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Oskari Rentola

Twenty Years of Photovoltaics in the Northern Europe

– Innovations & Projections of Solar Technology

Metropolia University of Applied Sciences

Bachelor of Engineering

Sustainable Building Engineering

Bachelor’s Thesis

21 April 2020

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Title	Twenty Years of Photovoltaics in the Northern Hemisphere – Innovation & Projections of Solar Technology
Number of Pages	40 pages + 7 appendices
Date	21 April 2020
Degree	Bachelor of Engineering
Degree Programme	Civil Engineering
Professional Major	Sustainable Building
Instructor	Sergio Rossi, Senior Lecturer

The goal of this Bachelor's thesis was to present the development of photovoltaic systems from the earliest application to modern-day technology. For a purposeful study, the Finnish photovoltaic market was further analyzed and dissected, to compare its' maturity to the evolution in southern Europe.

The methods used in the project consisted of background research, an enquiry on citizens' opinions, and further analysis of the results. Thus, a wide variety of resources were gathered, to decide on relevant points to examine. The inquiry produced a response from 14 participants, six representatives from the field, and eight non-professionals, which yielded a meaningful set of data for analysis.

The results highlighted the diverse opinions of contemporaries on photovoltaics while emphasizing how they see great potential in solar energy. The ongoing climate-change discourse had inspired some participants to install solar systems for their homes already, while others felt it is important to decrease emissions and are considering it in the future.

The research concluded that there is a growing interest in renewable energy amongst citizens. This growth could be further promoted by the government's investments in renewable energy. Moreover, an earlier move toward renewable energy production would support economic well-being while also encouraging sustainability.

Keywords	solar, photovoltaic, PV, photovoltaic market, future

Tekijä Otsikko Sivumäärä Aika	Oskari Rentola Kaksi vuosikymmentä aurinkosähköä Pohjois-Euroopassa – Innovaatiot ja tulevaisuuden näkymät 40 sivua + 7 liitettä 21.4.2020
Tutkinto	insinööri (AMK)
Tutkinto-ohjelma	Civil Engineering
Ammatillinen pääaine	Sustainable Building Engineering
Ohjaaja	lehtori Sergio Rossi

Tämän lopputyön tarkoitus oli kartoittaa aurinkokennojärjestelmien kehitys ensimmäisestä sovellutuksesta nykypäivän teknologiaan. Tavoitteena oli saavuttaa syvällisempi näkemys alan nykytilanteesta sekä tulevaisuudennäkymistä. Tutkimus tarkasteli Suomen energiamarkkinoita yksityiskohtaisesti, verraten niitä edelleen Etelä-Euroopan pidemmälle kehittyneisiin olosuhteisiin ja sen perusteella tehtyihin havaintoihin.

Tutkimusmenetelmät koostuivat taustatutkimuksesta, mielipidekyselystä, sekä tulosten syvemmästä tulkitsemisesta. Laaja-alainen taustatyö aiheesta antoi hyvän mahdollisuuden valita tärkeitä aiheita jatkotutkimuksta varten. Mielipidetutkimukseen osallistuneista 14 vastaajasta kuusi henkilöä edusti teollisuuden asiantuntijoita, ja loput kahdeksan olivat alaa vähemmän tuntevia siviilihenkilöitä.

Tutkimus osoitti että kansalaisilla on kasvavaa mielenkiintoa uusiutuvaa energiaa kohtaan. Tätä kasvua voidaan entisestään tukea valtion investoinneilla uusiutuvaan energiaan. Tämän lisäksi aikaisempi siirtyminen uusiutuvan energian lähteisiin tukisi talouskasvua sekä kestävää kehitystä samanaikaisesti.

Avainsanat	aurinko, aurinkoenergia, aurinkopaneeli, sähkö, tulevaisuus

Contents

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List of Abbreviations

AI	Artificial Intelligence. An area of computer science applying human traits to computer programs; such as speech recognition, learning, and problem-solving.
BAPV	Building Applied Photovoltaics. Systems and components fixed on existing structures for photovoltaic power generation.
B.C.	Before Christ. Used in referrals to the past before the beginning of the adoption of the calendar and chronological time-records.
BIPV	Building Integrated Photovoltaics. Materials capable of being utilized in photovoltaic power generation that replace traditional materials of building facades, roofs, sidings.
CDP	Carbon Disclosure Project. It supports organizations to reveal the environmental impact of their operations. Based in the United Kingdom.
CEO	The Chief Executive Officer. The highest singular authority in charge of management and leadership within an organization.
COVID-19	Coronavirus disease 2019. The virus was first identified in December 2019 and has since then spread to become a global pandemic.
DHW	Domestic Hot Water. Accessed to via faucets, spigots, or outlets which are installed in enclosures designed for human habitation, or other areas exposed to living beings.
Dr.	Doctor. In this context, it refers to an academic degree.
EPIA	European Photovoltaic Industry Association. From the 28th of May 2015 onwards the organization has been known as SolarPower Europe.
EU	The European Union.
GW	Gigawatt. A unit of energy. Equals to 1,000 kilowatts.

HOA Homeowners' Association. In Finland called the *household company* or *property company* (taloyhtiö) which is the owner of the property. A board consisting of all the tenants who own their apartment.

IEA The International Energy Agency. Acts as an adviser regarding policies and regulations. The Headquarters are in Paris, France, and it has 30 "membership states" that include countries as Australia, the U.S, and many Eu-countries among others.

IoT Internet of Things. The ability to transfer data over digital networks without human intervention.

ISO 9001 A constitution of quality management standards composed and published by the International Organization for Standardization.

ISS The International Space Station.

kW Kilowatt or kilowatt-hour. A unit of energy. Also, it equals to 3600 kilojoules.

kWh/m^2 Kilowatt-hour per square meter. A unit of radiation. In this context refers to global solar radiation. See also the Solar Resource Map.

kWp kilowatt peak. The maximum peak performance under standard conditions.

m^2 Square meters. A standardized unit for area.

MOI Magnitude of Importance. A standardization system specifically devised for this thesis project's interview-answers.

MW Megawatt. A unit of energy. Also, equals to 1,000 kW.

MWp Megawatt peak. The maximum peak performance under standard conditions.

NASA The National Aeronautics and Space Administration is the part of the U.S government concentrating on space research. Founded in 1958.

NREL	The National Renewable Energy Laboratory. The organization is owned by the US government and facilities are operated by contractors affiliated with the United States Department of Energy.
Oyj	Julkinen osakeyhtiö (public limited company). A direct Finnish abbreviation for the legal configuration of a business.
PV	Photovoltaic technology. It provides a means to harvest solar energy for electrical power generation by utilizing solar panels and an inverter.
SPE	SolarPower Europe. Aims to ensure increasing solar power generation.
tn	Trillion. The numerical value for a million millions or 10^{12}.
USA	The United States of America. Became independent from Great Britain on July $4^{th,}$ 1776.
U.S	The United States of America.

1 Introduction

Universally, humanity is now living challenging times: the escalation of the COVID-19 pandemic has brought the world to a momentary halt. Yet in the background, there remain the questions around the decades-long global warming debate, and the joint energy crisis, which have been imprinted into our minds by now. From the dawn of civilizations, man has yearned to harness the clean abundant natural energy of the Sun. Nonetheless, just a fraction of that power has been successfully manipulated through the methods of science. Despite the recent discoveries in the area of solar technology, it is evident that this technological progress will continue to thirst for further investments and research in order to advance and provide possible solutions.

From the viewpoint of cleaner-energy-production, it is vital to continue developing new and existing technologies that can diversify and eventually replace past carbon sensitive forms of energy. As a result, solar power and photovoltaic technology (PV) have been seen as a possible solution for this call. Moreover, having the power production taking place as close to the consumption-node as possible (e.g. on the roof of a residence), the transferring structure required would be reduced to the minimum. This would also promote resilient and independent methods of harvesting natural energy for inhabitants.

On this side of the millennium, the worldwide production capacity of photovoltaics has skyrocketed. In the Northern hemisphere, Finnish companies are also advancing and innovating new solar photovoltaic technologies. Despite the limited number of sunrays reaching the country, especially during the long winter months, the solar technology has presently been deployed for close to two decades. Moreover, the comparatively smaller size of the nation in the world-wide-scale has allowed innovations and improvements to be nimbly implemented, while high technological expertise and education enable wide and advanced research capabilities.

As the power of the sun has, throughout times, drawn man to harness it for civilizations, this thesis aims to dissect its whole history for reaching a deeper perception of the prospects of the technology. Hence, the evolution of photovoltaics from ancient Greece to futuristic visions of the post-millennium era will be meticulously analyzed. Furthermore, the characteristics of the market in Finland, as well as the prospective innovations in the field's future horizons will be examined.

1.1 History of Photovoltaics: From the Ancient Past to the Millennium

Solar power and the energy of sun rays has been utilized by man since the ancient civilizations. According to research by the U.S Department of Energy, from as early as in the 7th Century B.C. pieces of glass and mirrors have been used to concentrate sun rays to ignite a fire. [1.] The early examples of this include Greeks and Romans producing fire for religious festivities, and the legend tells that the Greek scientist, Archimedes, to set fire to wooden ships from the Roman Empire attacking Syracuse by employing reflective bronze shields, see figure 1. [2.] However, no definite scientific proof of this exists, but a recreation experiment in 1973 by the Greek Navy in Greece, was successful from the distance of 50 meters [1].

Figure 1. Archimedes and his solar Death Ray [3].

Ken Butti and John Pelin relate how, in 1767, the world's first "solar-cooker" saw the daylight after having been invented by Horace De Saussure [4]. This creative French-Swiss scientist started experimenting with solar energy by focusing sun rays into one point after discovering how little the maximum achievable temperature had been studied.

The device he fabricated consisted of a wooden box that had several glass-cubes inside each other thus magnifying the effect of sunrays traveling through the glass-walls and into the innermost cube, illustrated in figure 2. The device was small and portable, yet the contemporaries understood the great value it provided. Its ability to generate heat with such an inexpensive and simple manner fascinated people around the world. [5.]

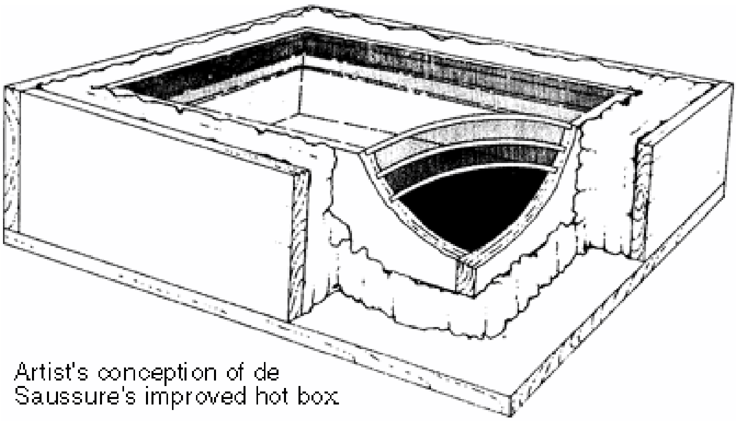

Figure 2. Saussure's Hot-Box [6]

Over the experiments with this Hot-Box, Saussure was able to attain temperatures over the boiling point of water (110º C). This new heating method was further field-tested by Sir John Herschel [5.], who in the aftermath of his expeditions with the Hot-Box in the 1830's South Africa, wrote:

> "…as these temperatures [up to 240 F] far surpass that of boiling water, some amusing experiments were made by exposing eggs, meat, etc. [to the heat inside the box], all of which, after a moderate length of exposure, were found perfectly cooked…[on] one occasion a very respectable stew of meat was prepared and eaten with no small relish by the entertained bystanders."

Butti and Perlin give great credit to De Saussure for this invention. Not only was it the first recorded application of solar power, but it opened opportunities for wider research. They highlight how this technology was the prototype of the modern solar collectors. [4, p. xiii]

Over the 18th Century, several momentous innovations in the fields of chemistry and electricity transpired. The Layden Jar, the earliest form of storing static electricity, was developed in Holland circa 1745 [7], and Benjamin Franklin had concluded that electricity is a single force (rather than consisting of two fluids as was the contemporary theory in Europe) after his well-known kite-experiment in June 1752 [8]. Emerging from these discoveries, a whirlwind of rapid advancement carried science, and in 1799 an Italian scientist, Alessandro Volta, produced an implement that later became known as the Volta Pile, the first battery in the history of man [9].

By the late 1830s, a 19-year-old Edmond Becquerel, in figure 3, had become an assistant to his father Antoine, who was the chairman of Applied Physics at the French National Museum of Natural History (Muséum National d'Histoire Naturelle) in Paris, France [10]. While conducting experiments in his father's laboratory in 1839, young Edmond discovered the “photovoltaic effect”. Later, this revolutionary realization became the foundation for the working concept of the solar cell [11].

In 1844, Charles Fritts was the innovator who installed the first rooftop solar cell array in New York, USA writes Meyers [12]. This new technology is said to have performed at an efficiency of below 1%. Nonetheless, the concept of electricity was still relatively new, and the contemporaries were expecting it to improve swiftly. However, the productivity improved with a snail’s pace making the solar energy expensive, and the output of electric generators made them a more viable solution to satiate the increasing demand for electricity [13].

By 1954, Bell Laboratories pioneered the solar cell technology to device more practical means of utilization. Building upon Russel Ohl’s patented work (United States Patent Office, 1941) on silicon and semiconductor materials from 1940, Calvin Fuller, Gerald Pearson, and Daryl Chapin collectively augmented the performance of solar cells from 1% to about 6% efficiency, based on APS Physics. [14,15] This was a huge improvement from any other known attempts, inspiring a new period of hype around photovoltaics. The New York Times [15] wrote at the time:

> “[the silicon solar cell] may mark the beginning of a new era, leading eventually to the realization of one of mankind’s most cherished dreams-the harnessing of the most limitless energy of the sun for the uses of civilization”.

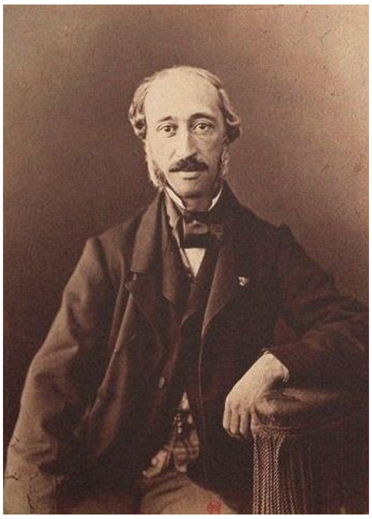

Figure 3. Edmond Becquerel [16]

In 1958, The Vanguard I space satellite used a photovoltaic array to power its radios. This proved the technology to be a viable alternative as a space operation energy source and raised awareness of its new potential. On the other hand, Andrea Hsu shines a light on the early development of PVs for residential use. According to her, it is ironic how the giant oil company Exxon Mobile participated in ground-breaking research on photovoltaic technology. [17] By 1960, Hoffman Electronics had pushed the efficiency of photovoltaic solar cells from 8% to 14%, and by 1970 a new solar cell design by Dr. Elliot Berman and Exxon corporation (figure 4) reduced the cost from $100/Watt to $20/Watt. This discovery made photovoltaics a suitable solution for remote locations requiring power while being too expensive to reach with landlines [17].

Figure 4. Elliot Berman (center, in a patterned tie) and his team, Massachusetts, in 1973. / Robert Willis/ Solar Power Corp. via John Perlin [18].

In 1985, The efficiency rate of 20% was attained for silicon solar cells through a project by The University of South Wales. Furthermore, by 1994 The NREL (USA) developed a gallium indium phosphate and gallium arsenide solar cell which reached a 30% conversion efficiency [1].

1.2 From the Millennium to 2010: Making PVs Affordable

In the wake of the Millennium, the International Space Station (ISS), received additional solar panels made of monocrystalline silicon, to increase the combined array size to 239.4 feet (73 meters) in the year 2000. [19-21] The sets of arrays can now generate from 84 KW to 120 KW of energy [22], enough to power over 40 households. [23] The price of this system has been estimated to be around $300 million (Reuters) [24], and its current operating efficiency between 14% - 29% based on the analysis of the technology available at the time, however, not disclosed by NASA [25].

The new age of photovoltaics started in the early 2000s. As for igniting the initial spark for the growth, Solar Power Europe (SPE) gives Germany kudos for encouraging the implementation of renewable energy technologies (biomass, geothermal, hydropower, wind, and solar) by adopting Feed-in tariffs to promote investments to renewables. [26.] Based on SPE's estimate, since then the global solar power capacity installed has multiplied "…by a factor of more than 150" [27], as seen in figure 5.

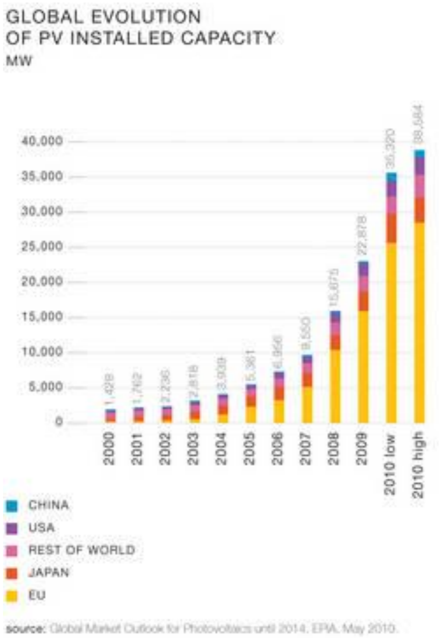

Figure 5. EPIA – Global PV capacity installed 2000-2010 [28].

The data gathered by the European Photovoltaic Industry Association (EPIA) shows that by the end of 2010, the global installed capacity had leaped up to 40 GW worldwide [27]. By the end of the decade, photovoltaic systems were being installed at an unprecedented pace, as seen in figure 6 below in chapter 1.3.

1.3 From 2010 to 2020: Lowering the Cost and Augmenting the Tech

A decade after the Millennium, Photovoltaic technology is still going strong. The prices per Watt have continued to fall making the installation more affordable. Thus, upon improved performance, price evolution, and improving support infrastructure, even a wider audience has been able to access the photovoltaic technology. As can be seen in figure 6 by the International Energy Agency, the growth has been exponential. [29, 30.]

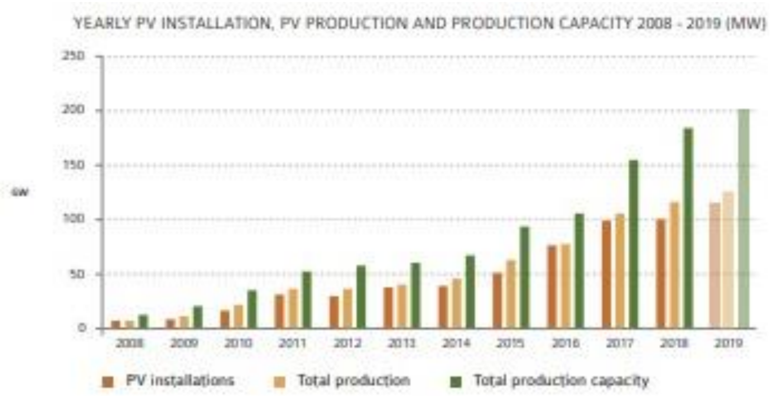

Figure 6. Global capacity 2008-2018 [31].

Moreover, in an interview on September 6th, 2017, Professor Poul Erik Morhorst, from the Technical University of Denmark, explained how every time the global installed capacity is doubled, the cost of photovoltaic systems will decrease by 22%. Specifically, he explains "…what we have seen until now is that typically the installed capacity doubles each 2nd or 3rd year". This can also be seen in figure 7 which illustrates well how the decline of prices has been a rapid downfall [32].

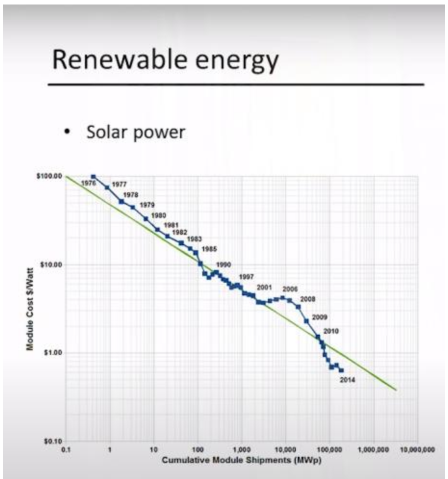

Figure 7. Cost of Solar / Poul Morhorst, DTU [32].

On April 13th, 2020, news from Natural Renewable Energy Laboratory (NREL), USA proclaimed: “NREL Six-Junction Solar Cell Sets Two Records for Efficiency”. The article unveils how scientists John Geisz and Ryan France, in figure 8, had fabricated a solar cell that reached nearly 50% (47.1%) operational conversion efficiency under concentrated illumination, and 39.2% efficiency under one-sun illumination which simulates standard natural light conditions [33].

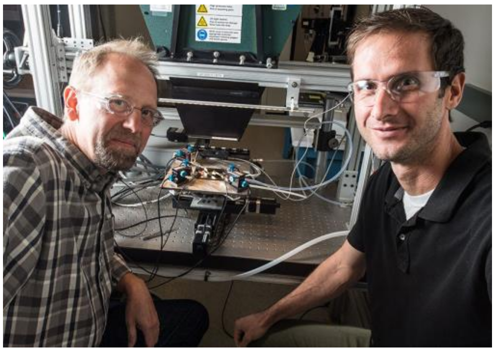

Figure 8. Geiz and France / Dennis Schroeder, NREL [34].

This high performing configuration of solar cells is a viable power source for satellites, due to the cost of the materials and manufacturing of the cells, yet the same product could also be utilized on earth as well. Consequently, Mr. France proposed a method of collecting sun rays with mirrors and then concentrating them into a single point. This would allow consuming fewer materials while also increasing the performance of the cell under higher concentrations of light. In figure 9 below, all known photovoltaic technologies are benchmarked and ranked based on efficiency.

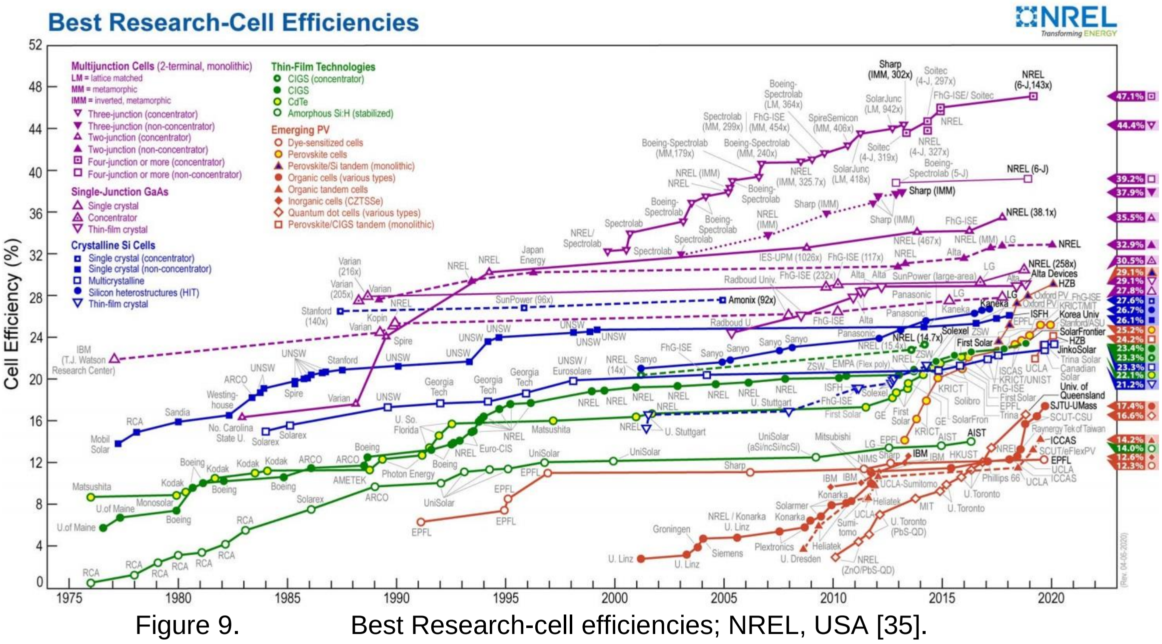

Figure 9. Best Research-cell efficiencies; NREL, USA [35].

In the close future, NREL scientists look forward to breaking the 50% barrier which is "actually very achievable", says Mr France. Hence, the scientists will now focus on enhancing the performance by reducing the restrictive barriers inside the cell hindering the flow. On the other hand, they do not believe in the efficiency of full 100% ever being attained due to the fundamental boundaries by thermodynamics [33].

2 Photovoltaic Technologies in Finland Today

Residing in the North and close to the North Pole, Finland receives slightly less solar radiation than nations settled in central Europe or the vicinity of the equator. The capital, Helsinki, receives annually 7% less solar radiation compared to Berlin, Germany, and a staggering 50% less than Rabat, Morocco, according to the PV*SOL Online PV dimensioning tool. [36] Even with the limited amount of sunlight in Finland, photovoltaic technology has now been employed for over two decades and counting.

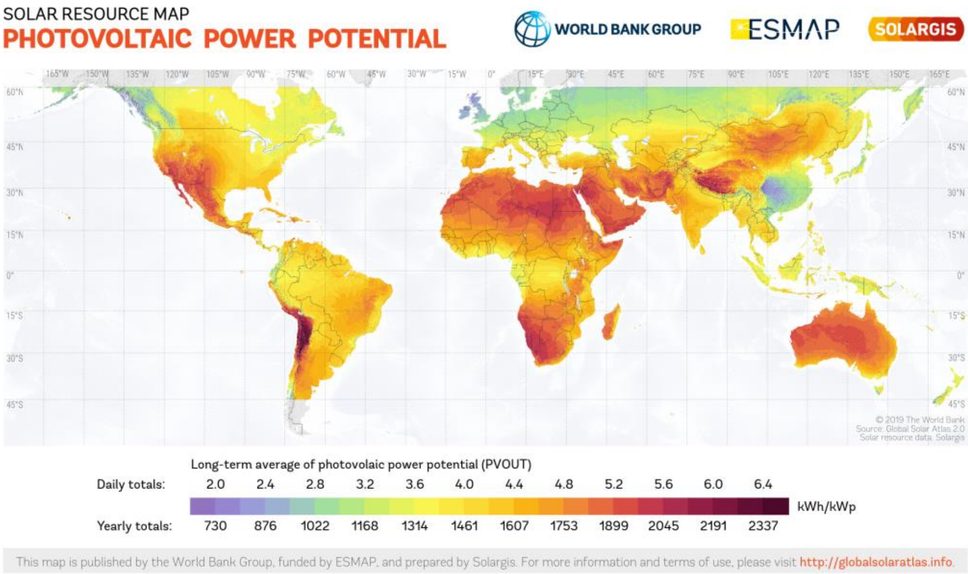

Figure 10. Solar Resource Map / World Bank Group [37].

The differences in global radiation are illustrated above in figure 10 Solar Resource Map, which does not quite reach Helsinki yet. For a reference, the Finnish Meteorological Institute determined the annual global radiation of the Helsinki-Vantaa region being 975 kWh/m^2. The study was conducted in 2011 (see Appendix 2; table L2.2.).

Nonetheless, Finland's compact size with a high level of education allows nimble tweaks in the infrastructure and policies, while providing sharp workforce to innovate new, even more refined solutions. Subsequently, there are existing subsidies to encourage the implementation of renewable energy and several new companies are honing the constraints impeding the systems' performance. Therefore, the number of solar power plants has been growing quickly along with the new players entering the market, as the interview material will further elaborate in the following subsections of chapter 2.

2.1 Shifts in the Focal Point

Over time, there have been several systems and methods for harvesting solar energy which have risen to the mainstream. Based on the interviews conducted for this thesis, around 2010, many people in Finland placed their trust in solar thermal collectors that transferred thermal energy through a carrier medium (e.g. H_20) inside a tube network, see figure 11 below.

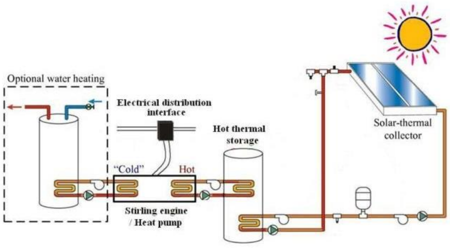

Figure 11. Solar-Thermal system / Basil Huffman [38].

Nonetheless, recently photovoltaic systems for electricity have become the majority, see in figure 12 Photovoltaic system.This shift is due to the long lifespan of PV- systems (some claim 30 - 40 years), and their ability to generate power during the peak-consumption, in the morning and evening. Furthermore, solar thermal production, while being less complex a system, is less versatile and mainly used for domestic hot water heating. Also, solar thermal production is often attributed to lower performance during the cooler temperature seasons which, in contrast, have lesser impacts on PVs as long as sunlight is present. This invest and forget solution of PVs has especially appealed to Finns who have an occasional demand of a few hundred kilowatts for basic needs, at a distant locale.

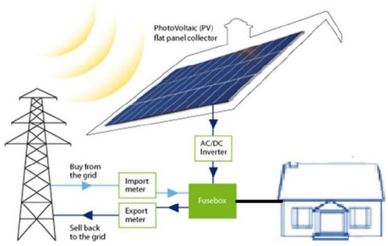

Figure 12. Photovoltaic system / Hrushikesh [39].

2.2 Summerhouses

As residents of a country of thousands of lakes, the Finns take tender care of their summer cabins of which quite a few are located at off-grid regions. In April 2020, an analyst estimated there are 80,000 off-grid cottages in the countryside, while supported by a simple 100-Watt solar panel for lighting and appliances. Furthermore, there are also 1,000 dwellings powered with home wind turbines while 4,000 cabins are still without a power source, for instance on the islands of the Baltic Sea. From this initial spark for cabin-solar, the movement over the past decade has been more toward private home-production. Nowadays, the panels are being installed in the more densely populated regions. This progression is further topped with some solar energy systems for grocery-chains and business organizations.

2.3 Businesses with Renewable Programs

Businesses, institutes and entities like farms, towns, and cities have also invested in solar energy and renewables around Finland. This is the most appealing choice in situations where the organizer can avoid costly electricity transfer fees and taxes while collecting the government's investment-subsidy for renewable energy sources, states Finnish Lähienergialiitto ("Local-Energy-Agency") on their website [40]. This all further adds to the marketed face-value of supporting the more sustainable future.

In 2020, private parties can usually apply for subsidies varying between 10-30% of the total investment expenses. The big-league players working on new technological projects can receive increased support of 30-40% of the investment [41]. Also, energy-inspections for the municipal-sector and micro- and mid-size businesses can be eligible for 50% coverage, while all other entities will get 40% for their analyses and inspections. [42] All these applications are processed by the innovation funding center Business Finland, while the Ministry of Employment and Economy will be granting the funding. By regulations, the share is dependent on the project's characteristics, yet for private home-owners, the solar thermal and PV subsidy was 20% in 2020 [43].

2.3.1 S-Ryhmä Aims for Carbon Neutrality by 2025

On the 16th of April 2018, the Finnish grocery-chain S-Ryhmä announced that within a year they will be installing solar panels on the roofs of 40 stores to meet their ambitious goal of reducing carbon emissions by one million tons by 2030. This meant that 37,000 panels were going to be installed on top of S-Market, Prisma, and ABC-stores around Finland. By 2025, the company aims to have increased its use of self-produced renewable energy to 80%, of which the majority is covered by wind power and annually 10% would come from solar power [44].

On the 15th of April 2020, S-Ryhmä published an article reporting a record of covering up to 97.5% of the first quarter of 2020 energy demand by its own renewable energy. This achievement was accredited to favorable wind conditions, a strong increase in the number of solar panels, and increased energy efficiency. figure 13 below depicts the progression of the demand covered with renewables: the darker green represents the total electricity consumption while the lighter green shows the amount of wind and solar power against the aggregate consumption [45].

Figure 13. Progression of renewables implementation/ S-Ryhmä [46].

By January 2020, S-Ryhmä had installed 50,212 solar panels on 71 mall-roofs generating 14 MW of electricity. The goal of 2020 is to install PVs to over 40 additional locations, totaling 70,000+ operating panels. On its website (s-ryhma.fi), the company broadcasted on the 23rd of January 2020 that these efforts have earned the chain an award from the Carbon Disclosure Project (CDP) which ranked the establishment in class A- which is the highest among the Finnish retail businesses [47].

Additionally, the company has committed to being fully carbon-negative in 2025. After reducing emissions and polishing energy efficiency, the company will compensate for the remainder by utilizing methods of forest and earth carbon-storing. S-Ryhmä believes the need for compensation will be reduced over time when combined efforts and optimizing will enhance the overall performance [47].

2.3.2 Finavia: Fully Carbon Neutral Since 2019

The international airport of Helsinki-Vantaa, Finland, has also set goals for reducing carbon emissions. According to Finavia who operates the airports in Finland the Helsinki-Vantaa Airport has officially been certified as carbon neutral from 2017, see figure 14. Moreover, the regional airports have also been carbon neutral since the Spring of 2019, a year before the set goal. Even by the standards of the European Union, aiming to reduce the carbon footprint by the aviation industry, this achievement is remarkable [48].

Figure 14. Helsinki-Vantaa International Airport Terminal 2/ Finavia [49].

Continuing to cut carbon emissions is important to Finavia. Currently, the airport-buses are fueled with diesel fully made from waste and residue, while smaller vehicles have long been powered by electricity. Additionally, energy efficiency and the use of renewable energy have been the pillars for reaching the goals of carbon neutrality. Yet, Finavia's Climate Programme lists many further goals and activities for the year 2020. The company plans on purchasing more eco-friendly vehicles, a significant increase in LED lights, and engaging other companies operating at airports to reduce their emissions. Meanwhile, the flagship of Helsinki-Vantaa will continue being a showcase of the greener aviation in Finland [50].

Over the past decade, Finavia reports having reduced carbon emissions by an average of 3% per passenger while having also constructed a solar power plant on the roof of its Terminal 2, see in figure 15. This plant came online in Spring 2017, as reported by the company on the 19th of May 2019, and generates around 330 kWp during standard conditions. In 2020, Finavia plans on installing additional solar panels on the façade of its new parking hall [51].

Figure 15. Finnavia's solar power plant on the roof of Terminal 2/ Finavia [52].

In addition to achieving carbon neutrality in its operations, the company has committed to aiding nations that have challenges with the reduction of emissions. Countries, such as India, have been seen in need of help with their environmental challenges. This assistance will be provided through the means of a compensation mechanism, the carbon-offset, which allows compensation of emissions that are produced elsewhere [48].

2.3.3 Senaatti-Kiinteistöt Invests Millions of Euros in Solar Power

Senaatti-Kiinteistöt (Senate Properties), is a state-owned enterprise and manages real estate assets of The Republic of Finland. An article in the Finnish construction-magazine reveals that by 2022, Senate Properties' goal is to have around 50 new solar power plants in operation and increase the production capacity up to 5 MWh peak. Thus, they will annually invest a million euros in the project until the end of the strategic term of 2022, writes Mikko Kortelainen, in Rakennuslehti. Also, new technology will be utilized in polishing the performance of the existing buildings [53].

2.4 Single-Family Homes

In recent years, solar energy has gained popularity and Lähienergialiitto states it is an energy form people want more of in the energy markets of Finland. [54] The thesis-interviews show that while people worry about the climate-change, businesses and cites see positive gains and image-value in renewable endeavors. It is noteworthy that the renewable subsidies in Finland vary usually between 10-30%, but Kotitalousvähennys ("household deduction subsidy") can also be used to cover some parts of the investment costs. However, it is only available for people living in a detached dwelling. Nevertheless, many experts interviewed share the opinion that despite virtually non-existent opposition, to enable further exploitation of solar energy, the progression could and should be expedited by revisions to impeding regulations while also dedicating additional resources to the cause.

2.4.1 Solar Thermal Energy Versus Photovoltaics

In Finland, selecting a solar power system for a detached dwelling is dependent on many conditions. The viability of picking solar thermal or photovoltaics is strongly influenced by the main purpose: is the power used for heating domestic hot water (DHW, figure 16), or for generating electricity? Although solar thermal energy has been attributed to overpowering performance over the warmer seasons, PVs are currently more visible and prominent in the discourse, say the experts interviewed.

Figure 16. Possibilities of Solar Thermal Energy/ Tampereen Sähkölaitos [55].

Comparing these two methods, Karoliina Auvinen from Aalto University wrote that the solar electricity production increased from 27 MW in 2016 to 66 MW in 2017, and further to 120 MW in 2018 [56].

Nevertheless, there is no collection of accurate data about solar thermal statistics. Yet, IEA, determined the solar collector capacity of Finland being around 37 MWp. From the extrapolation of general trends, depicted in figure 17, it can be deducted that the installations of solar thermal in Finland are following the EU-trends although up-to-date statistically viable data is scarcely available [57].

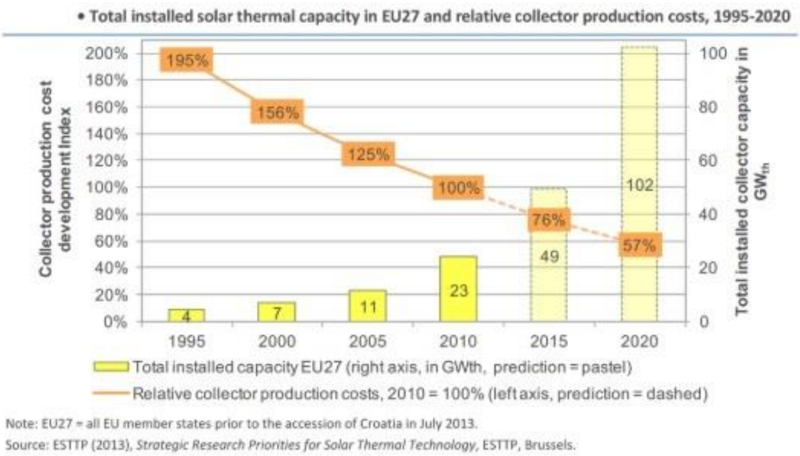

Figure 17. Solar Thermal production capacity by 2010/ ESTTP [58].

2.4.2 Common Configurations and Complications in Self-Production

Thesis-interviews showcase that while the awareness of the possibilities in solar energy is spreading amongst builders and homeowners, the susceptibility of installing solar harvesting systems is rising as well. Yet, when the daunting initial investment is being weighed, people might have misconceptions regarding the benefits of these systems. One analyst related how, on some occasions, questionable marketing tactics and promises have caused potential buyers to turn away upon learning about these unfortunate confrontations. Additionally, from the viewpoint of someone outside the energy-field, when the price paid for self-produced solar energy is still roughly four times higher than for the traditional forms, there is still a great amount of educating and work to do, to ensure newly signed producers having had the ability to make the decision based on accurate and scientific evidence. Else, the international aspiration for more diverse energy industry is vain perspiration.

According to the experts interviewed, the most common solar harvesting set-up in Finland simply consists of a set of panels on the roof, plus an inverter, and the main grid connection, as seen in figure 18 below. This results in lower self-use when 90% of the power is fed into the main grid due to non-existent power storage. Unfortunately, the high price of batteries has caused solar producers to postpone the storage upgrades for some later date in the future.

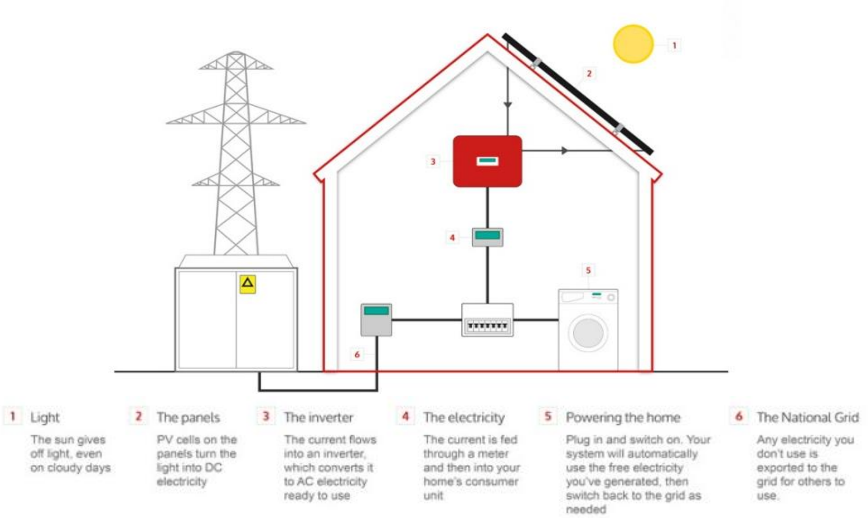

Figure 18. Main components of a solar PV system/ Evoenergy [59].

According to an expert participating in the study, the current average size of a system for a single-family home is usually around 5 KWp. The system is also connected to the main for selling the overspill. In contrast, firms and companies usually go for the 100 MW optimized systems (annual production) due to the threshold of 800 MW, above which the federal production tax will be applied. To avoid such a mishap, the big players tend to leave a fair amount of leeway in their system's capacity.

Homeowners who were interviewed, reveal that one of the major pains for private PV-owners, and an obstruction to wider adaptation in Finland, is the current pre-condition to use the power immediately. Since a PV system is a hefty investment, adding batteries for storing energy is not yet feasible enough, from their performance standpoint, to warrant the additional cost, says an expert. This has major implications for the incentives to implement solar energy since the inability to store energy for later self-use becomes impossible. This leads the homeowners to feed their solar power into the main (90% of production) and having to buy it later for a fourfold price. In other words, the energy companies will tax transfer fees for the energy sold too which causes one roughly profiting 4 Eurocents per kilowatt-hour sold, but paying 12 cents per kilowatt-hour purchased to meet the full demand. Obviously, this trade-off does not excite too many new investors.

The experts say there are still thresholds impeding the realization of the full potential. For instance, power storages are still rare due to the unbalanced equation of expected performance versus the magnitude of the investment. The challenges also include awareness and attitude education, answering questions regarding the general performance, revising lacking policies and subsidies to improve the incentives, reforming existing structures from all-commercial to private production and private-party market, and justifying the associated investment costs.

2.4.3 Advanced Configurations

In addition to simple direct-feed systems, there are also more advanced hybrid solar systems on the market, figure 19 below. A specialist interviewed confirms that this enables the storing of power which can be utilized during the night-time or cloudy days. The hybrid-model will also provide cushion over extended periods of low visibility since PVs are highly weather sensitive. Nonetheless, possibilities with these hybrid designs are up to the imagination − as long as the financial standing can support the expenditure.

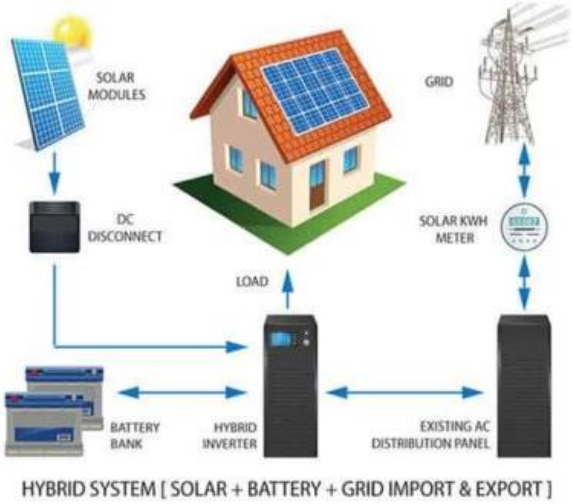

Figure 19. Hybrid PV configuration/ Apollo Power Systems [60].

As an example, a German company, SMA Energy Systems, provides solutions for the clients who want to "…generate, use and store their own solar power, monitor and control their electrical loads, heating systems and e-vehicles, or whether they want to achieve additional yields…". [61] The conglomerate was founded in 1981 and has operating offices in 18 countries. Hence, the extensive experience of over 35 years of renewable energy research has allowed them to become pioneering experts in the field. With advancing digitalization, the company envisions a bright future for centrally controlled and “smart” energy systems [62].

Figure 20. Augmented energy system/ Future Green Technology [63].

SMA’s systematic and intelligent energy management enables running home appliances like dishwashers and washing machines during times when PVs are delivering power, as seen in figure 20 above. This means that the homeowner can increase and optimize the use of self-generated power while decreasing their dependency on the utility grid. Yet, by integrating a high performing battery package in the configuration, no compromises in technology are inherent. However, variables such as location, climate, orientation, and nature still play a major role in the resulting yields [61].

The company claims that their Sunny Home Manager is also capable of controlling all operations automatically based on user-defined parameters (details in figure 21). Moreover, by utilizing an online weather forecast and user inputs, the program modells a day-by-day yield forecast thus predicting in advance when bountiful solar power will be available − consequently engaging, say the washing machine, accordingly [61].

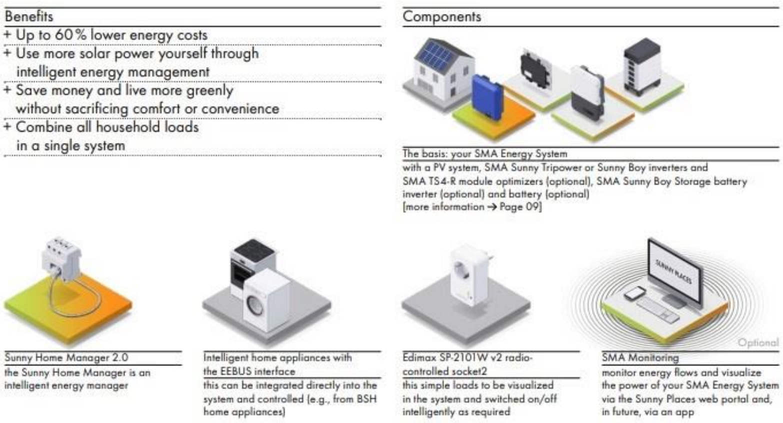

Figure 21. Sunny Home Manager by SMA Solar Technology/ SMA [64].

After the appliances are augmented with the EEBUS intelligent power control, and the components like SMA Sunny Boy Storage battery inverter is installed along with other features, the company claims the system saving up to 60% in energy costs. This is achieved by optimizing the operating efficiency of appliances, while the total energy flow is managed intelligently. When adding in the prospect of fine-tuning and monitoring the performance via an app in the future, the technology becomes yet another grade more intriguing for solar investors [64].

3 Finnish Companies and the Industry

Methods of harvesting solar energy have been studied in Finland since 1970. Despite the amount of extensive research conducted on solar power, the adoption-process has been relatively slow. Lähienergialiitto states on their website that the more challenging climate conditions, pre-conceptions, and lower subsidies compared to other EU-countries can explain the slow progress. However, roughly from the year 2015, the capacity of the installed solar power has been almost doubling every year, sometimes even beyond [65].

In Finland, investments in solar increased remarkably in 2015 when operational systems totaled 5 MW of generated power, says Lähienergialiitto. [65] Moreover, Jouko Lampila wrote in 2018 that the total accumulated capacity for solar energy production already reached 27.2 MW by 12/2016, and as much as 66.2 MW by 12/2017. [66] Energiavirasto (Energy Authority) reported on the 26th of June 2019 of an increase of 82% in solar energy production, which counted for 120 MW in the solar energy production capacity by 12/2018. [67] Experts interviewed say this exponential growth for PVs is not going to slow down in the future, rather the opposite, as seen in figure 22.

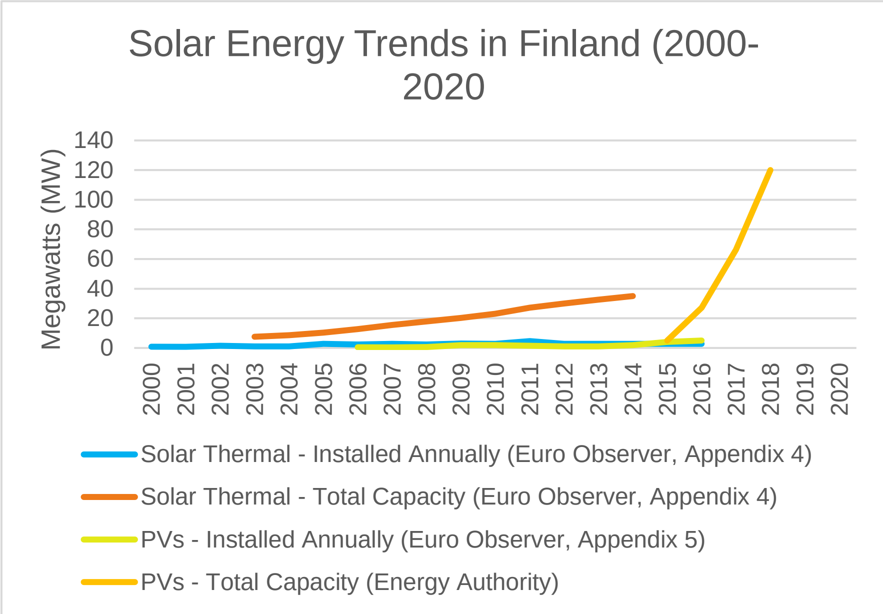

Figure 22. Now trending: Solar Power

This booming growth has been noted by the rising entrepreneurs as well. An industry expert, who was interviewed for this study, revealed that from 2015 to 2020, there have been over 300 new companies striving to get a foothold in the Finnish solar market. Although the majority of these firms are sales-driven and production-based, there are still some who concentrate on further advancing and pioneering the technology, concludes the expert. Upon this notion, three Finnish solar energy companies, the ones that were recognized the most by the individuals interviewed for the research, will be introduced briefly in the following sections of this chapter.

3.1 Naps Solar Systems

Naps is a Finnish company concentrating on pioneering, producing, and installing photovoltaic systems. [68] The company was originally founded in 1982 (later known as Neste Advanced Power Systems from 1986) after the Finnish oil production company Neste Oil Oyj (Fortum Oyj since 1998) decided to invest in alternative energy sources. In 2001, the company gained sovereignty after separating from Fortum Oyj, and the name was changed into Naps. By the dawn of the millennium, Naps had tirelessly ventured the global markets, delivering products and operating in countries such as Finland, Sweden, Norway, Denmark, France, England, Singapore, Australia, China, Kenya, Bahrain, Germany, and Estonia, among many others [69].

As of today, Naps concentrates on providing leading technology solutions with nearly 40 years of experience. Subsequently, several books and guidelines that have been produced over the years are a sign of this expertise acquired, shown in figure 23. Also, the ISO 9001 -certified management system will ensure that the cutting-edge products continue to find the international audience. Furthermore, Naps has been able to hire some of the field's leading experts in Finland and continues to pursue excellence through joint projects with networks and partners. One of the projects is conducted with Aalto University, one of the most distinguished universities in Finland, to develop a new nanotechnology solar cell [68].

Figure 23. The experience is visible in the form of solar energy literature [70].

In the future, Naps is looking forward to expanding its business in the world's fastest-growing energy-field, solar power. This will be achieved by accountable business practices and high-quality solar panels which are promised to yield at least 80% of the nominal power for at least 26 years. Moreover, the installations of these panels are guaranteed for local entrepreneurs to support local economies and sustainable growth [71].

3.2 Savosolar

Savosolar Oyj was founded in December 2009 in Mikkeli, Finland, and the company focuses on developing and providing solar thermal systems for its international client base. Just after 18 months from founding, the company won the prestigious Intersolar Award for its Direct Flow Absorber technology. Even today, this revolutionary innovation is still the core of the world's most efficient flat plate collector, states the manufacturer's website, savosolar.com. As of today, the company reports having delivered its products to 17 countries on four continents [72].

From its inception, Savosolar's management has been busy making attractive business-deals. In 2016, the company announced the delivery of a 15,300 m^2 solar collector to

Jelling Varmeværk, Denmark. After two years of successful operation, an addition of 4,835 m^2 was also installed, increasing the total area of the system to 20,135 m^2. Despite this success, the company still aims higher [73].

On May 2018, the company announced having signed its biggest turnkey-contract to the date regarding the delivery of nearly a 21,000 m^2 solar thermal plant in Grenaa Varmeværk, Denmark. [74] The total value of the contract was 3.5 million euros and the close-out was scheduled for April 2019. In March 2019, Savosolar reported that Greenaa Varmeværk was in full operation [75].

In August 2019, Savosolar reported that they will be manufacturing the largest solar thermal system in France for Kyotherm Solar, figure 24. The size of this solar thermal plant is 14,000 m^2 which also made it the largest industrial process heating system in Europe. The total value of this contract is over 3.8 million euros, making it the most expensive project for Savosolar so far. At the time, the close-out for this project was scheduled for the spring of 2020 [76].

Figure 24. Kyotherm — Savosolar's most lucrative contract so far [77].

In the future, Savosolar will strive to remain on top of the solar thermal markets worldwide. The CEO, Jari Varjotie, said in the company's 2019 financial statement that one of the reasons for a slightly lower net revenue lies in delivery delays which had not originated from Savosolar. On the same token, he rejoiced how the volume of orders had doubled, and cost-efficiency in production had also increased in contrast to previous terms. In conclusion, the company aims to continue racking up even more happy clients who are greatly satisfied with the performance of Savosolar's systems [78].

3.3 Solarvoima

Just before the rise of the new wave, Solarvoima Oy was founded in July 2014. The company concentrates on delivering solar panel systems for detached dwellings and commercial buildings on the turnkey-contract basis. The vision of the company is to provide its clients with the world's best solar panels, components, and installation teams, to guarantee their satisfaction [79].

Thus far, Solarvoima has installed over 1,000 solar systems in Finland. Yet, the variance in solutions has been great since the installed locations include single-family homes, commercial buildings, shopping malls, and summer homes. At the forefront, the company has taken part in the experimental project that, in 2014**,** installed Finland's first solar PV system in an apartment building in Käpylä, (figure 25). At the time, the project was unprecedented due to the challenges such systems had in the regulatory environment, according to Sari Alhava [80].

Figure 25. Janne Käpylehto presenting the system in Käpylä [80].

In Finland, the regulations regarding the utilization of PVs in apartment buildings have not been the most favorable. In addition to technical challenges in allocating the self-generated power between tenants, the current policy forces the tenants to pay transfer fees and taxes even for their own production, because by law, the power must circulate through an electric company's main property power meter, see figure 26. Hence, the majority of people living in apartments are left without the possibility of utilizing solar power, despite the growing interest [81].

One solution has been to replace all the unit-specific power-meters with a new type which are then owned by the Homeowner's Association (HOA). However, this would entail a 250-500€ cost per device, being a tough price to pay for something ordained by an outdated directive. However, this would allow each unit to install their own solar systems, and occupants manage their own production and usage independently. On the other hand, the so-called back-metering -method proposes a management method of having the HOA to own all the apartment specific power-meters of the building from the beginning. All these "unit-meters" are connected to the main meter, and the main property meter would still be owned by the energy company, like before. The specific characteristic for this model would be that the whole HOA and all the tenants would have a single electricity contract amongst themselves with a single provider which would again enable each resident to choose their own preferred system and power source [82].

Figure 26. Finnish power meter/ Petro Aaltonen, Yle [83].

With back-metering, the fees and taxes could be avoided if all tenants just unanimously agree to a permanent, mutual electricity provider. However, the current "Electricity Market Law" (Sähkömarkkinalaki) requires that consumers have the right to ask for bids and selecting their electricity provider without any restrictions [81]. Luckily, an analyst interviewed revealed that a revision to these regulations is currently making rounds for comments, and the Ministry of Employment and Economy has stipulated that tenants living in apartment complexes do not need to pay transfer fees or taxes for self-generated electricity. Henceforth, he predicts an explosion in the solar market focused on systems and services for apartment buildings.

Solarvoima has profiled itself as an innovative educator in the possibilities of solar energy, as advocated in figure 27 below. The company has been a partner in events that aired the news of “World’s Largest Ice Carousel: 122 meters”, and “Sailing a Sauna from Helsinki to Tallinn!” which both utilized solar power in the process. [84-86] Both projects attracted the attention of the international press, and the Sauna-event made news with media corporates such as Business Insider, The Times, The New York Times, and Reuters [86-90].

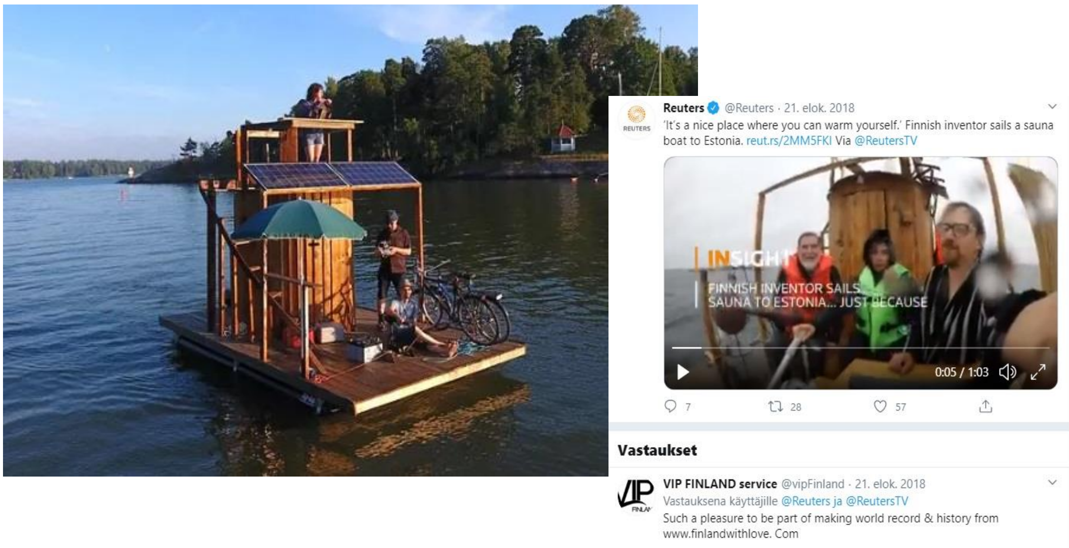

Figure 27. Solarvoima has attracted the international media with various exciting events/ Picture of the sauna by Janne Käpylehto [91].

The inventor and center figure of these events, Solarvoima’s Director of Development Janne Käpylehto, says that raising awareness of solar power is necessary. In Finland, PVs will be climbing at a staggering rate in the future and there is still a vast market to explore! Especially, there are great possibilities in adding solar to the multitude of apartment complexes that are homes for nearly 2.6 million Finlanders. Mr. Käpylehto firmly believes that in 10 years the prominence of solar energy will be exploding in the global energy market. In the meanwhile, he intends to “…continue teaching people how much fun energy can be!” [92].

4 Research Data

Chapter four will present and analyze research-data that was acquired by interviewing several individuals about their views on the rise of solar and photovoltaic technology, see table 1 for details. Roughly, half of the participants are currently working in jobs related to the industry, but also persons outside the immediate field were contacted. These interviews were carried out as phone-interviews in April 2020.

Table 1. Professions of the research participants.

Experts	Individuals
• Author of Energy Literature	• Army Lieutenant
• CEO of X PV company	• Bachelor of Social Services
• Professor of Real Estate	• Car Sales Manager
• Professor of Technical Physics	• Carpenter
• Project Engineer	• Engineering Student x2
• Representative of Y Energy Company	• Nurse
	• Interior Finishing Specialist

As can be seen from table 1, the participants are from all walks of life, holding various positions in business and profession. The diversity in the partaker pool was one of the set goals when gathering data for the research. This variance would ensure a great variety of opinions and views to analyze.

4.1 Common Views on Photovoltaics

Most of the participants believe that the ongoing climate-change discussion has motivated people to take part in the effort of implementing more energy-efficient construction practices, considering the overall performance of the buildings more carefully, and investing in less environment-taxing heating systems, as shown in figure 29 for the division answers. Yet, the total capacity of solar energy is still marginal compared to older practices, but the participants believe the prominence will grow by varying degrees in the future. In general, the views of solar power are positive, yet opinions regarding its significance in the future are rather diverse.

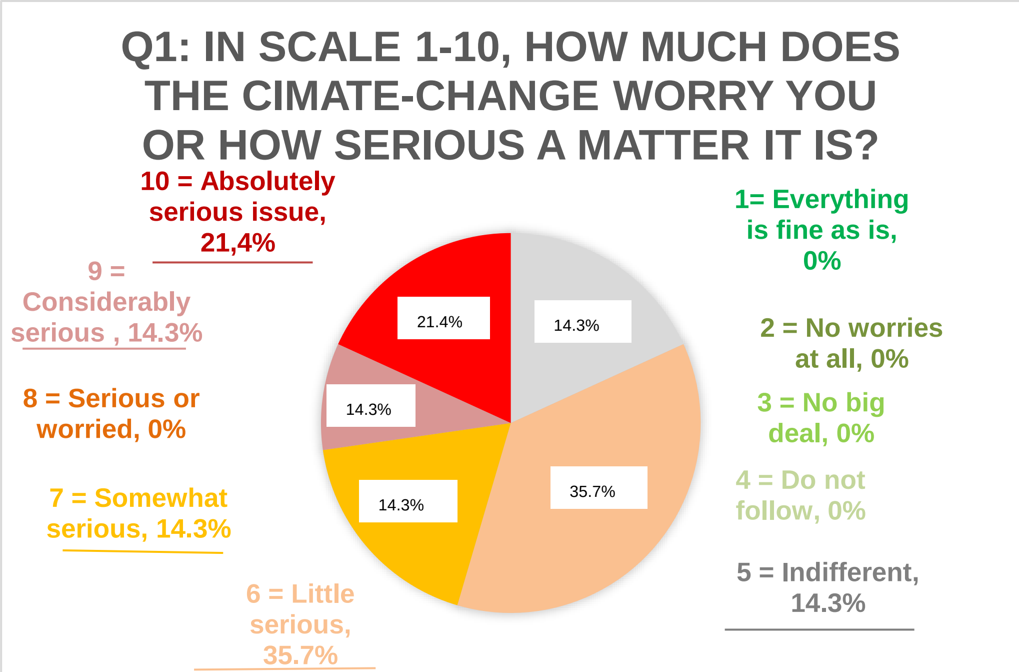

Figure 28. Q1 answers.

While the participants are not scared of global warming, they generally think it is a serious matter to consider. All have noted the rise of PVs, and the expert participants have had first-hand experience of how the prices of solar systems have come down in recent years. All parties agree that the shifts in the most popular technology have been visible in the trends of construction, cityscape, and amidst design-decisions of the most active homebuilders. Therefore, now is an excellent opportunity to decrease the carbon footprint, and advance implementation of renewables, as answers depict in figure 28.

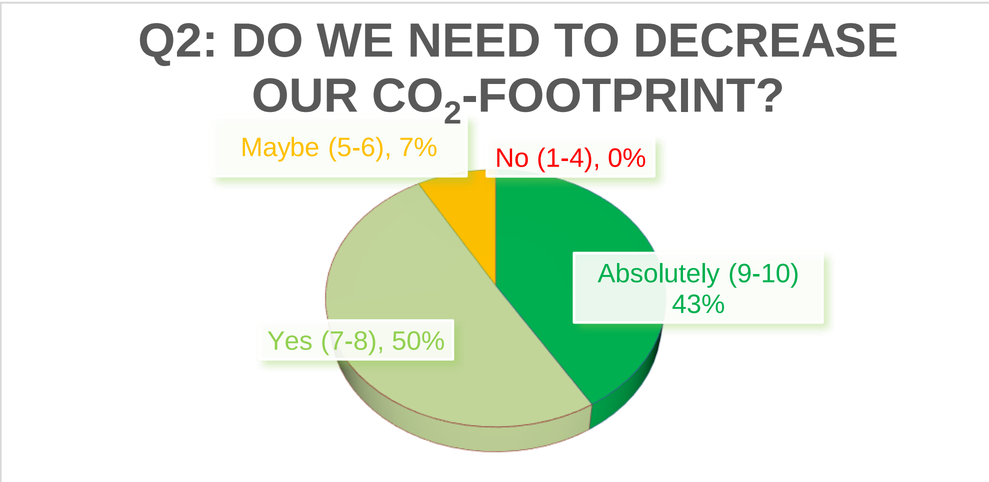

Figure 29. Q2 answers.

Generally, all participants think that PV systems will keep improving and their efficiency rising. Therefore, PVs can help to reduce carbon emissions, and further increase their share of total energy production in contrast to other methods currently prominent, refer to figure 30. On one hand, over half of the experts think that PVs alone will take over a significant portion of the energy market within the next 10-20 years while others see it rather as a welcome but partial component of renewables. The great majority of the experts advocate for a swift transfer to more sustainable forms of energy, calling for government intervention in increasing incentives for adoption of renewable energy systems. 60% of the experts already have a PV system in operation, either at home or summer residence.

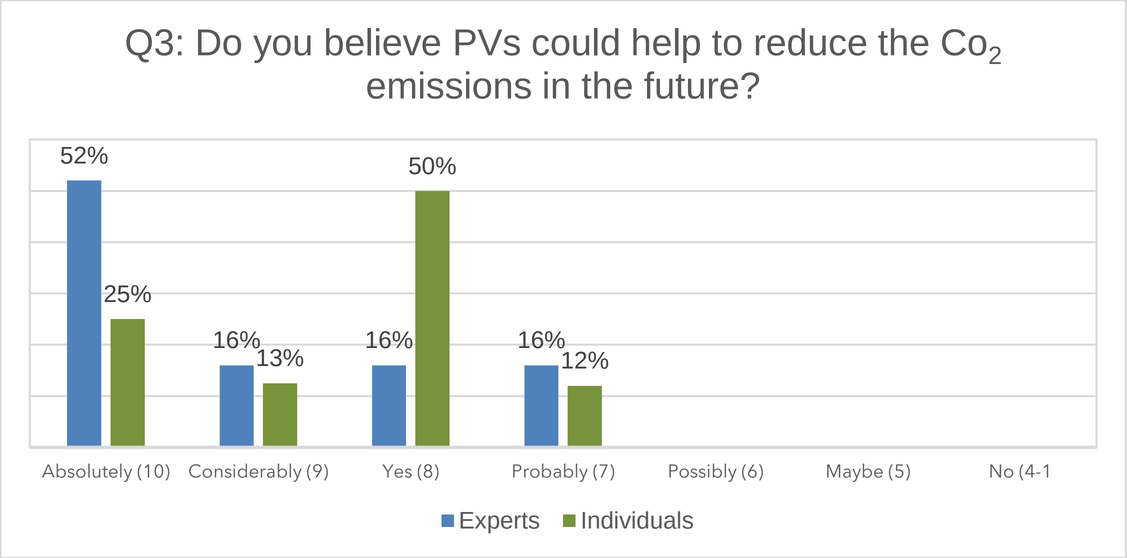

Figure 30. Q3 answers.

Most of the participants without a relation to PV industry think that as the wind energy is going strong and solar thermal systems have not quite kept up with PV systems, there will not be a singular, most promising technology of tomorrow, whether it is solar or other renewables, as depicted in figure 30. Anyhow, they still expect to see great improvements in solar applications. Nonetheless, the opinions seem to be more dependent on the experiences with, and affiliation to the types of renewable energy than to be an in-depth understanding of the national or international trends. Despite scattered opinions, 38% of the non-professionals would seriously consider installing a photovoltaic system for their house in the future. However, the main holdback is the current price and questions about personal financial gains in the long run.

4.2 Possibilities in the Market

As presented before, solar energy has gained popularity in recent years. Currently, solar power is a desired form of power in the energy market of Finland. Both individuals and businesses see great value in participating in voluntary climate-acts by advancing the implementation of renewable energy sources. The thesis-research revealed that from 2015 to 2020, there have been over 300 new businesses entering the Finnish solar market. Some analysts interviewed believe in even greater growth over the next 10-20 years, both domestically and globally.

The experts who participated in the interviews for this thesis are positive about the prospects of photovoltaic power systems, as can be seen in figure 31. In fact, the sun offers more energy daily than what is the current demand, plus it is clean & green, and the process is relatively simple. Thus, the experts' average expectation for improvements in PV technology is 9.5 ("considerable improvements") in a scale from 1-10. Consequently, the experts also see PV systems having an important role in reducing CO_2-emissions in the future, with an average of 9.17 out of 10 in the replies.

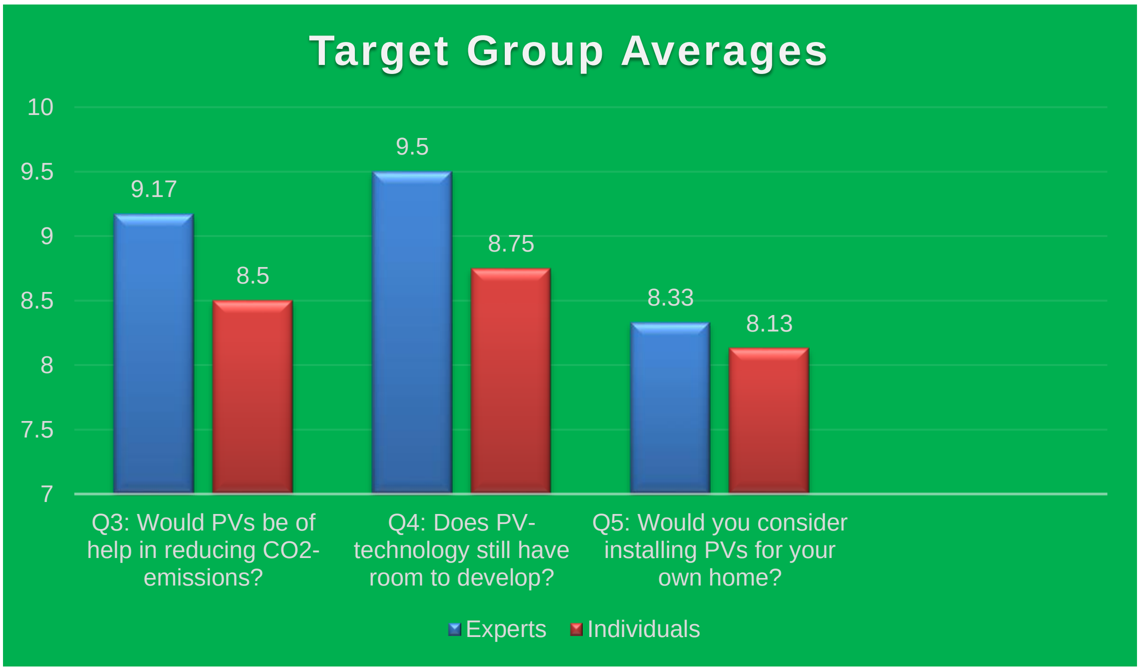

Figure 31. Averages of answers per group for questions 3-5.

At the same token, individuals outside the immediate field also think that photovoltaics still have room to develop (average 8.75). Additionally, they strongly agree with the experts that PVs would be of help when aiming to reduce CO_2 emissions, with a high average of 8.5 (“important/ considerable”). Most of the participants “individuals” are under the age of 30, thus not living in detached dwellings yet, but they would be considering solar PVs as an energy form in the future, should there be an opportunity to buy or construct their own home. Overall, the topic is important and close to contemporaries.

4.3 Experts’ Visions

The in-depth interviews with the professionals gave great insights into the advancement of new innovative forms of solar panels. One product developer saw transfer from Building Applied Photovoltaics (BAPV) to Building Integrated Photovoltaics (BIPV), pictured in figure 32, while another specialist hopes for the development of nanotechnology [93]. A third called for printable solar panels that could be “slapped on virtually any surface to generate power, and be the next big thing”.

Figure 32. BIVPs at work [94].

In experts' conclusion, most of them agreed that the development of battery technology would greatly increase private homeowners’ interest in solar systems, in comparison to the current growth-rate. Additionally, they hope the government sees the potential in PV systems worth investing in, by directing incentives toward the cause. On the European-scale, the support-structure in Finland is still in the making, but the current growth ensures that PV technology will continue to draw enthusiasts towards sustainable and renewable energy sources in the future as well.

4.4 Adventures + Affiliations + Assumptions = Actions

Tabula Rasa, the principle attributed to the philosopher John Locke, suggests that all humans are born as a blank slate. This slate will eventually be covered with recordings of experiences encountered and will influence all the activities that are undertaken. Consequently, the knowledge and experience regarding a specific area (or field) will influence our preconceptions and actions when making new decisions [95]. This bachelor's thesis is not trying to be philosophical in nature, but this idea of influential experience is also visible in the answers that the research-interviews accumulated, see table 2 for the questions asked.

Table 2. The template for interviews.

Rapid-fire poll:		
	In scale of (1-10)	Notes
1) Do the talks about global warming worry you?		
2) Do you think we need to decrease our CO2-footprint?		
3) Do you believe PVs would be of help with the goal?		
4) Do think the technology has still room to develop		
5) Would you consider installing PVs for your own residence?		

As illustrated in figure 33, the difference in Magnitude of Importance (MOI) -values (as seen in table 3), between the experts and individuals is intriguing. Yet, it visualizes the great challenge when pioneering visionary products for individuals from all walks of life. How to meet on the same level to realize common goals together when looking at things from slightly different angles?

Table 3. The Magnitude of Importance.

MOI	Definition
10	Absolutely (Serious/ Important)
9	Considerably (Serious/Important)
8	Yes (Serious & Important)
7	Probably (Serious and Important)
6	Possibly Important
5	Maybe / Indifferent
4	Not interested or following
3	No big deal ("overhyped")
2	No worries at all (Seriously)
1	All is fine as is

This question needs to be considered carefully to reach a more sustainable future. Surprisingly, this thesis illustrates (figure 33) how positive the response to solar energy is in Finland. Furthermore, it is noteworthy that most of the non-professional interviewees were individuals under 30-years-old which emphasizes the youth's favourable opinion to alternative energy sources.

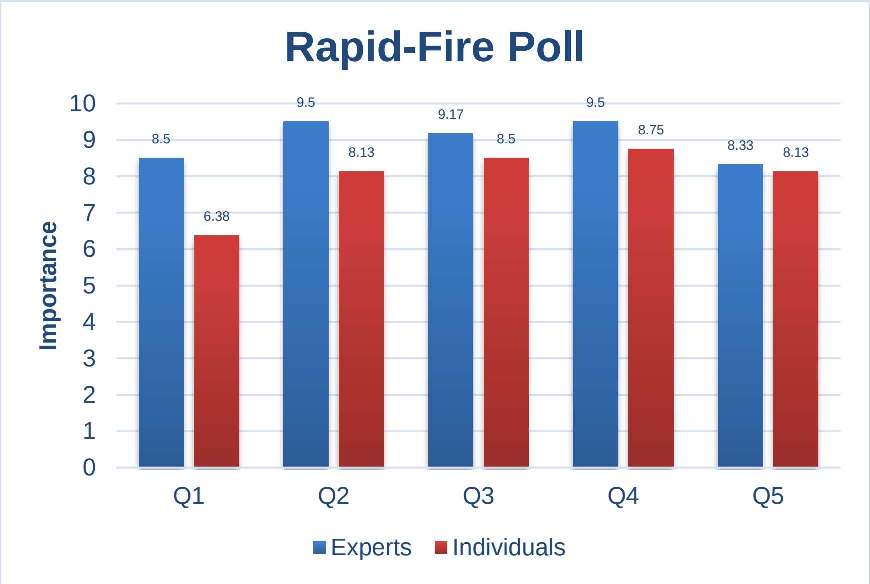

Figure 33. The collated responses of thesis interviews.

In other words, it is vital that the experts of the field continue to educate citizens and authorities regarding the potential of photovoltaic technology. Reaching a common level of know-how is necessary for supporting the advancement of renewables, and this would provide the nation a chance to distinguish itself as a frontrunner of the energy pioneers.

5 Over and Beyond Analysis

During the interviews, the experts pointed out inspiring observations from the analysis they had conducted on the current energy environment. Many openly gave their thoughts upon improvements on the many possibilities that are on the surface today. Often, I was given a peek into the future by the professionals with great insight into the energy field. Therefore, these intriguing ideas and principles will be further looked into in chapter five.

5.1 Observations

Globally, the bulk of PV production has moved to China where it increases with giant leaps. In the past, the nation has struggled with air pollution and this has greatly highlighted the cleanliness-benefits from renewable energy. This progression can also be seen in the IEA’s 2019 report on the “Trends in Photovoltaic Applications” which ranked the current leaders of the PV-market. The study situates China as number one by a staggering margin and for the sixth year in a row, as seen in figure 34 below [96].

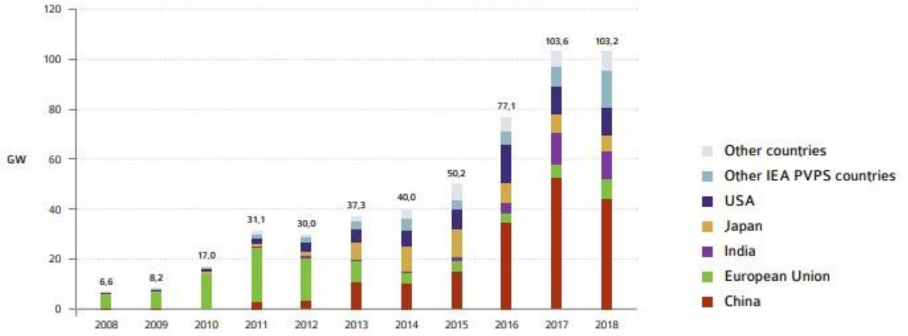

Figure 34. The cumulative PV capacity worldwide by 2018/ IEA [97].

By the numbers of 2018, the cumulative PV capacity in the world is now 512.3 Gigawatts. Of this number, the biggest shareholders are China with 175 GW, USA with 62.5 GW, Japan with 56.1 GW, and Germany with 45.5 GW. On the other hand, for perspective, Finland had the capacity of 0.134 GW of cumulative PV installed by the time [98].

5.2 Improvements

Many professionals agree that the greatest hindrance to a wider adaptation of solar technology is the legislation in Finland. Apartments that house 2.6 million Finns must be freely allowed to enter the PV market. Additionally, if authorities were to take heed of the German model of feed-in tariffs and introducing better subsidies, an earlier transfer to renewable energy forms would be possible. This would also make the transfer less chaotic and expensive than if the impacts of climate change are allowed to escalate further. If wisely harnessed, renewable energy could also be used to boost the global economy while also meeting the climate targets, writes Jillian Ambrose. She highlights how a report by the International Renewable Energy Agency has found that a return of $3 to $8 would be collected on every dollar invested in renewables by 2050. These gains would come from new jobs in the field, improved health and welfare scores by reducing toxins in the air, as well as reduced expenses of the climate change, such as subdued damages by wildfires and flooding in different locations [99].

In attempts to increase the portion of solar energy in the market, solar thermal technology should not be forgotten. Even if the technology's overall annual performance lies below that of the photovoltaic technology, it is simply an uncomplicated and affordable system to lower the dependency on less sustainable energy. One analyst lamented how solar thermal technology has suffered from a bad reputation although great performance can be acquired by a hybrid-system which can be a configuration of two parallel power sources, for example with a solar thermal system with a heat pump, or, especially, with district heating. This remark is supported by Karoliina Auvinen from Aalto University who wrote that solar thermal technology is economical in Finland if the dimensioning is done in the most optimal manner [98].

It is evident now that man can exist in a world that runs on cleaner principles than in the past. An unusual regarding COVID-19 is its benefits. Immediately it has to be strongly underlined that this train of thought is not meant to disregard or belittle the suffering of those whose lives have been greatly impacted by the global pandemic and are going through the most turbulent times after the millennium. These thoughts are pondered purely from and within the energy production industry's vantage point. Nonetheless, when touching such a sensitive topic, these restrictions need to be addressed.

The climate change is real, writes Damian Carrington in The Guardian. [100] However, its magnitude and effects are still being argued, while not even considering the methods of intervention. Today, we have seen an unprecedented period of industrial times when massive factories have been standing at a halt, population movements have been restricted whether traveling by foot, car, ship, or aircraft, and daily consumption has fallen by an astonishing margin. Hence, the flow of consumables, of which 95% are at the end of their lifespan within 6 months, has also dried up momentarily, according to one of the interviewed experts. Nonetheless, the world still operates, and the sun rises every morning. This indicates that even policies that momentarily slow production-rates could, after all, be implemented with minor impacts. Reporter Jillian Ambrose goes as far as stating that “Green energy could drive Covid-19 recovery with $100tn boost”. This bold claim was attributed to the International Renewable Energy Agency which had stated the invention would pay itself back manifold by 2050 [99].

5.3 Future

The sun provides an abundant source of energy that has been yearned after since the dawn of civilizations. As established in section 1.1, the first records of utilizing this power date back to ancient Greece. Since then, man has slowly learned to harness some of that power through methods of science. Despite the extensive development period of PV technology, even the modern scientists who are currently mapping the universe still struggle to convert the power of the rising sun to usable power. Yet, it needs to be noted that there has been a significant improvement in the efficiency of the derivatives of this technology over the past 20 years. Nonetheless, it is evident that technological progression will continue to thirst for further investments and research in order to advance. Therefore, in the following paragraphs, three key questions and viewpoints will be analyzed to conclude how to prepare the road for wider solar technology adoption and hence adaptation.

The first question in seeking wider audiences for adopting new energy forms is whether the method is upscalable or not? Solar power is advantageous in providing the opportunity to self-govern one’s full energy-cycle. This enables shifting the production from the centralized commercial market to private and dispersed production nodes that might not even have a main grid connection. This practice would also enhance resiliency when these nodes would be fully self-reliant. According to one industry expert interviewed, this concept of energy-ownership has been seen causing a movement from hourly-paid consumption (kilowatt-hour) to quarter-consumption, meaning the consumption being metered in 15-minute intervals. This would allow nimble jumps from provider to another in the quest for the lowest price. As the financial markets and stock companies have done for decades, this could be entrusted in the hands of a lightning-fast AI in the future.

The second question is, what materials should be used? These choices have many deterministic implications on the final product since the components will directly influence the final price of the end-product. The price for the general public, which has been deemed an insurmountable issue for some potential investors by this thesis, should not be forsaken in the pursuits of new technology. For instance, when the NREL's Six-Junction solar cell currently performs at 47.1% efficiency, but the average consumer affordable systems perform around 20% efficiency, it is evident how the increased performance through embedded astronomical costs renders such technology implausible ever being used for private production. However, commercial utilization is still a viable possibility with the proposal of concentrating sun rays. Nonetheless, the end of life use of these high-end products is an obscure matter. Conversely, the common panels of silicon and aluminum use abundant resources yet are relatively easy to recycle.

Third, considering the whole lifecycle of the products is sustainable thinking. As mentioned before, silicon and aluminum are commonly available resources in nature, yet they currently leave to be desired in the aspect of performance. These materials still require a substantial amount of engineering which increases the production cost. On the other hand, one of the experts who was interviewed suggested that the lifespan of current technology designs is 30-40 years, with warranties up to 25 years, which has appealed to clients and manufacturers relying on them. They trust that a suitable recycling solution will be available at some point in the future. Nevertheless, the number of components and materials in a solar panel is increasing which makes the product harder to recycle. Similarly, making panels easier to recycle will also increase the cost when utilizing the contemporary know-how and technologies available. However, these two dependencies are presented to emphasize how cheap does not equal to best or sustainable either. In 2016 [101], Nashon Okowa related a famous quote from NASA astronaut John Glenn regarding his feelings in the spacecraft during the flight:

> "As I hurled through space, one thought kept crossing my mind…every part of this rocket was supplied by the lowest bidder!"

An industry analyst interviewed related how studies reveal that the markets, after having relied on the most affordable products for a while, show an increase in less pleasant incidents involving the said products. Such occurrences have already taken place in more mature PV markets and entail an increase in the number of maintenance providers and end-of-life services, such as secondhand-markets. The analyst says this is going to happen in Finland as well. Elsewhere, this development has resulted in re-adopting the high-quality approach. He further elaborates how this has led to the rise of monitoring and management equipment and has promoted the IoT (Internet of Things) technology. Subsequently, this has promoted further development of AIs that optimize energy networks in the full-auto mode. In other words, there has been a movement from the invest and forget thinking to invest and optimize, the analyst continues. In addition, another analyst who participated in the study expects a shift from the Passive House buildings to the Active House -model, where buildings actively produce energy for the markets, is gaining traction abroad while not having reached Finland yet. All else equal, he thinks there will be further growth in the production capacity of photovoltaics in the future as well, regardless of the direction taken. Both of these experts conclude that continuing to invest in the development is necessary to collect data for the basis of good decisions. They suspect, even sustainable climate-policies are cheaper now than after a full-on escalation of the climate change.

6 Conclusions

This thesis-project has verified that the global markets for photovoltaic technology have been expanding exponentially and solar power is here to stay and grow. Yet, with the support, subsidies, and scientific progress the future horizons will remain sun bright. This path will secure sustainable growth alongside economic success.

The final year project showed that many individuals are interested in renewable energy today. In the PV market, some potential clients are deeply interested in advanced solar technology and BIVPs (building integrated photovoltaics), but upon price-reveal, the regular systems are suddenly often selected to lower the investment. Especially in Finland, there are a myriad of solar enthusiasts who are seriously considering PV systems but simply want a better return for their investment. One interviewee said they live in an apartment and are not interested in adopting solar power in the current legislative environment, yet, they feel that the practice is of great importance and would revise the opinion should there be some drastic changes to the policies.

6.1 Support, Subsidies, and Science Ensure Future Advancement

After the initial introduction, solar systems have become more feasible as an energy source since 2015 and 2016, causing the price of the technologies to sink. An expert interviewed for the study states that the system prices have fallen nearly 80% in five years and will continue to fall “close to zero”. However, another solar expert interviewee points out how the price of the equipment is lower but the price for installation has remained a constant. He says that after substituting the efficiency expectations and the most evident gains in the equation, it is unlikely that man will ever get to see industrial or large-scale commercial PV-production in Finland, except for experimentally. Hence, developing storage capacity is a vital priority, since currently 90% of power is now fed in the main grid. Hence, stronger support measures have to be devised to nurture the adoption of appropriate renewable sources and scientific research.

An author of energy literature interviewed suggested that one of the reasons for the late increase in PV production capacity in Finland can be explained by the cheaper electricity price. In the past, Germany had 2-3 times higher prices per kilowatt-hour of power compared to Finland, but since then the Finnish market prices have risen constantly, he explains. This can be attributed to increasing transfer-fees that could further be explained by upgrades on the main grid, costs of burying vulnerable air-cables underground, and general price-developments in the global economy. Nevertheless, it has led to the PV market in Finland to boom 10-15 years later than some parts of Europe he concludes.

To support this positive evolution of growth, reaching a common level of understanding on all levels of society is paramount. This can be grasped by carrying on with education and advising of the individuals outside the immediate field of renewable- and solar energy production. Additionally, the government-guided programs and subsidies play a major role in bringing the fruits of these technologies to hang lower for citizens to reach. Therefore, as stated before, it is vital to provide sufficient funding for scientific research to advance the applications of power that have been proven to attract the attention of contemporary citizens. Moreover, removing and revising laws and regulations that hinder the utilization of these applications should also be prioritized. In the future, the views of this thesis can be studied further with more abundant time-resources. Such studies could analyse the subject further, for instance, by extending the pool of participants to authorities and examine the past and current policies, to provide additional perspectives.

6.2 Promoting Economic Growth and Sustainable Future Together is Possible

Currently, man stands at an intersection. Traditionally, the most popular choice is not always the best in retrospect, or more sustainable. Today, the second option available is to choose quality over quantity, which inevitably comes with a price-tag. Nonetheless, by not compromising quality, safety, lifespan, or recyclability, a time when products last a lifetime, without wasting resources or materials, can be closer than it seems.

An argument stating that the manufacturing of items cannot be allowed to suffer on behalf of new energy practices and policies seems weak. So far, despite the implications of the COVID-19 pandemic, the world is not in a chaos but slowly recovering. This moment of slower consumables production has provided a breather for nature as well. By now, many have seen the pictures and heard the news of astounding improvements in air quality in the U.S, India, and China. These accounts by media, such as National Geographic, have aired around the world. Beth Gardner admires the fleeting moment of fresh skies world-wide. [102] It is unlikely that this little breather would bring the world together to adopt new climate-policies immediately based on this positive yet single experience alone [103;104].

Mutual accords on fabricating decisive climate-policies for the future will not be accomplished over-night. However, the COVID-19 situation presents an opportunity for all sides to resituate themselves after being provided with this new set of data. It truly seems that the capability of adjusting exists, but will there be enough collective readiness to commit for a shared goal of a more sustainable future? The global convections are slow to change yet this unlikely down-time experiment shows the immediate benefits from it.

By being bigger individuals, the people of today can reach new heights and make better decisions than earlier generations. This is possible only by building upon their hard work and tough lessons learned. Yet, this presented opportunity must be further seized by shouldering the inconveniences and the price equally. Only this allows building a wide-enough base that will enable realizing tomorrow's climate-goals faster. If nations can unify after the great halt of the world by COVID-19, tremendous future horizons can be grasped by advancing renewable energy, interim promoting economic success together with the more sustainable future.

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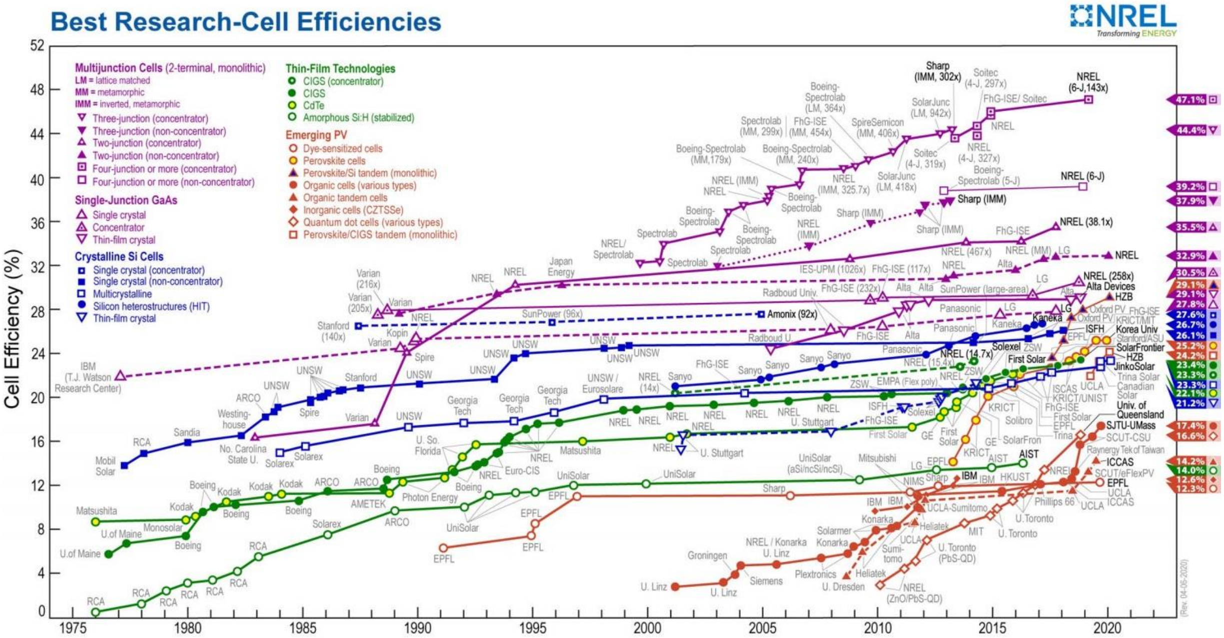


Companies/Institutions

Label	Full Name (If Different from Label)
AIST	National Institute of Advanced Industrial Science and Technology
Alta	Alta Devices
AMETEK	
Amonix	Amonix Inc.
ARCO	Atlantic Richfield Company
ASU	Arizona State University
Boeing	The Boeing Co.
DGIST	Daegu Gyeongbuk Institute of Science and Technology
EMPA	Swiss Federal Laboratories for Materials Science and Technology
EPFL	École Polytechnique Fédérale de Lausanne
EuroCIS	
FhG-ISE	Fraunhofer Institute for Solar Energy Systems
FirstSolar	First Solar Inc.
GE	
Georgia Tech	Georgia Institute of Technology
Groningen	University of Groningen
Heliatek	
HKUST	Hong Kong University of Science and Technology
HZB	Helmholtz-Zentrum Berlin
IBM	International Business Machines
ICCAS	Institute of Chemistry–Chinese Academy of Sciences
IES-UPM	Instituto de Energía Solar–Universidad Politécnica de Madrid
ISCAS	Institute of Semiconductors–Chinese Academy of Sciences
ISFH	Institute for Solar Energy Research Hamelin
Japan Energy	
Kaneka	Kaneka Solar Energy
Kodak	
Konarka	Konarka Technologies Inc.
Kopin	Kopin Corp.
KRICT	Korea Research Institute of Chemical Technology
LG	LG Electronics
Matsushita	
MIT	Massachusetts Institute of Technology
Mitsubishi	Mitsubishi Chemical Corp.
Mobil Solar	
Monosolar	Monosolar Company Ltd.
NIMS	National Institute for Materials Science
No. Carolina State U.	North Carolina State University
NREL	National Renewable Energy Laboratory
Oxford	
Oxford PV	
Panasonic	
Phillips 66	
Photon Energy	
Plextronics	Plextronics Inc.
RadboudU	Radboud University
Raynergy	
RCA	
Sandia	Sandia National Laboratories
Sanyo	Sanyo Electric Company Ltd.
SCUT-CSU	South China University of Technology - Central South University
SCUT-eFlexPV	South China University of Technology - eFlexPV
Sharp	Sharp Solar
Siemens	
Soitec	
Solarex	
SolarFron	Solar Frontier
SolarJunc	Solar Junction Corp.
Solarmer	
Solexel	
Solibro	Solibro GmbH
Spectrolab	Spectrolab Inc.
Spire	
SpireSemicon	Spire Semiconductor LLC
Stanford	Stanford University
Sumitomo	Sumitomo Chemical Co. Ltd.
SunPower	SunPower Corp.
Tek of Taiwan	
Trina	
U. Dresden	University of Dresden
U. Linz	University of Linz
U. Maine	University of Maine
U. Queensland	University of Queensland
U. So. Florida	University of South Florida
U. Stuttgart	University of Stuttgart
U. Toronto	University of Toronto
UCLA	University of California, Los Angeles
UniSolar	
UNIST	Ulsan National Institute of Science and Technology
UNSW	University of New South Wales
UNSW/Eurosolc	
Varian	Varian Semiconductor
Westinghouse	
ZSW	Zentrum für Sonnenenergie- und Wasserstoff-Forschung Baden-Württemberg (Centre for Solar Energy and Hydrogen Research Baden-Württemberg)

D3, The Finnish Building Code Collection of 2012, Ministry of Environment.

D3 Suomen rakentamismääräyskokoelma
Ympäristöministeriö, Rakennetun ympäristön osasto

Rakennusten energiatehokkuus

Määräykset ja ohjeet 2012

2/11
Ympäristöministeriön asetus
rakennusten energiatehokkuudesta

Annettu Helsingissä 30 päivänä maaliskuuta 2011

Ympäristöministeriön päätöksen mukaisesti säädetään 5 päivänä helmikuuta 1999 annetun maankäyttö- ja rakennuslain (132/1999) 13 §:n nojalla rakentamisessa sovellettaviksi seuraavat määräykset ja ohjeet rakennusten energiatehokkuudesta.

Määräykset ja ohjeet on ilmoitettu teknisiä standardeja ja määräyksiä ja tietoyhteiskunnan palveluja koskevia määräyksiä koskevien tietojen toimittamisessa noudatettavasta menettelystä annetun Euroopan parlamentin ja neuvoston direktiivin 98/34/EY, sellaisena kuin se on muutettuna direktiivillä 98/48/EY, mukaisesti.

Tämä asetus tulee voimaan 1 päivänä heinäkuuta 2012 ja sillä kumotaan ympäristöministeriön 22 päivänä joulukuuta 2008 antama asetus rakennusten lämmöneristyksestä ja ympäristöministeriön 22 päivänä joulukuuta 2008 antama asetus rakennusten energiatehokkuudesta. Ennen asetuksen voimaantuloa vireille tulleeseen lupahakemukseen voidaan soveltaa aikaisempia määräyksiä ja ohjeita.

Helsingissä 30 päivänä maaliskuuta 2011

Asuntoministeri *Jan Vapaavuori*

Yli-insinööri Pekka Kalliomäki

Euroopan parlamentin ja neuvoston direktiivi 2010/31/EU (32010L0031); EUVL N:o L 153, 18.6.2010, s. 13

Taulukko L2.2 Säätiedot laskentaa säävyöhykkeellä I ja II. Helsinki-Vantaa.

Kuukausi	Ulkoilman keskilämpötila, T_u, °C	Auringon kokonaissäteilyenergia vaakatasolle, $G_{aur,vaakataso}$, kWh/m²	Normitilanteen käytettävä lämmitystarveluku, S17, Kd
Tammikuu	-3,97	6,2	650
Helmikuu	-4,50	22,4	602
Maaliskuu	-2,58	64,3	607
Huhtikuu	4,50	119,9	354
Toukokuu	10,76	165,5	117
Kesäkuu	14,23	168,6	9
Heinäkuu	17,30	180,9	0
Elokuu	16,05	126,7	31
Syyskuu	10,53	82,0	161
Lokakuu	6,20	26,2	331
Marraskuu	0,50	8,1	495
Joulukuu	-2,19	4,4	595
Koko vuosi	5,57	975	3952

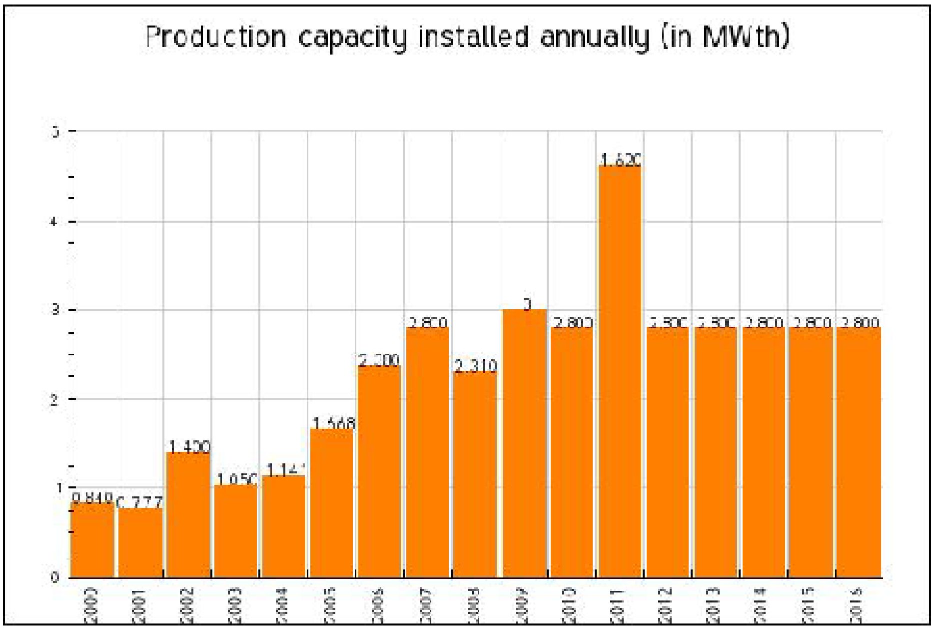
	Auringon kokonaissäteilyenergia pystypinnoille eri ilmansuuntiin, $G_{aur,pystypinta}$, kWh/m²							
Kuukausi	P	Ko	I	Ka	E	Lo	L	Lu
Tammikuu	6,2	4,7	3,8	9,5	12,9	9,5	3,8	4,7
Helmikuu	17,3	13,8	15,6	31,0	41,4	30,9	15,6	14,0
Maaliskuu	40,3	38,1	48,5	75,1	89,5	69,4	43,7	36,9
Huhtikuu	43,9	56,3	79,9	101,1	107,3	101,6	80,6	56,8
Toukokuu	57,8	82,1	112,8	123,3	116,0	117,5	104,5	76,3
Kesäkuu	70,6	87,9	109,6	109,9	101,6	110,9	111,2	89,1
Heinäkuu	66,3	91,1	118,8	123,1	115,5	128,6	122,7	91,2
Elokuu	50,0	66,4	91,8	106,0	100,4	92,8	78,8	61,1
Syyskuu	32,9	37,5	56,5	83,9	100,5	87,3	59,3	38,1
Lokakuu	17,9	15,6	17,5	28,3	37,0	30,0	18,8	15,7
Marraskuu	7,2	5,5	5,1	12,3	16,8	12,3	5,1	5,6
Joulukuu	4,2	3,2	2,6	8,4	11,8	8,8	2,9	3,2
Koko vuosi	414,6	502,2	662,5	811,9	850,7	799,6	647,0	492,7

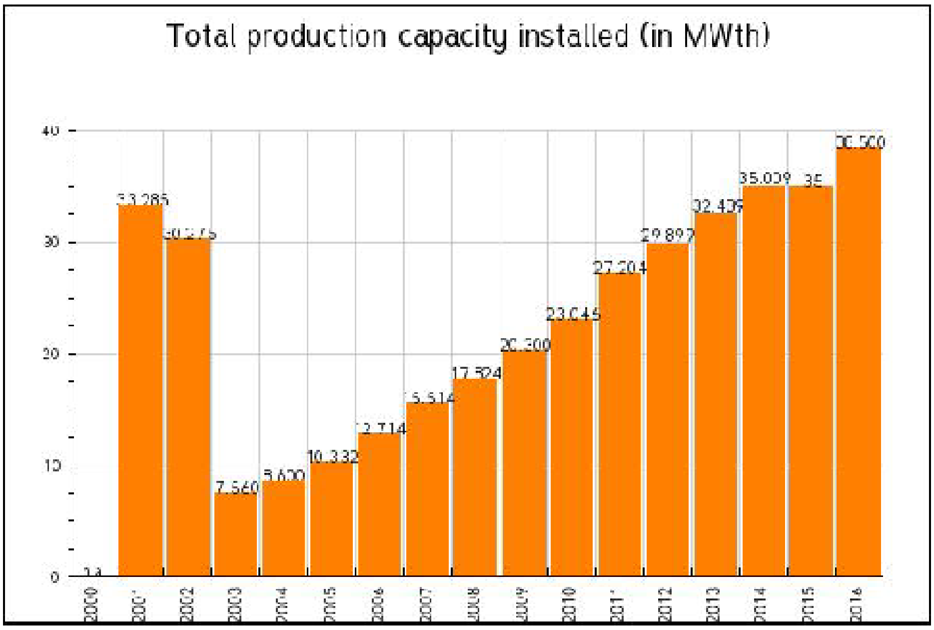
	Muunnoskerroin F_{muunto}, jolla vaakatasolle tuleva auringon kokonaissäteilyenergia muunnetaan pystypinnalle tulevaksi kokonaissäteilyenergiaksi eri ilmansuunnissa							
Kuukausi	P	Ko	I	Ka	E	Lo	L	Lu
Tammikuu	0,995	0,757	0,609	1,531	2,080	1,519	0,605	0,759
Helmikuu	0,774	0,618	0,700	1,387	1,854	1,381	0,700	0,624
Maaliskuu	0,627	0,592	0,754	1,169	1,392	1,079	0,679	0,574
Huhtikuu	0,366	0,470	0,666	0,843	0,895	0,847	0,672	0,474
Toukokuu	0,349	0,496	0,681	0,745	0,701	0,710	0,632	0,461
Kesäkuu	0,419	0,521	0,650	0,652	0,602	0,658	0,659	0,528
Heinäkuu	0,367	0,503	0,657	0,681	0,639	0,711	0,679	0,504
Elokuu	0,395	0,524	0,725	0,837	0,793	0,732	0,622	0,482
Syyskuu	0,401	0,457	0,689	1,023	1,225	1,064	0,723	0,465
Lokakuu	0,683	0,595	0,670	1,081	1,412	1,144	0,718	0,598
Marraskuu	0,888	0,683	0,632	1,519	2,068	1,519	0,633	0,686
Joulukuu	0,920	0,697	0,571	1,850	2,615	1,942	0,637	0,697
Koko vuosi	0,425	0,515	0,679	0,833	0,872	0,820	0,663	0,505

30

Solar Energy Trends in Finland: Solar Thermal 2000 – 2016, Euro Observer.

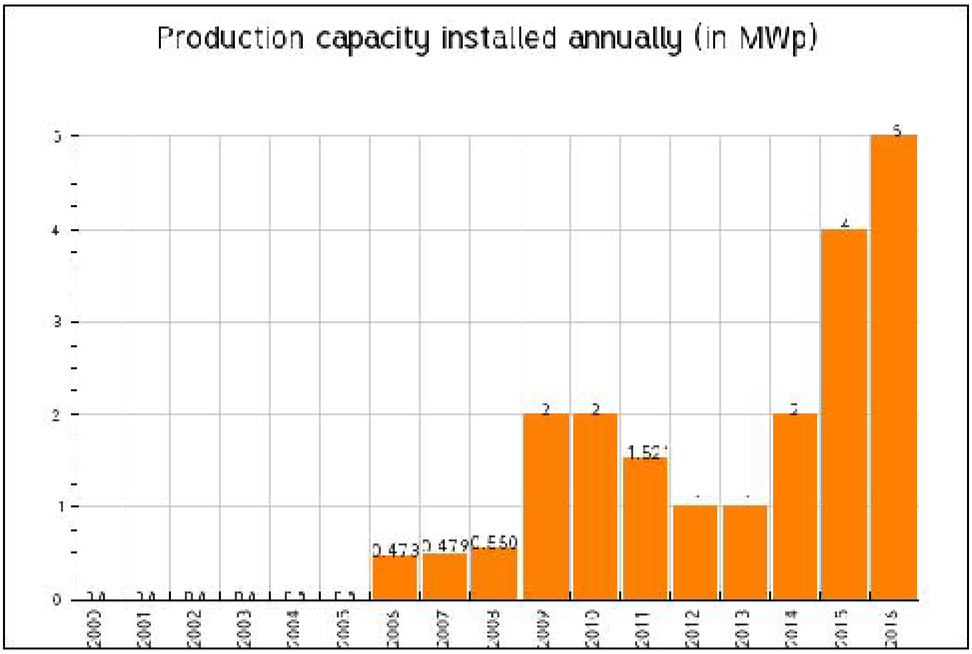
Finland
Total Solar thermal
From 2000 to 2016

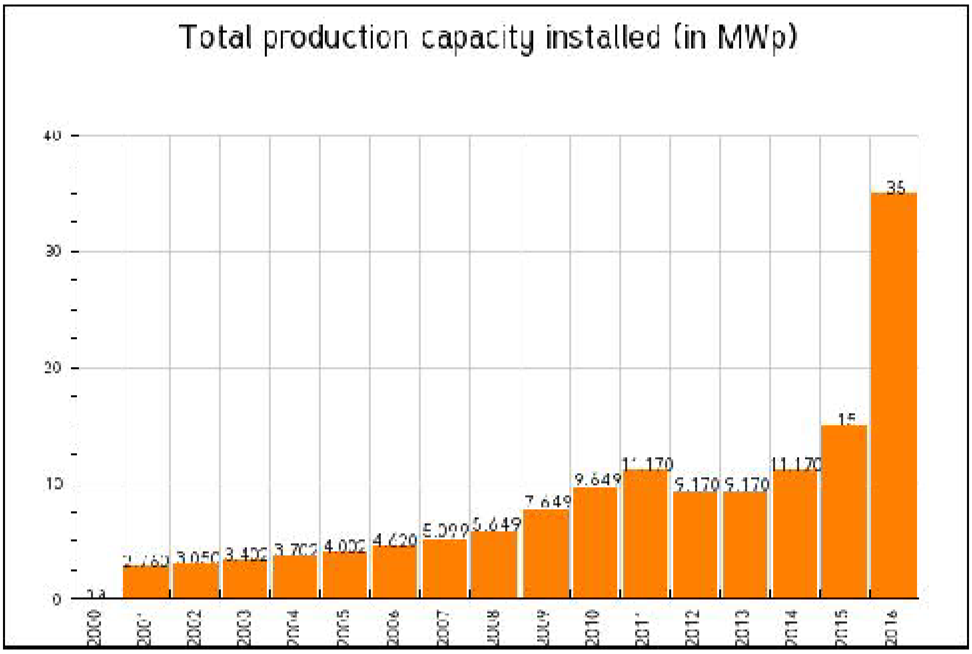




Solar Energy Trends in Finland: Photovoltaics 2000 – 2016, Euro Observer.

Finland
Total Photovoltaic
From 2000 to 2016





Questionnaire for Bachelor's Thesis Interviews.

Oskari Rentola
4/2020

Questionnaire

This questionnaire is composed to provide material for a bachelor's thesis at Metropolia University of Applied Sciences. The information collected will be presented at theseus.fi online-environment for further studying and research. All names and identifications will be removed upon publication.

	Answers	Notes
Name		
Company		
Position		

1. What do you think about solar photovoltaics and their development in the world?		
2. Do you believe this is a source of energy for the future?		
3. What are the major improvements in the technology that have led/ would lead into wider implementation? -> 2000: efficiency around 12-15% (crystalline silicon) -> 2020: over 20% -> The price per kW has also decreased to less than a fifth (Amos Han, Lafayette College, US)		
4. What are the most implemented configurations today/ what kind of system would you have?		
5. Do you know any Finnish companies working in the field(s)? -> what do you think about their prospects in the market		
6. "Any last words"? -> vapaa sana		

The Rapid-Fire Poll: Section 7 of the interviews

Oskari Rantala
4/2020

7. Rapid-fire poll:		
	In scale of (1-10)	Notes
1) Do the talks about global warming worry you?		
2) Do you think we need to decrease our CO2-footprint?		
3) Do you believe PVs would be of help with the goal?		
4) Do think the technology has still room to develop		
5) Would you consider installing PVs for your own residence?		

Do you know someone else who would like to participate?

The Interview Results: The sheet of analysis.

Participant	Q1	Q2	Q3	Q4	Q5
Expert 1 (JN)	5	8	7	10	5
Expert 2 (TT)	10	10	8	7	10
Expert 3 (JK)	10	10	10	10	10
Expert 4 HH	9	9	10	10	10
Expert 5 (RK)	7	10	10	10	5
Expert 6 (PL)	10	10	10	10	10
Average	8.50	9.50	9.17	9.50	8.33
Individual 1 (ET)	6	5	9	10	8
Individual 2 (PS)	6	10	10	7	10
Individual 3 (HP)	5	8	8	7	6
Individual 4 (JPJ)	6	8	10	8	8
Individual 5 (VS)	6	9	7	9	6
Individual 6 (LK)	7	8	8	10	10
Individual 7 (LB)	9	10	8	10	9
Individual 8 (MP)	6	7	8	9	8
Average	6.38	8.13	8.50	8.75	8.13