YRKESHÖGSKOLAN NOVIA

Solar Panels as a Complement to Grid Connected Electricity

A case study on family house sized solar panel systems

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Abstract

This thesis is about the possibilities of using solar panels as a complementary energy source in real estate and in family homes in particular. Usually, people have an awareness of the challenges of global warming and recognize the need for solutions to reduce the atmospheric CO_2 levels. One way of doing this is to increase the usage of renewable energy sources - such as wind, wood, wave or solar energy - in the production of electricity. One of the most popular options for small scale energy production is the use of solar panels due to low investment costs and easy and inexpensive installation. The effectiveness of this, however, depends on many different factors such as the amount of energy produced, how much energy the owner of a solar panel system can use and how much energy is sold out to the grid.

Six different solar panel systems sold by two different dealers in Finland have been included in the research for this work. Collected data has been used to study the amount of electrical energy produced by the solar panels and compared it with how much energy has been used for customers' own consumption. The research was carried out using data collected from the solar panel system's inverters during the period May to September 2017 and 2018. The results show that a large amount of the electricity produced was either sold back to the grid or left unused, and this naturally affects the profitability of the investment. By concentrating the household's electricity consumption to the time when the panels produce the most energy, it is possible to improve the panels' profitability.

Language: English

Key words: solar panels, inverter, photovoltaic process, energy production

EXAMENSARBETE

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Abstrakt

Arbetet handlar om möjligheterna att använda solpaneler som en kompletterande energikälla i fastigheter och särskilt i egnahemshus. Det är allmänt underförstått att många människor har en medvetenhet om utmaningarna med global uppvärmning och behovet av lösningar för att minska den atmosfäriska koldioxidnivån. Ett sätt att göra det är att öka användningen av förnybara källor i elproduktionen, som vind, biomassa, våg eller solenergi. Ett av de mest populära alternativen för småskalig elproduktion, är användningen av solpaneler, på grund av låga investeringskostnader och enkel och billig installation. Solpanels investeringens lönsamhet är beroende av många olika saker, såsom hur mycket energi som produceras, hur mycket energi ägaren till ett solpanelsystem kan använda själv och hur mycket som går ut i elnätet.

Sex olika solpanelsystem som säljs av två olika återförsäljare i Finland har inkluderats i forskningen för detta arbete. Insamlad data har använts för att studera mängden elektrisk energi som produceras av solpanelerna och jämfört den med hur mycket energi som har använts för kundernas egen konsumtion. Forskningen genomfördes med hjälp av data som samlats in från solpanels systemens invertrar under perioden maj till september 2017 och 2018. Resultaten visar att en stor mängd av den el som producerades antingen såldes tillbaka till nätet eller lämnades oanvänd, och detta påverkar naturligtvis investeringens lönsamhet. Genom att koncentrera hushållets elförbrukning till den tid då panelerna producerar mest energi är det möjligt att förbättra panelernas lönsamhet.

Språk: Engelska

Key Words: solpaneler, inverter, fotovoltaisk process, energiproduktion

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Tiivistelmä

Tässä työssä käsitellään mahdollisuudet käyttää aurinkopaneeleja täydentäväksi energialähteeksi kiinteistöissä ja erityisesti omakoti taloissa. Yleisesti ymmärretään, että monet ihmiset ovat tietoisia ilmaston lämpenemisen haasteista ja tarve ratkaisuihin ilmakehän hiilidioksidipitoisuuksien vähentämiseksi. Yksi tapa tehdä tämä on lisätä uusiutuvien energialähteiden käyttöä sähköntuotannossa, kuten tuuli-, bio massan-, aalto- tai aurinkoenergian käyttöä. Pienimpien sähköntuotannon suosituimmista vaihtoehdoista on aurinkopaneelit, niiden alhaisien investointikustannuksien ja helpon asennusten takia. Aurinko paneelien investoinnin kannattavuus riippuu monista eri asioista, kuten kuinka paljon energiaa tuotetaan, kuinka paljon energiaa aurinkopaneelijärjestelmän omistajan voi käyttää itse ja kuinka paljon menee ulos sähkö verkkoon.

Tämän työn tutkimukseen on sisällytetty kuusi erilaista aurinkopaneelijärjestelmää, joita myy kaksi erilaista jälleenmyyjää Suomessa. Kerättyjen tietojen avulla on tutkittu aurinkopaneelien tuottaman sähköenergian määrää ja verrattu sitä siihen, kuinka paljon energiaa on käytetty asiakkaiden omaan kulutukseen. Tutkimus tehtiin aurinkopaneelijärjestelmän inverteriltä kerätyillä tiedoilla touko-syyskuu 2017 ja 2018 aikana. Tulokset osoittavat, että suuri osa tuotetusta sähköstä joko myytiin takaisin verkkoon tai jätettiin käyttämättä, ja tämä vaikuttaa luonnollisesti sijoituksen kannattavuus. Keskittämällä kotitalouden sähkönkulutus aikaan, jolloin paneelit tuottavat eniten energiaa, on mahdollista parantaa paneelien kannattavuutta.

Kieli: Englanti

Avainsanat: aurinko paneelit, inverteri, aurinkosähköprosessi, energia tuotanto

Index

1. Introduction

The idea of utilizing the energy that comes from the sun has been known for over 600 years. According to the historian John Perlin, architects used the benefits from the sunshine when planning houses in China over 600 years ago. (Käpylehto, 2016)
Also, in other parts of the world people have been utilizing solar energy when building houses. In north America, for example, houses were built in a model where the south wall was higher than the north wall with a sliding roof. (Käpylehto, 2016)

In southern Finland it has been common to place houses in a north – south direction with windows concentrated to the south side of the houses. There are examples of churches built in 1470 that has been built with no windows on the northside and large windows on the south side in order to keep the building as warm as possible. (Lönnberg, 2020)
Although the knowledge of the advantages of the energy from the sun and the possibility to use its source of energy have been known for a long time, it seems that every new generation of architects has to realise the benefits for themselves and the knowledge seems to be easily forgotten until the next generation again is reminded of the benefits. (Käpylehto, 2016)
Glass windows was maybe the first invention that remarkably increased the benefits of passive solar radiation. The sun could shine in through the windows and warm up the house, but the glass prevented cold air coming into the house. The modern insulated double glasses have made it possible for half of the energy that the houses need for warming, to be done by passive solar radiation. The more the insulation capacity of the windows increases, the more it is possible to use passive solar radiation for warming up the houses. (Käpylehto, 2016)

1.1 The development of solar collectors and photovoltaic cells.

At the end of the 19th century the American market saw its first solar collectors that could warm up water with the help of solar energy by leading water trough modules of pipes placed on the roof of the house. The popularity of the solar collectors, however, did not

last too long, as the use of fossil fuels became more popular and cheaper. (Käpylehto, 2016)
Oil and gas were considered a better option since it could be used whenever heat was needed and was not reliable on weather conditions. The problems with global warming and CO_2 was not well known at that time.

Whenever there has been some oil crisis or increased oil prices, the popularity of solar energy has increased. This happened during World War II when oil prices rose. Japan was very poor after the World War and many people did not have the possibility to warm washing water by using gas or oil. This caused them to develop solar collectors that was placed on rooftops. At the end of the 1960s Japan had over 3,7 million solar collectors. Solar thermal Energy (STE) used to warm up water is a cheap and effective way to achieve benefits from the sun’s energy, especially in warm countries. In small scale it is however limited to meet the need of warm water, but it is not able to use it to produce electricity. (Käpylehto, 2016)

In 1876 William Grylls and Richard Evans Day discovered that selenium creates electricity when exposed to sunlight. A few years later, in 1883 Charles Fritts managed to produce electricity from solar cells made from selenium wafers. Charles Fritts is considered by some historians to be the inventor of solar cells. Daryl Chaplin, Calvin Fuller and Gerald Pearson created the first silicon based photovoltaic cell in 1954. Modern solar panels (PV cells) are much more efficient then the first photovoltaic (PV) cells but the principles are the same and silicon is still the most common material in modern solar cells. (Energysage, 2009) (R, 2017) (Sidén, 2015)

Since then, the technology has been developed, and solar panels has been ccontinuously increasing in popularity. 2017 was an exceptional year for solar energy globally, for the first time more solar power capacity was installed than fossil fuels and nuclear power combined. A total of almost 100 GW grid connected solar panels were installed in 2017 and in 2018 the amount was 107 GW. At the end of 2019, there was globally a total of over 650 GW grid connected solar panel systems (Wattson, 2019). Finland had a total of 120 MW solar power connected to the grid in 2018 compared to 70 MW in the year before and 27 MW in 2016. Over the last 15 years, the production volume of solar panels has increased with a compound annual growth rate (CAGR) of over 40 %. According to market forecasts, the installed solar power capacity, could reach up to 1.4 TW by 2024.

Germany is, with its 41,3 GW installed solar panel system capacity, the country in EU that has most grid connected solar systems, followed by Italy that have a total of 201 GW (Jäger-Waldau, 2020)
The largest solar plant in Finland in 2020 is in Nurmo in Seinäjoki with 22000 solar panels and an effect of 5300MWh/year (Saloarigo, 2020).

There is a great potential for private houses to produce their own energy by using solar panels. The advantage of solar panels is that everybody with their own property can use them. Solar panels have been a good way of producing energy for many years, but during the last few years there has been a breakthrough in terms of popularity. (Lovia, 2016) The reason for the raised popularity globally over the last few years is mainly because of the development of solar technology and a marked decrease in prices; much of this is due to China which has put a lot of effort in increasing the use of renewable energy within China, where many new solar panel mega factories have been opened and because of this the price per unit has decreased (Zhen, 2018).

Many companies, including local companies in Western Uusimaa, Finland such as Ekenäs Energi and Solklart, have begun for about 5 – 10 years ago to sell solar panel packages for residential houses and small factories. In their opinion most customers have little knowledge and experience of solar panels. When speaking to owners of residential houses in different forums for residential house owners in South Finland, I often get the response that many house owners are considering in investing in solar panels, but they would like to have more information on the financial and the environmental aspect as a base for their investment decision.

1.2 The energy use and profitability of solar panels.

In most investments, the profitability is a major factor when deciding if the investment is feasible? When will I be paid back? As mentioned further down in the text, , the main profitability factor for solar panels is the percentual amount of electricity they are able to use for their own consumption.
This work is about the possibility of using solar panels in residential houses in meeting a global need for a rising demand of renewable energy sources in order to prevent or minimize global warming. Research includes a case study about how much solar panel owners in

Western Uusimaa region in South Finland have been able to use the electricity they have been producing and how much have been sold out to the grid.

In this work I have studied eight different solar panel systems on residential houses. My research questions are:

- When is a household using most electric power and what time during the day are the solar panels producing the most?
- Is the produced electricity being used in the household or is it left unused or sold out to the grid and how is that affect the profitability of the investment?
- Could the solar system owners get more profit from their solar panels by changing the time they use electricity so that their own consumption would be focused to the time when the solar panels produce the most?

2. The energy production and the climate

Most of the Finnish population agree that global warming is a threat to the ecosystem and the climate (Hoppi, 2014). According to Nasa's Climate Change Synthesis Report the level of atmospheric CO_2 has risen by 70% since the industrial revolution in the 1950s (Fig 1) (IPCC, 2020), Variations in the climate have occurred in about 100 000-year cycles but scientists agree that the current change in the climate is caused by human activities. (IPCC, 2020)

During the last 70 years the atmospheric CO_2 has doubled compared to the levels before the industrialization in the 1950s. Effects of the global warming include: A rise in global temperature, warming oceans, shrinking ice sheets, decreased snow cover, a rise in sea levels, diminished arctic sea ice, ocean acidification and extreme events such as intense rainfall, extreme dryness and exceptionally hard storms. (IPCC, 2020).

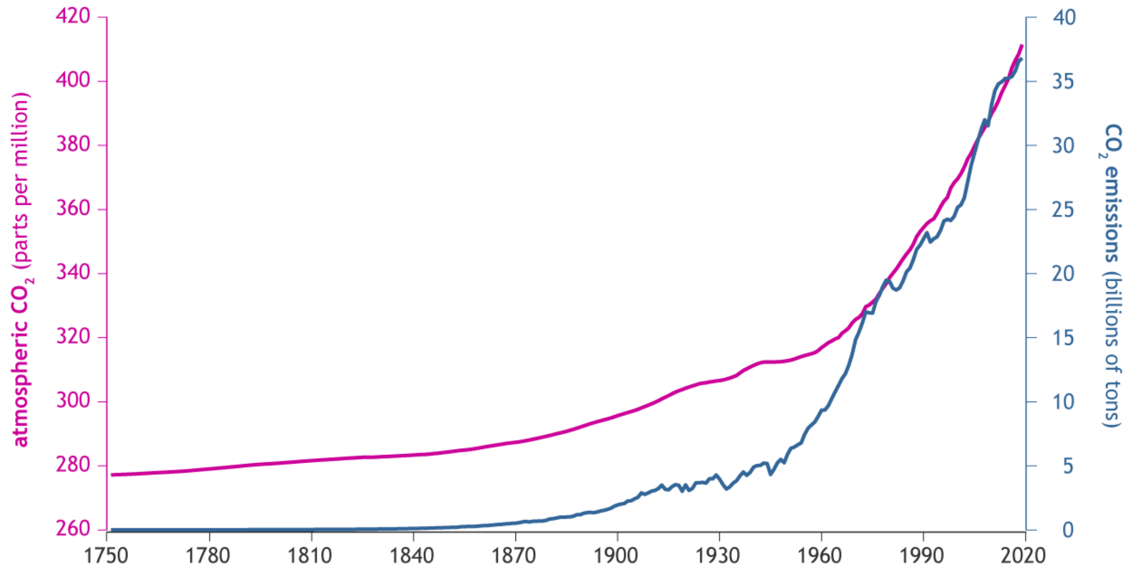

Figure 1. The atmospheric carbon dioxide has grown by 80% during last 70 Years (IPCC, 2020)

Most likely there is not one single solution to the problems of rising CO_2 levels and global warming, but the solution lies in every small action taken and every local solution found. A way to reduce the CO_2 emissions is presented as the wedge concept by Socolow (Socolow, 2011). It is based on a stabilization triangle, where the goal is to stop the CO_2 emissions to rise above the current levels. Any level of CO_2 emission exceeding that of today is the problem triangle, which needs to be addressed to keep CO_2 levels on the same level as they were in 2010. According to Socolow (2011) there are eight wedges including fuel efficiency, fuel switching (from fossil fuels to renewable types of fuel), carbon capture and storage, nuclear, wind and solar generated electricity, biofuels and natural carbon dioxide sinks that would solve the problem triangle (Fig 2).

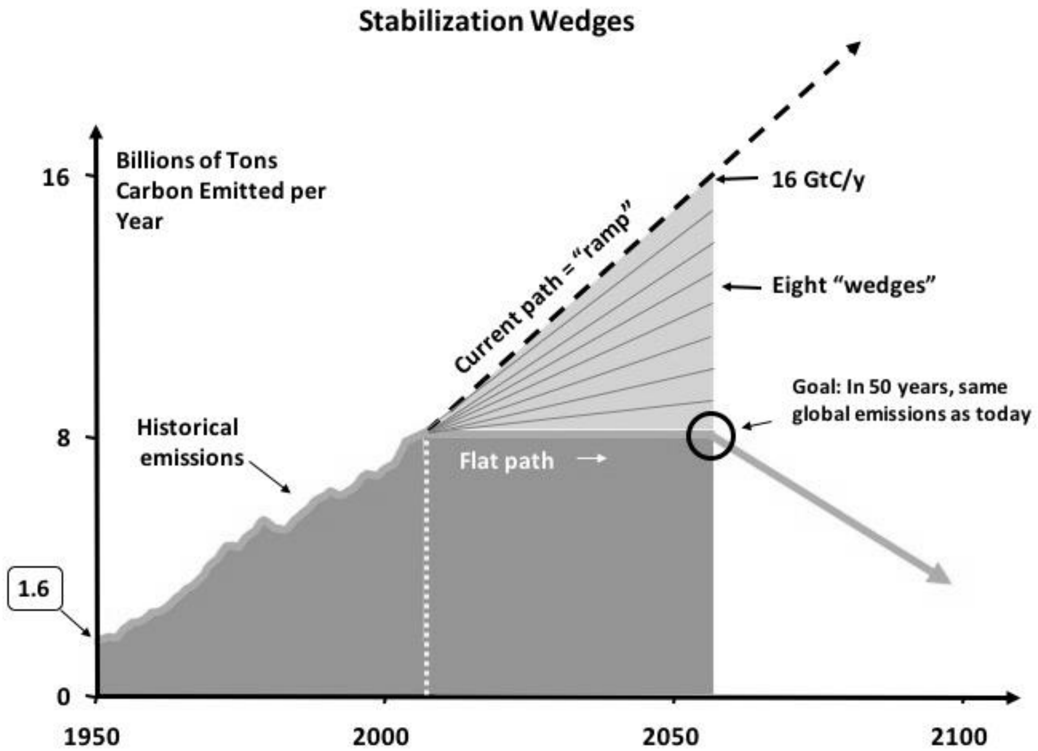

Figure 2. The stabilization wedges, Fuel efficacy, fuel switching, carbon capture and storage, Nuclear energy, wind energy, solar energy, biofuel and natural CO_2 sinks that need to be solved in order to prevent the CO_2 emission from rising from 2010s level (Socolow, 2011).

3. Actions and agreements for minimizing the climate change

To achieve a global effect and coordinated actions against global warming, national and international agreements are needed. In this the UN plays a great role in order to coordinate and pursue global agreements and action plans.

3.1 Global actions and agreements

Worldwide efforts have been made reduce the greenhouse gas emissions to decrease the global warming, have been set worldwide. Important meetings, statements and agreements has been made that have given directions for the usage and development of green energy. (IPCC, 2020)

One of the most important institutions for following up the climate change is The Intergovernmental Panel on Climate Change (IPCC) established by the United Nation's Environment Program and the World Meteorological Institute by the UN General Assembly in 1988. The aim was to prepare a comprehensive review and recommendations based on the scientific knowledge of climate change. Since then IPCC has delivered five Assessments Reports, which have provided policymakers with scientific facts about global warming and climate change. . The reports such as the Global Warming of 1,5°C special report, released in October 2018, has provided important material for governments on climate change and has set the groundwork for international climate agreements such as the Kyoto protocol and the Paris agreement. (IPCC, 2020)

The Kyoto protocol I s a framework connected to the United Nation's framework convention on Climate Change that obligates its parties to limit their Greenhouse gas (GHG) emissions. The Kyoto protocol puts a greater responsibility on the developed countries that stands for the majority of the global GHG emissions. (UNFCCC, 2020) The Kyoto protocol was adopted in Kyoto in 1997 but entered into action in 2005. It first commitment period started in 2008 and ended in 2012. During this first period, 37 developed countries agreed to reduce their emissions to five percent of the 1990 level. During the 2012 – 2020 commitment period, parties agreed to reduce their emission by at least 18% below the level of 1990. (United Nations, 2019)

Finland has achieved the Kyoto Protocol's goal of stabilising greenhouse gas emissions in the period 2008–2012 at the level of 1990. (Finlands environmental administration, 2020)

The Paris agreement (UNFCCC, 2020) that was adopted in Paris in 2015
and entered into force in 2016 aims to limit the global temperature rise to below 2°C above the pre-industrial levels and to pursue efforts to limit the increase to 1,5°C. Parties that have adopted the agreement aims to strengthen the ability of countries to deal with the effects of the climate change.

The Paris agreement requires all parties to make their best efforts to reduce the CO_2 released into the atmosphere. All parties are obligated to regularly report on their emissions and their implementation efforts to the European Commission. In 2020 there was 194 states and Finland that have signed the agreement. In 2016 the United states and China, which together stands for almost 40% of the global emissions, issued a joint statement that they will sign the Paris Climate agreement. (United Nations, 2019) . In 2017 USA, however, announced that they will withdraw from the agreement. (Mulligan, 2018)

The green deal is a part of EU. s strategy in implementing UN:s 2030 agenda and the sustainable development goals including the goals of the Kyoto protocol and the Paris agreement. The Green deal's main points include supplying clean, affordable, and secure energy, a zero-pollution ambition for a toxic free environment and accelerating the shift to sustainable and smart mobility. These aims fits verry vell with solar energy and its zero-emission electricity production. Other points in the green deal is to mobilise the industry for a clean and circular economy, to impose building and renovating in an energy and resource efficient way, to preserve and restore ecosystems and biodiversity, a fair and healthy environmentally friendly food system and accelerating the shift to sustainable and smart mobility. (European Comission, 2019 a) All these important actions requires a sufficient environmentally friendly emission free energy production.

The "Green deal" shows the European union's way to become a low carbon society and economy as widely described in the Commission's three steps: the European climate law, European climate pact and the 2030 target plan. (European Commission, 2019)

The 2030 target plan has set clear targets for the period of 2021 to 2030 and can be crystalized into three goals, at least 40% cuts in greenhouse gas emissions from 1990:s level, at least 32% share of renewable energy and at least 32,5% improvement in energy efficiency. (UNFCCC, 2020)

National climate and energy plans were required from the member states by the end of 2019. A draft of the plans was expected to be submitted by the end of 2018. (European Comission, 2019 a)

The EU commission presented its long-term strategic vision on a climate-neutral economy by the end of 2018. The long-term strategy focuses on the transition into a prosperous, modern, competitive, and climate-neutral economy.

EU aims to be a global leader on the way to climate neutrality.

The original target int the 2010-2030 action plan for the share of renewable energy sources in energy production was 27% but was revised upward because this aim was seen to been reachable before 2030. (European Commission, 2019)

3.1 Finland's climate strategy in response to the international agreements

Finland belongs to the leading countries in the world when it comes to the usage of renewable energy sources and especially bio energy (Motiva, 2020). The share of renewable energy sources in the end consumption in Finland is over 40%. According to the national climate program (Ministry of Agriculture and Forestry of Finland, 2020), the aim is to grow the share of renewable energy to over 50% before 2030. The most important types of renewable energy sources in Finland are bioenergy, waterpower, wind power and ground heating. The government has set a goal of reducing greenhouse emissions with 39% by 2030, 50% by 2030 and 80 - 95% by 2050 compared to CO_2 levels in the 1990s the domestic use of imported oil will be reduced, and the use of coal as a source of power will be phased out by increasing the usage of renewable energy source such as wind power and solar power. (Ministry of Agriculture and Forestry of Finland, 2020)

The national energy and climate strategy " Energy and climate roadmap 2050" set out the milestones to achieve the goals that is set in the Government programme and the national commitments within the EU. The climate strategy is then adopted in the government program. (Huttunen, 2017) (Ministry of Agriculture and Forestry of Finland, 2020)

According to the governmental report on National Energy and Climate strategy for 2030, the energy and climate policy have three dimensions that constantly need to be balanced. . The future energy system must be cost effective, it needs to enable the growth of the national economy and Finnish companies´ competitiveness in the global market and it needs to be sustainable and offer a sufficient security of supply.
The main way of reducing the CO_2 is done by improving the production of energy, the energy system and improvement of the use of energy (Finlands Ministry of Economic Affairs and Employment, 2017)

In 2015, 79% of Finland's energy production was emission free and 45% was from renewable sources, which was a lot greater than Finland's own climate goal that was set at 38% by 2020. (Fig. 3) (Kostama, 2016)

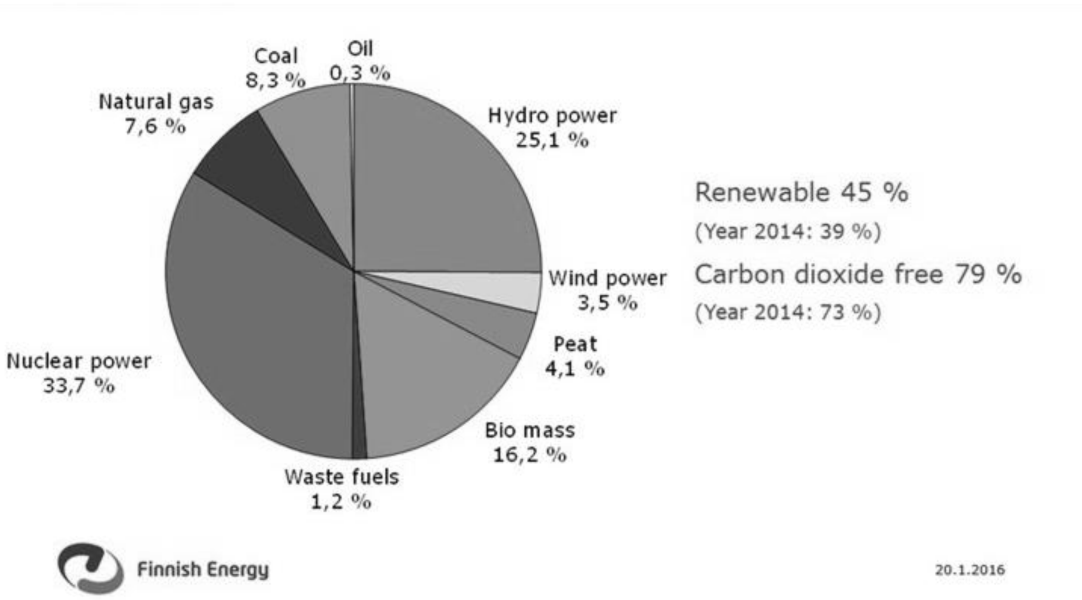

Figure 3. In 2015, 79% of electricity generated in Finland was emission-free, and renewable energy sources in electricity generation accounted for 45 per cent. (Kostama, 2016)

As a lead in the national aims to minimise the greenhouse gases, the Finnish Environment Institute (SYKE) has initiated a project in 2008 called Hinku, which stands for "CO_2 neutral municipality" (hiilineutraalinen kunta in Finnish) ". It´s aims to bring municipalities, businesses, citizens, and experts together to find solutions to reduce greenhouse gas emissions. There are 74 (in 2020) participating municipalities that are committed to reduce their greenhouse gas emissions with a more ambitious timetable than the EU requires from their member countries (Suomen ympäristö keskus, 2018). The aim with the Hinku project is to encourage to solutions that have economic, social, and environmental advantages. The focus for the project is to reduce emissions when it comes to transportation, housing, and food.

The municipalities involved in the network aims to reduce its greenhouse gas emissions by 80% in 2030 compared to the 2007 level compared to the EU:s goal of cutting the emissions by 55% (European comission , 2020)

The participating Municipalities are required to make a yearly plan about investments that reduces the CO_2 emissions. The Municipalities are also expected to encourage their residents to climate smart solutions and climate smart living, for example investing in solar panels This includes installation of solar panels on buildings owned by the municipality and urban planning so that new buildings is suitable for solar energy production. This could also include the directions of the roofs when planning new housing areas, requirement of roof types that are suitable for solar panels installations and other possible factors that can affect the possibility of producing renewable energy and climate smart building area development (Seppälä, 2019)

4. Electricity production from renewable energy sources

Many of the renewable energy sources such as solar energy, wind power, bioenergy, wave energy and geothermal are sometimes controversial or hard to implement into the energy system. Wind turbines, for example, do produce electric power with zero CO_2 emissions but carry problems such as noise pollution, reflections and shadowing (U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy , u.d.). (Council of Canadian Academics, 2015) Solar power is only working when the sun is shining, wave energy works when there are waves and so on.
It is hard to produce renewable energy on demand, but the technology is developing all the time.in (Salokoski, 2017)
The coastal region in Finland is suitable for electricity produced by solar panels. Especially the southwest coast has a good level of solar radiation.

To reach the climate goal set by the Kyoto target Finland relies on its nuclear power, its growing import of natural gas from Russia and its development of new technology for energy production. (Huttunen, 2017) Especially wind power is growing rapidly in Finland. At the end of 2019 there were 754 wind turbines with a total effect of 2285 MW, which makes a 7% of the total electrical energy consumption (Motiva, 2020)

Research shows that the consciousness of renewable energy varies among different demographic groups. People in the age group of 20-30years seem to be more concerned about environmental problems and global warming than older groups. However, the level of knowledge about renewable energy varies a lot between people in all different demography groups. According to a study, 53% of the respondents think it is important to develop renewable energy technology and 43% would want to take practical steps in the development and use of renewable energy technology. Many of the respondents, however, think that the government and the municipalities should take the first steps of introducing renewable energy. (Moula, Munju, Maula, Hamdy, Fang, Jung & Lahdelma 2013)

New ways of producing energy, especially on a small scale and on a local basis, may feel unfamiliar for people and cause them to stick with old solutions. Renewable energy sources, however, can create jobs in manufacturing, installation, and maintenance and that can affect people's attitudes in a positive way. Renewable energy sources investments can also have a positive impact on tourism as a growing number are searching for green options for their travelling. (Paravantis, 2013)

5. The Finnish electrical system

In many cases, the alternative to fossil fuels as an energy source is electricity produced by renewable resources. The amount of electricity used in Finland is expected to grow by 13,6% from 88.4 TWh to 100 TWh between 2020 and 2050 The grid connected solar power is expected to grow from 0.1 TWh in 2020 to 6 TWh by 2050. (SKM Market Predictor, 2019) This makes demands on developing the electric power system in Finland, that consist of powerplants, a nation-wide transmission grid, regional networks, distribution networks and electricity consumers and producers.
The power grid is connected to the inter-Nordic power system that includes Sweden, Norway, and Eastern Denmark. Finland also has transmission links to Russia and Estonia. Fingrid that is public limited liability company is responsible for the functioning of the Finnish transmission grid that includes 400 kV, 220 kV and 110 kV lines. Regional distribution networks are then connected to the national grid and secures the transmission to the end user and vice versa if the end user also produces electricity, for example by solar panels. (Fingrid, 2018)

The electrical grid system is based on a precise 'balance between supply and demand. (Fingrid, 2018) The amount of electricity that is coming into the system must be in balance with the amount that goes out. If the amount of electricity entering the system differs from the amount that leaves, it could lead to huge damages for the end user such as major failure in the end user's electrical equipment and in the grid's equipment as well.

Many renewable energy sources such as solar and wind energy are weather sensitive. Renewable energy is currently on the rise and the prediction is that this will most likely rise even more in the future. Renewable energy has a strong support in society and among many politicians in Finland since moving towards green electricity is an important step in achieving the 2030 environmental goals set by the Finnish government. This, however, puts a high demand on a rapid transformation of the national electrical system; a transformation which includes change for both consumer and the producer. In the future, the role of the consumers - in terms of balancing the level of demand with supply – will increase. Fingrid (i.e., Finland`s transmission system operator) sees that the future green electricity could be concluded in three themes: Strengthening the position of the electricity consumer, developing the marketplace in line with the changing structure of electricity generation and the active participation in market operators in balancing the electricity system (Finngrid, 2018)

The consumers' role will grow in the future electrical system. Today the balance in the grid is kept up by night and day tariffs and in cooperation with the industry. In the future when the renewable production makes up a bigger part of the total production, the balance in the grid needs more flexibility and have to be adjusted on a level unit under 15 minutes instead of an hourly basis as it is today. It is called flexibility on demand. The consumer is in an important role, where the consumer is expected to be able to impact on the transmission fees and the electricity price based on when he is using the electricity. (Salokoski, 2017)

Smart technology in electronic equipment can adjust the consumption based on the demand of the network and the momentary price level. Today most consumers have an electric purchase agreement that have a fixed price for example two years, or they have a day and night tariff. In the future it is predicted that the prices can vary many times during the day based on the demand. Smart technologies can then optimize the consumption according to the price and adjust the use of their own produced energy. Energy could, for example, be produced by solar panels be stored in a battery pack and used when the electric price is at its peak. (Bremer, 2017).

5.1 Selling electricity to the grid

In Finland it is possible for private persons to sell electricity produced with for example solar panels into the grid. This requires that the system is connected to the national grid and that the producer has made an agreement of selling overflow electricity to the electricity provider.

The electricity producing companies commonly pay a price for the overflow electricity that is connected to the grid, to the market price based on the hourly Spot-price (the electrical price on the Nordic electricity market Nord Pool). Then the solar panel owner can sell the overflow electricity at the same price that he pays when he is buying electricity, when their own system is not producing enough for his own use.
However, it is important to know that the profit he gets from selling out electricity to the grid does not include transmission cost and taxes. Transmission costs and taxes can sometimes make 2/3 of the price that the consumer is paying for the electricity (Fig. 4). (Lehto, 2020)

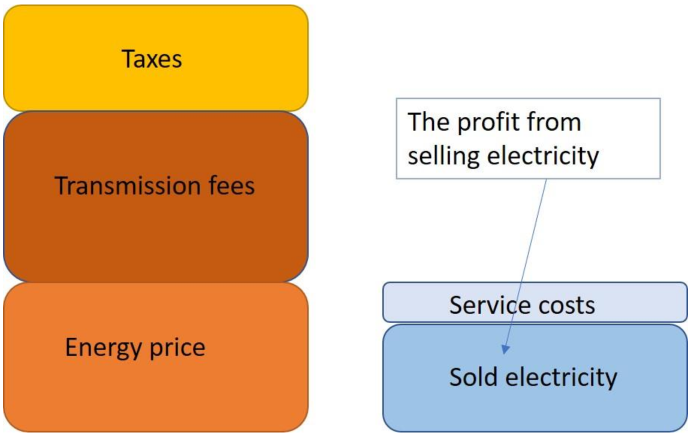

Figure 4. When buying electricity, the price consists of taxes, transmission fees and the price for the energy its selves. When selling energy out to the grid you only get the price for the energy minus possible service cost from electrical company. (Motiva, 2020)

The transmission fees can sometimes be higher than the electricity price itself and on top of that there are energy taxes that make up the total price of the electricity that the consumer is buying. It is better, if calculating the payback time of the investment, to size the solar panel system so that you can use most of the produced energy yourself. (Motiva, 2020)

6. Solar Energy

The sun produces an enormous amount of energy all the time and it is free for everyone to use it. It is not necessary to own a piece of land on a specific location such as a water stream, the sea or in a windy spot to produce solar electricity - all that is needed is an open sky and a roof where they can be placed.(VTT, 2016). According to Tahkokorpi (2016) the amount of energy that comes to the earth from solar radiation is about 10000 times more than the whole human population used in 2008. The EU Photovoltaic geographical information system shows that solar radiation in southern Finland is not far from the radiation level in northern Germany. There is a great potential in the energy that comes from the sun, if we just manage to use it in a way that is cost effective compared to more traditional alternatives.

The peak time of solar production in Finland (in total) is between June and August. A single sunny day can also boost the production of energy outside the time of peak production.
(Fig 5)

Date

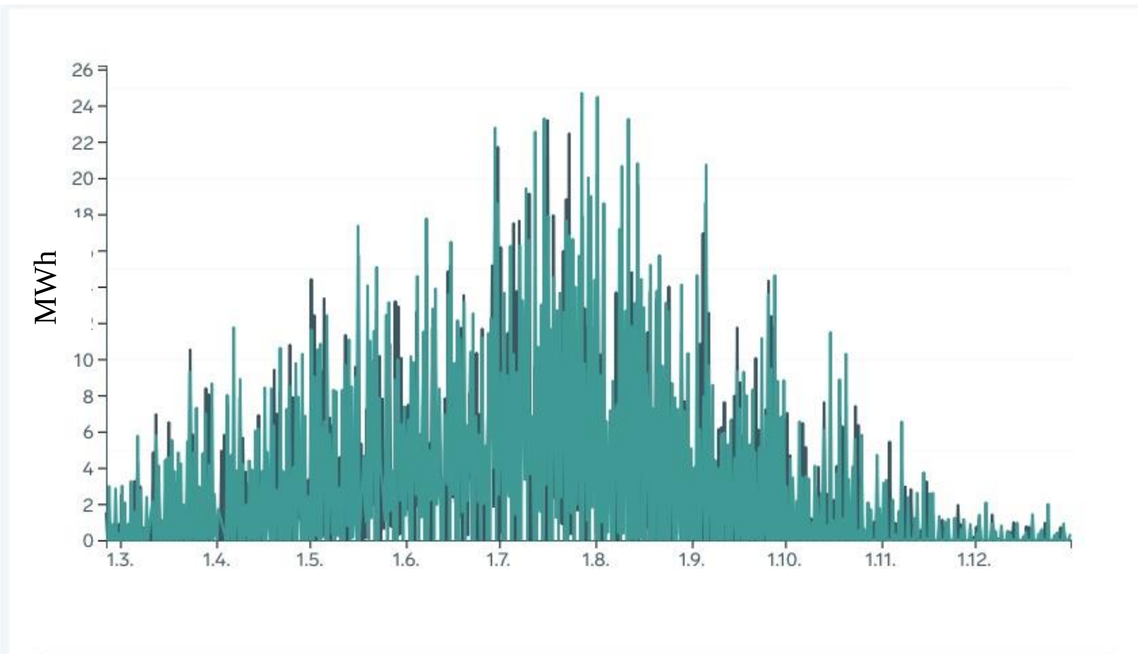

Figure 5. Total Production of Solar Power in Finland 1.4 - 31.10.2017   (Fingrid, 2018)

In Finland, the production of solar panels started around the 1970s. and increased at the beginning of 1980s, during the 90s the popularity diminished and began rising again at the beginning of 2000 and the so-called “third wave” of increase started around 2014 (Loviio, 2016). Solar panels have become much cheaper in recent years and this has led to a growing interest in investing in solar panels (Roney, 2013).

The environmental impact of solar panels is quite low. The energy payback time, that describes the time a powerplant needs to function before it has compensated for the energy needed for the manufacturing and installation, varies between 0,75 – 5 years for solar panels. Compared to the lifespan of a solar panel that has/needs about 30 years for the energy payback time, the panels are considered to have low environmental payback compared to other more traditional energy sources. The energy payback time is affected by different factors such as the placing of the panels, the minerals needed for manufacturing and the lifespan of the panel. One of the biggest environmental impacts of solar panels are the minerals used for manufacturing. (Muller, 2015)

6.1 Solar radiation

Germany is the leading country in Europe when it comes to grid connected solar panel systems with a total capacity of almost 50 GW, therefore, Germany is often used as a reference when comparing different countries’ grid connected solar panel systems. (Fraunhofer Institute for Solar Energy Systems, ISE, 2018)

Mid and south European countries have more days of sunlight than Finland but the total radiation in Rostock is not much lower than in Helsinki, which implies that solar panel production could be as effective in southern Finland as in northern Germany (Palz, 2013). (Fig 6)

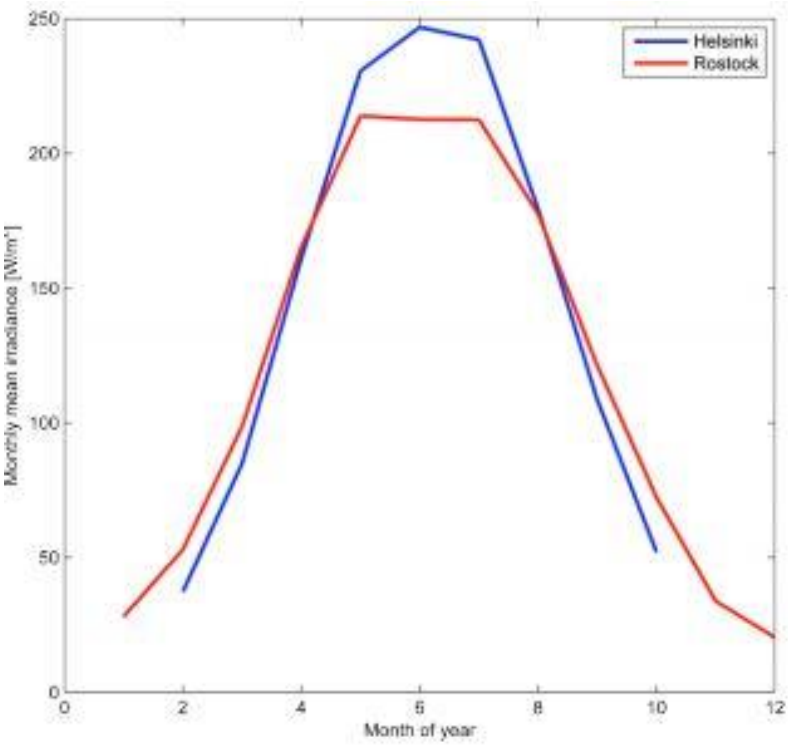

Figure 6. The pictures show the average monthly solar radiation in Helsinki and in Rostock. (Palz, 2013).

The days are very long in Finland during the summer and the sun moves in a large bow over Finland. This means that during the day the sun comes in a wide range of angles. This affects the effect of the PV panels and their placing and the mounting angle or if they are a model that follows the movement of the sun. This can be seen in Fig. 7. (Lindfors, 2014)

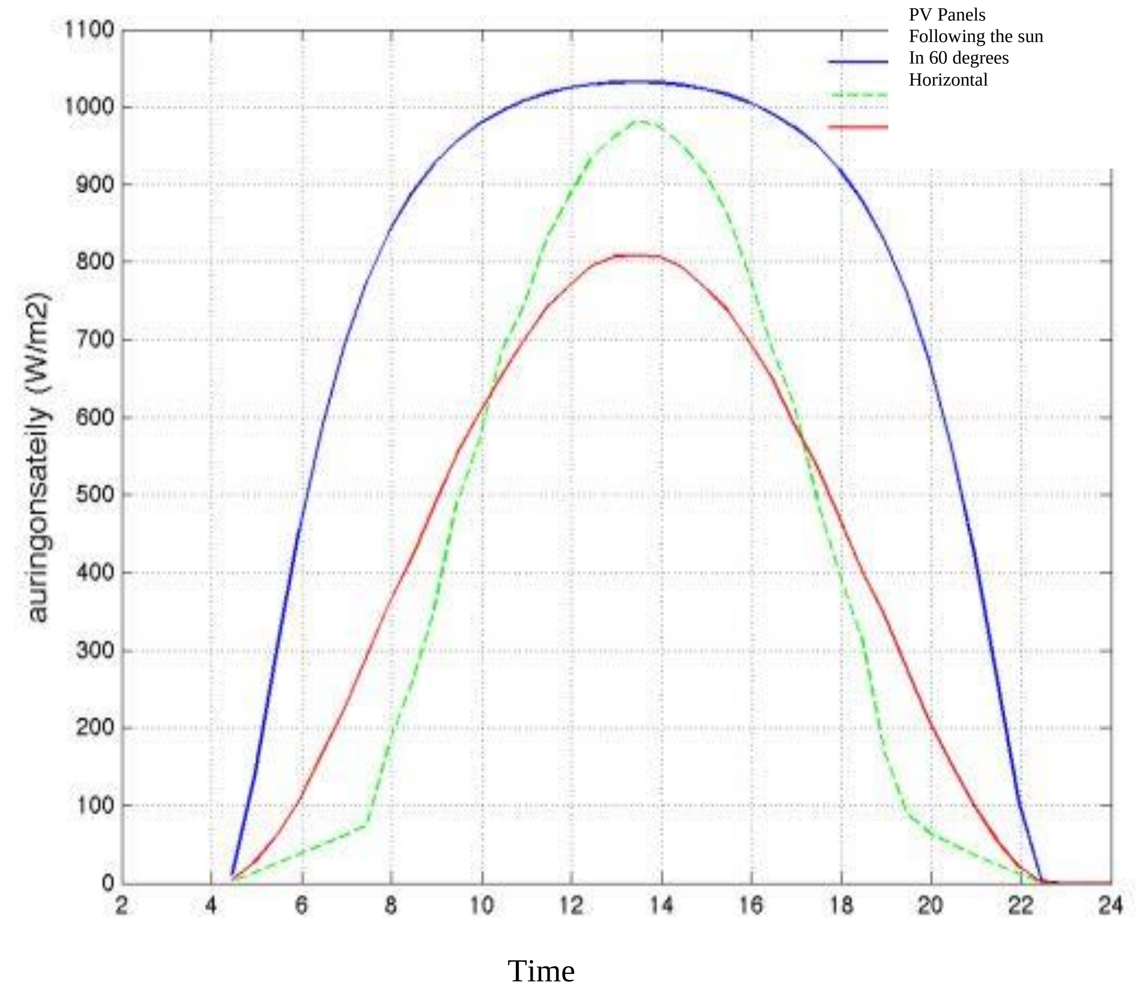

Figure 7. The difference between solar panels that follows the sun and panels mounted in a 60 degrees angle and panels that are horizontal varies up to 24% in production (Lindfors, 2014)

6.2. Solar panels

There are two main types of technologies used in solar panels Photovoltaics (PV) and concentrated solar power (CSP), also sometimes called solar thermal power. The most used technology for converting solar light into some type of electrical energy is the photovoltaic process. (R, 2017)

PV materials convert solar radiation directly into electricity. A solar panel is normally built up of many PV cells, where each cell produces energy when exposed to solar radiation. An individual PV cell produces about 1 or 2 W of power. (Käpylehto, 2016)

The PV effect was discovered in 1839 when the French scientist Edmond Becquerel first discovered that some materials react with sunlight in such a way that they generate electricity (Palz, 2013). A common PV solar cell is built up of two layers of semiconductors. The most common material used is silicone or crystalized silicon. The silicon crystal is usually combined with boron on the bottom layer that causes the silicon crystal to gain a positive charge. The top layer of the cell is combined with phosphorus and that gives the top layer a negative charge (Fig. 8). When the sunlight hits the cell, it knocks electrons loose from both the top layer and the bottom layer. These electrons then travel through a circuit from one layer to another, providing a flow of electricity. (Office of Energy efficiency & renewable energy, 2015)

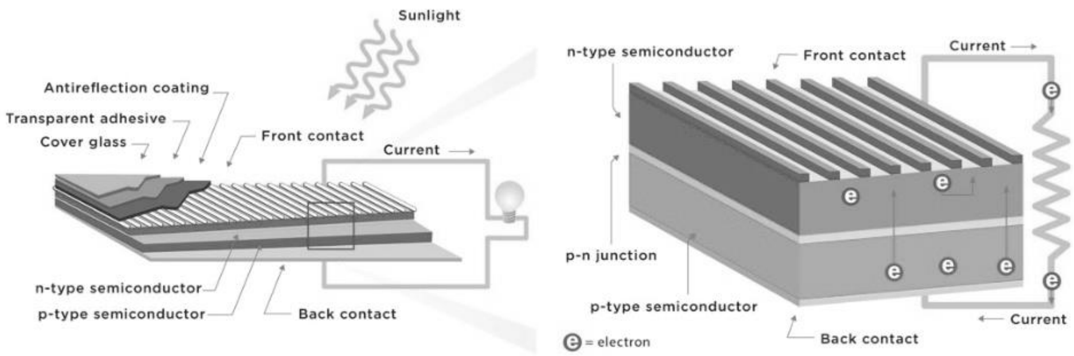

Figure 8. Solar Radiation is Transformed into Electrical Energy by the Photovoltaic Process. ©Aaron Thomason / Srpnet.com

The electricity is produced when the solar radiation hits the front side of the PV cell and an electric voltage occurs between the front and the back of the cell. The front and the back side are connected. (Energimyndigheten, 2013)

There are three major types of solar cells: single-crystal, polycrystalline and thin film cells. The panels included in my research are all polycrystalline panels. Regardless of the type of panel all solar panels work according to the same principles as mentioned above.

1. Single-crystal, or monocrystalline solar panels,. The silicon is formed into a long bar or cylinder that is then cut into wafers. This process gives more space for the electrons to move from the front layer to the back layer and becomes more effective in taking the solar radiation and turning it into electric power. The downside of this

option is that it takes more material end energy to build such panels and thus they are more expensive to buy. (Fig 9). (Energysage, 2019)

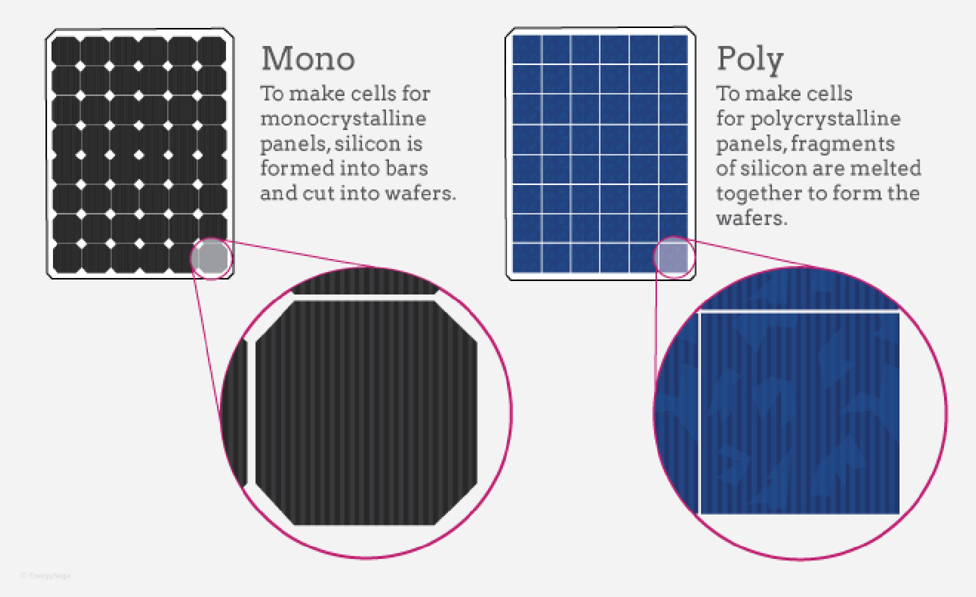

Figure 9. The difference between mono- and poly- crystalline cells can be seen on the colour or the structure of the sell. (Hollars, 2002)

2. Polycrystalline cells are also made from silicone. They are not, however, made from a single crystal of silicone but rather they are made from many small pieces of silicone to form the wafers for the panels. This method takes less material to manufacturer and because of this they are cheaper, although less effective, than the monocrystalline solar cell. (Energysage, 2009)

3. Thin film cells are thin flexible cells that can be placed on materials such as glass or metal. Thin film cells are normally produced by spraying a molybdenum base electrical contact layer on a substrate such as glass, metal, foil, or any other suitable material. This gives a flexible material that can be used in many various ways such as windows, walls or as a pocket solar panel. The efficiency of a thin film cell is lower than single and polycrystalline cells but can be much cheaper to produce and offers a lot of different possibilities for use. (Hollars, 2002)

The most popular type of panel is the multi crystalline cell, the popularity of which has been steadily growing during the new millennium. (Fig. 10)

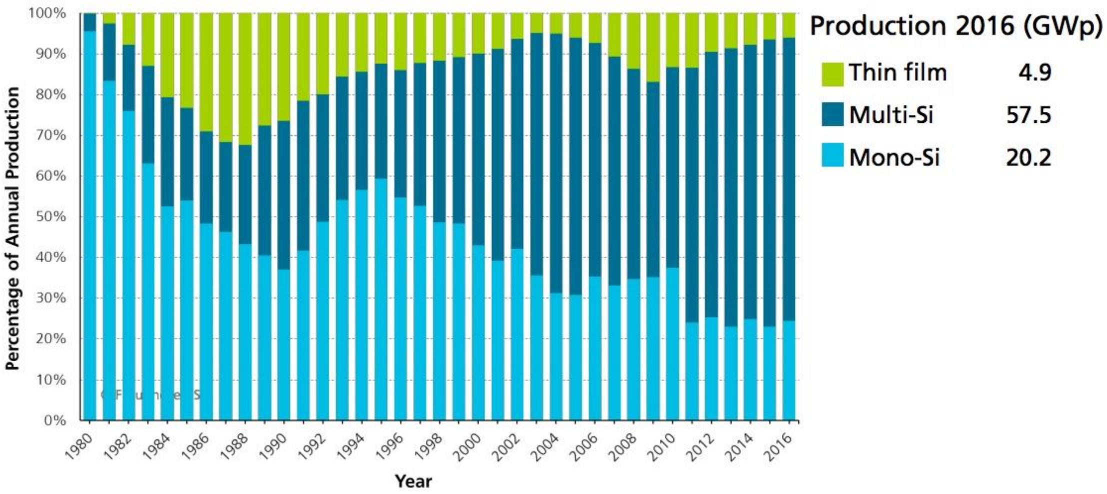

Figure 10. The multi crystalline panels have increased in popularity due to their low cost and relatively high effectivity. (Fraunhofer Institute for Solar Energy Systems, ISE, 2018)

If some part of the panels is being shadowed, by for example a tree or a flagpole, the whole production of the panels in a string is lowered to the panel that produces the least.

Shading of one cell reduce the total power output remarkably. Therefore, it is crucial that the placing of the PV cells is made in a way that minimize shadowing of the panels.
(Gila Masters, 2004)

6.2.2 Inverters

The inverter plays a crucial role in the solar panel energy system. Irrespective of whether the system is a small home solar power system or a large scale industrial solar power plant it will not work without an inverter. An inverter's task is to "invert" the incoming direct current (DC) to alternating current (AC) i.e., the standard used by all commercial appliances. The inverters and the technology behind them have advanced during the last years alongside the development of the solar panel technics. Inverters are the "brain" in the system. They control the incoming power as well as the power sold back to the grid and it also gives the user information about the system. Some inverters can be connected to the internet and can give the user a lot of usable information about the electricity production. (Zipp, 2013)

There are two major types of inverters: string inverter and micro-inverter. Both types are used in minor panel solutions particularly those used in residential and small commercial systems.

A micro-inverter is directly attached to each solar panel and converts the electricity from Direct Current (DC) to Alternate Current (AC) in the panel. This solution is good if the solar panels are in a place where some shadowing occurs on some of the panels during the day, when the sun is otherwise shining. For example, a nearby tree or flagpole could cause a major loss in production. This was observed in one of my research objects that is displayed in the results in chapter 24. The negative side of using a micro inverter is that it is one more thing which can be broken. Maintenance is also a lot harder and more expensive to perform when the inverters are attached to the panel on the roof or another place where the panel is placed.

A string inverter is more commonly used because it is cheaper and easier to install. The name string inverter comes from the way it is connected to the panels, where the inverter is connected to a "string of solar panels and collects all the electricity from all the panels and converts it from DC into AC". The string inverter is usually located in a place that is sheltered and easily accessible. (LG energy, 2018)
There are a few ways of getting around the problem of shadowing. One, as mentioned above, is to use micro inverters, which invert the power from DC to AC separately for each panel. Another way is to connect the panels with parallel strings so that panels that are easily shadowed are connected on a separate string (Fig. 12). Many home inverters support 1 – 4 different strings or more.

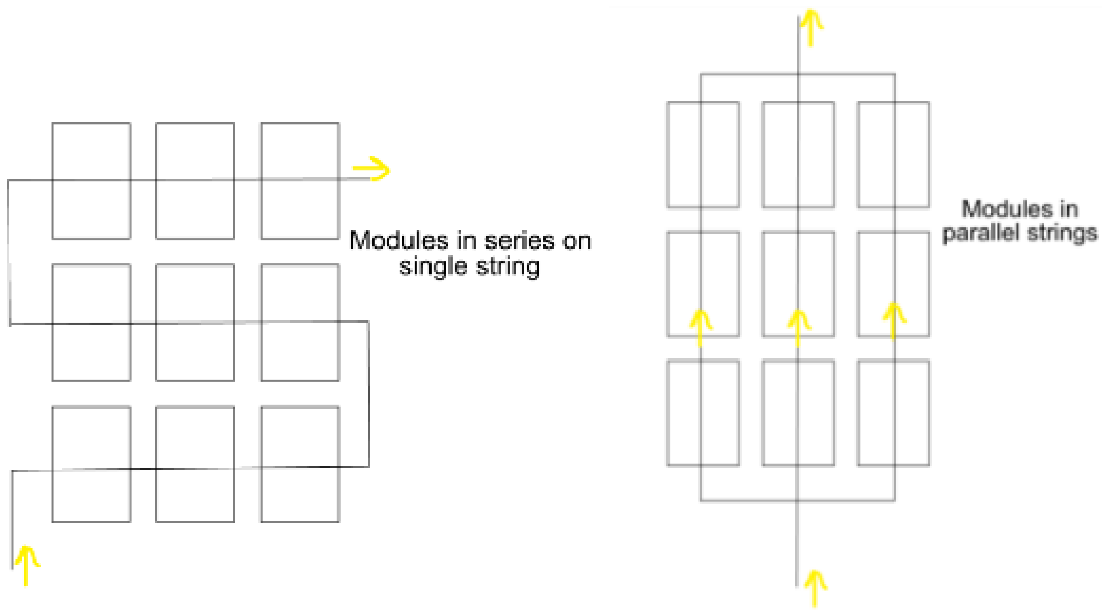

Figure 11

The Picture Show the Difference between Modules that are Connected in One Series of Strings and Modules that are Connected in Parallel Strings. (Gil Masters, 2004)

Another way of solving the problem of shadowing is to add a bypass diode between each cell. When a solar cell is in the sun there is a rise in the voltage, the bypass diode is cut off and the electricity flows as normal. When the cell is in the shade, the drop of the current will turn on the bypass diode so that the electricity can flow around the shaded cell i.e. bypass it. (Gil Masters, 2004)

7. The possibility for real estate owner to produce their own electricity

Electric power produced by solar panels are feasible when the electricity is replaced by more expensive purchased electricity from the grid.
Current electricity prices mean that large scale PV (photovoltaic) power plants? require a long payback time. Without subsidies PV plants do not offer a feasible way of reaching short term goals of reducing CO_2 emissions. Higher transmission and electricity costs or cheaper investment costs could improve the investment rate for solar power plants. (Timo, 2015)
If the government were to introduce a strict environmental policy the cost of electricity would likely increase. There are other factors that would increase electricity prices and would have a positive effect on the feasibility of solar panel systems. E.g., summer cottages in Finland, are suitable for off-grid PV systems, where expensive connection fees and monthly fees to be connected to the grid, makes PV da feasible option the cottage is in use (Finlands Ministry of Economic Affairs and Employment, 2017)

The feasibility of a PV system is affected by factors such as the purchase price of the system, the placing and the direction of the panels, the surface, and the condition of surface where the panels are being installed, the price of purchased electricity and the sizing of the system in relation to its own consumption. (Auvinen, 2016)
When calculating the feasibility of the PV system, it is recommended to look at the system over its whole lifespan and compare the electricity that it will produce during its 30 years' lifespan. The feasibility can be calculated by calculating the net present value of the

investment, (NVP) That is the difference been the present value of cash inflows and the present value of cash outflows over a period.

The NVP can be calculated by using the following formula:

$NPV=_{t=1}\sum_{n}(1+i)_{t}R_{t}$

Where:

R_t = Net cash inflow-outflows during a single period *t*

I= Discount rate or return that could be earned in alternative investments

T=*number of periods*

(Kenton, 2019)

The feasibility can also be calculated by Internal rate of return, IRR that tells the percental return rate of the investment.

The IRR can be calculated by the following formula:

$0=NPV=_{t=1}\sum_{T}(1+IRR)_{t}C_{t}-C0$

Where:

C_t = Net cash inflow during the period t

C_0= Total initial investment costs

IRR=The internal rate of return

t = The number of time periods.

(Kenton, 2019) NVP was used the studied solar panel systems in this research to calculate the feasibility.

8. Material and methods

In this work focused has been laid on how consumers have been able to use their produced electrical energy. Eight different solar panel systems are included in the research. The research was made during the period of May - August 2017 and from May - August 2018. The households were selected based on the type of inverter used. Only those with an inverter connected to the internet were chosen to get access to the production data. The consumption data was provided by Ekenäs Energi. The research in this work focusses on the consumption of different solar panel systems on an hourly 24/7 basis between May and August 2017 and

2018(and how the different households have utilized their electricity during the different hours of the day by looking at the amount of electricity being used at different times of the day. .

Production data was downloaded from the different Inverter manufacturers' websites used by the solar power systems' owners. This required login details provided by the sellers of the solar panel systems: Raseborgs Energi and Solklart,

The inverter models that were used are Fronius, SMS and Kostal. The production data was downloaded from their websites.

Fronius -> www.solarweb.com, SMA -> www.sunnyportal.com, Kostal -> www.piko-solar-portal.com

Table 1. The Different Panel Packages Included in my Research, showing maximum capacity and the Manufacturer that was either Salo solar or Heckert Solar

Solar system	Inverter Type	PV system power	Panel Model
Salo 1	SunnyBoy 240-10 18xmicroibverter	4740Wp	Salosolar
Salo 2	SunnyBoy 240-10 4xmicroibverter	1060Wp	Salosolar
Salo 3	Sunny Boy 2.5 1VL-40	2600Wp	Salosolar
Salo 4	SunnyBoy 240-10 6 x microinverter	1575Wp	Salosolar
Salo 5	Sunny Boy 2.5 1VL-40	2600Wp	Salosolar
Heckert 1	Symo 5.0-3-M (Fronius)	5200Wp	Heckert solar
Heckert 2	Kostal Piko 5	5200Wp	Heckert solar
Heckert 3	Kostal Piko 5	5000Wp	Heckert solar

The webservices that the different manufacturers offer varies considerably. Some services provide an easy to use and very informative site while others provide only the basic information. Some of the services provides basic information with the basic login and then some more information if the customer chooses to pay more for the PRO service. The basic login could for example show information on the webpage on an informative picture daily but not the possibility to download electricity production with an hourly accuracy. It was, therefore, hard to obtain reliable, comparable electricity production data for all the different systems at the time of my research.

External factors such as trouble with the internet connection for the inverter also resulted in a lack of information at certain times and because of that the data could not be used in my research. If the data was not accessible to download with an hourly accuracy or showed enough data for the whole period, was left it out from the research.

9.1 Interviews

In May 2017, interviews were made (over the phone) with the leading building inspectors from the municipality of Hanko, Raseborg, Inkoo and Lohja. Questions were asked to them about the regulations and the need for permits required for solar panel installations in their respective municipalities.

9.2 Analysis of data

For all the households studied, the production data was downloaded is within 15 minutes accuracy in a csv file. The data has been converted from W per 15min into to kWh by using the formula:

$$W/15 \text{ min} \times 4 \times 0{,}001 \qquad (1)$$

In order be able to compare it with consumption data, provided by Ekenäs Energi, that was in kWh . The data was subsequently calculated into an average kWh for production and consumption during a certain hour during a certain month, so the average data was obtained, for example, at 12am for a certain month. This was done using excel Pivot table tool. By doing this I was
able to compare households' solar panel systems and display the difference between consumption and production.

9.3 Feasibility of the investments of solar panels

There are many different factors that affect the feasibility or the net present value of the investment (NVP) of a solar panel system, such as the price of the investment, the price of bought and sold electricity, the actual rate of the financing of the investment, the percentual part of the level of own usage of the produced electricity. When calculating the feasibility of my investigated cases, the Finn solar projects tool for the feasibility of solar systems, as presented below was used. (Finsolar, 2021)

Table 2. Finn solar calculating sheet (Finsolar, 2021)

The price of bought energy	cent / kWh
Transmission fees	cent / kWh
Electricity taxes	cent / kWh
Value added tax on bought energy	Percent
Summary	Cent / kWh
Estimated annual growth on bought energy	Percent / year
The total consumption per year	kWh / year

Information about the solar panel system and the investment costs

The effect of the solar panel system	Wp
The calculated area of the solar panel system	M^2
Investment costs	euros
The system price/kWp without subsides	*euros / kWp*
Possible subsides, %	percent
Goodwill (such as reputation)	*euros*
Investmentcost with subsides	*euros*
Rate on finacing costs	percent
Expected annual revennua	percent
The calculated rate on the investment	percent
Own percental usage of the produce electricity	percent
Price on sold electricity	Cent / kWh
Price for renewing the inverter after 15years	percent
Yearly maintenance costs	percent
Annual production	kWh / kWp
Yearly production	*kWh*
Yearly decrease in effectivity	percent

10. Results

The result from the research shows that that there is a surprisingly small part of the produced energy that was used in the own facility and a big part that was sold out to the grid or left unused. The research shows that the sizing and the planning of the solar panels system is important to gain a maximum profit.

10.1 The level between produced and consumed electricity

The data for all the different solar panel systems that was studied showed that in both April and September in 2017 and 2018 all the households were able to use the electricity they produced and, therefore, it was not necessary to include data for those months in the research.

The average value for the researched objects shows that the peak time for consumption is in the evening between 7 pm and 11 pm, a time when the solar radiation is not at its highest. (Fig 13).

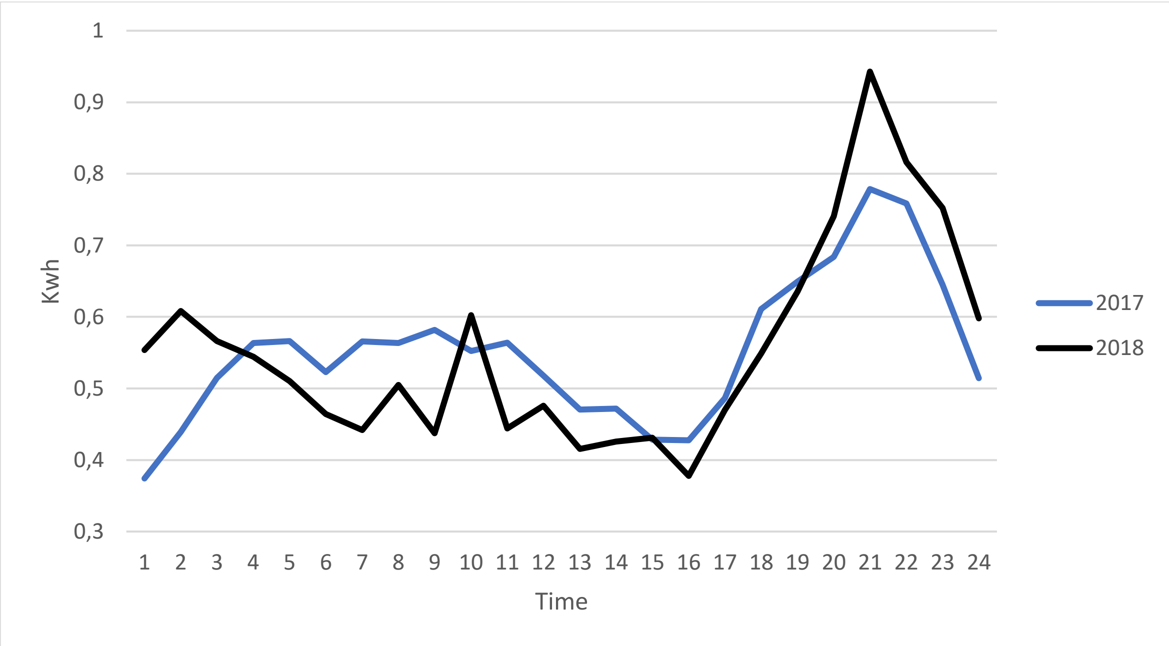

Figure 13. The average electricity consumption in July 2017 and 2018 mean value for all solar panel systems .

When comparing the level of consumption to the level of production during the whole year of 2017, it shows that the optimization target of interest is between May and August, during the other months the production was so low that the amount that was produced was consumed in all solar panel systems studied. From May - July there was an overproduction in all of the studied solar panels . This does not mean that the solar panel system is oversized, because in April and September all panels are needed for production. The effective time for production during the peak period (May - August) is from approximately 10 am until 6 pm The results indicate that the peak production was from 9 am to 6 pm in July and from 10 am until 3 pm in June (Fig. 14). Production is weather dependent, and it should be noted that this sample is only from 2017 and 2018.

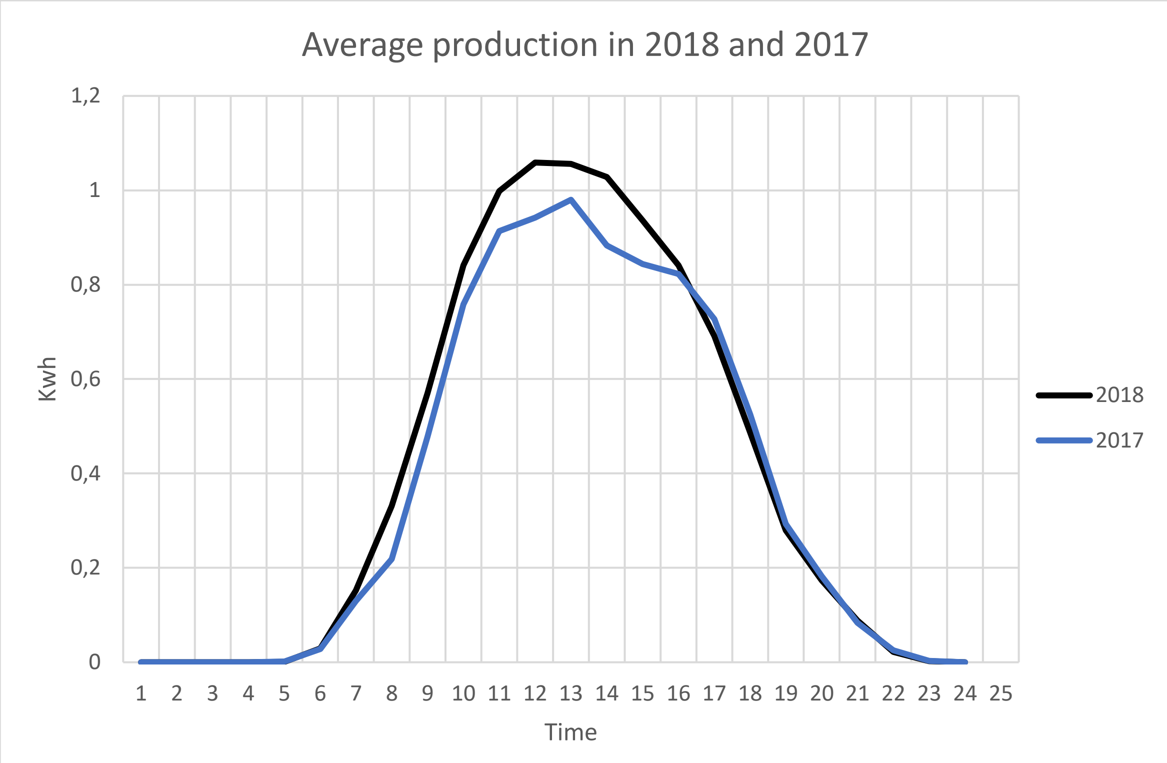

Figure 14. Combined Production in July 2017 and 2018 *for all objects included in the research.*

The average temperature in 2017 was 6.6 °C and in 2018 the average temperature was 7,3 °C. This could explain the greater production level in 2018 than in 2017.

10.2 Challenge with shadowing

It is important that solar panels are placed where there is a minimum risk of shadowing during the peak time. In one of my samples the data shows that shadowing during mid-day May results in a great loss in productivity which, in turn, leads to a very long payback time. Shadowing also increases the environmental impact of the panel because of the materials and resources used in its construction. only It is desirable, for economic and environmental reasons, for panels to produce as much electricity as possible during their lifespan.
Figure18 shows the difference between production and consumption levels. It also shows the problem of shadowing and the energy loss caused by it. In this case minimizing the shadowing was attempted with the use of microinverters. This improved the balance somewhat, but production remained compromised as can been seen from the curve, which is quite negative compared to a normal level. (Fig 15)

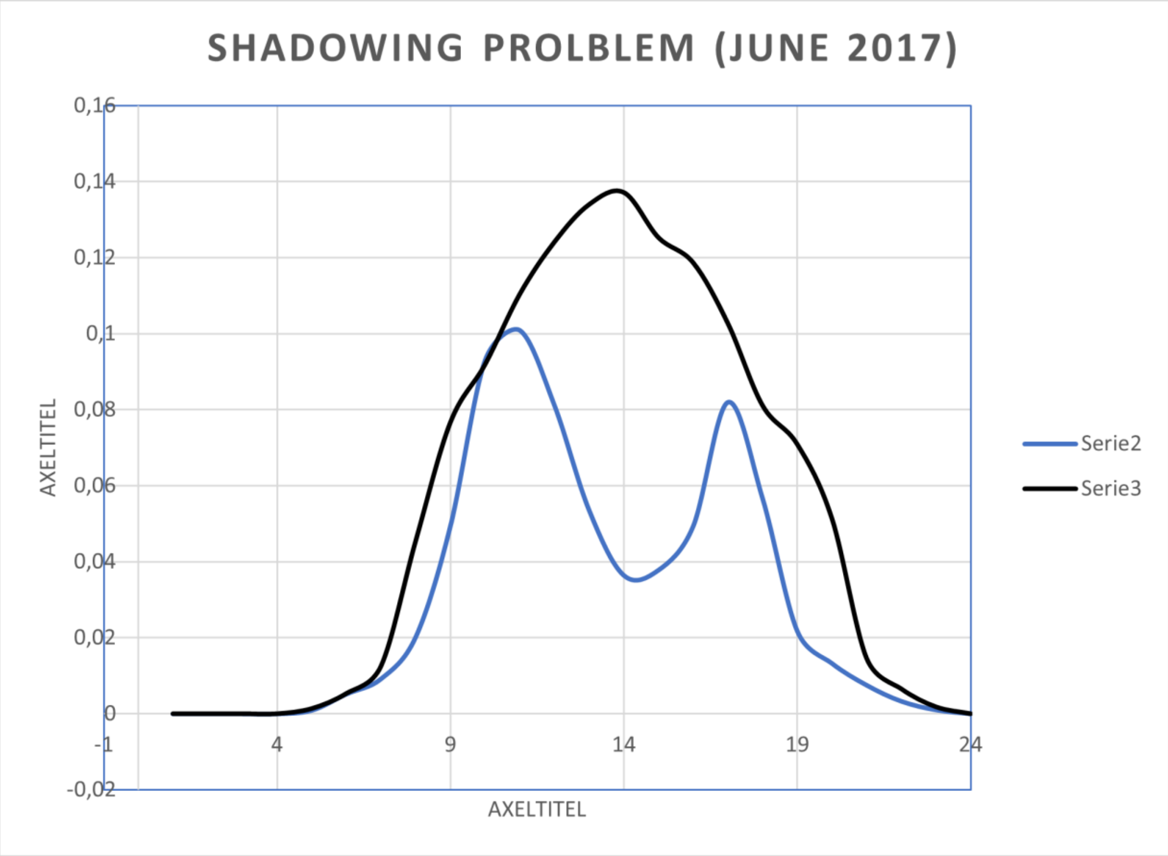

Figure 15. Shadowing Problem. The orange line shows a system with a problem of shadowing between 11am and 5pm compared to two other similar sized systems where there was no shadowing.

10.3 The Difference in Levels between Consumption and Production

The energy system consumption of course varies between different households and people. Every household ought to follow up their consumption profile compared to their production profile. The information offered to customers by different inverter suppliers varies considerably. Some give their customer a lot of information while others give very little information. In my samples, there were quite many owners of solar panels systems who did not have their inverters connected to the internet. This means that they had no access to information about their production and therefore it was impossible to see how their electricity production levels compared to the production.

In one sample the owner used night-time electricity to heat up his house (Fig. 16). There is clearly a peak in energy consumption between 10pm and 3am. If the owner was able to change the time of heating to the middle of the day, he could easily use all the electricity that produced by the solar panels and could even enlarge his system.

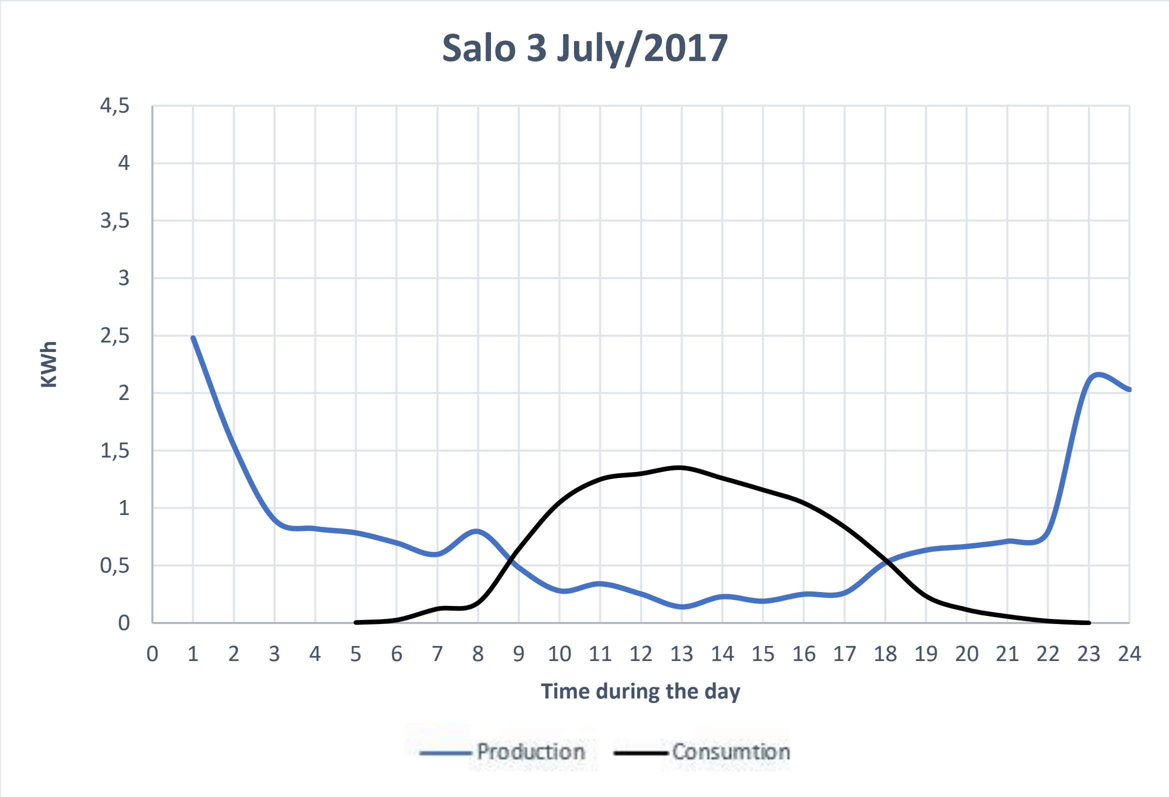

Figure 16. A family house where night electricity tariff is used for heating water and the house and shows a peak during 10 pm and 3 am (The blue line)

In one of the researched objects (Salo 2) the owners had been able to utilize their electricity at quite an optimal level. This means that the payback time for the investment was optimized compared to the level of investment. There is a peak in consumption just before and after the production time. By using a storage battery, the owner would be able to be self-sufficient during the summer month. This means that the size of the solar panel system is suitable, and the investment cost for the system can be repaid quickly as they are able to use all the energy they produce (Fig. 17)

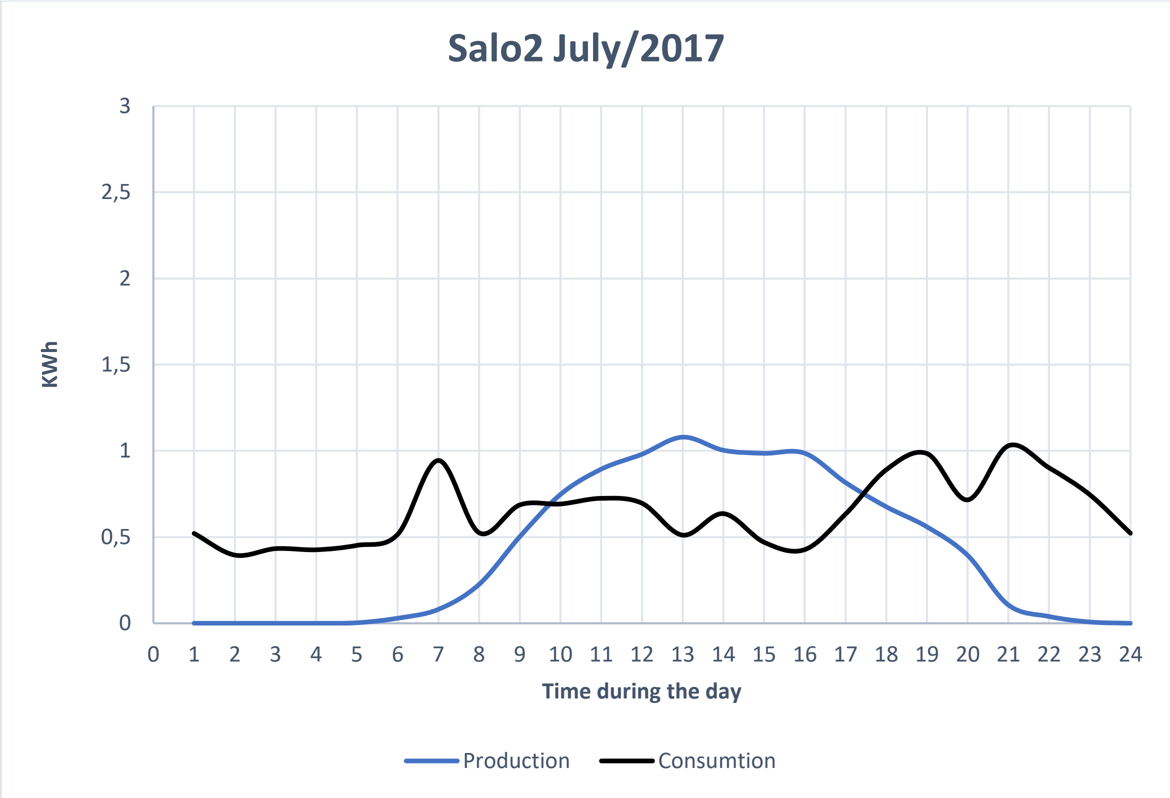

Figure 17 Production compared with consumption where the production is on a good level compared to consumption.

In 2018 production was on quite the same level as in 2017 for the same house but note that the consumption was remarkably higher, and the user managed to use almost all the electricity he produced. (Fig 18).

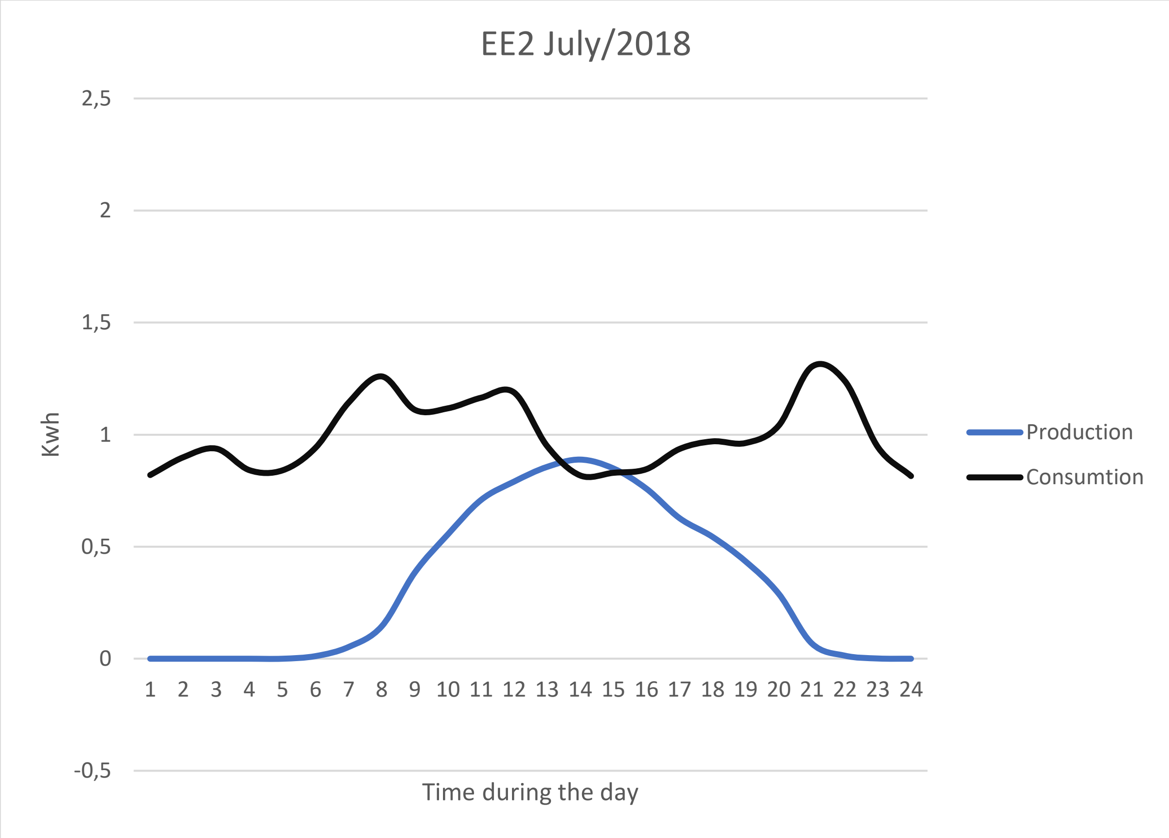

Figure 18. Average Production per Hour for EE2 in June 2018 where almost all the produced electricity was used for own consumption.

Some of the systems in my research was over sized compare to the consumption and the own usage of the energy was below 15% in some of the cases (Table 3)

Table 3. A Month by month (May –August 2017 and 2018) Comparison (as a percentage) for Each Household of How much of All Energy Used by a Household was from Own Solar Power System (Degree of Self Sufficiency) and the Utilization of Energy Produced.(Salo 4 - = *No data)*

2017/2018	May	June	July	August
Salo1 / 4740Wp				
Degree of self-sufficiency	28,5/26,7 %	30,4/34,7 %	25,3/29,6 %	22,97/20,6 %
Own use of produced energy	57,9/56,4 %	66,4/70,5 %	65,8/75,3 %	92,5/97,1 %
Salo 2 / 1060WP				
Degree of self-sufficiency	41,8/28,7 %	47,6/31,9 %	47,9/32,9 %	41,2/26,2 %
Own use of produced energy	82,4/99,5 %	79,9/100 %	73,3/98,9 %	80,2/100 %
Salo 3 / 2600Wp				
Degree of self-sufficiency	28,5/28,3 %	30,4/44,8 %	25,3/40,6 %	22,9/34,3 %
Own use of produced energy	57,9/50,2 %	66,4/52,6 %	65,8/45,9 %	92,5/51,1 %
Salo 4 /1575Wp				
Degree of self-sufficiency	- /28,3 %	- /36,7 %	51,6/32,5 %	38,8/31,4 %
Own use of produced energy	- /19,9 %	- /27,8 %	53,9/19,6 %	42,3/29,6 %
Heckert 1 / 5200Wp				
Degree of self-sufficiency	36,7/32,1 %	34,6/40,6 %	40,7/37,4 %	30,4/32,8 %
Own use of produced energy	13,9/10,5 %	13,5/12,9 %	13,2/13,7 %	15,7/10,5 %
Heckert 2				
Degree of self-sufficiency	49,1/52,9 %	55,0/71,8 %	54,9/40,0 %	71,3/73,2 %
Own use of produced energy	17,77/15,4 %	18,24/13,3 %	12,65/13,4 %	13,54/10,9 %

There seems to be no significant difference in production levels between the different suppliers Salo solar and Heckert. The annual production per panel was between 128 KW and 208 KW. However, there are many different factors that affect the final output such as the effectiveness of the panel, the placing of the panels, the type of inverter and the problem of shadowing. The biggest difference when it comes to profitability, however, is how much of the energy produced could be used by the owner instead of selling it out to the grid.

10.4 NVP (net present value of the investment)

Results show clearly that is has a negative impact on the NVP if the owner is not able to use the electricity himself but sells it out to the grid. In my cases it seems that own usage that is under 25% results in a case where the panels will never be paid back. The NVP is going to be longer than the lifespan of the solar panels.

Table 4. Calculated payback time for the researched systems

	Salo1	Salo2	Salo3	Salo4	Heckert 1	Heckert 2
Payback time if 100% own usage:	11yr	16yr	13yr	18yr	12yr	12yr
Actual usage:	75%	98,20 %	49,50 %	24,25 %	14 %	15,40 %
Payback time:	>30yr*	16yr	24yr	30yr	>30yr	>30yr

*Without the shadowing problem this would be 14years.

Table 5. Calculating tool for calculating NVP

Researched object:		Salo 1	Salo 2	Salo 3	Salo 4	Heckert 1	Heckert 2
The price of bought energy	cent / kWh	6,03	6,03	6,03	6,03	6,03	6,03
Transmission fees	cent / kWh	5,6	5,6	5,6	5,6	5,6	5,6
Electricity taxes	cent / kWh	2,253	2,253	2,253	2,253	2,253	2,253
Value added tax on bought energy	Percent	24 %	24 %	24 %	24 %	24 %	24 %
Summary	Cent / kWh	*17,2*	*17,2*	*17,2*	*17,2*	*17,2*	*17,2*
Estimated annual growth on bought energy	Percent / year	0,2%	0,2%	0,2%	0,2%	0,2%	0,2%
The total consumption per year	kWh / year	19000	15000	19000	21000	18000	25000
The effect of the solar panel system	Wp	4,7	1,6	2,6	1,6	5,2	5,2
The calculated area of the solar panel system	*M^2*	*32,232*	*10,88*	*17,68*	*10,88*	*35,36*	*35,36*
Investment costs	euros	€8 290	€3 570	€5 309	€3 900	€9 440	€9 440
The system price/kWp without subsides	*euros / kWp*	*1 749 €*	*2 231 €*	*2 042 €*	*2 438 €*	*1 815 €*	*1 815 €*
Possible subsides, %	percent	5 %	5 %	5 %	5 %	5 %	5 %
Goodwill (such as reputation)	*euros*	€0	€0	€0	€0	€0	€0
Investmentcost with subsides	*euros*	*7 876 €*	*3 392 €*	*5 044 €*	*3 705 €*	*8 968 €*	*8 968 €*
Rate on finacing costs	percent	0,0%	0,0%	0,0%	1,0%	0,0%	0,0%
Expected annual revennua	percent	2,0%	2,0%	2,0%	2,0%	2,0%	2,0%
The calculated rate on the investment	percent	*2,0%*	*2,0%*	*2,0%*	*3,0%*	*2,0%*	*2,0%*
Own percental usage of the produce electricity	percent	100 %	99,6 %	100,0 %	100 %	100 %	100 %
Price on sold electricity	Cent / kWh	5,0	5,0	5,0	5,0	5,0	5,0
Price for renewing the inverter after 15years	percent	8 %	8 %	8 %	8 %	8 %	8 %
Yearly maintenance costs	percent	0,1 %	0,1 %	0,1 %	0,1 %	0,1 %	0,1 %
Annual production	kWh / kWp	850	850	850	850	850	850
Yearly production	*kWh*	*900*	*1360*	*2210*	*1360*	*4420*	*4420*
Yearly decrease in effectivity	percent	-0,5%	-0,5%	-0,5%	-0,5%	-0,5%	-0,5%
Paybacktime	Year	>30 yr*	16 yr	24 yr	30 yr	>30 yr	>30 yr
Payback time if 100% own usage of production		11 Yr	16 Yr	13 yr	18 yr	12 Yr	12 Yr

* Without the shadowing problem this would be 14years Picture 18.

10.4 The need for permissions in different municipalities

Bureaucratic systems behind any solar panel project may also affect the purchase, and thus, also from an environmental point of view, it is vital that it would be as easy and cheap as possible to install solar panels on a roof of a house.
I conducted four interviews with the building inspections department in some municipalities in western Uusimaa to find out whether there are any differences between the rules and regulations pertaining to the installation and use of solar panels.
Over the past few years (2017 -2019) most municipalities have updated their regulations pertaining to solar panel installation so that they are now quite liberal, and, in most cases, a special permission is not required. In most cases, except for Hanko, where a notification of action is required, no permission is needed for installing panels on the roof of a building, if the building is not protected in the city plan.

11.0 Discussion and conclusions

The total payback time for solar panels is directly in relation to the total cost for purchase and installation since the panels require very little maintenance and their lifespan normally at least 30 years or more. Every installation cost, however, affects the payback time for the investment and this can affect the purchaser's decision as to whether to purchase the solar panels or not.
There are many of online services that offer calculators to count how much a solar panel system will save money and what the NVP would be. They are most likely correct, but that would be in a perfect condition. My research shows that in many cases the own use of the produced electricity is quite low during the summer months and the actual payback time is so long that it will never be paid back during the system's lifespan. Therefore, it is good to rather choose a smaller system than a bigger one. This is of course if the case is seen as an investment with an expected NVP. The reason someone decides to by a solar panel system could be other reasons than saving money. Such reasons could for example be an aim to produce as much solar energy as possible to "cover" their own electricity usage over the whole year and they? could see the system as a way of reducing their own ecological footprint. A storage battery for solar energy would help the owner to use his own produced energy during the time when the sun is not shining. At the moment these kinds of battery

solutions are so expensive so it is not profitable to do so, but if new battery technology will be developed and the prices will fall, this solution could be well used in the future.

In one of the cases in my research, shadowing caused reduced production. Many companies that offer solar panel packages has online calculators where the customer can easily count how much energy they could produce with a system and approximately how long the payback time would be. My research, however, shows that the feasibility and payback time can vary a lot from system to system depending on the circumstances and how much the customer uses the produced energy themselves. My research also shows that their own consumption can vary a lot from household to household and the online feasibility calculators seldom takes this in attention on an hourly basis.
This, however, is important if the buyer has the intention to make an investment that will paid back in a reasonable time. But if the intention for the buyer is to produce as much energy as possible and the feasibility is not that important, then it is not a problem. But I think it is important that the customers are informed about the variation in the feasibility and how their own consumption is affecting the feasibility.

The challenge of green electricity as seen in my research, is the one of supply and demand. The best solution to this dilemma would be mass storage of electricity so that on a windy or a sunny day, windmills and solar power plants would generate as much electricity as possible and the excess energy (i.e. not immediately utilized) could be stored in some kind of storage solution until (it was) needed. At the moment an economically or commercially viable storage solution like this is not yet commonly available. The biggest hope in this area may be in the form of high-capacity batteries such as Tesla’s mega-battery in SA, Australia. It is connected to a windfarm run by the French company Neon. The battery can, when fully charged, power up to 30 000 homes for an hour. In 2018 a battery storage facility 50% larger than Tesla´s in Australia will be turned on in South Korea. Many similar and bigger battery storages are most likely to be installed around the world in the near future. (Neoen, 2017)

Another option to store solar energy is to place the solar panels close to a waterpower plant and use the solar electricity to pump water to the dam above the powerplant.
The main challenge of solar energy, particularly in Finland, is that the peak of production is most often not equal to the demand for electricity. This problem is called “the duck curve” when the consumption is high for example in the evening when people are at home, doing laundry, washing the dishes and so on, the solar radiation is much lower than during the day

when the sun is up. The challenge is that the time when households need most electricity co-indices with the time when their own production of electricity is at a minimum. Conversely, during the day when the sun is up and shining, consumption is low (Beca, 2017). This can clearly be seen in the result chapter.

Globally the need for electricity is increasing: Developing countries continue to improve their common standard of living, and for example in India and China and in other Asian countries there is a growing middle class, rising incomes and increased reliance on electricity-enabled machines and solutions. (OECD, 2018) Similarly, the growing rate in the use of electric cars will also affect the need for electricity. The global demand for electricity is expected to double by 2060 and this will require enormous infrastructure investments as the need grows and powerplants using fossil fuels need to be replaced by greener options with low CO_2 emissions. In 2018 Solar and wind energy accounted for 31% of global electricity production. (Pollier, 2019)

Another factor that will affect the usage of green energy is the cost to produce the energy compared to other energy sources and the electricity price on the market. If the electricity price and the transferring costs are high the more profitable it will be to produce the energy at the place of consumption, such as solar panels on a house roof.

The decisions made globally and nationally regarding the usage of renewable energy alongside the technological development will have a remarkable effect of the profitability of producing one’s own electricity.
To reduce the CO_2 emissions green energy options should be pursued on all-different levels such as global agreements, EU guidelines, national legalizations, and subsidies.
Action taken locally could be, for example, the use of solar and wind power, use of electric or low CO^2 emission cars and the building of more-ecologically sustainable housing (Socolow, 2011).

Some PV Systems solution could be more challenging in Finland than in southern Europe. This is for various reasons, including the cost and the extreme cold winter weather and long dark periods during the winter. According to Fingrid’s publication: “The Future of the Electric Market” (Finngrid, 2018), the solution for Finland lies in a smart network where the consumer is involved in balancing the demand for electricity with its supply.

The future of the electricity market is very interesting now. The technology is developing rapidly, new, and cheaper solutions to produce energy with for example solar panels are constantly coming out on the market. Globally and nationally steps are taken to reduce the CO^2 emissions and I believe it is hard to predict what the energy market will look like after ten years. But it would not surprise me if most of new houses that will be built also will produce most of the energy they need for heating, electricity and charging the cars.

Nationally, the challenge faced by Finland’s energy sector is to reduce the growth of energy consumption. Traditionally, economic growth has gone hand in hand with a growth in energy consumption. However, due to structure changes in recent years the economic growth has not caused a huge growth in energy consumption. Nonetheless, the electrical consumption continues to increase, as there are many old powerplants which need to be replaced. New production capacity is estimated to be at least 7500MW by 2020. (VTT, 2016)

An example of how the smart and flexible electrical network could look like:
The house is heated by electricity. The fridge, freezer, dishwasher is connected to internet through a smart hub. The house is equipped with solar panels. During sunny summer days when the solar panels are producing much, the dishwasher and the washing machine starts so it matches the calculated peak of production. The freezer and the fridge cool down 2 degrees. The rest of the overflowing energy is stored in a power storage located in the house. In the evening when the car is back in the garage, the car’s battery is charged with electricity from the storage battery.
The house is through the smart hub connected to the grid and follows the electricity prices on a 15-minute basis. When the price is low the storage battery is being charged and when the price is high the house disconnects from the grid and uses the stored electricity. The house owner also has an agreement with the national electricity supplier so when the demand is higher than the production, they can for a short time lower the power used in the house´s equipment such as heaters and the freezer by changing the temperature with for example one degree for a short time of a period or they can sell electricity from their storage int the grid. For this the house owner gets a financial compensation. A technological revolution is commonly seen as the best option to reduce the global warming, and I am sure that solar panels is included in that solution. The prices have been coming down during the past years and that is affecting the feasibility of the investments. Electric cars is commonly seen as an effective way to reduce the co^2 that comes from the traffic. Electric cars combined with solar panels can bee a good solution. Especially in

those places where cars are being parked during the day when the sun is shining. I could be verry likely that a major part of our energy comes from solar panels in the future as a lead in our fight against global warming.

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