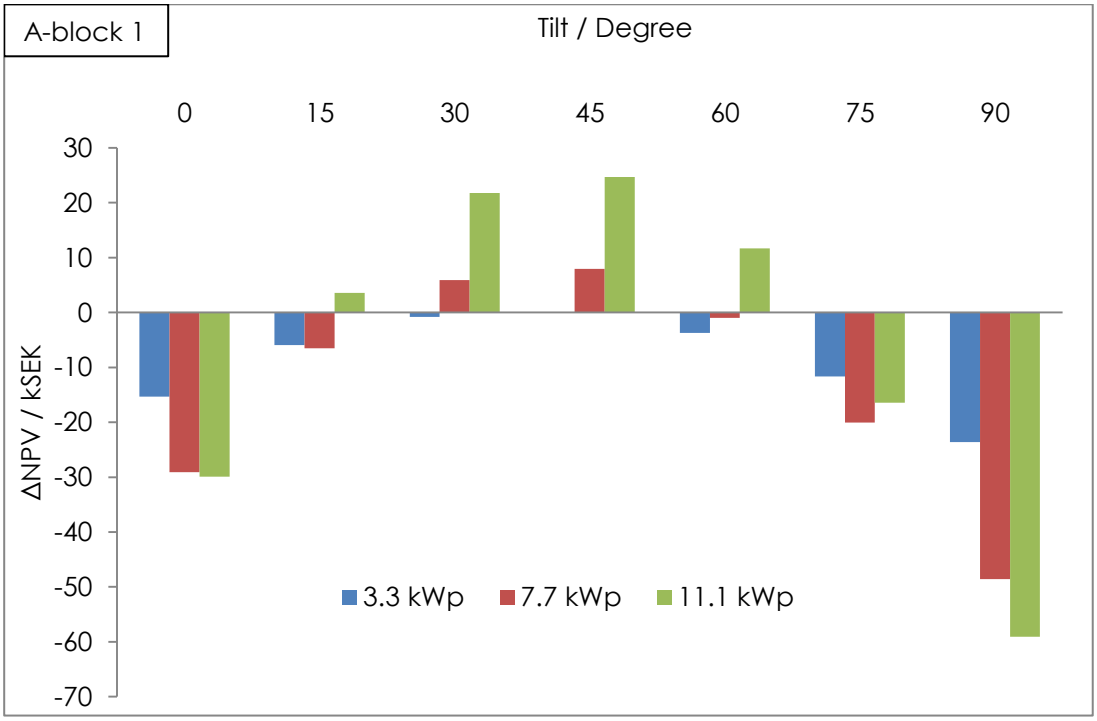

Figure B. 9.7 – Variation in NPV for different system sizes compared to the most beneficial option for apartment block 1 with varying tilt angles.

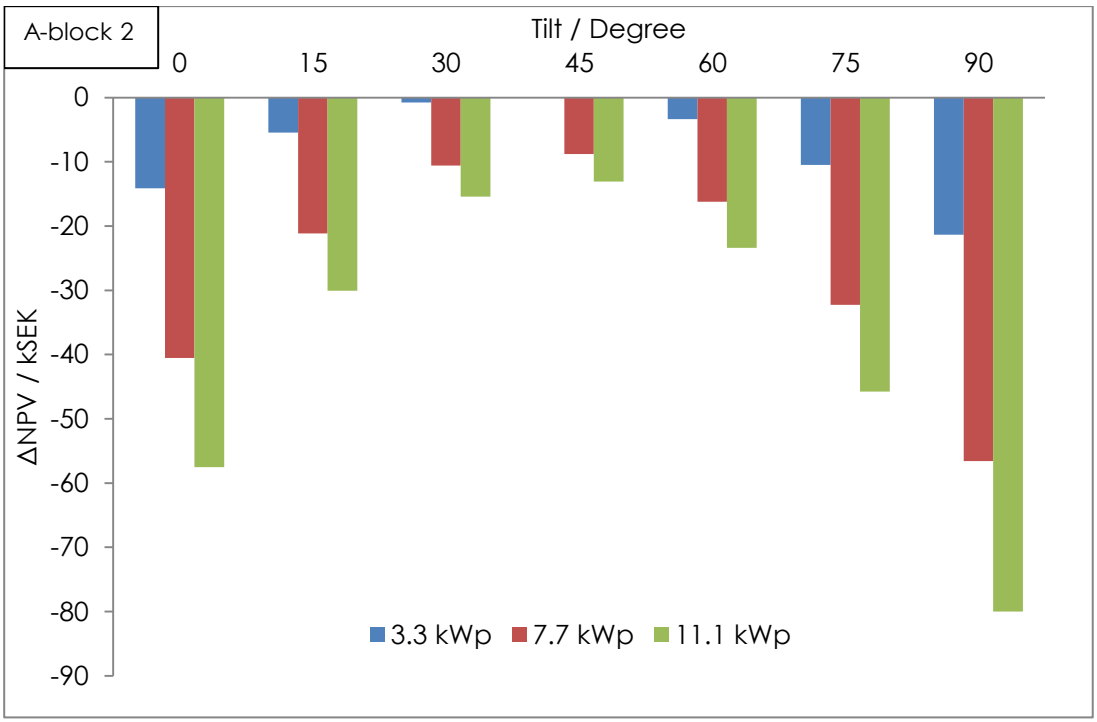

Figure B. 9.8 – Variation in NPV for different system sizes compared to the most beneficial option for apartment block 2 with varying tilt angles.

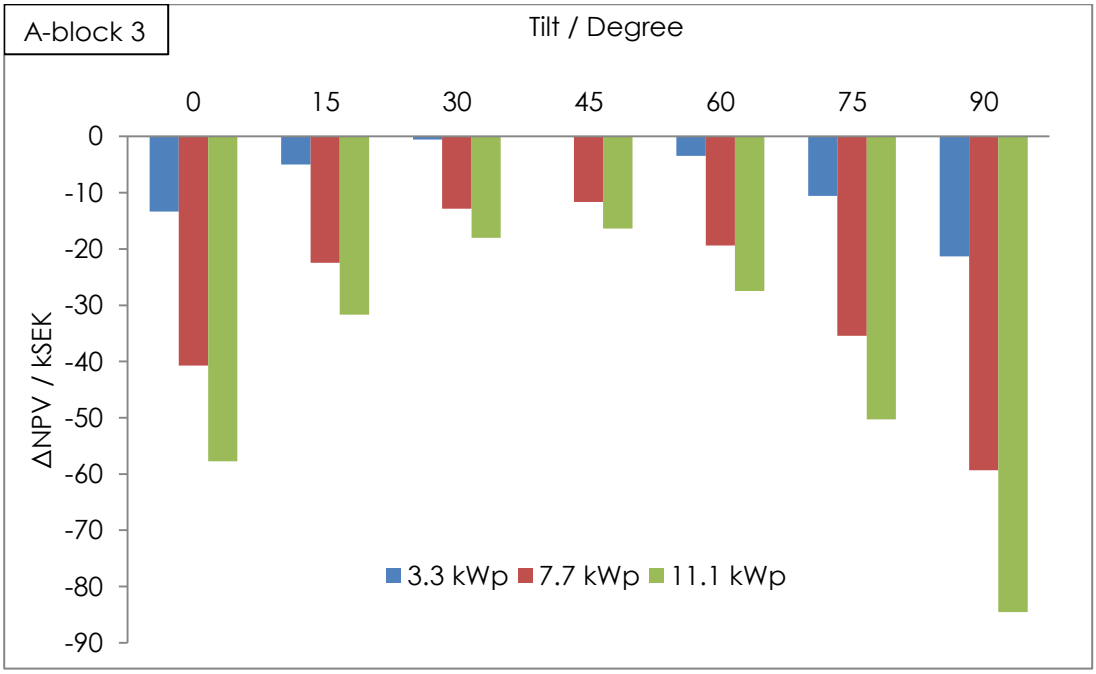

Figure B. 9.9 – Variation in NPV for different system sizes compared to the most beneficial option for apartment block 3 with varying tilt angles.

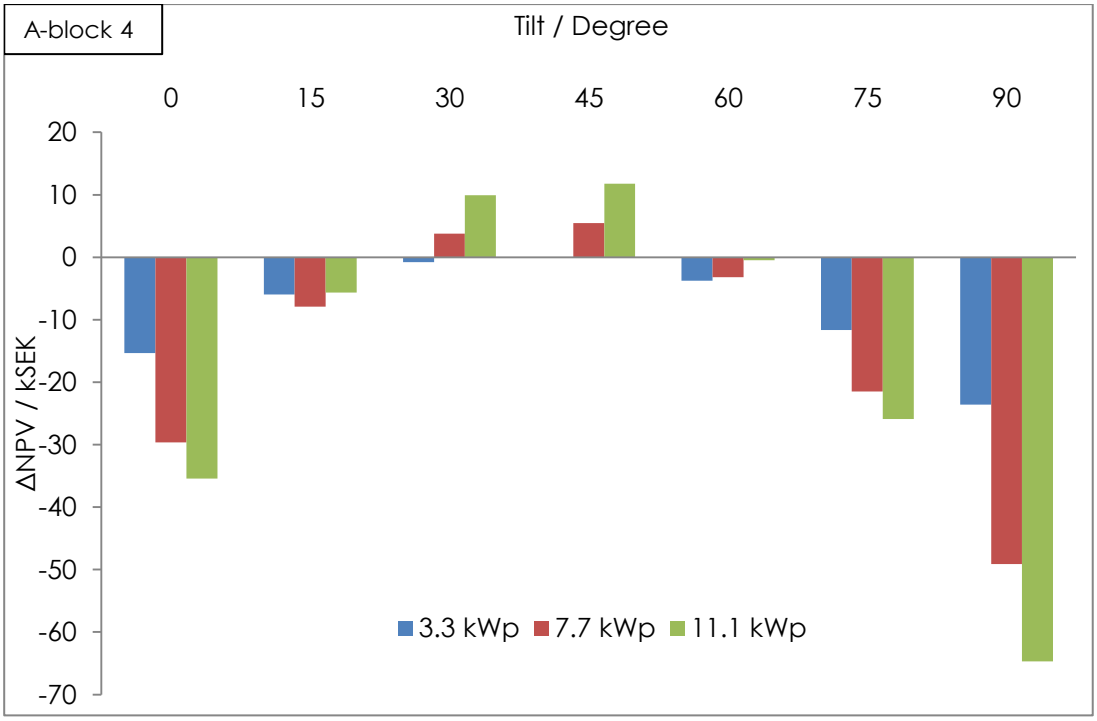

Figure B. 9.10 – Variation in NPV for different system sizes compared to the most beneficial option for apartment block 4 with varying tilt angles.

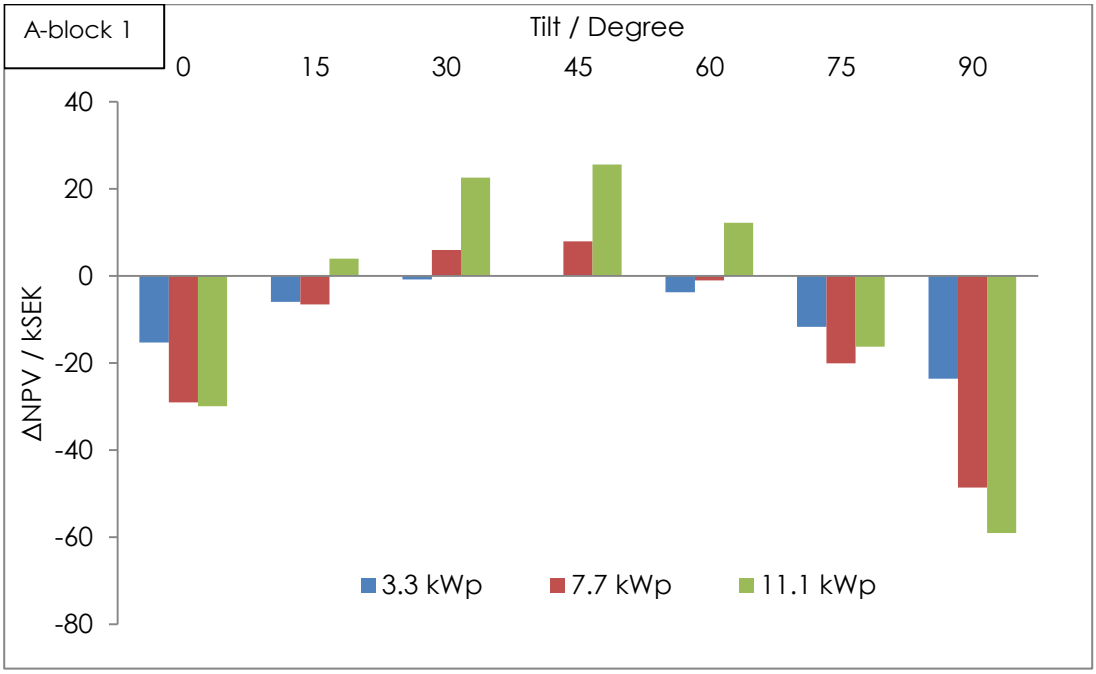

Figure B. 9.11 – Variation in NPV with tax reduction added, for different system sizes compared to the most beneficial option for apartment block 1 with varying tilt angles.

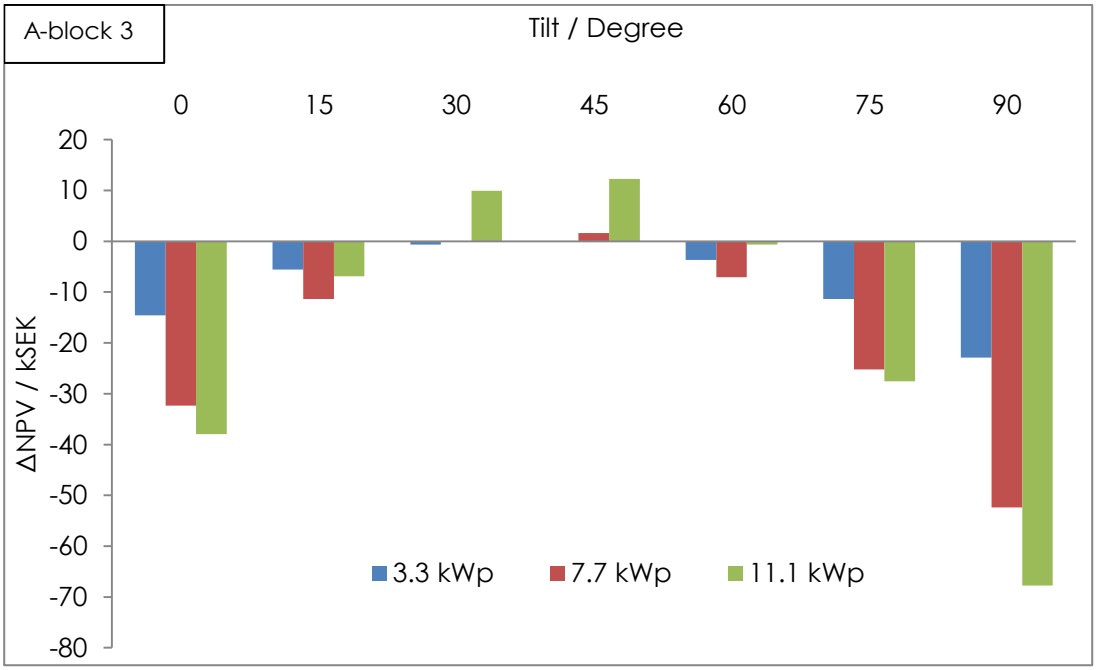

Figure B. 9.12 – Variation in NPV with tax reduction added, for different system sizes compared to the most beneficial option for apartment block 3 with varying tilt angles.

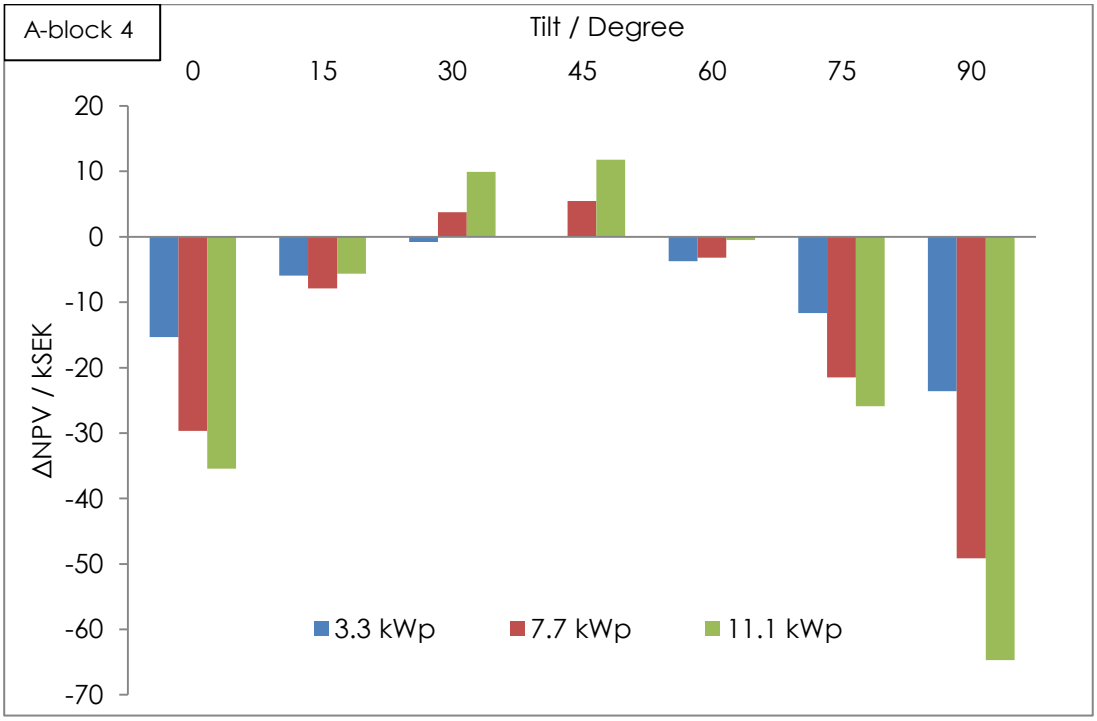

Figure B. 9.13 – Variation in NPV with tax reduction added, for different system sizes compared to the most beneficial option for apartment block 4 with varying tilt angles.

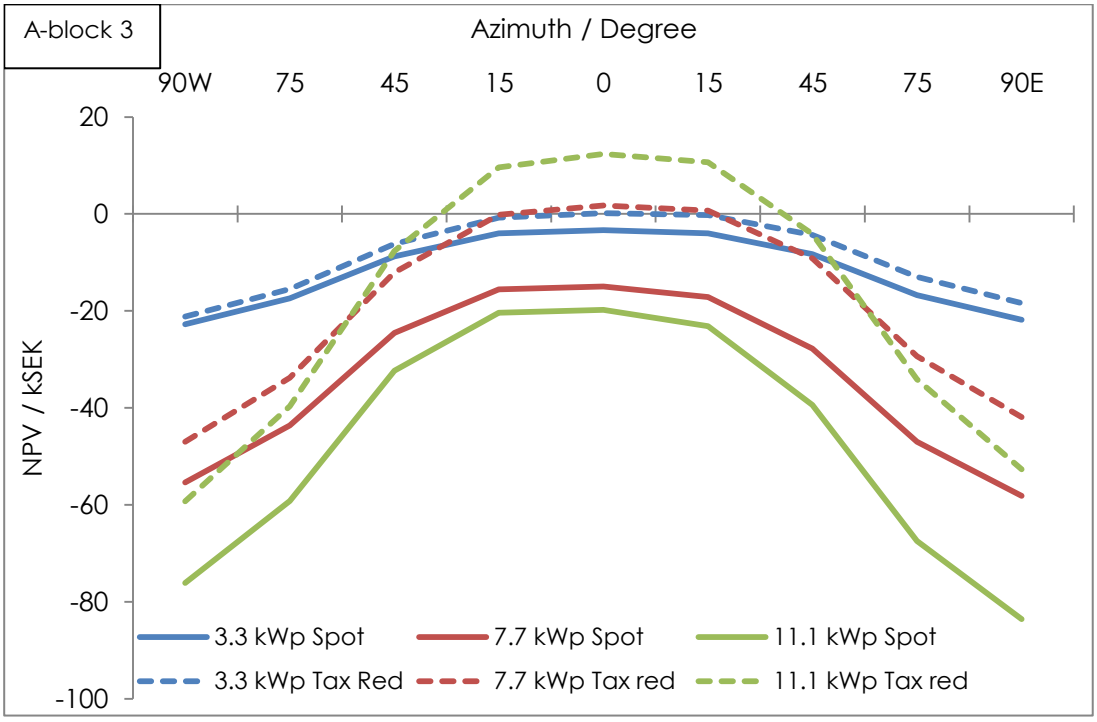

Figure B. 9.14 - How tax reduction affects the NPV for different system sizes and azimuth angles for apartment block 3.

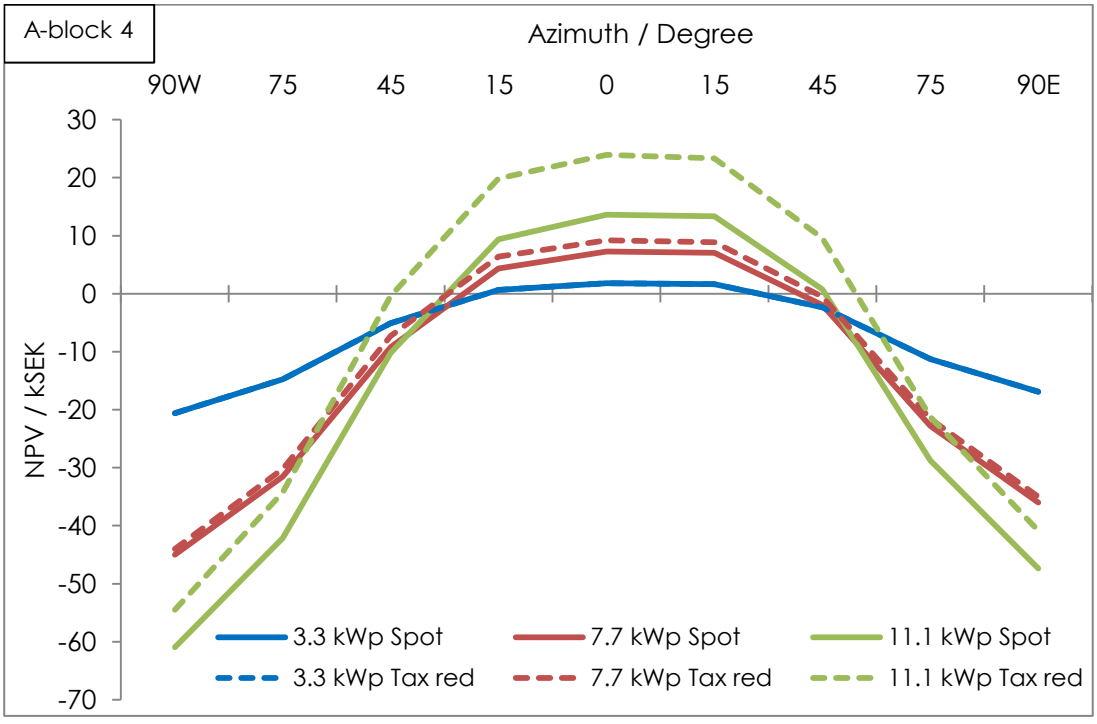

Figure B. 9.15 - How tax reduction affects the NPV for different system sizes and azimuth angles for apartment block 4.

Appendix C - Offices

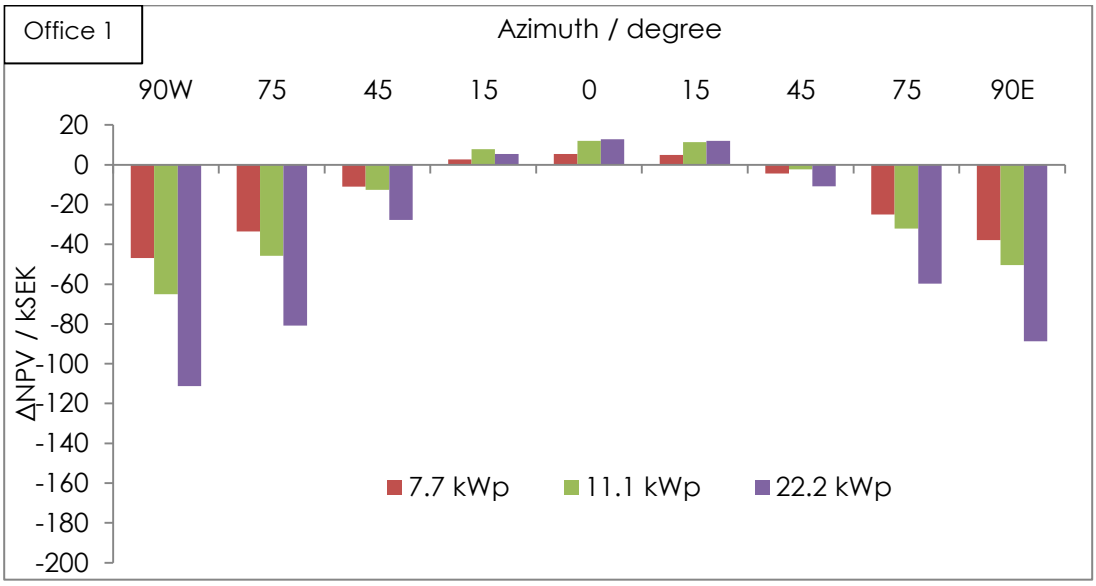

Figure C. 1 – Variation in NPV with the current selling price of different system sizes for office 1 with varying azimuth angles.

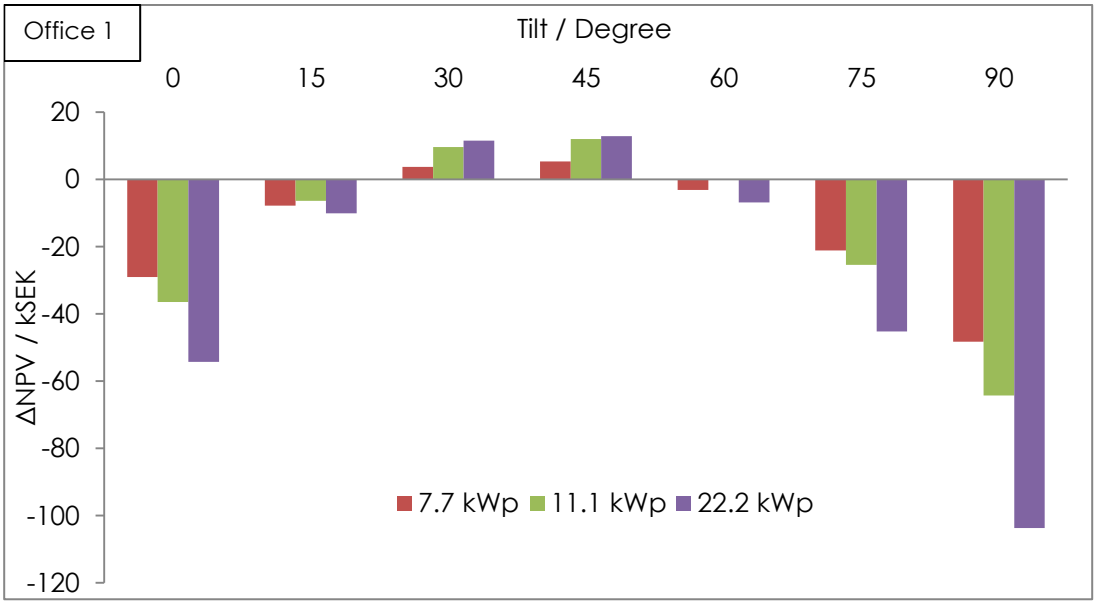

Figure C. 2 – Variation in NPV with the current selling price of different system sizes for office 1 with varying tilt angles.

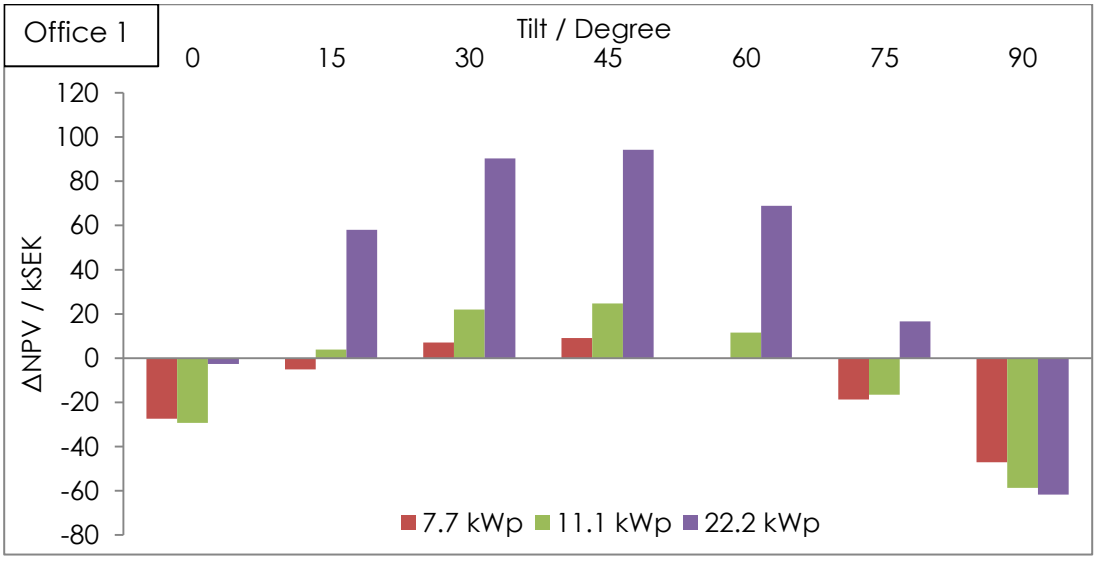

Figure C. 3 – Variation in NPV with added tax reduction on different system sizes for office 1 with varying tilt angles.

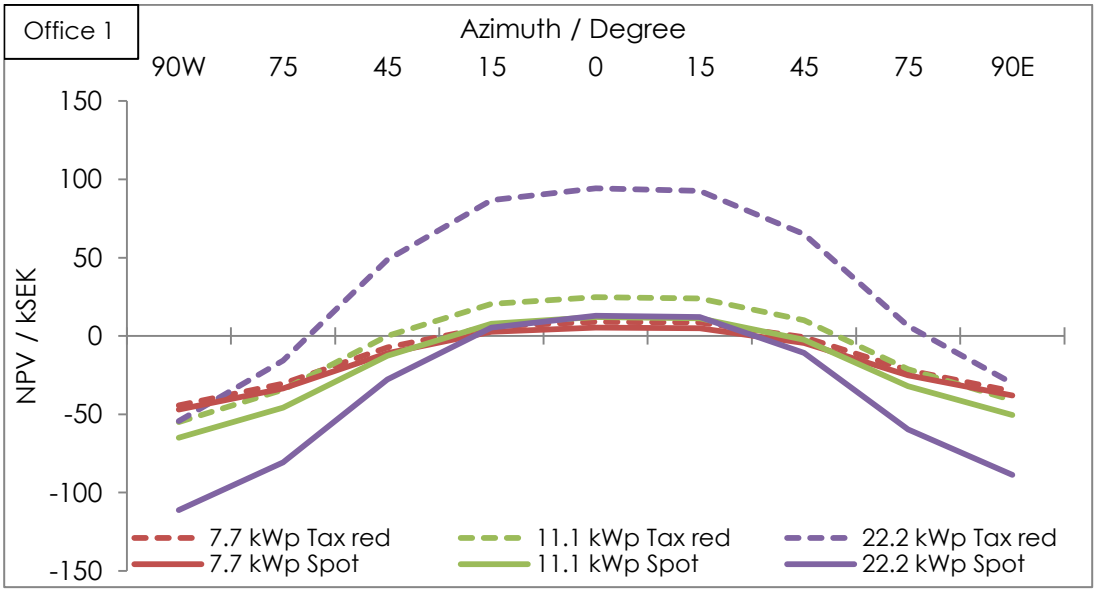

Figure C. 4 - Comparing NPV of the current and future selling price with varying azimuth angles for office 1.

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Dept of Building and Environmental Technology: Divisions of Building Physics and Building Services