Photovoltaic Systems for Swedish Prosumers

A technical and economic analysis focused on cooperative multi-family housing

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Executive Summary

Solar photovoltaic (PV) installations are growing at an exponential rate worldwide. This trend is also seen in Sweden, but with a 50 MW_p market in 2015, it is only in its infancy. Solar energy has long been an interest of the Swedish public, and now that costs have declined to a point where it is competitive with the greater wholesale market, interest is growing and early adopters are taking action. At the same time, the government has responded with rapid policy changes in an attempt to maintain technology neutrality, comply with EU tax and competition laws, and while still promoting renewable energy development to meet the nation's 100% renewable energy and climate-neutrality goals. All of this occurs within a deregulated electricity market, which is well-functioning but laden with uncertainty when it comes to making investments in new generation assets.

The majority of the installations are on buildings, meaning prosumers are quickly becoming a new actor and investor in the energy market. Building owners, be it in single family houses, housing cooperatives, or commercial entities, are not typically experts in electricity markets or finance. Therefore to move past early adoption and reach broader solar PV diffusion, it is important to educate them about the opportunities and risks that come with investment. This requires more than just traditional engineering economic indicators, but also comprehensive risk analysis which is also easy to understand.

This report is designed to be a comprehensive information resource for Swedish prosumers considering an investment in solar PV systems. The target audience are multi-family cooperative houses, however much of the information is applicable to other building owners and solar energy more broadly. The primary question to be answered; *is a rooftop PV investment profitable in Sweden?* Naturally there are many variables that can affect the answer; therefore a Monte Carlo methodology is used to convert the uncertainties into risks, where the results can be presented as probabilities rather than a vast collection of sensitivity analyses. Several policy scenarios are tested, where the relative impact of each current program on profitability can be seen. Profitable is assumed to mean a 3% real return on investment.

The results show that a well-designed and located PV system in a Swedish cooperative has a 70% chance of being profitable in a *common-case* scenario of policy support. When all support is taken away, the probability falls to 8%. However there is no potential for loss of the original investment, meaning a positive return should always be expected even if it is not the desired 3%. The time to recoup the investment is still long, with the most likely simple payback time being 18 years. The most likely time to profitability is 25 years. However, with the policy support in place today, the most likely real return on investment is 4%, which is the same as a 6% nominal return.

A sensitivity analysis supporting the Monte Carlo simulation shows that in the absence of subsidies, installation cost, annual generation and self-consumption rate are the most important factors towards the success of a PV investment. Therefore, profitability charts have been created which give the rate of return considering a range of inputs for each variable. The charts can be used as a preliminary design tool for prospective prosumers. Self-consumption is the only variable which the prosumer has ultimate control over, meaning there should be future technological developments, such as batteries, smart home energy management, and thermal storage, towards increasing self-consumption as a way to increase system sizes and/or maintain profitability under uncertain market or policy conditions.

The primary conclusion from this study is that solar PV investment is likely to be successful for well-positioned Swedish cooperatives. However, the investment must be considered as long-term, much like new roof or windows. It can also be concluded that for the continued near-term growth of the market, direct support policy from the government is necessary. The policy cases and profitability charts can be a helpful tool for lawmakers as well when scheduling reductions in support. With increased education from academia and industry through reports like this and public events, as well as government support, Sweden is on its way to a more mature and sustainable prosumer PV market.

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Nomenclature

AC	Alternating Current
a-Si	Amorphous Silicon
BAPV	Building Applied Photovoltaics
BIPV	Building Integrated Photovoltaics
BTES	Borehole Thermal Energy Storage
CdTe	Cadmium Telluride
CIGS	Cadmium Indium Gallium (di)Selenide
DC	Direct Current
ETS	European (Carbon) Trading System
EV	Electric Vehicle
FiB	Feed-In Bonus
GBM	Geometric Brownian Motion
GSHP	Ground Source Heat Pump
HVAC	Heating Ventilation Air Conditioning
IRR	Internal Rate of Return
MLPE	Module Level Power Electronics
MPPT	Maximum Power Point Tracking
M-Si	Mono-crystalline silicon
NPV	Net Present Value
O&M	Operations and Maintenance
OP	Overproduction
PoP	Probability of Profitability
PPR	Probability of Principal Return
P-Si	Poly-crystalline silicon
PV	Photovoltaic
SLA	Straight-Line Amortization Loan
VAT	Value Added Tax

Units

°C	Degrees Celsius
kg	Kilogram
km	Kilometer
kSEK	Thousands of Swedish crowns
kW	Kilowatt
kW_p	Kilowatt-peak
m	Meter
m^2	Meters squared
mm	Millimeter
MSEK	Millions of Swedish crowns
SEK	Swedish Kronor (Crown), currency
W	Watts
W/m^2	Watts per square meter

List of Related Academic Publications

International Conferences

Sommerfeldt N. On the economic effects of metering schemes in community owned residential PV systems. ISES Solar World Congress 2015; Daegu, South Korea.

Sommerfeldt N., Muyingo H. Lessons in community owned PV from Swedish multi-family housing cooperatives. 31st European Photovoltaic Solar Energy Conference and Exhibition (EU PVSEC), 2015; Hamburg, Germany. doi: 10.4229/EUPVSEC20152015-6AV.4.8

Sommerfeldt N., Madani H. Improved methodology for determining the value of energy from distributed renewables using statistical analysis combined with normative scenarios. International Conference on Applied Energy 2014. Energy Procedia;61;1089-1092. doi:10.1016/j.egypro.2014.11.1029

Sommerfeldt N. Opportunities for large scale solar photovoltaic systems in Swedish multi-family housing. 3rd International Workshop on Integration of Solar Power into Power Systems; 2013; London; Energynautics Gbmh. ISBN 978-3-9813870-8-7

Peer-Reviewed Journals

Sommerfeldt N., Madani H. On the use of hourly pricing in techno-economic analyses for solar photovoltaic systems. Energy Conversion and Management, 2015; 102, 180-189. doi:10.1016/j.enconman.2015.02.054

Muyingo, H. Organizational Challenges in the Adoption of Building Applied Photovoltaics in the Swedish Tenant-Owner Housing Sector. Sustainability, 2015; *7*, 3637-3664. doi:10.3390/su7043637

Submitted Journal Articles

Sommerfeldt N., Madani H. Revisiting the techno-economic analysis process for building-mounted, grid-connected solar photovoltaic systems: Part One – Review.

Sommerfeldt N., Madani H. Revisiting the techno-economic analysis process for building-mounted, grid-connected solar photovoltaic systems: Part Two – Application.

Foreword

The electricity system in Sweden began a dramatic transformation into the nuclear era four decades ago. At the time, decisions that drove the entire market were being made by a small number of engineers, businesses, and politicians. Today, the electricity system is beginning a new transformation into a sustainable era. This time, the decisions are being made *by* the market rather than *for* the market. This time, customers are not simply rate payers but active participants, where an average household or business can produce their own electricity to use themselves or to sell to others. The producing-consumer, the prosumer, is a new class of investor and solar photovoltaics are the key which opens the door to bring them into the energy system.

This report was written as a comprehensive source of technical and economic information on photovoltaic for Swedish multi-family housing cooperatives. The bulk of the information is generic to solar energy and energy markets in Sweden and the economic results are applicable to most residential prosumers. There are, however, specific sections dedicated to cooperatives, such as designing for load demand patterns and collective decision making. The target audience is therefore the executive committees for cooperatives, who can use this report as a guide towards making an investment in solar. At the same time, given the broader application of the background, method, and results, the report will be interesting to other prosumers, politicians, and researchers.

Funding for this study was provided by The Swedish Research Council Formas (no.2012-256) for which the authors are very grateful. Additional support came from Riksbyggen, who introduced us to executive committees in several cooperatives and energy data, and Sustainable Innovation who provided guidance on disseminating the results. A special thank you goes to the cooperatives who took the time to sit down with us and provide access to their detailed energy and accounting data. Any errors that remain the responsibility of the authors.

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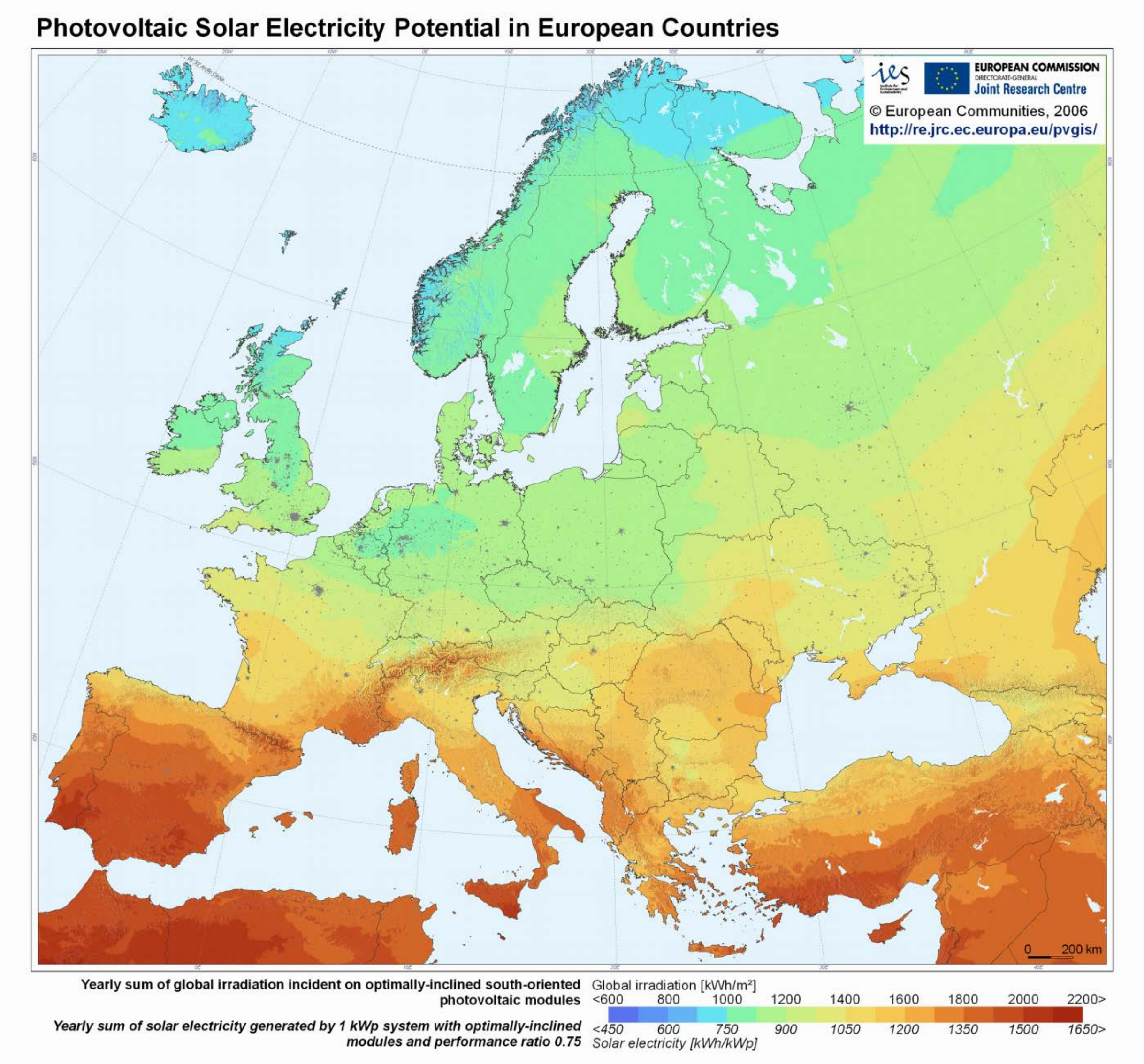
1 Introduction

Solar photovoltaic (PV) technology has been in an accelerated development since its initial terrestrial deployment in the 1970’s. Increasing fossil fuel prices combined with concerns over carbon dioxide (CO_2) emissions has ushered in a new wave of research focused on improving cost and increasing deployment. The motivation is to make solar PV a competitive energy source in the open market and help create a new era of sustainable energy.

Sweden has a global reputation of being a leader in sustainability and energy systems transformation, however solar energy is often disregarded. The extreme northern latitudes often instill images of long dark winters. However as Figure 1 shows, the solar irradiation is comparable to the U.K. or northern Germany on an annual basis, the former which had the largest PV market in Europe in 2014 and the latter with the most installed PV capacity in the world [1].

Figure 1 - Annual solar radiation for optimally tilted surfaces in Europe [2]



During the past decade, several countries have enacted favorable policies towards manufacturing and deployment of PV which has created a feedback loop of rapidly decreasing prices. The result is that PV has become the fastest growing form of solar energy collection in the world and the second fastest renewable source behind wind power [3]. The costs are low enough now that even in Sweden the growth has also been rapid, with the market doubling in size each year since 2010 [4]. The penetration is still quite small, however, as only 36 MW_p was installed in 2014, as compared to 2400 MW_p in the U.K.

One method for installing PV is on existing buildings, which allows electricity to be generated where it is needed and reduces environmental impacts of greenfield land conversion. This allows building owners to become both producers and consumers of electricity, making them *prosumers*. Compared to traditional wholesale electricity producers, there is an economic advantage for prosumers in that when they use their electricity generation directly in the building they avoid paying the retail price of electricity. Taxes, grid fees, and retailer markups make retail prices many times more expensive than wholesale, which makes rooftops an interesting location for PV technically, environmentally, and economically.

Tenant-owned cooperative housing, known in Sweden as a *bostadsrättsförening* and here after referred to as cooperatives, provides a unique opportunity to rapidly deploy significant amounts of solar PV. A single decision by the executive committee can cover tens or sometimes hundreds of households. The size of the systems lends themselves to economies of scale, meaning lower potential installation costs than single family villas. The size of the buildings and community nature of cooperatives can also lead to interesting energy system combinations, such as with ground source heat pumps (GSHP) or electric vehicles (EV), which can be more challenging with villas [5,6].

1.1 Housing Cooperatives in Sweden

Cooperatives account for approximately 22% of the housing stock in Sweden, considerably exceeding the average of about 10 % in other European countries [7]. Within multi-family dwellings in Sweden cooperative tenant-ownership forms the largest sector as shown in Table 1 [8]. It is typical for a cooperative to only own one housing estate or apartment building with an average of 30 dwellings and their business is limited to providing housing services only [7]. They can be sorted by their organization; attached, which belong to the two nationwide cooperative organizations *HSB* and *Riksbyggen*; and independent, which are those founded by building companies, groups of households, etc. [9]. In April 2014 there were 23,271 active cooperatives in Sweden. Though only about 10% of them consist of more than 100 dwellings, on average, the ones formed during the period 1965-1975 comprise of 300 to 500 apartments each[1].

Table 1 - Distribution of dweling and tenure forms in Sweden 2012 [8]

Total number of dwellings	4 550 779	100 %
Owner-occupied single-family	2 014 394	44 %
Multi-family housing	2 536 385	56 %
- tenant-owner cooperative	955 000	37 %
- rental (Private)	830 000	33 %
- rental (Municipal)	751 000	30 %

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[1] Statistics come from behind a paywall at HittaBRF.se

The term *bostadsrätt* translates in English to *right to reside*. The cooperative owns the building and common areas with the members owning a share of the capital of the association. The share is associated with an apartment, which is what a member purchases on the open market. The market price for apartments depends partly on the state and location of the building, as well as the level of the annual fee for communal expenses. The member pays an annual fee for the management of the common areas and financial responsibilities of the cooperative, which is determined by the size of their apartment. A majority of cooperatives are initiated by a builder-sponsor. This type of cooperative is populated by members who buy into the development, which is advertised by the contractor. Another formation method is through a tenure conversion process. Only sitting tenants are eligible to form this type of cooperative, and by law a 2/3 majority of the residents must agree to participate in the transaction.

Management is done through an executive committee that is elected by the cooperative's members. Committee members serve on a voluntary basis for an average term of two years but can be re-elected successively. The committee often consists of laypersons that are elected mainly because they are available to serve, not necessarily because of their qualifications, and usually have the liberty to make decisions without consulting the members. Members can take part in decision making through their right to vote on issues presented during general meetings. However in practice, attendance is usually low at general meetings and most of the decisions are left to the committee. The issues brought to a general vote also tend to be decided solely by the committee.

Whereas matters concerning the operation of the property are decided within the executive committee, they often seek approval of the members on decisions involving investments that can have a significant effect on the size of the annual fee. Thus the decision to adopt PV may be taken directly by the committee or after being approved at a general meeting depending on how the measure will be financed. Issues brought to a vote are decided by majority among those present at a single meeting. Decisions that affect the number of shares or those with far reaching consequences, such as the decision to have one electricity meter for the whole cooperative, are in most cases decided through voting during two consecutive general meetings. On the contrary, decisions which reduce the communal fee, such as the adoption of individual metering, will be left to the executive committee to take without a vote as long as it is not too costly to implement.

1.2 Objective

While costs for PV systems have declined rapidly, it is still difficult to determine the economic benefits of making an installation. With the majority of costs being born with the initial installation, payback times tend to be relatively long, and Sweden's deregulated electricity market has a high uncertainty with regards to price development. Likewise, the dynamics of energy markets with regards to climate policy and renewable development are nearly impossible to predict with certainty. For a potential investor, especially a cooperative who should act with a rational economic strategy, it is important to know what the risks are and how they could affect the financial outcome.

In the young Swedish PV market there is a lack of experience and understanding among building owners about the costs, benefits and risks of becoming prosumers. The objective of this report is to give a comprehensive understanding of the technical and economic parameters surrounding PV investment, with a focus on Swedish cooperative housing. This is accomplished with descriptions of PV technology, how it can be integrated in the building structure and energy system, and strategies for maximizing the economic benefits under uncertainty. There is also a discussion regarding decision making within the board of directors and recommendations for successful projects.

1.3 Scope and Definitions

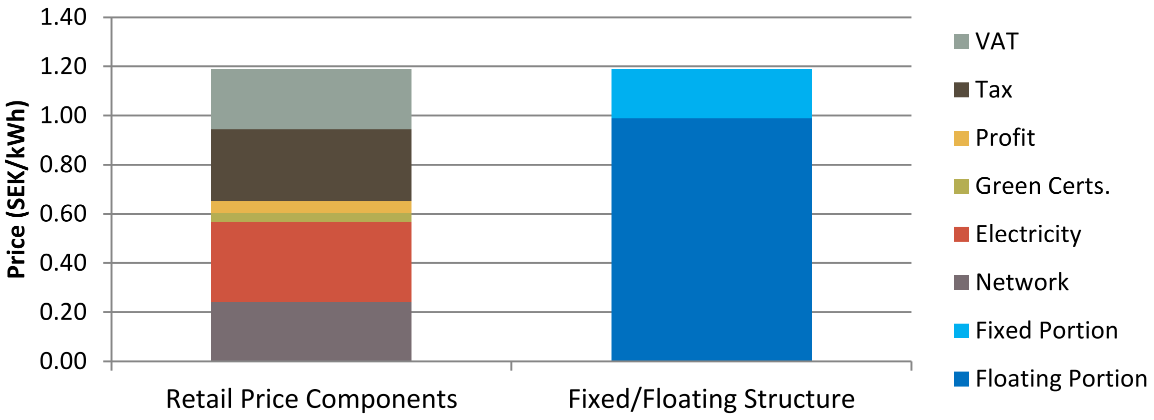
An economic and policy analysis can take many forms, therefore it is necessary to identify the approach used in this report and its boundaries. It is the intention of this report to give as broad yet comprehensive investment analysis for housing cooperatives as potential PV investors, considering various policies with an approach similar to a professional energy analyst. It is not the intention of this report to suggest any specific policy action based on macro-economic welfare or environmental optimization. However the results are capable of giving policy makers a view on how the energy landscape is viewed by prosumers, which may be a key stakeholder in renewable energy objectives and policies.

In addition to policy, the report is also limited to the current electricity market design in Sweden, which is currently based on the value of energy. There has been increasing political discussion and research around Europe regarding the potential for capacity markets in light of increasing shares of renewables and future climate goals [10,11], however for this study it is not assumed if, when, and how new markets would be implemented. The wholesale market, Nord Pool Spot, although deregulated has a relatively clear structure. In contrast, the retail market allows suppliers the freedom to structure their services and offer unique deals, making it difficult to identify a single price for delivered electricity. Therefore, it is helpful at this point to define the wholesale and retail rate structures, as the terms are used throughout the report.

As stated above, the value of electricity is based entirely on energy. The term *wholesale price* is synonymous with *Nord Pool Spot price*, which is the same amount whether it is being bought or sold by a prosumer. The retail price is the value of a single kWh delivered to the cooperative, and includes; the network fee, wholesale electricity, green certificates, profit margin for the retailer, electricity tax, and VAT tax, as shown in the left column in Figure 2. The retail price is not only linked to kWh use, but has a combination of fixed and floating portions as shown in the right column in Figure 2. The exact ratio varies with electricity retailers and distributers, and in this study it is assumed that 0.20 SEK/kWh are attributed to fixed fees that would not be deferred by PV generation. Therefore the final retail price used in the analysis is only the floating portion shown below.

When selling electricity, at a minimum it is assumed that the prosumer will earn the wholesale price (shown in red) plus a small amount for grid loss compensation. The combination of both is simply referred to as the wholesale price for simplicity. Any additional earnings to sales (e.g. green certificates) or costs (e.g. VAT tax) are treated separately from the basic market structure and treated in detail in Chapter 5.4.

Figure 2 - Breakdown of retail electricity prices by component and structure



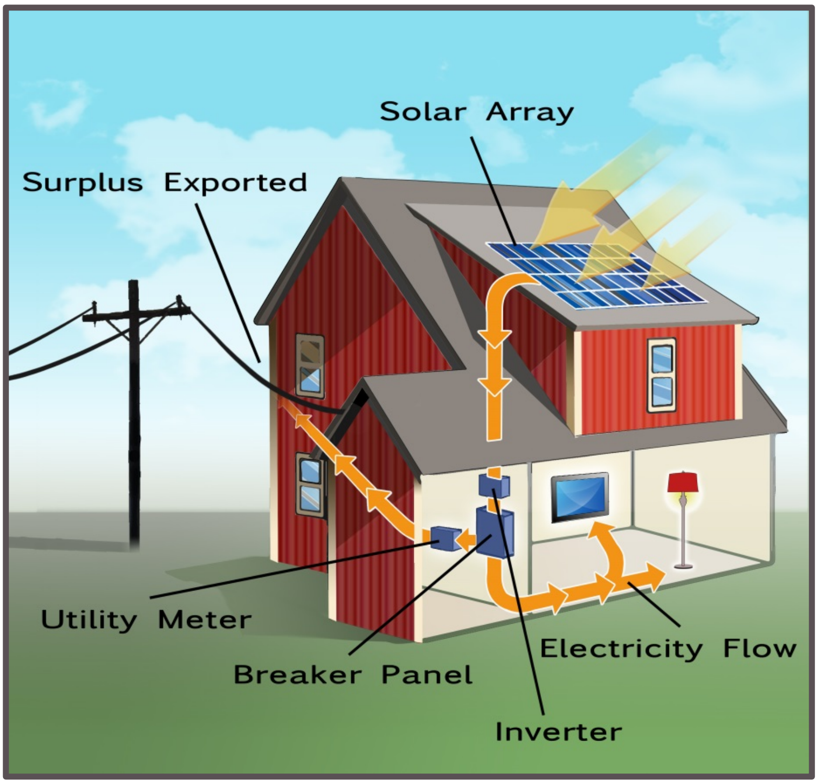
2 PV Systems: Fundamentals and State of the Art

A photovoltaic material converts light into a direct electric current. The fundamental unit of a PV system is the cell, which is combined in groups to form a module, which is combined in groups to form an array. There are several applications for PV modules and arrays which result in a wide variety of system configurations. One of the fundamental categorical divisions is off-grid or grid-connected, which describes if the system is part of a larger electricity network. Swedish cooperatives are by-and-large grid-connected, so the remainder of the report will be presented considering this type of configuration.

2.1 System Configuration and Components

Beyond the PV array, a grid-connected system requires the use of an inverter whose primary function is to invert the direct current (DC) electricity from the array into the alternating current (AC) used by the building and the grid. For safety, there are also switches and/or fuses which must be included in the wiring. A diagram showing the connection of all the electrical components is shown in Figure 3. Since the PV system is installed behind the utility meter, the electricity generated will first flow to the demand within the building. If there is more generation than is needed, it will flow out through the meter and onto the grid. While not necessary, battery storage can be added to a system as a method for increasing the self-consumption of PV generation, which can be economically interesting in markets where there is a large difference between the wholesale and retail prices.

Figure 3 - Basic electrical diagram for a grid connected PV system



Beyond its primary task of inverting, the inverter also performs two other critical functions; maximum power point tracking (MPPT) and grid synchronization. For a given solar irradiance striking the module a certain amount of current is produced. The power output then depends on the voltage, which can be controlled by the inverter by varying the resistance. Naturally the maximum power is desired and this is what the inverter tracks. Since each module can have a different current and thus maximum power point, the inverter must determine the maximum for the system as a whole. Alternatively, an inverter or optimizer can be placed on each module which are known as module level power electronics (MLPE), including micro-inverters or DC optimizers. This allows module level MPPT and can result in higher energy production, particularly in complex shading conditions.

2.2 PV Technology

There are a wide variety of photovoltaic materials, but only a small number which are deployed commercially. They can be divided into three generations; crystalline silicon, thin films, and a range of materials for generation three. To make a module, the cells are wired together in series, encapsulated in non-conducting polymer, sandwiched between a front layer of glass and a back layer of glass or plastic film, and typically surrounded with an aluminum frame. Thin film cells are often flexible such that they do not necessarily require the rigid glass structure, but commonly do. For building applications, modules are approximately 1m x 1.6m in size and have a peak power of 200 W_p to 300 W_p depending on the efficiency of the cell material. Efficiencies for commercial modules range between 15% and 22% [1].

2.2.1 Crystalline Silicon (Gen 1)

Despite its status as a first generation technology, crystalline silicon is by far the most common PV cell material in the world accounting for over 90% of the modules in the market [12]. There are two primary types; mono-crystalline (m-Si) and poly-crystalline (p-Si). In both cases, an ingot of highly purified silicon is produced and the cells (also known as wafers) are sliced off with a saw at about 0.2 mm thickness. The difference is that m-Si is cooled in a slow and controlled method that results in the growth of a single crystal. P-Si is cooled much faster and thus results in multiple crystal growths throughout the ingot. M-Si cells are more expensive to manufacture but have a higher efficiency, typically in the range of 16%-24%. P-Si cells are typically 14-18% efficient but the lower cost makes them more popular than m-Si cells. As shown in Figure 4, there is a visual difference between m-Si and p-Si.

Figure 4 - Commercial crystal silicon modules with varying cell materials and back sheets[2]

Mono-crystalline with white background

Mono-crystalline with black background

Poly-crystalline

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[2] The modules in the photos are SolarWorld AG products: http://www.solarworld.de/en/service/contact/

2.2.2 Thin Films (Gen 2)

Thin films describe several cell materials, however there are three which are most common in the marketplace; cadmium telluride (CdTe), amorphous silicon (a-Si), and copper indium gallium (di)selenide (CIGS). CdTe and CIGS have nearly equal production, which is dominated by the companies First Solar and Solar Frontier, respectively. A-Si has seen a dramatic reduction in use within the past four years due to low efficiencies (appx. 11%), issues with degradation, and high failure rates. CdTe and CIGS have traditionally had relatively low efficiencies as well, but are now achieving module efficiencies that compete with p-Si (appx. 17%) [12]. However the primary advantage has been a superior temperature coefficient, which results in higher efficiencies when the cells are at operating temperatures. This is particularly advantageous in hot climates with very high irradiation, which is where utility scale plants are typically constructed. Use in buildings is relatively limited, often being used for architectural projects which seek out the homogenous black surface finish, as seen in Figure 5.

Figure 5 - First Solar thin film CdTe modules[3]

2.2.3 Research Technologies (Gen 3)

Covering a broad field, generation three materials can be classified in two ways; high efficiency and low cost. High efficiency materials include gallium arsenide (GaAs) and multi-junction (MJ) cells. GaAs modules can reach efficiencies over 24% and have been used in space applications for many years; however the high costs have prevented commercial terrestrial use. Recently, a novel thin film method of manufacturing has been developed by Alta Devices, who plans to develop military products. MJ cells layer multiple silicon cells tuned for specific wavelengths on top of each other. They are capable of efficiencies above 40% but require high concentration, limiting their application to areas with high direct radiation and 2-axis tracking. Neither of the high-efficiency technologies exhibits a near-term application in buildings.

Low cost PV developments are producing more building relevant technologies. Dye sensitized cells, also known as Grätzel Cells, can be printed using common ink jet printers making their manufacturing costs very low and intricate designs possible, as seen in Figure 6. Challenges to

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[3] Photo source: http://firstsolar.com/en/Technologies-and-Capabilities/PV-Modules

commercialization include low efficiencies, toxic materials, and rapid degradation [13]. Another material, perovskites, has had a rapid increase in research activity and may lead to relatively short term commercialization. This is particularly noteworthy since the first research in 2009 produced efficiencies of 3.6%, whereas the most recent confirmed record is 20.1%. Like Grätzel cells, toxicity and stability are the primary issues [14]. One final notable technology is transparent solar cells, shown in Figure 6, which could be used in windows. Past efforts have created tinted windows; however a recent advance has created an 86% transparent cell with no color shifting [15]. Efficiencies are currently below 1%, but are expected to reach 10%.

Figure 6 - Examples of dye-sensitized[4] and transparent solar cells[5]

2.3 Building Integration

Adding PV to a building involves applying or integrating the modules into the envelope. Rooftops are the most common location; however facades, windows, and shading elements can also be used. When PV is not an integral part of the building envelope, meaning it does not influence the weatherproofing, it is considered *applied* (BAPV). When the PV replaces a traditional building material, such as roofing tiles or windows, then it is considered *integrated* (BIPV). While the concept shows promise, BIPV is still relatively expensive and difficult to implement, making it a niche application usually reserved for custom architectural projects.

2.3.1 Mounting Racks

PV modules are most commonly fixed to buildings on the roof using a mounting rack. Modern racks are easy to install, work with a variety of panel manufacturers and mounting surfaces, and provide an air gap between the panels and the roof to allow for cooling. On pitched roofs, it is common to penetrate the roof surface to secure the rack, although systems exist that can mount directly to standing seam steel roofs. The state of the art racking system comes from Zep Solar, shown in Figure 7, which uses a proprietary rail-less technique that uses the frame of the module to assemble the array. On flat roofs, modules are usually mounted on a standing structure with a

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[4] Photo source: Fraunhofer ISE, http://www.colorsol.de/en.html

[5] Photo from the cover of Advanced Optical Materials, 2014, Volume 2, Issue 7

shallow tilt (10° to 20°), also shown in Figure 7. Flat-roof systems can be fixed like a pitched roof or simply placed on the roof and secured using ballasting from concrete blocks. Building application is treated in greater detail in Chapter 4.

Figure 7 - Zep Solar[6] and flat-roof[7] racking systems

2.3.2 Roof Tiles

The application or even integration of PV modules with traditional roofing materials can be considering by some owners or community/municipal boards to be aesthetically unacceptable. In these cases, a BIPV roofing tile may provide the solution. As seen in Figure 8, the tiles are made to look nearly identical to traditional tiles with the addition of a PV cell applied. While costs can be saved on roofing materials, PV roof tiles can still be an expensive solution due to the small production volumes and long installation times given the large number of individual PV units.

Figure 8 - Samples of BIPV roof tiles[8]

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[6] Photo source: http://www.ecodirect.com/Zep-System-Curved-Tile-Roof-Mount-p/zep-solar-zs-ctm.htm

[7] Photo source: Nelson Sommerfeldt

[8] Photo source: http://www.smartroof.be/indexEN.html

2.3.3 Windows/Glazing

An increasingly popular method of integrating solar cells into commercial buildings is in glazing, an example of which is shown in Figure 9 from the campus of KTH. The only difference between these panels and traditional crystalline silicon are the spacing of cells and the glass back layer, making manufacturing relatively simple. The modules have shown to provide multiple benefits by not only producing electricity, but reducing cooling loads through shading and reduced lighting loads [16]. The use of these types of windows is not as common in residential applications since the view is impeded in a façade window and skylights are rare.

Figure 9 - BIPV glazing on the campus of KTH[9]

2.4 Operation and Lifetime

One of the more interesting features of PV systems is that they have no moving parts, therefore after a system is installed the maintenance effort is minimal. Regardless, most of the system is exposed to the natural environment and it is important for production, longevity, and safety reasons to perform an annual inspection by a qualified electrician (i.e. the PV installer).

The lifetime of a PV system is usually associated with the lifetime of the modules; however this is not always associated with a physical end of life. Power output degrades over time, and if a module is still producing adequate electricity, it does not necessarily need to be replaced. Long term testing of PV modules manufactured in the 1980's indicate that even with relatively immature technology and minor damage, lifetimes could be expected to be much longer than the 20 year production warranties [17,18]. Manufacturers now typically offer a 10 year manufacturing warranty and a 25-30 year power warranty, which is an indication that a system can be expected to last 30 years and potentially into perpetuity if individual components are simply replaced as needed. Inverter lifetimes are shorter but have improved rapidly in recent years. In the 2000's expected lifetimes were only 5-7

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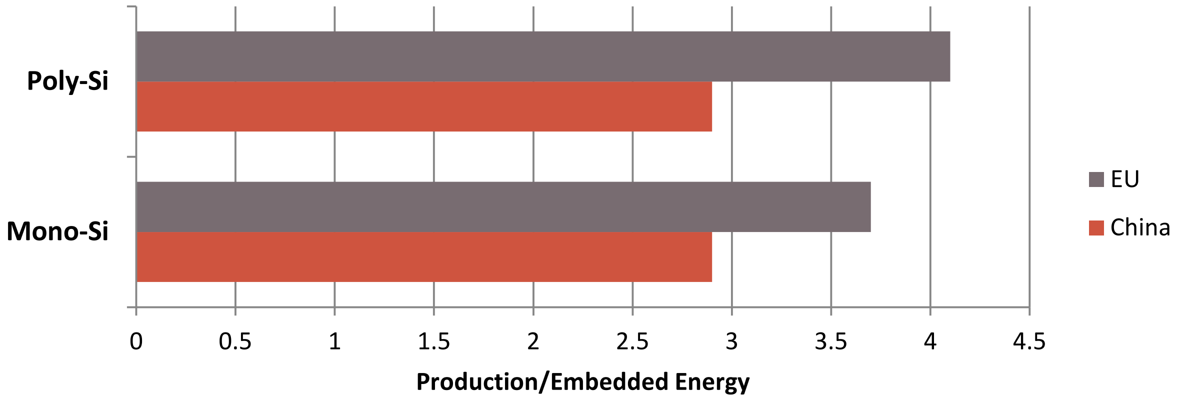
[9] Photo source: Nelson Sommerfeldt

years [19], but now high-quality models can last 15-20 years depending on the operating conditions. Although major component lifetimes are increasing, the likelihood of minor maintenance or replacement of minor components exposed to the elements (wiring, mounting, building, etc.) increases over time, thus it should be expected to have higher maintenance costs as the system ages.

2.5 Environmental Impact

The manufacturing of PV modules requires several heavy metals, hazardous chemicals, and high amounts of energy, the balance of which depends on the technology and location of manufacturing [20]. For example, crystalline silicon modules manufactured in China have a higher amount of embedded energy, and higher CO_2 emissions, than EU manufactures due to the lower primary efficiency of the Chinese energy system [21]. Second and third generation thin film technologies require much less energy than silicon, but tend to have more heavy metals. Even with the high levels of embedded energy, Figure 10 shows that a PV module in Sweden will produce several times more energy over its lifetime (estimated here at 30 years) than it takes to manufacture it.

Figure 10 - Ratio of produced to embedded energy in crystalline PV modules for Sweden



Considering a systems-of-systems approach, Hadian and Madani [22] concluded that solar PV has medium level of environmental footprint; similar to hydropower but higher than all other renewables aside from biomass. This is largely due to material resource use efficiency, which has room for improvement. For prosumers concerned with the environmental impacts of PV manufacturing, a scorecard is published by the electronics industry pollution watchdog Silicon Valley Toxics Coalition[10] listing the performance of most top tier manufacturers across several metrics.

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[10] The 2014 scorecard can be found at http://www.solarscorecard.com/2014/2014-SVTC-Solar-Scorecard.pdf

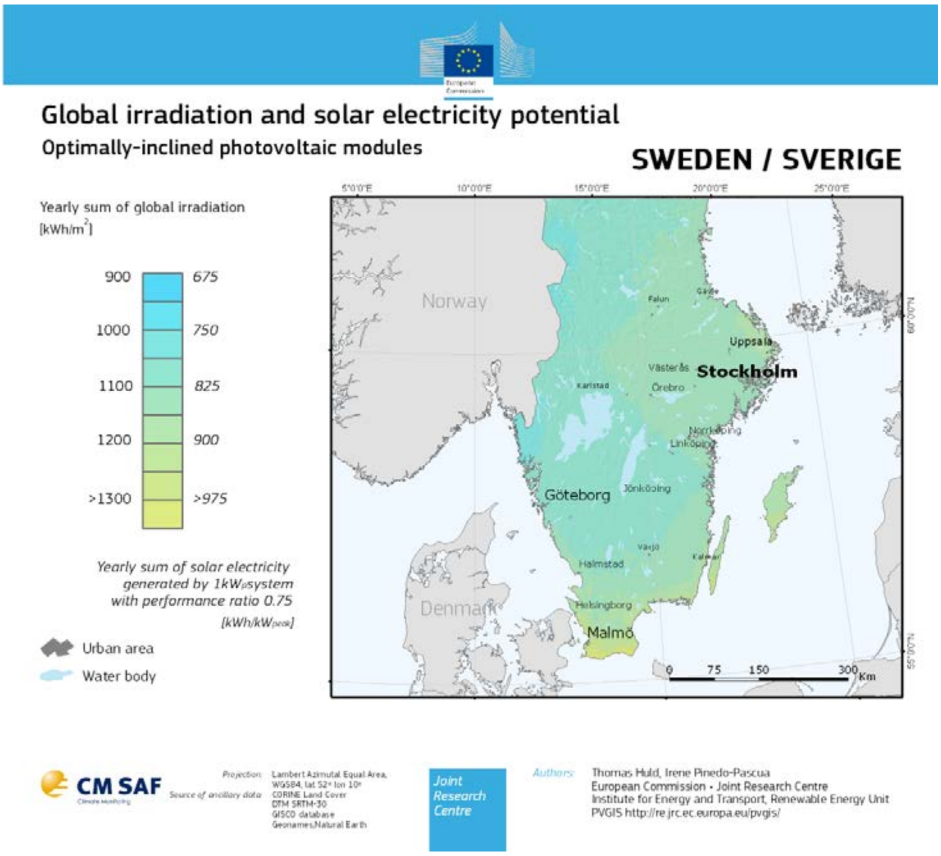
3 PV in the Cooperative's Energy System

Incorporating PV into the existing energy system of a cooperative requires consideration of the various demands of the building and the supply from the PV system. Energy demands in households have evolved in an energy system which permits near unlimited supply. It is a very rare event that homeowners turn a switch or open a valve that the electricity or hot water demanded is not supplied. By contrast, PV generation is only available when the sun is shining, which naturally has diurnal and seasonal variations as well as interruptions from clouds. In grid-connected systems, this imbalance is supported by the greater electricity system which provides electricity when the PV cannot meet the demand and accepts electricity when there is excess generation. Economic considerations, which are discussed in detail in Chapter 6, encourage a majority of the PV generation to be used directly in the building rather than be exported to the grid. This section will review the current status of electricity demand in cooperative buildings, the coordination with PV generation, and complementary technologies which can improve coordination of the two.

3.1 PV Production

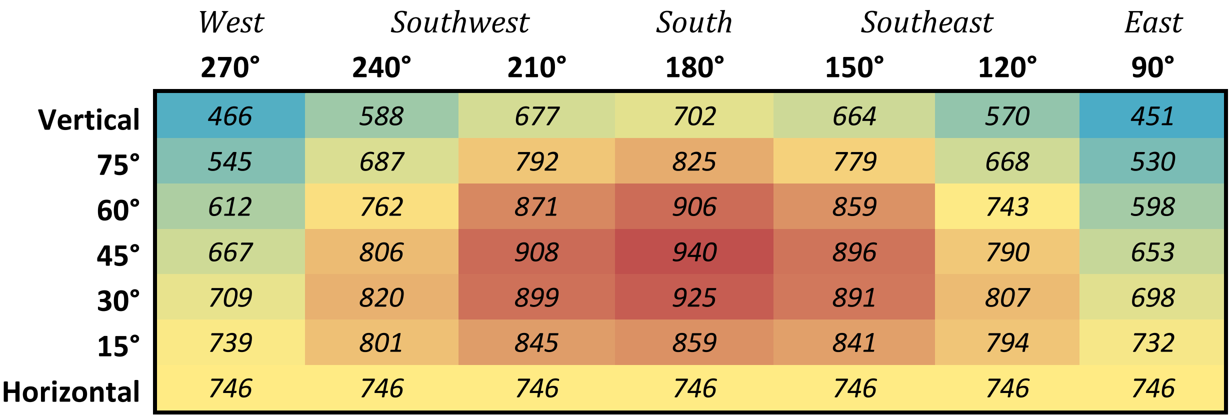
PV production is heavily dependent on the location and orientation of the installation. In Sweden, the optimal orientation for maximum production is facing due south with a 41°-48° tilt angle, with the shallower angles in the south. Without any shading, an optimally positioned PV system can be expected to produce between 900 and 1000 kWh/kW$_p$ in most places in mid- and southern Sweden. As can be seen in Figure 11, the sunniest locations are Skåne and the islands of Gotland and Öland, where systems can produce up to 1100 kWh/kW$_p$.

Figure 11 - Solar Radiation map of mid- and southern Sweden [2]



As can be expected, the majority of buildings are not optimally placed for solar production. Figure 12 is a chart with the expected annual production in Stockholm for orientations from east to west and flat to vertical. There is a greater penalty for more vertical tilts than horizontal, which is due to the considerable azimuth range the sun has during the long summer days and the relatively low irradiation during the winter when the sun is the lowest. Several cities in Sweden have made publically available solar maps, where users can see the annual solar resource on the rooftops taking into account orientation and shading (see examples for Stockholm, Gothenburg, and Lund).

Figure 12 - Production chart for Stockholm considering azimuth and tilt

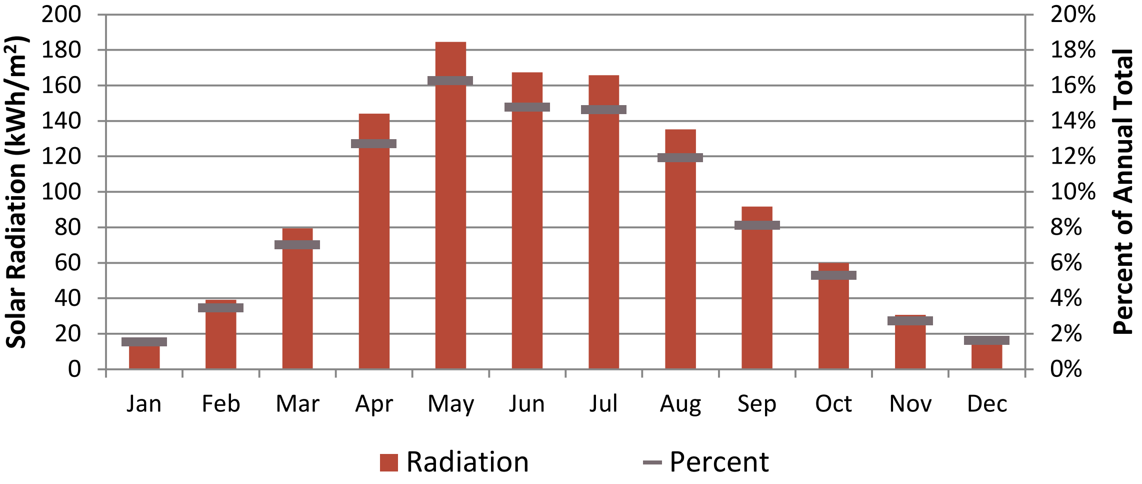


	West	*Southwest*		*South*	*Southeast*		*East*
	270°	**240°**	**210°**	**180°**	**150°**	**120°**	**90°**
Vertical	*466*	*588*	*677*	*702*	*664*	*570*	*451*
75°	*545*	*687*	*792*	*825*	*779*	*668*	*530*
60°	*612*	*762*	*871*	*906*	*859*	*743*	*598*
45°	*667*	*806*	*908*	*940*	*896*	*790*	*653*
30°	*709*	*820*	*899*	*925*	*891*	*807*	*698*
15°	*739*	*801*	*845*	*859*	*841*	*794*	*732*
Horizontal	*746*	*746*	*746*	*746*	*746*	*746*	*746*

One defining feature of solar energy in Sweden is the considerable seasonal variation due to the high latitude location[11]. Figure 13 shows the monthly radiation falling on a horizontal surface in Stockholm during a typical year[12]. The statistics are dramatic;

- There is a 10x difference in total supply between the darkest and sunniest months,
- 80% of the annual radiation falls between April and October
- Only 3% of annual radiation occurs during December and January, combined

Figure 13 - Solar radiation resource by month for Stockholm



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[11] Sweden stretches between 55°N and 69°N, but 90% of the population lives south of 61°N

[12] Radiation data is from the TMY2 data file for Arlanda airport, available from the U.S. Department of Energy

All of the production values thus far refer to the first year; however it is well known that PV modules degrade over time. The seminal source for historical degradation rates is the review paper from Jordan and Kurtz [23] which covered studies including nearly 2000 measured degradation rates from around the world. They find a median value of 0.5% per year for crystalline silicon, which is heavily dominated by modules installed before 2000. An Elforsk report from 2006 found that 25 year old modules installed in the Stockholm archipelago degraded at a much lower 0.17% per year [24]. Other studies reviewed by Jordan and Kurtz from cooler climates also had lower degradation rates, suggesting that PV systems in Sweden may have longer useful lifetimes than in hotter climates with more intense solar radiation.

It is important to note that all of the production values here are for unshaded systems, but it is not necessary to have a perfectly open area to have a successful PV installation. For example, if the shading occurs predominantly in early or late in the day or in winter months when the sun's elevation is low, there is little irradiation and may only result in marginal losses. However large trees or buildings that will shade the PV array for large portions of the year need to be considered in more detail. Objects on the roof, such as chimneys or ventilation pipes, can cause much higher losses than simply the fractional area on which they shade, in which case MLPE could reduce shading losses by 10-35% and increase annual performance up to 6% [25,26].

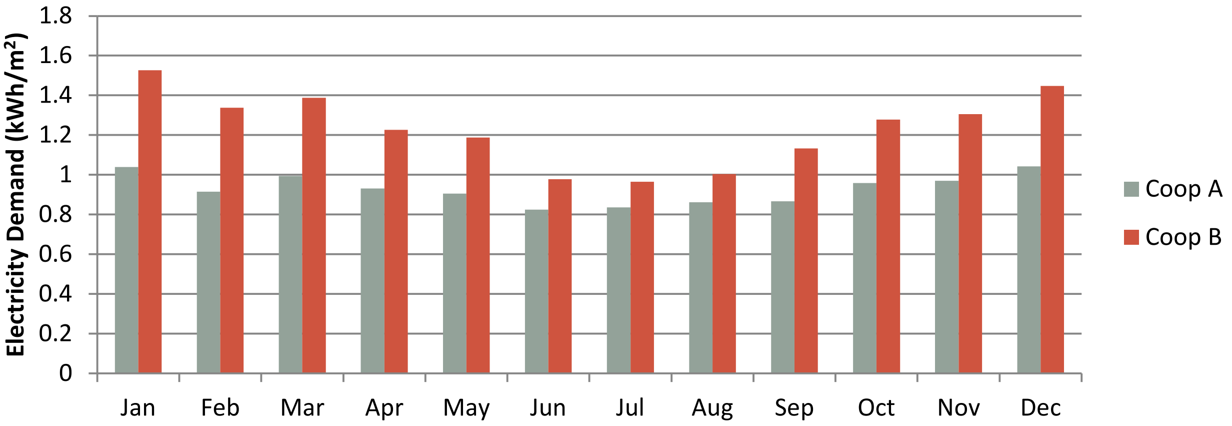
Other losses due to soiling or snow are typically not a significant issue in Sweden. Modules mounted on an inclination are cleaned with regular enough intervals by rain that dust, pollen, and bird wastes are washed away before significant build up. As shown in Figure 13, only 14% of production occurs during the winter months where snow cover is greatest. Previous studies in Ontario, Canada [27] and Munich, Germany [28] showed annual losses of 2-3% and 0.3-2.7%, respectively, suggesting that losses in Sweden would be similar or less due to the higher latitude. Only in regions with unusually high snowfall (i.e. several meters per year) do losses due to snow cover become significant (13-17% for tilted arrays) [29].

3.2 Electric Loads

Electrical demand in multi-family houses can be divided into two categories; communal and apartment. Communal loads (fastighetsel in Swedish) include exterior and stairwell lighting, laundry rooms, elevators, and the HVAC system. Apartment loads are the plug loads incurred in the residences. This division is useful because they are often metered separately, where the communal loads are on a single meter owned by the cooperative and the apartment loads are the responsibility of each individual apartment. To save on grid charges, some cooperatives purchase the electricity centrally and distribute/meter it internally. There are also cooperatives in which all of the utilities are included in the fee, however this is usually in connection with electric heating. Heating and hot water is supplied by district heating in approximately 80% of the area in all multi-family houses in Sweden [30], therefore the focus in this section will be on these types of buildings.

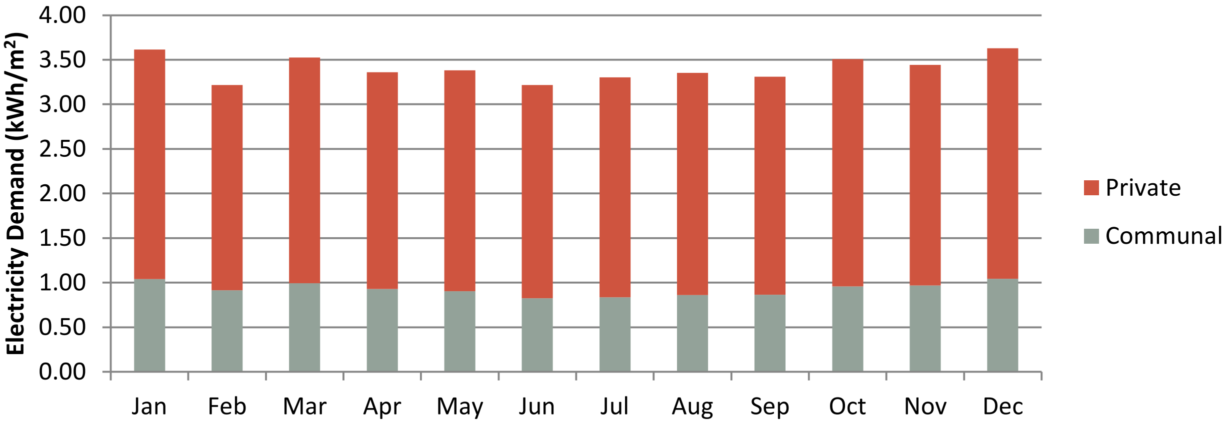
Measured communal electricity demand data from two cooperatives, labeled A and B, has been collected and their monthly usage values are shown in Figure 14. The differences between them are largely in the winter, which is dependent on the types of buildings (high vs. low houses) and the technologies uses (e.g. efficient equipment, auto-off timers, etc.). All of the cooperatives have a minimum load in the summer which is when PV production is greatest, making it difficult to have high fractions of solar PV relative to total demand without high amounts of overproduction.

Figure 14 - Monthly communal electricity demands for two cooperatives



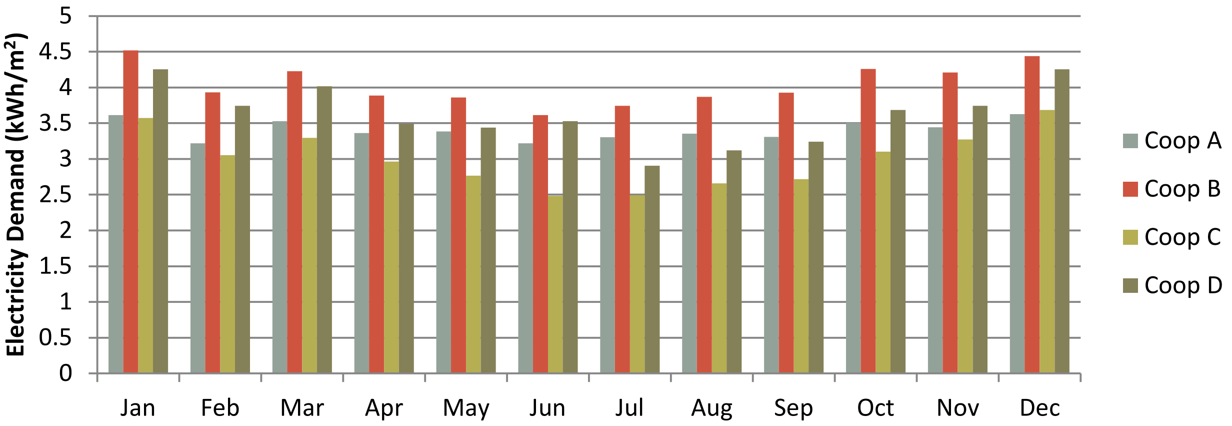
Apartment loads are generally much greater than communal. Focusing on Coop A, in Figure 15 private loads are now shown with communal loads. The apartment loads are not measured, but modeled using a stochastic load generator tool which uses high-resolution measurements from several hundred Swedish apartments as an input [31,32]. Across the entire cooperative, it can be seen that apartments demand nearly three times as much electricity as the communal loads. For specific buildings, the differences can be higher or lower depending on the presence of a laundry room.

Figure 15 - Monthly communal and private loads for Coop A



In addition to cooperatives A and B, two additional cooperatives provided load data but included both communal and apartment loads together. Figure 16 shows the monthly demand for all four, where A and B include a combination of measured+modeled data while C and D are all measured values. The general patterns between the measured/modeled and measured-only values agree, suggesting reasonably accurate values for the modeled private loads. There is a wide range of absolute demand values, which is not surprising given the wide range of energy usage technologies. The diversity between buildings means it is difficult to make sweeping conclusions about all cooperatives, but rather each one must determine what energy solutions are best for them. For all cases between the winter peak and summer low, there is approximately 10-30% less electricity demand.

Figure 16 - Monthly total loads for four cooperatives



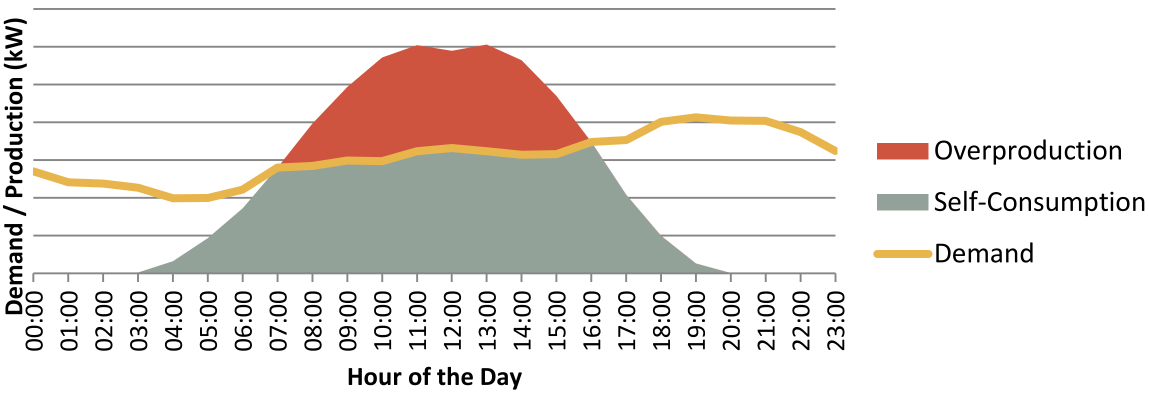
3.3 PV System Sizing

Unlike traditional electricity producers, prosumers need to consider the load of the building(s) and how it correlates with the generation of the PV. Optimizing economic outcomes are closely related to self-consumption, which is the PV generation used directly in the building. When there is more generation than demand, known as overproduction, the excess is sold to the grid. The ratio of self-consumed electricity over total generation in a year is known as the self-consumption rate.

Self-consumption is valued at the full retail price (not including fixed fees) which includes the electricity, network, taxes and subsidies. Overproduction is valued at the wholesale price of electricity only, plus a small amount for reduced grid losses. Currently in Sweden, the retail price is approximately three-four times greater than the unsubsidized[13] overproduction price, hence the motivation for higher self-consumption.

It has been estimated that the average annual self-consumption rate for Swedish PV systems is between 55%-72% [33], which similar to range shown in the case studies in Chapter 8. This section reviews the coordination between PV generation and building demand and the key factors that can affect self-consumption rates. Figure 17 is an example of PV production with load demand, with the production colored to highlight the difference between self-consumed and overproduced electricity.

Figure 17 - Example of self-consumption and overproduction of PV generation



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[13] There can also be additional subsidies outside the electricity-only market, which are discussed in more detail in Ch.6.

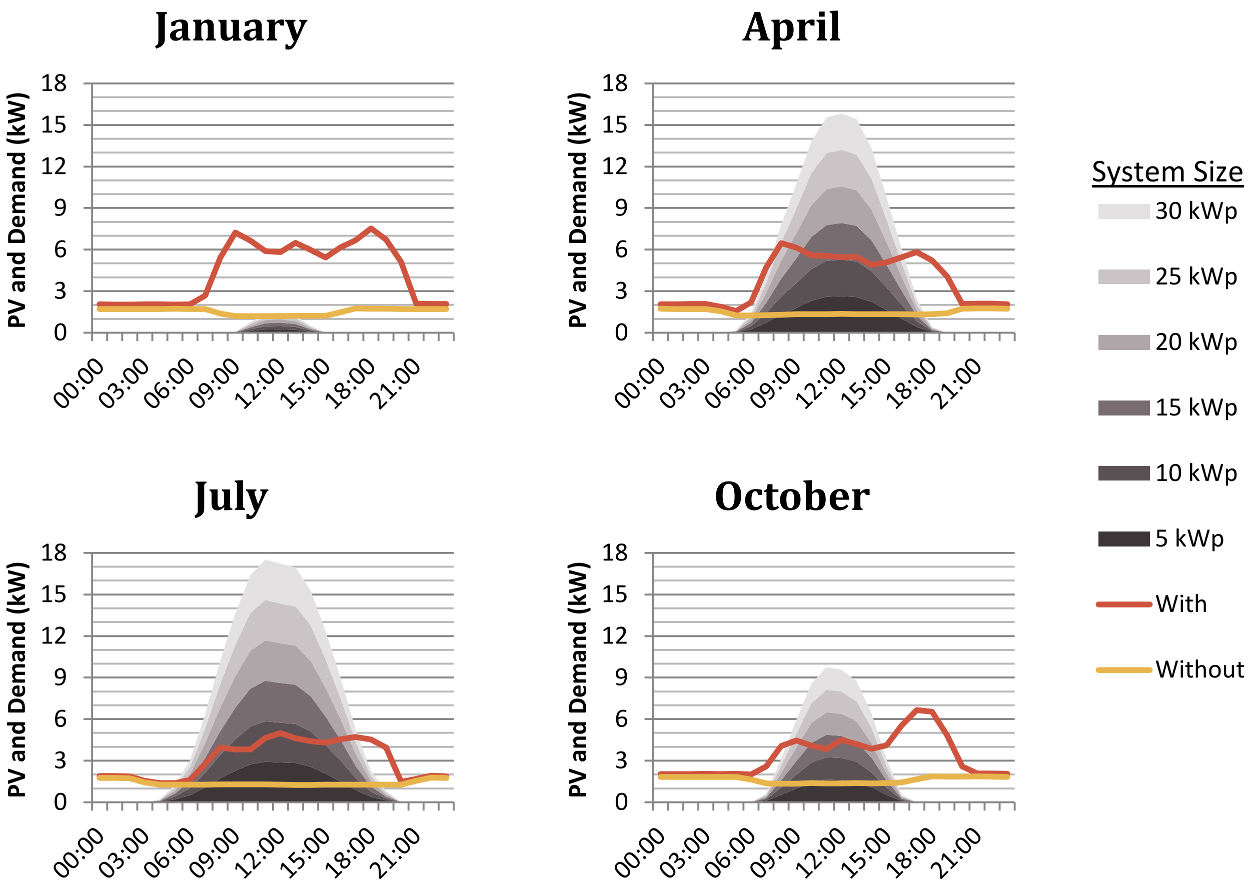
Sizing a PV system is a unique process for every building. It is difficult to derive a general rule given the unique load curve and production potential of each building, which ultimately determines the self-consumption. The examples in this section use measured load data from thirteen buildings, all of which were constructed during the 1960's and have a similar design. An example of practical system sizing is presented at the end of the section to connect the generic graphs to real world usage.

3.3.1 Sizing with Communal Loads

For a cooperative considering a PV purchase, the simplest arrangement is to keep the metering structure where the apartments are individually metered and the cooperative is responsible for communal loads. In this case, the PV system can only supply the communal load and the apartments are ignored. Additionally, each meter must be considered separately, which is often associated with a single building, meaning that cooperatives with multiple buildings must treat them as individual systems.

For a single building, the presence of a laundry facility will make the most significant impact on self-consumption. Laundry loads coordinate well with solar production since they are usually limited to the hours between 8:00 and 20:00. Figure 18 shows average daily production curves from a well oriented PV system (30° tilt facing due south) of various sizes in Gothenburg. It compares production to the load patterns for two similar buildings from Cooperative A; one with a laundry room and one without. It can be seen between the four seasons how the size of the PV system contributes to overproduction at various times of the year.

Figure 18 - Average daily PV production and demand for communal loads with or without laundry

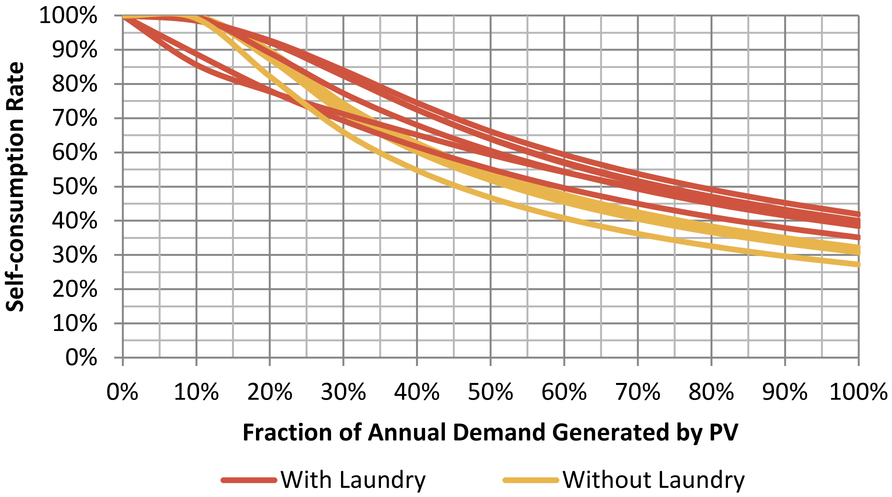


To appropriately size a PV system to the building load, annual values of production and self-consumption need to be considered. The example PV system here produces 970 kWh/kW$_p$ per year. The demand of the laundry room equipped building is 31,600 kWh/year and the building without is 13,100 kWh/year. To show how load and production profiles affect self-consumption, the annual self-consumption percentages for each example building as a function of fractional annual demand met by solar PV are plotted in Figure 19. The two buildings are similar until about 20% load generation, and above that the building with a laundry room has a 10% higher self-consumption rate. System size can be motivated by self-consumption rate, for example if a 60% self-consumption rate is targeted this translates to PV systems that generate 55% and 40% of the annual load for the buildings with and without laundry, respectively. This is equivalent to 17,380 kWh and 5240 kWh which at 970 kWh/kW$_p$ results in system sizes of 17.9 kW$_p$ and 5.4 kW$_p$.

Figure 19 - Example of self-consumption rates as a function of the annual demand from generation

To expand this concept beyond the two buildings in this example, all of the buildings in which measured communal loads were available have been plotted in Figure 20 and are colored according to the presence of a laundry room similar to Figure 19. Using the 60% self-consumption example, it can be seen that there is a range of demand fractions for each building type, ranging from 42%-60% for buildings with laundry and 35%-43% for those without.

Figure 20 - Self-consumption rates for ten buildings considering communal load

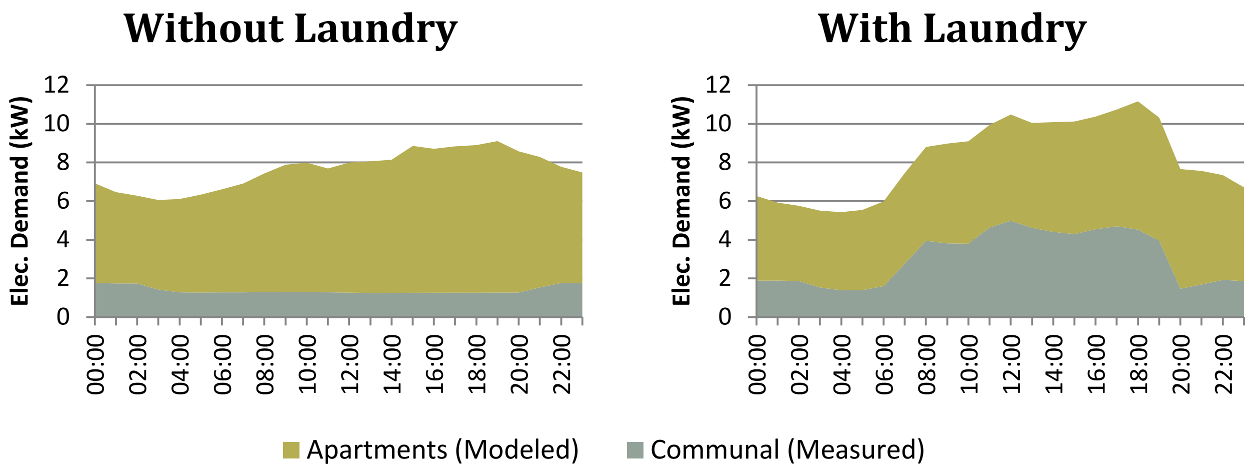


3.3.2 Sizing with Apartment Loads

For cooperatives with a high roof area relative to the floor area (i.e. having 1-3 floors) it can be interesting to include apartment loads as a way to increase the PV system size to utilize greater available roof space. This can be achieved by having a utility single meter on each building which includes both communal and apartment loads. To meet the EU directive on energy efficiency (2012/27/EU - Articles 9-11) and to maintain fairness between apartments, it is necessary to install replacement meters on each apartment which are then administered by the cooperative.[14]

As already mentioned, the loads in apartments are much greater than the communal loads. Figure 21 shows an example of hourly loads separated into communal and apartment during July for each of the buildings from Cooperative A presented in the previous section. Including the apartments, the annual demands become 78,200 kWh/year with laundry and 69,500 kWh/year without; an increase of 250% and 530%, respectively.

Figure 21 - Examples of average daily communal and apartment loads in July



The larger loads result in larger potential systems, and the revised shape of the load curves will have an effect on the self-consumption rates as shown in Figure 22. Given the already high correlation between the load profile and PV production, the self-consumption rate for the building with laundry was effected relatively little. The rate did however decrease for demand fractions higher than 30%. The building without laundry increases self-consumption by nearly five percentage points across nearly the entire range. If a 60% self-consumption target is maintained, the resultant load fractions are 52% and 48% for the buildings without and with laundry, respectively, which results in system sizes of 41.9 kW_p and 34.4 kW_p. A 40 kW_p system would be approximately 260 m^2, which is much larger than the roof of a typical single building. Therefore, the inclusion of apartment loads could be used as a technique for increasing self-consumption rates which can potentially improve profitability [34]. Details of the costs and benefits of including apartment loads are discussed in detail in Chapter 6.

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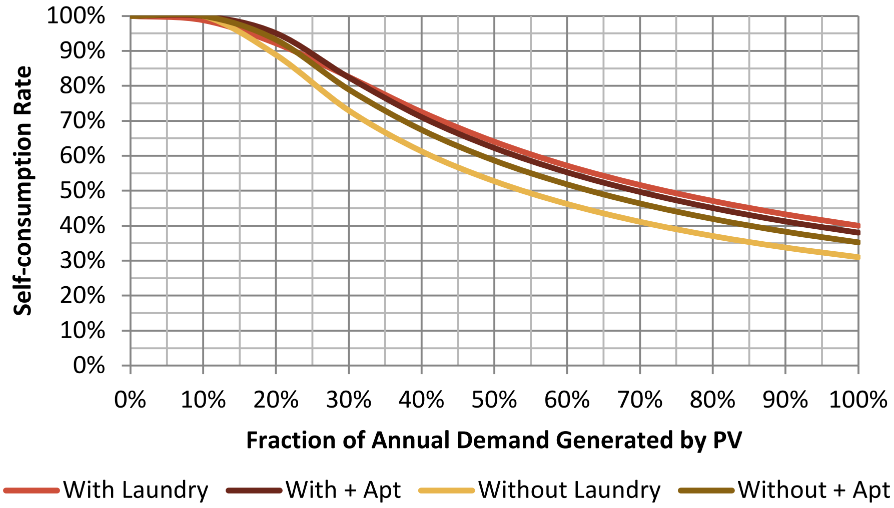
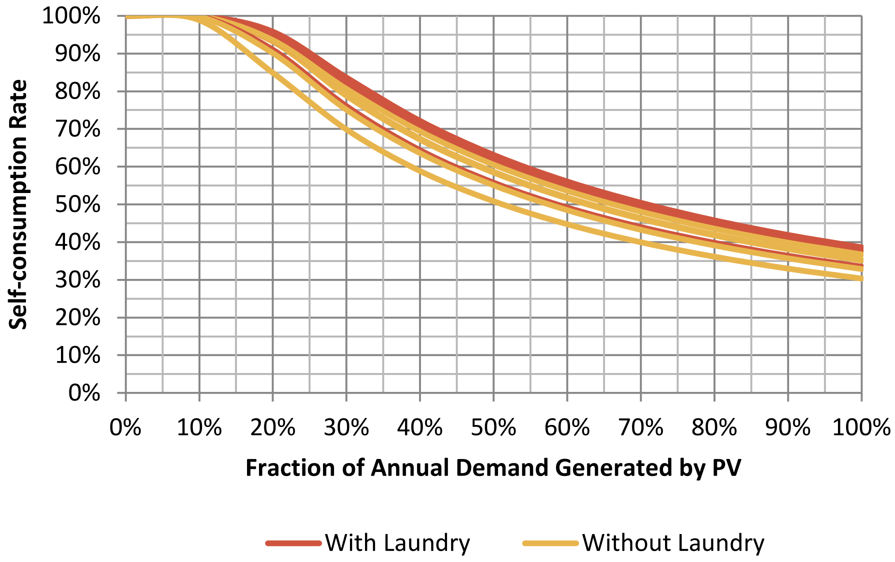
[14] At the time of writing, multi-family houses with electric heat were exempt from individual metering.

Figure 22 - Example of self-consumption rate curves considering total building load



Expanding the scope again to more buildings, the thirteen buildings for which hourly load values were available have been plotted in Figure 23. This includes the ten buildings from Figure 20 which then have modeled apartment loads added. The result is a more consistent curve shape and smaller ranges of demand fractions for buildings with laundry. Using the 60% self-consumption example again, the range for buildings with laundry is now 44%-55% with the majority being between 50%-55%. For buildings without laundry the range is now 38%-50%.

Figure 23 - Self-consumption rate curves for thirteen buildings considering total building load

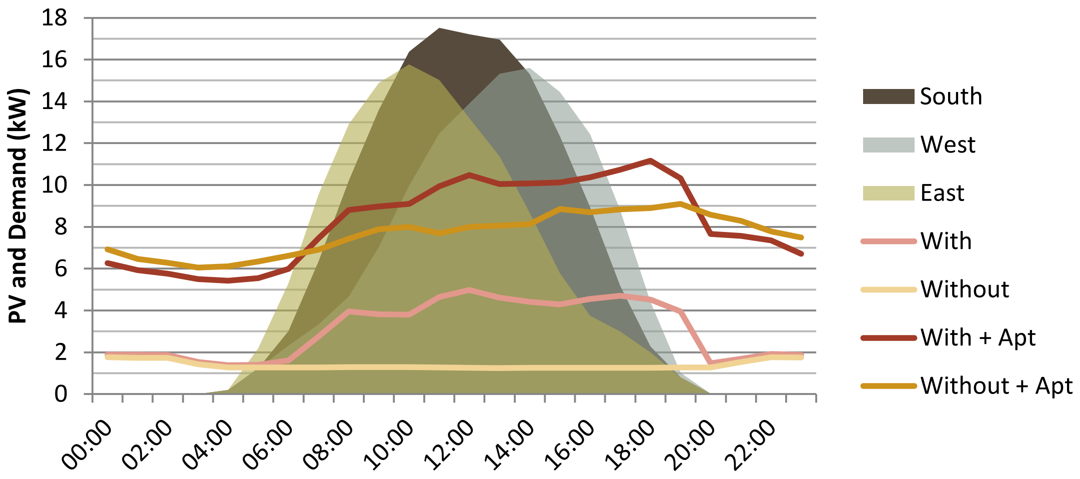


3.3.3 Effects of Orientation on Self-Consumption

In the previous two sections, the PV system under consideration was nearly ideally oriented for maximum annual production. Most houses will not have such an orientation, therefore it is necessary to consider the effects of alternate orientations on self-consumption. This is done with the same two building examples used in the previous sections which are now compared to PV systems with the same 30° tilt but facing due east and west.

It is well known that residential building loads tend to occur later in the day relative to the actual daytime hours. This is exemplified in Figure 24, where the average daily production of a 30 kW_p PV system facing south, west, and east in July is compared to the demand loads from the example buildings from Cooperative A. It can be seen that the western facing system is shifted to have its peak 2-3 hours later in the day than the southern facing system, which is more closely correlated with the load curves. It should also be noted that the eastern facing system produces 770 kWh/kW_p and the western produces 750 kWh/kW_p per year, approximately 22% less than the southern facing system.

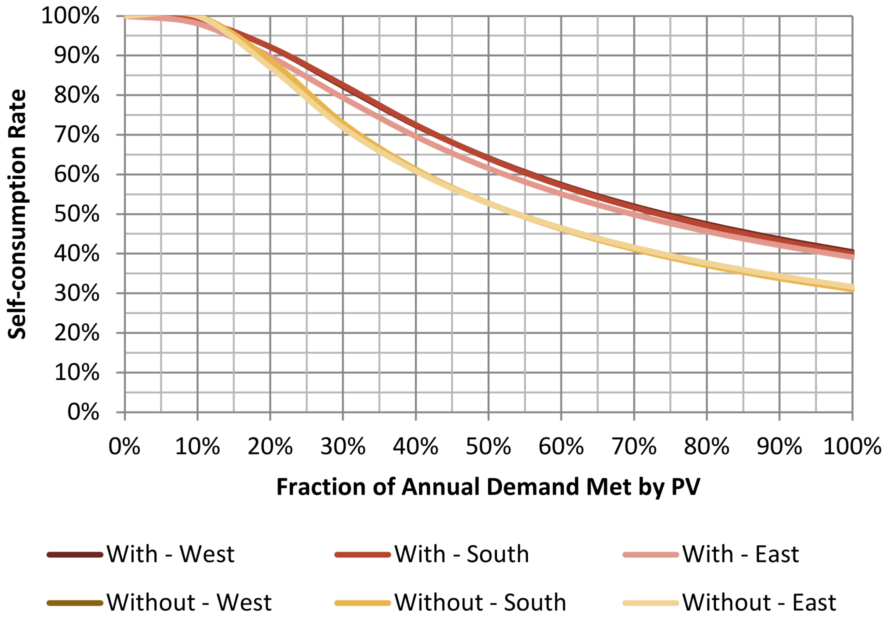
Figure 24 - Average daily production profiles of a 30 kW_p system in July facing south, west, and east



When considering annual values, however, orientation has relatively little effect on the self-consumption rate, which is consistent with previous work [35]. Figure 25 lists the self-consumption curves for both types of buildings (without apartments) and the three PV array orientations. In the building without laundry there is nearly no change with orientation, which is not surprising given the relatively flat demand curve. However in the building with laundry, the western facing system had almost no change in self-consumption while the eastern facing system reduced by about 2 percentage points. These results still support the credence that PV systems should be prioritized in the order of south, west, and lastly east, but the effect is relatively small.

The more critical issue with orientation is that the non-southern facing systems produce significantly less energy annually. For example, the 17.9 kW_p southern facing PV system which generates 55% of the laundry equipped building's load must become 23.2 kW_p if facing west to provide the same amount of energy. However, the 17.9 kW_p system facing west would generate 42% of the annual demand, resulting in a self-consumption rate of 70%. An increase of self-consumption helps to offset the economic losses of the lower production rate, which is covered in more detail in Chapter 6.

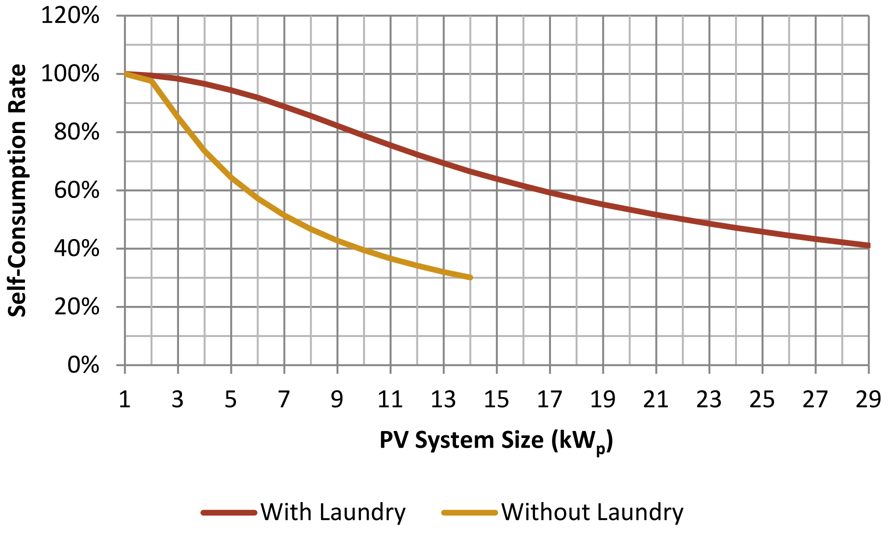
Figure 25 - Self-consumption curves considering east and west PV system orientations



3.3.4 Practical Example

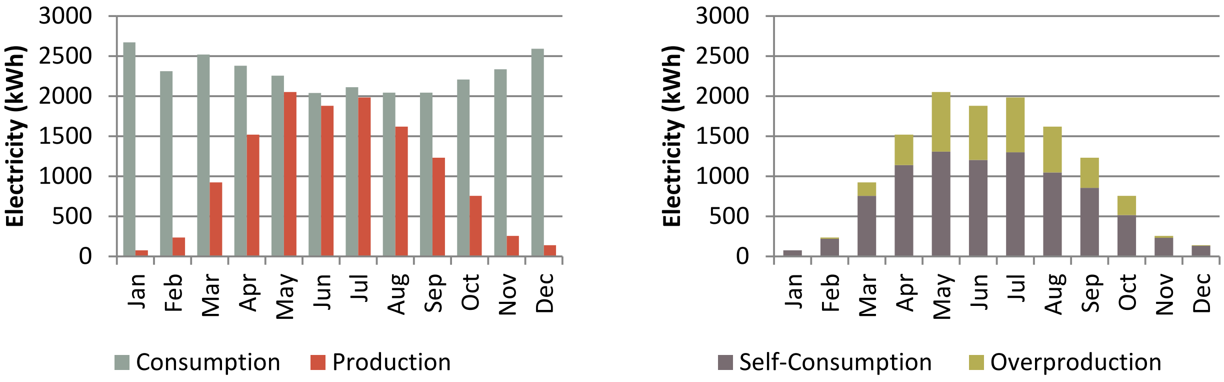
In a real world case, a potential system owner is likely to be considering how large a system to place on a particular building. The charts above make it possible to determine self-consumption for any building given enough information, however this also makes it difficult to interpret. Therefore using two sample buildings from Coop A, the self-consumption rates are presented here in Figure 26 considering PV system size rather than the percentage of building load coverage. The total demand of the building with a laundry room is 27.5 MWh/year, while the building without laundry is similar in area and has an annual load of 13.2 MWh. The PV system is facing due south at a 30° tilt with no shading and is located in Gothenburg.

Figure 26 - Example of self-consumption with regards to system size



The results are shown for each building up until the point where the PV system reaches 100% of the annual demand. For the laundry equipped building the curve is nearly linear. In the non-laundry building, moving from small to large systems show a rapid decline in self-consumption at small sizes and gradually reduces in slope as they get larger. A closer look at monthly production, shown in Figure 27, reveals how production, demand, and self-consumption compare over the year. The graphs represent the laundry equipped building and a 13 kW$_p$ system, which covers approximate 45% of annual demand with nearly equal production and demand in the summer months. It also results in nearly 70% of production being self-consumed, with considerably more overproduction during summer than winter. This example will be revisited again in Chapter 6 to demonstrate the economic considerations of system sizing with regards to self-consumption.

Figure 27 - Example comparison of demand, production, and self-consumption



3.4 Complementary Technologies

All of the instances presented thus far have considered building loads as they currently are, however a PV installation introduces an opportunity to modify the building energy system in response to the generation profile. The objective of these technologies is to increase self-consumption and reduce the negative pressure on pricing that can occur when large amounts of non-dispatchable renewables are dumped on to the grid. For example, in Germany, where wind and solar now account for 16% of the annual electricity supply, on average wholesale prices have declined steadily since 2011 and there are increasingly regular hours with negative prices [36]. It has also been shown that the value of PV generation in Germany would be eroded to half of today's value if annual PV supply reached 15% [37]. Currently Sweden has under 0.1% of annual generation from solar [38], however if it's to play a significant role towards the goal of a 100% renewable energy system then energy system integration solutions will be necessary.

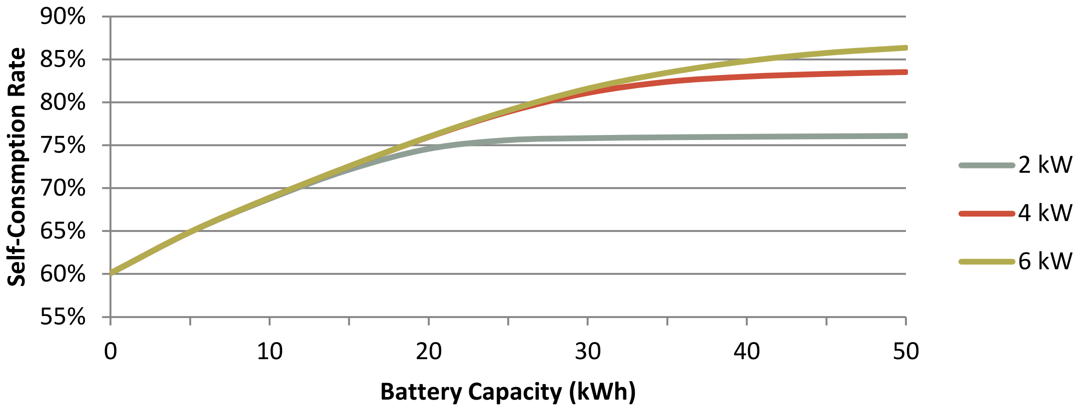
In this section, three relatively mature technologies available to the consumer market are reviewed; stationary batteries, electric vehicles, and electric heating. These are some of the most frequently studied technologies [39] and could be considered the most relevant for prosumers in the near term; however other technologies, like hydrogen, may also become interesting in the coming years.

3.4.1 Stationary Batteries

During 2015, stationary batteries designed to work with grid-connected solar PV systems became a consistent talking point for analysts and the media as a viable option for homeowners. This was due in part by the introduction of the Tesla Powerwall, a 7 kWh lithium-ion battery pack with a cost of approximately €3000 (excluding VAT and installation). Driven by the development of electric vehicles, battery costs have dropped on average 14% per year between 2007 and 2014 with expectations of continued cost reductions associated with increased production and economics of scale [40]. These developments make it interesting to determine what effect batteries can have on PV systems in Swedish cooperative housing.

The example considered here is the building with a laundry room from Cooperative A and a PV system size of 18 kW_p, facing due south with a 30° tilt. Using the hourly modeled production and hourly measured demand values, this system is expected to produce 55% of the annual demand and with 60% of the generation self-consumed, which is typical for existing Swedish installations [41]. Figure 28 shows how self-consumption is effected as a function of increased battery capacity added to the system. The batteries have peak power ratings of 2, 4, and 6 kW, and are modeled after lithium-ion types with state of charge/discharge limits of 95%/20% and a round trip efficiency of 90%. The charge controller is designed for daily cycling with PV; it will only charge from PV overproduction and will discharge as much as possible to meet any load not met by PV.

Figure 28 - Self-consumption rates relative to normalized battery capacity and power



The results show a constantly reduced marginal increase of self-consumption with increasing battery capacity. It can also be seen where the battery's peak charging rates begin to have an effect, at approximately 15 kWh and 25 kWh for 2 kW and 4 kW, respectively. The non-linear shape of the curves is common of storage systems, where it is exponentially difficult to cover increasingly extreme events. To absorb the high summertime production and achieve 100% self-consumption, the battery would require a peak charging rate of 13 kW and a 2300 kWh capacity.

3.4.2 Electric Vehicles

The electricity sector in Sweden uses very little fossil fuel while the transport sector is nearly entirely fossil fueled, providing a strong motivation for electrified transportation towards meeting climate goals. One challenge with combining electric vehicles (EV)s with PV in a residential setting is that the vehicles are typically not available when the PV has overproduction. A study considering Swedish single family houses using an EV as the primary transport mode showed an increase of self-consumption of 3 to 6.5 percentage points with the inclusion of EVs with 35 kWh batteries [6]. While the charging strategy for EVs differs as compared to stationary batteries, the negative correlation of EVs and PV makes self-consumption improvements considerably less than the 33 percentage point increase made possible with the 35 kWh stationary battery shown above.

One possible solution to for EVs unique to cooperatives is a car sharing pool. For cooperatives in or near urban centers, daily commuting is often done using public transport, while personal car use is reserved for evenings and weekends. If the cooperative had a small fleet of EVs shared by its owners and they were used similar to how their cars are used today, it could increase the battery's availability for PV storage. This concept is not treated in detail here, but is suggest for future work.

3.4.3 Electric Heating

Energy and electricity demand in Sweden peaks during the winter months primarily due to the large demand for space heating. The focus of this report is on cooperatives, which are most commonly connected to district heating for space heating and hot water. Prices for district heating vary significantly by region, city, and time of year, however the benchmark price for cooperatives in 2014 is 0.9 SEK/kWh [42]. This is significantly higher than the wholesale price for electricity, meaning it may be interesting to use overproduction to make heat rather than sell to the network.

Usage in individual apartments varies widely, but on average approximately 80 liters of hot water are used per apartment per day [43], which requires approximately 4.3 kWh. In many buildings with 10 apartments, the available roof space would be possible to have a PV system where overproduction during summertime could be matched with hot water demand at 30-50 kWh/day. Hot water usage is dominated by a peak in the morning hours and a smaller peak the evening, therefore storage will be necessary [44]. This concept was considered in a single family house in Sweden using a ground source heat pump (GSHP) and was found to be a lower-cost option than batteries for increasing self-consumption [5]. One drawback in cooperatives is that rates are often based on volume, meaning the reduced demand for district heating could result in higher rates which reduce or eliminate savings.

In cooperatives using GSHPs, another option could be the storage of heat in the ground. Borehole thermal energy storage (BTES) has the advantage of shifting summertime oversupply to help meet the peak wintertime demand. The concept has been studied for single family houses, where it was determined to be unnecessary for well-designed boreholes and more efficiently used directly in the house [45]. In multi-borehole systems, such as those appropriate for larger cooperatives, the geometry of the boreholes makes seasonal storage more efficient. A 144 borehole community system in Alberta, Canada, covers nearly 100% of its heating needs with solar thermal collectors and a BTES, however the high ground temperatures (40-65°C) result in over 60% of the heat being lost [46]. This corresponds with experience of a pilot project in a suburb outside of Stockholm [47]. A computer simulation using the Canadian system but with low ground temperatures (10-15°C) and a GSHP indicates that round trip efficiencies could be increased to 85%, which is similar to batteries [48]. The concept has been used in Switzerland for very-low energy buildings with success [49,50] and will be explored further for Sweden in an Effsys Expand project.

3.4.4 Hydrogen

Because of hydrogen's complicated requirements for operation, research is often done focusing on commercial or industrial projects rather than residential [51]. Some recent studies have considered systems in residential buildings [52,53], however there are no commercial products known by the authors. During the 2000's, Honda Motor Company was developing a home-based electrolyzer to work with their fuel cell vehicle. However there have been no new announcements since 2007 and the website has not been updated since 2013 [54]. The relatively high cost and low efficiency indicate more research is necessary before it can compete with other technologies [55].

4 Practical Aspects of Building Application

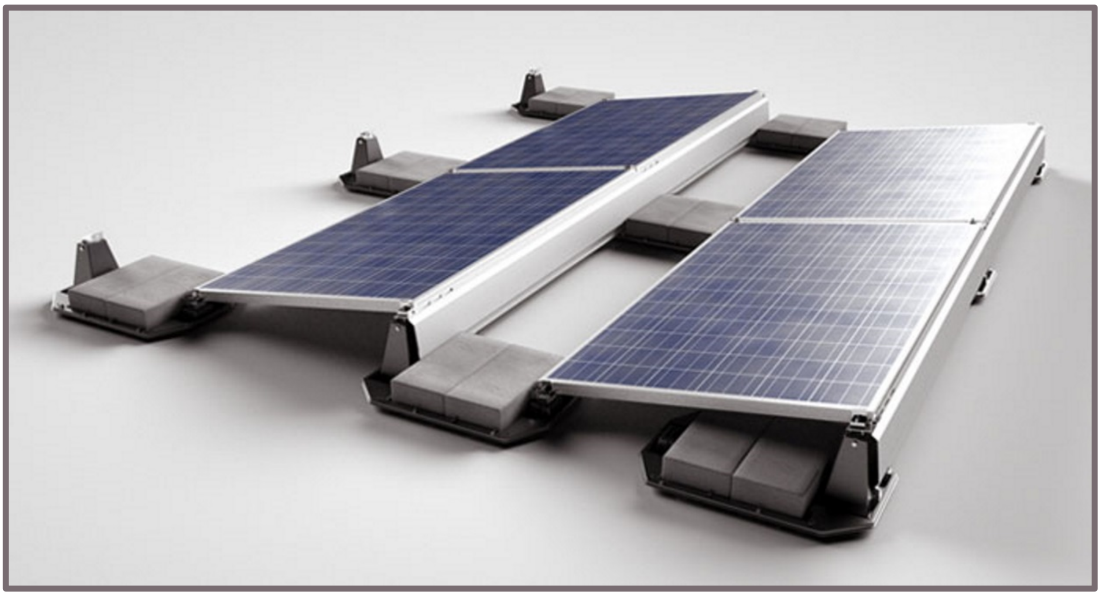
The addition of PV modules onto or into the building envelope requires special consideration with regards to mounting and maintenance to preserve the integrity of the building. Like most building materials, there are many solutions that when used properly can be as reliable as the original roof before the modules were installed. Installers and building entrepreneurs (contractors) are the experts on building application due to their practical field experience; therefore several interviews have been conducted with technicians and CEOs of solar installation companies, building maintenance managers, and construction firms to gain insight into the best practices of PV installation on buildings. A list of the interviewees is available in Appendix G.

4.1 Flat Roofs

It was previously shown in Figure 12 that a horizontal array produces 15% to 25% less electricity annually than a southern facing tilted array. Therefore racking for flat roofs tends to be moderately tilted, usually between 10° and 20°. Lower tilt angles are used because they are less susceptible to wind, and the reduced shading from one row to the next allows more modules to be placed on the roof. There are three mounting options; ballasted, fixed, and hybrid.

In a ballasted system, the racks are placed directly on the roof, linked together, and then weighted down to prevent displacement by the wind as shown in Figure 29. Depending on the rack design, ballasting can be done with concrete blocks, sand, or water. This method has the benefit of avoiding penetrating the roof's membrane, which reduces risks of leakage and is generally cheaper than fixing. Care does need to be taken to ensure the roof surface is protected from abrasion in the event the modules do move so that holes are not worn through the membrane. This can be solved with an extra layer of roofing material (e.g. asphalt paper or felt) under the racking. It is also critical that the load rating of roof structure is known and/or tested to ensure the additional weight of the panels and ballast can be handled in addition to the snow load.

Figure 29 - Example of a concrete ballasted mounting system[15]



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[15] Photo source: http://www.solarpanelsplus.com/products/PV-flat-roof-ground/

A fixed mounting will penetrate the roof membrane and tie directly into the building structure. This may be necessary on roofs that cannot handle the weight of ballasting or experience unusually high wind loads, but come with an increased risk of leaking. An alternative to penetrating the membrane while maintaining the benefits of fixing are called lifelines. Lifelines are perforated steel plates that are approximately 400 mm squared with a threaded bolt standing in the center. The plate is heat welded to the membrane and then covered with another layer or roofing material approximately 800mm x 1200mm which is heat welded to the plate and original roof. This process is shown in Figure 30. The bolt passes through a hole in the upper layer and can be used to fix a PV rack. Swedish standards are that a lifeline should be capable of holding a 100kg load that has fallen 2.5m. Lifelines are designed as safety connection points for roof workers in the event of falling, so they may not last the many years of low, repeated loads expected with a PV array.

Figure 30 - Installation of a Lifeline roof connection[16]

4.2 Pitched Roofs

Pitched, or sloped roofs have the benefit of already being tilted, therefore the PV array can be mounted parallel with the surface. Arrays are typically mounted as close to the ridge as possible since higher locations are less susceptible to shading. Standard racking consists of feet which are mounted to the roof joists and rails that sit on top of the feet which the modules are then fixed to. On steep roofs or if a high snow load is expected, both horizontal and vertical rails must be used. There are mounting solutions for every type of roofing material, and the three most common types to Sweden are reviewed here; tile, standing seam, and corrugated steel.

There are many items which are commonly fixed to tile roofs (e.g. fire ladders, snow fences, etc.) and PV racking is functionally the same. A chicaned bracket is fixed to the roof under the tile, and then protrudes out from the end and above the next lower tile, as shown in Figure 31. Since the roof surface under the tile is the waterproof layer, it is important to use rubber grommets around the screws fixing the bracket. To reduce the risk of breakage, care should also be taken such that the portion of the bracket extending out from under the tile does not rest or apply force to the lower tile.

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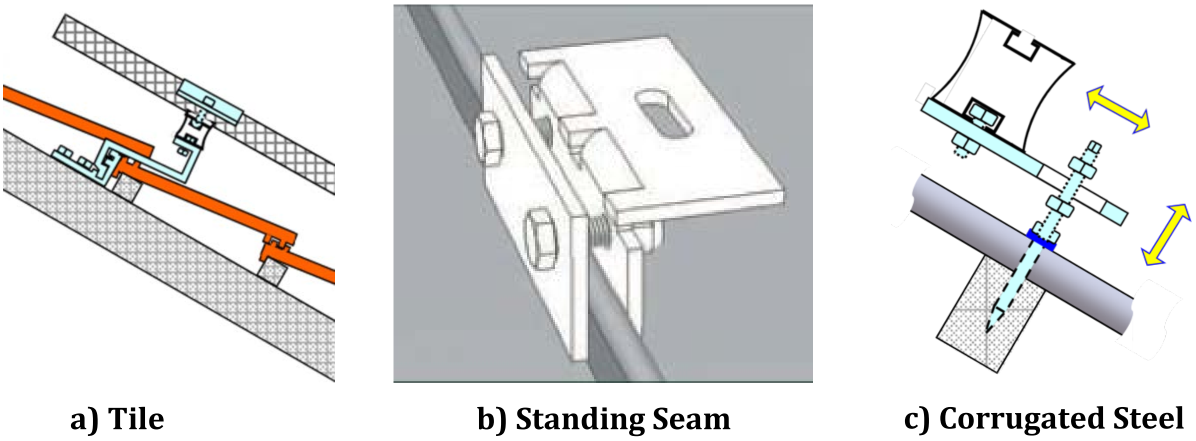
[16] Photo source: www.cwlundberg.se via Takguide för infästning av solceller, Paradisenergi

Figure 31 - Common PV racking mounts for pitched roofs[17]


a) Tile

b) Standing Seam

c) Corrugated Steel

Standing seam steel roofs are an excellent match with PV because the seams act like built in mounting points. As shown in Figure 31, small brackets can be clamped onto the seam without penetrating the roof or the seam, making the process fast, low cost, and with minimal leakage risk. Rails are then mounted on the brackets as in any other system. Corrugated steel roofs already have a system for penetrating the roof, so mounting PV racking is no different. Like the tile roof, screws are simply installed with a rubber grommet under the head to create a watertight seal. The screws may need to be longer than those used for the roof due to the higher loads.

4.3 Other Considerations

When designing a PV system, it should be known what snow and wind loads can be expected at the specific roof. Every module is load rated and should be listed on the specification sheet. Load calculations should be done according to Eurokod regulations[18].

The dimensions and surrounds of a building can dictate how the roof is accessed for installation. For example, low roofs with plenty of open space will allow the use of scaffolding. However, high roofs or buildings in dense, urban locations may need special consideration, like the use of a small crane, elevator, or sky lift. It is also important to note that PV modules cannot be walked on; therefore care should be taken during the design and planning phases that the array does not interfere with other equipment on the roof that requires access.

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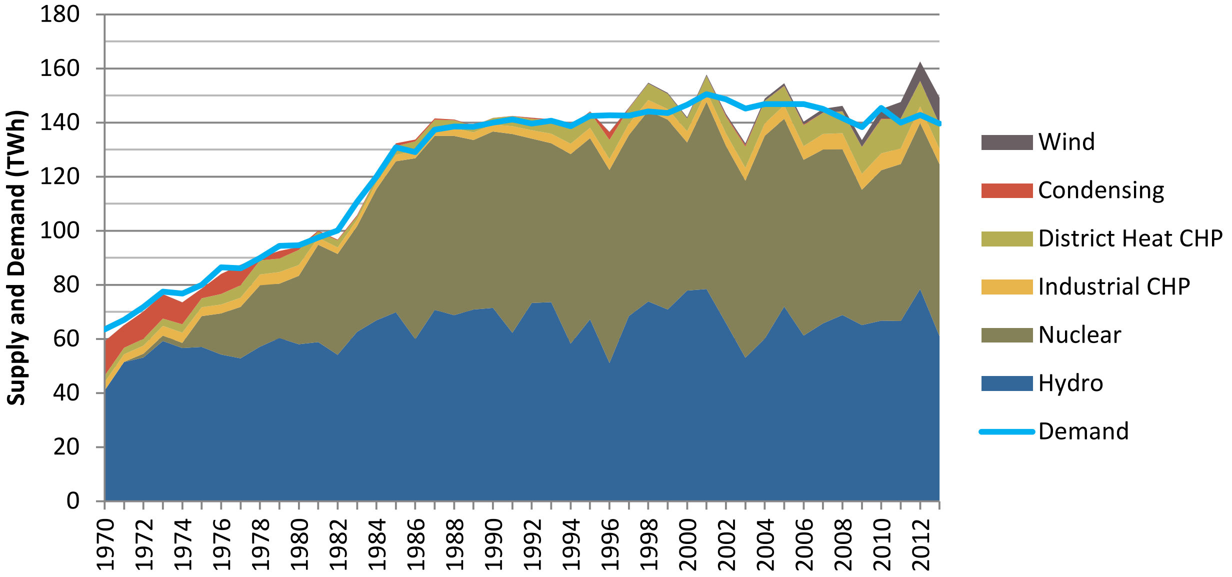
[17] Photo sources: Mikael Kaack, Mapab montageanvisning, Takguide för infästning av solceller, Paradisenergi

[18] Methodologies available at Teknikhandboken.se (In Swedish)

5 Swedish Electricity Markets and Policy

The electricity system in Sweden is remarkable in that it provides energy with a relatively low environmental impact and low cost. Electricity is supplied by two primary sources, hydro and nuclear, and is supported largely by biomass fired co-heat and power (CHP) plants and increasingly wind power [38]. Demand for electricity increased sharply in the 1970's and 80's with the transition from oil based heating to electric, but has remained nearly constant since 1990. The supply and demand for electricity in Sweden is shown in Figure 32.

Figure 32 - Electricity supply by source and demand in Sweden, 1970-2013 [38]



In 2009, the government adopted comprehensive energy and climate strategies[19] towards the elimination of fossil fuels and decarbonization [56]. During the same year, the planned nuclear phase out was annulled and reactors were given permission to extend lifetimes or rebuild on existing sites. However in early 2015, motivated by low market prices and new taxes, operators of two facilities announced that four of the ten reactors would be closed earlier than expected [57]. Then in the fall of 2015 leading up to the COP21 climate conference, the government used the 2016 budget[20] to announce a new objective to reach a 100% renewable energy system by 2050. Long-term targets aside, electricity is still traded in a largely deregulated market. This means prosumers need to be aware of the retail and wholesale market conditions, now and in the future, more so in Sweden than in other countries.

5.1 Wholesale Electricity Market

The Swedish wholesale electricity market is part of the greater Nordic market, known as Nord Pool Spot, and has bidding areas in nine countries in Northern Europe [58]. Nord Pool Spot is a deregulated market, founded in 1991 in Norway and joined by Sweden in 1996, and is considered one of the more successful deregulations worldwide. This is largely due to the simple structure, high fraction of flexible hydro power, the high number of participants (over 380) which reduces market

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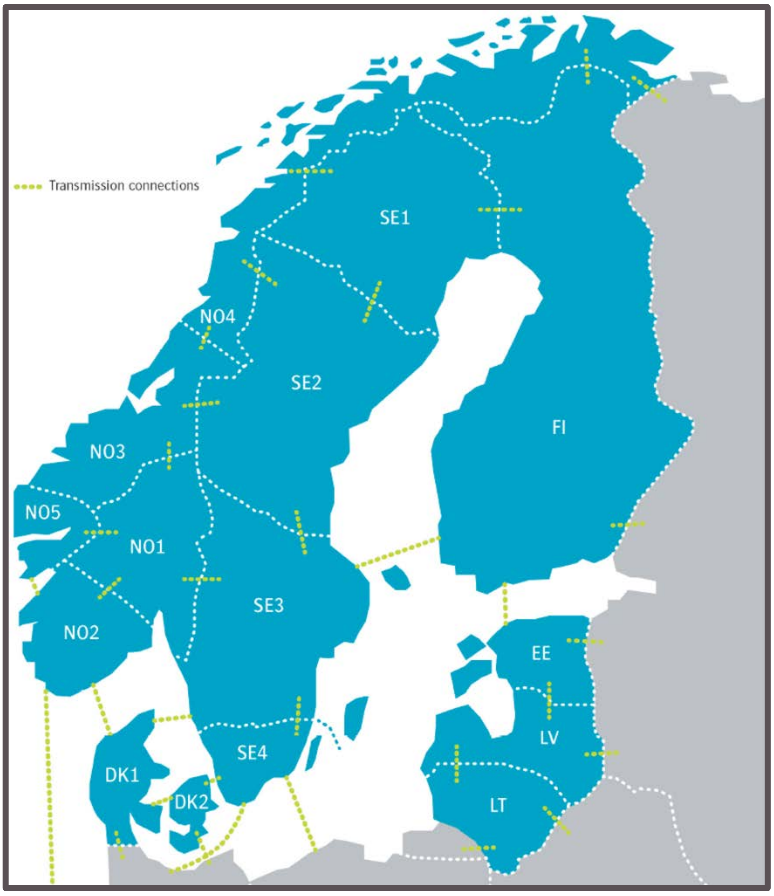
[19] Government proposals 2008/09:162 and 2008/09:163 titled "An integrated climate and energy policy" (In Swedish)

[20] Government proposal 2015/6:1 titled "Budget proposal for 2016" (In Swedish)

power, transparency, and the strong political and industrial support for the system [59,60]. There are four bidding areas in Sweden, as shown in Figure 33, however prices are rarely different between them [61].

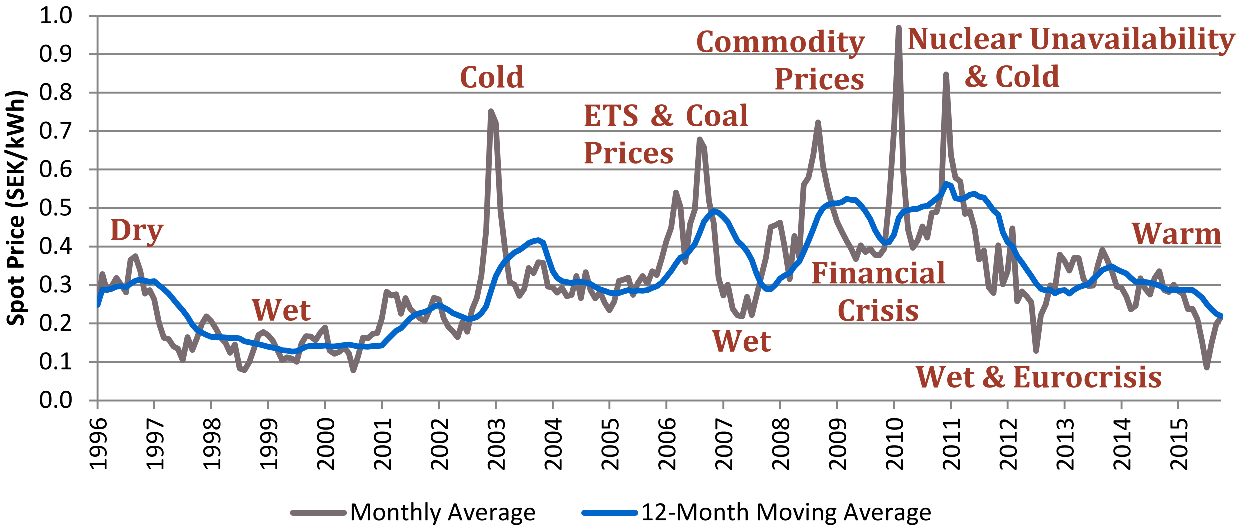
Figure 33 - Nord Pool Spot bidding areas in the Nordic and Baltic regions [61]



The majority of trading happens in the day-ahead, hourly spot market (Elspot), however there are two other markets; intra-day (Elbas) and futures contracts (Eltermin). Intra-day trading occurs up to one hour ahead of delivery, and is used for unexpected changes in supply or demand. This market is growing in significance as the installed capacity of intermittent wind power has grown. Futures contracts are handled in the financial market (NASDAQ Commodities) and can be purchased a few days up to ten years in advance. The focus of this report will be on the spot market since nearly 90% of all electricity produced in the Nordic Region is traded there and it is the primary driver of wholesale prices for prosumers [62].

Electricity is a unique good in that it is difficult to store, meaning a near-perfect balance of supply and demand must be met in order to maintain the system. Additionally, the marginal cost of supply increases exponentially once the hydro and nuclear power capacity has been utilized. This can cause dramatic changes in prices which are reflected in the monthly averages shown in Figure 34. At an hourly resolution, prices can jump much more dramatically, reaching over one SEK/kWh at times and becoming nearly zero at others. Price formations are complex and have many factors, however the primary driver in Sweden is climate [62,63]. This is due to the high fractions of hydro production and electric heating affected by precipitation and temperature, respectively. The driving force of specific price trends are also identified in Figure 34, adapted from industry group Swedenergy [64].

Figure 34 - Monthly and moving average Nord Pool Spot prices and trend drivers [64,65]

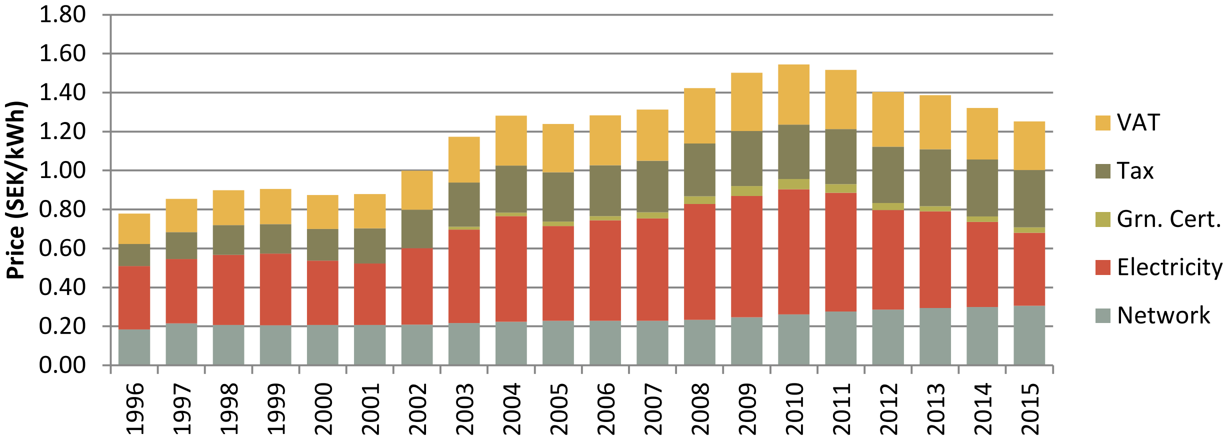


5.2 Retail Electricity Market

The retail electricity market in Sweden is also deregulated, where retailers are free to supply customers anywhere in the country with no specific laws on how contracts should be formatted. In total there are over 120 retailers, however the three largest control 43% of the contracts [61]. The most popular contract type is floating price, where the price tracks with Nord Pool Spot and is adjusted monthly. Other contract types include one, two, and three year fixed price, as well as hourly time-of-day pricing that follows the Nord Pool Spot day-ahead market. Because of the strong competition, retailers are typically only able to earn a 0.05 SEK margin on each kilowatt-hour [66].

Retail prices are composed of five main cost components; network, electricity, green certificates, tax, and VAT. Because of the wide variety of contract types, where there are discounts for large volumes, fixed fees vary, and electricity prices move over the year, it is difficult to identify a single representative price. Figure 35 shows typical prices for large consumers (20 MWh/year) since 1996, and is broken into cost components [38,63]. The largest share of price is taxes, which is a combination of the national electricity tax and VAT. The electricity tax has grown at an average rate of 3% per year.

Figure 35 - Retail electricity prices for large residential consumers (20 MWh/yr), 1996-2015 [38,63]

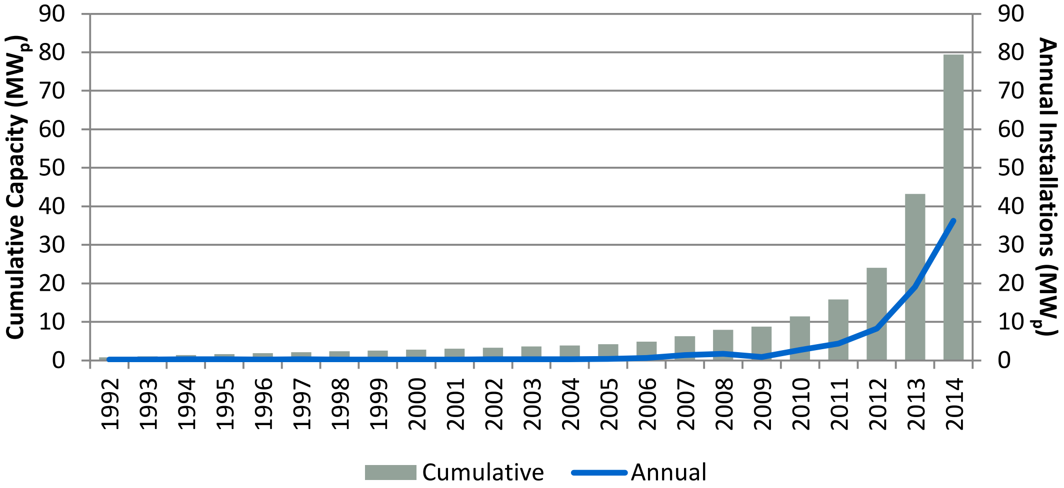


Unlike the energy markets, distribution networks are considered natural monopolies and have remained regulated. Cost structures include fixed and variable portions related to the fuse size (i.e. maximum power demand) and energy used, respectively. For large consumers, such as a cooperative, the fixed fee is usually about the same total amount as the variable portion [61]. Apartments typically have the smallest fuses, and therefore have much higher fixed fees which lead to per kWh costs being two or three times higher than a cooperative. Since maintaining a grid connection is necessary after the installation of a PV system, only the variable portion of the network cost should be considered as being displaced by self-consumption. Network prices overall have increased 1.5%/year on average since 1996, and with increased investment in transmission expected to handle increased renewables, connectivity to Europe, and replacement of existing infrastructure, the growth rate can be expected to remain the same or even increase [61].

5.3 PV Market

Relative to many other countries in Europe, the Swedish market for solar PV is quite small. In 2014, 36.2 MW_p were installed for a cumulative total of nearly 80 MW_p [4]. Traditionally only an off-grid market, Figure 36 shows installations rates have increased rapidly in recent years dominated largely by grid-connected systems. More specifically, prosumers are the largest segment of the market, making up over 90% of the installations by capacity.

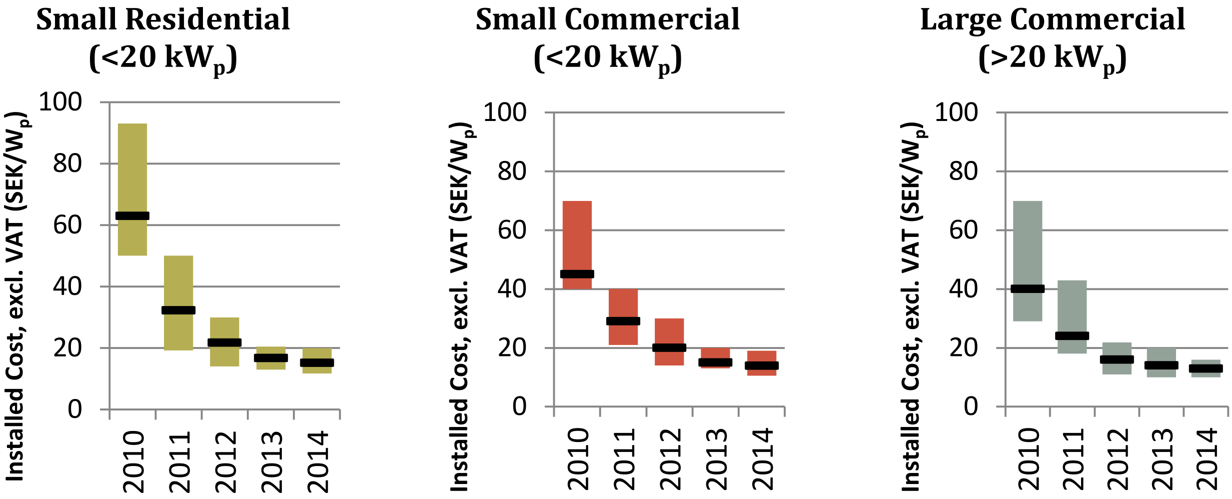
Figure 36 - Annual and cumulative PV installations in Sweden [4]



The primary driver for installation growth has been the rapidly declining costs. The rapid expansion of manufacturing in China has driven PV module costs down by 80% since 2008 [67]. This caused a significant oversupply in the market which is now stabilizing, therefore module prices are expected to remain relatively stable in the short term but in the medium term continue to decline. Inverters have also experienced price declines at a similar learning rate as modules; however the changes have been more consistent.

The total installation cost for PV systems in Sweden has declined 30-75% since 2010 depending on type [4]. Figure 37 lists the range of typical installation costs reported by installers (excluding VAT), with the average marked with a black bar. Assuming cooperatives are more similar to commercial than small residential installations, a total installation cost of approximately 13-14 SEK/W_p can be expected. Equipment (e.g. modules, inverters, racking, etc.) makes up approximately 50% of the total cost, while soft costs (e.g. installation, engineering, permitting, etc.) are 30% and VAT 20%. The installation cost can vary significantly from the modules and inverters selected, as there is a wide range of quality and performance available.

Figure 37 - High, low, and average installation costs for PV systems in Sweden by type [4]



5.4 Public Policy for PV

Even with a commitment towards long-term sustainability goals, support for PV has been dynamic over the past decade. There are three primary policies that directly benefit PV owners, as well as several indirect benefits. Tax policy will also be covered briefly in this section. A more comprehensive review of all relevant policies, their motivations, and impacts can be found in the IEA-PVPS national report for Sweden [4].

5.4.1 Capital Rebates

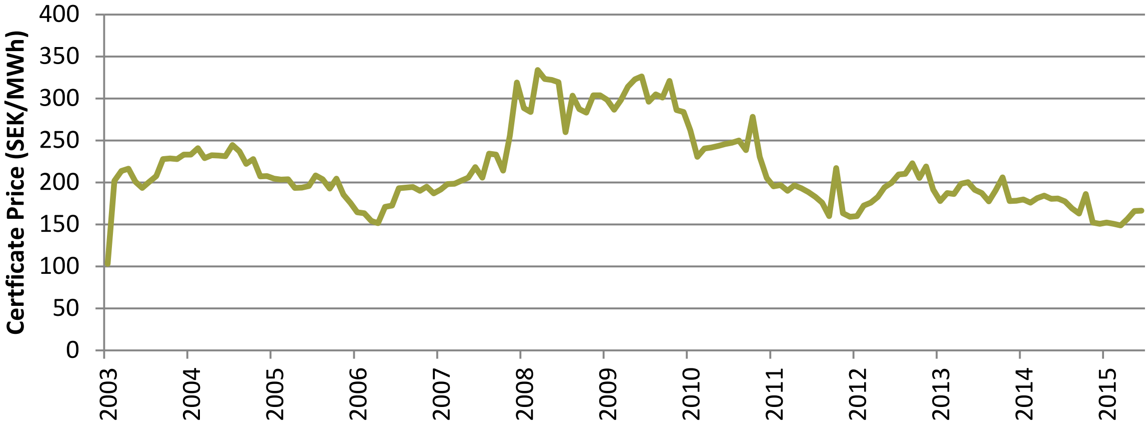
Capital subsidies, which reduce the investment cost of a PV installation, have been available at various levels from the national government since 2006. In 2009 the program was rewritten to include any micro-generation system, gave a 60% rebate on total installation cost, and was scheduled to run through 2011. This was eventually extended through 2012 with a 45% rebate while a new budget was written to refund the program. The next version was scheduled to run from 2013 to 2016 and award a 35% rebate. The budget for this program was exhausted in 2014 and a queue of applications totaling 490 MSEK formed, over double the original budget [68]. The program was refunded in early 2015 with 50 MSEK and the support reduced to 20% of total costs. The latest government budget proposal has once again refunded the program for the long term, with 1395 MSEK for 2016 to 2019.

The latest Swedish Energy Agency recommendations to the government (published October 2015) are to remove the capital subsidy for villas and cooperatives completely [69]. The report claims that the dedicated rebate is unnecessary due to other support measures, including the home renovation rebate program. They estimate the rebate is equivalent to a 15% deduction, however the rebate is 30% on labor only, which in a typical solar installation is approximately 15% of the cost [4], resulting in a 5% discount. Additionally, cooperatives do not qualify; only natural persons.

5.4.2 Green Electricity Certificates

Since 2003, the green certificate system has been the primary tool for renewable energy development in Sweden towards meeting EU energy goals [70]. It is a quota based system where the government sets a minimum level of certificates which must be owned by generators. Certificates are earned by producers of new renewable electricity and sold in an open market with floating prices, shown in Figure 38. In 2012 Norway and Sweden agreed to have a joint market, where the goal is 28.4 TWh of additional annual renewable electricity generation in 2020 as compared to 2012 (of which 15.2 TWh is Sweden's share). Thus far, wind and biomass generation has generated the most electricity under the system, whereas solar PV represents approximately 0.06% of annual generation [38].

Figure 38 - Historic monthly average green certificate price [71]



For prosumers, the green certificate system can be difficult to benefit from [4]. All of the electricity produced whether it is self-consumed or overproduction can earn certificates. This requires the installation of a second, qualified meter which costs 2000 to 3000 SEK and an annual reporting fee that is often too costly for smaller systems. Cooperatives are more likely to be in a position to install the additional meter because of the larger system sizes. Alternatively, certificates can be earned on only overproduction without any additional costs, but reporting must be done by the local network utility. Finally, to qualify for green certificates the owner must be on an hourly metering contract.

5.4.3 Feed-in Bonus

Beginning on January 1, 2015, a feed-in bonus program[21] was enacted which gives 0.60 SEK/kWh for overproduction up to a maximum 30,000 kWh/year (18,000 SEK). This program differs from a feed-in tariff in that the bonus is earned on top of the market price, grid compensation, or green certificates. The target group is micro-producers (i.e. prosumers) and therefore systems cannot export more than what is purchased over the year. The main fuse must also be under 100A. Rebates are given as a tax deduction; therefore a sufficient tax liability is necessary to benefit and all systems owned under a single tax number are included. There is no specified length or guarantee to the program, meaning it could be removed as early as 2017 when the first government review is scheduled.

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[21] Full description on the Swedish Tax Agency webpage

5.4.4 Guarantees of Origin

Guarantees of origin are certificates that confirm the source of electricity production and are intended to allow customers to choose where their electricity comes from. The program was introduced in 2010 and is open to all forms of electricity production, not just renewables. In 2015, there were a similar amount of green certificates issued for solar as were guarantees[22], however all green certificates have the same price in a single market whereas guarantees are valued by source. The low volumes, voluntary format of the system, and lack of public publication of transaction data makes it is difficult to know the exact value for solar guarantees. There are some retailers offering to buy solar guarantees at rates similar to or higher than green certificates, but there is little certainty of the long term value or income from this revenue stream.

5.4.5 Grid Compensation

Prosumers who feed electricity into the grid are entitled to earn compensation for the offset of losses saved by the network utility. The compensation is typically between 0.02 and 0.07 SEK [4].

5.4.6 Taxes

The Swedish Tax Agency has declared that prosumers who are natural persons are not operating a business, but must include profits from overproduced electricity as capital gains. For cooperatives, who are taxed like businesses (F-tax), the income must be included as part of the regular declaration and is currently taxed at 23.5%[23]. All prosumers must register for VAT, meaning 20% of all revenues from overproduction are paid as VAT before being declared as profits. In the spring of 2016, the Finance Ministry proposed to allow business activity under 30,000 SEK/year to be exempt from VAT taxes starting in January 2017[24]. This would likely cover most PV systems under 120-140 kW_p which may not include many larger cooperatives.

In spring of 2015, a new tax law was proposed by the Finance Ministry where prosumers who installed PV systems larger than 144 kW_p (later revised to 255 kW_p[25]) would no longer be exempt from the national electricity tax of 0.293 SEK/kWh for self-consumed electricity. The proposal comes due to pressure from Norway, who participates with Sweden in the green certificate system and believes it is unfair for wind parks owned by non-utilities to deliver electricity without the tax, while utility owned parks are subject to it. The proposal applies to legal persons (via tax identification numbers) rather than individual systems. Therefore if a cooperative were to own multiple small systems across several buildings which add up to over 255 kW_p, then they would be liable for the electricity tax on self-consumption. The law is planned to go into effect July 1, 2016.

Laws altering the tax system for distributed renewables have been proposed at almost an annual rate. As the market for PV grows, particularly with prosumers, there will be an increase in the attention paid to how the tax system should work with consumer oriented laws being mixed with producer oriented laws. It is likely that the law which will eventually be accepted long-term have not yet been written, and even once they are, it will still take time for the tax agency and courts to determine how best to enact them. This may be one of the most critical sources of uncertainty, but for now taxes must be considered for analysis in their current form.

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[22] Market statistics can be found at the Swedish Energy Agency's CESAR website

[23] Full description on the Swedish Tax Agency webpage

[24] Government press release (in Swedish)

[25] Government proposal 2015/16:1 (pp.293, in Swedish)

5.4.7 Barriers

There are some features of the existing electricity market and tax systems which can act as barriers to a PV installation. Some of these barriers are related to subsidy policy, but many are largely artifacts of a centralized electricity generation. When consumers are able to generate their own electricity, it challenges the existing tax laws and market structure. No current barriers will outright prevent a system from being installed, but they may cause economic limitations or underutilized roof space. As the presence of prosumers grows, it will place greater importance on technological and policy innovations to create markets which can accommodate them.

In the 2016 budget proposal (2015/16:1) it was also decided to create an investigation into solar PV systems which are producing and consuming electricity behind a single metering point, as they are a fundamentally different case from other generation facilities (i.e. a wind farm). A preliminary long-term plan for PV policy was delivered from the Swedish Energy Agency in March 2016[26] which reviews in detail current policies, markets, and barriers for continued development. No distinct recommendations have been made yet other than to create a single source for PV related information (technology, subsidies, taxes, etc.) similar to what has been done for wind power. This would include a high resolution solar resource map for most of the country, with many places using 3D maps, so people can easily assess their solar resources.

5.5 Future Scenarios

There is considerable interest and motivation in transforming the Swedish energy system; however the effect this will have on markets is highly uncertain. There has already been an attempt to phase out nuclear power, however renewable energy technologies are much more cost effective and politically accepted now than ever, suggesting a transition of the electricity system may be more likely over the next 30 years than the past 30 years.

For the potential prosumer acting as an investor, a critical considering is energy prices. There have been several large research projects dedicated to future scenarios for the Swedish and Nordic energy system [72–76], however it is rare that long-term price predictions are published publicly. One study performed by the North European Power Perspectives (NEPP) group does systems based modeling for the Nordic region and its interconnected markets. In their final report, they considered four policy alternatives to determine potential effects on generation portfolios up to 2050, including the resulting prices [77]. The four scenarios are[27];

A. Business as usual, all current policies and ambitions remain
B. Single focus on a build out of renewable energy
C. Single focus on CO_2 emissions reduction
D. Three pronged goals of renewables, carbon reduction, and energy efficiency

As shown in Figure 39, the resultant generation portfolios and electricity demand profiles from these scenarios are notably different. More specifically, these studies allow comparisons to be made in futures with and without nuclear power (although nuclear power is expected to remain in the Nordic market due to new capacity under construction in Finland). This is in contrast to previous studies where the generation mix tends to be relatively similar to scenario A.

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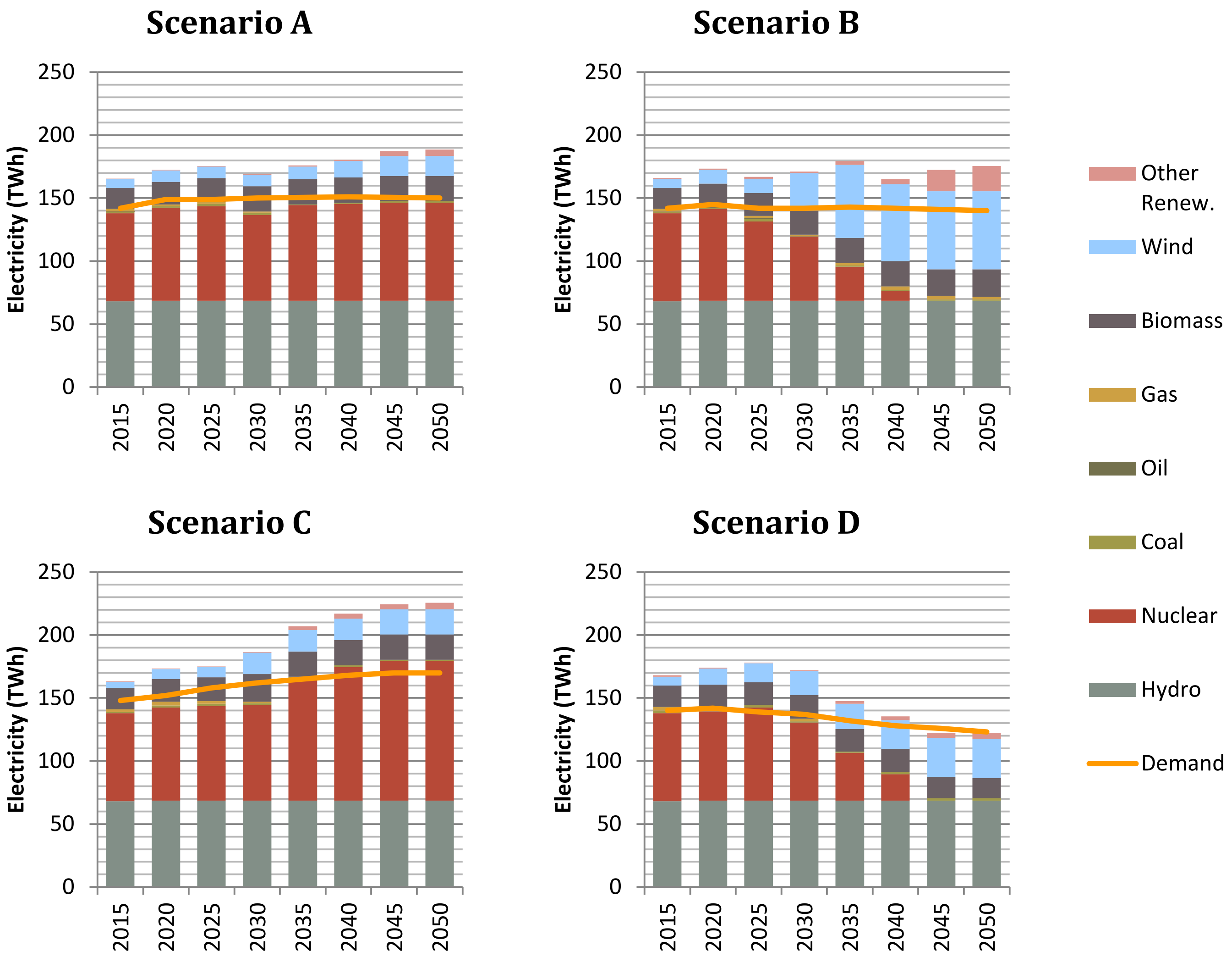
[26] Delredovisning av uppdraget att ta fram ett förslag till strategi för ökad användning av solel (in Swedish)

[27] More detailed descriptions of the scenarios are available in English in the NEPP Mid-Term Report

Figure 39 - Generation portfolios and demand profiles for NEPP scenarios [77]



The resultant price developments for each scenario are shown in Figure 40. For scenarios B and D there are two profiles, where the solid line represents the wholesale market price for electricity and the dotted line is the total price born by customers considering dedicated support programs (e.g. green certificates or capacity markets). The prices are based on the levelized cost of generation, which is considered a reasonable approximation for the long term mean price [78]. For comparison, the levelized cost of base load nuclear power in Sweden is approximately 0.35 SEK/kWh[28].

Aside from mid-term futures markets, prices for green certificates are difficult to forecast and more difficult to place into context with the NEPP scenarios above. Therefore, mean green-certificates are expected to return to their lifetime mean (0.215 SEK/kWh) by 2020 and remain there for the remainder of the program.

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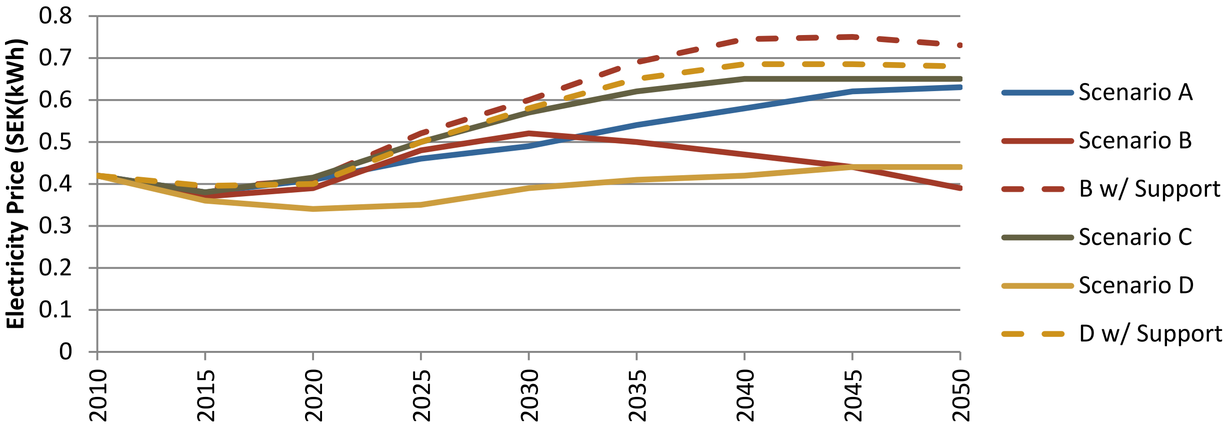
[28] Based on the average of the 2014 production costs reported by the owners of the Ringhals and Oskarshamn nuclear plants

Figure 40 - Potential future electricity prices under four policy scenarios [77]



5.6 Expert Panel Input on Future Scenarios

To help select the most plausible future scenarios and identify any other risks or possible developments for prosumers, an expert panel was assembled and interviewed using a Delphi method during spring 2015. The Delphi method uses a survey format with multiple rounds, where participants can see the answers and motivations from the previous round to help formulate answers for the next round. The goal for each question is to have a convergence around a single answer which is used to construct expectations for the future. The panel consisted of 17 participants from various backgrounds; academia, government, utilities, PV installers, and property companies. A further 13 participants provided answers to the survey but did not participate in all three rounds.

The survey questions, results from all three rounds, and list of participants can be found in Appendix F (In Swedish), with a full report expected to be published in spring 2016. It is important to note that the results of a Delphi study cannot be treated the same as a public poll, but are more similar to a workshop where engaged experts give their opinion based on their point of view in the energy system. Listed below are a summary of the main conclusions;

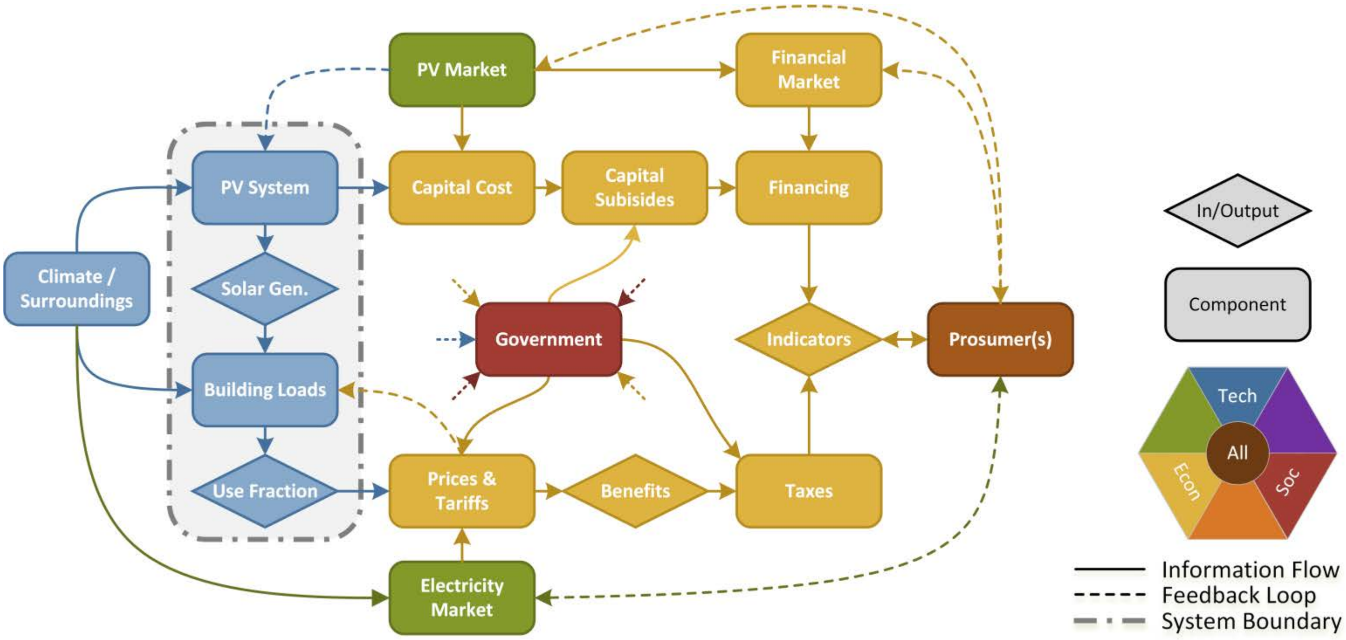
- A 100% renewable electricity system is considered the most likely, with scenarios B and D receiving near equal support
- The future for nuclear went from uncertain to the majority expecting reactors not to be rebuilt after the announcement of nuclear plant closures (between rounds one and two)
- Electricity demand is expected to rise in the future due primarily to population growth and the electrification of transport
- Prices are expected to rise but at a relatively low rate
- Business models and market structures are likely to change within the next 10 years, and almost certainly to change within 20 years
- The majority believe it is appropriate to shape policy to support renewable energy prosumers
- The number of prosumers in Sweden is expected to grow, reaching 10-15% of all customers in 10 years and over 15% in 20 years

6 Economic Evaluation

One the most important aspects, and often the primary motivation, in the decision to install a PV system is the expected economic outcome. A PV system requires a large capital outlay that is effectively irreversible; it's like prepaying for 30 years of electricity with no opportunity for a refund. At the same time, prosumers are investors in the energy system. More so than most countries, Swedish prosumers are exposed to the complexity, variability, and uncertainty of the electricity market.

The number variables, actors, and feedback loops that must be considered make a complicated investment landscape, which is represented by the diagram in Figure 41. The system boundary indicates the portion of the landscape prosumers have control over, demonstrating the importance of comprehensive risk analysis as a critical decision making tool. At the same time, the results must be approachable and easy to interpret for non-professional energy investors. In this chapter, the background information presented in this report is used to produce a variety of financial indicators constructed specifically for prosumer investment analysis.

Figure 41 - Diagram of the investment analysis process for prosumers



6.1 Methodology

Traditional economic analyses use deterministic methods to produce familiar economic indicators, such as; payback time, net present value (NPV), and internal rate of return (IRR). Uncertainty in the assumptions regarding long term variables commonly lead to scenario and/or sensitivity analyses. While these tools are helpful for determining a potential range of outcomes or identifying the most critical inputs, they cannot provide insight into the probabilities of outcomes.

Monte Carlo analysis is a mathematical simulation method which uses a random sampling of inputs and performs repeated calculations of the traditional deterministic process. The simulation can be run thousands of times, creating thousands of possible scenarios, whose results are then presented as a distribution rather than a single value. This has increased value because it takes uncertainties and turns them into risks, or in other words; turning *what could happen* into *what is likely to happen*.

There are three scenarios presented in the primary results based on the public policies affecting PV prosumers, Unsubsidized, Common Case, and Best Case, which are described in Table 2. Additionally, each policy is analyzed independently to identify its relative impact. The capital subsidy for cooperatives is currently 20%, however this is only used in the Best Case scenario and is assumed to be 15% in the Common Case due to the active discussion about reducing the rebate (Chapter 5.4.1). Green certificates are considered for both total production (All) and overproduction (OP) and the applicable length of the feed-in bonus (FiB) has cases for five, ten, and fifteen year terms. Due to the currently uncertain value of guarantees of origin, they have been omitted from the analysis.

Table 2 - Description of the policies composing each scenario

Scenario	Capital Rebate	Green Certificates	Feed-In Bonus
Unsubsidized	None	None	None
Common Case	15%	Overproduction	5 Years
Best Case	20%	All	15 Years

Due to the very wide variety of possible financial constructs of a PV investment, there are two additional sub-studies included in this chapter which provide examples of conditions which vary from the ones presented in the primary results. The first considers PV system sizing with regards to economic optimization, and the second considers the differences between financing with cash or debt. The primary results are intended to represent what a common PV installation may look like, however the additional sections can help decision makers during the preliminary design phase. Each sub-study uses the inputs and assumptions from the primary study as a starting point for comparison.

6.1.1 Economic Indicators

There are a considerable number of economic indicators to choose from, most of which are minor variations on a few core criterion [79,80]. There are only three indicators presented in the primary results; simple (non-discounted) payback time, discounted payback time, and internal rate of return (IRR). While it is often inappropriately used as a profitability indicator, simple payback time is more useful as a measurement of risk. It tells the investor how long it will take to have the original principal returned, which can then be assessed in terms of how confident they are in the advancement of the market during that time period. Discounted payback time has the same function, but with the time required to earn the desired profit. IRR[29] is a measurement of profitability, where the investment is deemed profitable if the IRR is equal or greater to the required return (i.e. discount rate). IRR is also easy to understand since most financial instruments are described with rates[30]. The study is structured such that the results can be applied to a range of prosumers, meaning inputs and results are normalized on a per kW_p basis.

Net present value (NPV) is not presented directly in the primary results, but is used in the calculation of probabilities. It is calculated with the same equation as IRR and is also used as a measurement of profitability, making it redundant. IRR was selected because it is a more intuitive value and is easier to apply broadly (i.e. normalized for system or investment size). NPV is used however in Chapter 6.4 where it was necessary to use absolute savings as a measurement.

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[29] IRR is also known as return on investment (ROI)

[30] Formally, it is inappropriate to compare two mutually exclusive investments with IRR [82]. However for prosumers, who may not be acting solely on economic rationality [131,132], the disparity is likely to be less damaging than the benefits.

Levelized cost of energy (LCOE) is the most common indicator not presented in the primary results. LCOE can be a useful tool for some comparisons [81], but the need to consider complicated pricing and subsidy schemes make it less capable as an investment indicator in this study.

Indicators are calculated using established engineering economics principles and discounted cash flows [82], and are fully described in Appendix A.

6.1.2 Monte Carlo Simulation

Developed in the 1940's for advanced defense projects, Monte Carlo simulation started being applied in finance in the 1960's [83], has been suggested for use in energy analysis since the mid 1990's [82,84], and has recently been applied to PV investment analysis [85–89]. The structure can be described as a shell surrounding the traditional economic indicator calculations, where inputs and outputs are managed. Randomly fluctuating inputs such as annual solar irradiance, self-consumption rate, and system lifetime, are selected from a probability distribution. Electricity and green certificate prices (and interest rates if a loan is considered) also fluctuate randomly but are influenced by previous values and long term averages, requiring the use of a stochastic time series model. Although the inputs are selected at random, they are bounded by distributions which converge to a single distribution of results with a sufficiently high iteration count. A complete description of the models is provided in Appendix C.

6.2 Assumptions and Basic Inputs

Perhaps the most critical assumption inherent in this method is the arrangement of the market, which is discussed in detail under the scope and definitions in Chapter 1.3 and discussed with relation to taxes in Chapter 5.4.6. As the expert panel indicated (Chapter 5.6), there is the distinct possibility that the basic market structure will change during the lifetime of the PV investment, or even before the simple payback time. It is impossible to know what those changes will be and it is outside this study's scope to develop potential market structures or policies. To handle the uncertainty, the four policy scenarios presented in Chapter 5.5 are used as potential future options and given a probability of occurrence. Based on the probabilities, one scenario is selected as the foundation for price development in each iteration. In Appendix D, each of the results considering each policy scenario independently are also given.

In Scenarios B and D, green certificates are used as policy instruments for increased renewable production much like the current market. Since the future of the policy is unknown, the assumption is made that the current energy market and policy structure continues forward with only the prices changing. In Scenarios A and D, this means the current program phases out in 2035 as planned. Assumptions for the first year prices and growth of each component are listed in Table 3. A detailed description of the pricing model can be found in Appendix C.2.

Table 3 - First year price values and growth rates by component

Input	Value	Units	Growth Rate	Reference Chapter
Nord Pool Spot*	0.219	SEK/kWh	Figure 40	5.1, 0 3.1
Green Support	0.03	SEK/kWh	Figure 40	6.2, 0
Network Price	0.20	SEK/kWh	1.5 %/year	5.2
Retailer Profit	0.05	SEK/kWh	0 %/year	5.2
Electricity Tax	0.293	SEK/kWh	1 %/year	5.2
VAT	25	%	0 %/year	5.2
Total Variable Retail Price	0.99	SEK/kWh	Calculated	5.2, 0
Green Certificates	0.166	SEK/kWh	See Scenario	5.4.2, 0

A list of the median inputs used to create sensitivity charts considering NPV is shown in Table 4. Using the deterministic calculations and constant wholesale prices (i.e. no change over time), the sensitivity analysis determined that the most critical variables to profitability are; total installation cost, annual generation, self-consumption rate, wholesale price, system lifetime, and discount rate. More details about the study and results are graphed in Appendix B. All of the identified critical inputs are given distributions or stochastic time series models in the Monte Carlo simulation, and marked in Table 3 and Table 4 with an asterisk. Details and motivations for the distributions and time series inputs can be found in Appendix C.

Table 4 - Median inputs for the investment analysis

Input	Value	Units	Reference Chapter
Annual Generation*	900	kWh/kW_p	3.1
Annual Degradation	0.3	%/year	3.1
Self-Consumption*	60	%	3.3, 6.4, 8
Installation Cost (excl. VAT)*	13	SEK/W_p	5.3
Fixed O&M Cost	50	SEK/kW_p	2.4
O&M Cost Escalation Rate	1	%/year	2.4
Inverter Lifetime*	15	Years	2.4
Inverter Replacement	2	SEK/W	5.3
System Lifetime*	30	Years	2.4
Salvage Value	0	SEK/kW_p	-
Real Discount Rate*	3	%	6.2
VAT Tax on Revenues	20	%	5.4.6

There are several values in Table 4 which are not yet motivated; self-consumption, salvage value, and discount rate. Self-consumption can vary significantly between individual buildings (Chapter 3.3) and identifying the financially optimal system size can result in a range of self-consumption rates between 60-80% (Chapter 6.4). A rate of 60% is used here since the case studies reviewed during this project show self-consumption ranges between 50% and 70% (Chapter 8) and corresponds more closely with a real system rather than a purely economically optimized system. Given the rapidly changing market and technology landscape for solar PV, the value of the system after 30 years is highly uncertain and thus conservatively assumed to be zero.

Selecting a median discount rate is not a trivial process [90–94] and can have a significant impact on the results. To avoid complexity and confusion, the cost of debt is used as a proxy for prosumer discounting. A survey of several Swedish banks' websites[31] indicates nominal rates for long term, non-mortgage loans are approximately 5% (December 2015). Removing the target inflation rate of 2%[32], the real discount rate is then 3%. It has been suggested in a previous PV profitability study in Sweden to use a rate 30% lower than the cost of debt due to the ability for natural persons to deduct this from their tax liability [95]; however this is dependent on individual tax liabilities and cooperatives are unable to take this deduction.

6.3 Probabilistic Results

The results of the Monte Carlo simulation are designed to answer three investment questions posed by the prosumer;

- What is the chance I will make a profit on my PV investment?
- What is the chance of losing money on my PV investment?
- How bad could the outcome be? How good?

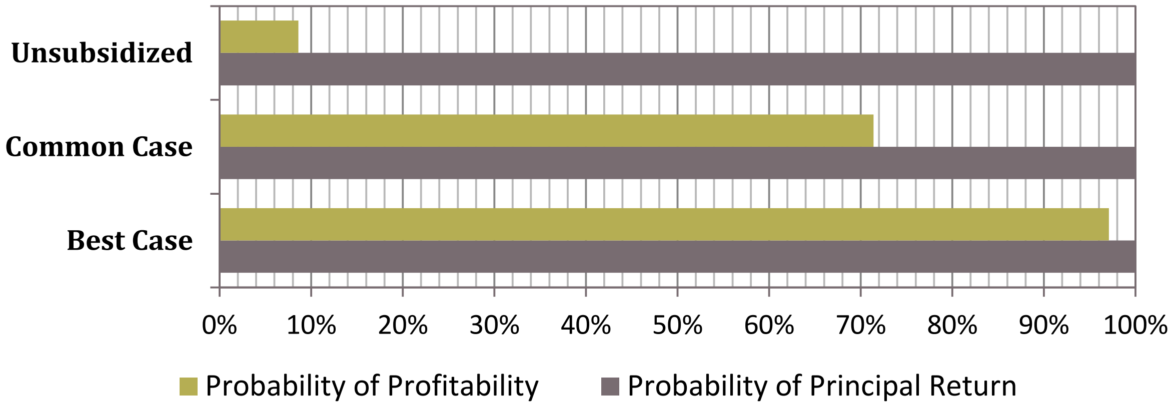
In addition to targeting investment oriented results, policy programs are tested individually to determine their influence on investment success probabilities.

6.3.1 Investment Success Probabilities

The first two questions are answered with single value probabilities; the probability of profitability (PoP) and the probability of principal return (PPR). Profitability is defined as earning at least a 3% real return on investment (i.e. 3% real discount rate) and a return of principal is having the original investment value returned without interest (i.e. 0% real discount rate). The probabilities are then a count of the number of scenarios (i.e. Monte Carlo iterations) that resulted in IRR's better than 0% or 3% for PPR and PoP, respectively.

The results for the three subsidy cases are shown in Figure 42. There is a notable increase in PoP between the Unsubsidized scenario at 8.6% and the other two scenarios at 71.4% and 97.1%. So assuming an investor can take advantage of all of the policies currently in place, the investment in a PV system is likely to earn a profit. It is also interesting that even without support, there is a near 100% chance of having the principal returned.

Figure 42 - Investment success probabilities for policy scenarios



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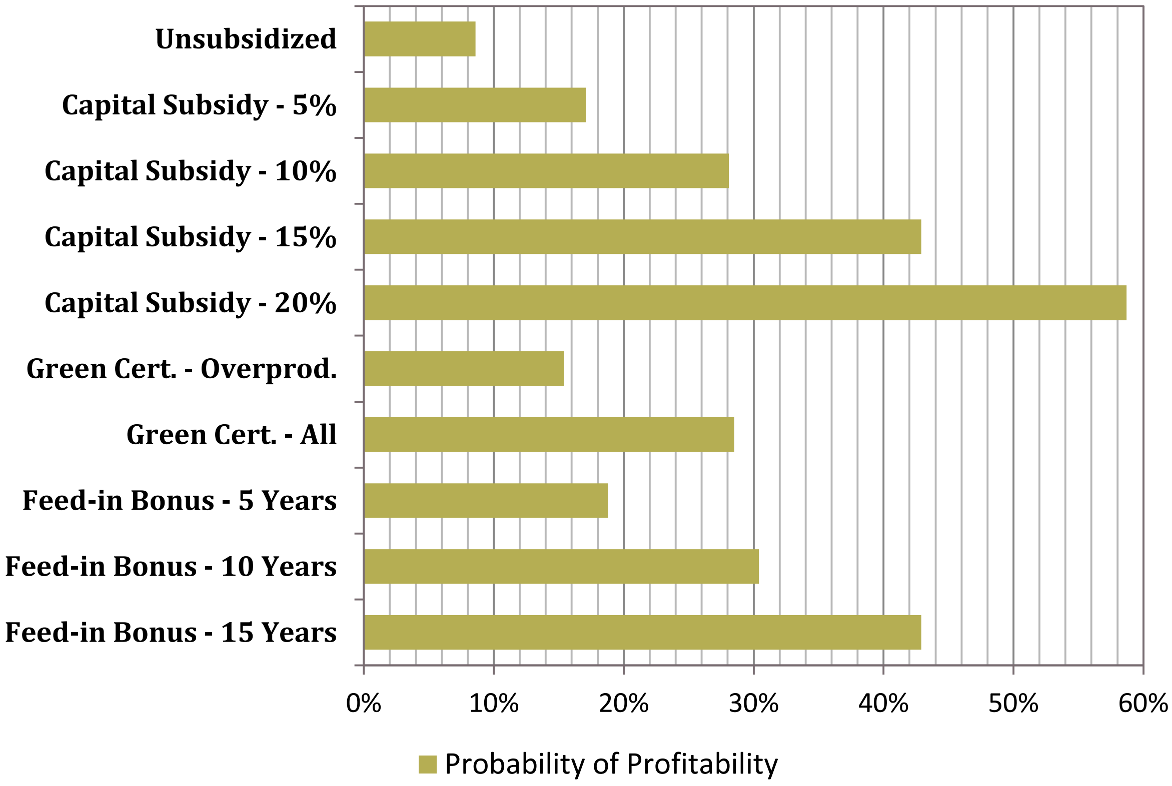
[31] SEB, Nordea, Swedbank
[32] Sveriges Riksbank

Examining the individual policies against the Unsubsidized case, shown with only PoP values in Figure 43, indicate that the capital subsidy is the most influential policy mechanism on profitability. Approximately 55% of the increase in probability within the Common and Best Cases is due to the capital subsidy. The green certificate program can increase probabilities by 7% to 20% depending on how the production is metered. Even at only five years in length, the feed-in bonus program improves the probability more than green certificates lasting 15 years. This is due to their much higher price per kWh, but the uncertainty surrounding the length of the program makes it difficult to rely on for longer term revenue.

Figure 43 - Investment success probabilities for each policy case

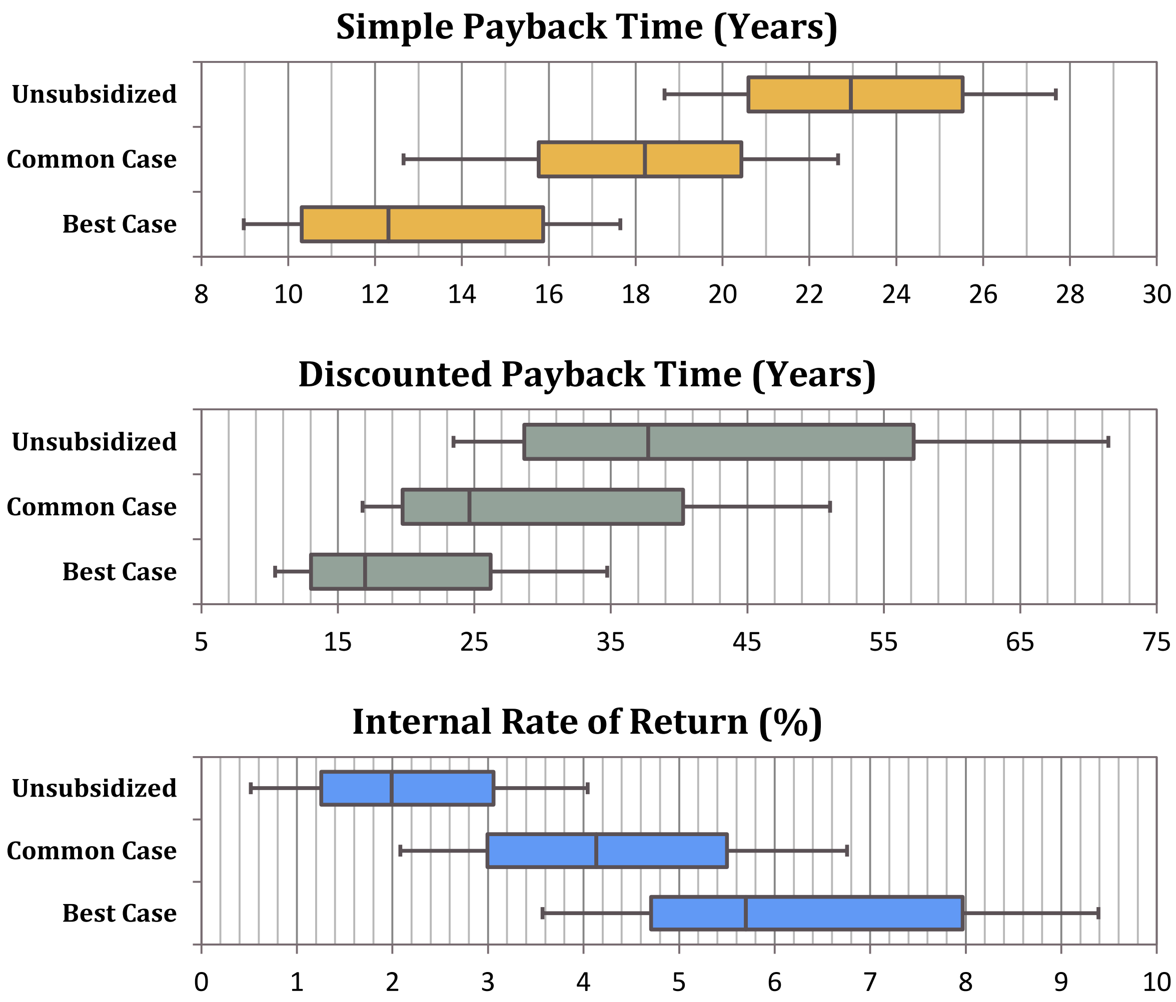


6.3.2 Distributions

For compactness, the results are shown with box plots with whiskers rather than cumulative distribution functions. The plots do not show traditional quartiles, but rather values which better represent probabilities of the investment. Therefore the center value is the mode, the ends of the boxes are the 95% range (±2σ), and the whiskers are the 99.7% range (±3σ). The second and third standard deviations are used instead of traditional quartiles because prosumers are assumed to be more risk adverse than typical investors, leading them to desire more knowledge of extreme outcomes (i.e. losses) [96,97].

The results for the policy scenarios are shown in Figure 44. Focusing on payback times of the Common Case scenario; most probable times for returning the original principal and earning the desired profit are 17.5 and 25.1 years, respectively. This highlights the need for prosumers to focus on a PV as being a long term investment, similar to how their pensions might invest in traditional energy utilities. The Unsubsidized IRR is relatively low, but the other scenarios offer returns similar to traditional utility stock dividend yield rates[33]. In the policy cases, shown in Figure 45, the pattern of impact is similar to that of PoP as expected.

Figure 44 - Probability ranges of the economic indicators for the policy scenarios



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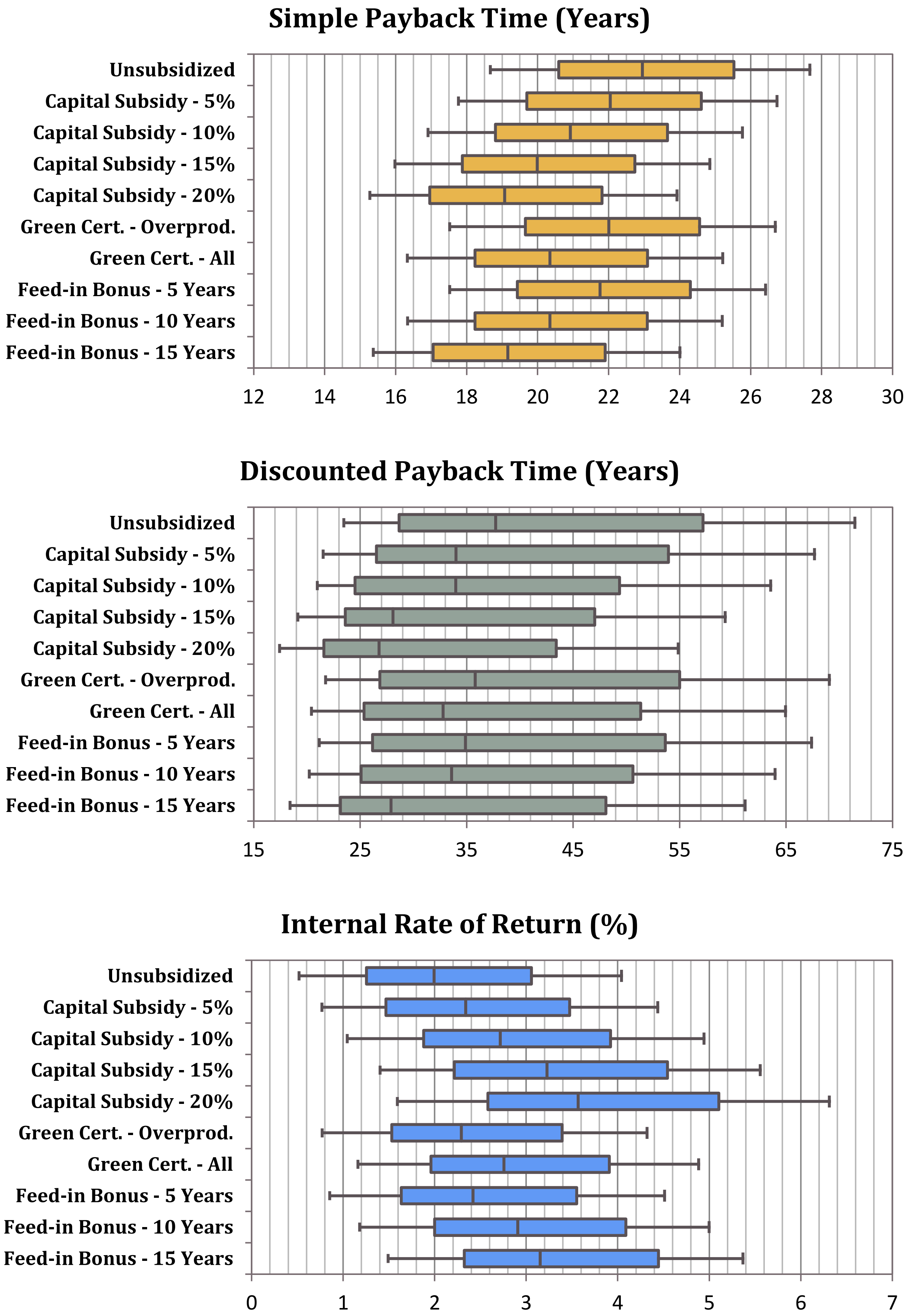
[33] Investor information from E.On and Fortum (December 2015)

Figure 45 - Probability ranges of the economic indicators for individual policies



6.4 System Sizing for Maximizing Economic Potential

There is a natural desire to simplify the PV design process such that a rule of thumb could be established, such examples could be; annual PV production should be “X%” of the annual demand or the production during summer months should match demand. However, as it has already been suggested in section 3.3, it is difficult to derive consistent patterns such that simple rules can be broadly applied to all buildings. The differences in building load profile, system orientation, irradiation, shading conditions, or personal economic factors can all play a role in economically optimizing the size a PV system. This section uses two examples each from Cooperatives A and B to demonstrate the differences in economic outcomes based on system size.

All of the building examples are assumed to be in Gothenburg, Sweden, have a well-positioned roof facing due south with a 30° tilt and no shading, which results in 970 kWh/kW$_p$ annual production. The simulation time step is hourly, which matches the measured load data and the available climate data for use in PV modeling. The median economic data described in Table 4 above is used with price scenario B and the Common Case subsidy scenario. The indicator, NPV, represents the discounted savings over 30 years between a building with PV and one without. The results are created by increasing the system size in 1 kW$_p$ increments until annual PV production reaches 100% of the annual demand. The annual demand and associated maximum system sizes for each building are listed in Table 5. Each cooperative has one building with a laundry room and one without studied to capture a variety of demand curves.

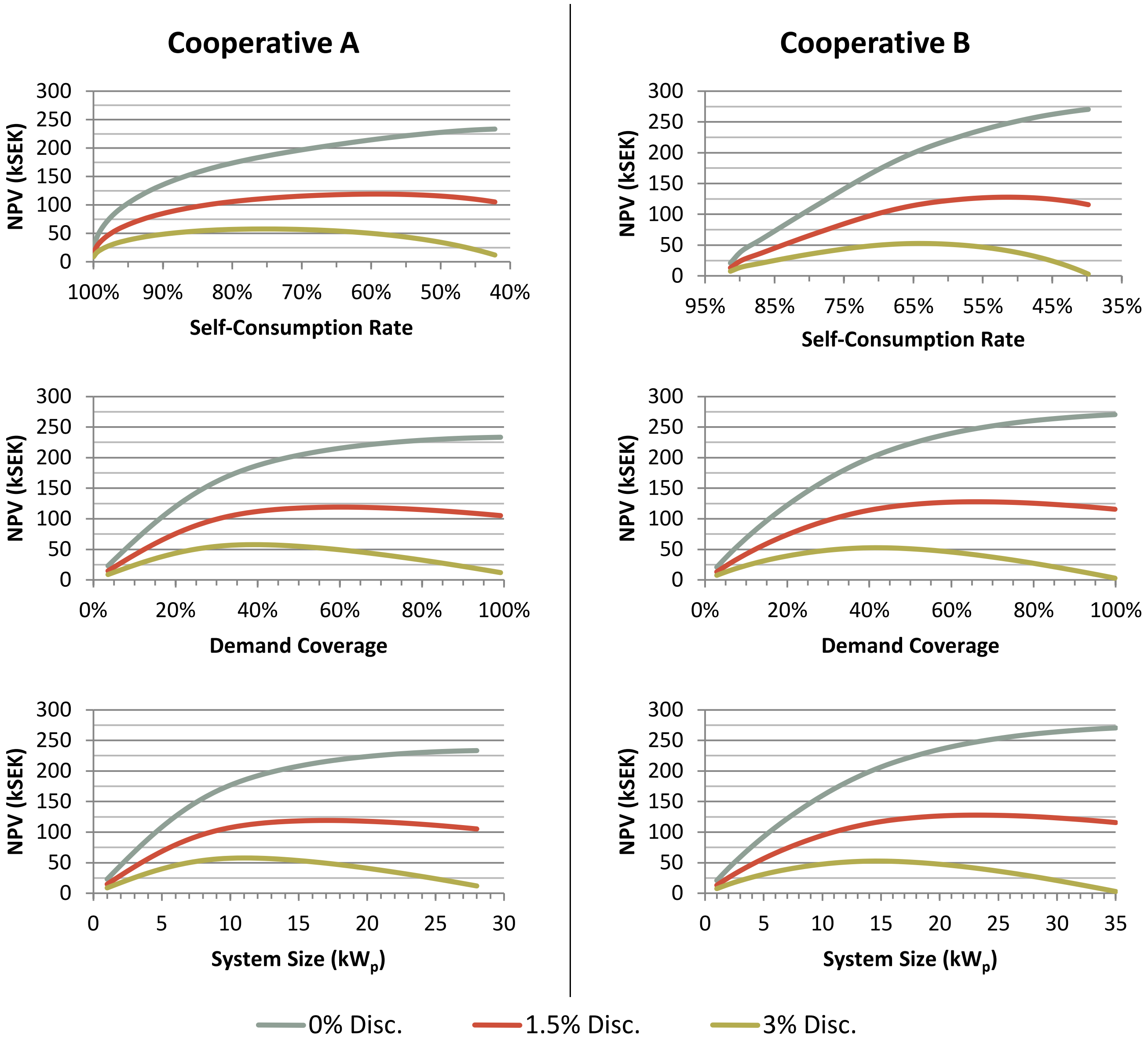
Table 5 - Building characteristics and maximum PV system size

Building	Annual Demand	Maximum Size
Coop A – Laundry	27,490	28 kWp
Coop B – Laundry	34,126	35 kWp
Coop A – No Laundry	13,153	13 kWp
Coop B – No Laundry	27,974	29 kWp

The results for the two buildings with laundry rooms are shown in Figure 46. Coop A on the left and Coop B on the right with NPV as a function of self-consumption in the top row and the ratio of solar production to building demand, called demand coverage, in the bottom row. Curves have been generated for three discount rates to demonstrate its effect, even though 3% is the recommended value for cooperatives. For this analysis, it is necessary to look at absolute NPV in SEK rather than an indicator normalized for system or investment size (e.g. IRR or NPV/kW$_p$). However it is important to note that the absolute values are not as critical as the shape of the curves and their maxima.

Focusing on the 3% discount rate, the results show that the maximum NPV for Coop A and B occurs at demand coverage rates of 39% and 43%, respectively. They also show that the peaks are not particularly sharp, meaning that there is a wide range of demand coverage which can produce near-optimal economic results. For example, the range of 30-50% demand coverage, NPV is only reduced by approximately 3000 SEK, which is about 5%. Using these results to extract self-consumption values is less conclusive; even though both buildings have a demand coverage rate close to 40% at the maximum NPV, one has a self-consumption of 75% and the other is 63%. A summary of statistics from the optimal points in each curve in Figure 46 is shown in Table 6.

Figure 46 - NPV curves in two different buildings with laundry



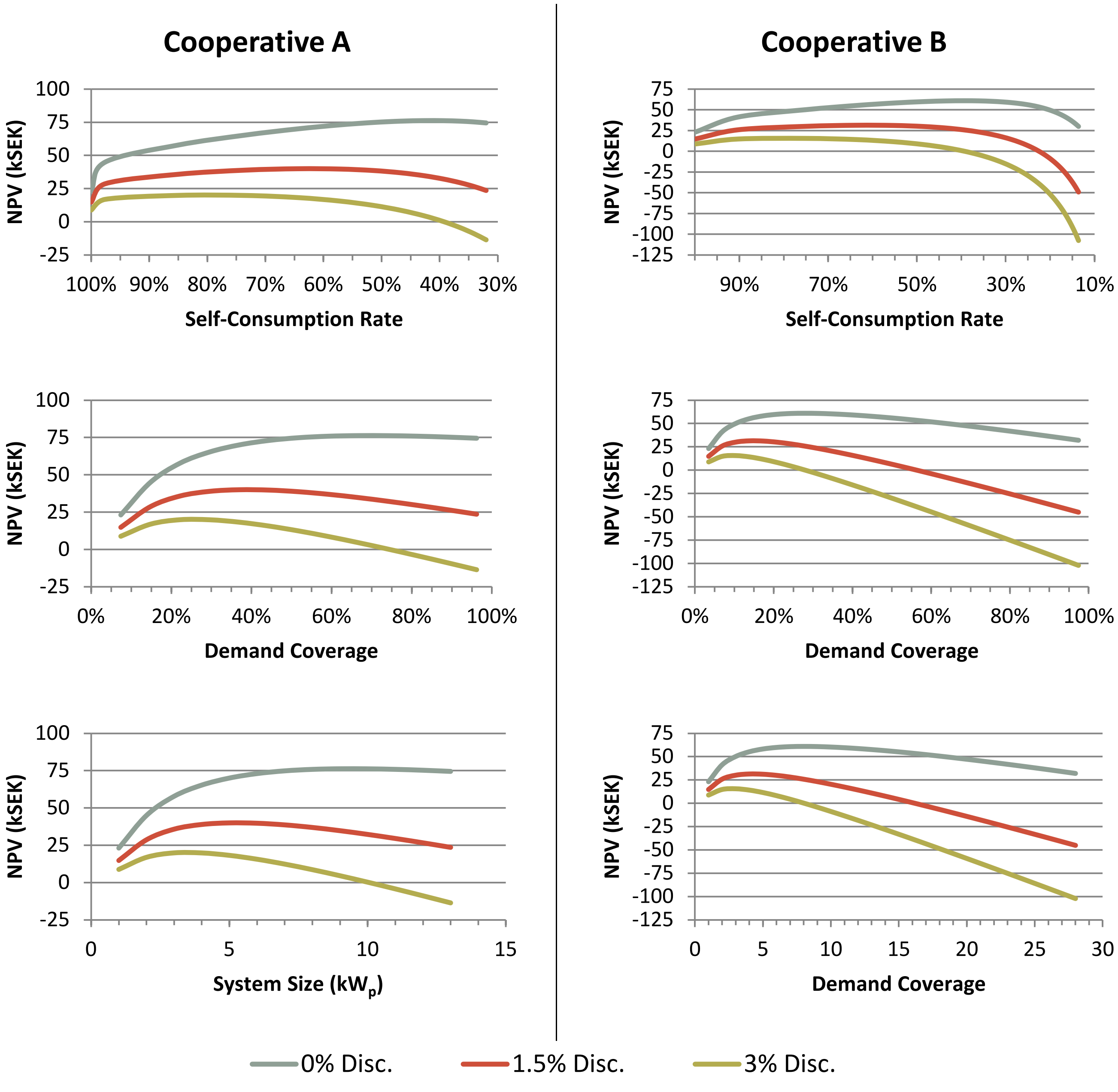
When considering lower discount rates, the optimal points shift significantly. Moving from 3% to 1.5% in Coop A increases system size from 11 kW$_p$ to 17 kW$_p$, resulting in a demand coverage of 60% and self-consumption of 59%. The curves also become flatter with lower discounting, where the ranges nearly double in the move from 3% to 1.5% in either building.

Table 6 – Optimal PV system sizing statistics considering laundry equipped building examples

Building	Discount Rate	Demand Coverage	Self-Consumption	System Size	Size Range Within 5% of Maximum
Coop A	3%	39%	75%	11 kW$_p$	8.5 – 14 kW$_p$
Coop A	1,5%	60%	59%	17 kW$_p$	12 – 23.5 kW$_p$
Coop A	0%	99%	42%	28 kW$_p$	19 – 28 kW$_p$
Coop B	3%	43%	63%	15 kW$_p$	13 – 18 kW$_p$
Coop B	1.5%	66%	52%	23 kW$_p$	16.5 – 31 kW$_p$
Coop B	0%	100%	40%	35 kW$_p$	26 – 35 kW$_p$

In the set of buildings without laundry rooms, Figure 47 shows that the resultant NPV curves are markedly different. The economic maxima are at a much lower demand coverage, peaking at 22% and 10% for Coop A and B, respectively. Interestingly, while the peaks of NPV as a function of self-consumption are approximately 10 percentage points higher in these buildings, the curves are relatively flat and NPV is nearly constant from 98% to 55%. However, this is likely due to the smaller systems since the size range for staying with 5% of NPV is smaller as well. A statistics summary from the optimal points from the curves in Figure 47 is shown in Table 7.

Figure 47 - NPV curves in two different buildings without laundry



It is interesting to compare Coop B without laundry to Coop A with laundry as they have the same load value but significantly different optimums. In Coop B, the systems are approximately 80% smaller and cover 30-70% less demand. This highlights the significance building load patterns can have on the system design and sizing process, emphasizing correlation between supply and demand as a way to profitably increase system size.

Table 7 – Optimal PV system sizing statistics considering building examples without laundry rooms

Building	Discount Rate	Demand Coverage	Self-Consumption	System Size	Size Range Within 5% of Maximum
Coop A	3%	22%	85%	3 kW_p	2.5 – 5 kW_p
Coop A	1,5%	37%	64%	5 kW_p	4 – 7.5 kW_p
Coop A	0%	67%	43%	9 kW_p	5.5 – 13 kW_p
Coop B	3%	10%	75%	3 kW_p	2 – 4 kW_p
Coop B	1.5%	14%	64%	4 kW_p	3 – 6 kW_p
Coop B	0%	28%	39%	8 kW_p	5 – 13 kW_p

The results from this investigation exemplify why it is difficult to extract a hard rule of thumb, however sum broad guidelines can be suggested for early stage design. In buildings with laundry rooms that have high-production potential roofs like the one modeled here, the PV system can be sized such that annual production is between 30-50% of the annual demand. This should correlate with self-consumption rates between 60% to 80% and provide economic benefits within 5% of the maximum. In buildings without laundry rooms, a 15% to 35% production-to-demand ratio can be sought, however more care should be taken not to over dimension since benefits decline more rapidly in these buildings as systems increase in size.

Another consideration is that these results are generated using the Common Case policy scenario, which includes 15 years of green certificates and 5 years of feed-in bonus. If these subsidies were not used, then NPV would be more sensitive to self-consumption and the curves would have sharper maximum points and the optimal sizing range would be narrower.

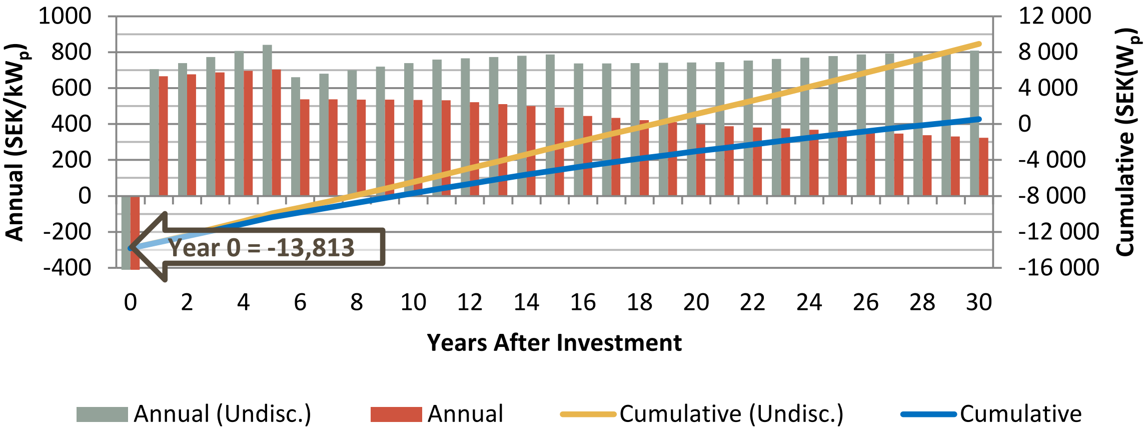
It should also be mentioned that potential investors may have alternative motives besides economic gains. For example, if a prosumer wanted to maximize their roof's solar production potential, they may consider a system which covers 70-80% of demand. While this may not provide the maximum benefit, it could still be economically positive. It is important to restate that these results are just an example and that all buildings and PV systems will vary to some degree. Consideration for hourly load patterns and PV production should be made in any system before deciding on a final configuration.

6.5 Ownership and Financing Structures

There are several financing structures which can be categorized into three main groups; direct purchase, debt financed, and third-party. Direct purchase is what has been described thus far, where the owner pays cash for the entire system and owns it outright. Debt financed is where the owner takes a loan and at the end of the loan owns the system outright. Third-party structures are where the building owner does not own the PV system, but instead gives permission to a third-party to use their roof and then is either paid for leasing the space or agrees to purchase the electricity. Contract arrangements for third-party structures can be more complicated and will vary based on local laws. Third-party solar companies are relatively rare in Sweden, but could become more common as they have shown to be a significant market driver in the U.S. [98,99] The details of third-party structures are too many to cover within the scope of this report, therefore this section will compare the cash flows of the generic system presented above financed with a direct purchase and a standard loan.

For this example, all of the inputs described in section 6.2 are applied to a 1 kW_p system using the Common Case policy scenario, and therefore could be scaled up so long as all of the other inputs remained constant. The electricity prices from Scenario B are used and the inverter costs are represented as annual rather than singular for simplicity. The annual and cumulative cash flows for a direct purchase structure are shown in Figure 48. The direct purchase is characterized by a large negative value in year zero (which extends off the chart) and 30 years of positive cash flow. It can be seen in years 5 and 15 where the FiB and green certificates are removed. Both discounted (at 3%) and undiscounted values are given to demonstrate the significance it has on the value of future income.

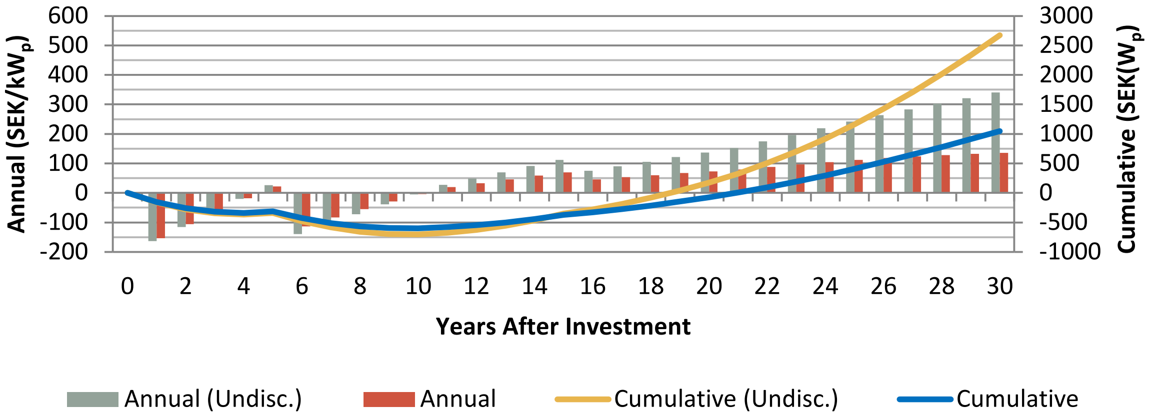
Figure 48 - Annual and cumulative cash flows of a directly purchased PV system



Although not as complex as third-party ownership, debt financing has several variables that can significantly influence cash flow, for example; interest rate, loan length, and the loan type. Straight-line amortization (SLA) loans are common in Sweden and tend to have higher payments in the early years (for a given interest rate), whereas annuity loans pay less principle at the beginning but have the same payment amount throughout the life of the loan. One of the benefits of using debt is that the initial cash outlay is significantly reduced or removed, thereby allowing positive net cash flow from year one, which makes debt an attractive option even if the cash flows are smaller.

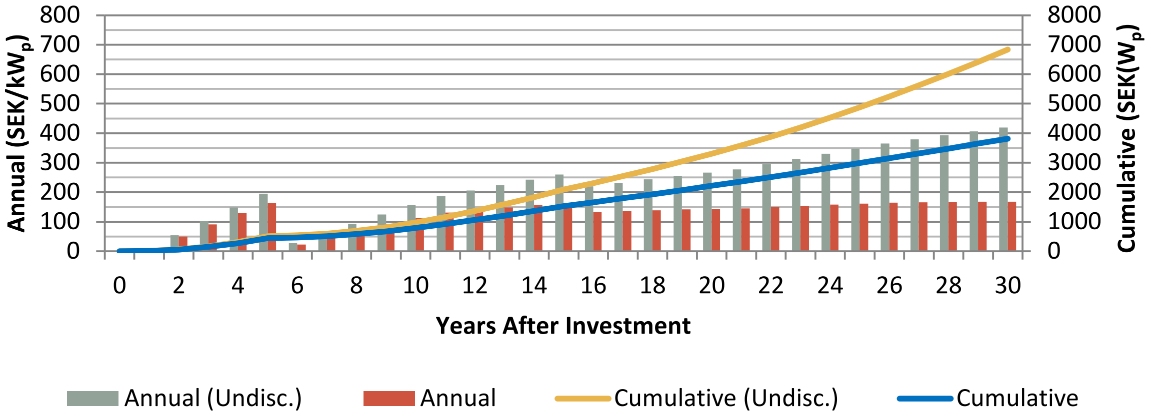
In this example, the purchase is 100% debt financed at a 3% real interest rate and has a term of 30 years in line with the economic lifetime. Figure 49 shows the cash flows of a SLA debt financed PV purchase, where it can be seen that cash flows are actually negative for most of the first decade. This is due to the high initial interest payments that come with an SLA loan, which are negatively correlated with the expected cash flows that will increase as the electricity price increases over time. Even the FiB and green certificates are not enough to gain positive cash flow in most years, and the result is cumulative positive cash flow in 18-21 years. It is worth noting that the discounted outcome is still better than the direct purchase, even with the negative cash flows.

Figure 49 - Annual and cumulative cash flow of a 100% straight-line amortization financing



An annuity type loan is shown in Figure 50, where the cash flows are significantly different. From the first year the investment is cash flow positive and ultimately results in a much higher final discounted cumulative value (which is the same as NPV). By better correlating the cash outlays with revenues, the profitability of the investment is improved, and it has even been suggested to have rising payment loans which would further correlate costs with revenues [100]. It should be noted that annuity loans tend to lock in the interest rate for the life of the loan, exposing the bank to more risk and thus potentially increasing the interest rate. Therefore it may not be appropriate to compare the same rate with each loan type and rates and terms ultimately depend on the individual borrower. The conclusion of this brief analysis is that it is necessary to review financing options and cash flows with a qualified advisor prior to purchasing a system as it can have a significant impact on the economic outcome.

Figure 50 - Annual and cumulative cash flows of 100% annuity loan financing



6.6 Profitability Charts

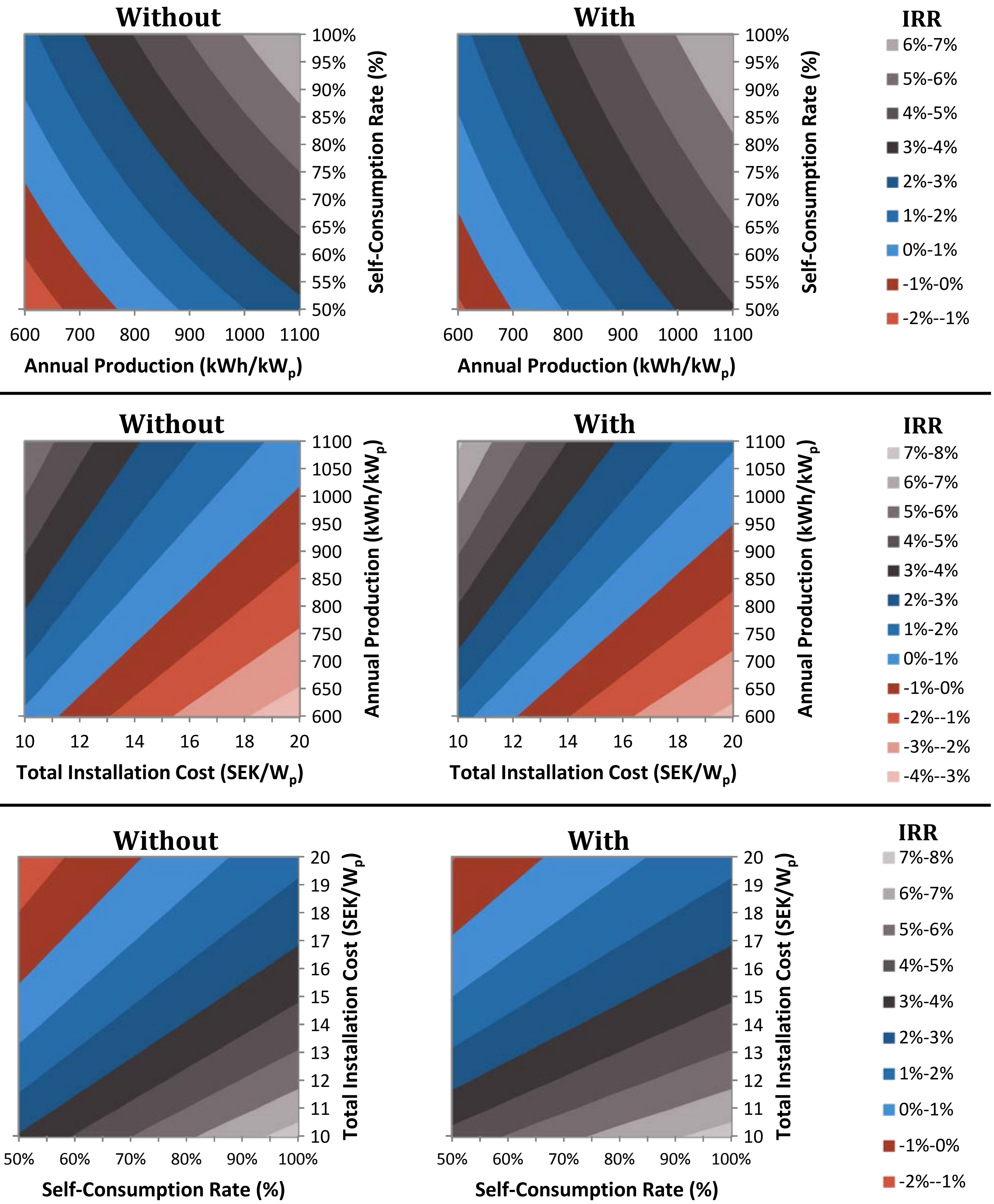
The wide range of variables and possible prosumer configurations, as well as the rapidly moving PV and electricity markets, can make it difficult to keep investment results relevant. Therefore this section includes profitability charts for a wide range of potential input values, shown in Figure 51 on the following page. The charts consider three critical inputs for system design; annual production, total installation cost, and self-consumption rate, and provide the real IRR (inflation is not included) as a function of two of the variables. The first row has a fixed installation cost at 13 SEK/W$_p$, the second row has a fixed self-consumption at 60%, and the last row has a fixed annual production of 900 kWh/kW$_p$. The remaining inputs are those presented in Table 3 and Table 4 and prices from Scenario B. Green certificates and a 5-year feed-in bonus is included in the right column (*With*), while the left column has no special support (*Without*). The capital rebate can be considered by adjusting the installation cost. The contours are colored such that combinations that result in an IRR above 3% are black to indicate profitability, blue for a return between 0% and 3%, and red for those under 0% which lose principal.

The charts can also be used as preliminary design tools, however it is important to note that because they're normalized they do not have a maximum value like the NPV example in section 6.4. Therefore they cannot help optimize a system size for maximum savings, but can give the rate of return of any given system. Alternatively if it is known what rate of return is acceptable, then the charts can be used to identify the necessary range of system parameters. For example, if a building owner wants at least a 2% real return and estimates that their roof can produce approximately 950 kWh/kW$_p$, then using the first row charts (with an installation price of 13 SEK/W$_p$) they know they need at least a 55% self-consumption rate and can have their system sized accordingly. The information in Chapters 3 and 6.4 can help size the system, but before a decision is made a solar expert should review the hourly meter data with modeled production values to more accurately predict self-consumption. The charts are repeated in Appendix E at a larger scale for more detailed review.

6.7 Profitability of Batteries

As mentioned in Section 3.4.1, there is a lot of excitement in the media and in selected markets surrounding batteries, making it interesting to explore the economics for Sweden. This can be done with simple estimate using the profitability charts above. In the 18 kW$_p$ example, it was shown that a 30 kWh battery pack would increase self–consumption by approximately 20%. Using the profitability charts above, a 20% increase in self-consumption adds approximately 2.5% to the IRR which corresponds to an NPV increase of 5700 SEK/kW$_p$. Considering the 18 kW$_p$ example in Section 3.4.1, this would result in a total profit gain of approximately 100 kSEK. Costs for state-of-the-art lithium ion batteries are 2500-3500 SEK per kWh of capacity [40], making the 30 kWh battery in the example 75,000-105,000 SEK. The battery is likely to only last 10 years, meaning three batteries would be necessary to last the lifetime of the PV system, placing the costs well outside of what is economically interesting. It is important to note that this example does not consider green certificates or the feed-in bonus. That means the price difference between wholesale and retail is at its greatest which is the best possible conditions for adding a battery. Battery costs will need to be about 1/3 their current level to become interesting in Sweden.

Figure 51 - Profitability charts showing IRR with and without policy support under price Scenario B



7 Decision Making Within Cooperatives

Market inefficiencies in the soft, rent-controlled rental housing sector in Sweden have, through tenure conversions and new construction, contributed to a rapid expansion of the tenant-owner cooperative sector, making this the most attractive housing sector in terms of market transactions [101]. Since 1990 the rental housing stock within the inner city of Stockholm has decreased from 73% to 36%, while at the same time the share of cooperative housing increased from 26% to 62% [102]. Between 1965 and 1975 more than one million dwellings were constructed in Sweden, with approximately one third of them in the cooperative housing sector [103].

Decision making in cooperatives is handled by non-professionals in property management, which creates several challenges. The management of common properties is generally influenced by conflicts of interest and various incentive problems that at times can complicate even the simplest decisions (e.g. see [104]). The risk for neglected maintenance is considered to be greatest within cooperatives that do not have professional assistance in property management, that are small or elderly, or new constructions that according to Boverket [105] (p. 103), are located in weak market regions. As part of this project, the basis of decisions and measures taken by executive committees in a number of cooperatives has been investigated. The aim is to study how the organization of property management and the decision-making structure in Swedish cooperatives enabled or hampered the adoption of large-scale residential building applied photovoltaics (BAPV) in this housing sector.

7.1 Communal Management and Agency-Related Incentive Problems

A number of factors influence decision making within multi-owned housing, including the issues of *who* makes *what* decisions. The matter of whether to finance measures through loans or other means will to a large extent depend on the demographic composition of the members [106]. The lack of easily accessible information required to make qualified decisions in combination with the executive committee’s lack of formal training creates difficulties in deciding between various options. This and the fact that committee members are volunteers is a problem that is compounded under self-management [105,107]. Furthermore, as building maintenance in this sector is usually outsourced, the committee also faces a challenge in having to monitor a third party’s performance [108]. Most of the challenges in the management of multi-owned properties, as well as the decisions taken, can be related to agency theory and various incentive problems.

When one or more persons [the principal(s)] engage another [the agent] to perform a service on their behalf, they delegate a portion of the decision making authority to the agent [109]. In a housing cooperative, these agency relationships are present in various forms according to the character of the activity at hand. For example, a property company or contractor serves as an agent of the executive committee, while the committee is an agent of the cooperative members. Due to the common ownership structure, any positive effects gained from an activity are shared equally among all of the members. This leads to incentive problems, where some members might avoid collective duties while partaking in the profits, which can be reflected in the management of the properties.

Three of these management problems are investment-related: the common property problem; the horizon problem and the portfolio problem. Four others are decision related; the monitoring problem, the follow-up problem, the influence-cost problem, and the decision-problem [104,110]. Challenges associated with incentive problems can be linked to tendencies of free riding and apathy among members, which leads to inefficiency and weak membership commitment, and together with myopic perspectives prioritize investments with short payoff horizons. Another challenge to decision making is the fact that the cost to monitor whether an agent is performing in the principal's interest might become quite steep in a situation where the cooperative is engage in complex operations. In situations where there are groups of members in the cooperative with opposing interests, unnecessary costs will be incurred due to internal lobbying activities aimed at swaying the decision makers towards a particular action. If the opinion among the members is widely varying, it becomes difficult for the executive committee to decide how to weigh the different members' views and might opt for a measure that is a suboptimal one [104].

7.2 Decision Making

Studies on the Swedish cooperative housing sector carried out within the Division of Building and Real Estate Economics at KTH have shown that in general, the persons that sit on the executive committees are well educated and that the majority are mostly middle-aged men. One explanation for the high number of males is that much of the decision making in attached cooperatives happens in negotiations with the national organizations [9]. Middle-aged men may be considered to be more able than young women to speak the technical and economic language of the professional managers in those organizations. However, this does not explain the observation of similar setups in the unattached TOCs. The average size of the dwellings also has an influence on the composition of the executive committee, but there is a low degree of participation by the members on collective actions (only 30% on average) regardless of the location or the number of dwellings in the cooperative.

Research within the sector reveals that it is not so much the general composition of the committee, but the presence of a strong spirited person(s) that often sways the decisions and consequently the kind of measures adopted [111]. The age of the cooperative is another major factor that influences the main focus of the executive committee's work, where young cooperatives handle issues related to financial indebtedness and significant maintenance needs dominate in the old.

Most cooperatives have difficulties in recruiting committee members, who are typically compensated with an annual dinner or symbolic cash gratuity of about 6000 SEK per year and person. Though competency in legal and financial matters is not very high, many committees utilize the help of non-committee members who have professional knowledge, especially those located in high property value areas in the major cities. A questionnaire sent to over 790 cooperatives revealed that many executive committees rarely base their maintenance decisions on the economic analysis of different alternatives when deciding between large-scale activities. Measures are prioritized based on the immediacy of repair or if maintenance needs becomes visibly noticeable, such as a failing façade. The risk for acute problems is by far the most important factor influencing the decision to carry out measures, followed by the need to lower operating costs and concern for the environment in third.

As lay persons, the executive committee members are aware that they lack professional property management competence. However they see themselves as sensible enough to know when to engage qualified consultants, which results in a very high degree of outsourcing. A major challenge is that the market for facility management services aimed towards large cooperatives is dominated by just a few actors. Furthermore, services in most of the builder-sponsored cooperatives are principally outsourced to the attached national organizations, limiting competitiveness. Principal-agent problems are particularly common in cooperatives with newly constructed buildings, where many find themselves unwittingly tied to long term technical service provision contracts with subsidiaries of the builder-sponsor firm. At times these types of contracts hinder decisions, for example a switch to more efficient energy equipment in the case where this is not part of the energy suppliers business.

A majority of the measures taken in cooperatives are often of a simple character, such as painting the stairways or securing the main entrances to the buildings, rather than the installation of geothermal heating or solar panels. There is a general lack of long term maintenance plans, and where such plans exist they are not always adhered to. In a study on barriers to energy efficiency measures within cooperatives attached to Riksbyggen, af Klintberg et al. [112] identify that hidden short-term incentives of some members can obstruct energy-efficiency measures, even when these would have positive effects for the cooperative (pg. 94). The age distribution of the members also plays a major role with financing related decisions, and the choices are not always based on an economic analysis of what is best for the cooperative since older members tend to be reluctant to take new loans.

Studies carried out in Stockholm revealed that cooperatives with a high apartment turnover frequency did not want to adjust monthly fees, as this was perceived as detrimental to the selling prices of the apartments. Many cooperatives with aged buildings also prioritize maintenance activities that are more likely to be financed without raising the monthly fees, a condition that in many cases leads to neglected maintenance. Though most have a maintenance reserve fund, it is viewed as "*an insurance against unexpected costs*". And when large-scale renovations were carried out this fund was rarely touched, especially in the older associations. Many of the older cooperatives also have amortized their mortgages, and while some are in a position where they could afford to lower their monthly fees, they have not done so [112].

7.3 Empirical Study on Adoption of PV

For the PV research project reported here, semi-structured interviews have been carried out in a group of seven purposively sampled cooperatives whose executive committees expressed a wish to install or had already installed a PV system [113]. The aim was to find out the motivations for installing/exploring PV on the cooperative's roofs, and in the cases where PV had been installed how the work had been organized and the challenges encountered. The results reflected many of the factors that influence decision making in cooperatives given above, with a need to lower operating costs leading over environmental awareness as the major factor behind the decision. The study further confirmed that economic analysis is not always used before measures are undertaken, even in cases where substantial capital is required.

Not all energy efficiency measures are economically worthwhile for a cooperative, as indicated by Case 1 reported in [113] and Cooperative A in [41]. The study further highlighted the various principal-agent relationships that had a major influence on the successful adoption of BAPV. However, the dependency on "champions of the cause" in carrying through various measures raises concern as some of these champions might have motives that are not always apparent in the short term.

The general conclusion is that property management within the cooperatives is dependent on individual efforts, which also influences the decisions taken. They are also influenced by factors and problems that are common within communal properties. Thus policies promoting energy efficiency and a sustainable environment within cooperatives also need to focus on promoting and raising the degree of competent decision making by the committee members in their role as agents of the cooperative. Regular utilization of economic analysis tools, such as those presented in this report, can raise proficiency when choosing between various alternatives and in procuring advisory help.

8 Case Studies

Understanding the complex dynamics surrounding energy and decision making can be aided through the experience of others, particularly first movers or early adopters. A number of interviews and case studies have been made with cooperatives around Sweden who have installed or are considering installing solar PV systems. The cases represent a wide array of applications, approaches, and outcomes, helping to give a broader understanding of the various challenges and opportunities present in real world conditions. Presented here are short descriptions of the systems, the experience from the executive committees, and techno-economic calculations considering the boundary conditions presented in Chapter 6. Not all cases have the same level of detail, and assumptions and omissions are noted where necessary. Hourly solar production values are calculated using System Advisor Model (SAM) [114].

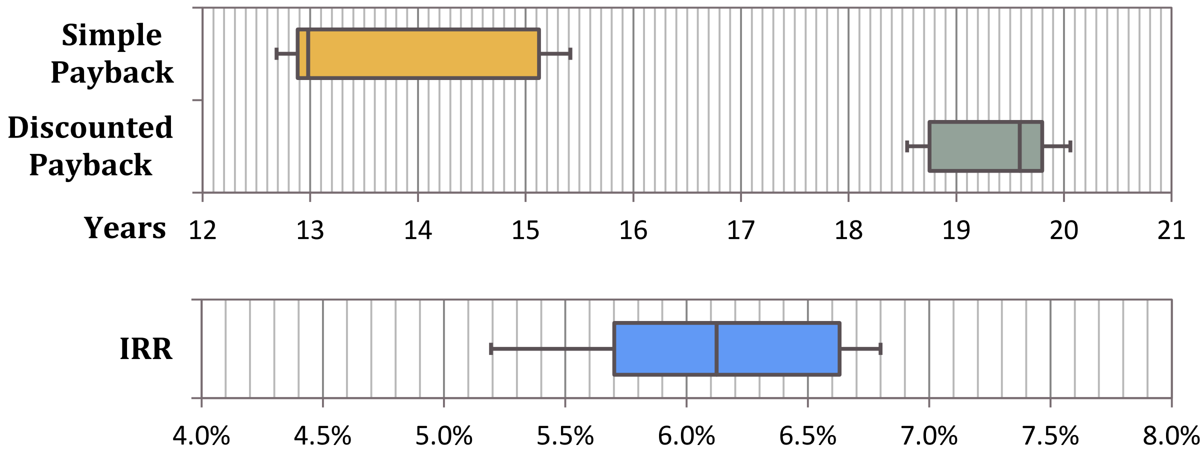
8.1 Cooperative A

Cooperative A was built in 1966 in Gothenburg and 312 apartments spread across 13 buildings. Six buildings had PV systems installed in 2014, each with 16 kW_p for a total of 96 kW_p. The total installation cost 1.62 MSEK with VAT (16.9 SEK/W_p), however the 35% capital rebate available at that time brought the cost down to 1.05 MSEK (11.0 SEK/W_p). Green certificates on over production are the only additional support considered.

All six systems face due south at an estimated 30° tilt with no nearby shading, resulting in an annual production of 940 kWh/kW_p. The PV is only associated with the communal loads handled by the cooperative, meaning apartments are not included in the load profiles. Four of the six apartments have laundry rooms; however those without still have relatively high annual demands suggesting the buildings are larger. Hourly load values for each building with PV under 2013 and 2014 were supplied by the local utility and averaged together to create the final load profile. The PV generates 49% of the buildings' communal demand and self-consumption is 64%.

The low installation cost after rebate, high production, and high self-consumption combine for some very good economic outcomes, shown in Figure 52. There is a 100% chance of profitability, most likely payback times are 13.0 and 19.6 years for simple and discounted, respectively, and the real IRR is most likely to be above 6.1%. The unusual distribution for simple payback time is due to the close timing with inverter replacement, which can cause cash flow to be negative for a year.

Figure 52 - Economic outcome distributions for Cooperative A



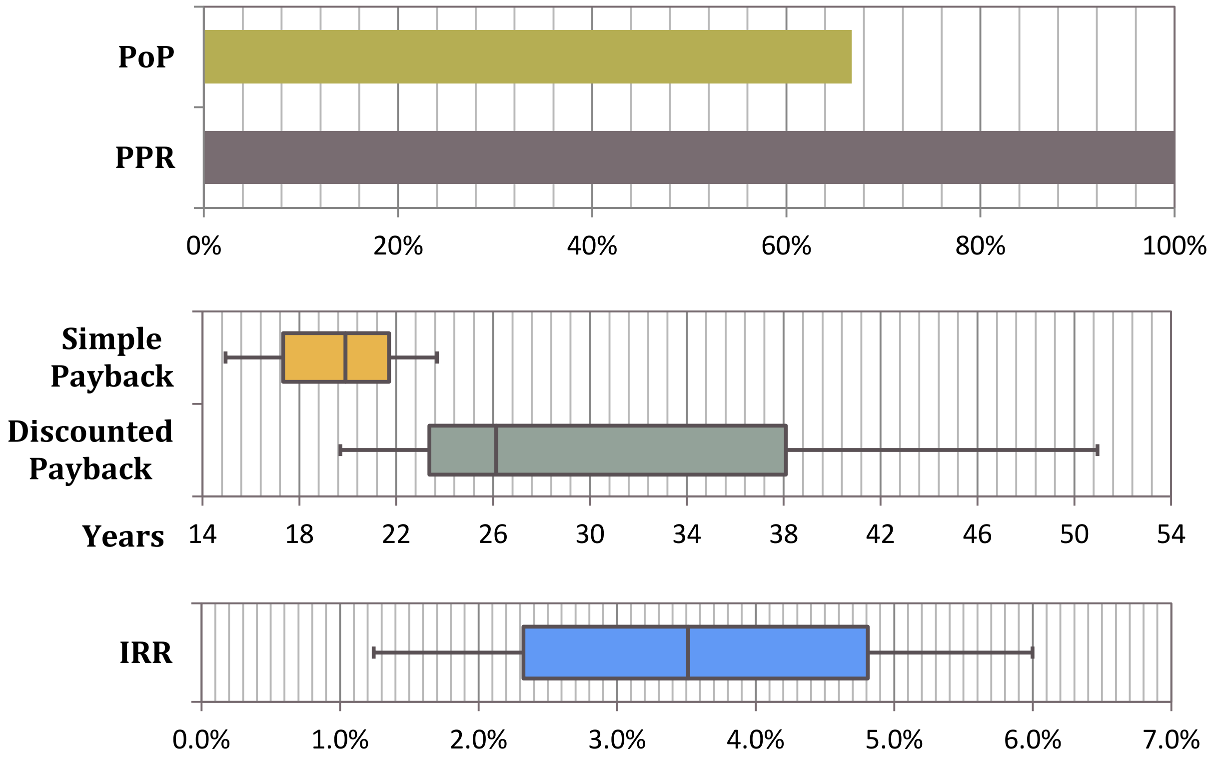
8.2 Cooperative B

Of the cooperatives presented here, this is the one which had not installed a PV system, but was interested in learning about the opportunities. The cooperative was built in 1968 with 506 apartments and has 12 low-height buildings (2-3 stories). The roofs have a predominantly east-west orientation, but there are eight buildings with potential for south facing arrays. Using satellite images, it was determined that 328 kW_p of PV could be installed. However with the potential for systems above 255 kW_p to be subject to electricity consumption tax, this was set as a maximum until further decisions are taken by the government.

Measured load data has been supplied from three buildings; two with laundry rooms and one without. If 60% self-consumption is targeted, then the buildings without laundry rooms can have a system up to 6 kW_p and those with laundry are limited to 20 kW_p. Only three of the buildings with southern facing roofs have laundry rooms, each with enough roof space for 20 kW_p. If all of the buildings had PV installed, it would total 90 kW_p.

The investment analysis results are shown in Figure 53, which include a 15% capital rebate and green certificates on overproduction. The outcome is slightly worse than the generic, most likely case presented in Section 0. This is not surprising since the system was designed to have a 60% self-consumption rate and the FiB is not included. However there is a considerable amount of roof space left unused due to the demand limitations of the buildings without laundry rooms, and installing many smaller systems is likely to have a higher cost than installing the same capacity on fewer roofs. Therefore it may be interesting to explore the option of including apartment loads.

Figure 53 - Economic outcome probabilities for Cooperative B considering communal loads

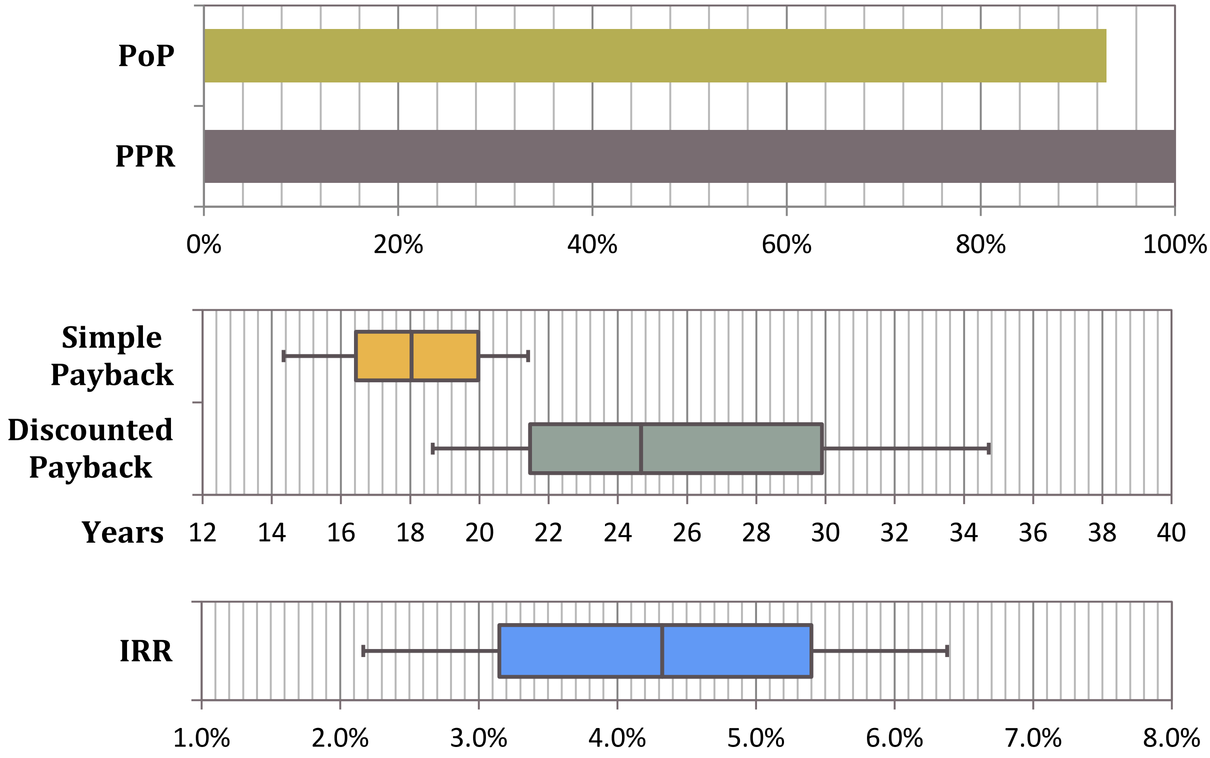


Including apartments will have the greatest effect in buildings without laundry rooms, particularly since those buildings tend to be larger and have more apartments. On average, each building could add another 100,000 kWh of annual demand, which is three times greater than the non-laundry equipped buildings and double those with laundry. The non-laundry buildings have space for approximately 50 kW_p, which means three will have 50 kWp installations and one will have 40 kWp. In total with the three 20 kWp systems on laundry equipped buildings, there are 250 kW_p.

In the laundry equipped buildings, this results in a self-consumption rate of 99.8%, and in non-laundry buildings self-consumption is 87%. It is assumed that apartment loads are self-metered in all buildings, not just those with solar, which at a cost of 1400 SEK/meter[34] is an additional 700 kSEK cost, or 2.8 SEK/W_p. It is also assumed that there will be an additional administrative cost of 10,000 SEK/year to monitor and bill the apartments. All other inputs and assumptions remain the same.

Including the apartments does improve the economic forecasts, but how significant the improvement is can be debated. As Figure 54 shows, the probability of profitability is notably better, increasing from 67% to 93%. Payback times are reduced only slightly and IRR increases 0.8%. However it should be noted that the replacement meters are a fixed cost independent of system size. If there were no risk of being taxed with a system larger than 255 kW_p, then it may be more economically interesting to cover all southern facing roofs and have a larger system. The larger system naturally comes with a larger initial investment, but this also means the absolute return value is higher. In the case without apartments, the NPV is 62.5 kSEK, while in the case with apartments it is 740 kSEK. This of course comes with a considerable burden to change metering systems, which the cooperative may or may not be willing to undertake. There may also be other reasons for a cooperative to install individual meters that are separate from a PV system, in which case the meter costs may not necessarily be entire associated with the PV investment.

Figure 54 - Economic outcome probabilities for Cooperative B considering all loads



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[34] Based on installations made in Cooperative C

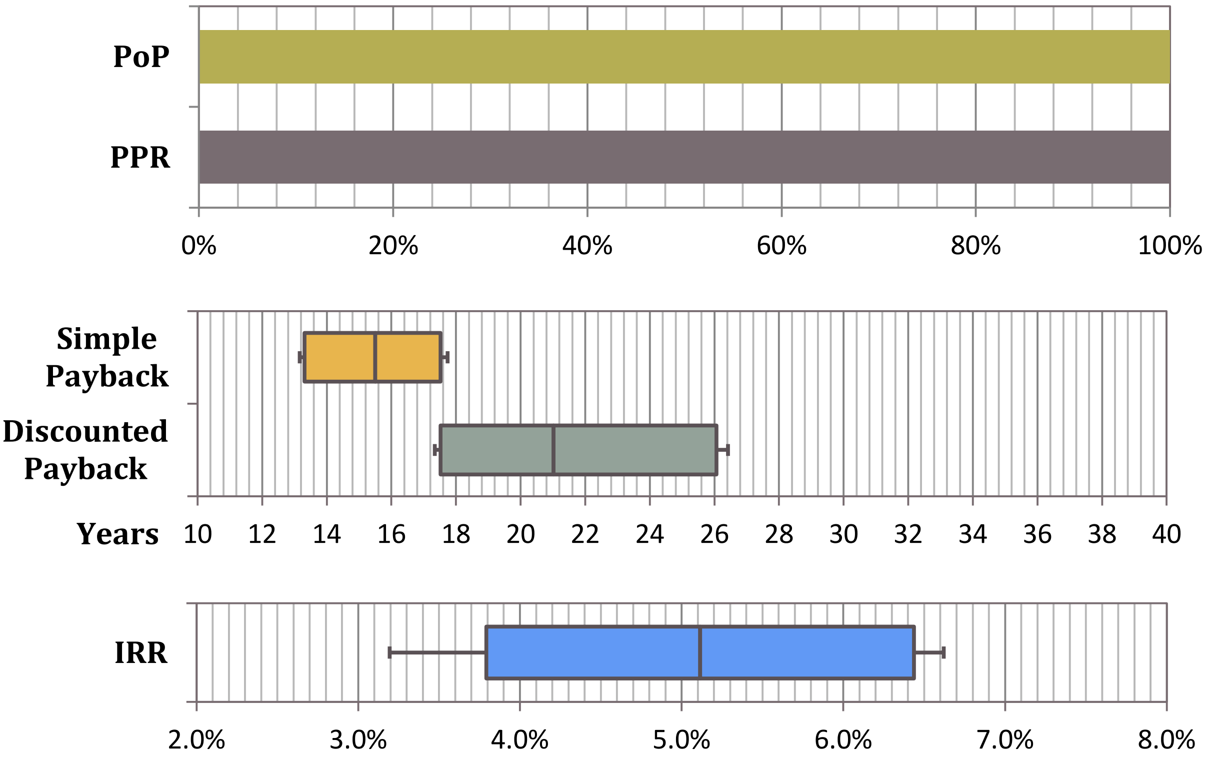
8.3 Cooperative C

The opportunity to install solar PV came to Cooperative C while planning for roof and wiring replacements in all of their 30 buildings, which were built in 1966, include 546 apartments, and are two to three stories tall. The motivations were two-fold; to reduce operating costs and CO2 emissions. Of all of the cooperatives interviewed, this one had the strongest environmental motivation. The result is a 627 kW_p system installed on 22 of their 35 roofs installed in 2012 and 2013, most of it facing south but a handful of systems also facing west, all at a 20° tilt. Total installation cost was 12.5 MSEK (20 SEK/W_p) and they expected to receive a 35% capital rebate[35].

As part of the wiring renovation, individual meters were installed on each apartment as well as DC cables run from the buildings with PV to those without. In this way they are able to use the entire cooperative's load rather than only the communal loads of buildings with PV. Hourly meter data from three sample buildings including both communal and apartment loads were used to determine the load for the entire cooperative and checked against annual values. The total load is 1640 MWh/year, production is 555 MWh/year (885 kWh/kW_p), and self-consumption is nearly 70%.

Before starting the project in 2012, the PV contractor provided an investment analysis concluding that they could expect a 5% to 13% nominal return and a simple payback period of 8-13 years. This relied on net metering, which they had a contract for but for an unknown length. Since the project started, electricity prices fell by over 60% and the government introduced the feed-in bonus. Cooperative B has been able to take advantage of the micro-producer program by considering each building its own system rather than as a collective, therefore 5 years of FiB are considered here, and the results are shown in Figure 55.

Figure 55 - Economic outcome probabilities for Cooperative C



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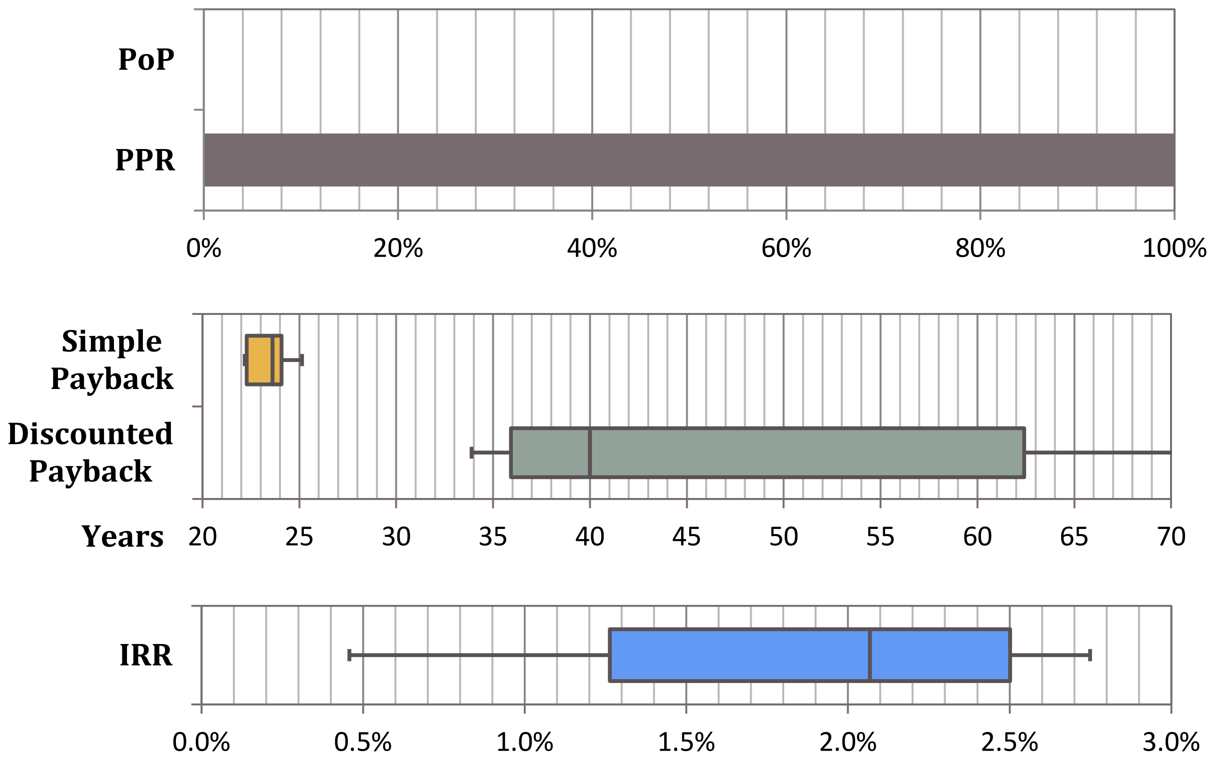
[35] At the time of the interview, they had only received 27%

The probability results here show an IRR at the lower end of the expected range, but no possibility of anything close to 11% (13% nominal). Payback times are also longer, largely due to the drop in electricity prices, which were counteracted by the feed-in bonus but not as beneficial as a lifetime of net metering. Even if not as good as expected, the system has a 100% chance of being profitable. A formal poll has not been taken, however the executive committee members believe that the members are happy with the project. They were also given an honorable mention award from the Solar Energy Association of Sweden (Svensk Solenergi).

A significant change, however, is the new tax to be placed on system owners who have more than 255 kW_p. If this were to be enacted, it would reduce the value of self-consumption by 0.293 SEK/kWh, which is about 30% of the current price. The results in Figure 56[36] show that the new tax would eliminate any chance of profitability for the system, and will extend the simple payback time to over 23 years. The investment looks much less appealing now, and may not have been made had the executive board known about the potential change. On a positive note, the system is still nearly guaranteed to earn a positive return, just not one high enough to be considered a reasonably profitable investment.

Figure 56 - Economic probabilities for Cooperative C with self-consumption tax



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[36] The 99.9% whisker for discounted payback reaches 93 years, but has been cut off for ease of viewing the primary results

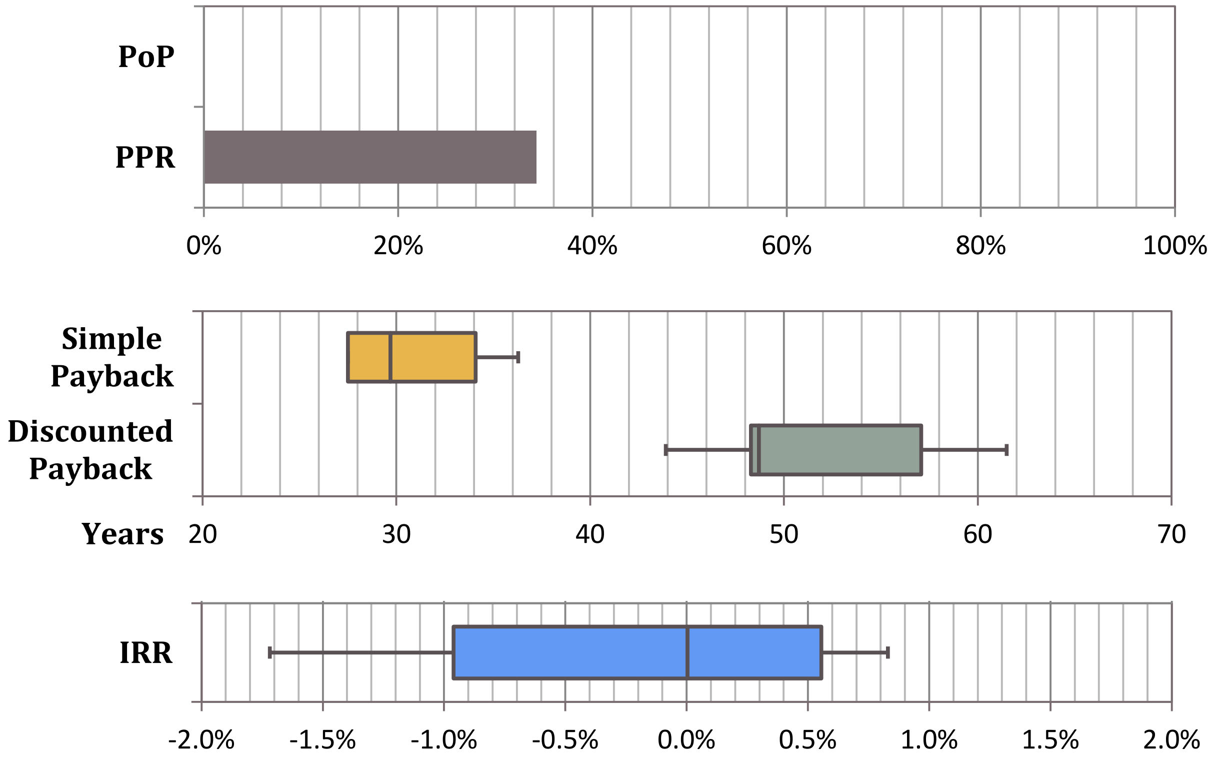
8.4 Cooperative D

Cooperative D was motivated to invest in solar energy by their high operating costs, due in part to energy costs dominated by district heating. The first plan was to install solar thermal, however the local utility would have put them in a lower volume group with higher prices, essentially negating the benefits. Therefore they switched to PV, seeking out as large a system as possible and combining all of the apartments onto a single meter. Cooperative D was constructed in 1947 and has 60 apartments in three buildings with four floors each.

The resulting PV system is 115 kW_p constructed in 2013 and mounted on east and west facing roofs. Typically, this arrangement would produce 700 kWh/kW_p per year, however there are a high number of obstructions on the roof (chimneys and vents) which partially shade much of the system nearly the whole day, every day. The result is an annual production of 560 kWh/kW_p. The system cost 2.1 MSEK (18.3 SEK/W_p) and a capital rebate of 35% was received. Hourly load values were made available, however the solar production was not separated from demand, making it difficult to determine the load profiles. Self-consumption rate, which is 55%, was instead calculated from the metered overproduction and the modeled annual production.

The executive committee never conducted an investment analysis for the PV system, only the original thermal collectors. The PV project manager estimated a 10 year simple payback time, but it is unknown what that estimate is based on. The results in Figure 57 are much less positive, with the most likely simple payback time being nearly 30 years, an IRR of 0%, and no chance of the project becoming profitable. It is very interesting to see that the probability of principal return is 34% which is the first time that figure has been anything other than 100%.

Figure 57 - Economic probabilities for Cooperative D



As the costs were not particularly high after rebate, and the self-consumption is not extremely low, the primary cause of the poor results can be attributed to the low annual production. If there were no losses due to shading, the IRR might be increased by one or two percent. This outcome is particularly discouraging since the process of constructing the system was notably difficult. During planning, the electric utility stated they could not connect their PV system to the grid, which was of course false. Next, the municipality planners would not issue a permit unless the roof was changed from orange to black tiles in order to match the color of the modules. All of the barriers and delays forced the two executive board members, who are professional project managers at an international manufacturing firm, to hire a project manager with experience with PV. The delays also caused a rush in contractor selection by skipping the bidding process in order to get the project completed in time to qualify for a 45% capital rebate, which was scheduled to be reduced to 35%. It was believed that this could have lowered costs by 25-30%, and the project still wasn't completed in time to receive the 45% rebate.

At the time of the interview, the cooperative was still challenging the utility over the commercial classification of the system. The large size means they do not qualify for the feed-in bonus, but they are trying to break the system up by house, similar to Cooperative C in order to get the tax rebate. There is no FiB considered in the results above. Even with all of the challenges encountered along the way, or even perhaps because of them, the board considers the project a success. They were also given honorable mention for an annual solar energy prize from the Solar Energy Association of Sweden, and should be highlighted as an example of the need for more experience and education for all actors (utilities, municipalities, and prosumers) to improve the PV installation process.

8.5 Cooperative E

The final cast study is unique from the others in that it is not connected to district heating. Cooperative E consists of 16 row houses constructed in 1992 that planned to replace their direct electric heating with more energy efficient exhaust air heat pumps. The PV system was added to the project as a way to further reduce operating costs and improve the environmental image of the cooperative. The executive committee also hoped that the lower operating costs would make the cooperative more attractive to owners and potential buyers, thus lowering turnover rate and increasing property values.

The 56 kW_p system was installed in 2013 and faces due south on a relatively steep 45° roof for an expected production of 940 kWh/kW_p annually. Total installed cost was 1.3 MSEK (23 SEK/W_p), which is relatively high and may be due to the high environmental standards for equipment, and a 27% capital rebate has been received. As is common with major infrastructure works in cooperatives, the new heating and PV systems are 100% financed. Therefore the structure of the analysis is slightly changed. The discount rate of 3% is removed and is instead applied as the interest cost of the loan. The loan is a straight-line amortization with annually updated interest rates and an assumed term of 30 years.

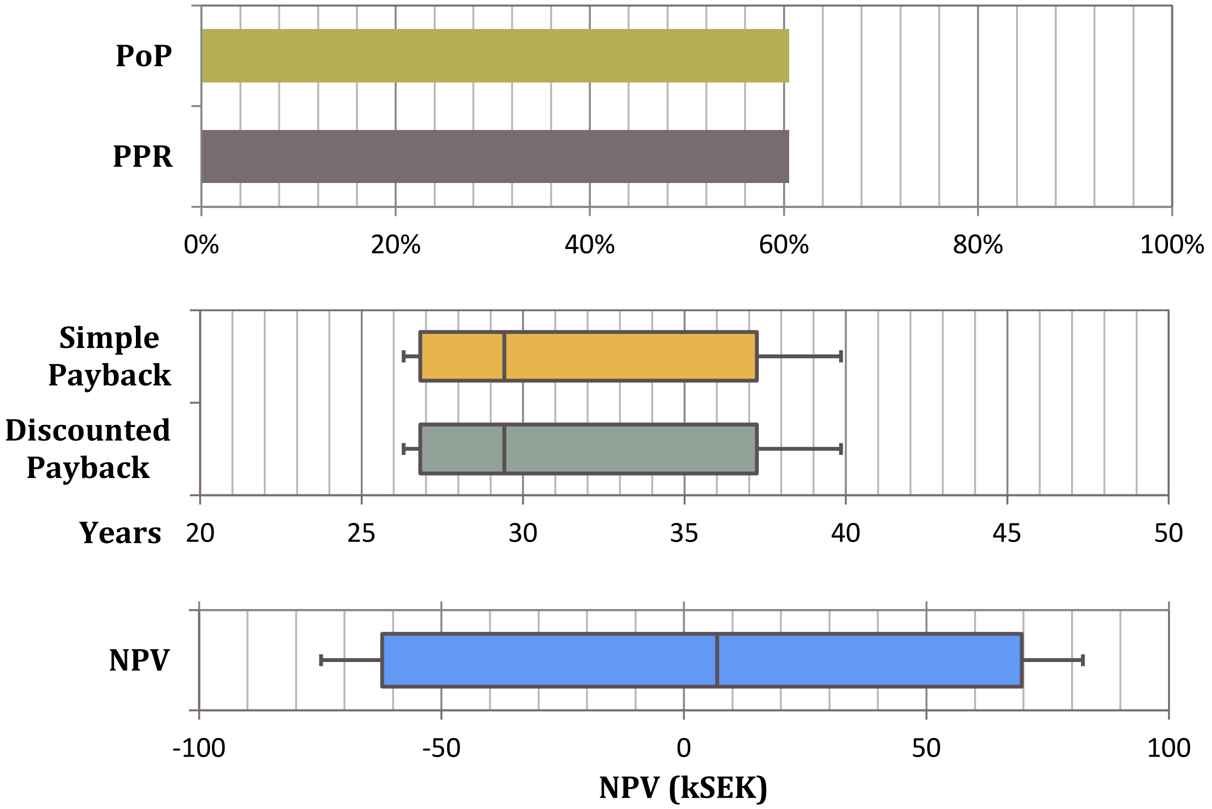
In addition to installing the new system, the metering was switched from individual apartments to a single meter for the entire cooperative, however individual metering is still done internally by the cooperative. Hourly electricity load data for 2014 was supplied and compared to modeled PV production, resulting in a 56% self-consumption rate. At the time of the interview, they had a contract to sell overproduction to a utility for the retail rate, effectively equivalent to net metering. The length of this contract is unknown but assumed to be 5 years.

Investment analysis prior to starting the project was performed by an economist in the local office of their national organization affiliate. The NPV was projected to be nearly 1 MSEK, however the results shown in Figure 58 are less positive. The NPV is just above zero, shown in the final plot which has replaced IRR to make comparisons with the original study easier. The PoP and PPR are the same due to the lack of an initial investment or discount rate, and are just above 60%.

The payback times also match due to the lack of a discount rate, but in this case indicate the year in which the project is cash flow positive since there is no initial investment to recoup. In most cases, 100% loan financed installations have positive cash flow immediately since the cost of the loan (interest + principal) is less than savings. In this case, the straight-line amortization loan combined with low electricity prices result in several years of negative cash flow that must be recouped. There is a small chance that electricity prices could rebound quickly, causing positive cash flow sooner, but it is much more likely to occur over the long term.

Beyond economics, the installation of the PV system led to an unexpected social benefit. The long and at times intense process, which necessitated regular meetings and decision making amongst the residents, increased the sense of belonging and brought the community closer together. Residents now participate in more collective activities and the turnover rate has decreased. Whether this translates into higher property prices is yet to be seen. In the interview, which occurred after the installation but before these results were calculated, the chairman of the executive committee suggested that the short term economics were less critical, and that the long term sustainability of the cooperative is more important. This is an important message for any cooperative considering a PV investment.

Figure 58 - Economic probabilities for Cooperative E



9 Conclusions

The exponential growth in PV markets around the world is being taken up in Sweden as well. While the volumes are still small, awareness and interest are growing such that more and more people are considering becoming prosumers. The results here show that PV investments in Sweden can be profitable, but without dedicated policy support the chances of earning an acceptable return are low. Taking advantage of all of the available support schemes turns an 8% chance of profit into a 97% chance, nearly a sure thing. Even what is perhaps the simplest policy, the capital rebate, is capable of creating nearly a 60% chance for profit on its own.

Even with positive investment indicators, it is important for prosumers to keep two things in mind; first, PV is going to be a long term investment. The absolute best possible payback time found was about 9 years, which is an extreme outlier, and it is much more likely to be closer to 18 years. Making a 3% real return is most likely to take close to 25 years. However, with policy support the risk is quite low. Even if it is not the desired 3%, PV is essentially certain to earn a return. Also the calculated IRRs, when compared to other low-risk, long term investments are quite competitive.

The second thing is that achieving good returns does still depend on a good solar resource and a well-designed system, which will limit the market in the short term. The three most critical factors in profitability are annual production, installation cost, and self-consumption; where self-consumption is under the most prosumer control. Production improvements are limited to simply making the best of the resources available. Installation prices continue to fall, but there is relatively little a prosumer can do to control cost other than wait or select low cost equipment (which can be a false economy in the end).

Therefore a good strategy is increasing self-consumption to boost profitability and hedge against low green certificate prices and the removal of the feed-in bonus. Ideally self-consumption rates should be 60% to 80%. In cooperatives, the simplest action to take is to target installations on buildings with laundry rooms. Cooperatives with combined communal and apartment metering will find it easy to have a high self-consumption rate, and motivated cooperatives without that setup can explore the possibility of conversion. Array sizing is also important, and in the absence of detailed modeling with hourly load values, a conservative estimate is to cover 30%-50% of the annual load with PV generation to achieve the ideal self-consumption rate in buildings with laundry rooms. For buildings without laundry, the load coverage should be lower, 15%-35%. These values apply specifically to the communal loads in cooperatives and should not be used with other building types or configurations.

The objective of this report is to provide a comprehensive technical and economic analysis of solar PV for cooperatives in Sweden. The formatting of the results are intended to capture as much detail as possible while remaining easy to interpret and relevant to as many cooperatives as possible. The use of probabilities was chosen to aid in the decision making process within executive committees, which provides a more natural language to discuss investment risks. It is also important for committees and members to take notice of the non-economic benefits PV projects have brought other cooperatives, including sense of place and pride in their actions, which in some ways have overshadowed the monetary aspect.

Policy support for PV has thus far been successful at stimulating the market without overheating like many other European countries. So long as the government maintains a rational, well-paced reduction of dedicated support, PV investments will continue to be interesting for prosumers and Sweden can continue on its path towards a 100% renewable energy system.

10 Recommendations for Future Work

At the outset, this project was given a very wide scope by covering all aspects of energy investments by prosumers. Early planning led to the generation of many interesting energy system concepts, however because the Swedish PV market is still in an infant stage, PV policy is constantly evolving, and the Nord Pool Spot price dropped over 50% after climbing for a decade, the focus shifted to handling economic uncertainty. The resulting probability models presented here are a valuable tool with yet untapped potential. The model is capable of handling hourly prices, and while that was determined not to be a significant factor in investment decision making [115], it may become more interesting after the PV system has been installed there are changes to the expected cash flows.

Assuming renewable installations continue to expand in Sweden, as well as interconnections with continental Europe, it is likely that pricing patterns will change and potentially become more volatile. Control strategies based on irradiation, load, and price models are not new, but the use of the probabilities as economic indicators provides a new assessment method that encourages additional stochastic inputs. In this study, annual prices and hourly apartment loads were constructed stochastically, but a solar irradiation model for Sweden and a load model for communal cooperative loads similar to Widén's [32] would move the whole model towards more realistic conditions. Widén et. al. [6,116,117] have already made several valuable studies with the stochastic load model, and there is room for continued expansion.

The use of a complete stochastic model could be applied towards the larger goal of managing high fractions of solar energy in buildings. Building energy systems that combine electricity, heat, and transport with demand, production and storage have yet to be adequately designed or implemented *en masse*. This type of model could be used to develop storage technologies and controllers that optimize for economy, grid stability, or unique outlier events.

The introduction of probabilities into prosumer investment is perhaps the principal contribution of this work. Using the language of probabilities allows the introduction of prospect theory, the foundation of behavioral economics by Kahneman and Tversky [96,97], which describes human decision making in terms of costs, benefits, and probabilities of occurrence. While this can be useful for describing human behavior in experiments, collecting feedback from prosumers about their insights, expectations, and preference with regards to PV investment is necessary to determine the usefulness of this model as a tool for technology diffusion.

Therefore an interesting extension of this project would be to build on online solar investment assessment tool for use by the public. Existing tools are either extremely simplistic so as to be understood by novices, or overly complex as to capture all of the necessary details. Most of the inputs to this model do not need to be given by the user, and those that are user specific may be retrievable with modern ICT. For example, by entering an address, it could be possible to access a 3D solar map to get PV production potential (resource and size) and meter data from a utility database, and when combined with all of the existential inputs produce similar investment analysis as presented here. Preference or opinion data from users could be collected through the tool, which would help develop the predictive abilities of the model. Google has recently started a build out of this concept called SunRoof[37], but there is much more that could be done.

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Appendix A Equations for Economic Indicators

Costs (C) can be divided into one-time and reoccurring costs. One-time costs include the PV system and installation (I_0), while reoccurring costs include operations and maintenance (OM_t) and financing (F_t). A one-time VAT tax on the system (T_0) is included as well as the required payment of VAT on income from oversold electricity (T_t). Capital gains tax on grid sales income is omitted (i.e. before tax) due to the individual nature of tax liabilities due to losses/gains and discounts. Equation (1) below represents the non-discounted lifetime costs in a PV system.

$$C = I_0 + T_0 + \sum_{t=0}^{L} [OM_t + F_t + T_t] \tag{1}$$

Benefits (B) in this case are defined as direct economic benefits, and are represented in non-discounted form by Equation (2). It consists of a one-time capital subsidy (S_0) and three operational components; savings from deferring purchases of grid electricity (Q_d) at the retail price (P_r), sales of excess electricity to the grid (Q_e) at the wholesale price (P_w), and earning of meter based subsidies with their own quantities (Q_s) and prices (P_s) for which they qualify. For this study meter based subsidies are in the form of green certificates and the feed-in bonus. Green certificates are applied to the entire production and to only oversold electricity in separate cases, while the feed-in bonus is limited to overproduction.

$$B = S_0 + \sum_{t=0}^{L} \left[(Q_d P_r) + (Q_e P_w) + \sum (Q_s P_s) \right]_t \tag{2}$$

The foundation for most indicators is a discounted cash flow analysis, where the costs and benefits for each year are discounted back to the investment time. The discount rate (d) can be nominal (includes inflation) or real (excludes inflation) so long as it is used consistently throughout the analysis. Real discount rates and prices are assumed in this study. It should also be note that the time series starts at year zero, meaning initial costs and benefits are included in the summation rather than being added separately, which can sometimes be seen.

Table A-1- Equations describing the economic indicators

Indicator	Equation	Units	Eq. Number
Simple Payback Time	$SPB = T \text{ where } \sum_{t=0}^{T} [C_t + B_t] = 0$	Years	(3)
Discounted Payback Time	$DPB = T \text{ where } \sum_{t=0}^{T} \frac{C_t + B_t}{(1+d)^t} = 0$	Years	(4)
Internal Rate of Return	$IRR = d \text{ where } \sum_{t=0}^{L} \frac{C_t + B_t}{(1+d)^t} = 0$	Percentage	(5)
Net Present Value	$NPV = \sum_{t=0}^{L} \frac{C_t + B_t}{(1+d)^t}$	Monetary	(6)

Appendix B Sensitivity Analysis Results

This appendix includes spider graphs showing the sensitivity of the net present value (NPV) relative to the percentage of changed input. NPV is used for two reasons; first, all of the potential inputs have an effect on NPV (e.g. discount rate does not impact SBP or IRR); second, using currency as the unit makes it easier to put the sensitivity into perspective of the entire investment value. This second point is handled by presenting results as ratio of the resulting difference in NPV to the original investment value.

The base case inputs and discussion relevant to their results can be found in Chapter 6.2 and the minimum and maximum values used for each variable are listed in Table B-1. The limits are chosen based on plausibly assumed values from previously published studies or market data. To isolate the effects of discounting on changing electricity or green certificate prices, a constant price used for the lifetime rather than using growth rates or the price paths in Figure 40. The base electricity price is the average value from Scenario B and the green certificate price is the historical average of the program.

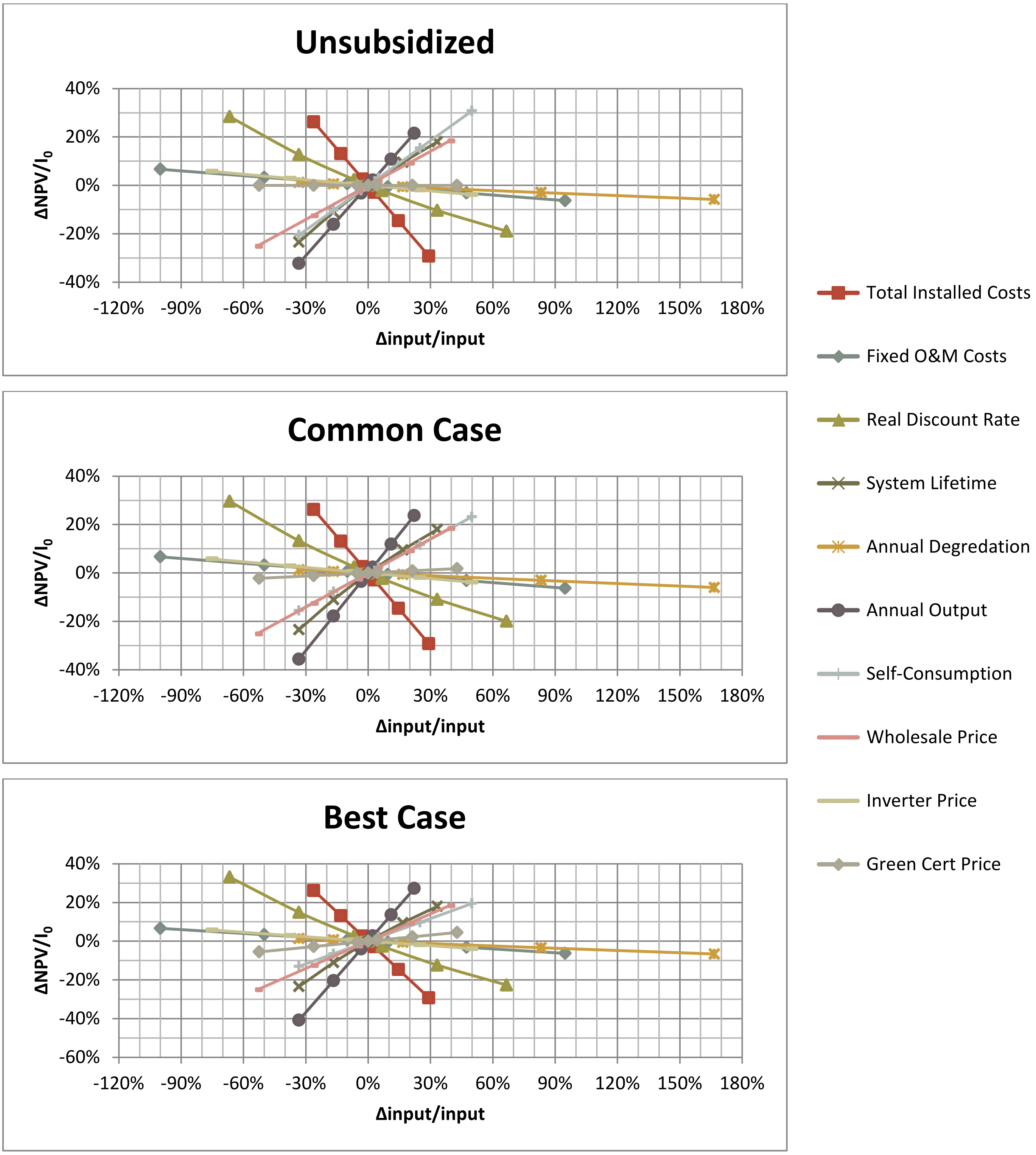
Table B-1- Sensitivity analysis input variables and values

Variable	Units	Minimum	Base Case	Maximum
Total Installed Costs	SEK/W_p	12	16.25	21
Fixed O&M Costs	% of I_0	0%	0.25%	0.75%
Real Discount Rate	%	1%	3%	5%
System Lifetime	Years	20	30	40
Annual Degradation	%	0.2%	0.3%	0.8%
Annual Generation	kWh/kW_p	600	900	1100
Self-Consumption Rate	%	40%	60%	90%
Wholesale Price	SEK/kWh	0.20	0.43	0.60
Inverter Price	SEK/W_p	0.5	2.0	3.0
Green Cert. Price	SEK/kWh	0.10	0.21	0.30

Due to the variety of potential cash flows caused by the various policies (e.g. inclusion of green certificates), each policy scenario has been tested and the results shown in Figure B-2. The results are very similar between cases with the only two notable differences; annual output, discount rate, and green certificate prices become more sensitive as the subsidies increase, and self-consumption becomes less sensitive as subsidies on overproduction sales are increased. But these differences do not change the major trends/conclusions from the study.

The data shows two groups of variables, one higher and one lower in criticality. The higher group has not only steeper curves, but nearly all maximum values are ±20% or greater. The other group is notably smaller, ±7% and lower. Therefore the Monte Carlo analysis will consider only those from the more critical group, which includes; total installed cost, annual generation, self-consumption rate, system lifetime, real discount rate, and wholesale price.

Figure B-2 - Sensitivity analysis results for each policy scenario case



Appendix C Monte Carlo Models and Inputs

The models and distributions for the nominal inputs described in section 6.2 are described. The selection of random inputs is done using Excel VBA's *Randomize* and *Rnd* functions, and is performed independently for every input and selection rate as needed. All simulations are performed with 100,000 iterations, which conversions to a variance of 0.01 SEK in the net present value.

C.1 Distributed inputs

Inputs which exhibit random variability without influence from previous time periods are determined with probability distributions. In some inputs, values are selected for each time step and others are only required once per iteration, which is listed in Table C-1.

Table C-1 - Distributed inputs and their selection rates

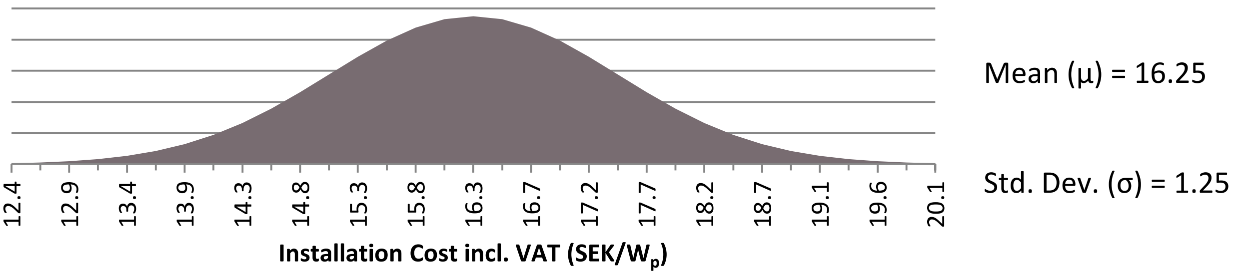
Input	Distribution	Selection Rate	Units
Installation Cost	N(1.80,0.139)	Once per iteration	SEK/Wp
Annual Generation	N(900,39.6)	Once per year	kWh/kWp
Self-consumption Rate	U(57,63)	Once per year	%
System Lifetime	Wei(30.5,23.5)	Once per iteration	Years
Real Discount Rate	Γ(15,0.002)	Once per iteration	%

C.1.1 Installation Cost

A wide variety of factors can influence quoted installation costs, including but not limited to; equipment quality, installer experience, and roofing conditions. Once an installer is selected and a contract signed, prices can still vary due to unforeseen building works, delays, or changes in equipment price. Alternatively, projects with longer build times could see equipment prices drop during the construction, leading to downward pressure on the final cost.

Without more data regarding known post installation costs and the potential for them to be altered higher or lower from the median, a normal distribution is assumed with 16.25 SEK/W_p (incl. VAT) used as the mean/median/mode as defined in section 6.2 and shown in Figure C-2 The spread of claimed installer prices {12.5, 20} are assumed to be the 99% bounds of the distribution, resulting in a standard deviation of 1.25 SEK/W_p.

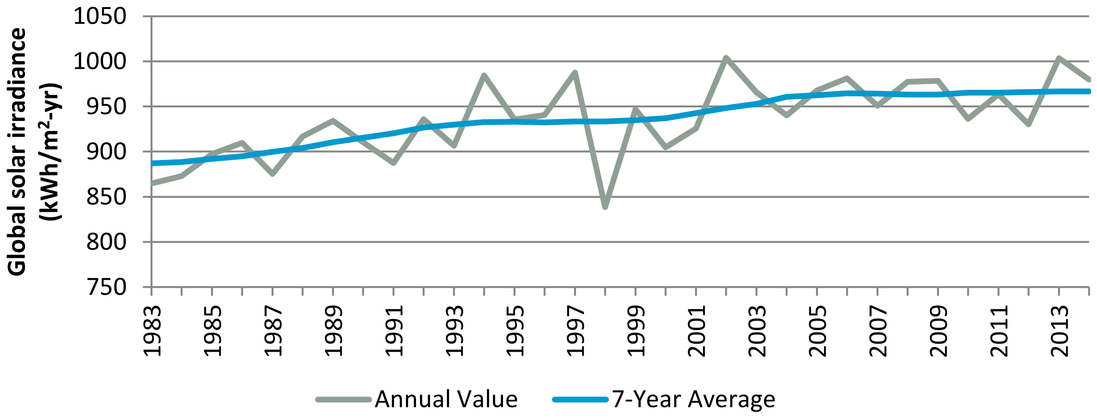
Figure C-2 - Normal distribution of installation cost (incl. VAT) based on published cost data



C.1.2 Annual Production

The assumed typical annual PV generation is 900 kWh/kW$_p$, which can be derived from a wide variety of system locations and orientations. However, considering a given system with this expected generation, the strongest driver of variation will be irradiation. The solar irradiation map shown in section 3.1 indicate optimal annual values, however solar resources vary from year to year. Figure C-3 shows this variation with combined weather station data combined from several locations in Sweden [118].

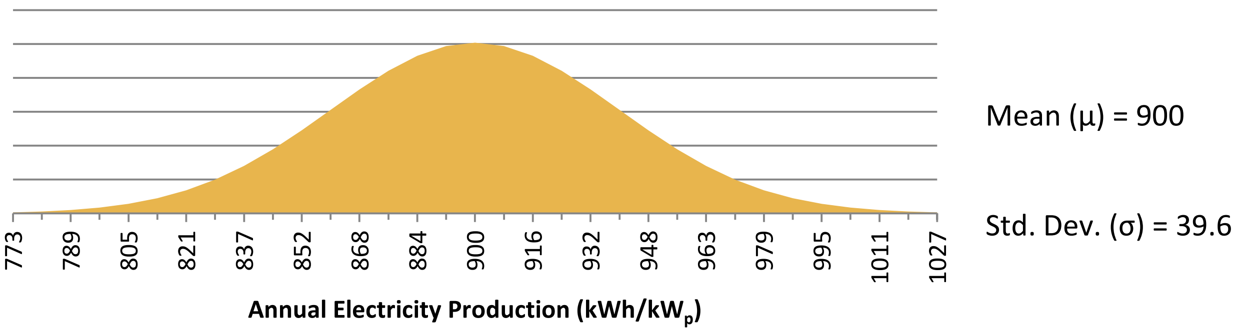
Figure C-3 - Combined global solar irradiation measurements for eight stations across Sweden



The observations show a trend of increasing irradiation at a rate of about 0.3% per year. There are some climate change models which suggest there may be a reduction in annual solar insolation in the Nordic region in the future [119,120]. Therefore if it's assumed that the measured trend and modeled predictions cancel out, the mean production could be expected to remain constant for the life of the system.

The mean and standard deviation of the measured irradiation values are 936 kWh/m^2 and 41.2 kWh/m^2, respectively. A Kolmogorov-Smirnov test of the measured values against a normal distribution results in a Lilliefors significance of P=0.200, confirming the fit. Therefore a normal distribution is assumed, shown in Figure C-4, for PV generation around the assumed mean of 900 kWh/kW$_p$-yr with a standard deviation of 39.6 kWh/kW$_p$-yr based on the mean-to-standard deviation ratio of the irradiation data equal to 4.4%.

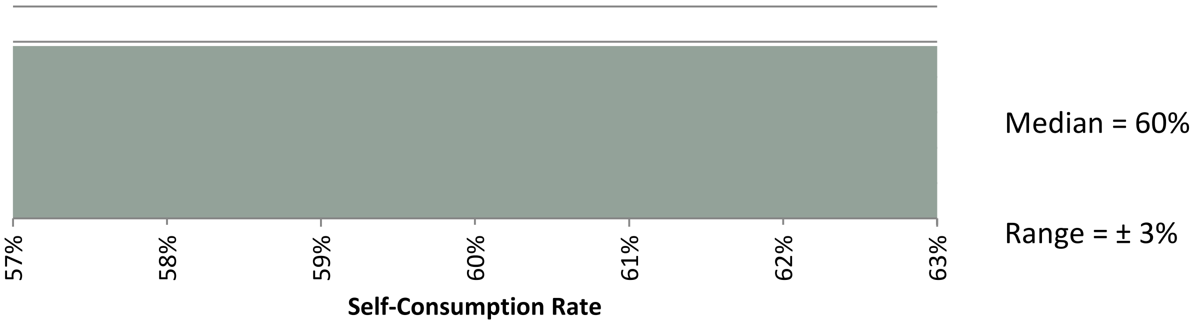
Figure C-4 - Normal distribution of annual production based on solar variability



C.1.1 Self-Consumption Rate

As discussed in Chapter 3, self-consumption is driven by system size, orientation, and the load profile. For a given system and building type, it was shown that the range of possible self-consumption rates can be nearly 20 percentage points. The stochastic nature of weather and human behavior will likely lead to annual variations in self-consumption, however the amplitude of this variation within a single building from year to year is unknown. For a single building with mostly the same occupants and activities, it is assumed that the variability is not as significant as it might be between buildings. Using a single year of hourly load data from the case studies and adjusting modeled generation values suggest outer bounds of ±3 percentage points from the median 60%. Since the exact pattern is unknown without additional load data, the distribution is assumed to be uniform and shown in Figure C-5.

Figure C-5 - Uniform distribution for self-consumption rate

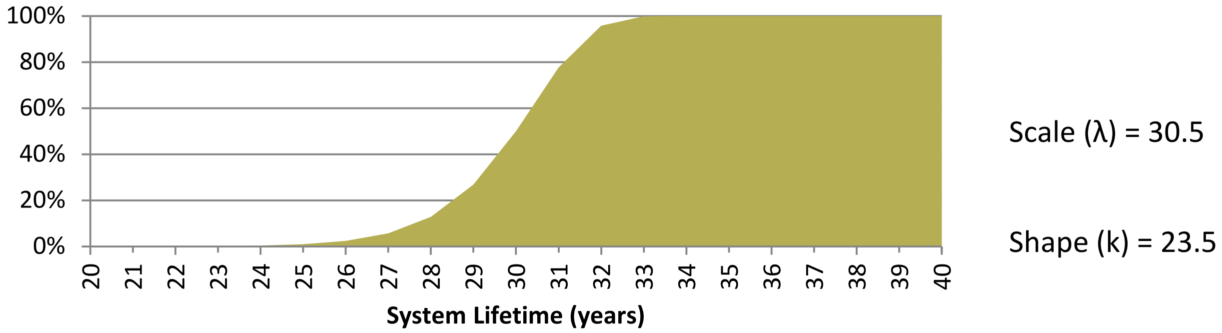


C.1.2 System lifetime

The difficulties of establishing a firm end-of-life for a PV systems discussed in section 2.4 apply to distribution selection as well. Weibull distributions are commonly used to describe product end-of-life studies across industries, including power electronics [121], and therefore used here. The expected system lifetime (L_i) is the median, thus determining the scale (λ) with Equation (7). Given that manufacturers typically offer 25 year power warranties, 1980's modules have shown a 5% failure rate of their 20 year warranties [17,18], and that manufacturing techniques has improved considerably since then, the shape (k) is then set such that there is a 1% chance of failure before the 25 year mark, resulting in a shape value of 23.5. The resultant cumulative Weibull distribution is shown in Figure C-6. To avoid unrealistic scenarios where the inverter is replaced directly before the end of life (e.g. inverter life is 15 years and the system life is 32 years), the inverter life is adjusted to be half of the system life such that only one replacement is necessary.

$$\lambda = \frac{L_i}{(\ln 2)^{1/k}} \tag{7}$$

Figure C-6 - Cumulative Weibull distribution representing system lifetime

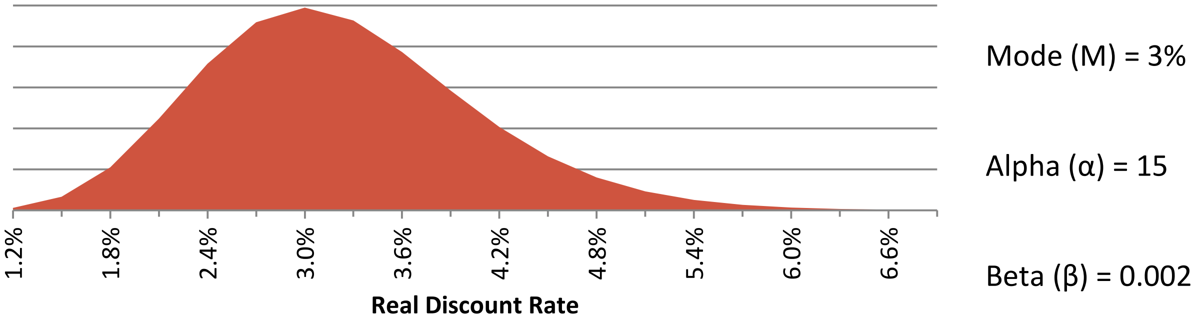


C.1.3 Real Discount Rate

In the main Monte Carlo analysis, the PV purchase is made with cash rather than debt, therefore the discount rate is assumed to represent the opportunity cost of not investing the money elsewhere. Considering several major central bank indices over the past 25 years, the current cost of money is relatively low in Sweden [122], suggesting that real investment returns can generally expected to be lower than average. As real interest rates have been much higher in the past, it is possible they could return to high levels after the PV investment is made and thus would be a missed opportunity. Since there is a possibility for a higher increase than decrease in discount rate, an asymmetrical gamma distribution where 0.03 is the mode (M) and alpha (α) is 15, resulting in a beta (β) of 0.002 using Equation (8). The distribution is shown in Figure C-7.

$$\beta = \frac{M}{\alpha - 1} \tag{8}$$

Figure C-7 - Gamma distribution representing discount rate



C.2 Time series inputs

Inputs which are randomly fluctuating but have additional influences which bounds their fluctuations over time cannot use distributions, but require a time series model. One option is a geometric Brownian motion (GBM) model with mean reversion, which has been used as a prediction tool for electricity prices in several energy investment analysis studies [123–127]. There are three terms that determine the price at each time step; the long term mean (δ_t), a volatile stochastic variable ($\sigma P_{t-1} W_t$), and the mean reversion ($\alpha(\delta_{t-1}-P_{t-1})$), which can be seen in discretized form in Equation (9).

$$P_t = \delta_t + \sigma P_{t-1} W_t + \alpha(\delta_t - P_{t-1}) \tag{9}$$

In Chapter 5, it is explained that wholesale prices are set hourly while retail prices can be set hourly, monthly, annually, or even over multiple years. The most common and fastest growing retail contract is for prices to adjust monthly. While there has been little consistency in pricing patterns since Sweden joined Nord Pool, in general prices tend to be higher in the winter since that is when the demand is highest. In most years the difference in average values is unremarkable. Additionally, the daytime prices tend to be higher than nighttime, especially in summer. However the long term impact of these pricing details on PV investment is relatively low. Sommerfeldt and Madani [115] showed that there was less than 5% error in NPV when considering average annual prices as compared to hourly. This finding is consistent with previous studies on hourly pricing, where variations are not economically significant enough for consumers to modify their behavior [128,129]. Therefore, PV production, household demand, and pricing are considered on an annual basis.

C.2.1 Long Term Mean

In a traditional GBM, the long term mean (δ_t) is determined with a fixed rate of change, known as drift. A novel modification in this model is that custom, non-constant price paths can be used to represent more complex market developments. Additionally, multiple price paths can be considered in a single simulation where each path is given a probability of occurring. This allows the analysis of multiple market development scenarios in a single simulation.

The drift component of the GBM is determined by the wholesale price paths of the NEPP scenarios. The selection of a scenario is done at random for each iteration based on the probability of that scenario occurring. Based on the feedback from the expert panel in the Delphi study (results in Appendix F), the probability of each scenario has been defined as;

- Scenario A: 15%
- Scenario B: 40%
- Scenario C: 10%
- Scenario D: 35%

C.2.2 Volatility and Mean Reversion

The stochastic term consists of three variables; volatility (σ), price from the previous time step (P_{t-1}), and a Weiner process (W_t). Considering the average annual prices in the Nord Pool wholesale spot market, the volatility has been 0.356. If it is assumed that volatility will remain constant into the future, the prices generated by the time series model should target the same volatility, discussed further in the next section.

The stochastic nature of the Weiner process means it is possible for unrealistic developments to occur, i.e. extended periods of very low or very high values. Since prices are a market signal, profit seeking actors respond during times of unusual circumstances which force prices back to the long term mean [78,130]. The strength of the response varies depending on the time scale and market conditions; therefore a response modification term (α) with a range from 0-1 is applied to the previous price's distance from the long run mean (δ_{t-1}-P_{t-1}).

Even with mean reversion, it may be possible that unrealistic futures are created by the model; therefore additional bounding criteria are used as a filter. A price floor is instituted at 0.14

SEK/kWh, which is the historical minimum. Likewise, a ceiling is set at 0.98 SEK/kWh, which is 50% above the maximum value in any price path. A limit is also placed on volatility such that it cannot be more than double the historical value. Any pricing output that does not meet these criteria is rejected and replaced.

C.2.3 Input Selection

To determine the appropriate input volatility and mean regression (MR) values for the model, a sensitivity analysis is performed considering the target output volatility and the results listed in Table C-8. Scenario B is used as the drift since it has the highest probability and the GBM model is run 100,000 times for each test. If the number of iterations reaches 200,000 due to rejected price series, the input combination is considered to have failed. Cells whose value is within 5% of the historic volatility are highlighted in red.

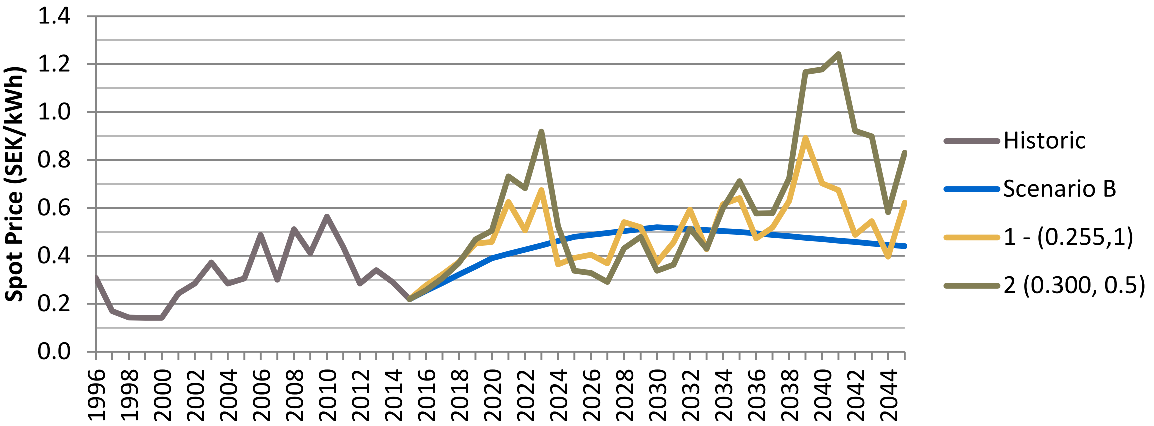
Table C-8 - Mode of volatility results from the GBM spot price time series

		Mean Regression Factor										
		0	**0.1**	**0.2**	**0.3**	**0.4**	**0.5**	**0.6**	**0.7**	**0.8**	**0.9**	**1**
Volatility	**0.210**	0.204	0.212	0.220	0.229	0.241	0.230	0.258	0.254	0.274	0.281	0.295
	0.225	0.217	0.234	0.240	0.241	0.255	0.262	0.262	0.283	0.284	0.304	0.324
	0.240	Fail	0.236	0.255	0.255	0.269	0.274	0.290	0.291	0.289	0.323	0.322
	0.255	Fail	0.257	0.259	0.275	0.288	0.276	0.301	0.312	0.310	0.327	0.367
	0.270	Fail	0.258	0.277	0.302	0.298	0.311	0.305	0.320	0.343	0.344	0.384
	0.285	Fail	0.283	0.301	0.302	0.298	0.314	0.333	0.349	0.345	0.360	0.382
	0.300	Fail	Fail	0.304	0.311	0.322	0.343	0.350	0.357	0.376	0.405	0.404
	0.315	Fail	Fail	Fail	0.329	0.331	0.354	0.366	0.374	0.382	0.413	0.443
	0.330	Fail	Fail	Fail	Fail	0.350	0.381	0.368	0.402	0.425	0.407	0.420
	0.345	Fail	Fail	Fail	Fail	Fail	Fail	0.396	0.425	0.423	Fail	Fail
	0.360	Fail	Fail	Fail	Fail	Fail	Fail	Fail	Fail	Fail	Fail	Fail

While there are eight acceptable combinations of input volatility and MR factors there is a wide range of extra iterations required, the lowest being 15,265 and the highest being 88,334. In general, the lower the volatility the fewer iterations that are needed, and for MR factors inputs closer to 0.5 result in a lower iteration count. Two examples are presented in Figure C-9; number one has the lowest volatility and lowest iteration count (0.255, 1) and number two has the lowest iteration count of those with an MR of 0.5 (0.300, 0.5). Both outputs are generated using the same Wiener process values and shown along with historical Nord Pool prices and the price path B which was also used.

The higher volatility can be seen in output 2, which has more extreme changes in values and enough so to exceed the maximum limit, demonstrating why combination two requires 25% more iterations to complete. This is only one example however, and there are others that would show the two curves much closer together. Given the 25% reduction in processing time for similar volatility results, the first input volatility/MR factor combination (0.255, 1) is used.

Figure C-9 - Example of a GBM electricity price series with Scenario B as the drift

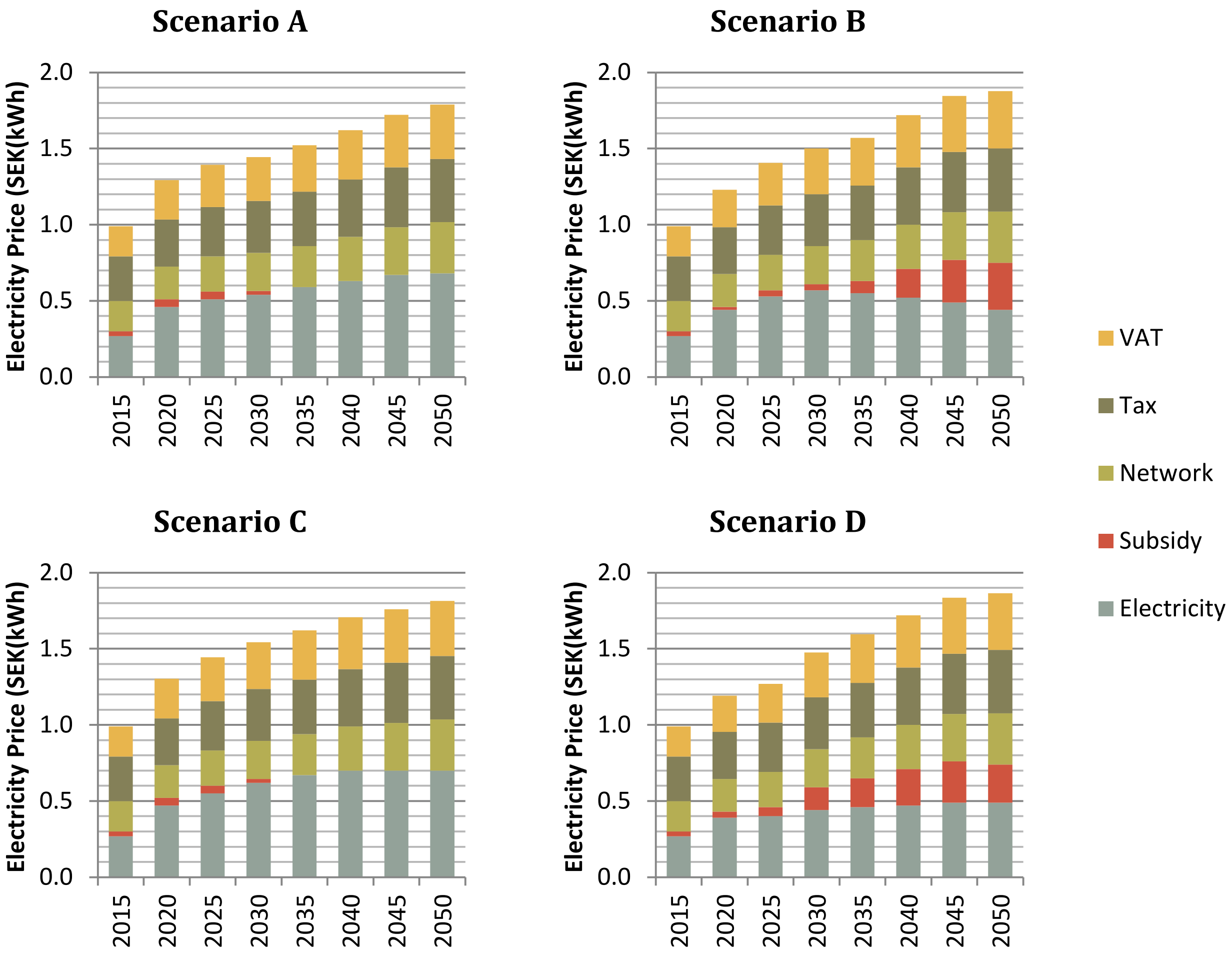


C.2.4 Retail Prices

Only the wholesale prices are considered in the GBM model. The retail price is then constructed based on the output wholesale price and the price of each component determined in that year (considering spot price (P_w), retailer markup (P_m), subsidy support (P_s), network price (P_n), electricity tax (P_t), and a 25% VAT (P_{VAT})) which are combined in equation (10). The network price and electricity tax rates are assumed to grow at 1.5% and 1% per year, respectively, which is similar to their historical rates. The retail price of each drift scenario is shown in Figure C-10.

$$P_r = (P_w + P_s + P_n + P_t + P_m) * (1 + P_{VAT}) \qquad (10)$$

Figure C-10 - Retail price development of each drift scenario by component



Appendix D Distribution Results for NEPP Policy Scenarios

The primary study uses all four NEPP policy scenario prices with probabilities to produce a single distribution of indicators. However it can be interesting to know the results for each future scenario independently. The three policy scenarios describe and presented as distributions in Chapter 6 are presented here for each NEPP price scenario.

Figure D-1 - Probability results for NEPP Scenario A

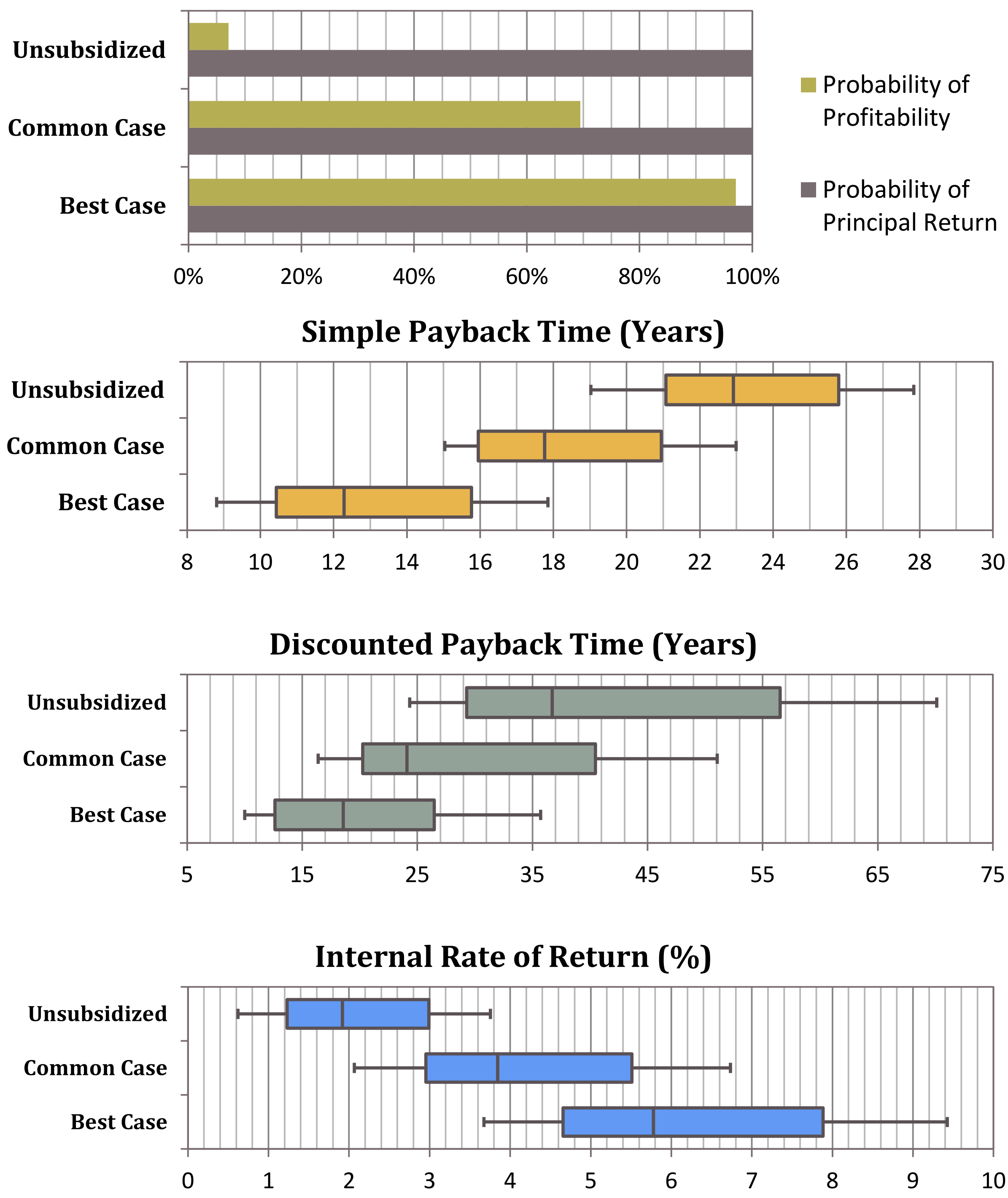


Figure D-2 - Probability results for NEPP Scenario B

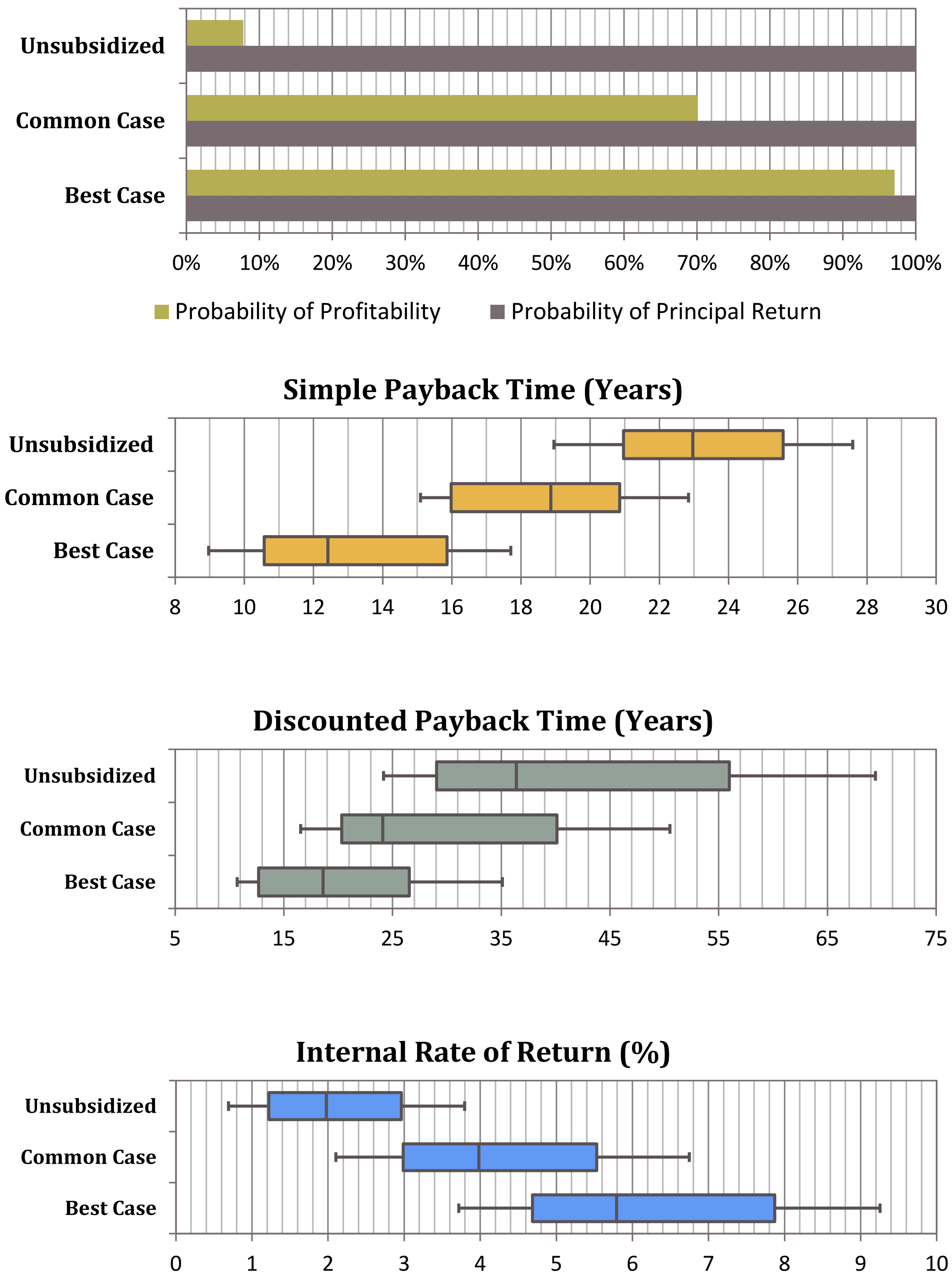
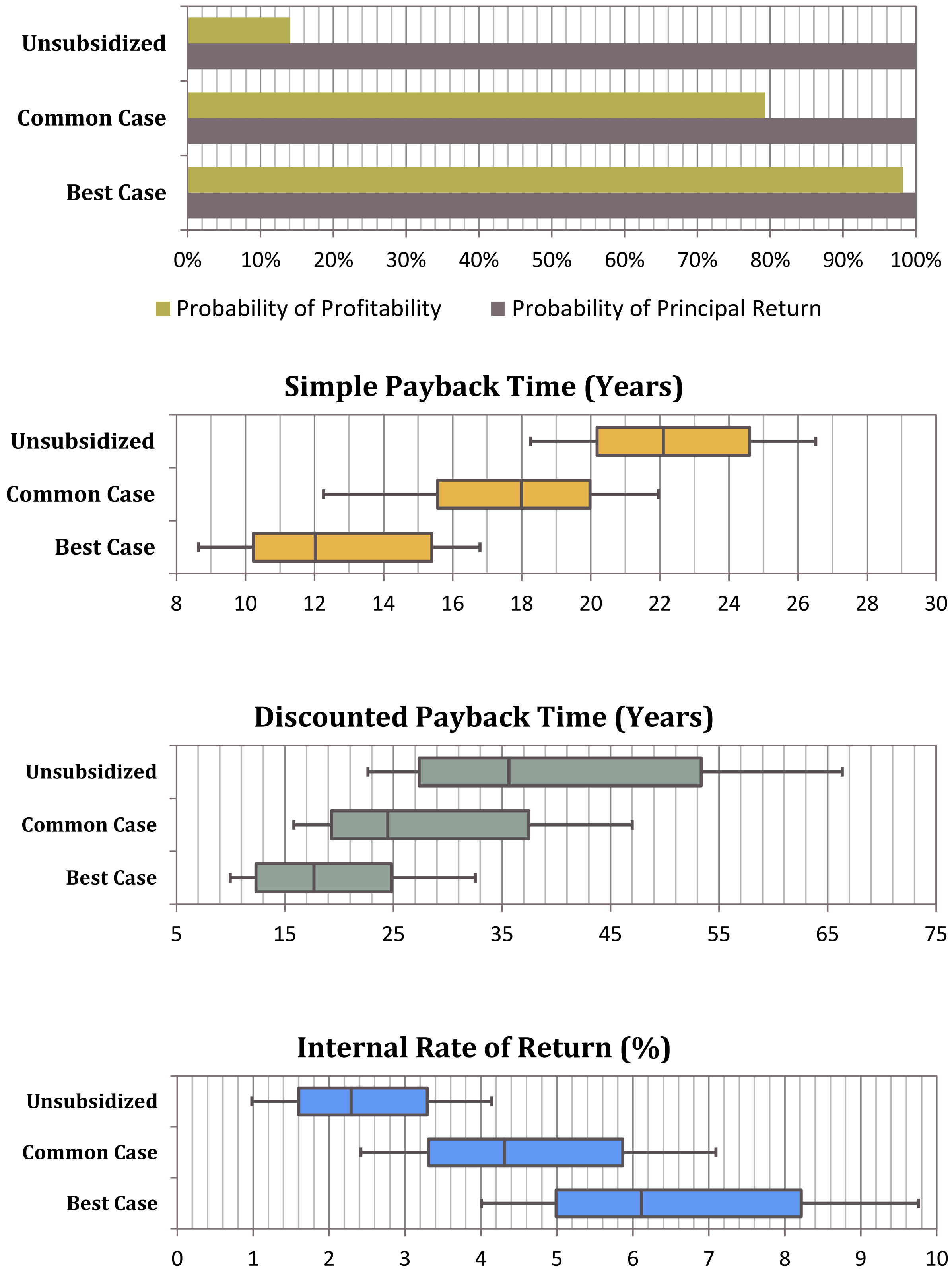


Figure D-3 - Probability results for NEPP Scenario C

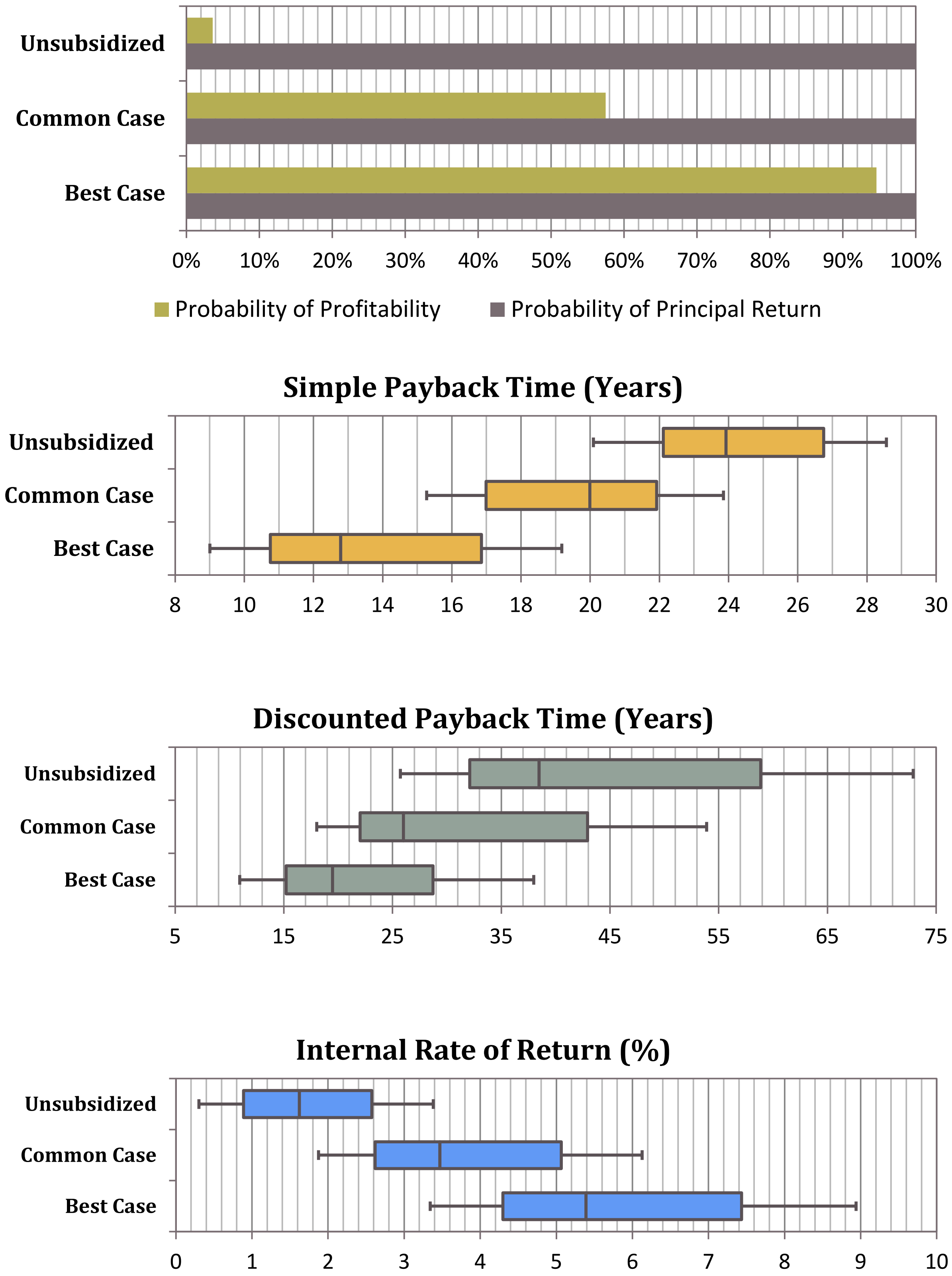


Simple Payback Time (Years)

Discounted Payback Time (Years)

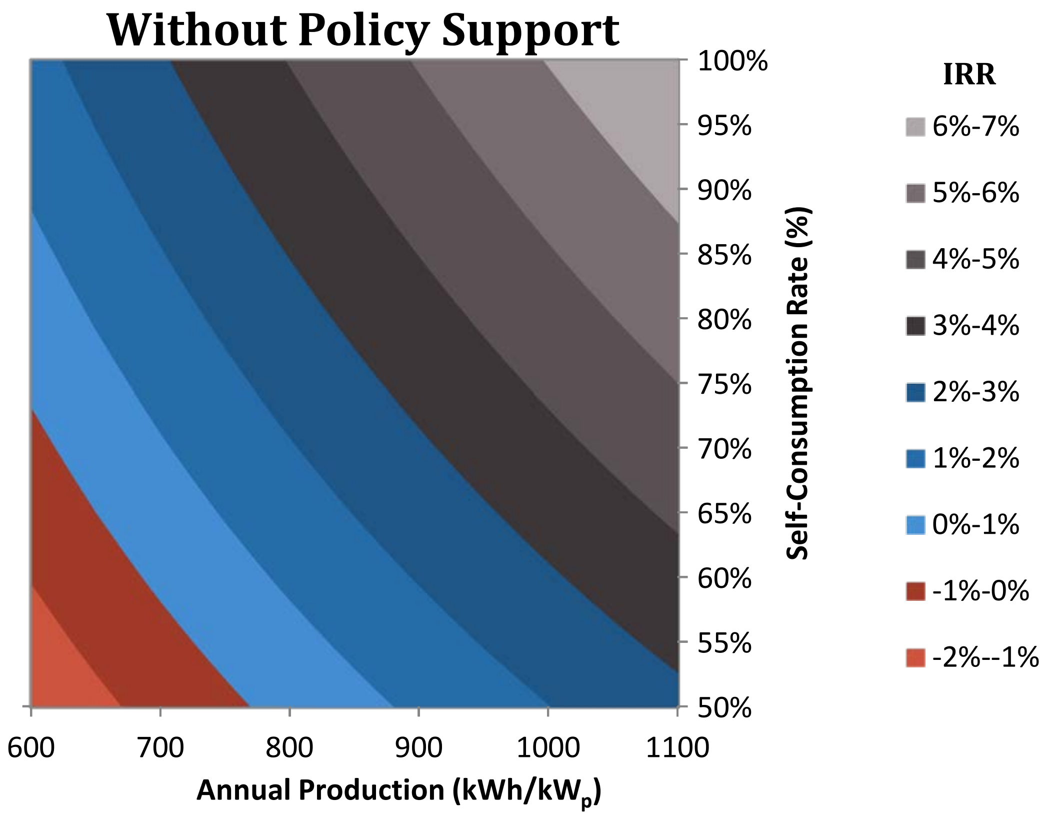
Internal Rate of Return (%)

Figure D-4 - Probability results for NEPP Scenario D



Appendix E Profitability Charts

Figure E-1 - Profitability charts showing IRR considering production and self-consumption (See 6.6)


Without Policy Support

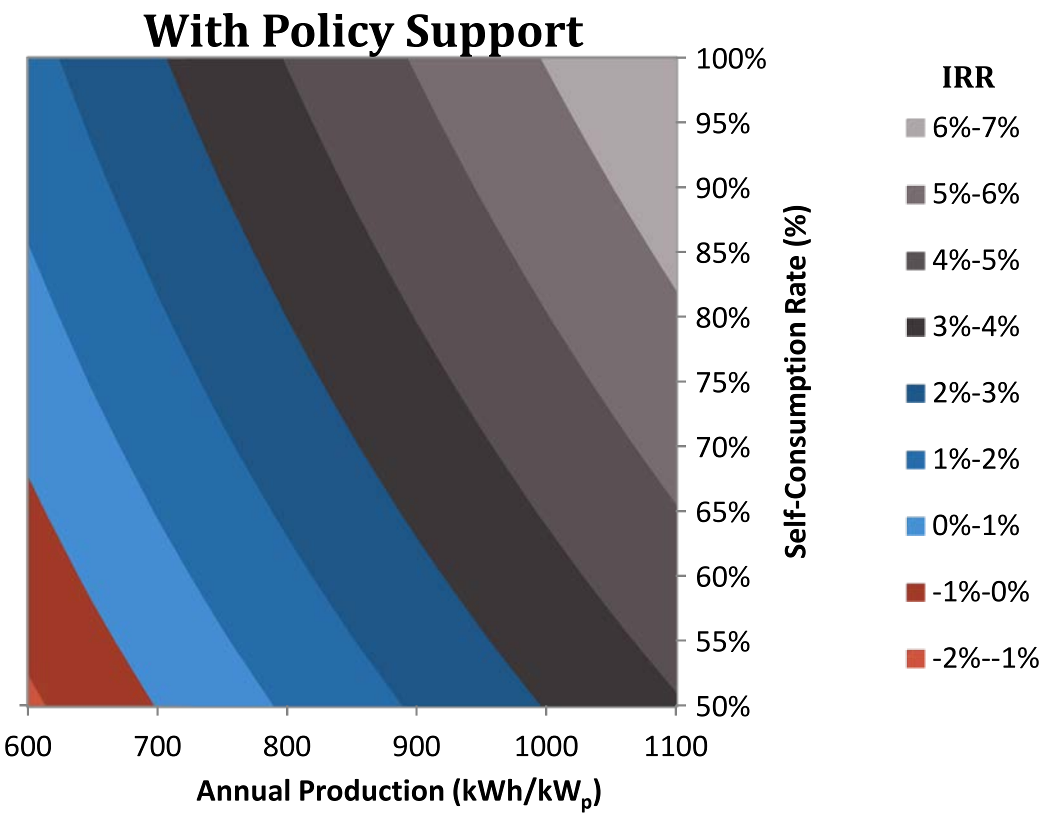
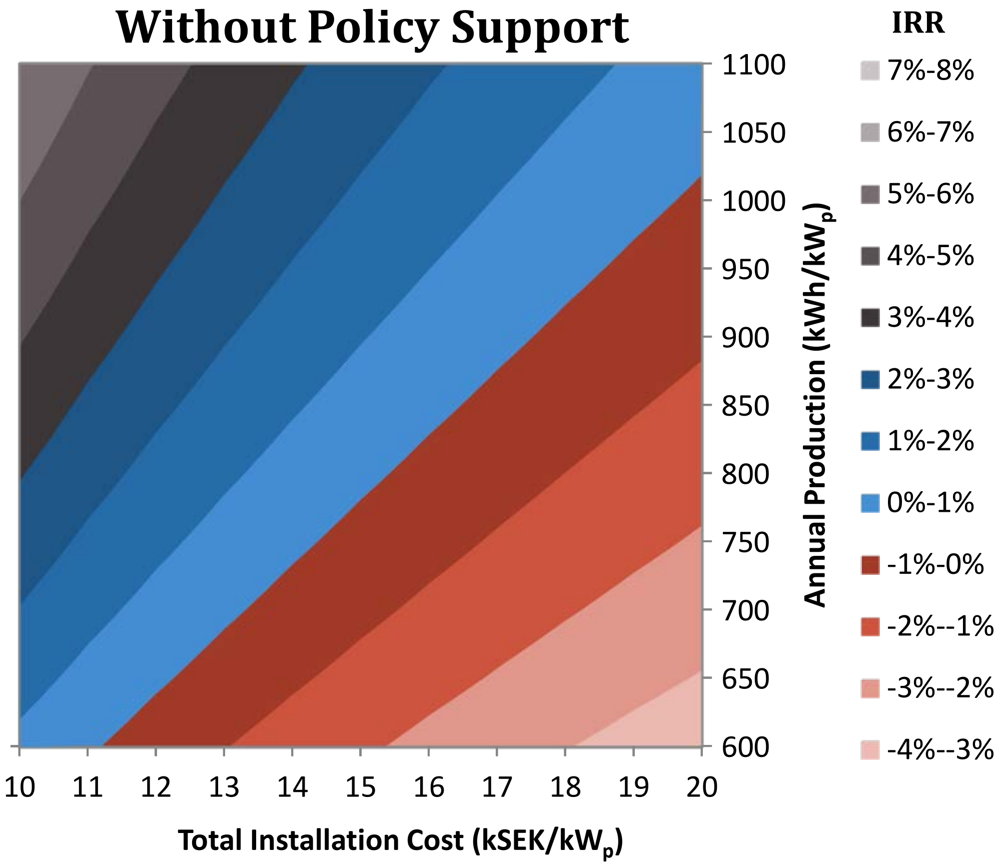

With Policy Support

Figure E-2 - Profitability charts showing IRR considering installation cost and production (See 6.6)



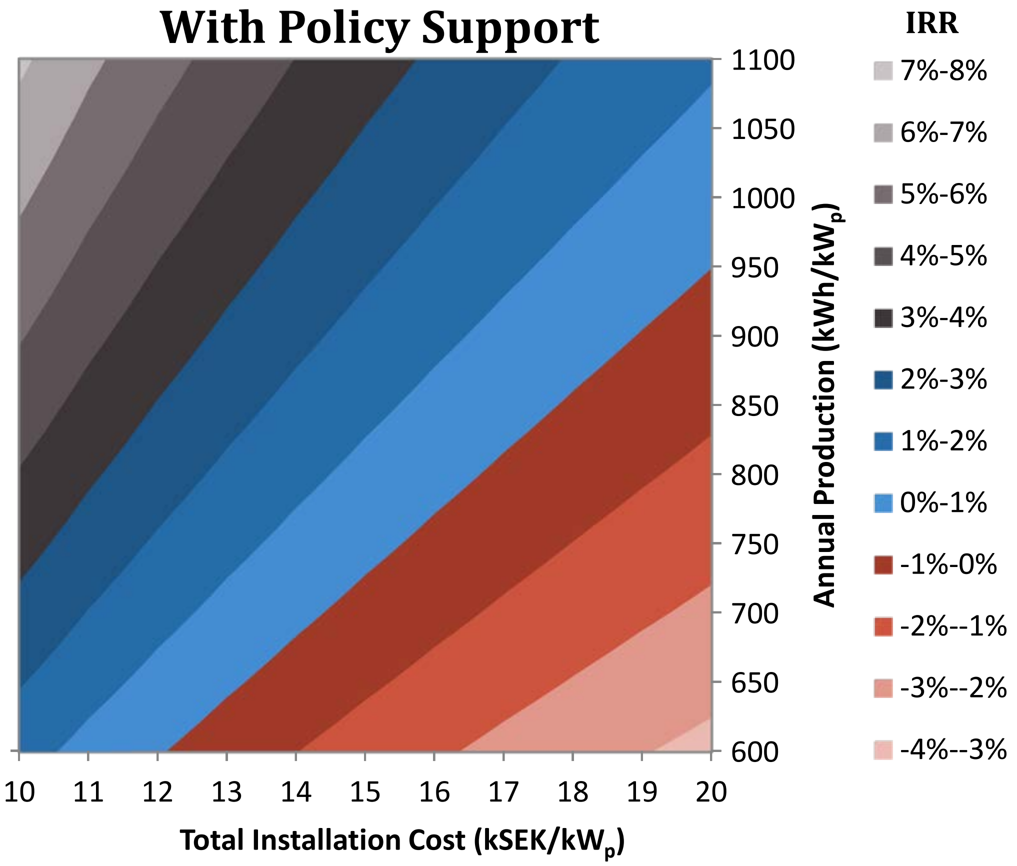
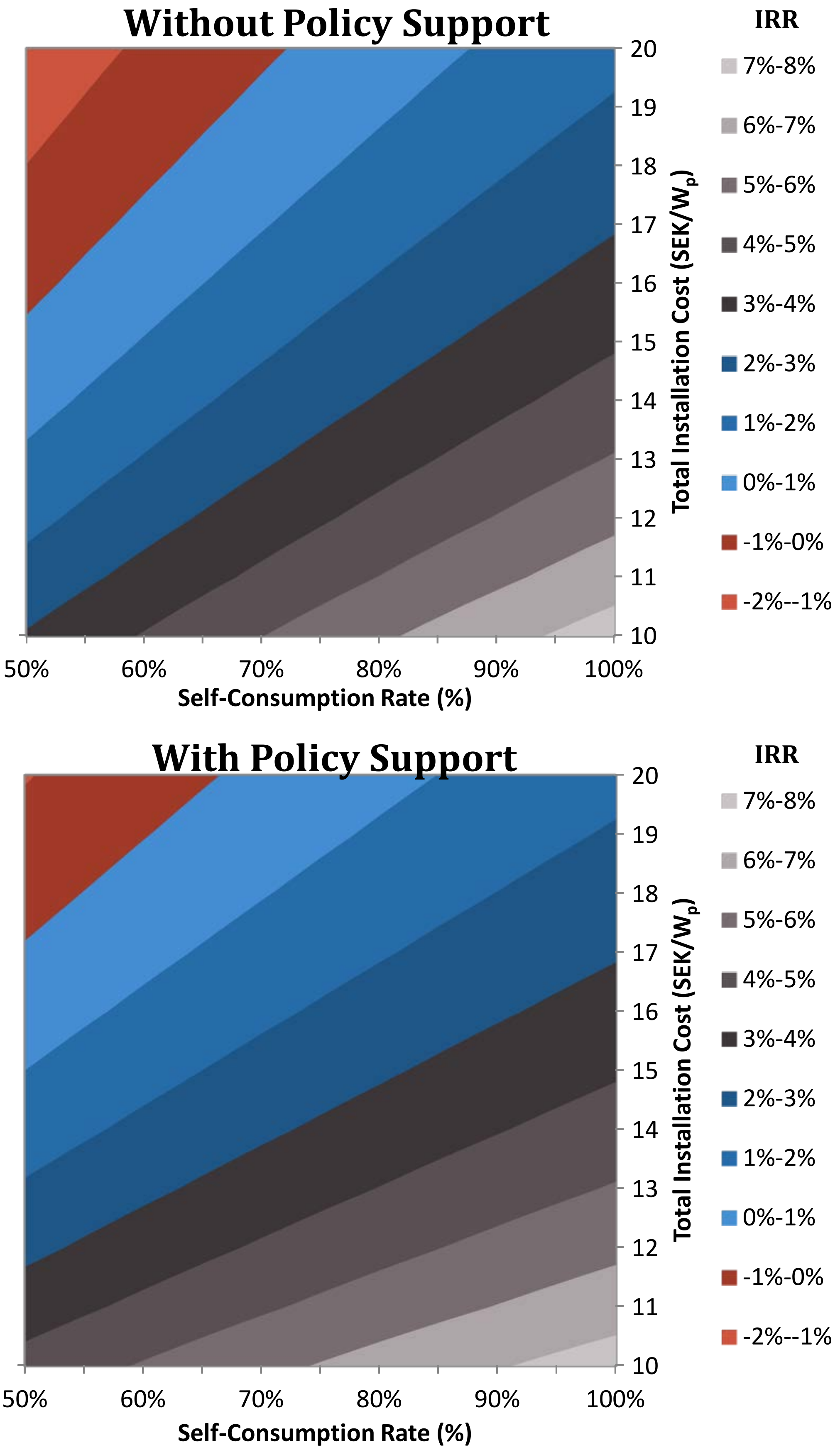


Figure E-3 - Profitability charts showing IRR considering self-consumption and installation cost (See 6.6)

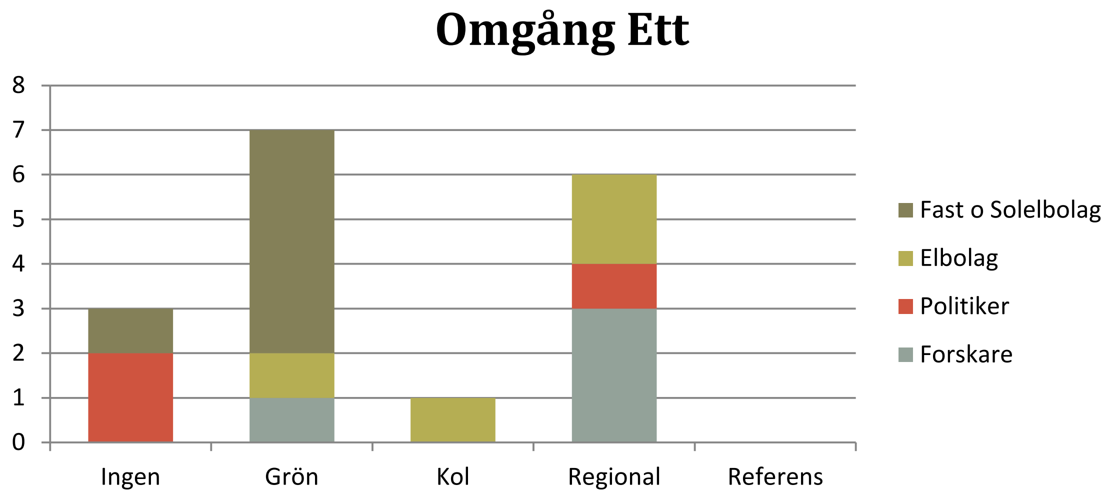


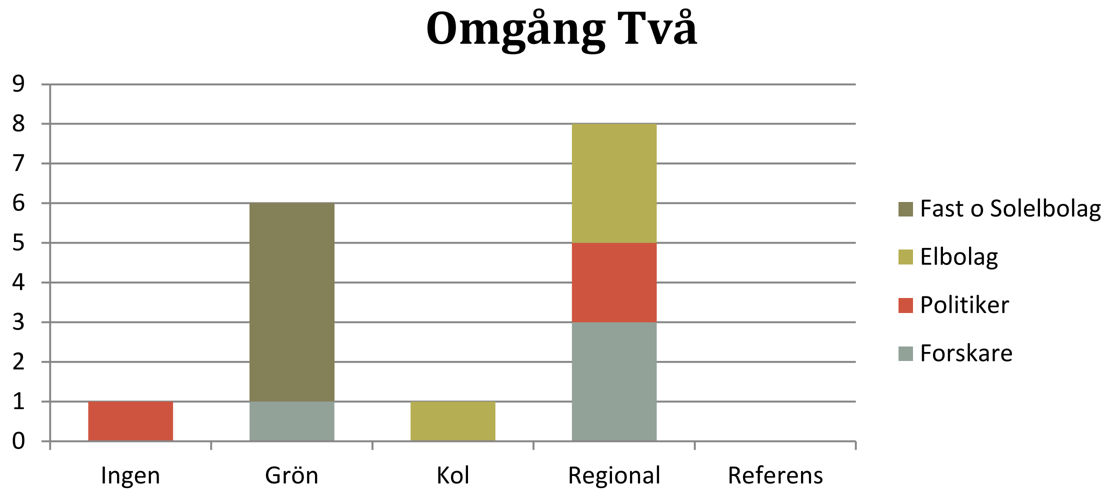
Appendix F Questions and Results of Delphi Study

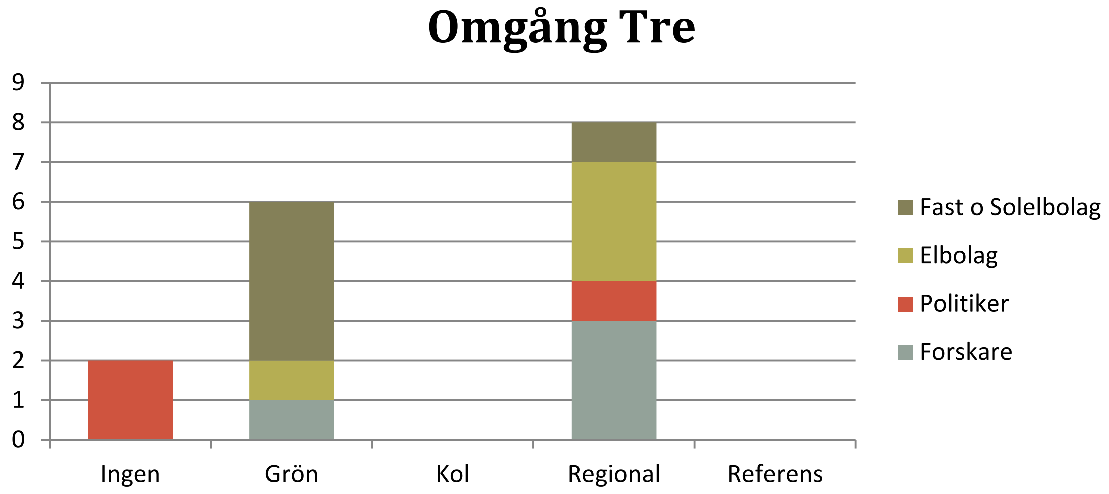
Included here are all of the participants, the questions, and the responses over the three rounds of the Delphi Study, performed online between March and July, 2015. The surveys were performed in Swedish, and therefore the data is presented in Swedish as well.

Name	Title	Organization	Category
Andreas Kertes	Chef Affärsstöd (Head of Business Support)	Öresundskraft AB	Utilities
Andreas Molin	VD (CEO)	PPAM.se Sweden AB	Solar / Property Companies
Erik André	Projektledare (Project Manager)	Hållbar Utveckling Väst	Government
Göran Fermbäck	Produktchef (Product Manager)	Fortum Markets	Utilities
Håkan Jutterdal	Fd Styrelseordförande (Former Board Chairman)	HSB BRF Gasellen	Solar / Property Companies
Ivo Martinac	Professor	KTH Installations and Energy Systems	Academia
Jenny Palm	Professor	Linköping University	Academia
Johan Ehrenberg	VD (CEO)	ETC	Solar / Property Companies
Johan Lindahl	Solar Market Expert / PhD Candidate	IEA-PVPS / Uppsala University	Academia
Johan Linnarsson	Seniorkonsult (Senior Consultant)	Sweco Energuide AB	Academia
Johan Löfstrand	Riksdagsledamot (MP)	Sveriges Riksdag	Government
Jonas Persson	Marknadschef (Marketing Director)	Mälarenergi Elnät AB	Utilities
Lise Nordin	Riksdagsledamot (MP)	Sveriges Riksdag	Government
Mikael Lundin	VD (CEO)	Nord Pool Spot	Utilities
Mikael Ronge	Head of Project Execution	Eneo Solutions	Solar / Property Companies
Ulf Viktorsson	Teknisk Chef (Technical Manager)	AB Botkyrkabyggen	Solar / Property Companies
Yngve Green	Energiansvarig (Energy Manager)	AB Svenska Bostader	Solar / Property Companies

Enligt dig, vilket (om något) av de fyra NEPP resultaten som nämndes i texten om elektricitet i Sverige representera det framtida elsystemet I Sverige?

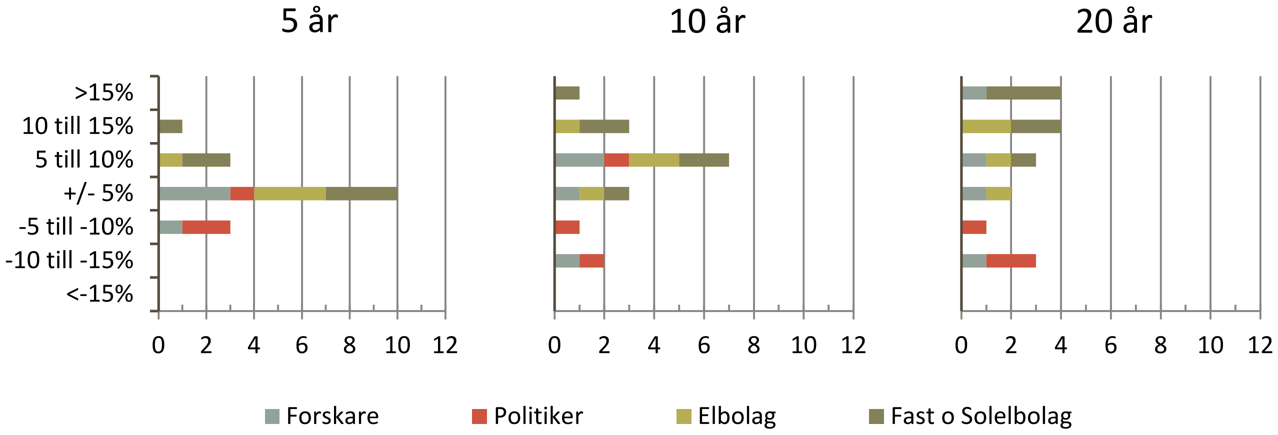




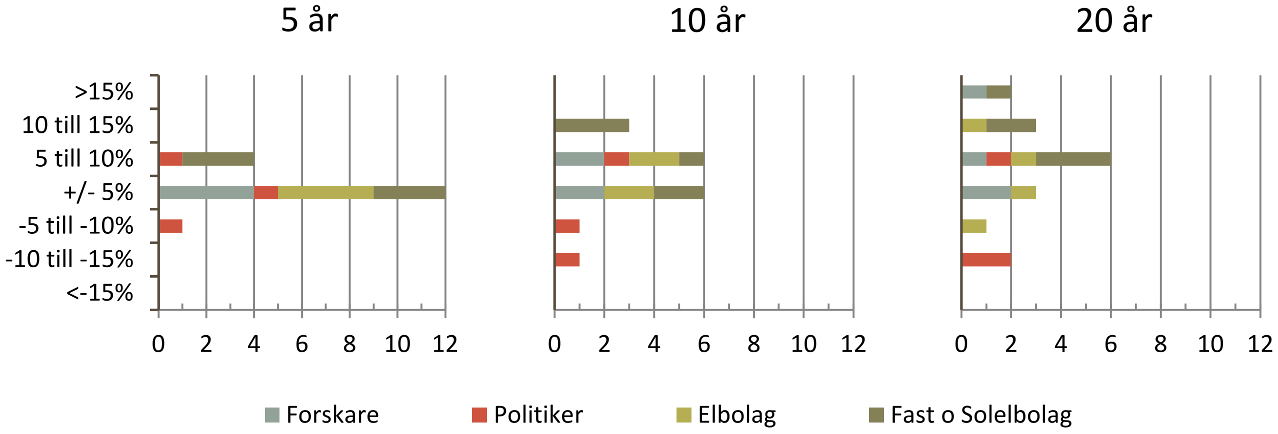


Jämfört med idag, hur tror du att elefterfrågan kommer att förändras på 5 år; 10 år och 20 år?

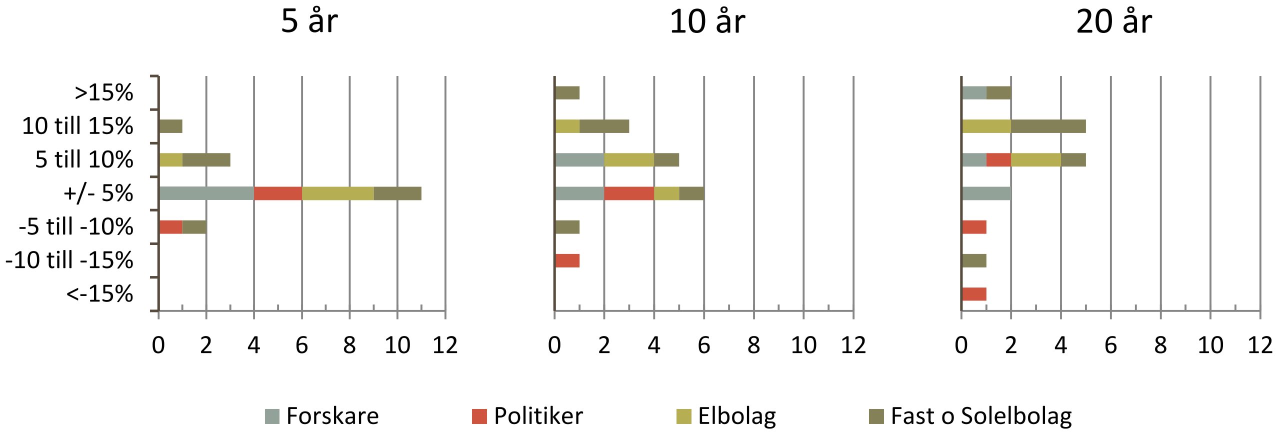
Omgång Ett



Omgång Två

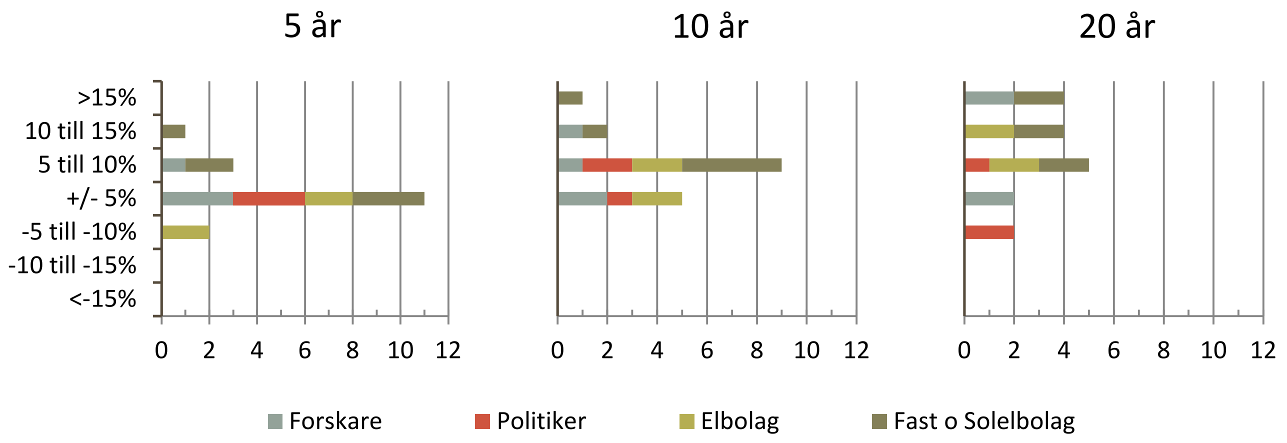


Omgång Tre

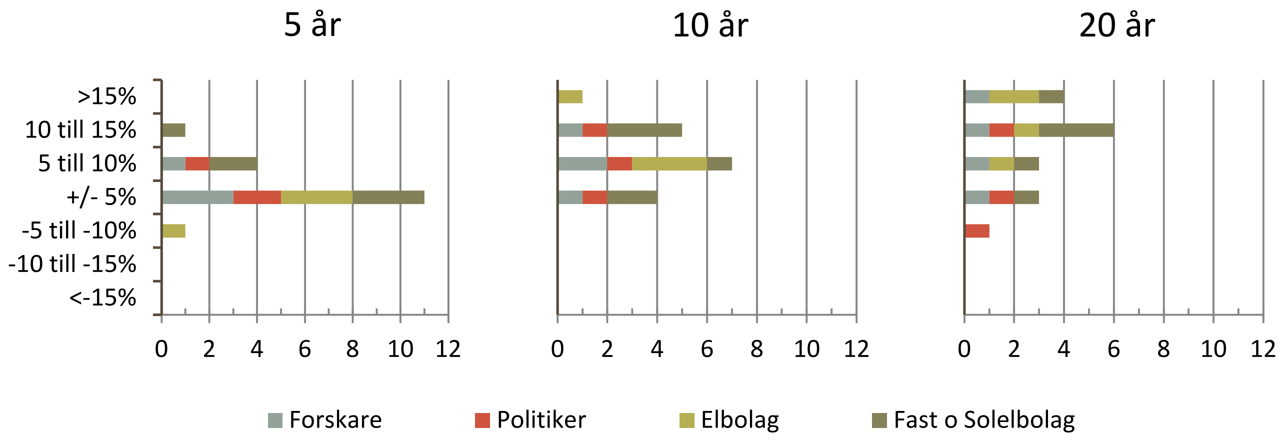


Jämfört med idag, hur tror du att konsumerters elpriserna kommer att förändras på 5 år; 10 år och 20 år?

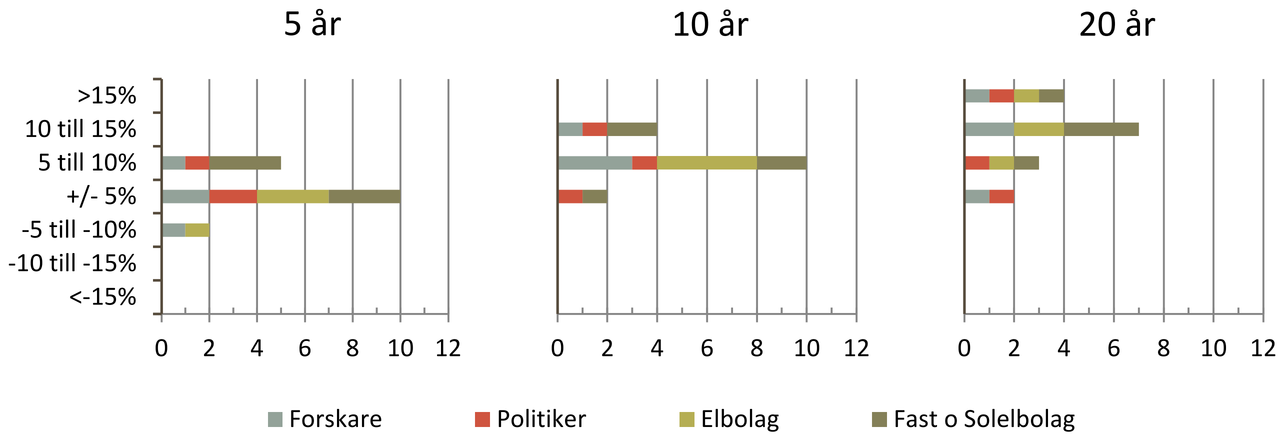
Omgång Ett



Omgång Två

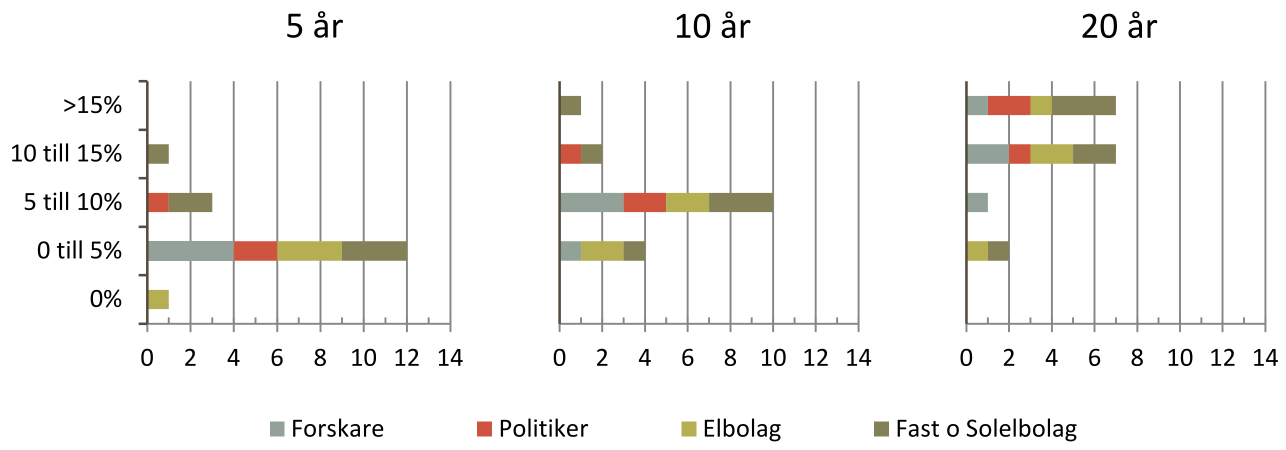


Omgång Tre

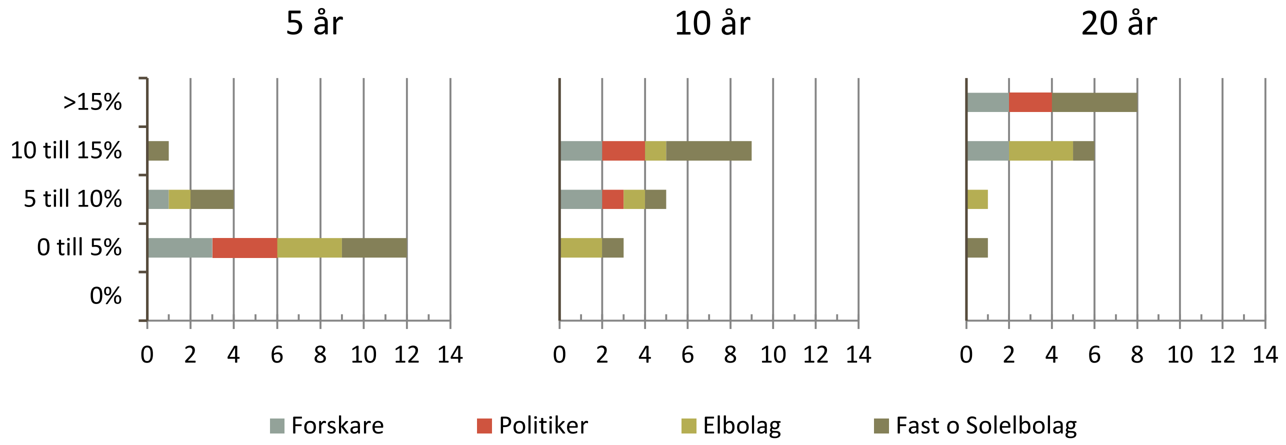


Enligt din uppfattning, hur många hushåll/företag kommer, procentuell sett, att vara både elkonsumenter och elproducenter (prosumers) om 5 år; 10 år och 20 år?

Omgång Ett



Omgång Två



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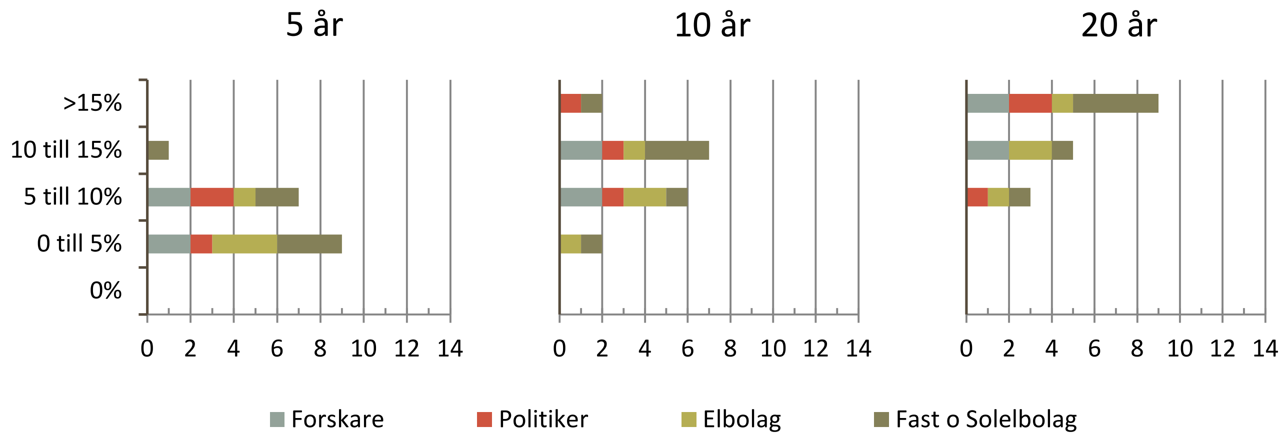
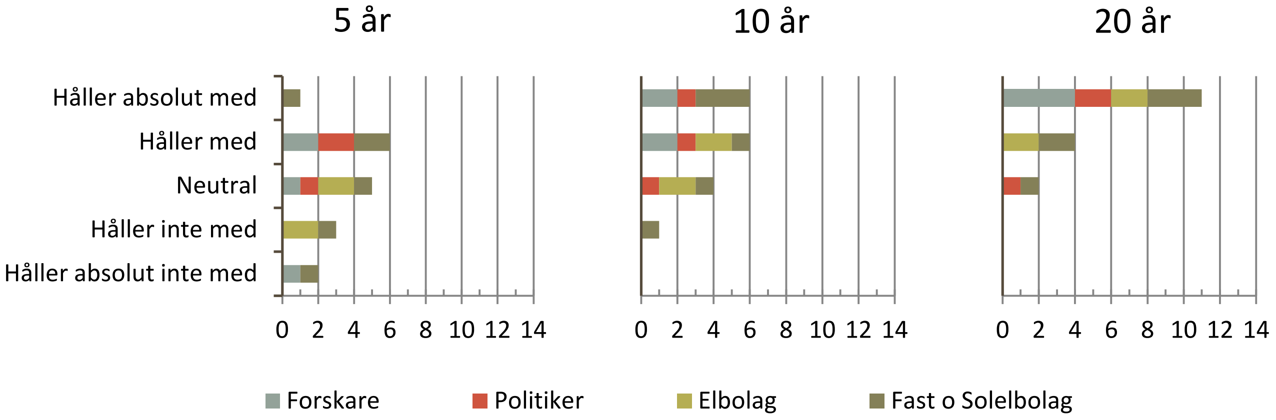
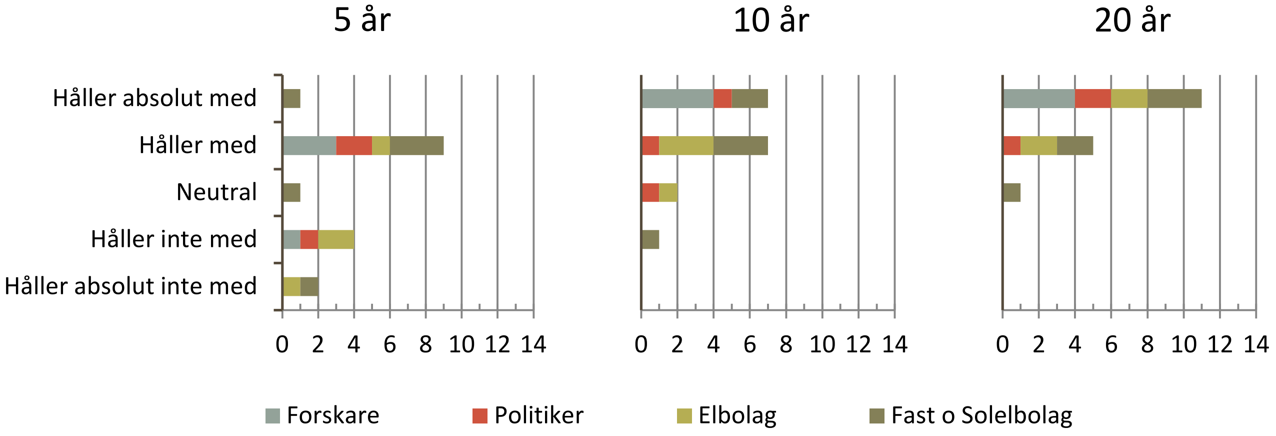


Jämfört med idag, hur ställer du dig till påståendet att elmarknadens affärsmodeller kommer att vara mycket olika om 5 år, 10 år och 20 år; med både nya teknologier, nya aktörer och en ny marknadsstruktur?

Omgång Ett



Omgång Två



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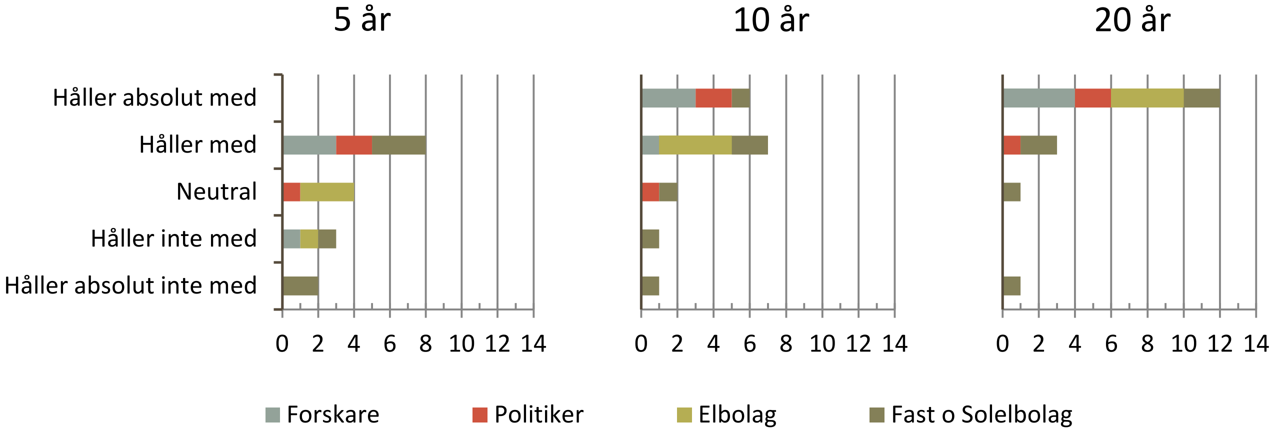
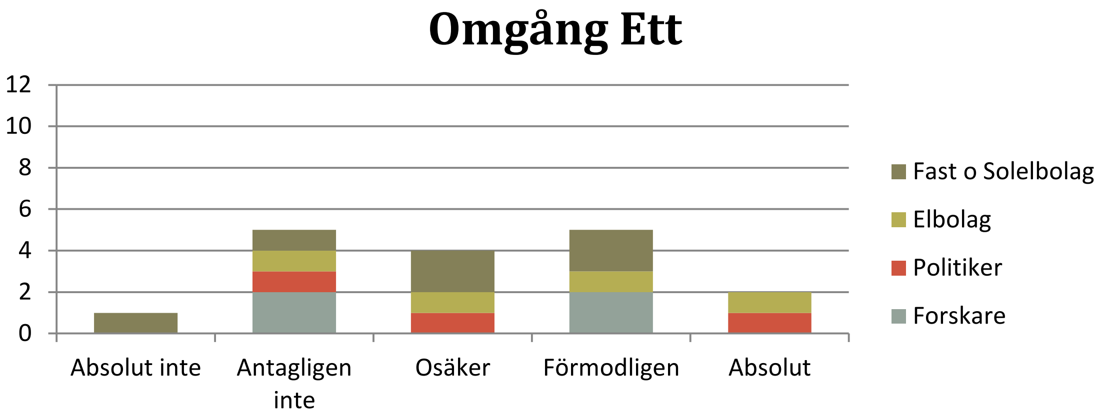
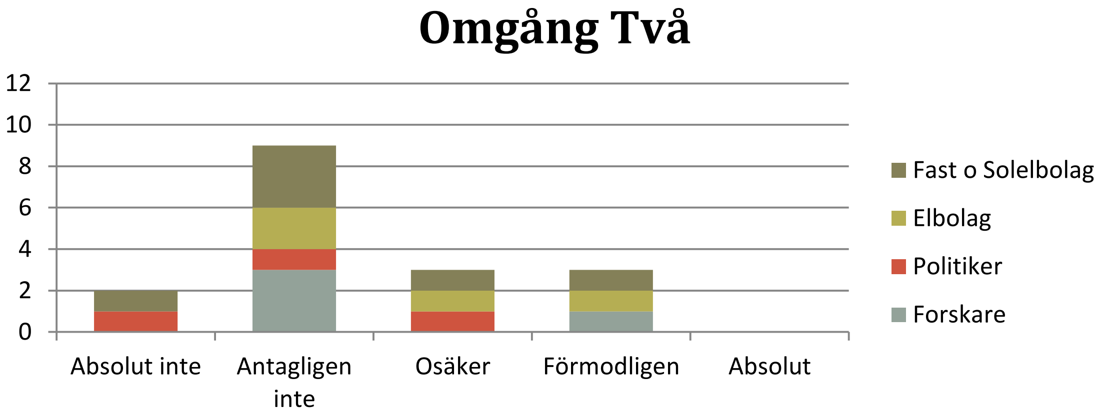
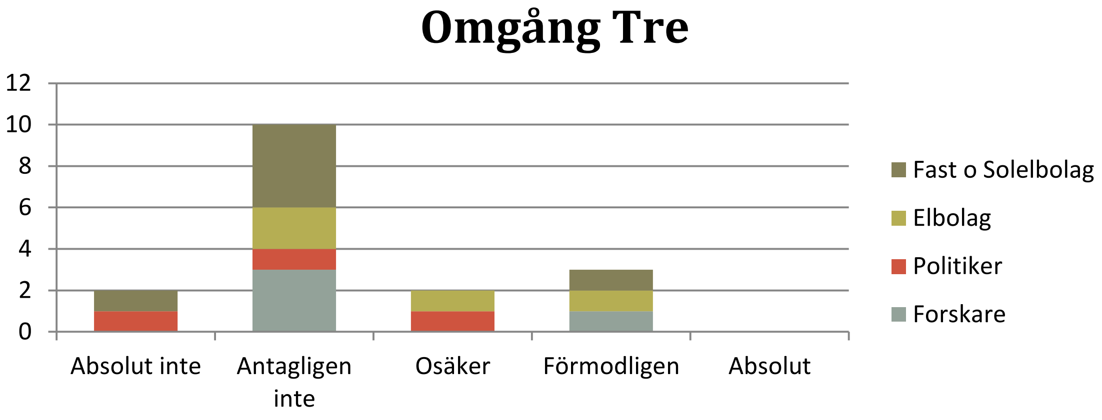


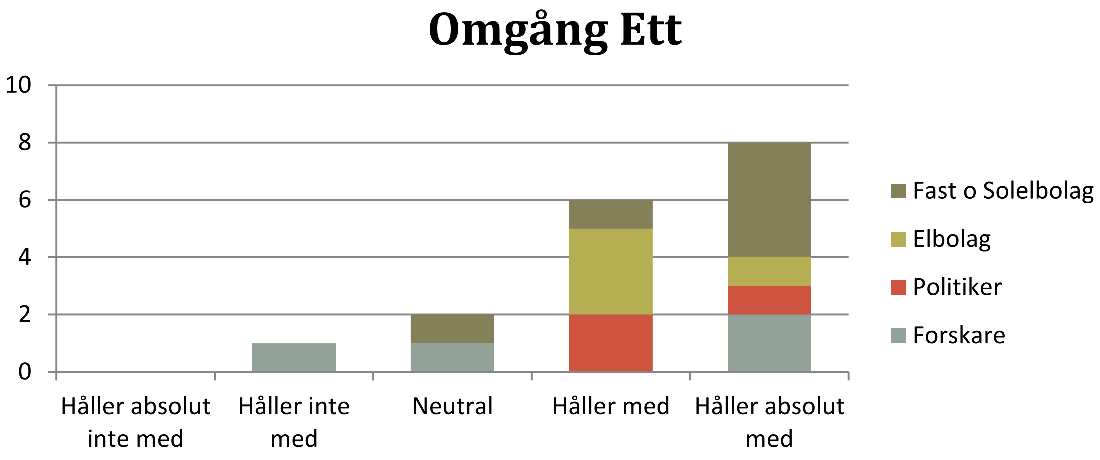
Med hänsyn taget till alla politiska och ekonomiska faktorer, tror du att de nuvarande kärnkraftverken kommer att bli ersätta med nya kärnkraftverk när de uppnår sin livslängd? Det första verket når livslängd kring 2025 och det sista verket runt 2045.

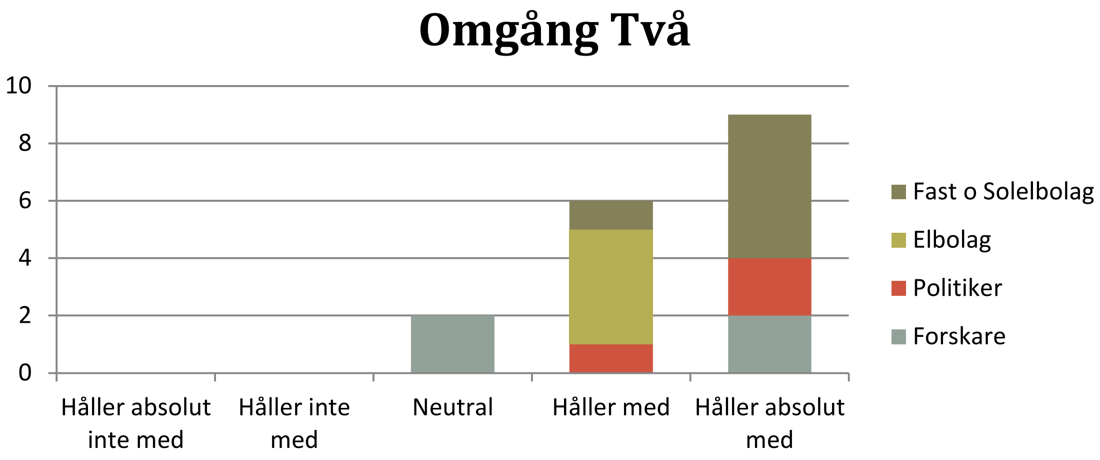


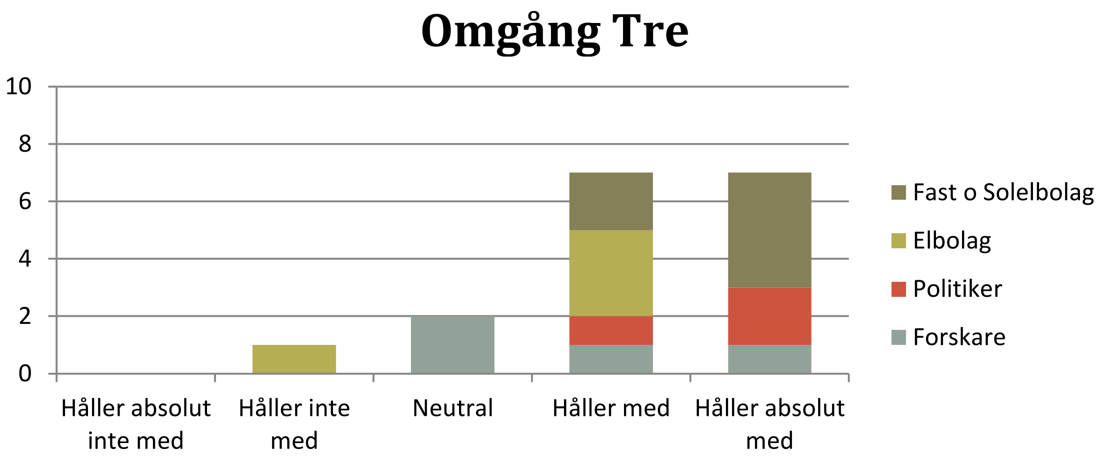




Hur ställer du dig till påståendet att tillväxten av mikroproducenter av alternativ energi är en bra företeelse och bör stödjas fortsättningsvis av politiska instanser?







Hur ställer du dig till följande påståenden?

Mikroproducenter ska kunna få ett fast fixerat pris på den el som de köper från nätet.

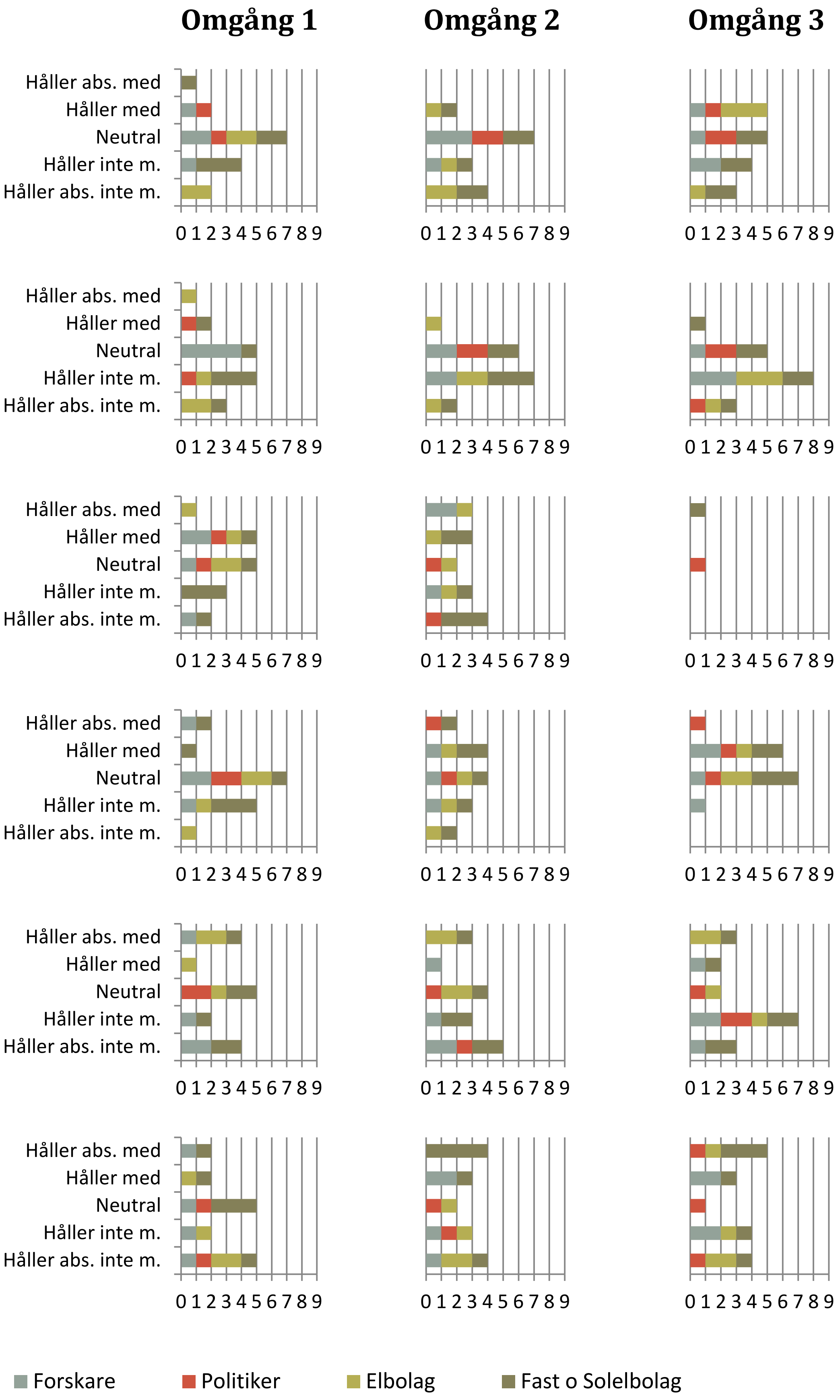
Mikroproducenter ska bara få köpa el till ett rörligt timpris.

Mikroproducenter ska kunna sälja sin överskottsel till nätet för Nord Poolpris och den ska beskattas på gängse sätt.

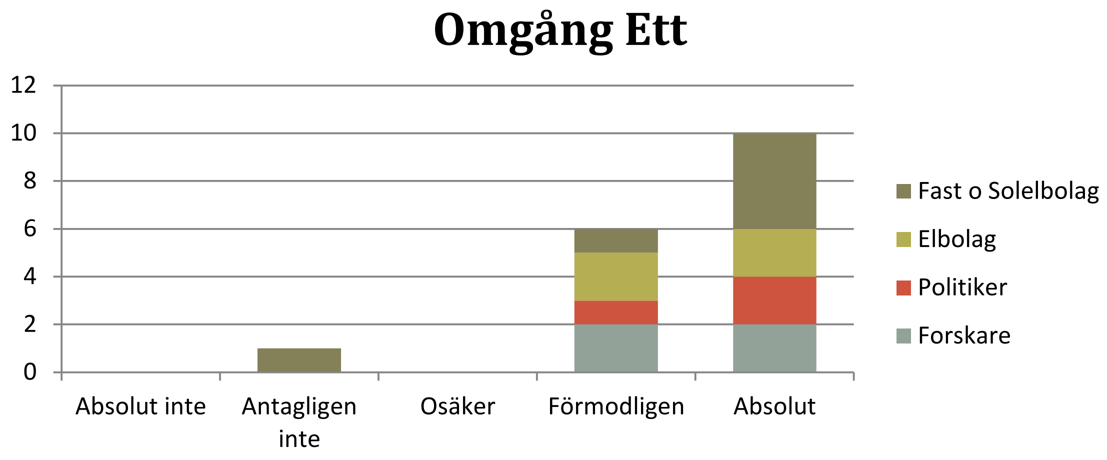
Mikroproducenter ska kunna sälja sin överskottsel till nätet för Nord Poolpris utan skattepåslag.

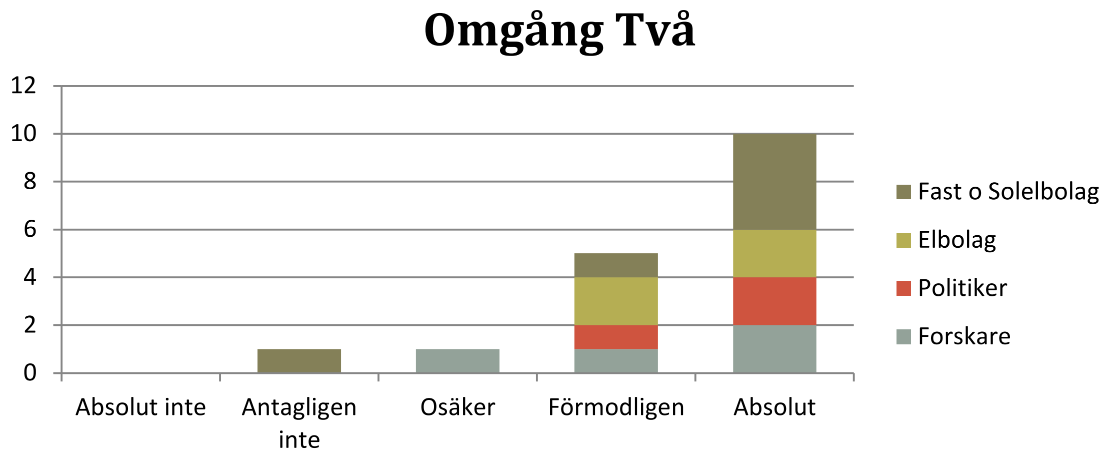
All el som produceras av mikroproducenter ska säljas till nätet för marknadspris, beskattas och i övrigt behandlas som vilken producerad el som helst.

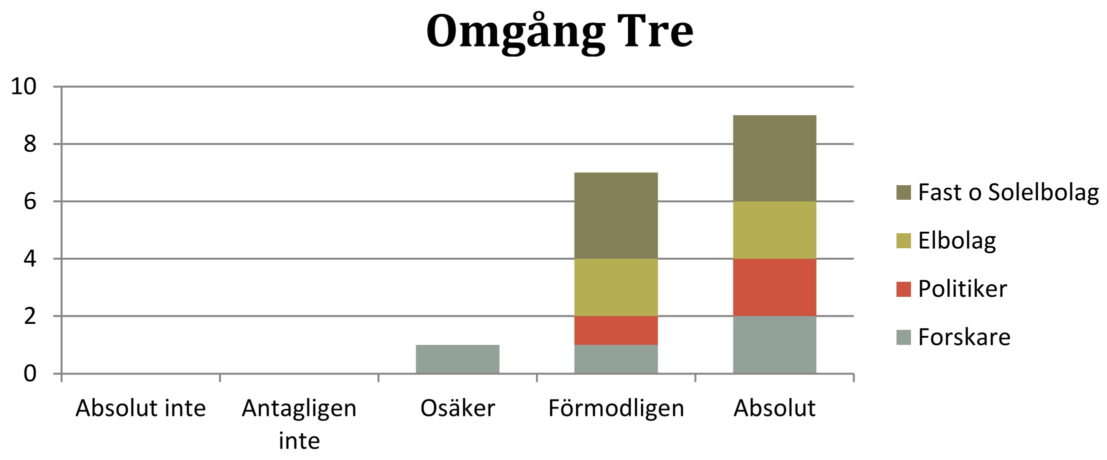
All el som produceras av en mikroproducent ska användas i fastigheten och inte säljas på nätet, inte heller beskattas. Åtgärden ska ses som en energibesparande åtgärd.



Har din inställning till det framtida energilandskapet (energikällor, marknaden, priser etc) förändrats under de senaste 5 åren?







Appendix G Interviewees for Building Application

Since the majority of information presented in Chapter 4 was sourced from interviews with contractors, electricians, and PV installers rather than published sources, a list of interviewees is presented here with all relevant information.

Name(s)	Professional Affiliation	Topics Discussed	Date	Interview Method
Grudeborn, L.O.	Solarope	PV Mounting	May 7, 2014	In-Person
Palm, R. Lundberg, C.W.	N/A	Flat Roof Mounting	Dec. 16, 2014	Telephone
Molin, A.	PPAM	Mounting, Economy, Security	Nov. 20, 2014	Telephone
Lavegren, O.	Electrician	N/A	Nov. 12, 2014	Telephone
Nilsson, H.	Solarope	PV Mounting	Nov. 20, 2014	Telephone
Ekenhall, M.	2byggotak	Snow Clearing	Dec. 11, 2014	Telephone
Iskander, S.	BRF Södertäljehus no.3	Regulations, Mounting	Dec. 5, 2013	In-Person