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Emma Pihlakivi

POTENTIAL OF SOLAR ENERGY IN FINLAND

– Research for Solar Leap

TURUN AMMATTIKORKEAKOULU
TURKU UNIVERSITY OF APPLIED SCIENCES

BACHELOR'S THESIS | ABSTRACT

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Tero Reunanen

Emma Pihlakivi

POTENTIAL OF SOLAR ENERGY IN FINLAND

The purpose of this thesis work was to research the bottlenecks in solar energy, to calculate energy payback time and to increase solar energy in Finland. This thesis was made as part of the Solarleap project, where Turku University of Applied Sciences and Satakunta University of Applied Sciences are partners together. This thesis is the first step on this project, and there will be more researches when the project goes forward.

The theory part consists of solar energy and its effectiveness in Finland. The most common photovoltaic and thermal photovoltaic technologies are also presented. In the theory part, renewable energy sources and possibilities in Finland and also photovoltaics supply chain is discussed. The research part includes a discussion on the bottlenecks in solar energy, the investment costs of photovoltaic systems and the payback time of energy.

Solar energy has lots of potential in Finland, but solar energy’s market share is small and the knowhow could be better. Also the energy payback time is bigger than in Europe.

KEYWORDS:

Solar energy, photovoltaic, thermal solar energy, supply chain

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Tero Reunanen

Emma Pihlakivi

AURINKOENERGIAN KANNATTAVUUS SUOMESSA

Tämän insinöörityön tavoiteasetteluna oli tutkia aurinkoenergian pullonkauloja, käyttöönoton mahdollisuuksia sekä takaisinmaksuaikaa Suomessa Tutkimus tehtiin osana Solarleap hanketta, jossa ovat mukana Turun Ammattikorkeakoulu ja Satakunnan Ammattikorkeakoulu. Tämä tutkimus on hankkeen ensimmäinen vaihe ja hankkeen edetessä tullaan tutkimustyötä jatkamaan.

Työn teoriaosuudessa paneudutaan aurinkoenergiaan yleisesti ja Suomen säteilymääriin sekä esitellään yleisimmät aurinkopaneelivaihtoehdot. Tässä osuudessa käsitellään myös uusiutuvan energian kehitysmahdollisuuksia Suomessa sekä aurinkokennon toimitusketjun osia. Tutkimusosiossa perehdytään tarkemmin havaittuihin pullonkauloihin, laitteistojen hintoihin sekä energian takaisinmaksuaikaan, josta on esitetty myös käytännön esimerkki.

Aurinkoenergian tulevaisuuden näkymät Suomessa ovat hyvät, mutta tarvittavaa osaamista ei löydy vielä riittävästi. Myös energian takaisinmaksuaika on huomattavasti pidempi kuin muualla Euroopan maissa.

ASIASANAT:

Aurinkoenergia, aurinkokennot, aurinkokeräimet toimitusketjut

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LIST OF ABBREVIATIONS (OR) SYMBOLS

PV	Photovoltaic
RES	Renewable Energy Sources
RE	Renewable Energy
IEA	International Energy Agency
NREAP	National Renewable Energy Action Plan
SCM	Supply Chain Management
PVT	Photovoltaic Thermal
TW	Terawatts
KWh	Kilowatts per Hour
kWp	Kilowatt-Peak
IEA-RETD	International Energy Agency's Agreement on Renewable Energy Technology Deployment
DG	Distributed Generation
FIT	Feed-In Tariff
c-Si	Silicon Crystalline
μm	Micrometer
kW	Kilowatt
mfg	Manufacturing
CHP	Combined Heat & Power
W	Watt
EU	European Union

CdTe	Cadmium Telluride
CIS	Copper Indium Selenide
CIGS	Copper Indium Gallium Selenide
a-Si	Amorphous Silicon
kVa	Kilovolt-amps
m^2	square meter
AC/DC	Alternating Current/Direct Current
VAT	Value-Added Tax

1 INTRODUCTION

Finland is one of the world's leading users of renewable sources of energy. Renewable energy sources provide one fourth of Finland's total energy consumption, most important sources of energy includes bioenergy, wood-based fuels, hydropower, wind power, ground heat and solar energy. The objective of the national energy and climate strategy is to increase the use of renewable sources of energy. In addition to energy conversation, this is one of the most significant means by which Finland's climate targets can be achieved. Renewable energy sources do not increase dioxide emissions in use, while promoting employment and regional policy goals and enhancing security of supply.

This thesis is made for Solarleap project, which is a two-year research for finding bottlenecks in solar energy and how to lower delivery processes and total expenses. With right developing methods, the potential business for solar energy in Finland is going to increase. The main goal is to improve the competence of companies and improving education for solar energy technologies. Solarleap is a project of Turku University of Applied Sciences and Satakunta University of Applied Sciences. The time period for this project is from 1st January 2015 to 31st December 2016. This thesis concentrates finding bottlenecks in solar energy and calculating investment and energy payback time costs.

Chapter two consist of the theory part, where solar energy, solar radiation and its effectiveness in Finland and renewable energy sources and solar energy's possibilities in Finland are investigated.

Chapter three consists the theory of different kinds of photovoltaic technologies, and the next chapter is about solar thermal energy. The research part includes only examples of photovoltaic technology. Thermal energy is also mentioned in the thesis, because it is one of the sources of solar energy.

Chapter five starts with the supply chain management theory, and in that chapter also photovoltaics supply chain has been explained. In the same chapter has also explained Lean method and the seven key areas of waste. This method can be used for removing obstacles from photovoltaics supply chain.

The research is presented in chapter 6. The research part discusses the bottlenecks in solar energy and photovoltaics supply chain, investments costs and energy's payback time. This work is the first step in the Solarleap research and more researches are to be made when the project goes forward.

The research starts by finding bottlenecks in solar energy and Photovoltaic supply chain. In Finland the photovoltaic markets are quite small, so for this part was used E4tech & Avalon Consulting final report, which was made to International Energy Agency's Agreement on Renewable Energy Technology Deployment in 2012.

In the second and third part of this research, investment costs and energy payback time were studied. There are two example calculations in both chapters and one energy supplier is used to make these calculations.

Last part consist renewable energy's future and how is it going to change.

2 RENEWABLE ENERGY

Renewable energy sources can be defined as “energy obtained from the continuous or repetitive currents of energy recurring in the natural environment” or as “energy flows which are replenished at the same rate as they are used”. (Chaar, Iamount, Zein, 2011, 2166) The global use of fossil fuels has caused grave environmental crises including energy depletion and pollution and is projected to increase by more than one-third by 2035. To combat this, there has been growing interest in new renewable energy (NRE). According to the *‘Medium-Term Renewable Energy market report 2012’*, global renewable energy generation will increase by 40% over the period from 2011 to 2017. Regarding the global energy and environmental issue, solar energy is recognized as playing an important role in renewable and sustainable development. Especially, given the continuous downward trend in the cost of photovoltaic (PV) systems, it is expected that the PV market would be expanded to achieve the net-zero energy buildings and the carbon emissions reduction target. (Hong, Koo, Park, 2013, 190-191)

2.1 Solar Energy

Solar energy is the cleanest and most abundant renewable energy source available (Solar Energy Industries Association, 2015). It has the potential to contribute a major proportion of the renewable energy sources (RES) in the future. Solar energy has many advantages: it cannot be monopolized by handful of countries; it has neither excessive maintenance and management costs nor the conversion mechanisms producing troublesome emissions, and it can easily be integrated into both public and private buildings without external environmental impacts. According to the International Energy Agency (IEA), solar energy could be the largest source of electricity by 2050. (Haukkala 2015, 50)

There are three primary technologies by which solar energy is commonly harnessed: photovoltaics (PV), which directly convert light to electricity; concentrating solar power (CSP), which uses heat from the sun (thermal energy) to drive utility-scale, electric turbines; and heating and cooling systems, which collect thermal energy to provide hot water and air conditioning. Solar energy can be deployed through distributed generation (DG), whereby the equipment is located on rooftops or ground-mounted arrays close to where the energy is used. Some solar technologies can also be built at utility-scale to produce energy as a central power plant. Modern technology can harness solar energy for a variety of uses, including generating electricity, providing light or a comfortable interior environment, and heating water for domestic, commercial, or industrial use. (Solar Energy Industries Association, 2015)

2.1.1 Solar radiation and effectiveness

All the earth's renewable energy sources are generated from solar radiations, which can be converted directly or indirectly to energy using various technologies such as photovoltaic. The radiation that comes from sunlight is perceived as white light since it spans a wide spectrum of wavelengths, from the short-wave infrared to ultraviolet. This radiation is a major player in generating electricity, either producing high temperature heat to power an engine mechanical energy which in turn drives an electrical generator or by directly converting it to electricity by means of the photovoltaic (PV) effect. (Chaar, Iamont, Zein, 2011, 2166)

The amount of energy that comes from solar radiation is enormously large. The Earth receives about 170 000 terawatts (TW) of incoming radiation at the upper atmosphere, but the amount of energy that can be used is very small. Restrictions for solar energy are costs, number of places where the heat generating technologies are used and radiation amounts by the time of the year. (Energiateollisuus, 2015)

Because the Earth is round, the sun strikes the surface at different angles, ranging from 0° (just above the horizon) to 90° (directly overhead). When the sun's rays are vertical, the Earth's surface gets all the energy possible. The more slanted the suns' ray are, the longer they travel through the atmosphere, becoming more scattered and diffuse. The Earth revolves around the sun in an elliptical orbit and is closer to the sun during part of the year. When the sun is nearer the Earth, the Earth's surface receives a little more solar energy. (Energiateollisuus, 2015)

As sunlight passes through the atmosphere, some of it absorbed, scattered, and reflected by example from air molecules, water vapor, clouds, dust and pollutants. This is called diffuse solar radiation. The solar radiation that reaches the Earth's surface without being diffused is called direct beam solar radiation. The sum of the diffuse and direct solar radiation is called global solar radiation. Atmospheric conditions can reduce direct beam radiation by 10 % on clear, dry days and by 100% during thick, cloudy days. (EnergyGov, 2015)

Solar radiation incident on the atmosphere from the direction of the sun is the solar extraterrestrial beam radiation. Beneath the atmosphere, at the Earth's surface, the radiation will be observable from the direction of the sun's disc in the direct beam, and also from the directions as diffuse radiation. Even on cloudless, clear day, there is always at least 10 % diffuse radiation irradiance from the molecules in the atmosphere. (Twidell & Weir, 2006, 87)

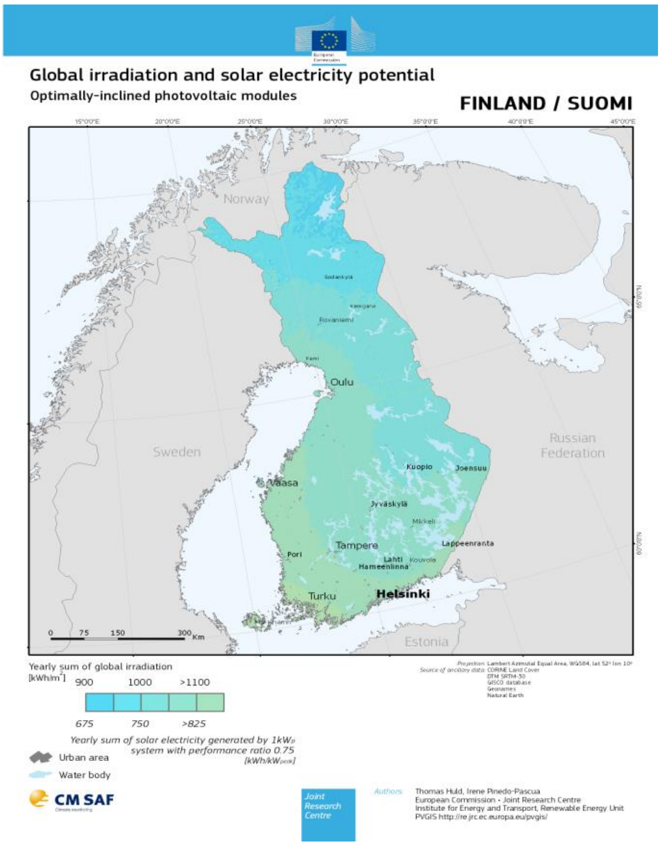
2.2 Renewable and solar energy in Finland

Finland is one of the few countries in the EU that has taken hardly any direct subsidies into use for solar energy. At the same time, the transition to renewables is crucial in mitigating climate change. Finland's irradiation is almost the same as that of Germany, a country that is one of the top markets for photovoltaics in the world, also due to its successful support policy. The use of solar energy in Finland has been relatively limited compared to other RES. "In the 1970s and 1980s was an initial boom in solar energy, but the experiments were too radical at the time and it “did not take off” thinks Teresa Haukkala in her article. According to the National Renewable Energy Action Plan (NREAP), the use of RES is to be increased in Finland by 9.5 % from the 2005 to 2020, when it should be 38 % from the energy consumption. This applies also to solar energy. At this moment, the share of solar energy is about 0.01 percent. (Haukkala, 2014, 50-51)

The renewable energy sector in Finland has many key elements for successful export, such as advanced innovation systems, strong traditional competences in the bioenergy sector, and versatile research and development activities and related policies. The strengths of Finland in the wind and solar energy sector lies in more narrow segments. Highly qualified component manufacturing and technology knowhow built on R&D intensive ICT sector forms strong technological competences also for wind power and other RE, as well as for development of future smart grids and smart energy systems. Finland has also implemented several policy measures to promote energy efficiency and RE, such as obligation scheme for RE 2010, investment grants, and technology programmers related to RE by the Finnish Funding Agency for Technology and Innovation (Tekes, 2015).

The amount of solar energy is about the same in Finland as in Central Europe, but most of the radiation (1170 kWh/m² per year) is generated in the southern part of Finland during May to August. (VTT, 43, 2015)

In Finland, there is more diffuse radiation than direct radiation. Diffuse radiation is more effecting, because in southern Finland half of the radiation is diffuse radiation. Diffuse radiation means that the sunlight has been scattered by molecules and particles at the atmosphere, but has still made it down to the surface of the earth. Solar irradiation is lower in northern Europe than in central or southern Europe. The average daily irradiation in Finland is about 900 kWh/m². Finnish Meteorological Institute announced in June, 2014 radiation amounts in horizontally and optimally inclined surfaces in Finland, and the results are shown in picture 1 and table 2. The results were in Helsinki around 980 kWh/m² and in Sodankylä around 790 kWh/m². (Motiva, 2014)



Picture 1 Yearly sum of global irradiation on horizontal and optimally inclined surface in Finland (Joint Research Centre, 2012)

Picture 1 represent yearly sum of global irradiation on horizontal and optimally inclined surface. All data in the photo are given as kWh/m². The same color represents also potential solar electricity (kWh/kWp) generated by a 1 kWp system per year with photovoltaic modules mounted at an optimum inclination and assuming system performance ratio 0.75. (Motiva, 2014)

Table 1 shows measurement from Helsinki which covers also zone I and II (shown in picture 2 below). In the table the collected data are from PV's that are in 45° angle and facing south. Data has been collected monthly, and the table shows that greatest amount of radiation is in summer time. (Ilmatieteenlaitos, 2015)

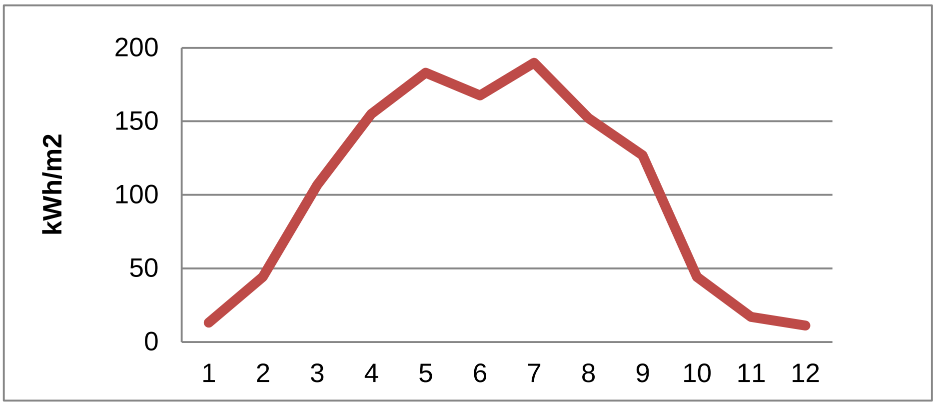
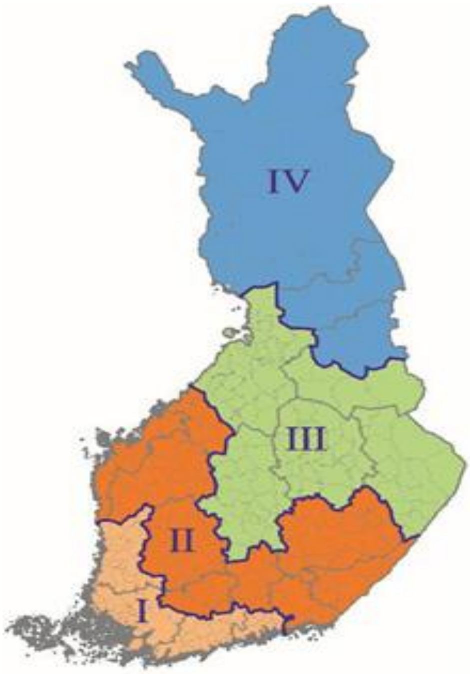


Table 1 Radiation amounts, which are measured monthly from PV's that are 45° angle. (Ilmatieteenlaitos, 2015)



Picture 2 Zones I-II, III and IV. (Ilmatieteenlaitos, 2015)

Table 2 shows radiation in all three regions in Finland. Used by same measurement as in table 1. The table shows that radiation in south is more powerful than in northern Finland. (Ilmatieteenlaitos, 2015)

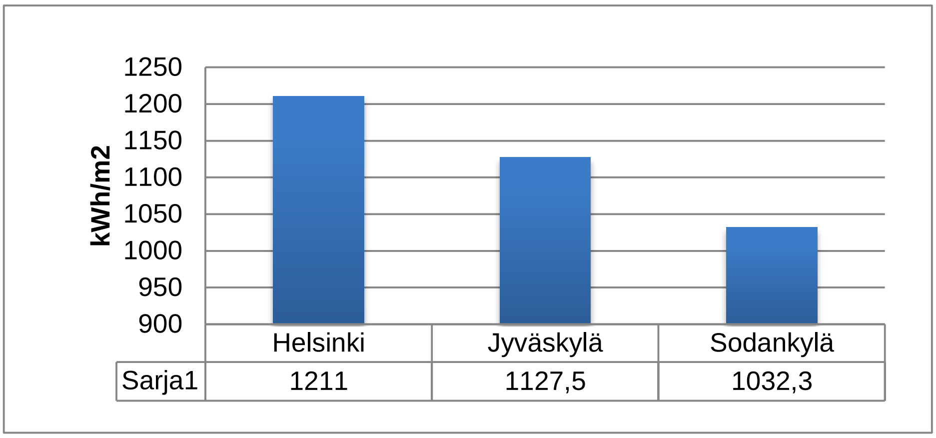


Table 2 Radiation amounts in different cities. (Ilmatieteenlaitos, 2015)

2.3 European Union energy policy

The EU's energy policy is going to have huge challenges and changes in the future. The operational environment of energy policy is facing challenges because of the climate change. The founders of the European Community realized the meaning of energy to the society, that it can secure the of energy's supply and also act as an engine for political integration. The EU's energy policy has three main aims: sustainable development, maintaining competiveness and ensuring security of energy supply. (Finnish Energy Industries, 2015)

3 PHOTOVOLTAICS

Photovoltaic (PV) devices provide an effective way to generate electricity from the sunlight. It is accepted that PV is the simplest technology to design and install, but it is still one of the most expensive renewable technologies. However its advantage will lie in the fact that it is environmentally friendly non-pollutant low maintenance energy source. The competiveness of PV’s are increasing: according to Pew Charitable Trusts, in 2013, for the first time in more than a decade, solar outpaced all other clean energy technologies in terms of new generating capacity installed with an increase of 29 % compared with 2012. (Haukkala 2015, 50)

3.1 Silicon crystalline

Crystalline silicon cells (c-Si) are the most common type PV; it can be of many semiconductor materials. Each material has unique strengths and characteristic that influence its suitability for specific applications. Silicon crystalline PV cells are made of silicon atoms that are connected to one another to form a structure called a crystal lattice. It comprises the solid material that form the PV cells semiconductor. This comprises the solid material that focus the PV cells semiconductors. In crystalline solar cells, pieces of semiconductors are sandwiched between glass panels to create modules. Crystalline silicon cells thickness is between 150-300 µm, and it has dominated the PV markets for very long time. (Chaar, Iamont, Zein, 2011, 2168)

3.2 Thin-film technology

Thin film technology holds the promise of reducing the PV arrays costs by lowering material and manufacturing without jeopardizing the cells lifetime. Unlike crystalline cells, putting thin layers of certain materials on glass or stainless steel substrates makes thin film panels. The advantage is that the thickness of the deposited layers are barely a few micron thick (5-20 μm), example compared to the crystalline wafers, which tend to be several hundred micron thick. Depositing layers to stainless steel sheets, it allows the creation of flexible PV modules. Technically when the layers are thinner, PV's material to absorb incoming solar radiation, hence the efficiencies are lower than crystalline modules, and the ability to deposit many different materials and alloys has allowed improvements in efficiencies. There are four kinds of thin film cells; the amorphous silicon (a-Si) cell (multiple-junction structure), thin poly-crystalline silicon on a low cost substrate, the copper indium selenide (CIS), copper indium gallium selenide (CIGS) and the cadmium telluride (CdTe) cell. (Chaar, Iamont, Zein, 2011, 2168-2169).

3.3 Nanotechnology

"Making solar cells ultra-thin reduces their material costs, but often at the expense of their efficiency. Researches have summarized the most effective ways that nanostructures can improve the efficiency and lower costs of PV solar cells in a recent analysis. Sculpting ultra-thin solar cell surfaces at the Nano-scale has been found to effectively boost their efficiency". (European Commission, 2015)

According to European Commission nanostructures can increase the amount of light entering the PV module by reducing reflections from its surface. A polished silicon wafer reflects more than 30 % of the light that it receives. Densely packed nanostructures can be used to create thin anti-reflective coatings, which work across a wide range of wavelengths and angles of light. (European Commission, 2015)

European Commission also studied in their research that how nanostructures can be used trapping the light depending on the location of the new ultra-thin film PV's that uses silicon films that are between nanometers and tens of micrometers thick. (European Commission, 2015)

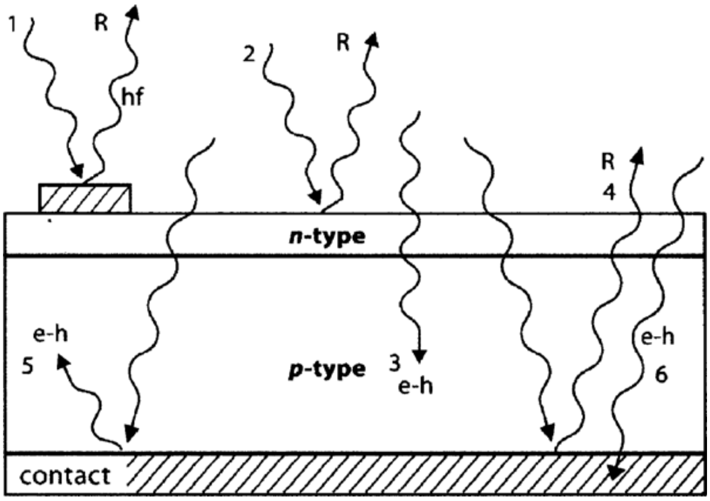
3.4 How does the photovoltaic work

Photovoltaic (PV) is the direct conversion of the light into electricity at the atomic level. Photovoltaic devices generate electricity via an electronic process that occurs naturally in certain types of material, called semiconductors. Electronics in these materials are freed by solar energy and can be induced to travel through an electrical circuit, powering electrical devices or sending electricity to the grid. (New Renewable Energy Systems Group, 2015)

Photovoltaic consist of small solar cells, which are combined together. Solar radiation consist photons. Photons strike and ionize semiconductor material on the solar panel. The energy of the photon transfers itself to the positive and negative charge carriers, which can move freely at the cell. Photovoltaic consist of two-semiconductor materials that are almost the same (p- and n-material), only difference is that the stored charge distribution of the atoms. These small differences develop electric field inside the solar cell, which takes the positive and negative charge carriers opposite directions inside the solar cell. Charge carriers are transported to the external circle, where they can be used, for example lightning an electric light bulb. (New Renewable Energy Systems Group, 2015)

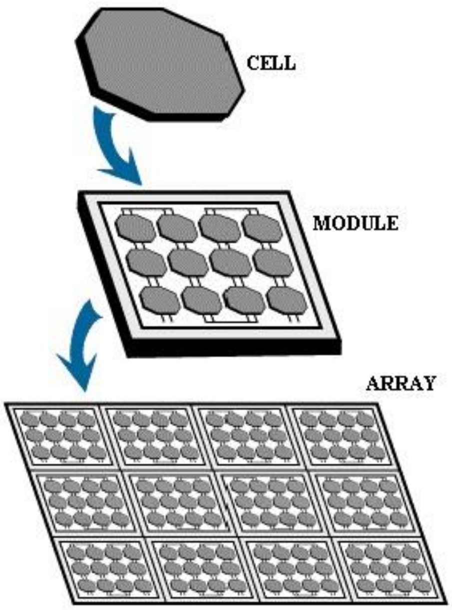
Different PV materials have different energy band gaps. Photons with energy equal to the band gap energy are absorbed to create free electrons. Photons with less energy than the band gap energy pass through the material. (Energy.Gov, 2015)

Photo 3 is a typical crystalline silicon solar cell. To make this type of cell, wafers of high-purity silicone are “doped” with various impurities and fused together. The resulting structure creates a pathway for electrical current within between the solar cells. (Solar Energy Industries Association, 2015)



Picture 3 Behavior of light on a solar cell. (Chaar, lamont, Zein, 2011, 2167)

A number of solar cells electrically connected to each other and mounted in a support or frame are called a photovoltaic module (photo 3). Modules are designed to supply electricity at a certain voltage, such as a common 12 volts system. Multiple modules can be wired together to form an array. In general, the larger the area of a module or array, the more electricity can be produced. Photovoltaic modules produce direct-current electricity. (NASA, 2002)



Picture 4 Photovoltaic module (NASA, 2012)

Picture 4 shows typical photovoltaic module and photovoltaic array, which consist many photovoltaic modules attached to each other. (NASA, 2002)

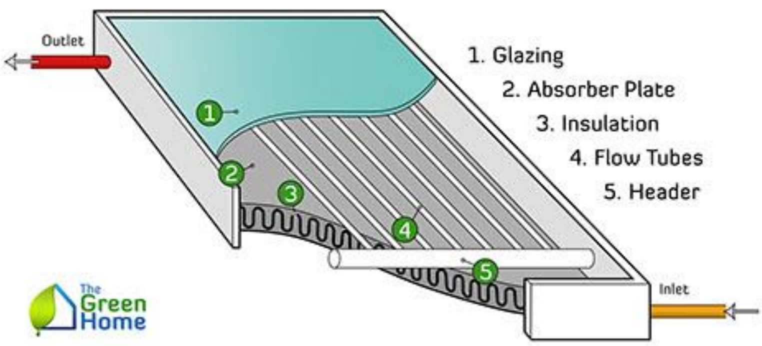
In Finland most of the radiation comes from diffuse radiation, which means that locating and finding the right position for PV's affects the amount how much energy the system can collect. Example snow, water and shiny rooftops can increase the radiation for a moment nearly 20 percent. Yearly amount stays still normally at 2 percent. The efficiency of traditional PV panels increases in lower temperature, so the real production difference between Nordic and central European countries can be even lower. (Motiva, 2014)

4 SOLAR WATER HEATING

Solar thermal energy technology is to produce heat from solar energy. Solar thermal energy is collected by the solar collectors, which absorb the sun's ray and convert them to heat. The major applications for solar thermal energy are for heating swimming pools, water for domestic use and buildings. The difference to solar photovoltaic is that the system generates heat rather than electricity. (Sun water solar, 2015)

4.1 Flat-plate collector

Flat-plate collector (picture 5) is the most widely used heater among the solar collector system. Flat-plate solar collectors have the advantage of simple structure, high-pressure bearing, durable, low maintenance rate, high heat efficiency and low production costs. These collectors are the non-focusing-light components, which receive the solar radiation and transfer heat to the heat transfer fluid in the solar collector system, which finish the process of solar-thermal conversion. At the same time, during the process of heat transfer, the collector will lose part of heat because of conduction, convection and radiation. (Jiandong, Hanzhong, Susu, 2014, 193-194)



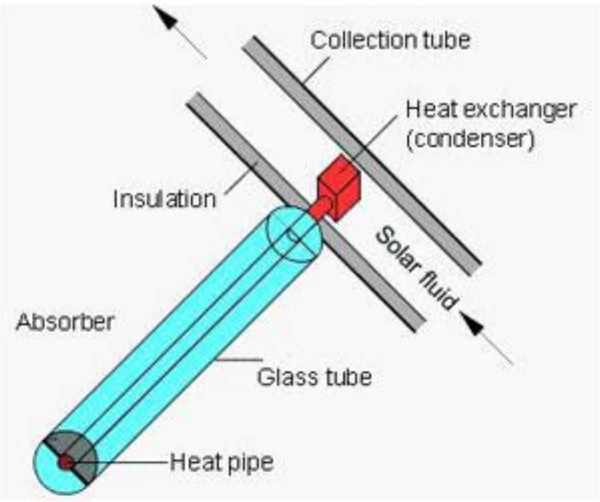
Picture 5 Flat-plate solar collector (Thegreenhome, 2013)

4.2 Evacuated tube collectors

There are three types of evacuated tube collectors: water-in-glass evacuated tube solar collector, U-type evacuated tube solar collector and heat pipe evacuated tube solar collector. (Mishra & Saikhedkar, 2014, 33)

4.2.1 Water-in-glass evacuated tube collector

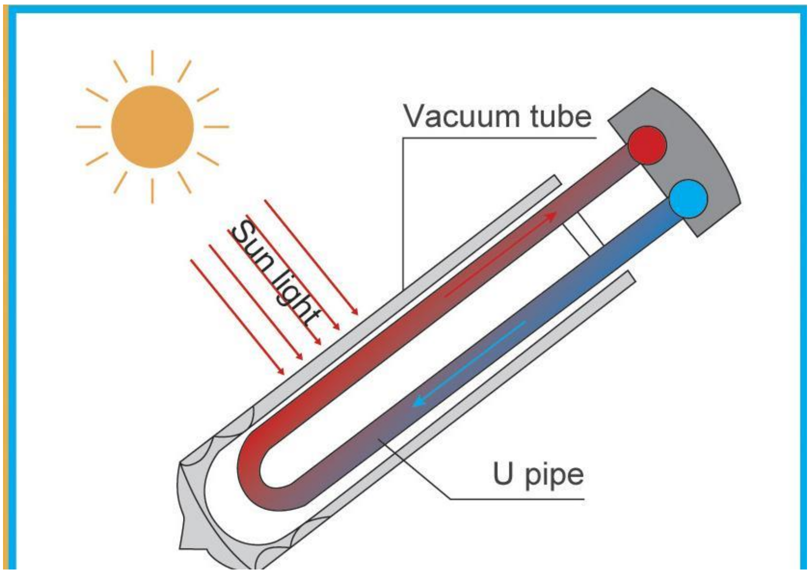
Water-in-glass collector (picture 6) contains two concentric glass tubes connected to a manifold. The tubes have an empty space between them where air is evacuated at a pressure below the atmospheric value. The inner tubes are filled with water and the outside wall of each inner tube is treated with an absorbent selective coating. The coated wall tube is exposed to the solar radiation in order to receive the necessary heat flux to increase the water temperature of the inner tubes and subsequently the temperature at the outlet of the solar collector. (Mishra & Saikhedkar, 2014, 33-34)



Picture 6 Water-in-glass evacuated tube collector (TS solar, 2015)

4.2.2 U-type evacuated tube collector

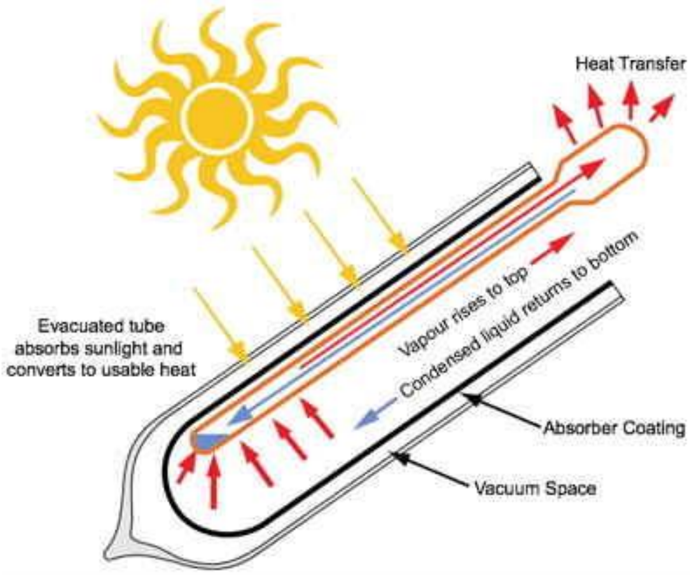
The construction of evacuated U-type tube collector (picture 7) is almost the same than water-in-glass collector, expect a circular fin to store heat and conduct collected heat and a U-type tube of copper elements. Solar water heater is based on a natural circulation of water within the system. (Mishra, Saikhedkar, 2014, 34)



Picture 7 U-type evacuated tube collector. (Hi-min, 2015)

4.2.3 Heat pipe evacuated tube collector

A heat pipe tube collector (picture 8) consists of a heat pipe inside the evacuated tube. The vacuum envelope retards convection losses greatly and conduction losses which helps it to operate a higher temperature. Heat pipe consist of a hollow copper pipe and it is of liquid water is added into the hear pipe and it is heated from the absorbed to the water. (Mishra, Saikhedkar, 2014, 34)



Picture 8 Heat pipe evacuated tube collector (TS solar, 2015)

4.3 Hybrid solar thermal

Solar photovoltaic and thermal applications appear to be one of the potential solutions for current energy needs and greenhouse gas emissions. The technology of Photovoltaic thermal (PVT) allows productions of electrical and thermal energy at the same time, using the solar radiation. The operating principle is that the generation of electricity while transferring the thermal energy absorbed by the photovoltaic cells to a fluid, enabling its subsequent use. The hybrid PVT water system allows removal of a part of the thermal fraction of solar radiation collected by PV cells which is not converted into electricity bur used for example hot water. The thermal fracture is transferred from PV cells to the fluid through a channeled plate, which is connected to the cells. The total conversion efficiency of solar energy into electricity and heat is the main parameter that characterizes the performance of a hybrid PVT collector. (Liang, Zhang, Ma, Li, 2014, 487-490)

5 SUPPLY CHAIN MANAGEMENT

A Supply chain consists of the series of activities and organizations that materials move through on their journey from initial suppliers to final customers. (Waters 2009, 9) A supply chain consists of all parties involved, directly or indirectly, for accomplishing a customer request. It consists manufacturers and suppliers, transporters, warehouses, retailers, and customers. Within each organization, such as manufacturer, the supply chain includes all functions involved in receiving and filling customer request. These functions include, but are not limited to, new product development, marketing, operations, distribution, finance, and customer service. (Sunil Chopra & Peter Meindi 2010, 20)

5.1 Supply chain

Every product has its own unique supply chain, and how long and complicated the chain is, depends on the specific product. The supply chain describes the total journey of materials as they move. Logistics are responsible for the flow of materials through supply chain. The overall aim of the logistics is to achieve high customer satisfaction. It must provide a high quality service with low – or acceptable – costs. The supply chain describes the total journey of materials as they move from beginning to the end. Easiest and simplest way to look a supply chain is a view a single product moving through a series of organizations, which each somehow adds value for the product. There are two points of view looking one organization, activities that are before (moving materials inwards from original suppliers) are called upstream; and those that are after the organization (moving materials outwards to final customers) are called downstream. (Waters, 2009, 8-9)

In table 3 is shown most common supply chain for PV’s.

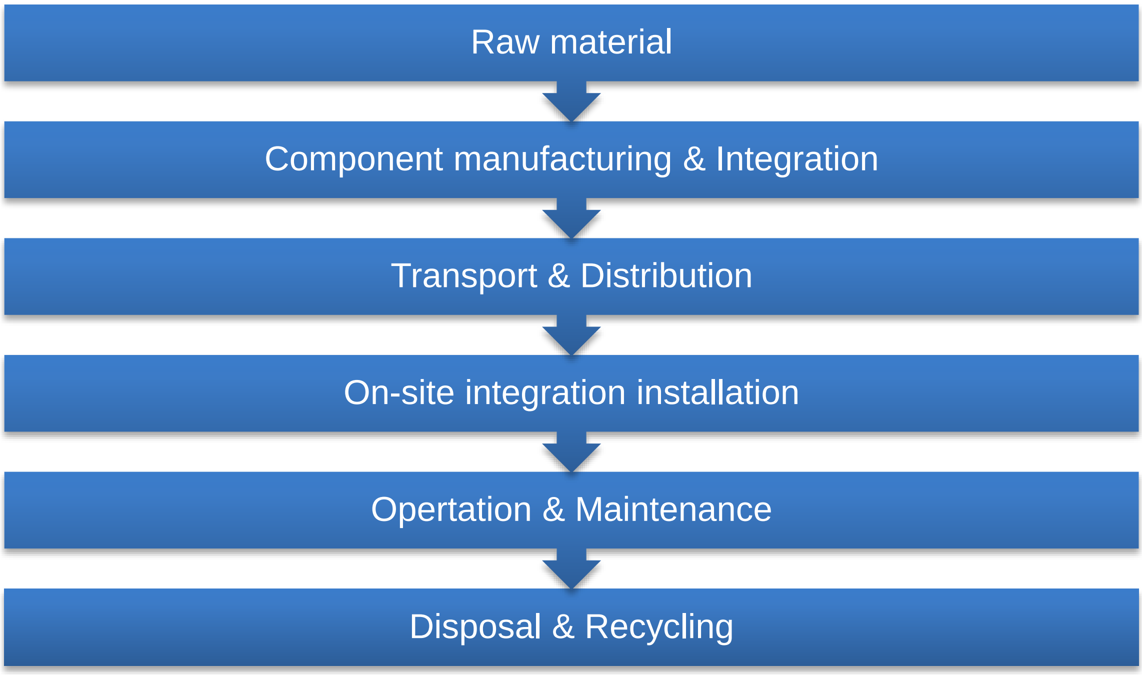


Table 3 Photovoltaic supply chain (E4tech & Avalon Consulting, 2012)

The steps on entire supply chain of PV, from raw materials to end-of-life are shown in table 3 and 4. Different PV technologies are manufactured in different ways, but the chain in table 3 and 4 is still onto the same generic supply chain.

Raw material	**Module level:** aluminum, copper, steel, polymers
	Wafer: silver, solar grade silicon
	CdTe: cadmium, tellurium
	CIS/CIGS: copper, indium, gallium, selenium, cadmium sulphide
	a-Si: silicon
Component manufacturing & Integration	**Upstream products:** float glass, sealing materials, back sheet
	Cell/module mfg: front contact, texturing, metallization, anti-reflective coating
	Balance of system mfg: frame, fittings, tracking system, DC/AC inverter, wiring, surge protection and electirc meter
Transport & Distribution	Modules & balance of system equipment
On-site integration installation	Installation
	Grid Installation
Operation & Maintenance	Reactive maintenance
	Preventive maintenance
Disposal & Recycling	Reverse logistics and recycling technology

Table 4 Photovoltaic supply chain (E4tech & Avalon Consulting, 2012)

Raw materials consist different components, depends on the photovoltaic type. In the table 4 above is listed typical PV panels and the raw materials that are used for making these PV panels systems.

The difference between reactive maintenance and preventive maintenance are that, preventive maintenance includes routine inspections and servicing of equipment to prevent breakdowns and production losses. Reactive maintenance in other hands addresses equipment breakdowns after the occurrences. Reactive maintenance has low upfront costs, but bears the risk of unplanned downtime and higher costs in the end. (Scott Madden, 2010)

Reverse logistics and recycling technologies in PV supply chain means after the sale. In other words it is called aftermarket logistics, and it includes example customer service (helpdesk), fulfillment services and warranty management. (Reverse Logistics Association, 2015)

5.2 Lean Manufacturing

The word "lean" refers to lean manufacturing or lean production as it uses less of everything, compared to mass production. It only uses half of the human effort in the factory, half of the manufacturing space, half of the investment in tools and half of the engineering hours to develop a new product on half the time. (Wahab, Mukhtar, Sulamain 2013, 1293)

"In order to improve efficiency, effectiveness, and profitability, focus relentlessly on eliminating all aspects of manufacturing process that add no value from customer perspective". (Leanproduction, 2013) The aims of a lean strategy are to do every operation using less of each resource – people, space, stock, equipment, and time and so on. It organizes the efficient flow of materials to eliminate waste, give the shortest lead-time, minimum stocks and minimum total cost. (Waters 2003, 66)

Lean method is to minimize the total costs of logistics, while ensuring acceptable levels of customer care, and to make it as cheap as possible. Toyota Motor Company was one the first companies who work on lean operations. The method was considered good, and it spread into other areas, eventually developing a lean enterprise. (Waters 2003, 66-67)

“Why not make the work easier and more interesting so that people do not have to sweat? The Toyota style is not to create results by working hard. It is a system that says there is no limit to people’s creativity. People do not go to Toyota to ‘work’ they go there to ‘think’.” – Taiichi Ohno (Lean5)

Principles of lean are:

- Value – designing a product that has value from a customer’s perspective
- Value stream – designing the best process to make the product
- Value flow – managing the flow of materials through the supply chain
- Pull – only making products when there is customer demand
- Aim of perfection – looking for continuous improvements to get closer to the aim of perfect operations. (Waters, 2003, 66-67)

Basic idea for lean is to eliminate anything and everything that does not add value from perspective for customer. Another way to look at lean manufacturing is as a collection of tips, tools and, techniques that have been proven effective for driving waste out of the manufacturing process. (Leanproduction, 2013)

“All organizations are at least 50 % waste – waste people, waste effort, waste space and waste time” – Robert Townsend (Waters, 2013, 67)

Lean identifies seven key areas of waste that adds cost or time without adding any value:

Waiting	Time when work-in-process is waiting for the next step in production (no value is being added)
Overproduction	Making something before it is truly required
Defects	Production that is scraped or requires rework
Motion	Unnecessary movement of people (movement that does not add value)
Over processing	More processinf than is needed to produce what customer requires
Inventory	Product (raw material, work-in-process, or finished goods) quantities that go beyond supporting the immediate need
Transport	Unnecessary movement of raw materials, work-in-process of finished goods

Table 5 Seven key areas of waste (Leanproduction, 2013)

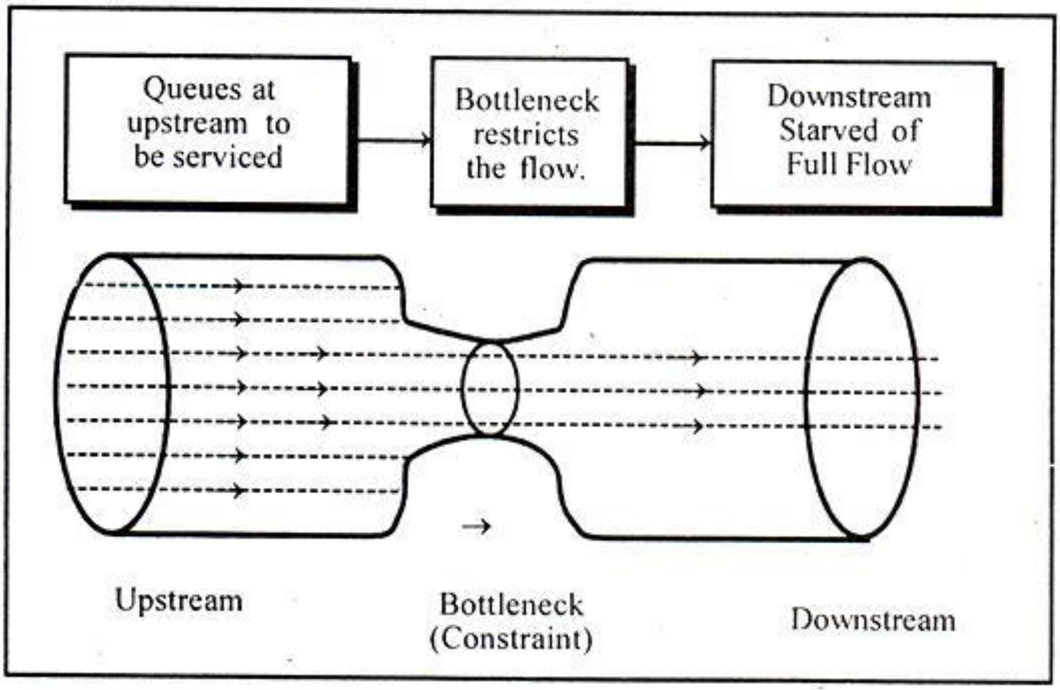
The Lean method is a good way for the photovoltaics supply chain. When identifying the bottlenecks in solar energy, the seven key methods can be used for “cleaning the waste areas away”.

5.3 Bottlenecks in supply chain management

Bottleneck is the part of a supply chain that limits throughput because it has the smallest individual capacity. A supply chain does not have a constant capacity along its length, but each operation has a different capacity. Bottleneck is formed by the resource or facility that limit the overall throughput of the chain. The bottleneck limits the overall capacity of a supply chain, which means that the specific part is working at full capacity. The more unbalanced a chain is, the more unused capacity it has away from the bottleneck. Only way to increase the overall capacity is by adding more capacity at the bottleneck. (Waters, 2009, 235-237)

Identifying the most important limiting factor that stands in the way of achieving a goal and then systematically improving that constraint until it is no longer the limiting factor. In manufacturing, it is also referred as a bottleneck. Every process has a bottleneck and focusing improvement efforts that constraint is the fastest and most effective path to improved profitability. Eliminating bottlenecks means there will be less work-in process. (Waters, 2009, 235-237)

“I say an hour lost at a bottleneck is an hour out of the entire system. I say an hour saved at a non-bottleneck is worthless. Bottlenecks govern both throughput and inventory.” – Eliyahu Goldratt (Lean5)



Picture 9 Bottleneck in supply chain (Transtutors, 2015)

In picture 9 is shown the typical image how bottlenecks effects the throughput when manufacturing products.

Bottleneck is the main cause for the low material flow from the upstream to the downstream. Bottleneck can also be named as constraint.

6 RESEARCH

This research part consist finding bottlenecks from solar energy and photovoltaics supply chain, investments costs and energy's payback time.

In the payback time section all the numbers that are used are from Fortum and the panels that are used in the example are made up for complete the case study

Fortum was picked for this research, because it offers complete PV systems, including installations. And Fortum also provides electricity and buys the surplus electricity from consumers.

For the calculation part are used two different examples, order to show some calculations and more information how much is the investment price for PV system and how much is the energy payback time nowadays.

In the examples all the PV system assumptions are made for detached houses, and all the panels are installed on rooftop facing south in 45° angle.

6.1 Bottlenecks for solar energy and photovoltaics

A bottleneck is considered to be any constraint along the entire physical supply chain of PV technologies, from the source of raw materials all the way to end-of-life. PV is nowadays likely to be constrained by a range of bottlenecks, many of these are related to supply-demand differences, while some are due to absolute constraints on materials. (E4tech&Avalon, 10)

International Energy Agency's Implementing Agreement on Renewable Energy Technology Deployment (IEA-RETD) made a research in November 2012, where they studies bottlenecks in solar energy and they identified 25 bottlenecks across the wind and PV sectors. (E4tech&Avalon, 10-11)

In this chapter just few of the bottlenecks that were identified in the IEA-RETD final report are shown in this this research. In Finland, almost all the PV technology systems and grids are coming from abroad. China is nowadays the biggest supplier in PV sector. (Holmberg, 2015) That is the reason why in this research do not handle more about the bottlenecks in raw materials supply chain, where lies many of the bottlenecks according to the final report. Some of these bottlenecks are shown in table 6. (E4tech & Avalon Consulting, 2012)

According to the IEA-RETD final report the main issue is that grid connections are holding back PV deployment and it is going to have a severe connection issues and administrative and regulatory barriers. Regulations to ease PV connection and enforce the upgrading of grids at fair return on investment are needed, in conjunction with widespread smart grid infrastructure. (E4 tech & Avalon Consulting, 2012, 15)

	- Insufficient silver availability for c-Si PV - Insufficient tellurium availability for CdTe PV - Insufficient indium availability for thin film PV
- Capital intensity of solar grade silicon production for c-Si PV - Potential restrictions on CdTe PV from hazardous substances regulations	- Technical, commercial and regulatory barriers to grid access for PV projects
- Lack of distribution channel for PV in future growth markets	- Insufficient skilled personnel for installation - Time consuming and uncertain permitting procedures for PV projects
- Insufficient PV module take-back schemes and recycling processes	- Lack of appropriate solutions for dust removal from PV modules

Table 6 Criticality assessment of bottlenecks in photovoltaic (E4 tech & Avalon Consulting, 2012, 15)

Table 6 shows the IEA-RETD identified critical bottlenecks in PV technology. The parts that are in red color are considered high criticality level, orange color is considered medium criticality, and the yellow part is considered low criticality.

A question of critical materials for cells is important in developing solar technology. These materials are silver (used in c-Si panels), tellurium (used for thin films) and indium. These materials are considered as bottlenecks according to E4tech & Avalon Consulting's final report to IEA-RETD in November 2012.

Time consuming and uncertain permitting procedures are delaying the deployment of PV projects in some countries and there is scope for transferring lessons learned in permitting across PV markets. Insufficient skilled personnel are available for PV installation, especially as PV moves to markets where sunshine levels are high but skill levels are often lower. This requires careful skills planning and knowledge transfer by companies, supported by national education policies and PV industry associations. At industry level, there is a need to integrate skills considerations in product design, in particular through provision of simpler PV system (ideally 'plug and play'). The absence of product distribution infrastructure may hamper deployment particularly in developing countries. Long terms planning and collaboration between policymakers and industry would allow this to be avoided. Vertical integration downstream from distribution down to planning and installation is one way for module manufacturers to also gain better control over the channel to market. (E4 tech & Avalon Consulting, 2012, 15-16)

From supplier's point of view the biggest issues are trained human resources, and the knowhow knowledge for the PV technology. Most suppliers in Finland order their grid connections and panels from elsewhere example from Germany. In Finland the knowhow is more in marketing, designing, delivery and installing the photovoltaic systems and grids. The system deliveries in Finland are around of ten companies, which most of them bring solar grids from abroad. (Holmberg, 2015)

From consumer’s point of view the biggest bottlenecks lies in the energy payback time and investment costs of the PV systems. The payback time depends on the size of the solar system and sun’s irradiation. In Finland the best time for sun’s irradiation is summer time. Other issue that was pointed is that there is not enough information about solar panels, and its efficiency. (Holmberg, 2015)

Pöyry Management Consulting says in their energy markets success story that “As everyone knows, there is a problem with relying wind and sun to generate power. Sometimes the wind does not blow and the sun does not shine. Investors, energy companies and policy makers need robust and detailed market analysis that guides investments”.

Solar irradiation is lower in northern Europe than in central or southern Europe, but the difference is not as large as in believed. The average daily irradiation in Finland is slightly over 900 kWh/m^2 it is almost the same than in northern Germany or Belgium. The efficiency of PV panels increases in lower temperature. In Germany for higher PV capacity is because the feed-in tariff system, and not the actual difference in irradiation. The lower use of solar energy in northern countries seems to be the lower or even non-existing financial support. (Motiva, 2015)

The challenge for Finland is that the solar energy market share is small. However, renewables should be seen as affecting energy systems, which is why future business opportunities are looking better. (Holmberg, 2015)

Tekes organized summer seminar at 2014 where they spoke about future of the solar energy. In that seminar one of the topics were: what are the things that are slowing down the development solar energy technology in Finland and what would make the growth easier. Solar energy is used at summer cottages all around Finland, so the technology is familiar. But still many of the people are not aware the possibilities for solar energy technology. Tekes named custom for the biggest bottleneck, because all the consumers have to register to custom and pay the taxes for consuming electricity. Except consumer does not have to pay electricity taxes, if the produce is less than 50 kVa. (Tekes, 2015)

Fortum’s CFO Timo Karttinen says in the press release at 2 March, 2015 that in fortum’s view, the key issues in the electricity markets are related to assessing generation adequacy, securing sufficient investments in generation and transmission, increasing renewable energy, better utilization of hydropower, and developing the retail markets. (Fortum, 2015)

6.1.1 Feed-in tariff

The feed-in tariff (FIT) system has been designed for increasing the use of renewable energy sources in electricity production. The EU has set requirements to achieve an increase in renewable energies whereby they will account for 38 % of final consumption by the end of 2020. The FIT paid in Finland comprises a state subsidy granted by the Energy Authority. Electricity producers that receive FIT are responsible for the sale of the electricity produced and for any arising net energy costs. In Finland a FIT is available only for: new wind power plants new biogas power plants, new wood-fuelled power plants and for timber chip power plants.

For solar energy, the FIT is not available, but for example Germany uses feed-in tariffs, and the solar energy markets are livelier than in Finland. Feed-in tariff came to Finland at 2011, and the latest increase for the system was wind power plants.

For example the German Renewable Energy Act stipulates the level of the IFT and grants priority to the feeding in of solar power. The purpose of the FIT is to give investors a reasonable return on investment. Since the beginning of 2012, newly installed, small rooftop installation also has achieved grid parity. (Fraunhofer, 2015)

In Finland the government should support more solar energy technologies. Now the support goes to other RE technologies such as wind power.

6.2 Costs

In this chapter all the prices that are used for calculate PV systems are Fortum's prices. These prices are trendsetting prices; PV system prices can be different with other suppliers. Also the total price for the PV system depends if the panels are ordered separately from abroad. Fortum sell only PV system packages, and all the needed equipment's came with the package price. In this research are shown two example calculations for PV systems and all the panels are installed to detached house rooftop.

Energy Agency made an annual report from the year 2014, where is shown everything that is happened in the RES field. It is shown that in January 1st 2015, the generation of household consumer's electricity price was 15.57 €/kWh. Picture 4 is shows how the market shares are divided in Finland.

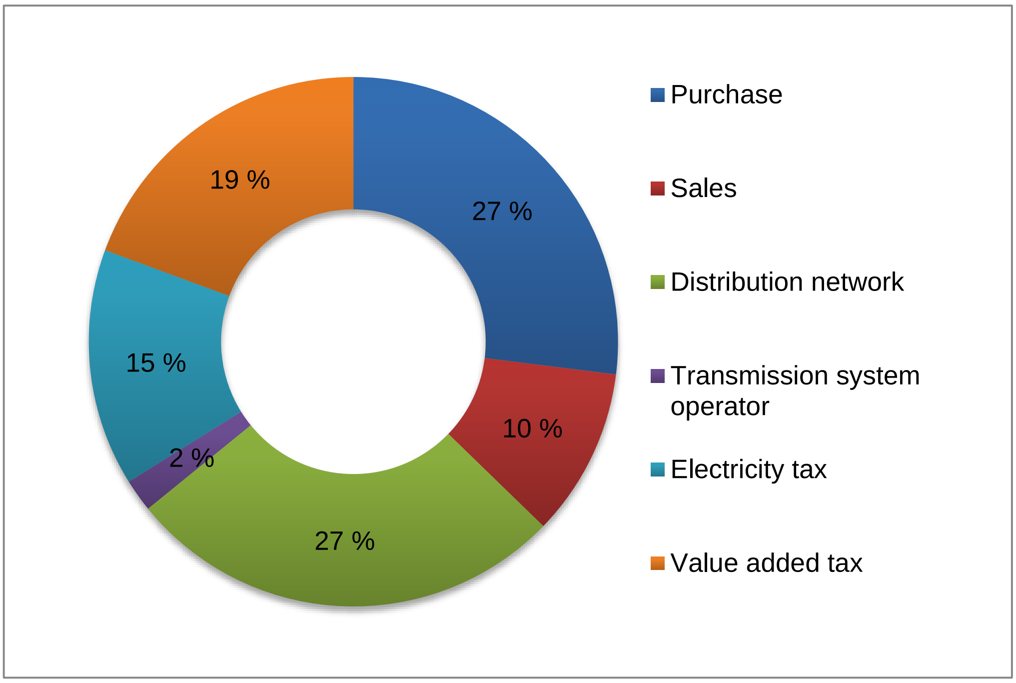
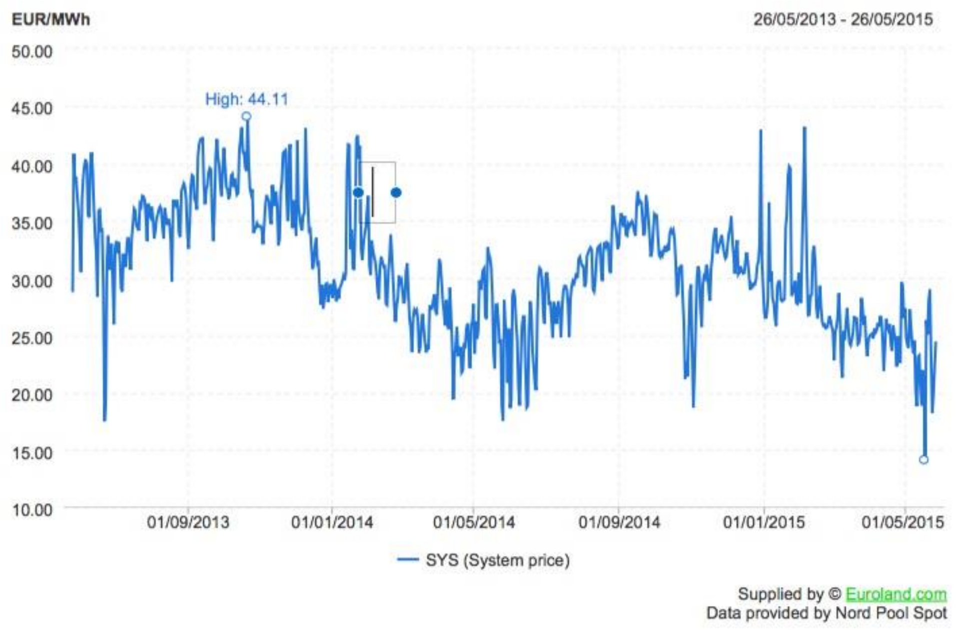


Table 7 Generation of household consumer's electricity price in 2014. (Energy Agency, 2014)

In the diagram (table 7) 37 % of the electricity price consist sales, 29 % transmission and 34 % of taxes. (Energy Agency, 2014)

Electricity price now is 2.62 €/kWh (30th May, 2015, Fortum), in picture 10 is shown the development of electricity price from 09/2013 to 05/2015. As shown the markets are for the electricity price is lowering rapidly. But still it is hard to predict the price for electricity for the future. (Fortum, 2015)



Picture 10 Electricity price in Finland. (Fortum, 2015)

Solar energy is more and more profitable renewable energy source in Finland. It market share is increased more in last years. Karoliina Auvinen point out in Finsolar project that the PV system installed to a commercial property makes it to 6-euro cents per kWh for the next 25 years. (Finsolar, 2015)

As a rapidly developing technology, assumptions about solar PV technology include significant reductions in investment costs. The Technical Research Centre of Finland (VTT) made in end of 2012 report where they compared different costs development. In 2010 the investments costs were 5.0 €/W, and in the most optimistic view of point in 2050 the costs would be 0.25 €/W and the PV systems would drop 60 % by 2020. More realistic point of view the PV systems would drop 40 % and the investments cost would be more likely around 0.5 €/W. In this scenario, it would be still 90% lower than the cost level in 2010. (VTT, 2015)

The photovoltaic systems are from 5000 to 20 000 euros in Finland. The price depends on the system area, smallest systems consist 6 panels (rated power 1.5 kWp) and the biggest systems are made for 36 panels (rated power 9.0 kWp). (Fortum, 2015)

In this case example are shown two calculations, were both systems are installed to rooftop for detached house. The prices for these PV systems are shown in table 8.

Solar system size (kWp, rated power)	Solar system	Installation work	Total price (Includes VAT 24 %)
9 panels (2,25 kWp)	4 750 €	1 870 €	6 620 €
12 panels (3,0 kWp)	5 675 €	2 335 €	8 010 €

Table 8 Photovoltaic system prices (Fortum, 2015)

The total solar system package includes: panels, inverter, rooftop brackets, electrical equipment's, consultation at home, installation, and help with the system introduction. (Fortum, 2015)

6.3 Energy payback time

As the solar energy and PV markets grows, it is important to understand the energy performance. PV systems have a long useful lifetime estimated around 30 years.

Energy payback time (EPBT) is the time it takes for the panel to generate the same amount of energy that was required for its manufacture. The EPBT is defined as the years required for a PV system to generate a certain amount of energy for compensation of the energy consumption over its life cycle. The EPBT includes: manufacturing, assembly, transportation, system installation, operation and maintenance and system decommissioning or recycling.

The exact payback period depends on a various number of different factors:

- The amount of clean energy that the PV installation generates. Output depends on the amount of direct irradiation
- The price of a PV system
- The total cost of installation, including taxes

Unsubsidized residential PV systems in Finland had payback times of more than 40 years. The production-based support for PV generation needs to be two to three times the buying price of electricity, to make it possible to pay back the initial investment in 20 years. Low capacity systems with more than 50 % self-consumption (under 3 kW) were favored by self-consumption incentives, while high capacity systems with less than 40 % self-consumption (over 5 kW) were favored by the FIT-type support schemes. (Indoor Environment, 2015)

Defining the EPBT for investments can be difficult, because it is hard to predict the future price for purchased electricity. Karoliina Auvinen says on her Finsolar report 16th of May 2015 that the energy payback time is not a good method to use, because it does not give the right image for the investment. PV's (and also solar thermal systems) lifetime cycle is around 30 years, and these systems are technically very reliable. In EPBT calculations the investments holding time, outstanding taxes and interests. For individual investment the EPBT can be defend only, if the limitation risk is outstanding. Device risks in PV systems before the EPBT closes down are very small and also the maintenance and services are slightly small. (Finsolar, 2015)

PV's technical lifetime-cycle can be even over 30 years, and almost all the supplier's gives 25 years guarantee for the systems. The guarantee make sure that the panels will give the rated power first 10 years with 90 % efficiency from the amount that the supplier announces. And for the 25 years 80 % efficiency from rated power that supplier promises. (Motiva, 2015)

For calculations are used the case study example, with that we can estimate the energy payback time and see if the PV system is profitable. All the calculations and numbers are Fotum's prices, which are available in the Internet.

With this example is used southern Finland's irradiation, which is around 900 kWh/m²/year, and the PV's are facing south in 45° angle.

Example 1, the PV systems consist 9 panels, and the total area is about 14 m². One panel is 1.5 m². The maximum output is around 2025 kWh/year. Rated power is 2.25 kWp, which is 225 Wp.

One panel produces 225 kWh/year, which can be calculated:

$p = \frac{x}{n}$ p = Produce (kWh/year)

x = Maximum output (kWh/year)

n = Number of panels

$$p = \frac{2025\ kWh/year}{9} = 225\ kWh/year$$

Efficiency of the panels is,

$t = a \times x$ t = produce of one panel (kWh/m²)

a= Area (m²)

x = amount of radiation/year

$\eta = \frac{p}{t} \times 100\ \%$

η = Efficiency (%)

p = Produce (kWh/year)

t = produce of one panel (kWh/m²)

$$t = 1{,}5\ m^2 \times\ 900\ kWh \frac{\frac{kWh}{m^2}}{year} =\ 1350\ kWh/year$$

$$\eta = \frac{225\ kWh\frac{kWh}{m^2}/year}{1350\ kWh\frac{kWh}{m^2}/year} \times\ 100\ \% = 16{,}7\ \%$$

The formulas for calculating EPBT:

$EPBT = \frac{x}{y}$

EPBT = energy payback time (years)

X = price of the solar panel system (€)

Y = system return (€/years)

$$EPBT = \frac{6\ 620\ €}{228\ €} = 30\ years$$

The results are, that in example 1 the EPBT is around 30 years. The System return price 228 € is given in the calculation that Fortum shows in table 9. In the appendix 1 is shown the screenshot from Fortum's website, where is the same calculation than in table 9.

Own power generation	
Amount of the panels	9 panels
Yearly estimated electricity produce	About 1775 kWh
Estimated annual savings	
Estimated annual savings	228 €
Costs	
Photovoltaic system	5 280 €
Installation work	1 340 €
TOTAL	6 620 €
Estimated domestic help	503 €

Table 9 Total prices for 9 panels PV system. (Fortum, 2015)

Example 2, the PV solar system consist 12 panels, and the total area is around 19 m². The one panel area is the same than in example 1. The maximum output is around 1700 kWh/year. And the rated power is 3 kWp = 300 Wp. The produce amount is also same 225 kWh than in example 1 and the efficiency for the panels are 16.7 %. In the appendix 2 is shown the screenshot from Fortum's website, where is the same calculation than in table 10.

The EPBT for these example calculations are 26 years.

Own power generation	
Amount of the panels	12 panels
Yearly estimates electricity produce *	About 2340 kWh
Estimated annual savings	
Estimated annual savings **	304 €
Costs	
Photovoltaic system	6 460 €
Installation work	1 550 €
TOTAL	8 010 €
Estimated domestic help * **	597 €

Table 10 Total prices for 12 panels PV system. (Fortum, 2015)

* All the electricity production amounts are estimated, because there are many factors that affect, for example the amount of the sun’s irradiation, temperatures, installation angles and possible obstacles that can block the PV panels.

** For estimating annual savings, there are used electricity price 0.13 €/kWh, which includes transfer of the sales and taxes. It is also estimated that the produced electricity are used for own power generation.

*** For PV installation work can apply domestic help. The amount in 2012 were 45 % of the total work, or up to 2000 €/person. (Fortum, 2015)

If the price of the electricity would increase example 10 % a year, the payback time would be smaller. In table 11 is shown example if the prices would increase 10 %.

Year	Investment	Annual savings
1	6620	228
2	6392	251
3	6141	276
4	5865	303
5	5562	334
6	5228	367
7	4861	404
8	4457	444
9	4013	489
10	3524	538
11	2986	591
12	2395	651
13	1744	716
14	1029	787
15	242	866
16	0	952

Table 11 Payback time for the investment if the electricity price would increase 10 %.

If the electricity price would increase 10 % yearly, the EPBT would be around 16 years.

There is also possibility to sell the surplus electricity for Electricity Company for example Fortum. Fortum has announced that they also buy any surplus electricity produced by the consumers. (Fortum, 2015)

Fortum pays from the surplus electricity the price that is shown in the Nord Pool Spot. Fortum takes only 0.24 €/kWh for brokerage. And consumer's produce is exclusive from VAT. (Fortum, 2015)

Nord Pool Spot is the leading power market in Europe; it offers day-ahead and intraday markets to customers. Nord Pool Spot AS is licensed by the Norwegian Water Resources and Energy Directorate to organize and operate a market place for trading power, and by the Norwegian Ministry of Petroleum and Energy to facilitate the power market with foreign countries. (Nordpoolspot, 2015)

6.4 Future for renewable energy and solar energy

“The sun could be the world’s largest source of electricity by 2050, ahead of fossil fuels, wind, hydro and nuclear”, says IEA in their press release at September 2014.

IEA made roadmaps to show how solar photovoltaic systems could generate up to 16% of the world’s electricity by 2050 while solar thermal electricity from concentrating solar power plant could provide an additional 11 %.

“The rapid cost decrease of photovoltaic modules and systems in the last few years has opened new perspective for using solar energy as a major source of electricity in the coming years and decades. However, both technologies are very capital intensive: almost all expenditures are made upfront. Lowering the cost of capital is thus of primary importance for achieving the vision in these roadmaps”. (viittaus IEA, Maria van der Hoeven, 29 September 2014, Paris)

In the future the importance of electricity use will increase. In passive houses, very low energy houses, overall electricity use is between 30-40 % of the total energy use of the building. For new buildings, the EU has set the target close to zero energy buildings by 2020. In order to achieve the zero energy buildings targets, interaction between different parts of the infrastructure is crucial, and communications are needed between energy supply and consumption. (VTT, 26)

In the future, solar energy may be both electricity and heat in the same cell, called multijunction cells. Viewpoints for technology developments and for the future of solar energy:

- Thin film solar cells; the life-cycle in outdoor use must be longer; thin-film wallpaper for artificial light
- Energy storage at northerly latitudes will be solved. Advances batteries (Example Tesla's new battery), hydrogen, compressed air storage etc.
- Solar cell CHP material development is needed
- Solar energy improves process efficiency and economy in traditional CHP plant Solar cooling technology applications
- Solar technology integrated into building envelope elements and rapid connections
- Solar microbial-synthesis processes for energy production (VTT, 47)

Finland has the conditions for increasing emission-free renewable energy in a way that is sustainable for the environment. Increasing the RE sources the national economy and employment benefits from that. (TEM, 2014)

7 SUMMARY

This thesis was a pilot search and it was part of the Solarleap project. The work starts with solar energy theory and the effectiveness in Finland. There were not so many sources to use, because the use of solar energy in Finland has not been so extensive, but the use and need for solar energy is increasing. On the theory part, the supply chain and Lean method for photovoltaics were explained. The research part studied existing bottlenecks in solar energy, and what is the effectiveness to the consumers and suppliers. On the research part were also calculated investment costs and payback time of energy by using two different examples. Those calculation could tell that the energy payback time in Finland is quite long, if compared, for example, to Germany.

There is also a possibility not to order the whole photovoltaic system and all the panels from one supplier. Research and articles tell that people order photovoltaic systems from abroad, because it is cheaper and a supplier is used only for the installation work in Finland. In the research was shown that removing the obstacles from the identified bottlenecks can help lowering the solar energy's delivery process in the future. In Finland the biggest challenge is that the energy market share in small, but it is increasing all the time and future is looking better. When the know-how increases, the market share will rise and the future goals are achieved more easily. Many reports have been made about the year 2050, and it is predicted that the solar energy could then be the largest source of electricity. Finland has also its own goals for renewable energy's usage for 2025 and 2050.

Many considered bottlenecks in solar energy were found, and many of them were in raw materials. But the lack of knowledge in Finland were pointed out on this research, and not the challenges for raw materials. Also the Lean method was mentioned in the theory part. The Lean method's base idea is to remove all the waste, so using that in the photovoltaics supply chain can help to lower the costs and unnecessary steps. Lean identifies in the seven key areas that unnecessary movement of raw materials and transportation increases waste in the supply chain and for the delivery process. Bringing the know-how to Finland could remove this waste form the supply chain and it brings also more job positions when all the manufacturing would happen in the same place and same country. And this could also remove the bottleneck for the know-how section, which means that Finland could use more solar energy as the renewable energy source. The goal for the future is net-zero energy buildings, this can only be achieved by increasing photovoltaic technology and know-how in Finland. In table 12 is shown the biggest bottlenecks in solar energy and the suggestion how to remove these obstacles are shown.

Bottleneck	**How to remove**
Know-how	More education to increase the know-how
Photovoltaic system delivery from abroad	Lean method/transport: Removing unnecessary movement
Energy payback time	Depending energy price, government should support more, feed-in tariff.
Raw materials	Incresing recycling

Table 12 Biggest bottlenecks in solar energy

On April 30th, 2015 Tesla announced that their new Powerwall home battery that charges using electricity generated from solar panels, or when utility rates are low. With this the energy harvested form the photovoltaic panels can be used in the evening, when sun is not shining (anymore). With this development, the consumer does not have to sell the energy surplus to electricity companies. There are batteries for photovoltaic systems, and those batteries are used more often in summer cottages than in detached houses. But with this new battery improvement more energy from the sun could be harvested by keeping it on the battery.

The opportunities for solar energy are good in Finland. Finland is large and growing country, which means that the benefits for improving the efficiency of renewable energy use is good. Technology knowledge, product development and competence will be helpful when the future goal is to increase solar energy and its efficiency.

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Näin paljon voit säästää CO2-päästöissäsi

Tästä näet kuinka paljon vähennät CO2-päästöjäsi valitsemallasi kokoonpanolla [1]. Esimerkiksi normaali perheauto tuottaa 140 grammaa CO2-päästöjä kilometriltä.

Laskelma perustuu arvioihin ja sen toteutumista ei voida taata.

CO2-päästövähennyksesi on

1695 kg

Näin paljon voit säästää sähkölaskussasi

Ohessa kooste valitsemastasi aurinkopaketista, sekä arviot vuotuisista tuotanto- ja säästömahdollisuuksistasi. Hinnat sisältävät ALV:n (24 %) ja ne ovat arvioita. Tarkka hinta määritellään aina kotikäynnin perusteella.

Oma sähköntuotanto	
Paneelien lukumäärä	9 kpl
Arvioitu vuotuinen sähköntuotanto [2]	n. 1755 kWh
Arvioitu vuotuinen säästö	
Arvioitu vuotuinen säästö [3]	228 €
Kustannus	
Aurinkopaneelijärjestelmä	5280 €
Asennustyö [4]	1340 €
Hinta yhteensä	**6620 €**
Arvioitu kotitalousvähennys [5]	**503 €**

Fortum tarjoaa myös maksusopimusmahdollisuuden.

[1] Verrattuna hiilivoimalla tuotettuun sähköön. Lähde

[2] Sähköntuotantomäärät ovat arvioita, sillä niihin vaikuttavat muun muassa auringon säteilyn määrä, aurinkopaneelien kallistuskulma ja suuntaus, lämpötila, aurinkopaneelien ikä, sekä mahdolliset aurinkoa varjostavat esteet, kuten puut ja lipputangot. Fortum ei tästä syystä voi taata sähköntuotantomääräarvioiden toteutumista.

[3] Vuotuisen säästöarvion laskelman perusteena on käytetty sähkön hinnalle arviota 0.13€/kWh, joka sisältää myynnin, siirron, ja verojen osuuden. Laskelmassa on myös oletettu, että valitulla järjestelmällä tuotettu aurinkosähkö kulutetaan kokonaisuudessaan, eikä osaa tuotannosta myydä eteenpäin.

[4] Asennuksen hintaan saattaa tulla lisäyksiä, mikäli aurinkopaneelijärjestelmän asennus kohteeseen vaatii erityistoimenpiteitä, jotka eivät kuulu aurinkopaneelijärjestelmiemme standardiasennustyöhön. Lopulliset kustannukset vahvistetaan asiakkaalle aina ennen tilausta, sen jälkeen kun Fortum on saanut tarkempaa tietoa asennuskohteesta.

[5] Huomioithan, että voit halutessasi hakea kotitalousvähennystä suoritetusta asennustyöstä. Tuen määrä vuonna 2012 on 45 prosenttia maksamastasi työkorvauksesta tai enimmillään 2 000€/henkilö.

Näin paljon voit säästää CO2-päästöissäsi

Tästä näet kuinka paljon vähennät CO2-päästöjäsi valitsemallasi kokoonpanolla [1]. Esimerkiksi normaali perheauto tuottaa 140 grammaa CO2-päästöjä kilometriltä.

Laskelma perustuu arvioihin ja sen toteutumista ei voida taata.

CO2-päästövähennyksesi on

2260 kg

Näin paljon voit säästää sähkölaskussasi

Ohessa kooste valitsemastasi aurinkopaketista, sekä arviot vuotuisista tuotanto- ja säästömahdollisuuksistasi. Hinnat sisältävät ALV:n (24 %) ja ne ovat arvioita. Tarkka hinta määritellään aina kotikäynnin perusteella.

Oma sähköntuotanto	
Paneelien lukumäärä	12 kpl
Arvioitu vuotuinen sähköntuotanto [2]	n. 2340 kWh
Arvioitu vuotuinen säästö	
Arvioitu vuotuinen säästö [3]	304 €
Kustannus	
Aurinkopaneelijärjestelmä	6460 €
Asennustyö [4]	1550 €
Hinta yhteensä	**8010 €**
Arvioitu kotitalousvähennys [5]	**597 €**

Fortum tarjoaa myös maksusopimusmahdollisuuden.

[1] Verrattuna hiilivoimalla tuotettuun sähköön. Lähde

[2] Sähköntuotantomäärät ovat arvioita, sillä niihin vaikuttavat muun muassa auringon säteilyn määrä, aurinkopaneelien kallistuskulma ja suuntaus, lämpötila, aurinkopaneelien ikä, sekä mahdolliset aurinkoa varjostavat esteet, kuten puut ja lipputangot. Fortum ei tästä syystä voi taata sähköntuotantomääräarvioiden toteutumista.

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