TECHNO-ECONOMICALLY OPTIMIZED RENEWABLE ENERGY NETWORK DESIGN FOR HOUSEHOLDS IN FINNISH WEATHER CONDITIONS

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ABSTRACT

The background to this thesis is related to Finnish households' energy consumption. It is recorded by Statistics Finland that in 2015, the electricity used in housing amounted to 61 terawatt hours (TWh). Most of the electricity is used for space heating and heating of domestic water, the rest is used for cooking, lighting or other electric devices. According to the difference in usage percentage and Finnish weather conditions, it is easy to find out that the use of electricity does not stay constant throughout the year. Electricity consumption raises during winter and is reduced eventually when the weather gets warmer. Therefore, it is essential to examine and take into use ren. energy systems as well as taking renewable energy systems into use to ease the urge of saving electricity in peak seasons and to reduce the high amount of carbon dioxide emissions by producing electricity from fossil fuels sources.

The goal of this project was to evaluate the possibility of designing a reliable techno-economical electrical grid by using wind turbines and Solar photovoltaic power. The study aimed to examine whether it was viable to use renewable energy sources to produce enough electricity that can feed on intermediate – large scale a household neighborhood in Finnish cold climates. The project work was divided into sperate parts: technology, technology working environment and economic issues. Basic operation principles of wind and Solar photovoltaic power, energy storing, and energy converting were focused in the technology part. The current situation, challenges and potential of these renewable energy sources in the Finnish energy market are focused on this thesis. Also, climates, wind flows, Solar irradiance in the entire country were also studied in order to evaluate the feasibility of the project. There was also an economic analysis made to comprehend the profitability of using an electricity grid that produces electricity from renewable energy sources.

The thesis was initiated by studying literature from various sources. Variable sources were studied, such as annual reports from energy authorities, scientific articles for renewable energy resources uses, and conference proceedings that were related to the research objectives…
In this project, mathematics and physics related knowledge was used in making calculations, critical thinking and information analysis were applied when designing the

energy network, engineering design and some other statistics related knowledge was also examined.

Keywords Energy system design, renewable energy, energy network, Finland, development, carbon – neutral

Pages 95 pages including appendices 18 pages

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1 BACKGROUND TO PROJECT

The EU and the Finnish national Greenhouse Gas emission and Carbon dioxide emission reduce targets for 2020, 2030 and 2050 play a critical role in promoting renewable energy resources, like solar photovoltaic energy and wind power energy. (Energy and Climate Roadmap 2050 –Report of the Parliamentary committee on Energy and Climate Issues on 16 October 2014, 2014). As renewable sources-based electricity is a Greenhouse emission free method to generating electricity, wind power and solar photovoltaic energy offered to achieve these goals in the future. Although the current situation of renewable energy use in Finland has not been utilized, with the support from society and government subsidies, it is expected that renewable energy in Finland will take off in a very short time.

Due to the difficulties provided by high latitude, cold climate and low temperatures nature of Finland, developing Wind Power has encountered a lot of challenges. Severe icing and low air temperature that may lead to partial or total system shutdowns or damages for the wind turbines. However, many standard requirements and solutions for those obstacles has been stated and in its way for further enhancement. Eventually, with all the support from scientific technology aspect, and from the authority, wind power will maintain its status in energy market and processing to raise to better heights.

It is always assumed that solar photovoltaic technology cannot be developed and applied to Finnish environment. All the natures factors like long, cold and dark winter, interrupted of unstable amount of solar irradiance during seasonal changes, has against the use of Solar photovoltaic. However, in this research, we have studied and collected information and data to prove that the potential of solar energy in Finland is feasible, and it has many opportunities to grow more in Finnish energy market.

Understanding the climate characteristics and electricity consumption demands, the project has carefully calculated and finally come up with two possibility of electricity set ups. In which the first scenario case has been decided to be the final design of the project. The set-up uses both wind power and Solar photovoltaic system mechanism so that the grid productivity is utilized, also, it is made sure that the grid itself is cost effective and environmentally friendly.

Financial calculations and economic analysis were done in purpose of showing the viability of the project designed grid.

We have met many difficulties while doing research work for the project. In searching for information and systematic data of Solar power in Finland since this technology is not yet well known and popular in national level. Lacking reliable sources has forced us to study harder to look up for the necessary data and index. As a result, we have learnt much more about Solar photovoltaic technology than we have ever expected. Moreover, although most of the report and reference proceeding that in scale of national level about energy are available in English, some that contains valuable information, unfortunately, are only in Finnish, this is one of the most challenging problems that we met, since it required lots of time and efforts to translate and to look for the desired data as well as to comprehend its meaning in a language that is unfamiliar.

2 INTRODUCTION

2.1 Background

The world currently relies heavily on fossil fuels such as natural gas, charcoal, oil… for its energy. However, these above-mentioned energy resources are non - renewable, which means, they will eventually be drained out, becoming too expensive and especially environmentally over damaging to retrieve. Fortunately, there are variable types of renewable energy resources available, waiting to be exploited and developed for a better, cleaner future. Thus, by working on this thesis, we hope to imply renewable energy into a realistic techno – economically optimized renewable energy network design for households in Finland, based on Finnish weather condition.

As Finland is known to be one of the world's leaders in renewable energy sources use. By the end of 2015, the proportion of electricity production by renewable sources has reached 45%, surpassed the government goal and is predicted to be continued of powerfully strive to new heights in Finnish energy market. The objective of the national energy and climate strategy is to create a Carbon – neutral society with minimum Carbon dioxide emissions. Therefore, the aim of the thesis project is considered as respect to the authority's renewable energy development goals.

In this project, we focused on studying the Wind Energy, Solar photovoltaic Energy Technology and their effectiveness in Finland. Climates, geographical locations, government and society support, impacts and benefits, or in general, factor that directly or indirectly affect to the growth possibility and developing potential of the mentioned renewable energy resources is researched and analyzed.

The first chapters consist of the theory parts, concepts such as solar photovoltaic, wind power, their applications and benefits, also operation principles and essential extra mechanisms for grid connection.

The research is presented in chapter 10. In which, the energy consumption circumstance in Finland is discussed. We concentrated in wind power and solar power's potential, opportunities, challenges and solutions. Available manufactures, solution suppliers and energy projects are also studied and analyzed.

Chapter 11 stated operation experience in Finnish climate characteristics, for example, icing conditions and low air temperatures. The damages and delays or losses of productivity caused by climate hazards of wind turbines that leaded to system shutdown is considered and conferred. In addition, solutions and requirements for wind turbines that tended to work in cold weather and icing climate were given.

Subsequently, based on the performance, subjective and objective factors and the electricity demand, we have come up with different set up cases for the designed electricity grid. Technical calculations are made in an excel file, the brief result will be attached in the thesis report appendix and the file shall be submitted to thesis supervisor.

In the final part of this thesis, a cost estimation and an economic analysis were made. Investment costs and the payback period is calculated. Feasibility of the projects is then evaluated.

2.2 **Renewable energy**

Renewable energy is the primary, domestic and clean or inexhaustible energy resources. These renewable resources are constantly replenished and will never run out, which means, the renewable energy lasts forever. There are many types of renewable energy, most of them comes either directly or indirectly from the sun. The well – known renewable energy resources that can be listed are Biomass, Hydro energy, Geothermal, Solar, Wind and Marine (AyhanDemirbas, 2005) . For example: sunlight (Solar energy) can be used directly for heating and lighting households, hot water heating, as well as tons of other industrial uses; meanwhile, heat that comes from the sun also drives the wind, whose energy could be captured with wind turbines and later on became wind power… In this thesis we focus on choosing Solar photovoltaic technology and wind energy since other sources of Solar energy are already popular in renewable energy market of Finland, we would like to do research and evaluate the possibility and feasibility of these potential yet not so well – used in Finland because of subjective stereotypes based on the Finnish weather conditions and the natural climate as well as the geographic location of the country.

2.3 **Why renewable energy**

Renewable energy is the key to a better world. It provides several benefits, such as:

- *Energy for our young generation*: renewable resources are infinite, within a limit, so do renewable energy

- *Environmental benefits*: renewable energy is clean, no environment pollutions, no environmentally damaging as when we used other non – renewable energy

- *Economy benefits*: most investment in renewable energy are spent on workmanship to create and maintain the facilities as well as on materials, rather than luxury energy imports (oil, gas…). This does not only help with economic growth but also offers more job opportunities

Because of those key benefits that renewable energy provides, it is believed to be a right step to plan and design techno – economically optimized renewable energy network for households in Finland.

3 DESIGN PROCESS

"Design can be defined in many terms depending upon the field of applications. In the engineering field, however, it is defined as the creative, iterative and often open-ended process of conceiving and developing components, systems and processes. Design requires the integration of basic engineering and mathematical sciences. A designer works under constraints, considering economic, health, safety, social and environmental factors of practice and applicable laws." (Engineering Design 2006, 131)

3.1 Problem approach (Electricity Consumption)

The problem is identified under the basis of needs and constraints of itself. In this thesis, the problem is defined as households' electricity consumption. During high peak seasons (winter), the electricity consumption in Finnish households raises since the need of heating increases. Thus, solutions for this problem is needed to ease the urge saving electricity and reduce air pollution during electricity produce. At this very beginning stage, detailed scope and objective of the method were generated and used as reference for further analysis.

3.2 Collecting information

To have a close approach to the current problems, a lot of information was needed in this project. Time was spent on gathering essential information in order to come up with significant solutions that is not only efficient but also cost-friendly. Information was collected from variable resources such as internet, journals, and other trust-worthy sources.

3.3 Solution analysis

Certain types of renewable energy were narrowed down and analysed to fit with the need of Finnish households, its weather condition, financial situation etc. Rough design of the network is discussed in this paper. Also costs of material, building and maintenance cost were taken into consideration in this project.

3.4 Solution selection

As the solutions are being generated and compared, they are ranked based on pros and cons they provide. After comparing, a final case is decided to be the chosen design.

4 WIND POWER

4.1 Fundamental

Wind power is one type of renewable energy. Wind power is obtained from harnessing the energy of the wind. The term “wind power” can be described in more details as the process by which the wind is used to generate mechanical power or electrical energy.

Wind power is a relatively new mode of electricity generation in Finland and has developed well in the last few years. Finland has the potential to increase wind power capacity considerably. At the end of 2014, there were 260 installed wind turbine generators, with a combined capacity of 627 MW. They generated 1,3% of Finland’s electricity consumption in 2014 according to *Finnish Wind Power Association*. (Finnish Wind Power Association, 2019)

4.2 Wind turbines (Wind power plant)

4.2.1 Definition

Unlike windmill or wind pump that covert the wind’s kinetic energy into mechanical energy to grind grains or pump water, wind turbines (also called wind power plant) is a device that convert wind’s kinetic energy into electrical energy.

4.2.2 Structure and operating principle

The appearance of a wind turbine is like an electric fan. However, wind turbine works the opposite way of the fan. Wind turbines use wind to make electricity instead of consume electricity to form wind. The power from the wind turns two or three propeller – like (depend on wind turbines type) blades around a rotor. The rotor is connected to the main shaft, which rotates a generator to produce electricity. The main components of basis wind turbines are:

- *Anemometer*: measures the wind speed and transmits wind speed data to the controller.
- *Blades*: lifts and rotates when wind is blown over them, causing the rotor to spin (most turbines have either two or three blades).
- *Brake*: stops the rotor mechanically, electrically, or hydraulically, in emergencies.
- *Controller*: starts up and shuts off the machine at required limited wind speed. Turbines do not operate at wind speeds above about 88,5 km/h because they may be damaged by the high winds.
- *Gear box*: connects the low-speed shaft to the high-speed shaft and increases the rotational speeds from about 30-60 rotations per minute (rpm), to about 1,000-1,800 rpm; this is the rotational speed required by most generators to produce electricity. The gear box is a costly (and heavy) part of the wind turbine and engineers

are exploring "direct-drive" generators that operate at lower rotational speeds and don't need gear boxes.

- *Generator*: produces 60-cycle AC electricity; it is usually an off-the-shelf induction generator.
- *High-speed shaft*: drives the generator
- *Low-speed shaft*: turns the low-speed shaft at about 30-60 rpm.
- *Nacelle*: sits atop the tower and contains the gear box, low- and high-speed shafts, generator, controller, and brake. Some nacelles are large enough for a helicopter to land on.
- *Pitch*: turns (or pitches) blades out of the wind to control the rotor speed, and to keep the rotor from turning in winds that are too high or too low to produce electricity.
- *Rotor*: blades and hub together form the rotor.
- *Tower*: made from tubular steel (as seen in Figure 1.), concrete, or steel lattice. Supports the structure of the turbine. Because wind speed increases with height, taller towers enable turbines to capture more energy and generate more electricity.
- *Wind direction*: determines the design of the turbine. Upwind turbines—like the one shown in Figure 1. face into the wind while downwind turbines face away.
- *Wind vane*: measures wind direction and communicates with the yaw drive to orient the turbine properly with respect to the wind.
- *Yaw drive*: orients upwind turbines to keep them facing the wind when the direction changes. Downwind turbines do not require a yaw drive because the wind manually blows the rotor away from it.
- *Yaw motor*: powers the yaw drive. (Abraham, 2014)

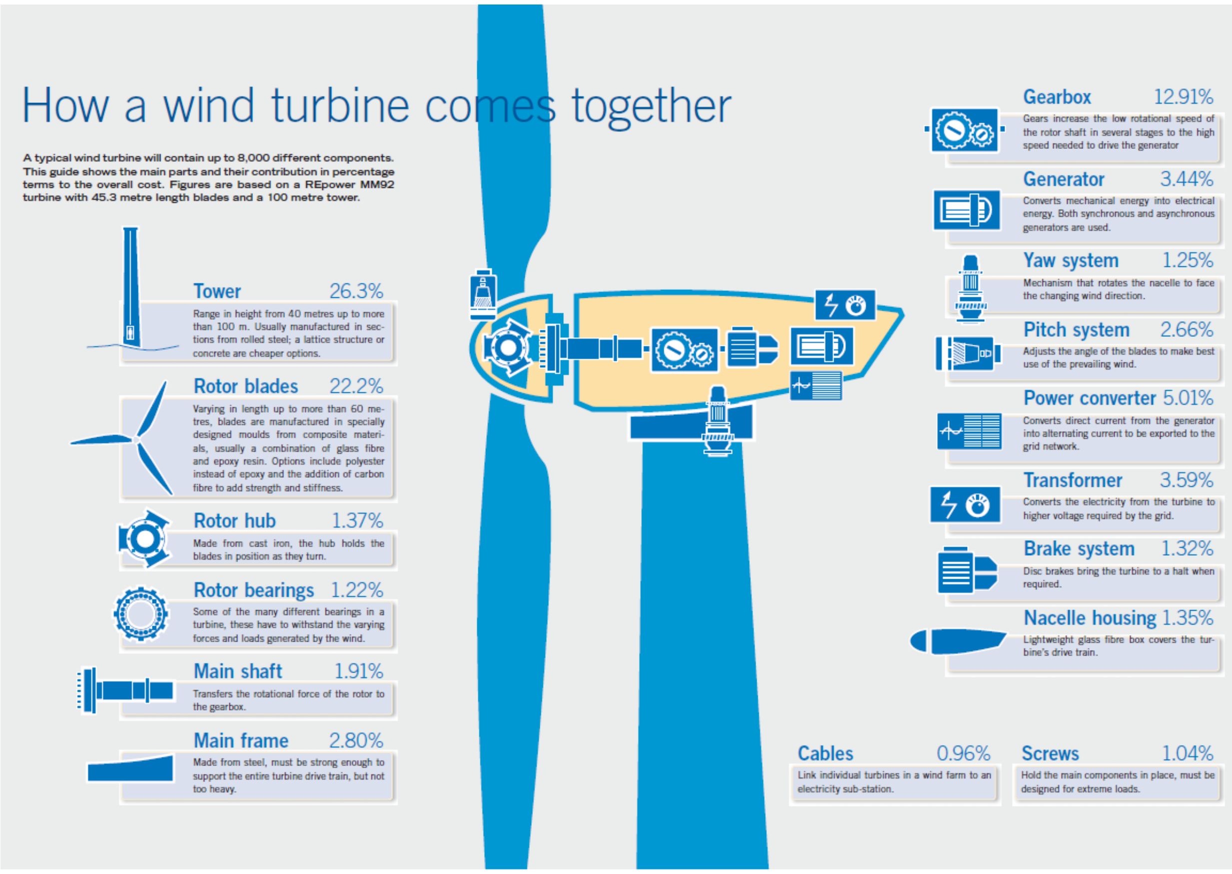


Figure 1. Inside a typical wind turbine (Morthorst & Awerbuch, 2009, p. 37)

4.2.3 Diverse types of wind turbines

In order to provide electricity for different use purpose, wind turbines vary in a wide range of types and sizes.

Modern wind turbines fall into two basic groups: the horizontal-axis variety, and the vertical-axis design, like the eggbeater-style Darrieus model, named after its French inventor. Horizontal-axis wind turbines typically either have two or three blades. These three-bladed wind turbines are operated "upwind," with the blades facing into the wind. Wind turbines can be built on land or offshore in large bodies of water like oceans and lakes.

Figure 2. Horizontal – axis wind turbine (Eolienne flexible, n.d)

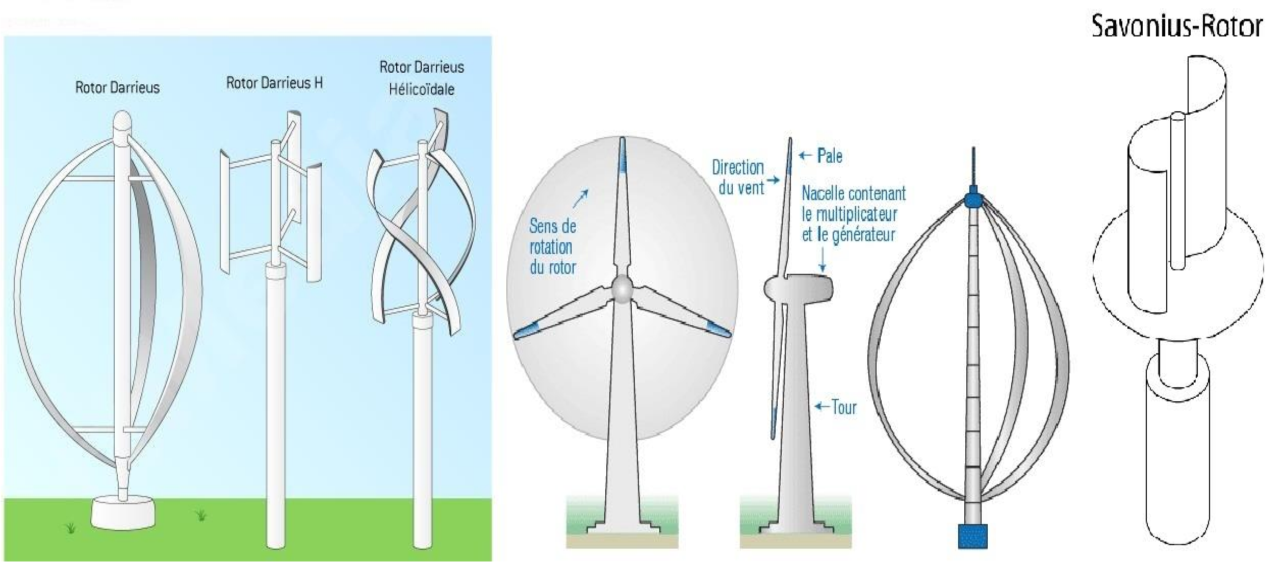


Figure 3. Eggbeater – style Darrieus model and Savonius wind turbine (vertical axis design) (Eolienne flexible, n.d)

The smallest wind turbines are used for traffic warning sign or auxiliary power for boats as battery charger or caravans. Single small turbines below 100 kilowatts are used for homes, telecommunications dishes, or water pumping. Small turbines are sometimes used in connection with diesel generators, batteries, and photovoltaic systems. These systems are called hybrid wind systems and are typically used in remote, off-grid locations where a connection to the utility grid is not available.

Utility-scale turbines range in size from 100 kilowatts to as large as several megawatts. Larger wind turbines are more cost effective and are grouped together into wind farms, which provide bulk power to the electrical grid.

Offshore wind turbines are larger, can generate more power, and do not have the same transportation challenges of land-based wind installations, as the large components can be transported on ships instead of on roads.

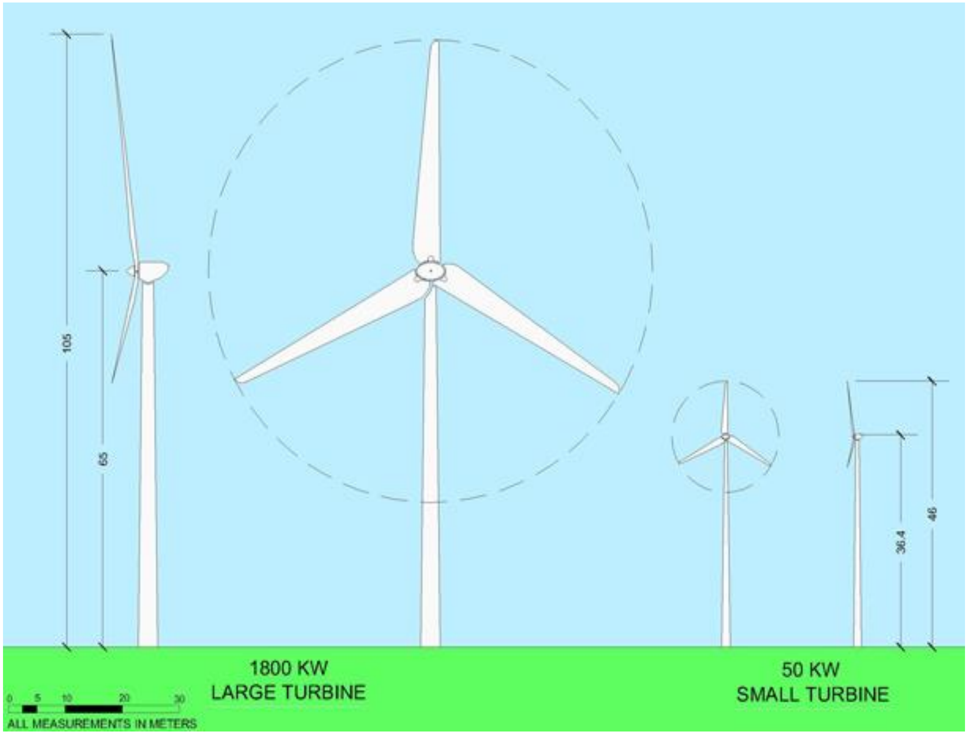


Figure 4. Diverse in sizing of wind turbines (Calgary, n.d)

4.2.4 Wind turbines comparison

When designing a grid, which stands alone and feeds energy for about 200 households on hourly, daily and seasonal needs, the energy available from the wind needs to be calculated. The reason for choosing the scale of the grid that is able to feed electricity for about 200 households is that we focused on a small to intermediate – scale project, and by choosing the mentioned project size, it satisfied the purpose and goal of the research. For that, it is reasonable to compare different wind turbines to get a clear picture of which kind of turbines are needed to get the best result in respect of power produced with sensible costs. Also, the available space, the power and the wind speed at which the turbine starts running had to be checked. For the wind turbines a lifetime expectancy of 20 years was used, and the maintenance cost expected to be 20% of the purchase price. By collecting technical data and then processing to take into comparison the wind turbines' performance, productivity and whether they are qualified and sufficient according to the project requirement. 4 wind turbines were used are AEZ12, Nordex N80/ 2500, V47/ 660 and Aeolos H-60kW. The comparison tables and charts could be found for further review in the attached excel file. Two wind turbines were taken into comparison after considering 4 different wind turbines in this case are:

- The EAZ 12:

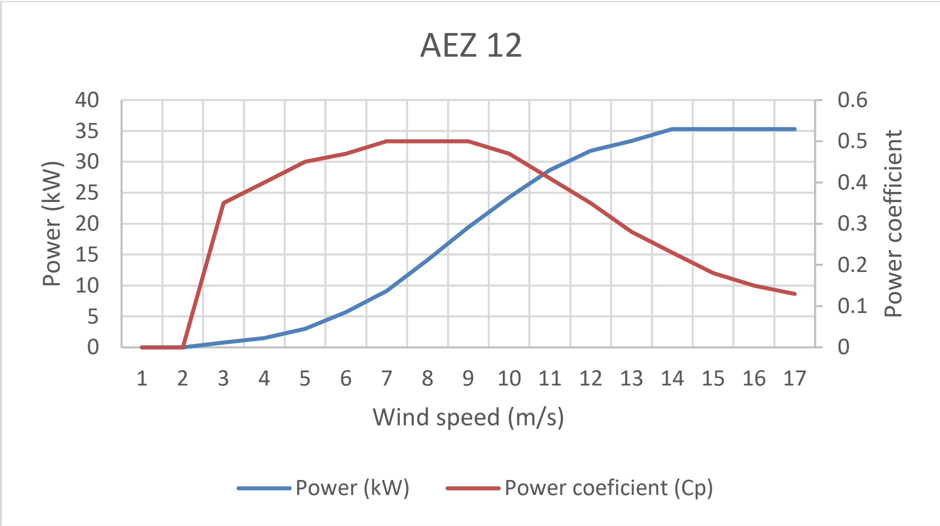
The EAZ 12 is a small wind turbine, as shown in figure 5.

Figure 5. EAZ 12 model wind turbine (E.A.Z Wind)

Table 1. EAZ 12 wind turbine’s index (unknown, 2017)

Model	EAZ 12
Price	€42.500,-
life expectancy	>20 years
Height	15m
power at 7.2 m/s	10kW
max power	35kW

Table 2. EAZ 12 model wind turbine’s power curve (E.A.Z Wind)



This EAZ 12 is a good wind turbine that has low cut in speed, also its productivity is impressive compared to other wind turbines that have the same range of sizing. It starts to generate at a low wind speed, which is very useful. Since its upper limit of wind speed is low, the turbines will operate well whether it is windy or not – so – windy season, which makes the amount of generated electricity increase. This means there will be less period of time that no energy is collected from the network. However, unfortunately that the power it produces is expensive compared to its purchasing price. An EAZ 12 wind turbine with a maximum power of only 35kW costs 42.500 euro and many of these are needed to fulfil the power demand.

- The Nordex N80/ 2500:

Nordex N80/2500 is a large turbine, much larger compared to the EAZ 12, as shown in figure 6.

Figure 6. Nordex N80/2500 model wind turbine (Renugen Renewable Generation)

Table 3. Nordex N80/ 2500 's index (Erwan, 2017)

Model	Nordex N80/ 2500
Price	€405,526.38
Life expectancy	25 years
Height	80m
Power at 7.2 m/s	550kW
Max power	2500kW

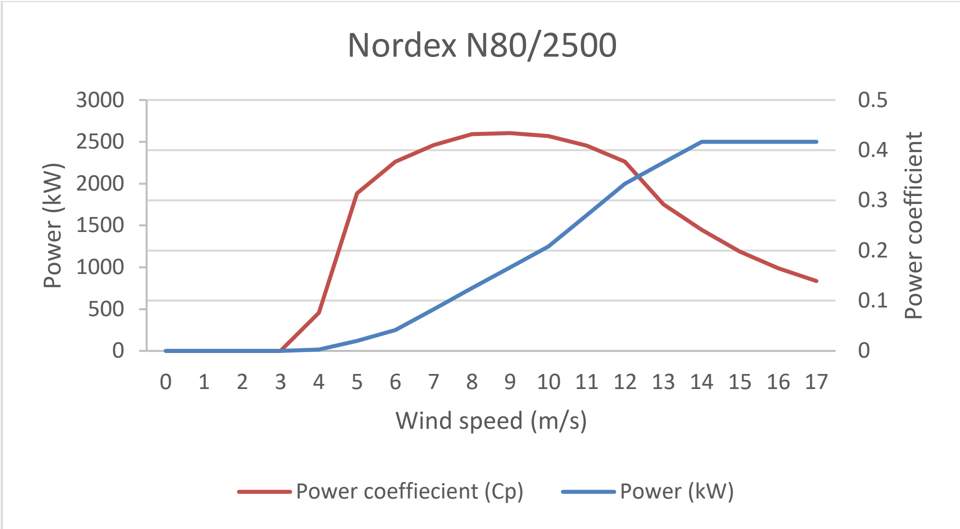


Figure 7. Nordex N80/2500 model wind turbine power curve (Renugen, 2017)

Comparing to the power's price per kWh, this Nordex 2500 is a great deal since it produces lots of energy, which means, when taken into account, the power produced is with sensible price. However, this might also be a disadvantage of this model, when the wind turbine produces lots of energy, it might produce way too much power than requirement when the wind is blowing strong (storms, snowstorm…), especially when we consider Finnish weather, those types of weather conditions occur quite often. Though thanks to the large sizing, the Nordex 2500 is pretty tall, it could receive wind's blown earlier compared to the EAZ 12 and as a result, start to generate and create energy sooner.

4.3 **Maintenance cost**

Wind turbines need to be maintained periodically to keep operating. Bearings will wear out and must be replaced, paint might fall off or faded and a paintjob might be needed, the oil will dry out and the components need to be re - lubricated at some points. Also, there will be a lot more maintenance jobs that a wind turbine need. To get an insight in the cost, some research was done, and it was found out that the maintenance costs are between twenty to twenty – five percent (20% – 25%) of the total cost of a wind turbine. (EWEA, 2017) In this research, we take twenty – five percent (25%) of the total cost for the maintenance.
A detailed Excel document on maintenance cost of wind turbine, which was being carefully considered and calculated, could be found in *appendix* section of the thesis.

4.4 **Calculating wind power**

As the power curves of two different wind turbine models have been shown earlier in the *wind turbines comparison* section, there were some calculations being taken place. To calculate the power output of the wind turbines at certain wind speeds, the power charts from the manufacturers were used. For example, for the Nordex 2500. Form the table with wind speed and power output, a graph was made. Then a trend line was made of this graph and the formula of this graph was used for calculating the power output of the wind turbines. This seemed very easy, but it was found that this was not the correct way. The power calculated with this formula differed too much from the power in the table from the manufacturer.

Nordex 2500	
0	0
1	0
2	0
3	0
4	0
5	125
6	250
7	500
8	750
9	1000
10	1250
11	1625
12	2000
13	2250
14	2500
15	2500

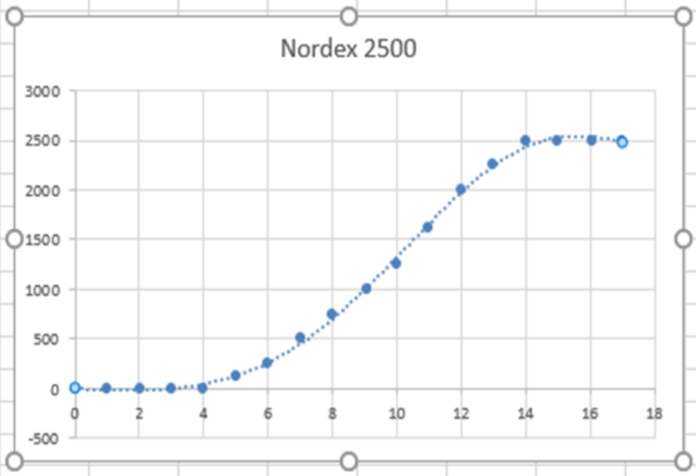


Figure 8. Manufacturer’s power table (Reneugen, 2017)

The reason for this problem is probably the complexity of the curve. It is not possible to make one formula that accurately describes the whole curve. To solve this, the graph was split up in different sections using trendline tool in excel.

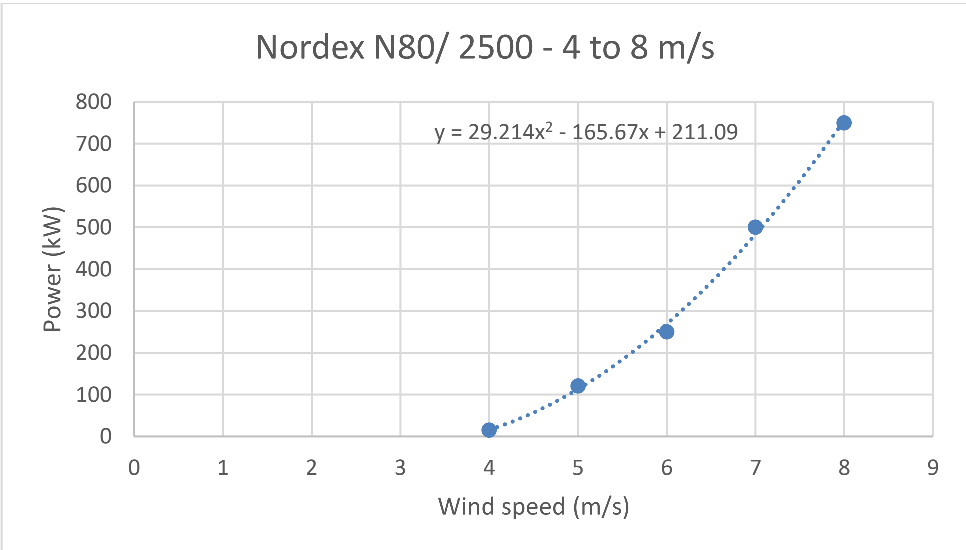


Figure 9. Nordex N80/ 2500’s power curve ($4\ m/s - 8\ m/s$)

Then from a wind speed 8 to 12 meter per second a straight line was the best way to describe the data from the table.

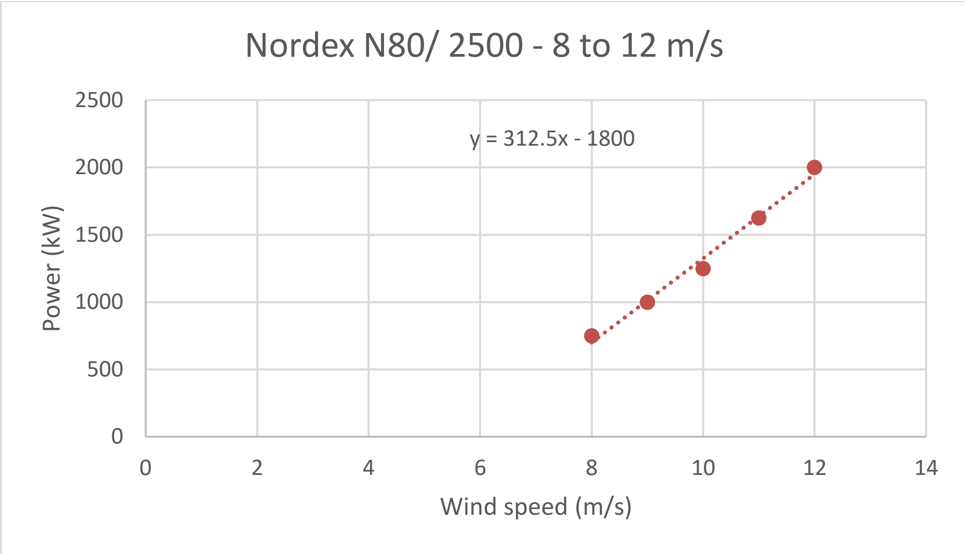


Figure 10. Nordex N80/ 2500's power curve ($8\ m/s - 12\ m/s$)

By this way there were five different formulas found for different wind speeds. Thus, when calculating the power output of the wind turbines, an if-structure was used to choose the correct formula for the wind speed. Below this *if-structure* with the formula's is shown.

"$ALS(D3 < 4; 0; ALS\left(D3 < 8; 26; 786 * D3^2 - 133,93 * D3 + 110,71; ALS(D3 < 12; 312,5 * D3 - 1800; ALS(D3 < 14; 250 * D3 - 1000; 2500))\right)\right) * setup! \$J\$5$" - Power output general formula is built using if – structure function in excel

Then the conclusion was drawn that the wind turbines did not run for many hours, this was due to the high wind speed needed for it to start running. But the wind speed used for these calculations was measured at a height of 10 meters. The axel of the small wind turbines is 15 meters, for the large one it is at 80 meters high. Since the wind speed at higher height in the air is larger than when it was calculated at 10 meters height, the wind turbines start to generate sooner than what was calculated in the first case. The formula below was used to calculate the wind speed at a certain height.

$$V_z = V_{10} \times \frac{z}{10} \times a$$

In which:

V_z is the wind speed at some height z (in meters)
V_{10} is the wind speed at 10 meters and an a of 0,2

An additional detail excel file for wind power calculation, which was being carefully considered and calculated, could be found in *appendix* section of the thesis for further review.

5 SOLAR ENERGY

5.1 Fundamental

Solar energy is a renewable energy that is generated by the sun. It is created by nuclear fusion that takes place in the sun. This nuclear fusion is called proton – proton chain reaction (PP chain reaction), which occurs when protons of Hydrogen atoms collide with the Sun's core and fuse Helium atoms, emits an enormous amount of energy. It is estimated that about 620 million metric tons is fused in the Sun's core every second.

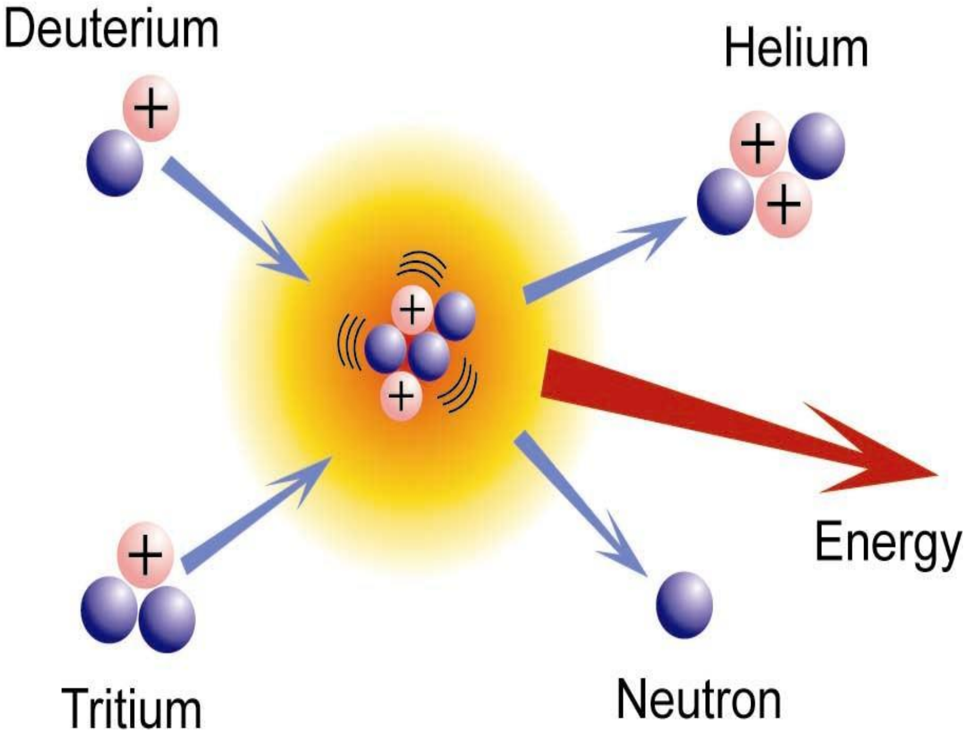


Figure 11. Nuclear fusion (Universe Today, 2019)

The Sun itself, is an Earth's life support system, providing light and heat. However, it is not all. Solar energy, which is a widely available, clean and renewable resource, which could excessively provide energy to meet the world's consumption needs. Therefore, technologies have been developed in order to harness a small share of this radiant energy.

There are variable ways of capturing and converting Solar radiation into usable energy.

The two main technologies have been popularly used to harness it are:

- Solar thermal technology

The Sun's heat is captured directly from the Sun rays or using its warm to heat up the transfer fluids and then use it to drive turbines, generate electricity or heat up water for either households or industries' needs.

- Photovoltaic Solar technology

Photovoltaic effect (photoelectric effect) was discovered by French physicist Edmond Becquerel in 1839 and was first used in industrial applications in 1954. It converts light into electricity directly. The principle of this effect is that when electrons are displaced, an electric current occurs. The displacement of electrons is caused by having photons (which are available light particles) excited the outermost electrons of certain semiconductor elements' atoms.

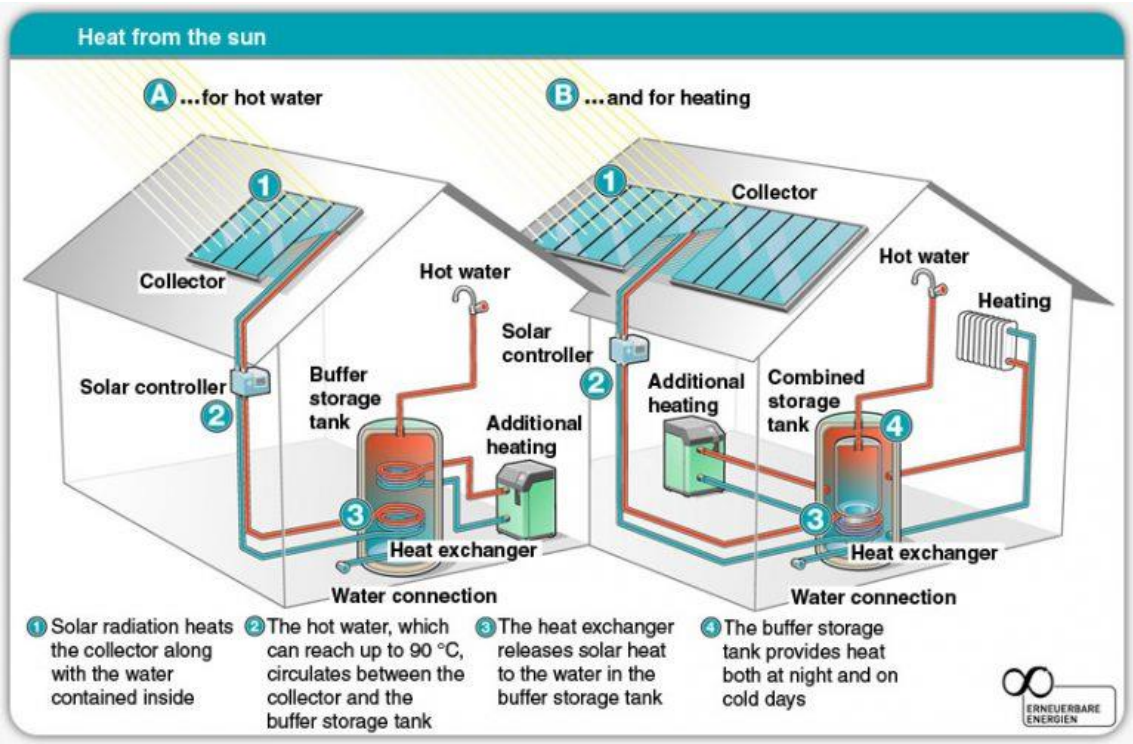


Figure 12. Solar thermal technology (Solar Tribune, 2019)

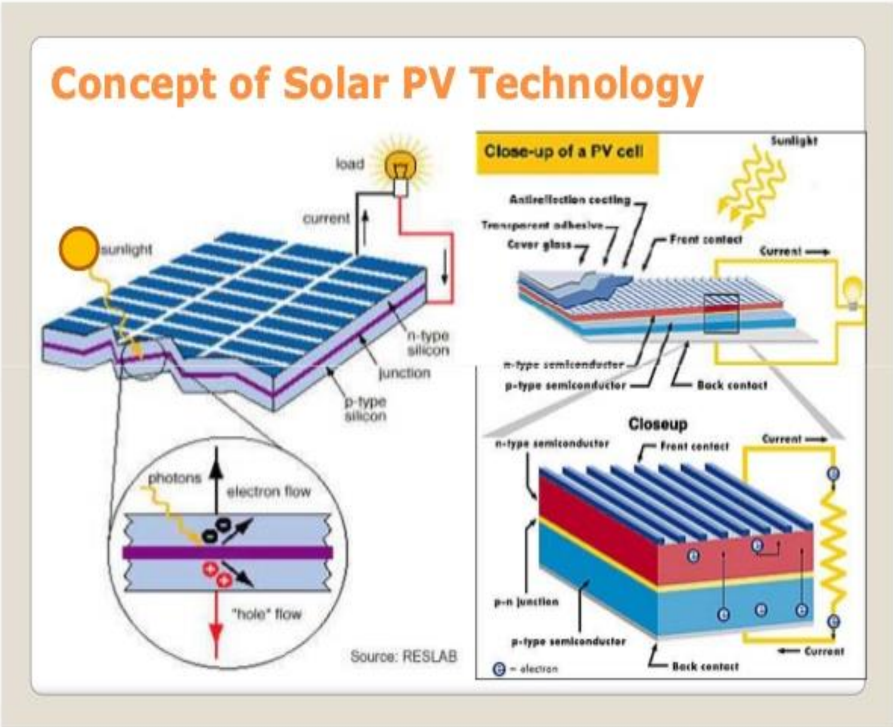


Figure 13. Solar photovoltaic technology (Bloomberg, 2019)

In this project, one of the ideas is to use Solar Energy, in detail, photovoltaic Solar technology to build a practical and economic renewable energy network.

5.2 **Solar cells**

5.2.1 Definition

Solar cell, also called Photovoltaic cell, is a solid – state electrical device acts as a converter. It converts light energy into electricity based on the photovoltaic effect's principle.

5.2.2 Structure and operating principle

A Solar cell (PV cell) consists of layers of distinct functions. The main structure is formed of two differently doped silicon layers (p- and n-). A barrier is built between these two layers, placed along the p-, n- junction. An antireflection coating is added to reduce light reflection. This coat is placed onto the top surface of the PV cell. Metal is used as front and rear contact to be able to channel light – generated carriers and generate electricity. Normally, a thin grid of Aluminium or Silver is used to form the rear contact in order to minimize the impact on light entering the silicon cells, meanwhile a full layer of the same material is screen-printed onto the rear contact. Generally, the working principle of PV cell are similar to semiconductors.

The photons will be absorbed and then an electric field is established. Electron-holes pairs are created by the p-, n- junction. Due to the joining of high concentration of hole or deficiency of electron (p-type) and high concentration of electron (n-type) semiconductor material, excess electrons try to diffuse with the holes of p-type whereas excess hole from p-type try to diffuse with the electrons of n-type. Movement of electrons to the p-type side exposes positive ion cores in the n-type side, while movement of holes to the n-type side exposes negative ion cores in the p-type side, resulting in an electron field at the junction and forming the depletion region (space charged region).

Absorption of photons to create electron-hole pairs. Electron-hole pairs will generate in the Solar cell provided that the incident photon has an energy greater than that of the band gap. However, electrons (in the p-type material), and holes (in the n-type material) are meta-stable and will only exist, on average, for a length of time equal to the minority carrier lifetime before they recombine. If the carrier recombines, then the light-generated electron-hole pair is lost and no current or power can be generated. Therefore, the p-n junction is used to separate the electrons and the holes, prevent them to recombine. The carriers are separated by the action of the electric field existing at the p-n junction. If the light-generated minority carrier reaches the p-n junction, it is swept across the junction by the electric field at the junction, where it is now a majority carrier. If the emitter and base of the Solar cell are connected (i.e., if the Solar cell is short-circuited), the light-generated carriers flow through the external circuit.

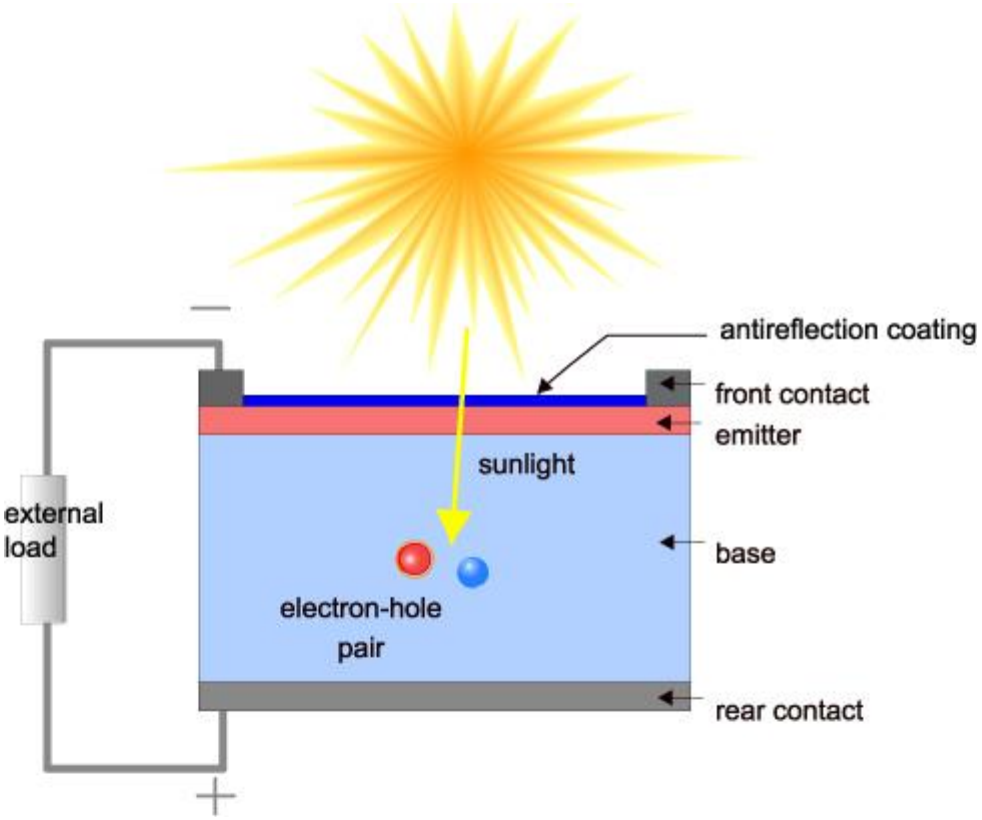


Figure 14. Structure of a Solar cell (Pukhrem, n.d)

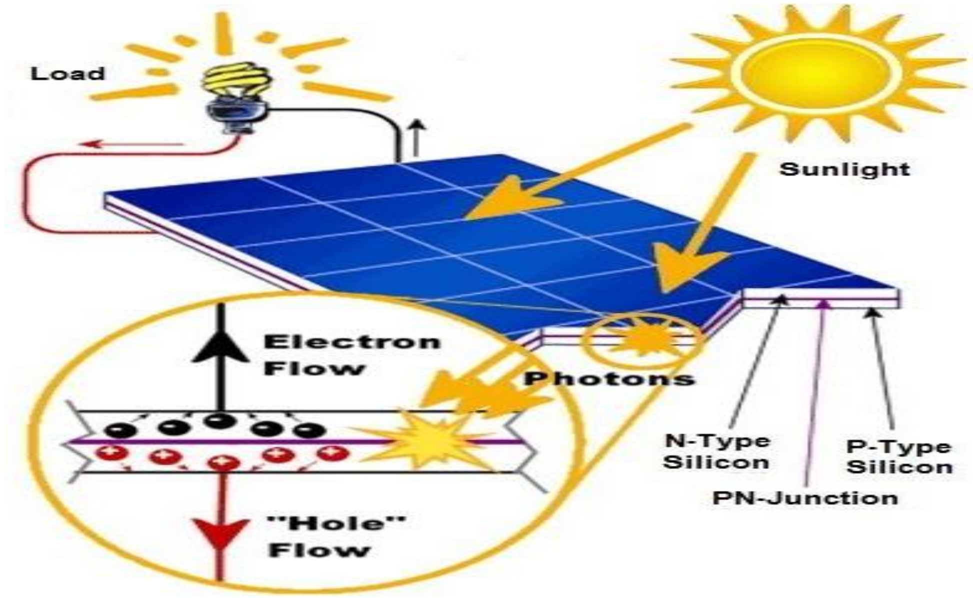


Figure 15. Operating principle of a Solar cell (Knix Semiconductor Electronic, 2019)

Solar cells are photovoltaic, which means they act as photodetectors, whether the sources are sun light or artificial light.

5.2.3 Material

Solar cells are normally made of semiconducting materials. Depends on the applications, Solar cells can be made of single - junction materials or multi - junction materials. Solar cells are named after the materials they made of. It is categorized into first, second and third generation cells.
First generation cells (wafer – based cells), the traditional cells that are made of Crystalline silicon. Crystalline silicon (c-Si) is the crystalline forms of silicon, either multi crystalline silicon (multi-Si) consisting of small crystals, or monocrystalline silicon (mono-Si), a continuous crystal. It is the most prevalent bulk materials for Solar cells so far.
Second generation cells are thin – film cells. These thin – film cells are made by depositing one or more thin layers, or thin film (TF) of photovoltaic material on a substrate, including amorphous silicon, CdTe and CIGS, glass, plastic or metal.
Third generation cells have not yet been commercially applied, mostly in research and development phases.

Table 4. Bulk type and Thin – film type PV cells

<table>
<tr><td rowspan="2"></td><td colspan="4">Bulk type / Wafer-based (Crystalline)</td></tr>
<tr><td>Mono-crystalline Si</td><td colspan="2">Poly-crystalline Si</td><td>Poly-crystalline band</td></tr>
<tr><td>Pros</td><td>• High efficiency</td><td colspan="2">• High efficiency with respect to price</td><td>-</td></tr>
<tr><td>Cons</td><td colspan="3">• Increased manufacturing cost caused by the supply shortage silicon</td><td>-</td></tr>
<tr><td rowspan="2"></td><td colspan="4">Thin-film type</td></tr>
<tr><td>Amorphous Si</td><td>CIGS</td><td>CdTe</td><td>Polymer organic</td></tr>
<tr><td>Pros</td><td rowspan="2">• Low price</td><td colspan="2" rowspan="2">• Low price
• Able to automate all manufacturing process</td><td rowspan="2">• Low manufacturing
• Can be more efficient (still in research)</td></tr>
<tr><td rowspan="2">Cons</td></tr>
<tr><td>• Low efficiency</td><td colspan="3">• Low efficiency</td></tr>
</table>

5.2.4 Application

A group of combined individual Solar cells forms a Solar module. These modules can be assembled into Solar panels (Solar arrays). PV cells can be arranged in a series to form a module, and modules can then be connected in parallel-series to form arrays. When connecting cells or modules in series, they must have the same current rating to produce an additive voltage output, and modules must have the same voltage rating when connected in parallel as well to produce larger currents. A layer of glass is placed on the sun – facing top of each Solar module to allow light to pass yet protecting the silicon wafers at the same time. The Solar arrays are often placed in suitable positions so that it could generate Solar power using Solar energy.

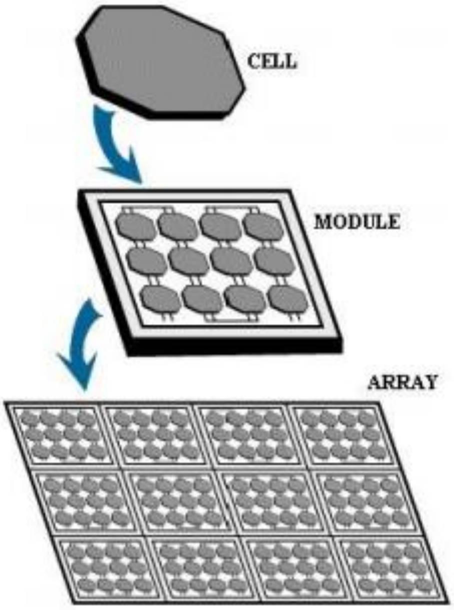


Figure 16. Photovoltaic module (NASA, 2012)

5.3 Solar cells calculation

Power output of Solar panel calculation
Calculations are based on the irradiance research table.
Formulas:

$$E = A \times r \times H \times PR$$

In which
E: Energy output of the Solar cell (KWh)
A: Total Solar panel area (m^2)
r: Solar panel yield efficiency (% depend on the Solar panel data)
H: Solar irradiance of the area(m^2) each hour (W/m^2)
PR: Performance ratio (Default 0.75-0.9)

Final power output with temperature efficiency:

$$P_{out\ put} = E - E \times n$$

In which
$P_{out\ put}$: Power output with temperature efficiency take into account (kWh)
n: Temperature efficiency (%)
With $n = (Tsp - Tnom) * Temperature\ Coefficiency$

Tsp: temperature of the cell is calculated based on the data available and average temperature of the region.
$Tnom$: standard temperature.
Temperature co-efficiency = 0.42% (TP660P panel)

Solar Panel Overview:

Solar panel model: TP660P

$P_{out\ put} = 270\ W$
Cell dimension: $156 * 156\ mm^2$
Cell arrangement: $60\ (6 \times 10)$
Weight: $18.5\ kg$
Lifetime: $25\ year$

Table 5. Electrical Parameters of Solar panel (Unknown)

ELECTRICAL PARAMETERS

Model	TP660P			
Maximum Power (Pmax/W)	255	260	265	270
Operating Voltage (Vmpp/V)	30.6	30.7	30.8	30.9
Operating Current (Impp/A)	8.36	8.51	8.62	8.74
Open-Circuit Voltage (Voc/V)	37.7	37.8	37.9	38.0
Short-Circuit Current (Isc/A)	9.06	9.16	9.25	9.33
Module Efficiency ηm(%)	15.7	16.0	16.3	16.6
Power Tolerance	0-+3%			
Temperature Coefficient	Pmax	-0.42%/℃		
	Voc	-0.32%/℃		
	Isc	+0.058%/℃		
Noct	45±2℃			

* STC: 1000w/㎡,25℃,AM 1.5

The power output curve of the TP660P for one year based on the irradiance table:

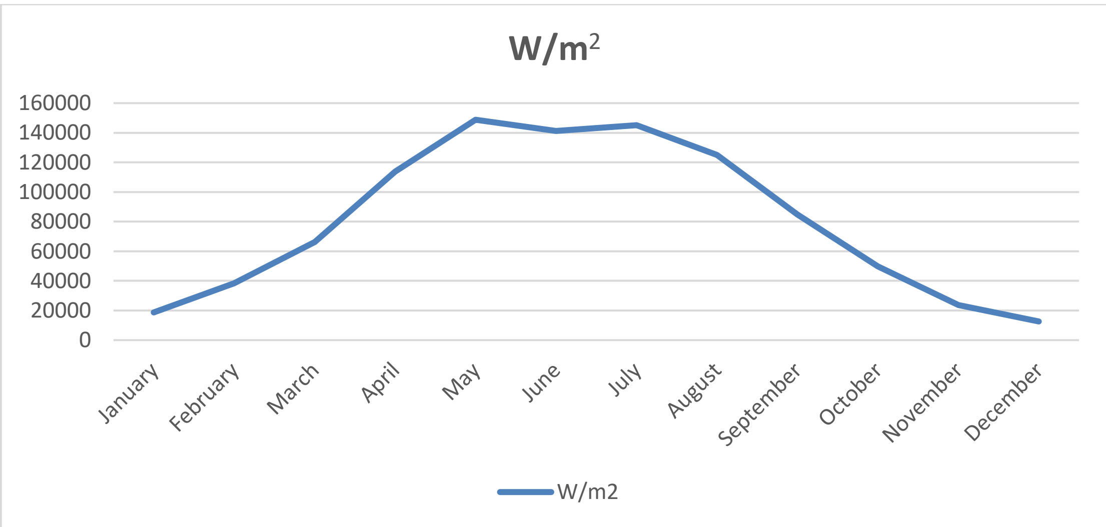


Figure 17. Power output curve of the TP660P for one year

6 SOLAR CONVERTERS AND BATTERY CONTROL UNITS

The Solar modules and batteries only produce Direct Current (DC). However, the wind turbines produce Alternating Current (AC) and the houses need alternating current (AC). To make sure the Solar modules produce the maximum power and the right power goes to the right place, Solar modules and battery control units are needed.

6.1 Solar inverters

6.1.1 Definition

Solar inverter is a type of electrical converter, it converts variable of Direct Current (DC) output of a Photovoltaic (PV) Solar panel, which is collected and then stored in Solar battery storage, into a utility frequency Alternating Current (AC) to feed home appliances. Whether it is a four-kW utility power plant or a 2-kW residential Solar system, inverter is a critical balance of system (BOS) component in a photovoltaic system. It is so important that it is often considered to be the brain of any Solar energy project, or the “gateway” between photovoltaic system and the energy off – taker, since AC is the standard used by all commercial appliances.

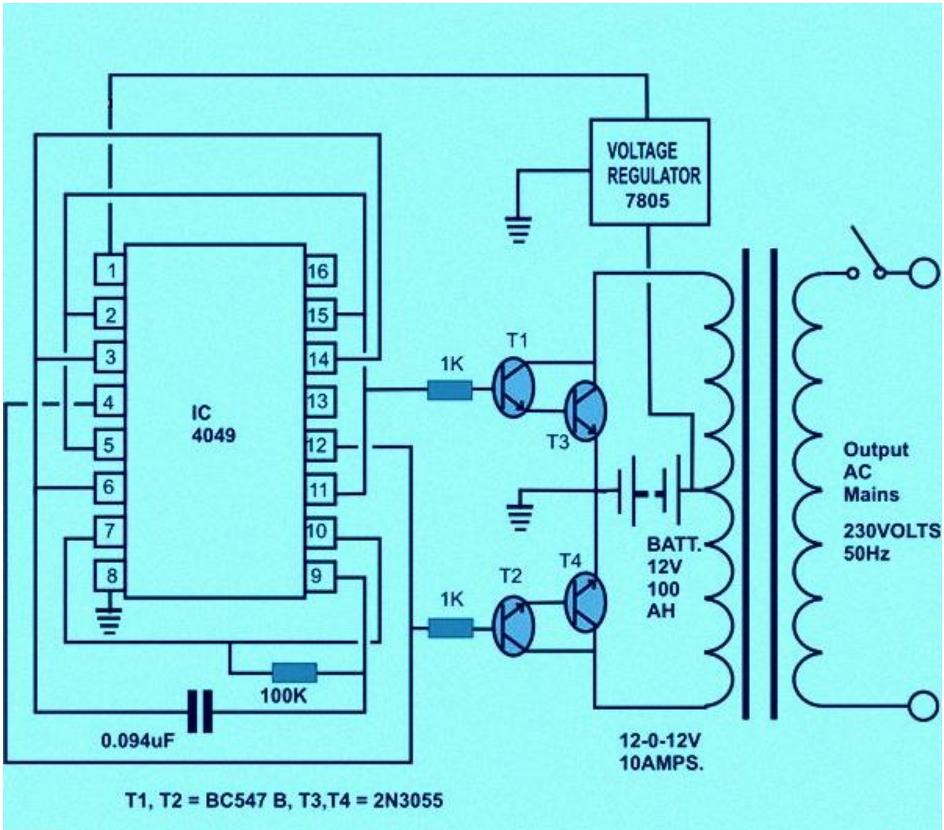


Figure 18. Solar inverter basis structure (Pukhrem, n.d)

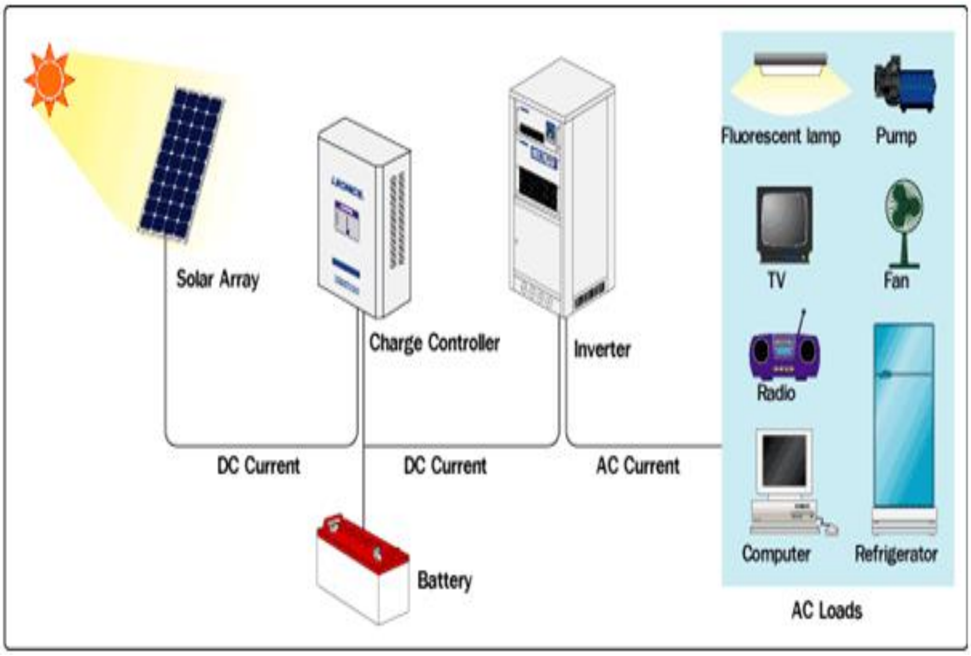


Figure 19. Solar inverter installation (Solar Tribune, 2019).

Inverter technologies have been growing and innovating non – stop ever since, such that converting DC to AC is not the only function of Solar inverters, but they also provide a number of other capabilities and services to ensure that the inverters can operate at theirs best, like data monitoring, applications and system design engineering or advanced utility controls. Among them, initiative operation and stop function together with maximum power point tracking (MPPT) function are the most significant. The following explain how these two significant functions are carried:

- Initiative operation and stop: this function allows the inverter works efficiently no matter it is sunny or rainy, morning, afternoon or dawn. The inverter starts to initiatively operate when the output power of Solar system cells increases and reach the inverter required output power in the morning after sunrise. The cell module's output is monitored continuously by the inverter itself during operation, as long as the output power is greater than the inverter's requirement. The operation is carried constantly until after sunset. Even in rainy days, when the output power is smaller, the inverter output is close to 0, the inverter will be in a standby status.
- Maximum power point tracking (MPPT): According to Solar radiation intensity and the Solar cell module's temperature, the output of Solar cell modules is changeable. As the voltage of Solar cell modules decrease when current increase ($V \sim \frac{1}{I}$), there is maximum power at one point. There is no doubt that the maximum power point is vary since the Solar radiation intensity is inconstant. Because of these changes, the system obtains the maximum power output from the Solar cell modules, which is the meaning of MPPT

control. Integrated maximum power point tracking (MPPT) function is considered as the most important feature of the inverter in Solar system.

6.1.2 Types of Solar inverters

- Base on application types:

Common Inverter

DC 12V or 24V input, AC 220V, 50Hz output, power capacity from 75W to 5000W, and some inverters have AC -DC switching function like UPS.

Inverter / charger integration

In this type of inverter, user can use various forms of power to feed the AC loads: if AC power available, inverter using AC power to feed the loads, or changing battery; if AC power no available, using battery to feed AC loads. This inverter can be used with a variety of powers, like batteries, generators, Solar panels and wind generators etc.

Post and Telecommunications Dedicated Inverter

High quality 48V inverter for post and telecommunications, good quality, high reliability, modular (1kW module) inverter, and has N +1 redundancy, scalable (from 2KW to 20KW) function.

Aviation, military dedicated inverter

Such inverters are 28V DC input, with AC output: 26V AC, 115V AC, 230V AC, the output frequency: 50Hz, 60Hz and 400Hz, output power ratings from 30VA to 3500VA. And there are aviation dedicated DC-DC converters and inverters.

- Base on output waveform types:

Square wave inverter

The inverter outputs square waveform is called square wave inverter. The inverter circuit of these inverters are not exactly the same, the common feature is simple circuit, less power switches. The design power generally between one hundred watts to one kilowatt. The advantages of square wave inverters are simple circuit, cheap and easy maintenance. The disadvantage is, due to the square-wave voltage contains a lot of high harmonics, which will result in additional losses in the loads with core inductor or transformer and have interferences to some communications devices. Besides, square wave inverters voltage range is not wide enough, protection function is not perfect, high noise and other shortcomings.

Step wave inverter

This inverter output step wave AC voltage waveform. Different step wave inverters output different waves; the step number may have great differences. The benefits of step wave inverter are, the output waveform is significant improved compare with square wave, high harmonic content decreased, it's close to sine wave form when the wave steps reach 17, which called modified sine wave inverter. It has high efficiency when there is no transformer output. The disadvantage is that the step wave superimposed line uses more power switches, some of them require multiple DC power input lines. This brings troubles to Solar cell phalanx grouping and wiring, and the balance charging of the battery. In addition, step wave voltage still has some high-frequency interference to radio communications devices. (Solar quote, n.d)

Sine wave inverter

Sine wave inverter output voltage waveform is sine wave. The benefits of sine wave inverter are, output waveform is good, low distortion, less interference to radio communication devices and low noise. In addition, comprehensive protection functions, high overall efficiency. The disadvantages are: complicate lines, require high technical repair cost.

6.1.3 Evaluating and selection

For the Solar inverter, the *Sunny Boy 7700 TL-US-22* is found to be the best Solar inverter. It has the lowest price per watt of power it can convert. One of these modules cost €3.020, and one unit can convert a maximum of 8000 watts. To find the number of Solar modules needed for this project the maximum power output of the Solar modules was found in the table and divided by the 8000 watts of power.

Figure 20. the Sunny Boy 7700 TL-US-22 inverter (Solar Electric Supply, n.d)

6.2 Battery control units

The *Sunny Island SI-80H-11* control unit was found to be the best choice for this case. It has the maximum power input of 11 kW, and maximum power input is 3,3 kW. Also, the price is reasonable with its 3470 Euros. The number of battery control units needed was found by using Excel program and looking at the maximum power going in to the batteries. Also, the maximum power out of the batteries were taken into consideration. Then the maximum in- and outputs of the batteries was multiplied by in- and outputs which one unit can handle, and the number of units was found.

7 ENERGY BACKUP

When designing an autonomous energy network, it must be taken in to account that it does not have any grid connection. In other words, the excess energy that is produced, cannot be sold to be delivered to the grid, or when the energy demand is high, any extra energy from the grid cannot be bought.

Especially when having a lack of energy in an isolated energy network, energy backup is needed. That can be implemented in different ways. On this project, it was decided to use batteries for energy storage and a generator driven by a biodiesel fuelled engine in a matter of situation that the energy output from other sources is not enough.

7.1 Battery storage

Storing energy in batteries when the energy available from the Solar panels or wind turbines is higher than demand of energy, gives more flexibility to guarantee that there is enough energy available when the production is low. When energy demand is higher than production, required energy can be taken from the batteries. There are four types of battery storages that are most used: Lead acid, Lithium-ion, flow and nickel – iron batteries. (Solar quote, n.d)

In this case nickel-iron batteries were elected because of its high endurance and high actual capacity. The battery chosen consists twenty 1,2V cells making it a battery of 24 Volts and 300 ampere-hours. To invest Ni-Fe batteries it was realized that despite the high price of a one battery, costs will stay reasonable when considering the long-life expectancy of the batteries, 11000 cycles. 80 % of the energy in the Ni-Fe battery can be used. The total installed capacity for energy storage was found by trying different set-ups into Excel sheet. Basically, it is all about finding a good balance between the price of the batteries and the running time of the generator.

Still, it is good to know that when the total battery capacity increases, one battery is not that beneficial or effective anymore.

The lifetime of the batteries was calculated. First, the number of cycles in one year was found by dividing the total energy flow in a year going into the batteries with the usable capacity. Then, the life expectancy in years was found by dividing the life expectancy in cycles with the number of cycles in a year. The outcome of these calculations was that the batteries will last approximately 167 years in this amount of use. The calculated lifetime is theoretical and in a practical use battery are not designed to last so long.

7.2 Backup generator

Backup generator will be needed if the energy output from the wind turbines, Solar panels and batteries are not enough to answer to the energy demand. In this case, it was found that there is a need for a backup generator for certain number of hours in a year. When generator is running, it will sometimes produce more power than the houses are using. Then the excess energy can be used to charge up the batteries, so no energy produced by the generator will be wasted.

It is also must be chosen how to rotate the generator. A biodiesel fuelled V12 engine with 552 kW and displacement of 21900 cm3 was found to be a reasonable choice. A little bit oversized making it reliable because there is no need to use engine with its full power at all the time when need of backup generator appear.

8 CABLES

Cables are needed to connect individual mechanisms of the network together. A few different types of cables are needed in this project. For most cables, it is often assumed that the cable themselves already are placed in the ground and capable with good electricity grind. However, in this circumstance, we need to use the cable to connect the wind turbine, which is placed at a remote location far from the houses and batteries. Therefore, a large and expensive cable is needed. Since the wind turbine can produce at its maximum capacity of 2500 kW electricity, it needs a suitable cable that can transport such amount of energy. It was calculated that a cable of at least 3 x 120mm^2 was needed for this power to be transported at a voltage of 400V.

$$\frac{2500\ kW}{400\ V} = 6.25\ kA$$

As found from catalogue of Rexel, the cable Draka TFXI turned out to be one of the appropriate cables needed. This is a 3 x 120 mm^2 cable that is possible to carry a maximum voltage of 1kV. It cost 145 € per meter.

Moreover, we also need to excavate the cable down to the ground, the service price for this is around 28 € per meter.

Altogether, the total price for cable and cable related issues is approximately 173 € per meter.

9 STABILITY OF THE GRID

When designing an autonomous grid, the key is that the grid itself must be reliable, stable and as cost effective as possible. This chapter is focusing on the stability of the grid.

Stability of the grid is composed of variable of factors. The most important entity for stability is that the sizing of the system is right, the components chosen are sufficient and appropriate, well made and they are designed for a certain climate condition. The converters should be able to handle the power output of the Solar panels, and the control units should be chosen in a decent way so there is not too much power that the controllers cannot handle. The highest power output of the batteries and the highest power input to the batteries should be carefully recorded, evaluated and considered. The number of battery converters needed should adjusted based on this input and output power. Good maintenance procedure for all components must be arranged and put into financial sheet.

10 ENERGY CONSUMPTION IN FINLAND

Carbon – neutral society is known as one of the most important long – term goals of Finland when mention environmental and energetic issues. Finland also has been known as one among the countries that lead renewable energy utilisation.

It is reported that in year 2016, while 54 per cent (54 %) of districted heating in Finland are from domestic fuels, 37 per cent (37%) is carbon – neutral. (Kostama, 2017)

Acknowledges the importance of renewable energy and energy efficiency in achieving carbon – neutral society in the near future, government has established Energy and Climate Strategy. According to unofficial translation of Government report of the National Energy and Climate Strategy for 2030 and Climate Roadmap 2050, the Ministry of Economic Affairs and Employment has set a goal to reduce 80 – 90 per cent (80 – 90%) of greenhouse gas emission by 2050. (Energy and Climate Roadmap 2050 –Report of the Parliamentary committee on Energy and Climate Issues on 16 October 2014, 2014) (Government report on the National Energy and Climate Stragegy for 2030, 2017, p. 49)

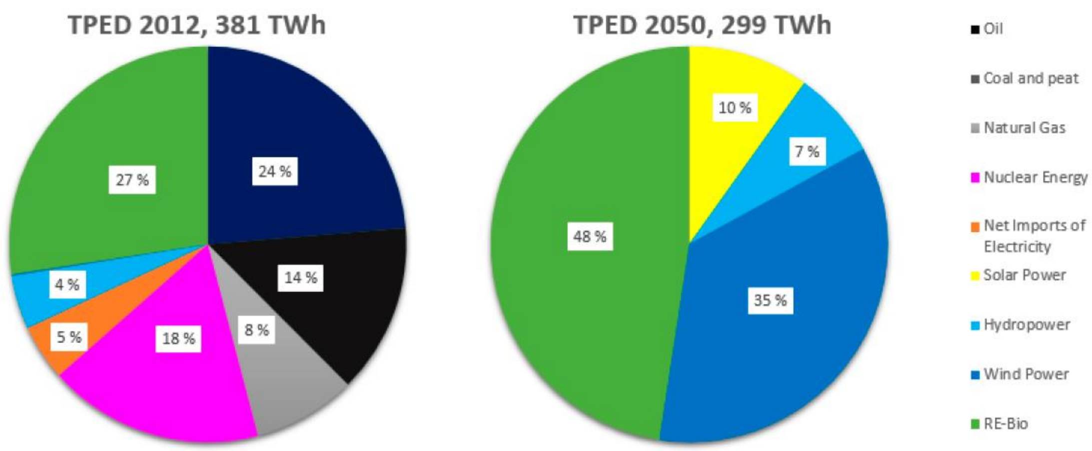


Figure 21. Finnish annual energy consumption in 2012 and Ideal model of Finnish annual energy consumption in 2050 (Energy and Climate Roadmap 2050 –Report of the Parliamentary committee on Energy and Climate Issues on 16 October 2014, 2014)

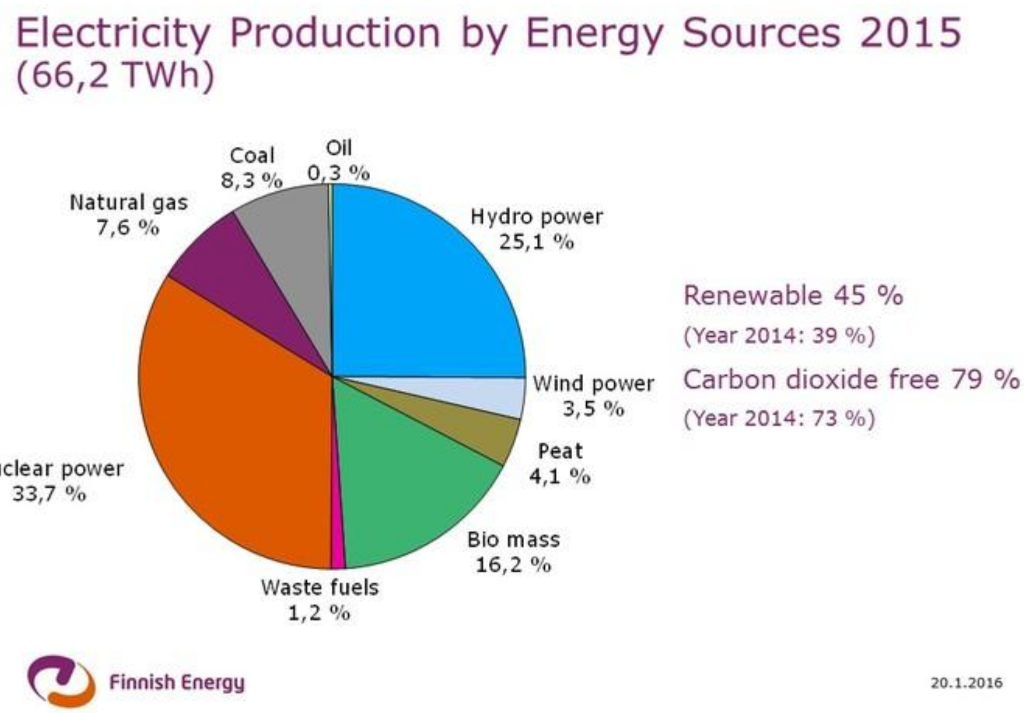


Figure 22. Finnish Electricity Production by Energy source in 2015 (Finnish Energia, 2015)

In Finland, renewable energy promoting is the key target to minimize the amount of greenhouse emission as well as reduce the power that is fossil fuels based and optimize energy efficiency in national level. In the meantime, significantly, Finland renewable energy sources consists of approximately 40 per cent (40%) of energy end – consumption and is believed to be risen more in the next few years.

In this thesis, we focused on researching wind power and Solar - power based energy network building in Finnish weather condition.

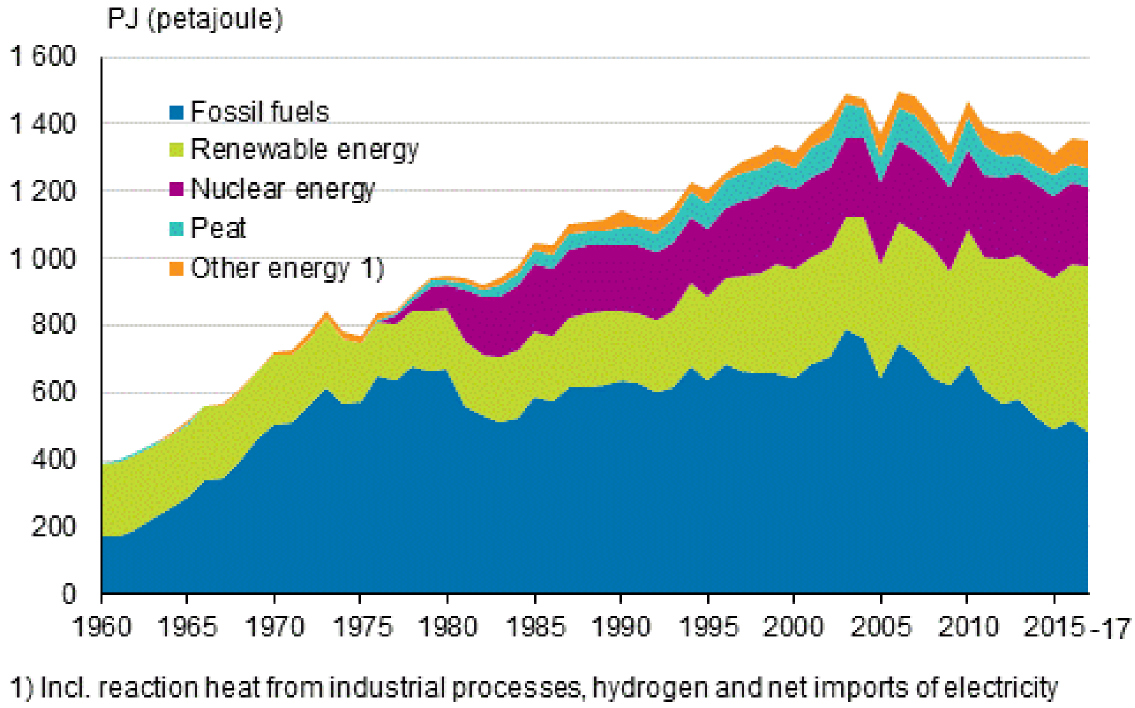


Figure 23. Energy Supply and Consumption (Statistics Finland, 2018)

Energy source, TJ 4)	2017*	Annual change-%*	Percentage share of total energy consumption*
Oil	314,169	-3	23
Coal 1)	116,319	-8	9
Natural gas	66,074	-8	5
Nuclear energy 2)	235,367	-3	17
Net imports of electricity 3)	73,532	8	5
Hydro power 3)	52,712	-6	4
Wind power 3)	17,286	57	1
Peat	56,123	0	4
Wood fuels	361,432	4	27
Others	62,693	4	5
TOTAL ENERGY CONSUMPTION	1,355,707	-1	100
Bunkers	43,064	11	.
CO2 emissions from energy sector	41	-5	

Table 6. Total energy consumption by source (TJ) and CO2 emissions (Mt) (Energy supply and consumption, 2017)

10.1 Wind power in Finland

Wind power is considered quite a new method to generate energy, which has noticeably grown in the past few years and has become one of the most important forms of renewable energy used in Finland, beside bioenergy, hydropower, etc...

Apparently, in 2014, the total capacity of wind turbine generators is 672 MW, comes along with the installation of 260 wind plants and generated over than 1 per cent of 2014 Finland's electricity consumption. (approx. 1.3%). There is no doubt saying that wind power has great opportunities and potentiality to develop strongly and act as a key role in Finnish electricity market without government's subsides soon.

Installed wind power capacity 2018		
Installed with turbines	0	WTG
Nominal Power of installed wind turbines	0	MW
Dismantled wind turbines	2	WTG
Nominal power of dismantled wind turbines	3	MW
Culmulative capacity (WT)	698	WTG
Culmulative capacity (TWh)	2041	MW
Production (TWh)	5857* (*Energyiateollisuus, 16.01.2019)	TWh

Table 7. Installed wind power capacity in Finland, 2018 (Finnish Wind Power Association, 2019)

10.1.1 Wind energy: Potentiality and impacts

The wind power curves published by EWEA in 2014 showed that not only in Finland's national level that wind power is predicted to drastically grow globally and attract long – term investment in order to sufficient the need of clean energy production in general. Finnish government has aim to raise the combined capacity of wind turbine generators to 2500MW by 2020, which, unfortunately, seem to be easy to achieve by the end of this year, 2019, since in the end of 2018, the total capacity is approximately, 2050 MW, (Finnish Wind Power Association, 2019).

The growth of wind power industry in Finland has brought lots of environmental and economic impacts.

Comparing to energy system using fossil fuels, wind power generation (including construction, assembly, transportation and maintenance) emits only around 10 grams of Carbon Dioxide per kilowatt-hour (~10g/kWh), satisfies Finnish goal of approaching carbon – neutral society. Currently, the main sources of energy that is used to produce electricity are natural gases, nuclear power and hydropower. This picture itself shows that the emission of greenhouse gas of Finland is already less than of countries that use coal – fired based electricity. By the time wind power takes more than 10 per cent of consumed electricity of Finland, it will reduce the greenhouse gas emission from 700grams CO_2 per Kilowatt – hour (700g/kWh) to 600 grams CO_2 per Kilowatt – hour (600g/kWh). (Holttinen, Sammi, Hanelle, & Tuhkanen, 2014)

However, despite of positive environmental impacts, wind power also has its downsides to environment. Inappropriate wind turbines siting or planting may cause damage to natural habitat. It is recommended that wind power system should be built followed the EKOenergy label awarded by Finnish Association for Nature Conservation, and should not be planted on sensitive area such as nature protection areas, landscape of interest, national heritages, …

Speaking of Wind Energy generation, its affects onto economy and employment are significant.

As wind power industry grows, it has provided direct and indirect employment for 238000 people in the EU in 2010. By the year 2030, the number of employments provided by wind power industry is expected to reach 794000, included direct and indirect employment. Job opportunities that are offer by Wind power industry is related to several fields, i.e, wind turbines' components manufacturing, wind park or wind farm planning and siting, maintenance jobs. One of the benefits when it has come to wind power and employment in Finland is that there are many Finnish companies well known as subcontractors for the world's leading wind turbines manufacturers. (Wilkes, Athanasia , Jacopo, & Raffaella , 2012). In the future, there is also potentiality for wind power generation energy to be export from Finland, which helps a lot in contribution to national GDP and EU GDP.

10.1.2 Wind energy generation in Finnish weather condition

In Finland, winters are cold and long. It lasts about 200 days in Lapland area and approximately 100 days in Southwestern Finland. The average temperature during winter varies from places to places. The below charts show temperature changes every month in Helsinki (Southern Finland) and Rovaniemi (Lapland, northern Finland).

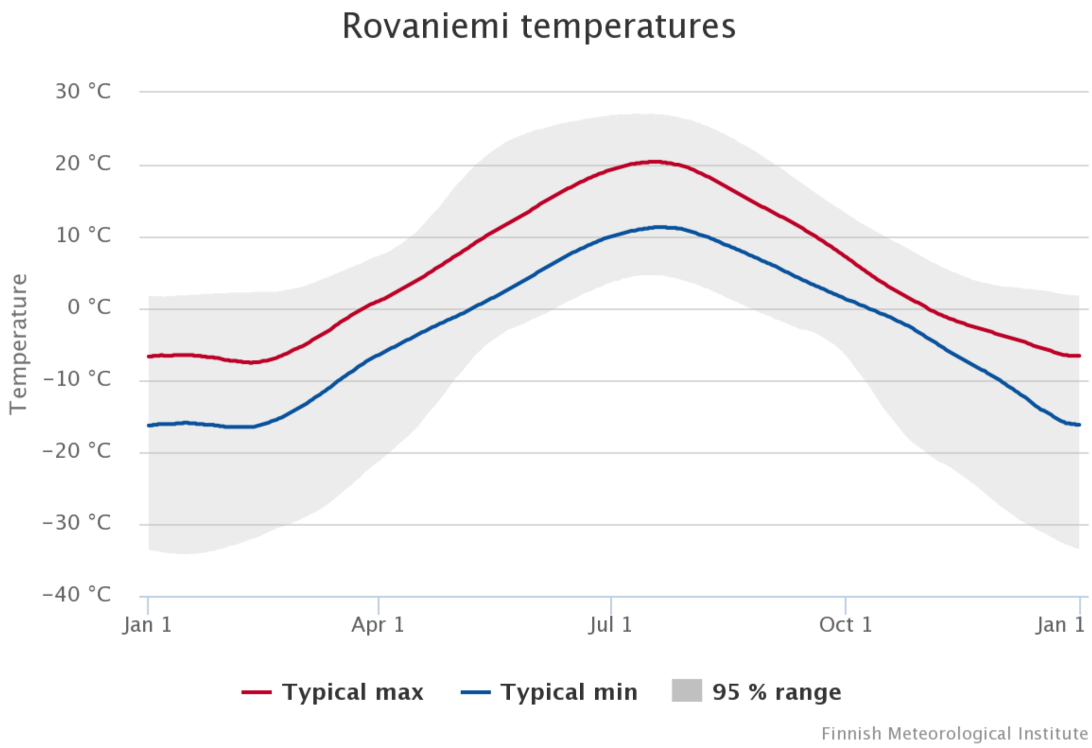


Figure 24. Rovaniemi temperature (Finnish Meteorological Institute, 2019)

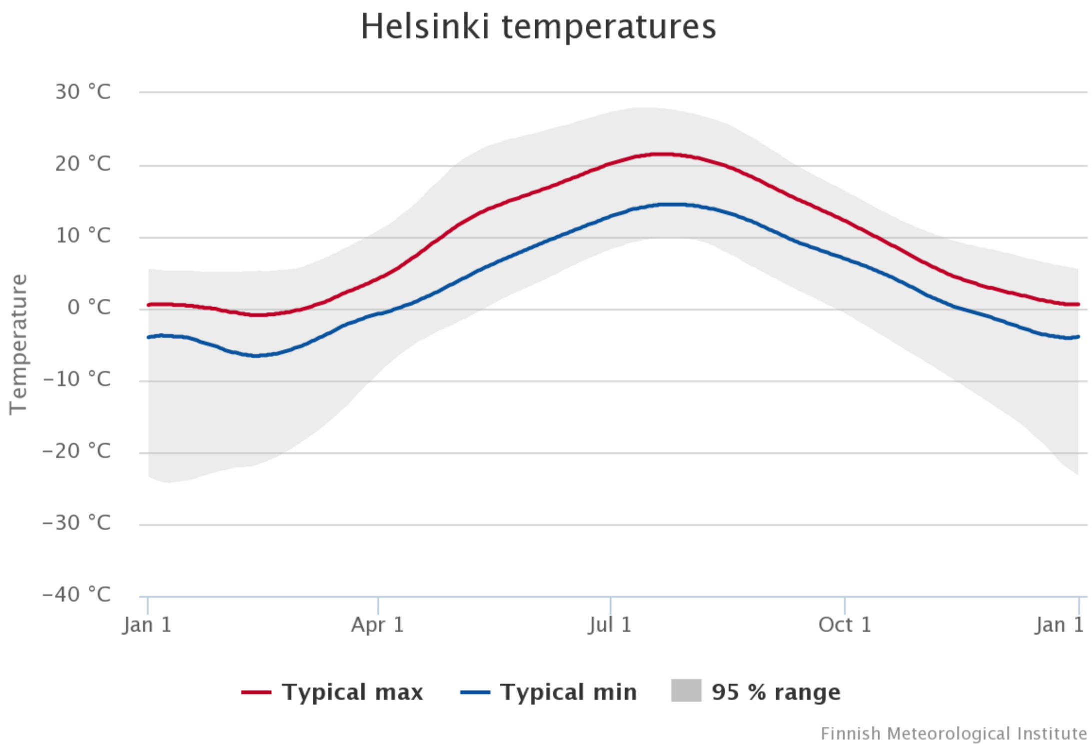


Figure 25. Helsinki temperature (Finnish Meteorological Institute, 2019)

With the cold climate Finland carries, especially for the winter situation, many people believe that wind energy is not feasible since it cannot generate electricity when the temperature drops below 0 Celsius degree, while the electricity consumption for heating in Finland at its peaks. However, this has been proofed to be an inaccurate exclamation.

Although considered as cold temperature climate and icing climate according to the nature of its attitude, the actual proportion of extremely cold winter days is not high. Yet during the winter, cold air produces more energy than warm air within the same speed since its air density is higher. Recorded index showed that in winter months November to March, about 60 per cent (60%) of annual wind energy is produced, much higher than during the Summer, Spring or Autumn.

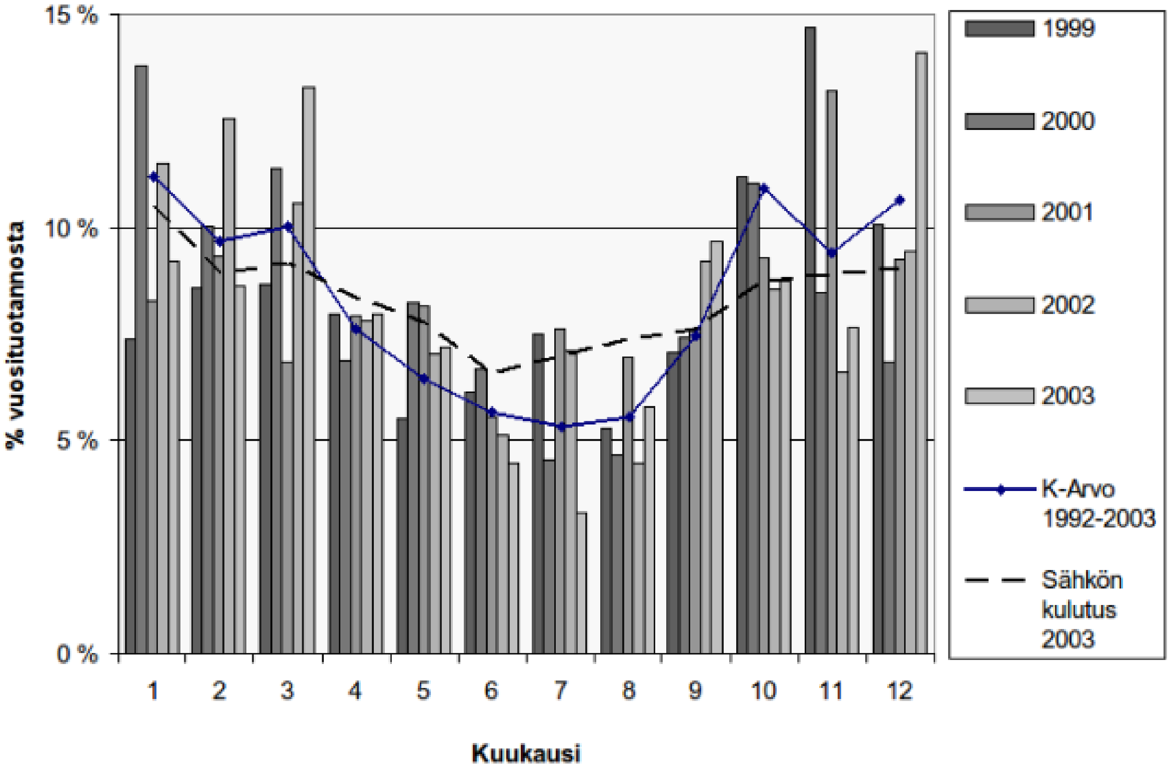


Figure 26. Off – shore wind power annual production and seasonal variation 1999 – 2003 (B.Tammelin & R. Hyvönen, 2002)

The above chart showed that the energy production using wind power technology (the pillars) matched the electricity consumption (blue line) well in the whole year round.

Also, the production cumulative capacity by region vary a lot, in which areas like Lappi (Lapland), Pohjois – Pohjanmaa (North Ostrobothnia), Pohjanmaa (Ostrobothnia) and Satakunta seem to take bigger proportion of combined wind power capacity.

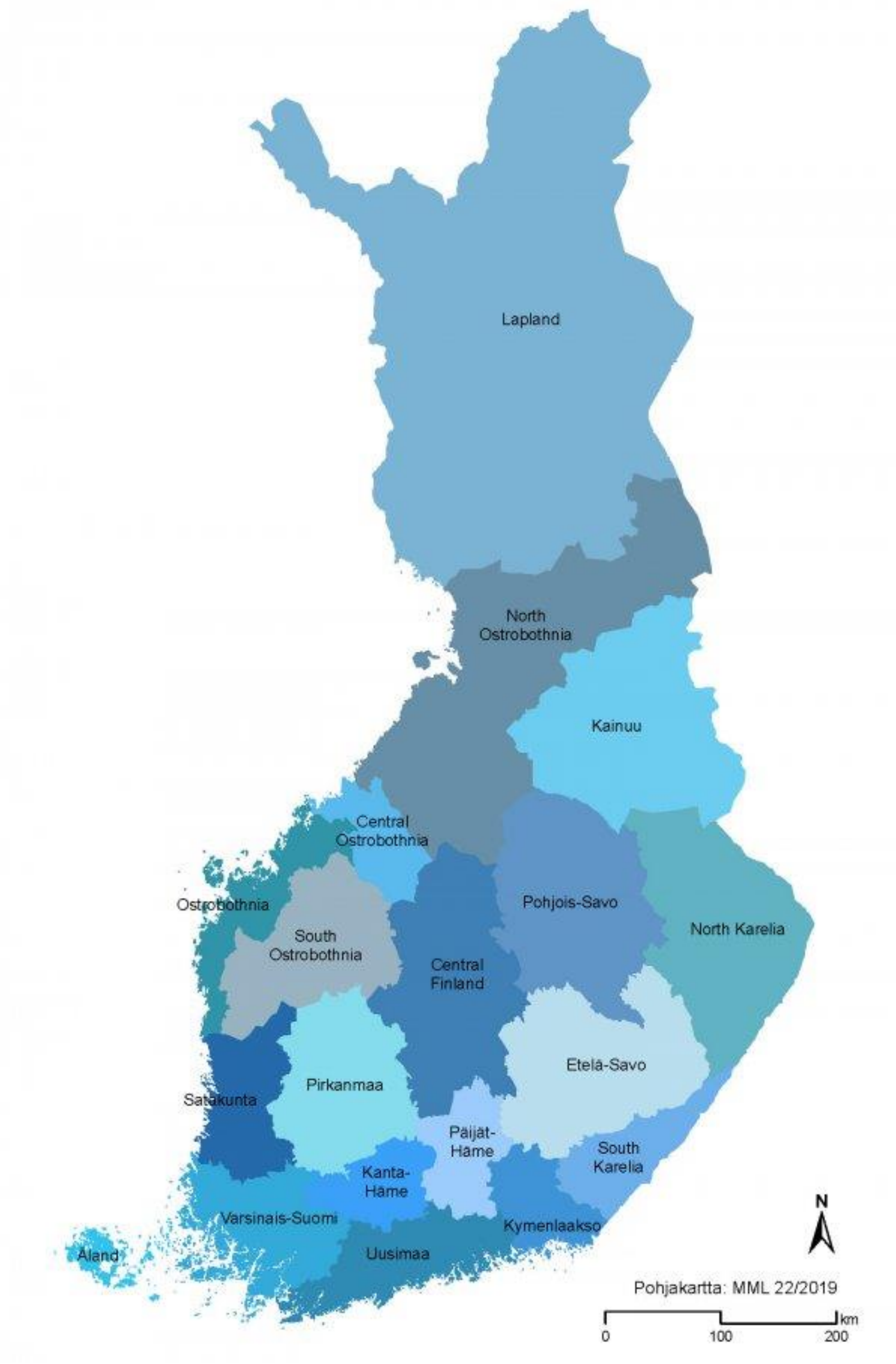


Figure 27. Regions of Finland (Varsinais - suomi, 2019)

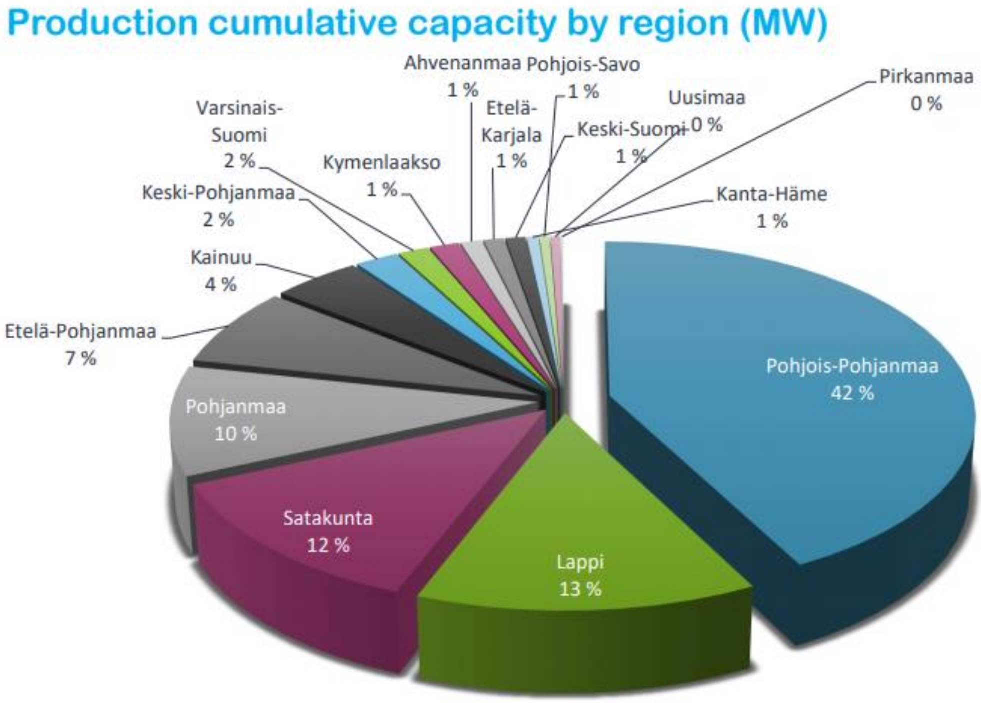


Figure 28. Production cumulative capacity by region (MW) (Finnish Wind Power Association, 2019)

10.1.3 Essentials to wind power projects

First step of planning a wind power project is to determine the location of siting. In order to keep the example as simple and easy to approach as possible, the project is theoretical, there have not been any publicized or known of plans to build a wind turbine on the selected area.

The example project was built for the area that is southern of Kaunissaari, an island nearby Helsinki, about 22-kilometer travel from Helsinki, lies at Southern Finland. The site was chosen for this project because of its decent flow of windiness annually according to Finnish Wind Atlas. Finnish Wind Atlas is a searching tool provided by Finnish Meteorological Institute, which allows us to observe forecasted wind situation like wind speed, wind power production and wind roses for 50 meters to 400 meters height. The below figures shown the location of the chosen site and windiness of the area in a 250 x 250 meters wind atlas grid, the suitable resolution for this small – scale examined project.

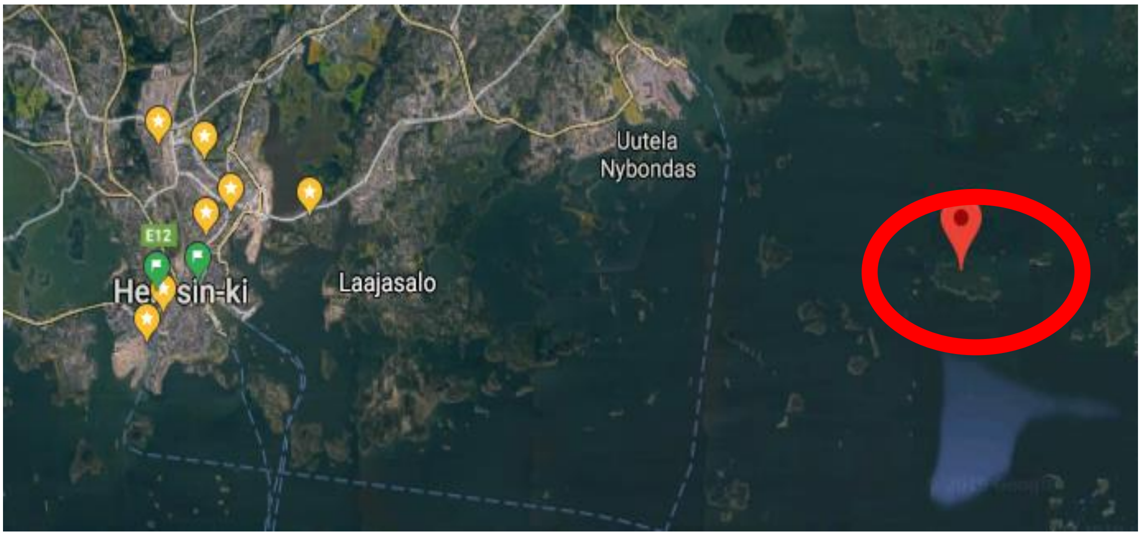


Figure 29. Wind turbine location Kaunissaari (Google map, 2019)

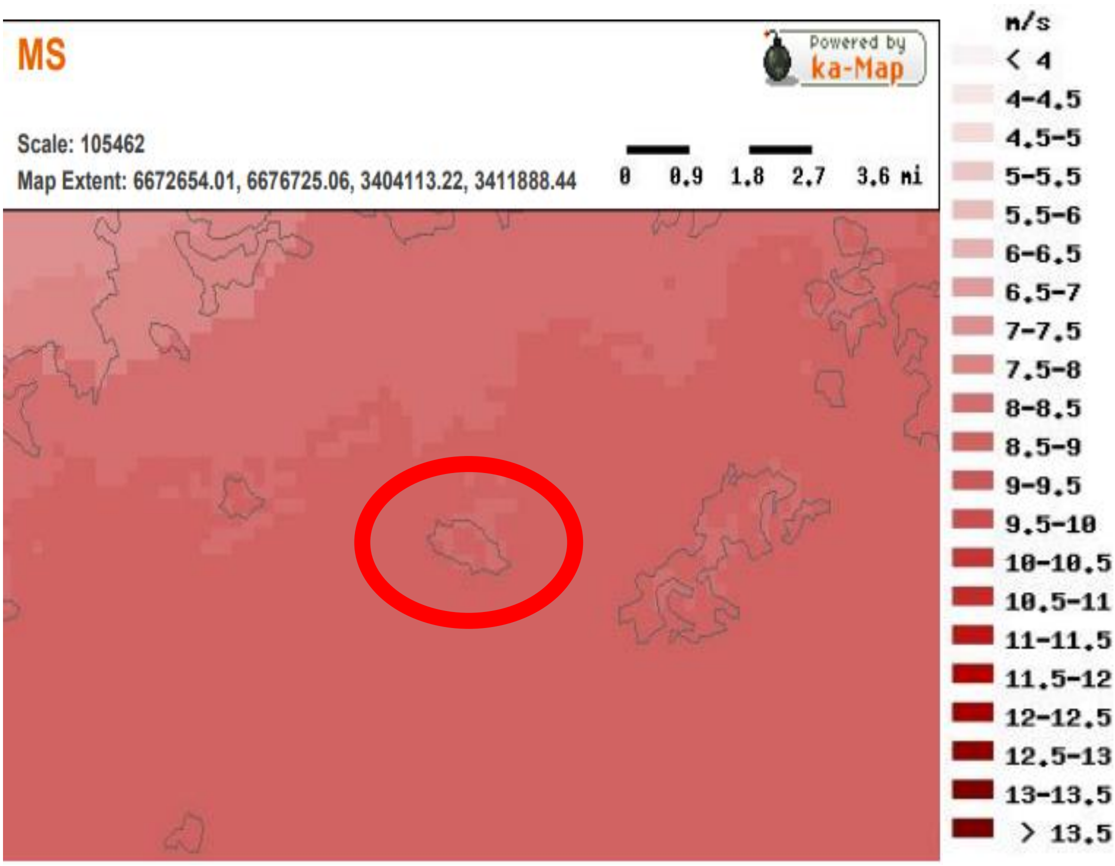


Figure 30. Average annual wind speed at the project site (Wind Atlas, 2019)

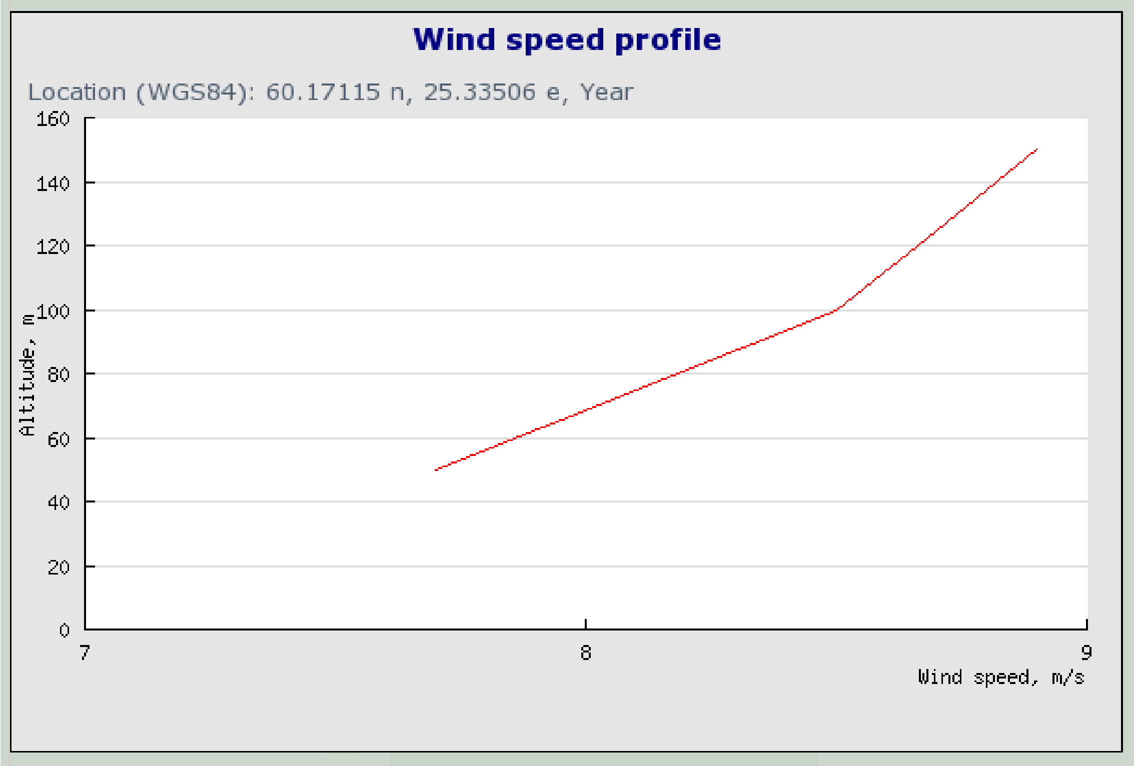


Figure 31. Annual wind speed at the Kaunissaari site (Wind Atlas, 2019)

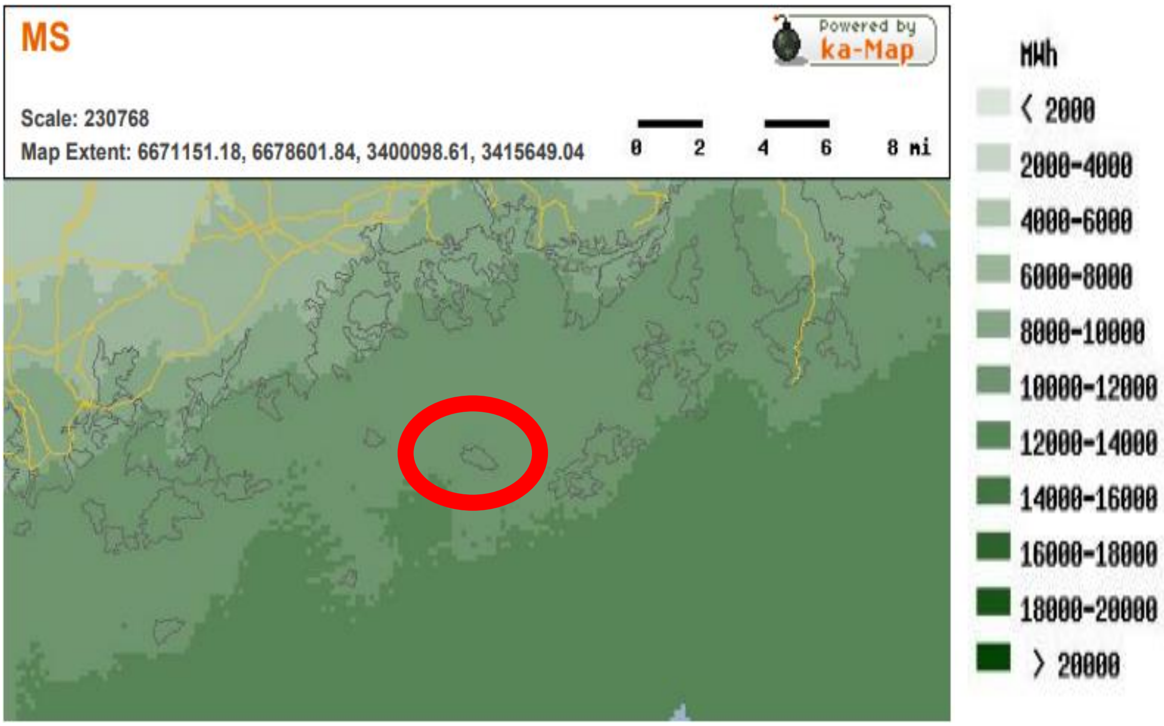


Figure 32. Average annual wind power production at Kaunissaari wind power project site (Wind Atlas, 2019)

At found from the charts provided by Finnish Meteorological Institution's Wind Atlas, Kaunissaari is a potential site which can averagely produces 10000 – 12000 MWh from the wind flow per year. According to the wind flow and expect power production of the sites, two suitable wind turbines is chosen and compared. Below is the data table of the mentioned wind turbines.

Manufacturer	Turbine type	Nominal power	Rotor diameter	Hub height
		Megawatt (kW)	Meters (m)	Meters (m)
Nordex	N80/2500	2500	80	80
EAZ	Twelve (12)	0.035	12	15

Table 8. Suitable Wind turbines data (E.A.Z Wind; Renugen Renewable Generation)

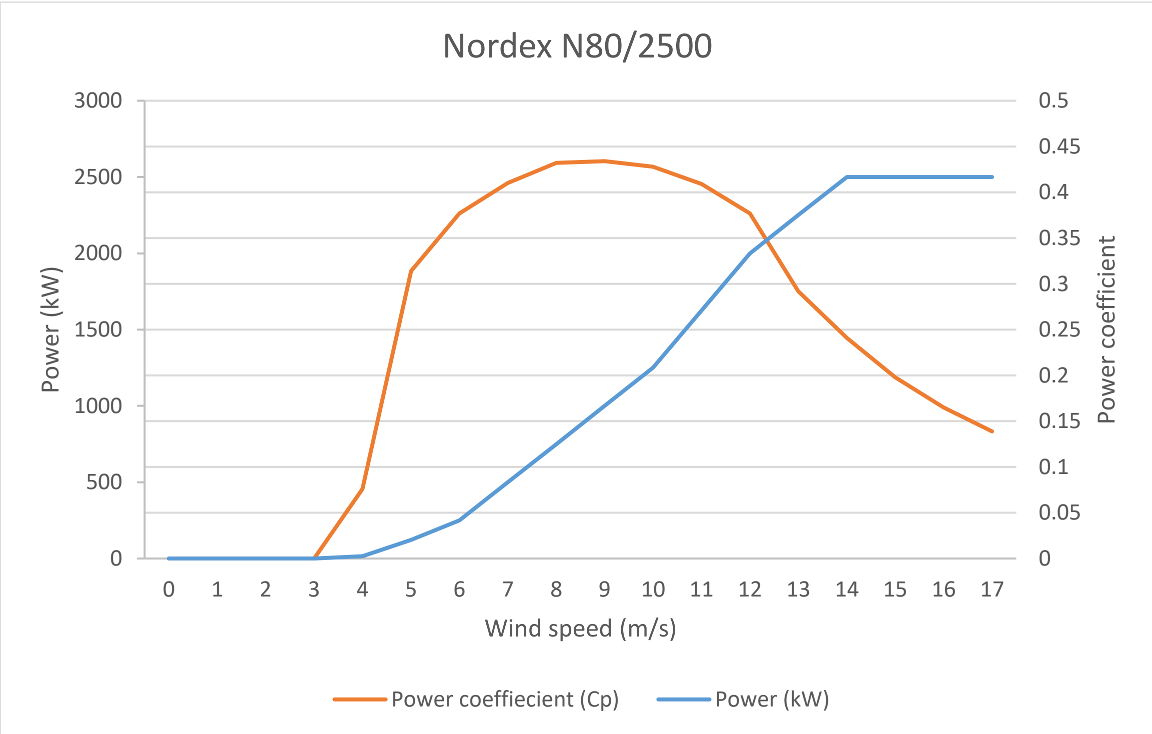


Figure 33. Nordex N80/2500 power curve

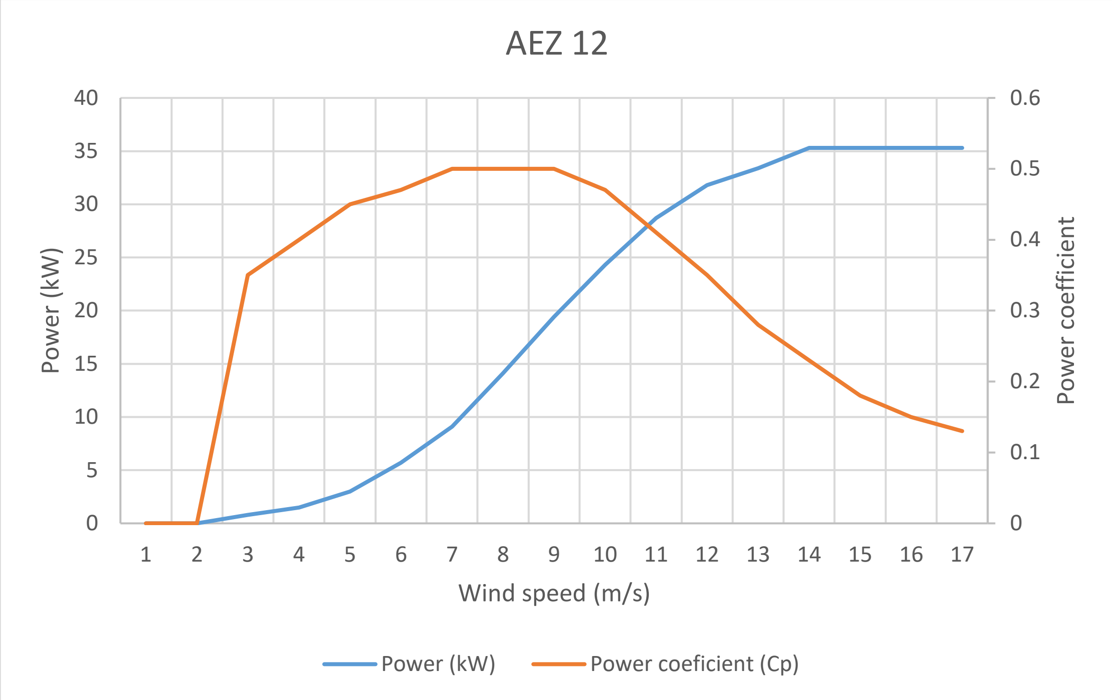


Figure 34. AEZ 12 power curve

10.1.4 Wind power projects in Finland

Laws and Regulations requirements for wind turbines siting in Finland: The building and placing process of wind turbines in Finland depends on general construction laws (Land Use and Building Acts.2003), noise level, height and sizing limitation set by municipality standard is taken into account. Building permit and action permit depend on the height of wind plant. Siting wind park or wind farm near water, residential area or sensitive area (landscape, rare plant life, preserved animal spices or areas listed in Natura 2000) is forbidden due to possibilities of causing unwanted damages or negative impacts. Environmental Impact Assessment (EIA) is a mandatory requirement for any wind power projects that need more than 10 wind turbines or the project's combined capacity is more than 30 MW. EIA is also needed for smaller – in – scale projects when their sites appear to be near environmentally sensitive landscapes. Action of contacting local authority for more information about project's requirements is recommended. (Tuomo Pimiä , 2014, pp. 62-64).

Renewable energy subsidies: The feed – in tariff arrangement offered by Finnish government and Finnish Energy Authority for Wind power, Biopower and others since 2011, under the provisions of The Act upon Production of Subsidy for Electricity Produced from Renewable Energy. For a period of maximum 12 years, electricity that is generated from Wind power source will receive the feed – in tariff on top of wholesale electricity price. The premium tariff is so called the difference of the fixed target price and the average market price for the latest previous 3 months will be paid for the wind turbines' owners. However, feed – in tariff is only valid until the target total capacity that is accepted by the feed-in tariff system has reached its maximum. (2500 MVA). The 'early bird period' for Wind power feed - in tariff was till 31/12/2015. It is necessary to applied for the feed – in tariff system in order to receive its benefits and support. For more detail about feed – in tariff system requirements and renewable energy subsidies governed by Finnish Energy Authority, please visit http://www.res-legal.eu/. You can also find out whether your projects are qualified for feed – in tariff via Quota calculator and fill out online application on SATU system at Energia webpage (Legal Sources on Renewable Energy, 2019) (Energiavirasto, n.d.).

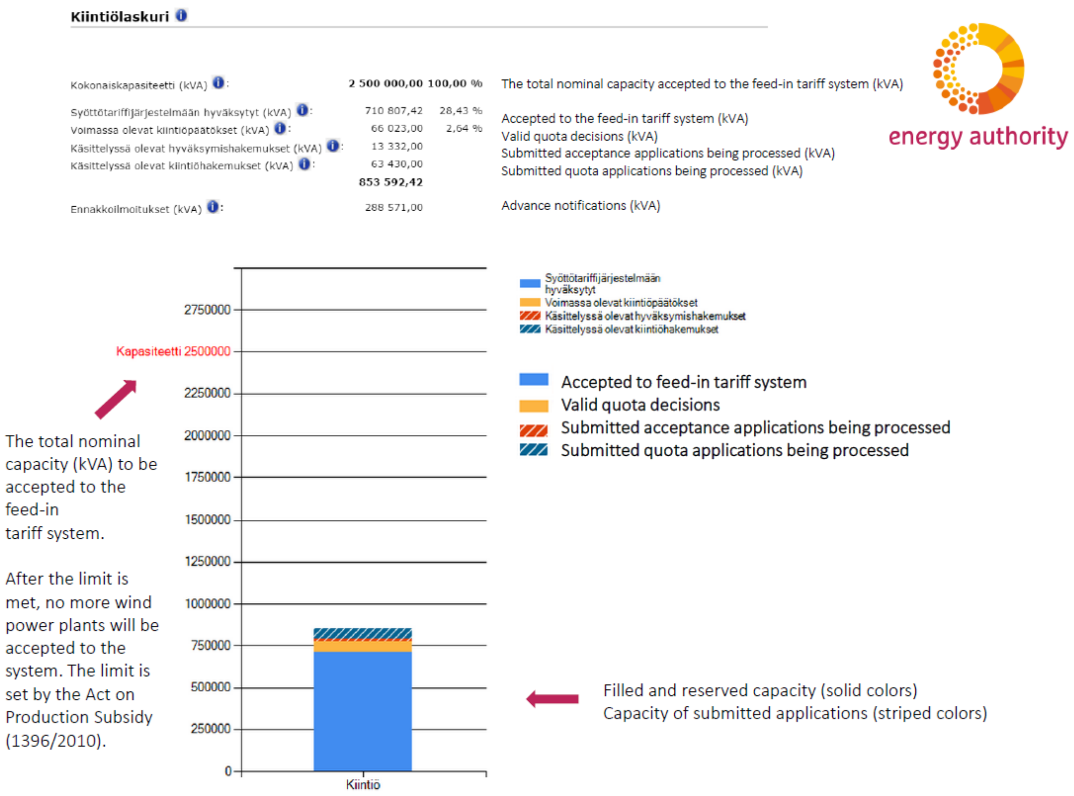


Figure 35. Quota calculator from energy authority (Energia, 2017)

Current situation of wind power projects in Finland: Apparently, Finnish wind power objective is to overcome the obstacles that are non - financial. It is facing the land use related challenges by promoting the construction of large – scale wind power projects, as in wind - farm or wind - park building plans instead of separate wind turbines or small – scale, for private used plans. As the projects' results act, its benefits will directly be considered, influenced and therefore ease the application process for land – use permit. Obviously, the surveillance radars operation may be disturbed by the construction of wind power projects. In such case, a bond or suggestion for reasonable compensation for the radar operator is a should. Fortunately, the Finnish Wind Power status in the last few years indicates the support from the government. In details, many wind power projects are researched, developed and in variable phases (planning, construction, operation), as shown in the following latest updated figures and tables.

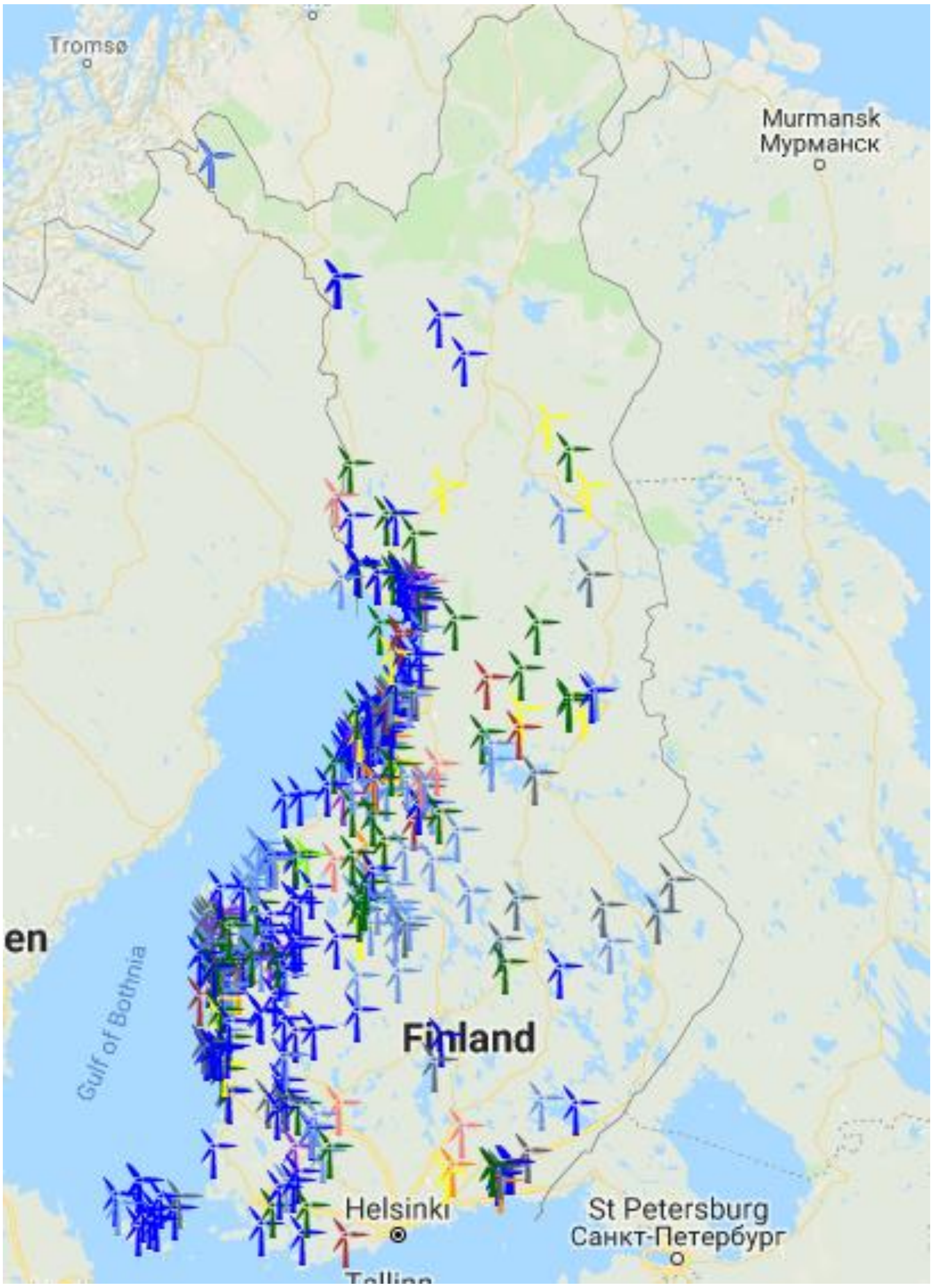


Figure 36. Wind power projects (on – shore and off – shore) distribution map (Finnish Wind Power Association, 2019)

Table 9. Public Finnish Wind Farms and Projects (Finnish Wind Power Association, 2019)

Maakunta	Region	Projects	Projects, %	MW	MW, %	Turbines	Turbines, %
Pohjois-Pohjanmaa	Northern Ostrobothnia	70	33%	7450	45%	1257	38%
Pohjanmaa	Ostrobothnia	33	16%	2297	14%	517	16%
Etelä-Pohjanmaa	Southern Ostrobothnia	23	11%	1702	10%	337	10%
Keski-Suomi	Central Finland	14	7%	359	2%	93	3%
Lappi	Lapland	13	6%	806	5%	178	5%
Satakunta	Satakunta	11	5%	872	5%	162	5%
Kainuu	Kainuu	7	3%	411	2%	114	3%
Keski-Pohjanmaa	Central Ostrobothnia	7	3%	1017	6%	260	8%
Kymenlaakso	Kymenlaakso	6	3%	178	1%	39	1%
Pohjois-Savo	Northern Savonia	5	2%	123	1%	33	1%
Varsinais-Suomi	Southwest Finland	5	2%	193	1%	54	2%
Pohjois-Karjala	North Karelia	3	1%	70	0%	19	1%
Pirkanmaa	Pirkanmaa	3	1%	62	0%	29	1%
Kanta-Häme	Tavastia Proper	3	1%	106	1%	31	1%
Uusimaa	Uusimaa	3	1%	540	3%	77	2%
Ahvenanmaa	Åland	2	1%	148	1%	56	2%
Etelä-Savo	Southern Savonia	1	0%	131	1%	29	1%
Etelä-Karjala	South Karelia	1	0%	27	0%	6	0%
Päijät-Häme	Päijät-Häme	1	0%	24	0%	5	0%
Yhteensä	**In Total**	**211**	**100%**	**16517**	**100%**	**3296**	**100%**

By March 2019, a total amount of 444,4 MW as combined capacity of 10 wind power projects have been approved and being put into construction phase. All the projects as seen in the list are confirmed to be built and developed. More information about details numerical index in excel files as in attached appendix.

10.1.5 Wind power companies and Wind turbines components manufactures in Finland

Recorded by Finnish Wind Power Association annual wind power annual report of year 2017, the ownership of wind farms or wind power related projects upon cumulative capacity, domestic ownership represents 70%, meanwhile foreign ownership takes a minor share of the rest 30%. In which the proportion of each company's wind projects origins is also shown and analysed in the below pie charts.

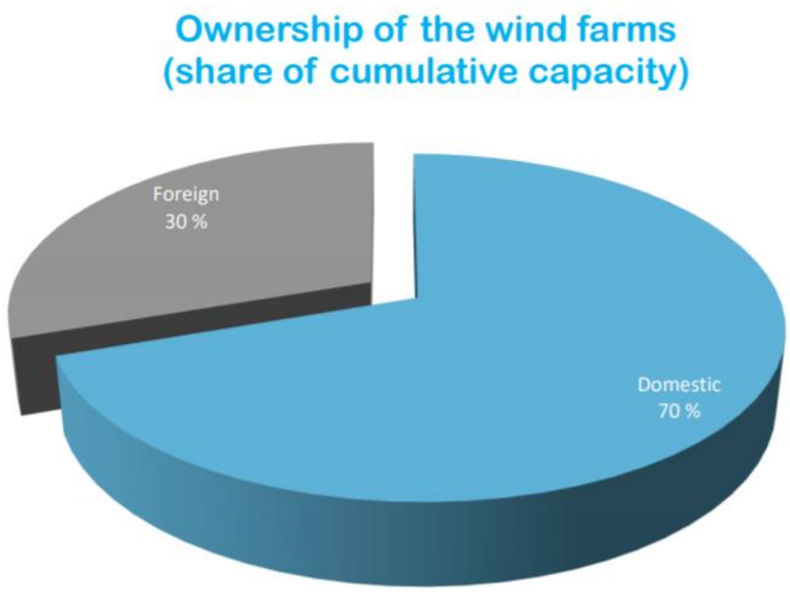


Figure 37. Ownership of wind farms (Finnish Wind Power Association, 2019)

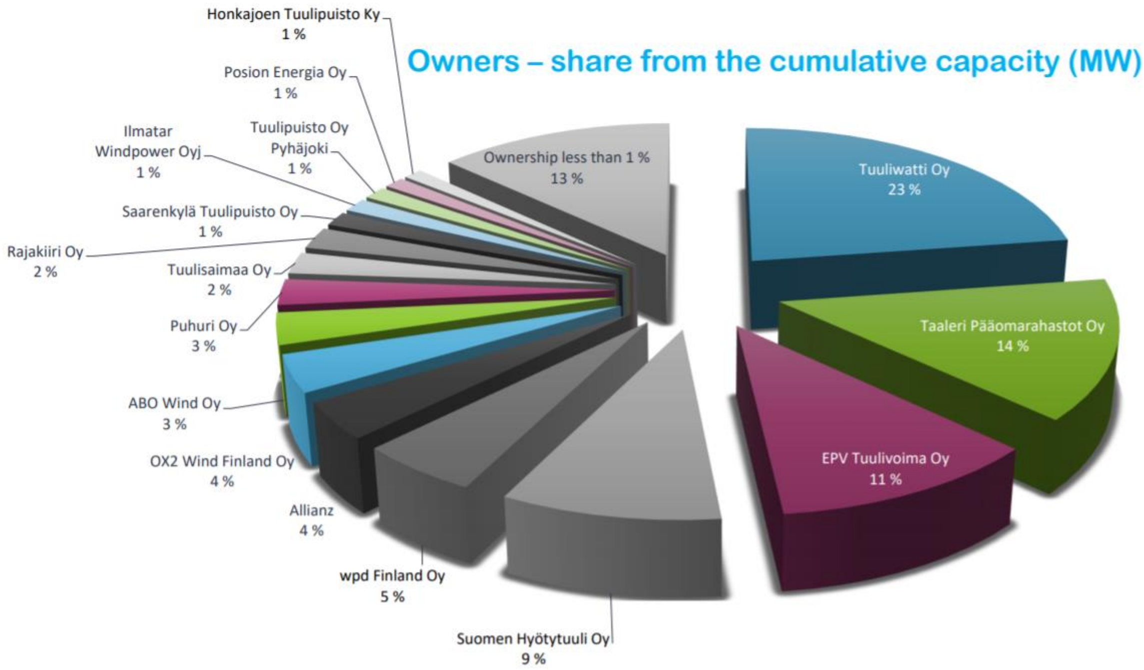


Figure 38. Wind plants ownership share (Finnish Wind Power Association, 2019)

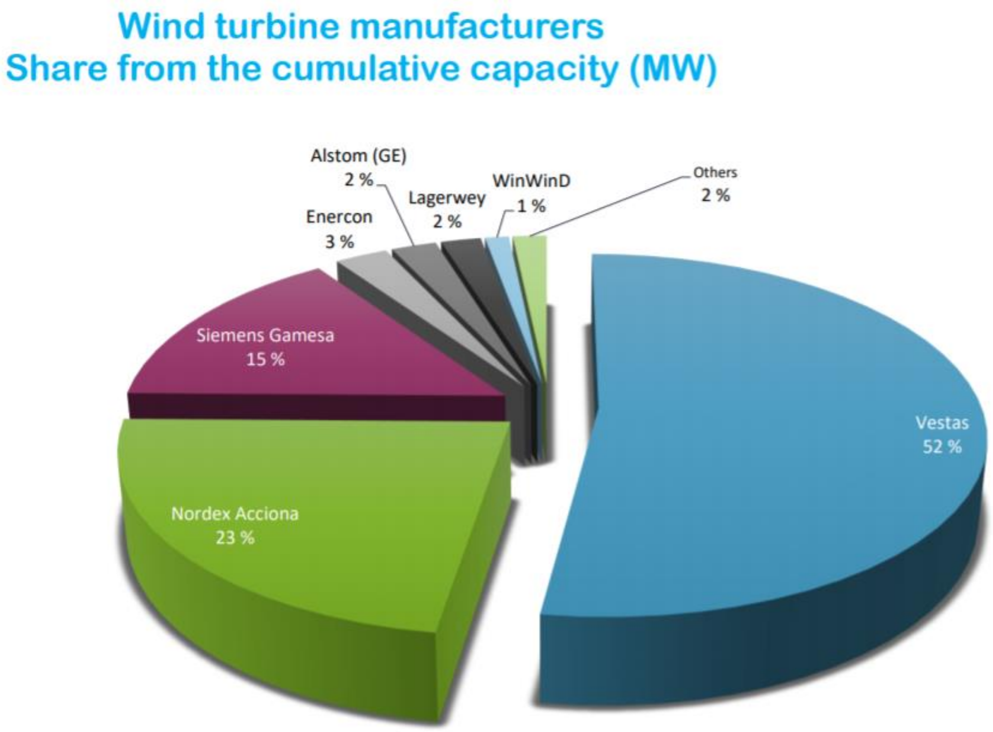


Figure 39. Wind turbine manufacturers share (Finnish Wind Power Association, 2019)

10.2 **Solar power in Finland**

As mentioned earlier that Finland has set the long-term goal to a carbon – neutral society. This explained why it has become the world's pioneer at forming and developing the habit of using renewable energy production as one of the main electricity suppliers for the consumption in national level. Besides of Wind power, bioenergy, hydro energy or ground energy (heat pump), Solar Energy is surprisingly a potential source of energy toward Finland. In this sub – chapter, we will explain why Solar energy has significant opportunities to grow in Finnish Energy market.

In Finland, the peak annual amount of sunshine hours is about 1900 hours in the South – Western maritime or nearby coastal regions, while the lowest amount is 1300 hours in Eastern Lapland. Because of the noticeable difference of Geographic Location and climate between Northern and Southern part of this country, there are considerably changes in level of Solar radiation during seasons in a year. It is considered a benefit that there is more diffuse radiation in Finland than direct radiation. When the sunlight is scattered by molecules and particles that exist in the atmosphere layer, but still being able to reach the Earth surface, it is called diffuse radiation. This type of radiation is more effective toward Solar power operating purpose in Finland since half of the combined irradiation received in Southern Finland is diffuse radiation. (Finnish Meteorological Institute, 2019)

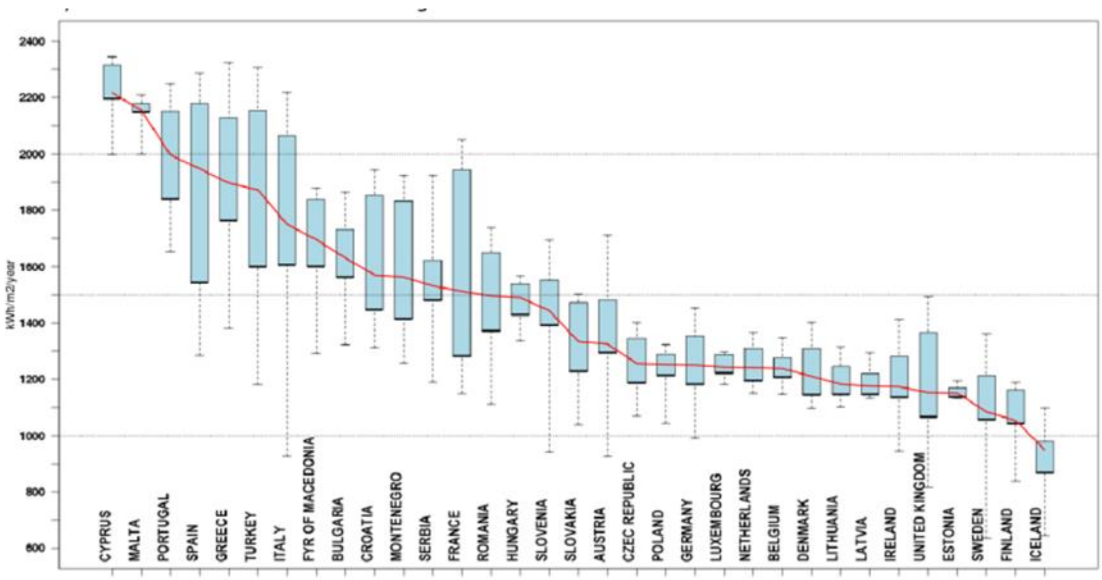


Figure 40. Comparison of global irradiation in urban areas per European countries (Huld & Pinedo - Pascua, Photovoltaic Solar Electricity Potential in European Countries, 2012)

The above chart provided by Photovoltaic Geographical Information System – Interactive Maps, represents the variation in yearly global incident on optimally – inclined Photovoltaic modules placed in urban areas of the EU – 27 and 6 candidate countries. As red line connects 33 country averages, the dashed lines indicate the range between the minimum and maximum per country. 90 per cent (90%) of the urban areas of each country have values that fall in the range of blue boxes showed in the chart. Finland's average yearly irradiation is 1040 – 1050 kWh per m^2 per year (1040 – 1050 kWh/ m^2/ year), quite humble compare to most of the other European countries (excluding Iceland), its maximum value is very close to the value of 1200 kWh/ m^2/ year. So, does this strengthen the opinion that Solar Energy is not that potential in Finland? Maybe that is a bit too early to give such conclusion.

10.2.1 Opportunities, Challenges and Solutions for Solar power in Finland

In order to develop and achieving the goal of making Solar photovoltaics one of the key sources in renewable energy system in specific and energy industry of Finland in general, there are a lot of obstacles to be removed. Not only because of its feasibility and practicality are put in doubts due to Finnish signature climate and weather but also the effectiveness and capability of this type of energy source compare to others, which has soon taken off in Finland's energy market, such as bioenergy, hydropower or wind power… Although the daily average irradiation in Finland is approximately 900 kWh/m2 (2015) and it shows that the Solar irradiation in Southern Finland and in Germany (one of the world's biggest Photovoltaics market) lies in the same magnitude band when observing the European irradiation distribution map (Pavlov, et al., 2006), Solar energy use in Finland has been very limited compared to other Renewable sources. In Finnish total energy consumption report of year 2016, the share of Solar power energy is found in "Others energy" section, approximately 0.01 – 0.02%. (Energy supply and consumption, 2017).

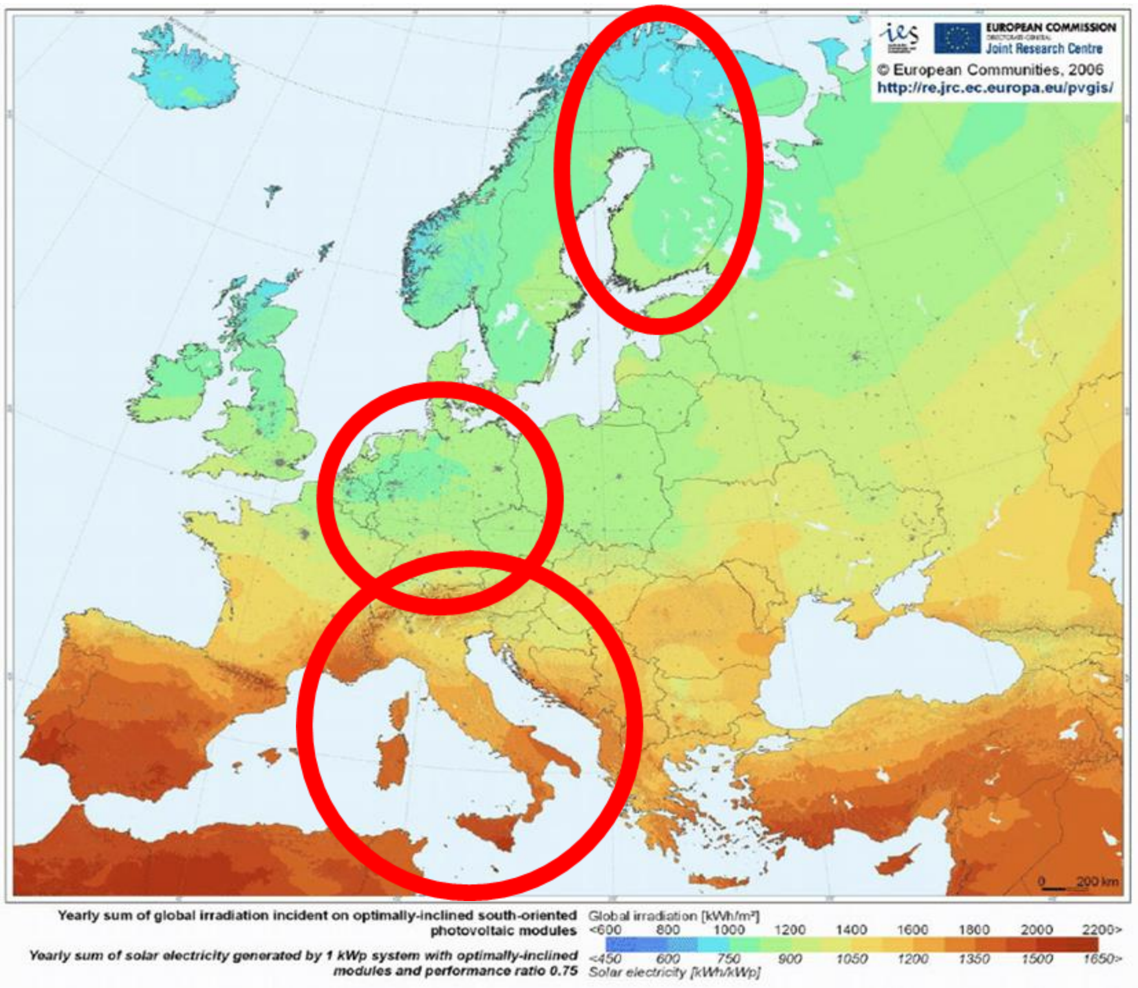


Figure 41. Photovoltaic Solar energy potential in Europe. (Pavlov, et al., 2006)

While doing some research on Finnish Solar power, we acknowledge the lack in systematic information collecting or statistic report for the use of this renewable energy source. This shows that Solar power status in Finnish Energy industry is not high. According to various sources of information, in 2013 the installed capacity in Finland is 37 MW_p and by the end of 2014, there is a total of 45000 m^2 of combined Solar collectors, which equals to 57 TJ of Solar power-based energy production per year. (Auvinen). In 2014, out of total electricity output capacity of Finland, Solar photovoltaic given only 11.38MW_e (approximately 0.1%) (Global Data/ Power Technologies, 2015). Unfortunately, there are no up – to – date research or collected data of individual or private photovoltaic system in Finland although most of Solar power projects or simply consider small – scale Solar system for individual households or groups, companies take most proportion in the share of Solar power use in Finland. By the end of 2014, there are in total 5 Photovoltaic plants which has greater than 500kW_p capacity in the summarized of about 200 MW_p Finnish national Solar photovoltaic installed capacity that time (Ahola & J., 2016). 2 largest Solar photovoltaic system installations (900 kW_p/each) that are in operation were found on the rooftop of Turku city's supermarkets in August 2017 (by the time this thesis is writing there might be some larger mounted system in Finland that theirs data or existence has not been found or collected) (NeroWatt Suomen Suurimmat Aurinkovoimalat, 2017). According to the scientific article, by the time it is written, there were some intermediate – scale Solar photovoltaic projects in power range of 8.7 MW_p in planning phase. However, the reference links that lead to those mentioned information regarding to the projects are all '404 not found' flaws at the time of writing this thesis. (Child, Haukkala, & Breyer, 2017)

There are solutions so that we can maximize the energy intake from all the available Solar irradiance we. Due to the climate and weather limitation in Finland, we can use the optimum angle calculation in Photovoltaic modules installation while designing the Solar power system for each project to reach the optimized result. The below map shows the needed Optimum inclination of Photovoltaic modules to maximize yearly energy yield.

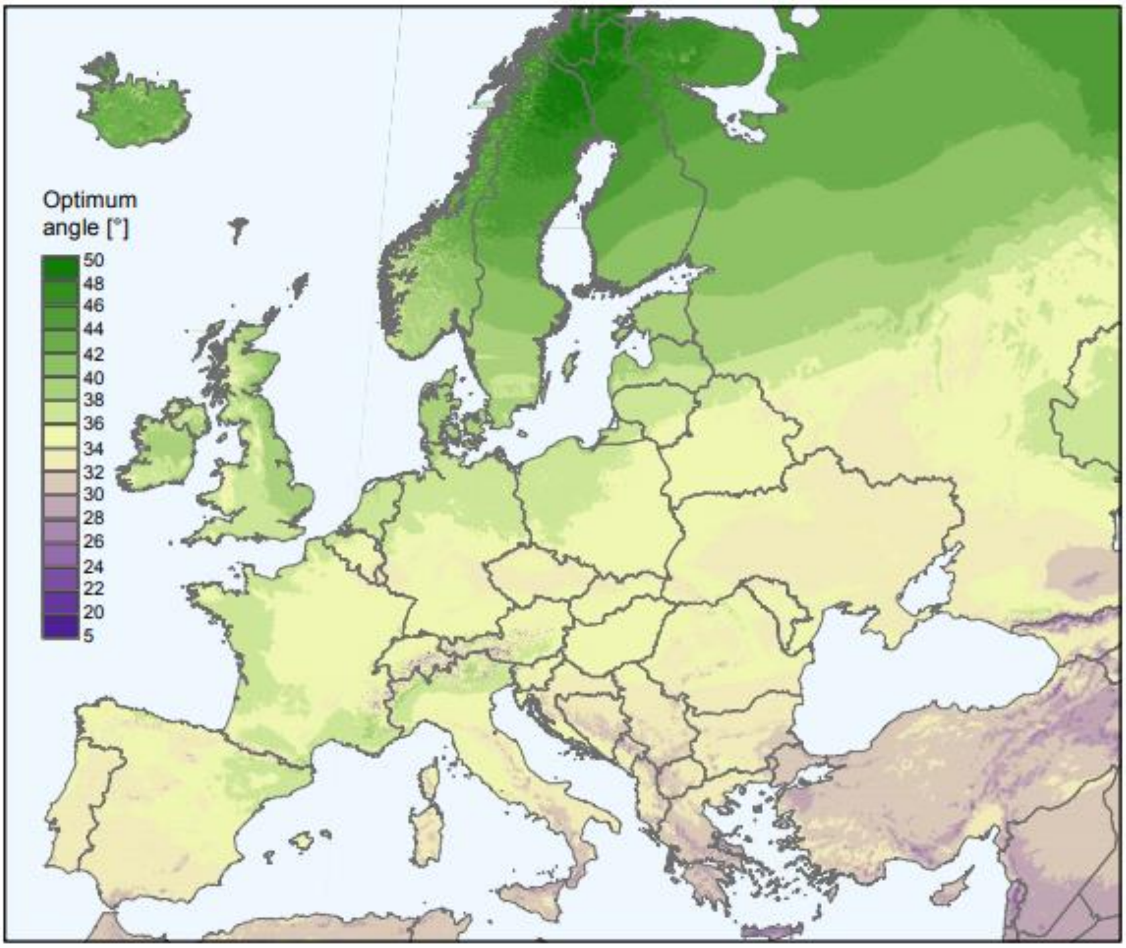


Figure 42. Optimum inclination of Photovoltaic modules to maximize yearly energy yield (Huld & Pinedo - Pascua, Photovoltaic Solar Electricity Potential in European Countries, 2012)

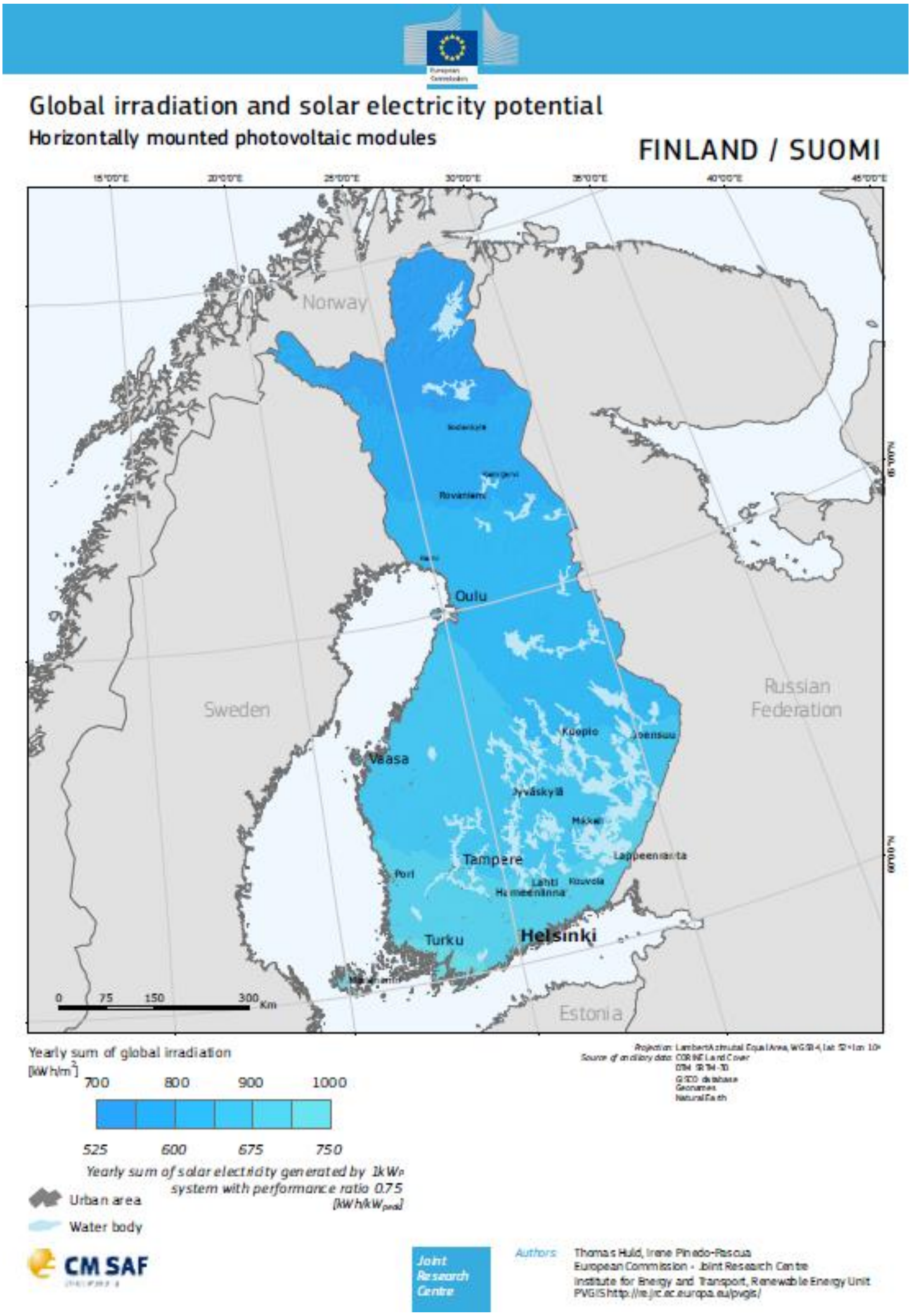


Figure 43. Global irradiance and Solar electricity potential – horizontally mounted photovoltaic modules (Huld & Pinedo - Pascua, Photovoltaic Solar Electricity Potential in European Countries, 2012)

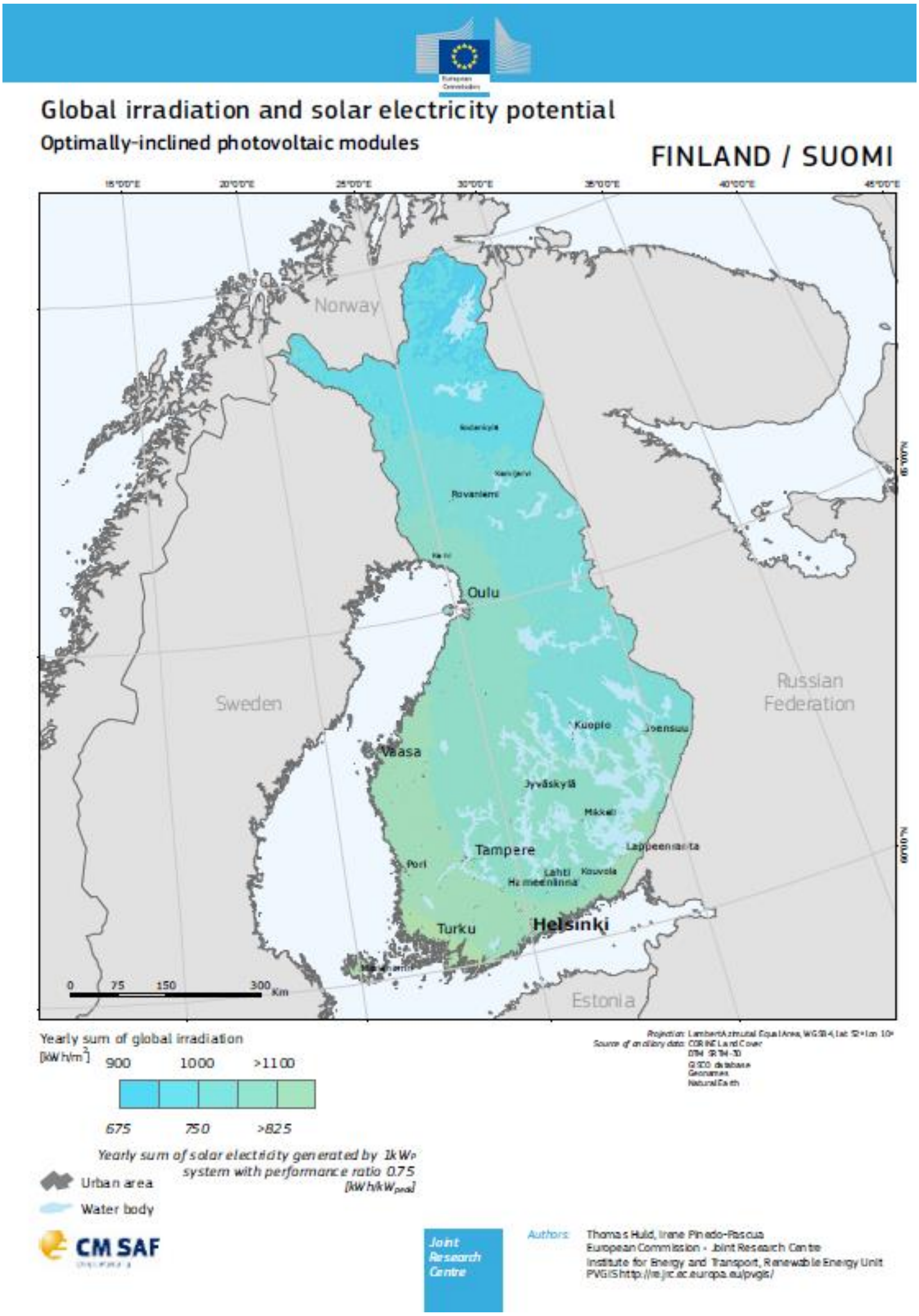


Figure 44. Global irradiance and Solar electricity potential – optimally – inclined photovoltaic modules (Huld & Pinedo - Pascua, Photovoltaic Solar Electricity Potential in European Countries, 2012)

The difference that brought out by the installed angle of Photovoltaic modules is very significant, as shown in the above maps. Taking Southern regions of Finland as an example, If the Photovoltaic modules is horizontally mounted, then the yearly combined value of Solar irradiation falls in 1000 kWh/m^2, and yearly sum of Solar electricity generated by 1kWp Solar system with 75% efficiency about 750 kWh/m^2, while its counterpart index respectively lies in more than 1500 kWh/m^2 range and approximately in range more than 825 kWh/m^2 in Solar electricity production if the angle is optimal as instructed by the map " Global irradiance and Solar electricity potential – optimally – inclined photovoltaic modules". Therefore, if the optimal inclination photovoltaic method is used while planning or designing Solar photovoltaic system, it will be very handful in a way that to mitigating the interrupted Solar irradiance and optimizing the output Solar generated electricity capacity during seasonal changes and in different latitude regions in Finland specifically and high latitude countries or countries with harsh climate in general. In order to find the Photovoltaic optimally – inclined mounted angle for specific destinations, some reliable online tools that available for free, speaking of which, for example "Solarelectricityhandbook.com". All you need is 'country, city, town and Solar panel direction' as inputs for the calculator, so that it could generate the result. Depending on the destination and difference in Solar panel direction choices, the result angle for best year – round performance varies a lot. Therefore, different Solar panel direction should be chosen and then the results should be manually compared in order to coming up with the ideal Solar panel direction as well as its optimal inclination.

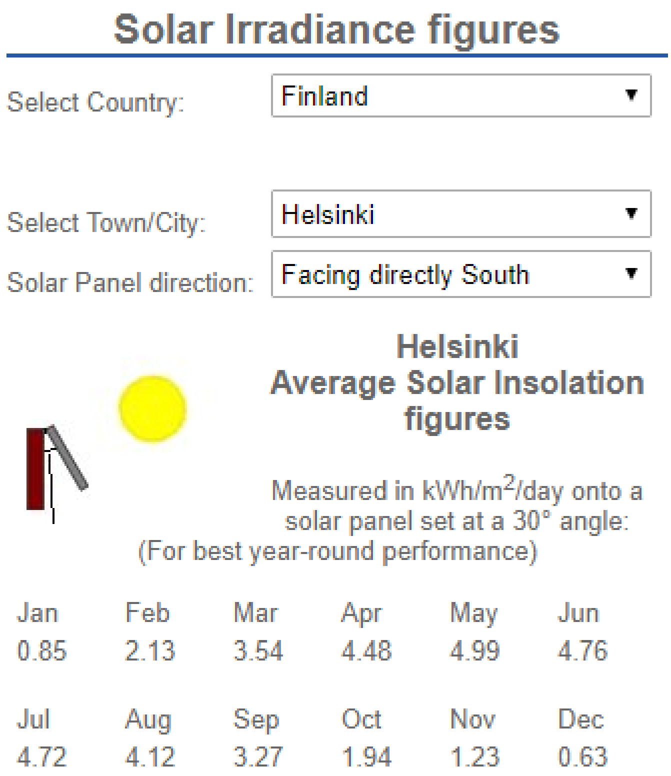


Figure 45. Solar Irradiance figure for optimal PV installation mounted angle calculator (Boxwell, n.d.)

Beside the doubts about Solar photovoltaic systems feasibility in limited weather condition of Finland, there also are barrier in developing this electricity generated technic as people concerns regarding to the use of Solar electricity during high peak season. Obviously shown that during Summer (May – June as peak in Finland), Solar photovoltaic energy systems function as its peak performance, nonetheless, in Finland, the peak electricity consumption time falls in late Winter – early Spring period, around mid-January. Reportedly, in 2014, Finnish peak electricity consumption of $14367MW_e$ on 20th January 2014 at 8 – 9 a.m. while the peak output of 13022 MW_e on 12th January 2014 (Energia. News and Publication, 2015). There is no point of using an electricity generated technology that is useless during the time that electricity consumption need is utmost. However, the fact that Solar irradiance is very high and effective scatters over the country during the months near Summer Solstices, and opposite during the months near Winter Solstices cannot be neglected. Thus, the solution of using storage technologies in daily use or seasonal basis is very useful. For example, using restored Solar energy for electricity generation during winter high peak season, or using Solar photovoltaic system and the energy storage together wind power system in the same grid modelling to support each other and optimize the results and efficiency. This is also the goal of this thesis; to research and design a smart, optimum renewable energy network that can feed small to intermediate – scale household neighbourhood in Finnish weather condition specifically and other countries with high latitude or similar limited issues. As if it works out in such harsh weather condition Finland hold, then most likely it can work out anywhere else. (Child, Haukkala, & Breyer, 2017)

In order to once again to prove that Finland indeed has the potential for Solar photovoltaic generated electricity to develop, the below chart represent the Solar irradiance amount of three (3) different European cities: Lappeenranta, Finland – Frankfurt, Germany and Lisbon, Belgium for comparison. Please note that Germany is one among the leader in Solar photovoltaic world's market.

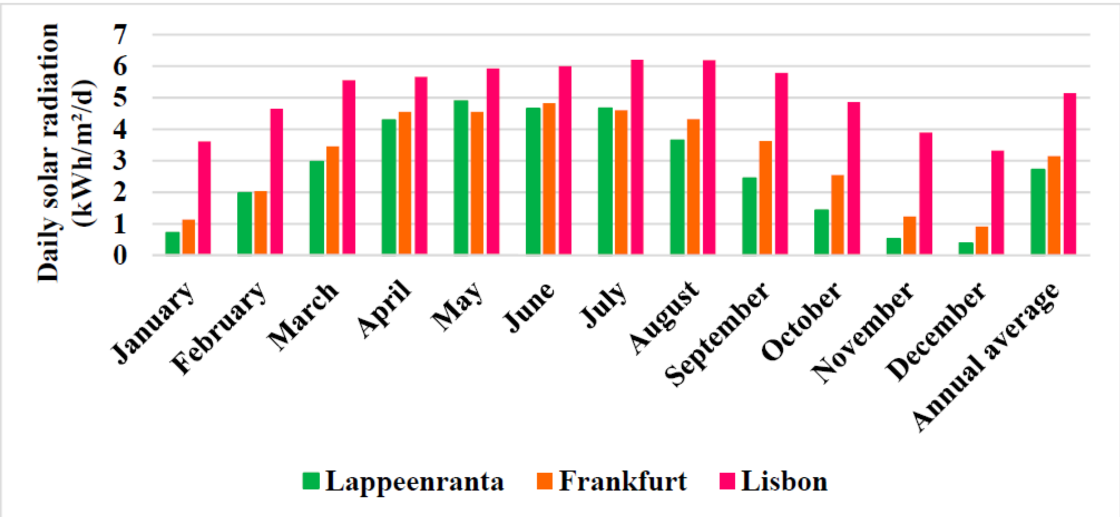


Figure 46. Daily Solar irradiance of three cities in Europe (Šúri, Huld, Dunlop, & Ossenbrink, 2007) (Huld, Müller, & Gambardella, A new solar radiation database for estimating PV performance in Europe and Africa, 2012)

According to the chart, the gap between monthly, annually average daily Solar irradiation of Lappeenranta, Finland and Frankfurt, Germany is not that big (averagely about smaller than 1 kWh/m^2/day), especially for the months near Summer Solstices, the smallest difference between Lappeenranta and Frankfurt is in June and July, especially during July, Lappeenranta city has the Solar irradiance amount slightly higher than Frankfurt city.

For the purpose of estimating the photovoltaic performance or efficiency, monthly/ daily Solar irradiation or stand – alone photovoltaic index (serve small – scale, individual use grid/ network) as accurate as possible in the limited data source situation, we have fortunately found an calculator engine supported by CM SAF (Climate monitoring company), which able to provide us free of charge complete analysed report including essential information and data for any Solar generated energy projects. This engine is simple and easy to use, yet effective and helpful.

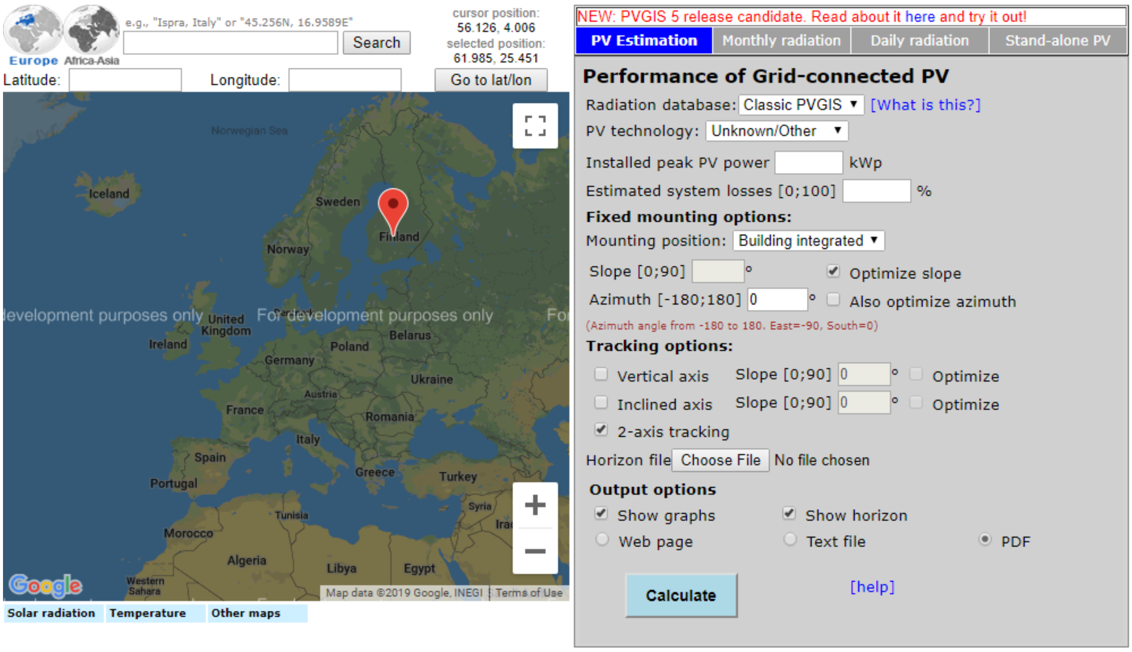


Figure 47. Photovoltaic grid performance calculator (Photovoltaic Geographical Information System - Interactive Maps, n.d.)

Furthermore, the Finnish Ministry of Employment and Economy stated that by developing technologies such as Solar energy, perhaps the goal of achieving 100% renewable energy system for Finland society could be sufficient.

10.2.2 Solar power companies and projects in Finland

As stated earlier that information related to Solar energy is very challenging to find. Since there is no systematic or statistic report or collected data in detail. Therefore, we have to look it up ourselves from variables of sources, via reports, thesis, scientific articles or researches. Thanks to the support of Theseus online library together with other media sites, we have finally come up with several of power companies that are interested in Solar photovoltaic technology.

As studying, we found out that almost every energy companies has at least one project or more that focus in developing Solar photovoltaic technology in order to produce clean and renewable energy. Speaking of which, we have:

- Sun Energia
- Aurinko Teknikka
- Green Energy Finland
- HELEN
- Savon Voima
- Elfin
- Sons of Solar
- Kuopion Energia
- PKS
- Porvoon Energia
- Tampereen Sähkölaitos
- Etc.

There are companies that specialized in developing and providing Solar photovoltaic system solution, some focus on Solar components manufacturing. More information about their services and projects could be found on their own websites.

11 OPERATIONAL EXPERIENCE IN FINNISH WEATHER CONDITIONS

11.1 Operational Experience in icing condition and in low temperature

Atmosphere icing in Nordic countries is very much a local phenomenon. Icing occurs at all existing wind farm sites in Finland and other neighbour Nordic countries: Norway, Sweden. The icing climate of different regions, however, noticeably variable. The average temperature at Lapland, Finland and Atlantic coast - two locations that share the same latitude, differ greatly due to the warming effect of the sea. Monthly average temperatures during winter are about 0◦C near Atlantic Ocean, and - 20◦C in the inland of Lapland, Finland. At can be seen that icing only occasional occur or nearly non – existent in coastal areas along Atlantic coast, whereas severe icing conditions occur at inland sites, especially those sites that located in high latitudes. However, this harsh climate does not affect the potential of wind power or Solar power in Finland that much. Although the challenging weather condition may affect the operation of the wind turbines and Solar panels itself, in this chapter we will discuss the experience of how renewable energy system function in such icing condition and low temperature and come up with solution or special equipment that may support the system operation.

It is reported that because of the server icing condition and low air temperature, the productivity of wind turbines has been lowered between 0.2% and 2.8% in total annually availability since 1997 to 2010. Depending on the year, 1 to 27 wind turbines have been forced to shut down due to low air temperature that exceed their upper limit standard working temperature per year. The average down time of wind turbines due to low temperature in the entire country period 1997 – 2010 is 123 hours, which taken up to 1.4% of the annual operation hours. The down time of wind turbines caused by low temperature that are mainly located in Northern Finland. Averagely, about 10 wind turbines were being shut down because of the low air temperature per year. Fortunately, the duration of shut down is low in Southern Finland.

Not much better than low air temperature, icing has lowered wind turbines availability approximately 114 hours per year per turbine, this equals to 1.3% of annual operation hours for those wind power plants that have been reported icing in 1996 – 2010. The productivity of wind turbines decreased due to icing condition varied from 0.3% to 4.1% per year per turbine. On average, around 16 turbines (varied from 4 to 30) has reported to be shut down due to icing annually. (Holtinen & Stenberg, 2011)

As the information and annual report of Solar energy in Finland is not yet available, it could not be found in order to show the impact of cold climate and icing condition toward the productivity of Solar photovoltaic systems in reality, but it is shown that icing and cold climate does not affect the productivity of Solar panels that much, ice covered surface of Solar panel shall be melted as it absorbs sunlight. It is proof that the Solar panels function well as long as there is Solar irradiance, no matter the weather is cold or hot. In fact, lower temperature helps Solar panels from overheating and prolong its life expectancy.

Icing on the blades cause production losses. Whether the icing condition is light or heavy, it can result in a delay or complete stop of the turbines or the PV systems, due to aerodynamic properties that is sensitive even to minor changes of the blade. Besides, glaze icing, however, may cause over production in case of wind turbines due to the delayed stall on stall-controlled wind turbines. This will also result in a turbine shutdown. Any overrated power operation may cause additional damages to the turbine components and shorter the lifespan of the generator, bearing and gear boxes.

The structural loads of a wind turbine may increase significantly due to blade icing. Ice usually sheds from the blade unevenly. This result in in undesired external loading on the turbine and imbalance, especially if the turbine is not shutdown on time and continue to operate. Extreme loads or fatigue loads can occur depending on the structure of the turbine and icing events.

The solution for this is ice – throw. However, the risk of ice throw is required to follow the health and safety and public safety. Risk analysis is needed by authorities, in which measured wind speed, direction and icing data should be included in purpose of defining the risk area around each wind turbine site and areas under Solar photovoltaic systems installation.

11.2 **Standards, requirements and solutions**

11.2.1 Wind turbine certification

Certifying wind turbines for cold climate regions requires reliable procedures for the prediction of the amount of ice accretion during standstill state and operation state. While the IEC – 61400 – 1 Wind turbines – Design requirements recommends taking ice loads into account, nonetheless the special load case is not given and there are no minimum ice load requirements are given as a standard. However, standardization work is going on and the maintenance group for revising the IEC – 61400 -1 version 3 to version 4 has recently started working and is planning to include ice load cases to the standard. (IEC Standard 61400-1 Design Requirements, 2005)
Furthermore, Germanischer Lloyd requires two icing cases must be considered when designing a wind turbine: for rotating parts and non – rotating parts. For rotating parts, the two cases are "all blades covered with ice" and "all but one blade iced over". Icing of 30 mm for all exposed parts must be taken into account for non – rotating parts case.

The standard IEC – 61400 – 3 Design requirements for offshore wind turbines, give in its informative Annex E recommendations for design of offshore wind turbine support structures with respect to sea ice.

11.2.2 Power performance measurements

international standard IEC-61400-12-1 Power performance measurements of electricity producing wind turbines states mostly indirect requirements and restrictions to power performance measurement in cold or icing climate:

- The standard requires that measurement data is obtained during normal operation of the turbine; data sets where external conditions other than wind speed are out of the operating range of the wind turbine shall be excluded from the power performance data set.
- The standard allows setting up a special data base for power performance measurements collected under conditions other than normal operation conditions. The special data base can be used when the purpose of the power performance measurements is to represent other than normal operational conditions. This data base and power performance calculations based on it shall be clearly marked to prevent confusion with figures of normal operation of turbine.
- The standard requires that anemometers used in power performance measurements are classified. The classification of anemometer should allow cold climate usage when operating in cold climate region. Anemometers which are classified for cold climate usage can be difficult to find.
- The standard sets requirements for air density measurements: both instruments and mounting suitable for cold climate and icing

conditions shall be used when air temperature and pressure are measured for air density calculations. Instrument has to be mounted in a way that possible ice and snow do not lead to malfunctioning of the instrument.

One, but maybe not so novel, way to deal with these issues is simply to exclude all the data where temperature is for example below +2 °C. The problem is that many times the winter is the windiest time in a year and because of such data exclusion the time period needed for complete power performance measurements might become too long or even impossible because of the lack of the highest wind speeds.

Another possible way to manage these problems is the use of reliable ice detector. If operator can be sure that neither the turbine nor the instruments are iced, power performance data can be included in the data base. This requires that the conditions are inside of the turbines normal operation conditions and instruments are suitable to these conditions. Extra care shall be taken when this method is utilised.

In addition, a new informative appendix for the IEC-61400-12-1 has been proposed which would describe how to include temperatures below 0 °C to the power performance measurement data base. (IEC Standard 61400-1 Design Requirements, 2005)

11.2.3 Solutions

To help minimize the operational difficulties for wind turbines in icing conditions and cold climate, some special technology could be used.

Sensors

Sensors for measuring wind speed, wind direction… are key opponents in wind energy technology. They are used for site assessment and turbine operation. For turbines operation in cold climate, the following sensors, combination of sensors or sensors and procedures are used for wind measurements and ice detection. It works so that the sensor in rotor blade monitoring systems measure the oscillation of blades, the normal frequency is detected when in ice free operation while the unusual frequency means damage has happened or icing on blade.

Thermal anti- and de-icing system of wind turbine rotor blade

This basically means that we use warm air circulation inside the wind turbine rotor blades to de-ice it. It shows that it is necessary to add thermal anti and de-icing system at sites that experience all-year-round icing such as inland Lapland or even higher latitude areas, or sites that has high safety requirement. The result of thermal anti – and de-icing system is really helpful, so that on perform tests, approximately 50% increase yield on the 5-month testing period was reached compare to other turbines without de-icing systems.

Anti-freeze coatings for rotor blades

This works in similar principle to anti-freeze spray that we use for our vehicles during winter. This has been tested widely for the recent time. However, the results show that it is not effective and has not meet the demand.

Low temperature materials and lubricants

Most turbine manufacturers offer products or upgrades to products for cold environments. The use of cold resistant steel in all structural members with welds does not increase the costs significantly. Standard hot-dip galvanized bolts have proven adequate in low temperatures.

In the area of lubrication and hydraulic oils, similar practical work has been conducted though few scientifically based reports are available. In all cases synthetic lubricants that are rated for cold temperatures should be used. All manufactures recommend specific lubricants based on their particular turbine design. In most cases these lubricants have been tested, but the operator is encouraged to obtain specific certifications prior to their use. (Ronsten, et al., 2012)

12 DIFFERENT SETUPS

12.1 Analysis and comparation of different cases

After studying and considering the weather condition, siting position, and other important influences, we have finally come up with 2 different cases of network set ups. Attached in the appendix section is financial overview of the cases

12.1.1 Case 1

The cost needed to setup the project in the first case is 2 463 988,60 €. It has an annual write-off of 184 829,31€. This makes an electricity price of 0,28 euro per kWh.

The Nordex N80/ 2500 wind turbine is very cost effective. It produces a lot of power for low cost compared to the EAZ 12 wind turbine.

While the Nordex N80/ 2500 produces a decent amount of energy compared to the EAZ 12, Nordex needs a higher cut in wind speed to produce stable energy output.

- Less reliable when in region with small wind speed.
- In Finland, according to the Finnish wind atlas, the wind speed fluctuates a lot in different seasons, and depend on the geographic locations, Nordex N80/2500 will have reduction in efficiency compare to coastal regions.

The state of charge of the batteries is more stable. This makes the batteries last longer because it has fewer cycles. The generator will have to operate for shorter period because there are fewer moments without any power in the batteries.

One large wind turbine is placed far away from the houses, so it does not disturb the neighbourhood. In case where many small wind turbines are used, more space will be required, and the wind turbines must be placed closer to the residential areas since the wind power site area stays constant.

The Nordex N 80/ 2500 with the rotor diameter of 90m required 450m distance between other wind turbines. This is a high distance requirement.
While the EAZ 12 with the rotor diameter of 12m required only 60m distance between each other.

The large wind turbine with high output capacity will produces a great amount of energy, even when the batteries are full, this will cause waste of energy.

The whole set up is highly dependable on the wind power of one turbine if we use such high capacity wind plant Nordex N80/ 2500. This will result in energy shortage in case of sudden wind turbine failure or during maintenance.

Thus, we have come up with an idea so that in which we use both Nordex N80/ 2500 turbine and EAZ 12 turbine and some extra Solar panels as support system. This combination of both Nordex and EAZ wind power plants will reduce the flexibility of the space distribution and housing plan of the project. The solution has eased the down sides of itself to minimum.

12.1.2 Case 2

The EAZ 12 can produce energy at the minimum wind speed of 3m/s. This will have advantage over the Nordex in regions with low wind speed.

The usage of 40 wind turbines will reduce power shortage during maintenance time/ downtime and failure.

The required distance of 60m between each wind turbine will bring more flexible in the set-up of the project.

Compare to case 1, case 2 will have higher price due to many factors: higher maintenance cost, total cost of the wind turbines etc…

Requires a total of 975 hours of generator usage resulting in higher fuel cost.

12.2 **Case summary**

Table 10. Comparison of the two project cases

Case 1	**Case 2**

Pros	
Provide decent amount of Energy	Provide suitable energy output.
More stable chart.	More flexible in space plan.
Cheaper cost.	More reliable in case of turbine failure.
Cost less space.	Production and use are better tuned
Less depandable on the generator	

Cons	
More wasted power	More expensive
Dependent on one wind turbine	Less stable chart.
Require high wind speed	Many generator hours usage.

Evaluation:

Case 1 is a combination of wind turbines set up (1 Nordex 2500 and 6 EAZ 12) together with 2000 Solar panels with the total cost of 2 463 988,00€ (electricity price of 0.28 Euro per kWh in 20 years life expectancy of the project).

The high production of energy (mainly because of Nordex N80/ 2500's power output) and decent energy of the Solar panels maintain the system sustainability for each year, we can see this in the stable of the SoC chart and small amount of hour usage of the generator attached in the appendix section.

The dependency on the wind turbine for power sustainability will result in power shortage during downtime (maintenance, sudden failure). Even so, the combination of case 1 still is feasible and a lot more cost - effective than case 2.

- ⇨ Case 1 of the project cases is chosen for its cost effective and feasibility.

13 COST ESTIMATION AND ECONOMIC ANALYSIS

13.1 Wind power project costs

The wind power project costs are the combination of wind turbine cost, the transportation fees, installation cost, operate costs and maintenance cost. Besides from all those mentioned above factors, available government subsidies should be studied. Economic analysis should be made based on given index, and should be compare to, for example, price of electricity grid or other means of electricity producing. Below provided the explanation of wind turbine project costs.

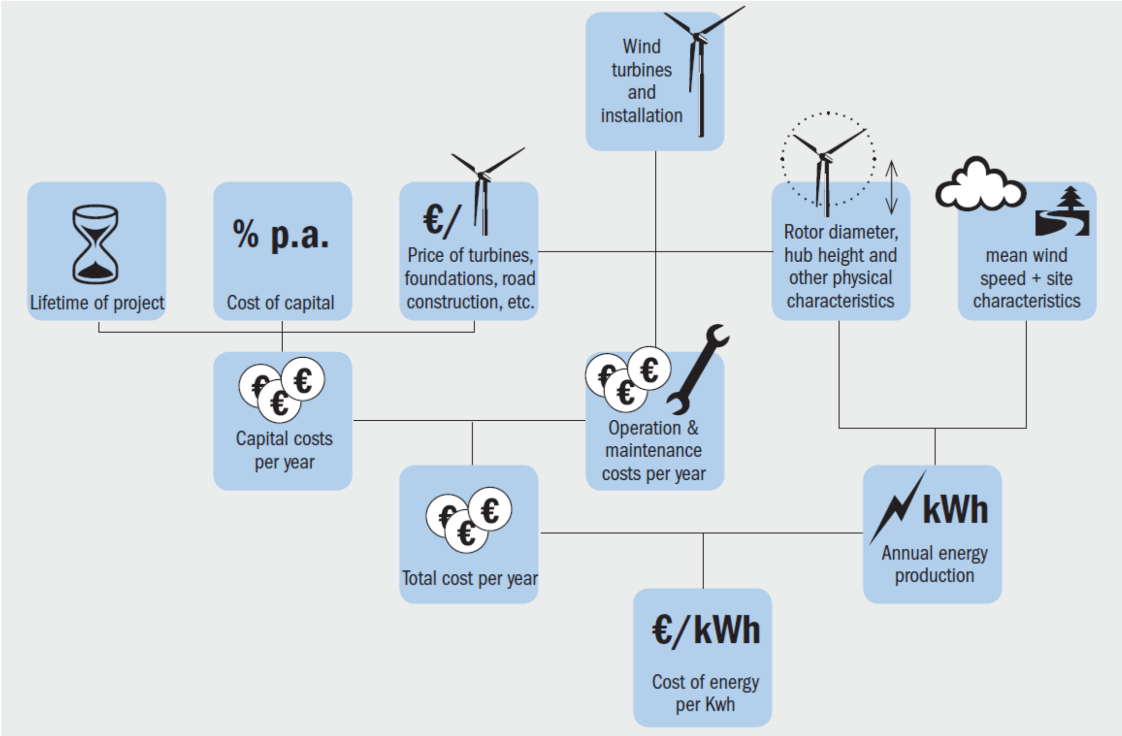


Figure 48. The wind turbines project costs. (Morthorst & Awerbuch, 2009, p. 30)

The economic analysis is done using financial calculations. Later on, in this chapter, these financial calculation methods will be explained in detail.

13.1.1 Wind turbine and turbine installation costs

Normally, a wind turbine comes to the ordered place in individual components and then will be assemble later. Some small wind turbine can be transport to desired location in assembly form. The cost of a complete wind turbine consists of essential components' costs. What most important for the turbines and represent significant high proportion in share cost of a wind turbine are transformer (26%), rotor blade (22%), gear box (13%), nacelle housing (11%). Knowing the components share costs is important since it does directly effect to the maintenance cost of the wind turbines.

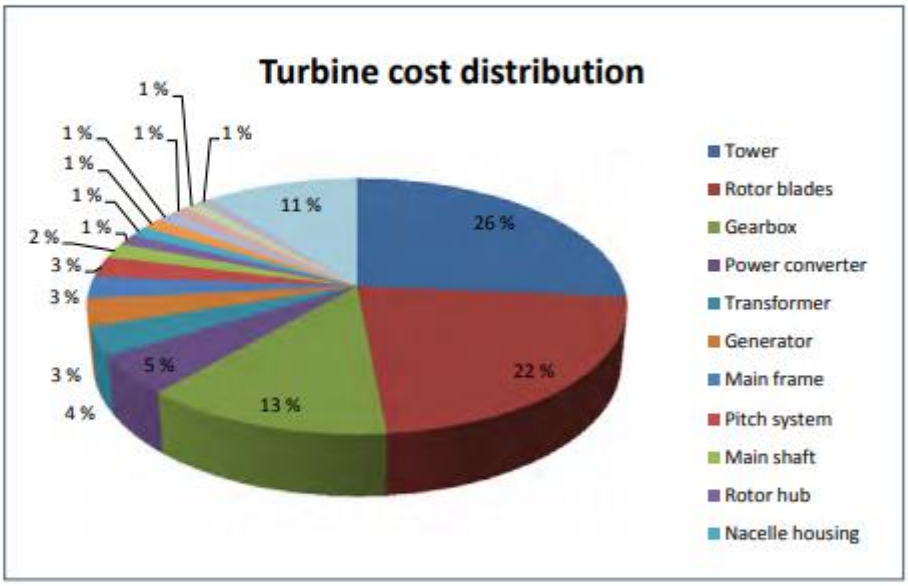


Figure 49. Wind turbine cost distribution (Morthorst & Awerbuch, 2009)

The price of wind turbine that is offered by manufacturer or suppliers normally does not include all of the essential components that is critical for wind turbine installation and grid connection. This makes the process of price comparing in financial calculations phase more challenging. Sometimes, even the wind power plant's tower can be excluded from the price. This completely depends on the manufacturers/ suppliers. The frequently challenging factors could be encountered are shipping cost, foundations, and so on. The shipping cost can be surprisingly high, depend on the location of the shipping address and how convenient it is to transport the wind turbine from the warehouse to installation site. The foundations always end up with extra expense top up to the total cost for only the installation of the wind power plant. In general, the installation costs vary depending on the wind turbine sizing, installation location and difficulty (if capable) of the installation. Following is a pie chart that show a break down by cost factors in small wind turbine installations in Europe.

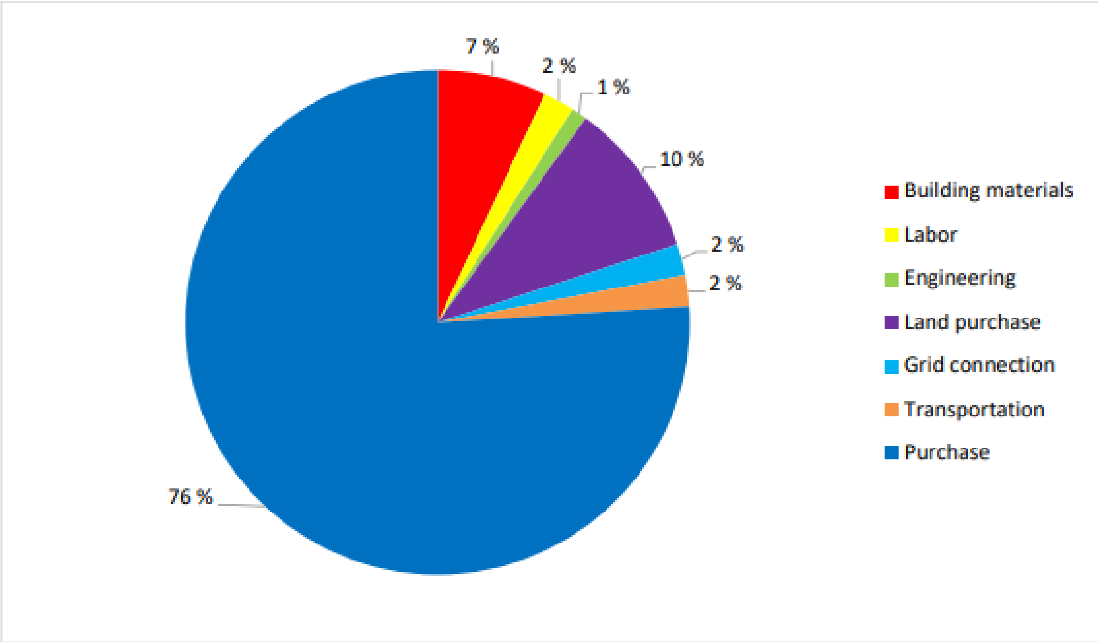


Figure 50. Average cost distribution of Wind Plants Installation in Europe (Bortolini, Gamberi, Graziani, Mazini, & Pilati, 2014)

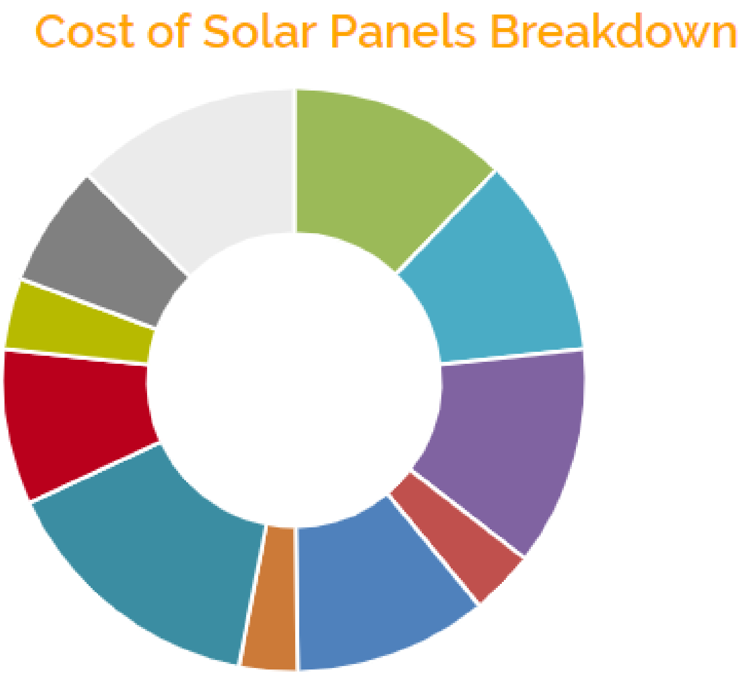
The total estimated installation costs based on wind turbine market falls between 1500 – 8000 €/kWh. As seen that the range gap is quite weighty, which makes the comparison of product cost very challenging. Basically, cost per kWh increases when the power produced by wind turbines decreases. As a result, it is most effective to gather quotations from products that fit the installation and then use those prices to make more detail assessment of the costs. (Leppänen, 2016)

13.1.2 Maintenance cost

Operation and maintenance costs are annual expenses that needed to be extracted from the annual income. As there is no fuel needed, wind turbine operation cost does not affect profits much. Mostly, the costs for maintenance jobs are majority. Maintenance job included checking, repairing, replacing and servicing the system. Manufacturers often recommend annual maintenance service, but there are always exceptions and differences depend on the manufacturers and suppliers. Average maintenance costs on average operation is around 650€.

13.2 **Solar photovoltaic system costs**

The cost of Solar panels consists of two major forms of costs: “hardware costs” and “soft costs”.



Item	Cost per watt	Legend
Profit	$0.34	
Overhead	$0.31	
Customer acquisition (Sales & Marketing)	$0.34	
Permitting, Inspection, Interconnection	$0.10	
Installation labor	$0.30	
Sales tax on equipment	$0.09	
Supply chain cost	$0.42	
Electrical BOS	$0.24	
Structural BOS	$0.11	
Inverter	$0.19	
Module	$0.35	
Total	$2.80	

Figure 51. Cost of Solar panels (Sunmetrix, 2019)

Components such as Solar modules, inverters, racking systems or other electrical and structural components are considered as hardware components. The costs of hardware components nowadays take about 32% share of total cost of Solar photovoltaic costs.

Soft costs consist of labour, contractor profits, contractor overhead, customer acquisition costs. These factors characterize about 68% of the installation cost.

Compare to wind power system, the maintenance cost for Solar photovoltaic is quite lower and more affordable. As researched from the recent Solar service market, depending on the Solar panels mounted positions, the height of the installations, the number of panels that the cost for annual maintenance are typically around 150 - 350€ including checking, and cleaning.

13.3 **Project case costs**

To find out how feasible this project is, the price of all components was looked up and put into the excel file for calculations. The maintenance cost and operation cost for components were put into the calculations. With these results, the total Capex and Opex were calculated.

The Capex is the investment cost needed to be paid before the project started. The Opex is the cost required to keep the project operating, consist of maintenance and fuels cost. The life expectancy was also taken into consideration as input for calculations.
With the achieved values from former calculations, the write-off per year, the total yearly price and price per kWh was calculated. Especially, in our case, as to make economical comparison, the price per kWh is an important value to compare its financial efficiency with other energy sources like electricity from the grid. We need to make the calculations for project case 1.

Case 1 is a combination of 6 wind turbines set up (1 Nordex N80/2500 and 6 EAZ 12) and 2000 Solar panels with the total cost of 2.463.988,00 Euro (with the price of 0.28 Euro per kWh in 20 years life expectancy of the project).

The high production of energy (mainly because of Nordex N80/2500's power output) and decent energy of the Solar panels maintain the sustainable of power system for each year, we can see this in the stable of the SoC chart and small amount of hour usage of the generator.

The dependency on the wind turbine for power sustainability will result in power shortage during downtime (maintenance, sudden failure). Even so, the combination of case 1 still is feasible and a lot more cost-effective than case 2.

Table 11. Cost estimation for project case 1 (project's Excel document)

Unit	Amount	CAPEX / Unit (€)	Total CAPEX (€)	OPEX / Unit / Year (€)	Total OPEX / Year (€)	Operating time (year)	Write-Off (€/year)
Wind turbine							
Nordex 25000	1	405,526.38	405,526.38	4,055.26	4,055.26	20	24,331.58
EAZ 12	6	45,000.00	270,000.00	562.50	3,375.00	20	16,875.00
Solar panel							
TP 660P	2000	108.00	216,000.00	5.00	10,000.00	25	18,640.00
BenQ Solar Sunforte PM096B00	0	318.00	-	5.00	-	25	-
solar converter							
Sunnyboy 7700	43	3,020.00	157,053.31			20	7,852.67
Battery							
Iron Edison	200	5,700.00	1,140,000.00		-	142	8,010.05
Battery converter							
Sunny Island SI-80H-11	52	3,470.00	180,455.29		-	20	9,022.76
Generator							
Doosan P222LE-S	1	113,980.00	113,980.00	300.00	300.00	30	4,099.33
Fuel	79300			1.35	107,055.00		107,055.00
Power cable							
Draka TFXI	500	173.00	86,500.00		-	50	1,730.00
Total			2,569,514.98		124,785.26		197,616.40

13.4 **Project set up case income**

When the wind blows meet the cut in speed, the wind turbine starts to operate energy. The generated electricity then is used on site or transferred to electricity grid. As a result, if the production of electricity from wind power can replace another electricity source, the reduced spending on electricity consumption is considered as income. Since the price established from the electricity which fed into the grid is low, it is normally more beneficial to replace the energy as much as possible. The price is offered by electric company and varies a lot. Also, it often does not exceed half of their wholesale electricity price. Thus, it is indeed very important that the designed system can reach the demand. (Abraham, 2014, pp. 28-30)

In Finland, the consumer price of electricity is the combination of electricity price, transmission fees and taxes. Electricity price inclines to swing hour by hour, depending on supply and demand. The Nordic Electricity market has been combined together since 1990’s and become the Nord Pool electricity market with the intention of compensate the electricity price fluctuation and the difference in electricity supply and demand in Nordic countries. Which means that electricity can be sold and bought between Nordic countries. Since 2011, Baltics countries has been accepted as a part of Nord Pool market. This is also an ease of economic competition for renewable energy when reaching out of energy market in partial Europe. Average cost of electricity in Nord Pool market in 2015 was around 21€/MWh. The price of electricity transmission is set by the grid owner. The electricity transmission varies in every location and tends to be higher in remote areas then in rural areas. An average Finnish urban family that consumes 5000 kWh annually, the transmission fees lies about 50 €/MWh. Taxes also plays a major role in the electricity consumer price. There are two different types of taxes for electricity: electricity tax and value – added tax, these taxes make up to 34% of the total electricity price, such a great proportion. At this time, electricity costs somewhere in between of 12 and 15 cents per kWh depending on the annual usage. In 2015, an average Swedish household paid 18.7 cents per kWh and Norwegian household 14.3 cents per kWh for their electricity. (Leppänen, 2016, pp. 70 - 71)

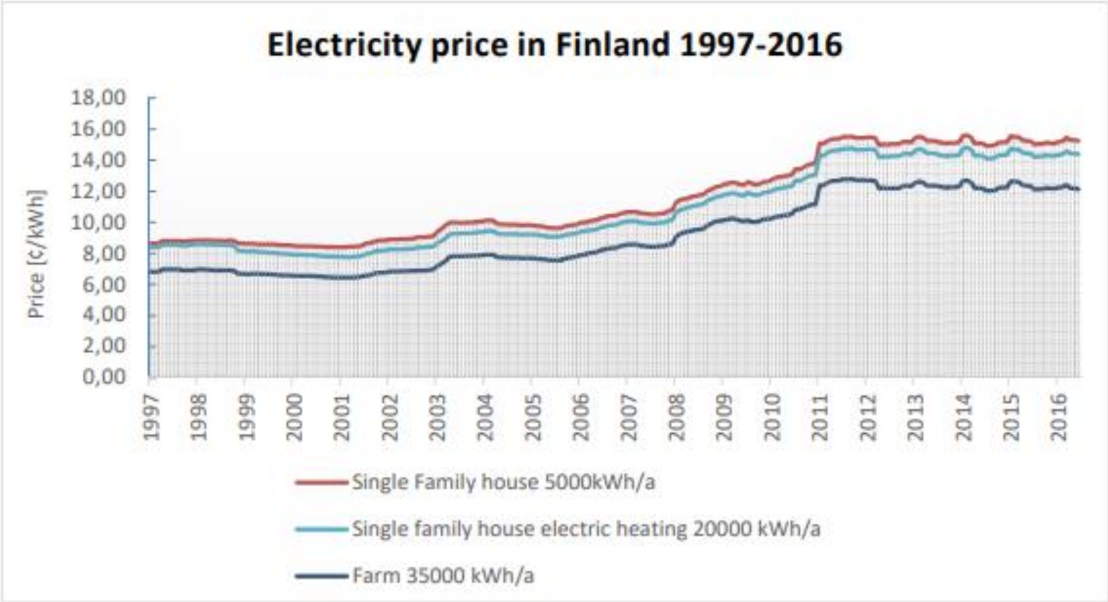


Figure 52. Electricity price in Finland period 1997 – 2016 (Energiavirasto, n.d.)

The above chart showed the situation of electricity price in Finland in 1997 – 2016 time period. Since Finland does offer feed – in tariff system for those projects which satisfied the requirements, this system courante a set price for the sold electricity. In some other countries, different government subsidies are available, such as tax credits, where government deducts taxes in correlations to the amount of electricity produced; or any other rebates that can make an unprofitable investment be economically viable and are government or authorities' methods of backing renewable energy development, they can be counted as a source of income. (Abraham, 2014, pp. 30-31)

13.5 **Economical calculations**

In this subchapter, we will get to know the formulas and method of calculating the economical values, which plays critical role in the project's feasibility. Depending on the calculated values outcome that the projects could be evaluated as success or fail, profitable, or unprofitable.

13.5.1 Payback period

Payback period is a common method to estimate the profitability of an investment. This can be explained as the time it takes to payback the initial investment on the project itself. The acceptable payback time is under 10 years range, and 5 years payback period is an ideal result. However, in some special case, for example, new technology that is on its start-up, or projects that received subsidies from government so that I can make some way to the market, as long as the payback period lays within the system expected lifespan, it is then considered as an profitable. (Abraham, 2014, pp. 32 - 33)

$$Payback\ period = \frac{Investment\ cost}{Annual\ net\ cash\ flow}$$

13.5.2 Return of investment (ROI)

ROI, in short for Return of investment is defined as the presence of return in relation to investment. This method helps us to understand if the invested capital will rise enough to be viable. By making ROI calculations, different investments can be compared. However, the result is just partially reliable since it does not include time factor. Because of which, discounted ROI is recommended. This solution uses discounted net present values instead of gains and costs, which equals that it also takes in to consideration the depreciation of currency over time. ROI is very simple and easy to use as well as to understand. Higher ROI is better than lower ROI, and negative ROI means the vestment is not profitable. (Abraham, 2014, p. 33)

$$ROI = \frac{Gains\ from\ investment - Cost\ of\ investment}{Cost\ of\ investment}$$

13.5.3 Net present value

Net present value is an economic calculation method that takes into account the inflation. The net present value sums the calculated values of cash flows. This method is used to evaluate the profitability of the investment over time. Negative result of Net present value indicates that the investment is unprofitable and should be discarded or eliminated. While positive net present value show that the investment is viable. Although the discount rates between investments are variable, the results in range of 5 – 10 % is often observed. For renewable energy in general, a discount rate of 6% is considered a good value. (Abraham, 2014, pp. 33 - 34)

$$Net\ Present\ Value = \sum_{t=0}^{n} \frac{C_t}{(1+r)^t}$$

In which:

$$C_t = Net\ cash\ flow\ in\ a\ specific\ period$$
$$t = year\ of\ operation\ (0, 1, 2, \dots, n)$$
$$n = investment\ time$$
$$r = discount\ rate$$

13.5.4 Internal rate of return

Internal rate of return is based on net present value and is the discount rate that gives a value of zero for Net Present Value. This means that there is no need to make an approximation for discount rate, but the calculations show a value for it and then It can be used to compared to others. A higher Internal rate of return shows additional value for the investment. And vice versa. Internal rate of return should always be at least higher than the interests rates you can get for the money elsewhere. The Internal Rate of Return equation is very similar to the equation of Net Present Value, but the discount rate is replaced with the Internal rate of return and the sum needs to be zero, as seen from the previous equation of net present value. (Abraham, 2014, p. 34)

$$Net\ Present\ Value = \sum_{t}^{T} \frac{C_t}{(1 + Internal\ \ Rate\ of\ Return)^t} = 0$$

13.5.5 Levelized cost of electricity

Levelized cost of electricity uses Net Present Value calculations to compare total project costs to electricity output. Both costs and electricity outputs are discounted to present values in order to ensure they are on the same reference point. Costs consist of investment, operation and maintenance cost over the whole operation period. The Levelized cost of electricity, however, does not consider any feed – in tariff, tax reductions or any other income. This implies that the result of levelized cost of electricity only demonstrates a value that can be used to compare to other sources of electricity. Levelized cost of electricity for renewable energy regularly found to be in the range of 0.1 €/ kWh – 0.25 €/ kWh and for fossil fuels, around 0.6 €/ kWh. In case the input is converted into production the levelized cost of electricity should be compared to the grid prices. (Kost, et al., 2013, p. 8)

$$Levelized\ cost\ of\ electricity = \frac{I_0 + \sum_{t=1}^{n} \frac{A_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{M_{el}}{(1+r)^t}}$$

In which,

$$I_0 = Investment\ [€]$$
$$A_t = Annual\ total\ cost\ [€]$$
$$M_{el} = Annual\ electricity\ output\ [kWh]$$
$$r = discount\ rate$$
$$n = investment\ time$$
$$t = year\ of\ operation\ (1,2,3,..,n)$$

It is predicted by Fraunhofer Institute that the value of Levelized Cost of Electricity from large – scale wind power will be under fossil fuel Levelized Cost of Electricity by 2020. Solar panels are expected to undercut fossil fuels by 2025 as a cheaper electricity source. (Kost, et al., 2013)

14 CONCLUSION

The conclusion was made based on examining renewable energy sources on how to design a techno-economically optimized renewable energy system for intermediate- to large-scale Finnish households. The second question in this project was how feasible the grid could be.

Designing an autonomous grid which draws its energy from renewable sources at a reasonable price is very challenging. There is an innumerable number of features to choose from and it is also known that a lot of experiences is needed to make it sustainable and with a sufficient capacity to meet the demands set for it. In this thesis report, there are two setups shown. When examining these two scenarios, there are always some needs for an energy backup. In this project, the first case turned out to be a more utilized choice, the calculated electricity price for this case was found to be € 0.28 /kWh, which is a reasonable price especially when taking into account that case one is really environment friendly with its low generator operational hours. Still it is difficult to tell how feasible it would be to implement this set-up into a real-life situation, but the we do believe that it is possible, and have really high hopes in our project.

After considering many factors, we decided to use grid set-up case 1 as the final outcome of our project.

If this project could be further developed, we would aim to not only focus in design the grid for Finnish households but also the calculation excel sheets could be used for other projects as well. Our intention is also to create an independent calculation engine that can help with calculations for other electricity grids using renewable energy resources.

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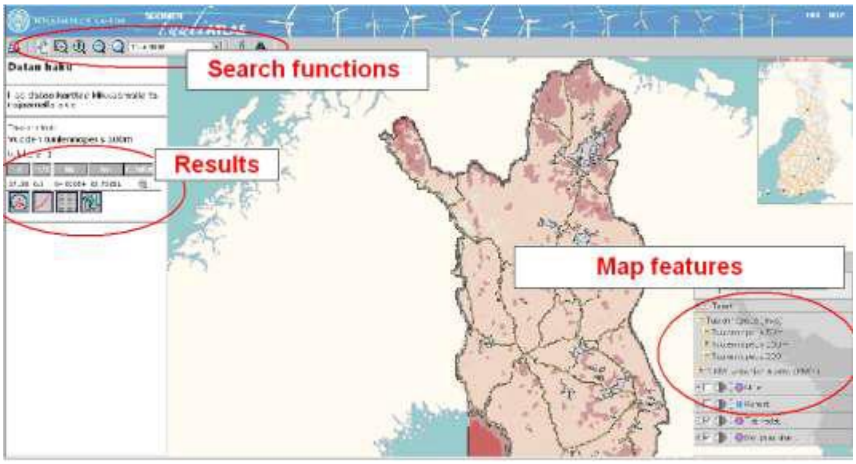
15 APPENDICES

15.1 Appendix 1

Finnish Wind Atlas

Wind Atlas Map interface

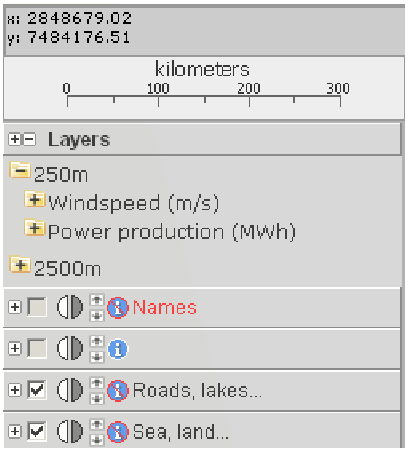
The map interface can be accessed directly at http://tuuliatlas.fmi.fi/en or using the link at www.windatlas.fi.



Picture 1. Map interface

Map features

Best way to start exploring wind conditions is defining features shown on the map. This can be done in the menu on the lower right hand corner of the view. The first step is to choose the resolution (250m x 250m or 2.5km x 2.5km cells). The 250m x 250m resolution doesn't cover the whole country. After that you have to choose between wind speed and power production (3MW turbine) and determine the time scale. The results can be viewed on monthly or annual basis.



Picture 2. Feature menu

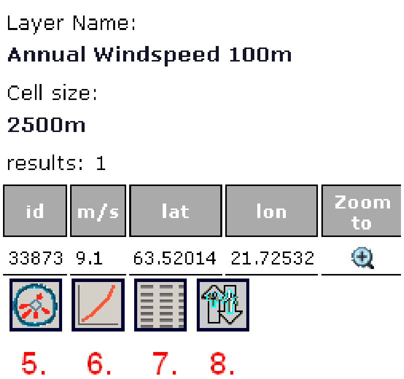
Search functions

Buttons in the top menu are used in finding locations. For example, the zoom and other functions work the same way as in most map programs (2). Map search based on name of the municipality is also possible (4). The print button (1) allows you to download map images e.g. in JPEG format. Information button (3) is used to get detailed information in a single or in a number of cells.

Picture 3. Search menu

Results

After selecting a cell (with the information button), a result table is opened in left side of the view. It allows more detailed examination of wind conditions. Average speed of the wind or power production figure of the cell is shown in the table. The table also shows the GPS coordinates (center of the cell). Wind rose (5) and wind profile (6) of the cell can also be examined and Lib files (8) downloaded from the menu. Excel table of detailed information about the wind conditions (7) can also be downloaded.



Picture 4. Result table and menu

15.2 **Appendix 2**

Wind projects in Finland data

Suomen Tuulivoimayhdistys

Onshore	Projects	MW	WTG
6 Under Construction	10	378	85
5 Fully Permitted	74	3849	945
4 Land Use Plan or STR Done	48	3177	754
3 STR Process Ongoing	1	18	4
3 Land Use Plan Proposal	15	1491	247
3 EIA Done	6	494	83
2 Land Use Plan Draft	4	222	44
2 EIA Process Ongoing	4	1120	212
1 Land Use Plan Process Started	9	1055	205
0 Identified Project / Pre-Screening	30	1153	306
In Total	**201**	**12957**	**2885**
Offshore	Projects	MW	WTG
4 Land Use Plan or STR Done	3	820	166
3 EIA Done	4	1920	140
0 Identified Project / Pre-Screening	3	820	105
In Total	**10**	**3560**	**411**

15.3 **Appendix 3**

Performance of Grid-connected PV

15.3.1 A Caution

We have made this PV performance calculator available online to help give users an idea of the potential of PV as an energy source. We have tried to make it as accurate as possible and to remove all errors, to the best of our capabilities and limited resources. However, there are a few reasons why the results we show could contain errors. Among these are:

Error in user inputs. If you don't really understand what you are doing when you enter numbers and choose options, you may end up with silly results. Section 1 and Section 2 gives information on how to use the PV calculator.

Uncertainties in the estimation of PV performance depending on PV technology and local conditions. This is an active field of research, and there is by no means universal agreement between researchers. We describe the methods we use in Section 3
Uncertainties and errors in the underlying radiation (and temperature) data. Some of these are due to our calculations and we have tried to calculate the uncertainty from our treatment of the data. But the underlying data themselves (whether from ground stations or satellite) have their own uncertainty which we often do not know. More on this in Section 4
Plain old bugs. If you find something suspicious, we would be very happy to hear about it.
In short: the fact that this web site was made available by the European Commission does not mean that the calculations are necessarily correct, nor that they are in any way "official". We are also not the only provider of such services. Several other organizations and companies offer data and guidance on Solar radiation and design and set-up of PV systems. Some are free, while others provide their services for a fee. A more detailed investigation can produce more accurate results than our rather generic approach, but at a cost in time and/or money.

For people interested in the details of all these studies, please see our list of publications.

Please also see our Legal Notice.

15.3.2 How to use the online calculator

The estimation of the power output from a given PV installation can be calculated if you supply a bit of information about the installation:

PV technology
The performance of PV modules depends on the temperature and on the Solar irradiance, but the exact dependence varies between different types of PV modules. Now we can estimate the losses due to temperature and irradiance effects for the following types of modules:
- crystalline silicon cells

- thin film modules made from CIS or CIGS

- thin film modules made from Cadmium Telluride (CdTe)

For other technologies (especially various amorphous technologies), this correction cannot be calculated here. If you choose one of the first two options here the calculation of performance will take into account the temperature dependence of the performance of the chosen technology. If you choose the other option (other/unknown), the calculation will assume a loss of 8% of power due to temperature effects (a generic value which has found to be reasonable for temperate climates). If the database does not have any temperature data the option to choose PV technology will not appear, and the estimated loss due to temperature will always be 8% for all technologies.

Peak power, or array nominal installed power
This is the power that the manufacturer declares that the PV array can produce under standard test conditions, which are a constant 1000W of Solar irradiation per square meter in the plane of the array, at an array temperature of 25° C. If you do not know the declared peak power of your modules but instead know the area of the modules and the declared conversion efficiency (in percent), you can calculate the peak power as power=area * efficiency / 100. See more explanation here
Estimated system losses
The estimated system losses are all the losses in the system, which cause the power delivered to the electricity grid to be lower than the power produced by the PV modules. There are several causes for this loss, such as losses in cables, power inverters, dirt (sometimes snow) on the modules and so on. We have given a default value of 14%. If you have a good idea that your value will be different (maybe due to an high-efficiency inverter) you may reduce this value a little.
Mounting position
For fixed (non-tracking) systems the way the modules are mounted will have an influence on the temperature of the module, which in turn affects the efficiency (see above). Experiments have shown that if the movement of air behind the modules is restricted, the modules can get considerably hotter (up to 15° C at 1000W/m2 of sunlight). In the application there are two possibilities: free-standing, meaning that the modules are mounted on a rack with air flowing freely behind the modules; and building-integrated, which means that the modules are completely built into the structure of the wall or roof of a building, with no air movement behind the modules. Some types of mounting are in between these two extremes, for instance if the modules are mounted on a roof with curved roof tiles, allowing air to move behind the modules. In such cases, the performance will be somewhere between the results of the two calculations that are possible here.
Inclination angle
This is the angle of the PV modules from the horizontal plane, for a fixed (non-tracking) mounting
Orientation angle, or azimuth
This is the angle of the PV modules relative to the direction due South. -90 deg. is East, 0 deg. is South, and 90 deg. is West.
For some applications the inclination and orientation angles will already be known, for instance if the PV modules are to be built into an existing roof. However, if you have the possibility to choose the inclination and/or orientation, this application can also calculate for you the optimal values for inclination and orientation (assuming fixed angles for the entire year).

Tracking options
The previous options assume that the modules are mounted in a fixed position at a given slope and azimuth (orientation). However, there exist systems that can move the PV modules to allow them to follow (track) the movement of the sun in the sky. In this way we can increase the amount of sunlight arriving at the PV modules. This movement can be made in several different ways. Here we give three options:
- Vertical axis: The modules are mounted on a vertical rotating axis, at an angle. It is assumed that the axis rotates during the day such that the angle to the sun is always as small as possible (this means that it will not rotate at constant speed during the day).

The angle of the modules relative to the ground can be given, or you can ask to calculate the optimal angle for your location.

- Inclined axis: The modules are mounted on an axis that forms an angle with the ground and points in the north-south direction. The plane of the modules is assumed to be parallel to the axis of rotation. It is assumed that the axis rotates during the day such that the angle to the sun is always as small as possible (this means that it will not rotate at constant speed during the day). The angle of the axis relative to the ground can be given, or you can ask to calculate the optimal angle for your location.

- Two-axis tracker: The modules are mounted on a system that can move the modules in the east-west direction and tilt them at an angle from the ground, so that the modules always point at the sun. Note that the calculation still assumes that the modules do not concentrate the light directly from the sun but can use all the light falling on the modules, both that coming directly from the sun and that coming from the rest of the sky.

User-defined horizon
PVGIS includes a database of the horizon height around each point you can choose in the region. In this way, the calculation of PV performance can consider the effects of mountains and hills casting shadows onto the PV system. The resolution of the horizon information is 3 arc-seconds (around 90m), so things that are very near, such as houses or trees are not included. However, you have the possibility to upload your own information about the horizon height.

The horizon file to be uploaded to our web site should be a simple text file, such as you can create using a text editor (such as Notepad for Windows), or by exporting a spreadsheet as comma-separated values (.csv). There should be one number per line, with each number representing the horizon height in degrees in a certain compass direction around the point of interest.

The horizon heights in the file should be given in a counterclockwise direction starting at East; that is, from East going to North, West, South, and back to East. The values are assumed to represent equal angular distance around the horizon. For instance, if you have 36 values in the file, PVGIS assumes that the first point is due east, the next is 10 degrees north of east, and so on, until the last point, 10 degrees south of east.

An example file can be found here. In this case, there are only 12 numbers in the file, corresponding to a horizon height for every 30 degrees around the horizon.

Note that the actual calculation made here will use the average Solar irradiation for the given location to estimate the power output. If you compare with the output for a given location, please remember that actual weather conditions can change the output by a large amount. If you had unusual weather for a period, the actual power output may be up to 100% smaller or larger than the value calculated here.

15.3.3 2. Peak power and efficiency, a guide for the confused

If you know the nominal peak power or rated power of your system, you don't need to know the efficiency, except to calculate the area of the modules. This is why:

The nominal peak power is the power rating given by the manufacturer of the module or system. It is the power output of the module(s) measured at 1000W/m2 Solar irradiance (and a module temperature of 25° C and a Solar spectrum corresponding to an air mass of 1.5). This means that if your modules were 100% efficient, you would need 1 m2 to get a system with a peak power of 1kW. These conditions are known as Standard Test Conditions (STC).

Since the modules are NOT 100% efficienct you need a bigger area. If you have 10% efficient modules you need 10m2 to have a 1kWp system. The module efficiency at Standard Test Conditions we will call effnom.

In other words, if Ppk is the nominal peak power and A the area of the module(s), we have

Ppk= A*effnom (1)

The actual power depends on the irradiance G and the real module efficiency eff which is a function of irradiance and module temperatureTm (and sometimes more things which we will forget about here). So you have the actual power:

P = G/1000 * A*eff(G,Tm) = G/1000*A*effnom * effrel(G,Tm) (2)

where we have written the actual efficiency as the product of the nominal efficiency effnom and the relative efficiency effrel(G,Tm).

Combining Eq. 1 and 2 you get:

P = G/1000 * Ppk * effrel(G,Tm) (3)

Therefore, if you know the relative efficiency and the peak power, you don't need to know the nominal efficiency or the area.

BUT: if you want to know either the nominal efficiency OR the area, you will need to know the other of the two parameters. If you know the nominal efficiency and the peak power, you can calculate the area using Eq. 1:

A = Ppk/effnom (4)

So, we don't have a nominal efficiency in the program. That would be useful only to tell the user how much area his/her system would use.

3. Calculating the performance of different PV module types

The actual energy output that you can expect from a given PV system depends on many factors. One of these is the type of modules chosen for the system. The power output of a PV module depends not only on the amount of Solar radiation that arrives at the surface. Among the reasons are:

The PV efficiency is affected to a greater or lesser extent by the temperature of the module, usually decreasing with increasing temperature.
Nearly all module types show decreasing efficiency with low light intensity. The strength of this effect varies between module types.
Some of the light is reflected from the surface of the modules and never reaches the actual PV material. How much depends on the angle at which the light strikes the module. The more the light comes from the side (narrow angle with the module plane), the higher the percentage of reflected light. This effect varies (not strongly) between module types.
The conversion efficiency depends on the spectrum of the Solar radiation. Where nearly all PV technologies have good performance for visible light, there are large differences in the efficiency for near-infrared radiation. If the spectrum of the light were always the same this effect would be assumed to be part of the nominal efficiency of the modules. But the spectrum changes with the time of day and year, and with the amount of diffuse light (light not coming directly from the sun but from the sky, clouds etc.).
Finally, some module types have long-term variations in the performance. Especially modules made from amorphous silicon are subject to seasonal variations in performance, driven by long-term exposure to light and to high temperatures.
Since there are many effects in play, it is difficult to design experiments that are both realistic and able to separate these effects. Furthermore, the importance of these effects varies with geographical location (sunny or cloudy climate, hot or cool). The debate about the relative merits of different PV technologies is still open, also because some of these technologies develop rapidly. Results from just a few years ago may no longer be relevant, especially for the newer thin-film materials.

The PVGIS energy rating method
The method used in PVGIS to estimate the actual PV output from a given type of PV module is based on a mathematical formula that takes into account the first three of the effects mentioned above. This means that the method can only be used on PV technologies that do not depend strongly on the Solar spectrum, and do not show effects of long term exposure to irradiation or high temperatures. Therefore, we do not at the moment try to calculate the output of amorphous silicon modules which are more dependent on these two effects.

The formula for estimating the relative efficiency used in Eq. 2 looks like this:

$$eff_{rel}(G',T'_m)=1+k_1\ln(G')+k_2\ln(G')^2+k_3T'_m+k_4T'_m\ln(G')+k_5T'_m\ln(G')^2+k_6T'^2_m \quad (5)$$

where $G'=G/1000$ and $T'_m=T_m-25$.

The coefficients k_1 to k_6 depend on the type of PV technology used. These coefficients have been found by comparisons with measured values for each of the different technologies.

The module temperature T_m is calculated from the ambient temperature by the following formula:

$$T_m=T_{amb}+k_TG \quad (6)$$

This formula shows how the modules are heated up by the Solar radiation. It is a very simple formula that doesn't take into account cooling effects such as wind. If your system is in a very windy area, this will reduce the temperature of the modules and this will help increase the efficiency a bit. The coefficient kT depends on the type of mounting used for the PV system. In general, a building-integrated system will be hotter than a free-standing rack-mounted system because the air cannot circulate freely around the back of the modules and cool the modules. In PVGIS we have used the following values:

kT=0.035°C/(W/m2) for free-standing systems, based on measurements done at our laboratory
kT=0.05°C/(W/m2) for building-integrated systems, based on values taken from literature
How we determined the coefficients for the different PV technologies
The coefficients in Eq. 5 have to be found from experimental data. These data may be measured using indoor Solar simulators or by putting the PV modules outdoors for a time.

For the crystalline silicon estimates we have based the calculations on data from a number of different PV modules measured indoors. The data from all the modules have been combined and used to make an estimate for an "average" crystalline PV module. The results show that there is not a significant difference in the behaviour of monocrystalline and polycrystalline modules. The spread in values between modules have a standard deviation of 1.25%, meaning that with 90% probability the deviation of a given module from the estimated value will be less than 2%. The estimate is only valid for "classic" crystalline silicon and not for the new types of heterojunction modules that have come on the market in the last few years.

For CIS modules the estimate is based on outdoor measurements performed in Ispra on three different modules from two different manufacturers. The modules were measured over a four months period during spring and summer. All the modules are rather new, produced in 2006/2007, and should therefore be representative of the current state of the technology.

15.3.4 Uncertainties in Data and Calculations

All measurements and mathematical models are affected by uncertainties and the chain of measurement data and calculations leading to the PVGIS estimates for PV performance is rather long, each link having its own uncertainty. We will try to look at each of them in turn.

Ground station measurements
The European database in PVGIS is based on ground station measurements. Most measurements are made with some sort of pyranometer measuring directly the amount of short-wave electromagnetic radiation, typically covering the spectrum from the near-ultraviolet to about 2.5micron in the near-infrared. However, in some cases the global irradiation is estimated from the number of sunshine hours and the (naked-eye) observed cloud cover. Generally, a direct measurement will be more accurate, but even

in this case there are reasons why measurements could have errors. Data may be missing and not interpreted as such, the pyranometer may be malfunctioning and reporting arbitrary results, and the pyranometer may be partially covered with dirt, snow or frost. Some of these errors are random in nature (results could just as well be too high as too low), but some of them will primarily lead to an underestimate of the radiation, in particular those connected with dirt or snow.

The underlying data have been measured by many different organizations in dozens of different countries. It is therefore very difficult to estimate the errors that affect each station. The data were checked and cleaned as a part of the European Solar Radiation Atlas. In addition, we have removed a number of suspicious data points, including stations in high mountains that were affected by shadows from nearby mountains.

Interpolation uncertainties

We have estimated the uncertainties involved in the spatial interpolation of ground station data in a number of places. See for instance here, where we give overall estimates of the uncertainty caused by the interpolation technique. In addition it should be noted that the uncertainty depends on the distance between stations. In areas with a high density of stations, the interpolation uncertainty is generally low while in areas with few stations it may be much higher. It also depends on local climatic conditions. If you are in a region with a climate that changes strongly over short distance, such as in mountains, the accuracy will depend on whether or not you have a station nearby with the same type of climate. As an example, the variation in Solar radiation with altitude is very well resolved in PVGIS for the Alpine Region, since we have stations at several different altitudes. But in other mountain regions, such as Scandinavia or the Caucasus, we have almost no stations at high altitude, and therefore the uncertainty in the estimates at high altitude are much higher than the estimates for the valleys.

Problems with diffuse radiation data

The basic data contains values both for the global horizontal irradiation and for the horizontal diffuse irradiation. Both are needed for estimates of the irradiation on inclined planes. Generally, the uncertainty is higher for the diffuse irradiation, both due to problems with the measurements and because a higher proportion of the diffuse data are not measured directly but estimated from other meteorological parameters. We do not know the uncertainty of the diffuse data used in PVGIS. However, we can estimate the effect of uncertainty on the predictions of PV performance. We have found that for an optimally inclined plane, the uncertainty in PV energy yield is only about one fifth of the uncertainty in the ratio between diffuse and global irradiation (D/G). Thus, if the D/G ratio has an uncertainty of 10%, this would result in an uncertainty of about 2% in the PV energy yield.

Problems from using long-term averages

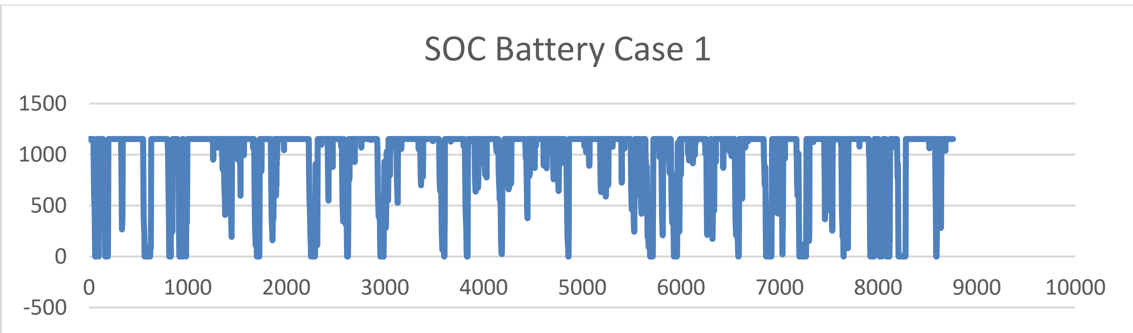
The model for PV performance describes the PV output as a function of instantaneous values of Solar irradiance and ambient (air) temperature. But this means that if you do not have instantaneous values but only long-term average values, you are likely to make an error. For this effect, we found that using averaged values will lead to an overestimate of the PV output for crystalline silicon of about 1%, probably depending slightly on the geographical location. This is since the irradiance and air temperature are not independent. In general, the higher the irradiance (the sunnier the weather), the higher the temperature will be. This will lead to an extra loss in module efficiency at high irradiances which is not considered when using averaged data. (Photovoltaic Geographical Information System - Interactive Maps, n.d.)

15.4 **Appendix 4**

Financial Overview of project cases

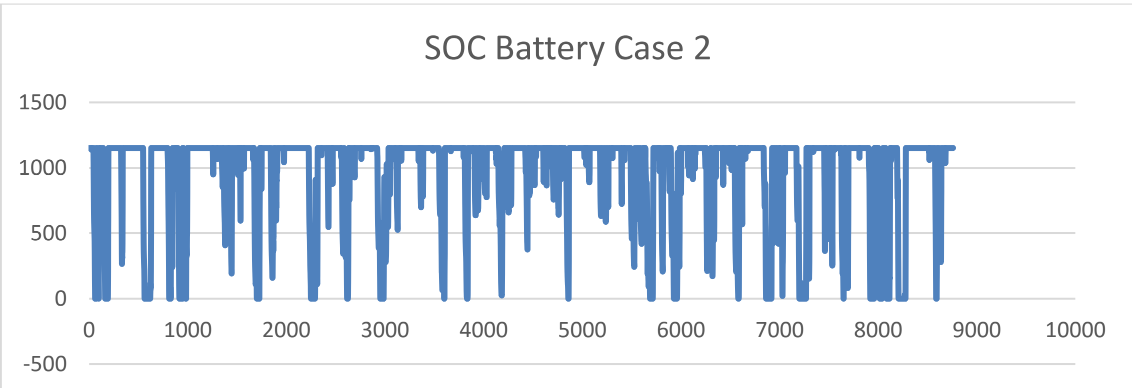
Case 1				
Unit	Amount	Total CAPEX (€)	Total OPEX / Year (€)	Write-Off (€/
Wind turbine				
Nordex 25000	1	405.526,38	4.055,26	18.000,00
EAZ 12	6	270.000,00	3.375,00	16.875,00
Solar panel				
TP 660P	2000	216.000,00	10.000,00	18.640,00
BenQ Solar Sunforte PM096B00	0	-	-	-
solar converter				
Sunnyboy 7700	43	157.053,31		7.852,67
Battery				
Iron Edison	200	1.140.000,00	-	1.554,55
Battery converter				
Sunny Island SI-80H-11	52	180.455,29	-	9.022,76
Generator				
Doosan P222LE-S	1	113.980,00	300,00	4.099,33
Fuel	79300		107.055,00	107.055,00
Power cable				
Draka TFXI	500	86.500,00	-	1.730,00
Total		2.569.514,98	123.730,00	197.616,40

price per kWh	0,28	euro
Working Time of generator	610	h



Case 2				
Unit	Amount	Total CAPEX (€)	Total OPEX / Year (€)	Write-Off (€/year
Wind turbine				
Nordex 25000	0	-	-	-
EAZ 12	40	1.800.000,00	22.500,00	112.500,00
Solar panel				
TP 660P	2000	216.000,00	10.000,00	18.640,00
BenQ Solar Sunforte PM096B00	0	-	-	-
solar converter				
Sunnyboy 7700	43	169.365,22		8.468,26
Battery				
Iron Edison	200	1.140.000,00	-	1.554,55
Battery converter				
Sunny Island SI-80H-11	56	194.601,76	-	9.730,09
Generator				
Doosan P222LE-S	1	113.980,00	300,00	4.099,33
Fuel	126750		171.112,50	171.112,50
Power cable				
Draka TFXI	500	86.500,00	-	1.730,00
Total		3.720.446,99	203.912,50	327.834,73

price per kWh	0,50	euro
Working Time of generator	975	H



15.5 Appendix 5

Kaunissaari Wind Flow and Wind Production data

Altitude (m)	V (m/s)	A	k	Potential Production	Power content
50	9.9	11.11	2.529	1249	923
75	10.4	11.71	2.553	1340	1075
100	10.8	12.13	2.564	1397	1189
125	11.1	12.53	2.576	1450	1309
150	11.4	12.86	2.576	1489	1413
50	8.8	9.93	2.209	944	728
75	9.3	10.47	2.232	1023	847
100	9.6	10.85	2.252	1076	937
125	9.9	11.19	2.244	1118	1027
150	10.2	11.46	2.244	1151	1105
50	7.8	8.81	2.467	846	474
75	8.3	9.36	2.436	949	571
100	8.6	9.74	2.416	1017	647
125	8.9	10.03	2.385	1063	712
150	9.1	10.26	2.357	1100	769
50	6.9	7.75	2.045	643	370
75	7.4	8.35	2.025	746	467
100	7.8	8.77	2.01	814	544
125	7.9	8.95	1.939	842	602
150	8.1	9.1	1.893	864	652
50	7.4	8.29	2.377	747	399
75	7.9	8.86	2.295	856	500
100	8.2	9.25	2.244	925	580
125	8.3	9.42	2.209	954	622
150	8.5	9.56	2.178	976	660
50	7	7.91	2.553	644	330
75	7.5	8.44	2.541	748	401
100	7.8	8.81	2.541	819	457
125	8	8.97	2.486	849	488
150	8.1	9.1	2.455	872	514
50	6.5	7.34	2.416	562	274
75	6.9	7.81	2.404	652	330
100	7.2	8.13	2.396	715	373
125	7.3	8.24	2.33	740	397
150	7.4	8.33	2.275	759	418
50	6.6	7.4	2.115	595	311
75	7	7.89	2.139	682	372
100	7.3	8.22	2.146	743	420
125	7.5	8.45	2.131	784	460
150	7.7	8.63	2.107	818	495

50	7.7	8.68	2.404	795	457
75	8.1	9.1	2.404	871	525
100	8.3	9.38	2.416	921	576
125	8.5	9.58	2.396	956	619
150	8.6	9.75	2.377	984	656
50	8.5	9.57	2.436	986	606
75	8.8	9.92	2.396	1047	683
100	9	10.16	2.377	1085	739
125	9.2	10.38	2.365	1120	792
150	9.4	10.56	2.357	1148	836
50	8.5	9.54	2.338	946	624
75	8.8	9.91	2.311	1007	707
100	9	10.17	2.287	1045	770
125	9.2	10.42	2.268	1082	832
150	9.4	10.63	2.26	1111	886
50	8.6	9.7	2.611	1017	594
75	9	10.11	2.588	1091	677
100	9.2	10.4	2.564	1139	738
125	9.5	10.69	2.576	1187	800
150	9.7	10.92	2.588	1226	853

15.6 **Appendix 6**

List of formulas being used in the project

Formula to calculate the wind speed at a certain height

$$V_z = V_{10} \times \frac{z}{10} \times a$$

In which:

V_z is the wind speed at some height z (in meters)
V_{10} is the wind speed at 10 meters and an a of 0,2

Power output of Solar panel calculation formulas

Calculations are based on the irradiance research table.
Formulas:

$$E = A \times r \times H \times PR$$

In which
E: Energy output of the Solar cell (KWh)
A: Total Solar panel area (m^2)
r: Solar panel yield efficiency (% depend on the Solar panel data)
H: Solar irradiance of the area(m^2) each hour (W/m^2)
PR: Performance ratio (Default 0.75-0.9)

Final power output with temperature efficiency:

$$P_{out\ put} = E - E \times n$$

In which
$P_{out\ put}$: Power output with temperature efficiency take into account (kWh)
n: Temperature efficiency (%)
With $n = (Tsp - Tnom) * Temperature\ Coefficiency$

Tsp: temperature of the cell is calculated based on the data available and average temperature of the region.
$Tnom$: standard temperature.

Financial Calculations

Payback period formula

$$Payback\ period = \frac{Investment\ cost}{Annual\ net\ cash\ flow}$$

Return of investment formula

$$ROI = \frac{Gains\ from\ investment - Cost\ of\ investment}{Cost\ of\ investment}$$

Net Present Value formula

$$Net\ Present\ Value = \sum_{t=0}^{n} \frac{C_t}{(1+r)^t}$$

In which:

$$C_t = Net\ cash\ flow\ in\ a\ specific\ period$$
$$t = year\ of\ operation\ (0, 1, 2, \dots, n)$$
$$n = investment\ time$$
$$r = discount\ rate$$

Internal rate of return formula

$$Net\ Present\ Value = \sum_{t}^{T} \frac{C_t}{(1 + Internal\ \ Rate\ of\ Return)^t} = 0$$

Levelized cost of electricity formula

$$Levelized\ cost\ of\ electricity = \frac{I_0 + \sum_{t=1}^{n} \frac{A_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{M_{el}}{(1+r)^t}}$$

In which,

$$I_0 = Investment\ [€]$$
$$A_t = Annual\ total\ cost\ [€]$$
$$M_{el} = Annual\ electricity\ output\ [kWh]$$
$$r = discount\ rate$$
$$n = investment\ time$$
$$t = year\ of\ operation\ (1,2,3,..,n)$$

15.7 **Appendix 7**

Technical information of the grid components and financial calculation.

Wind Turbine Unit		Nordex N80/2500	
Rated Power		2500	kW
Rotor Diameter		80	m
Height		80	m
Voltage		660	V
Life expectancy		25	Years
maintenance cost		4,055.26	Euro/Year
Price		405,526.38	Euro
http://www.renugen.co.uk/nordex-n80-2500kw-wind-turbine/			
Wind Turbine Unit		EAZ 12	
Rated Power		660	kW
Rotor Diameter		12	m
Power density		2.63	m2/kW
Height		55	m
Voltage		690	V
Life expectancy		20	Years
maintenance cost		562.50	Euro/Year
Price		45,000.00	Euro
Solar panel		TP 660P	
Maximum Power Output at STC		270	Watt
Cell Dimension	156*156		mm2
Total cell dimension		1.46016	m2
Module efficiency		15.7	%
PV system Efficiency		0.1849	
Yield efficiency		0.269983584	
Performance ratio		0.75	
Temperature Coefficient		-0.4	%/C
Total cell per panel		60	6*10
Panel dimension	990*1640		mm2
Price per module including installation cost		108.00	Euro
Solar Panel	BenQ Solar Sunforte PM096B00		

Maximum Powe Output		330	Watt
Panel Dimension	1159*1046		mm2
Module efficiency		20.3	%
Total cell per panel		96	cells
Price per module including installation cost		318.00	euro
Solarpanel converter	sunnyboy		7700 TL-US-22
power		8	kW
input voltage		600	VDC
ouput voltage	208/240		VAC
efficiency		97	%
price		3020	euro
price per kw		377,500.00	euro
Battery	IRON EDISON		Nickel Iron
Voltage		24	V
Capacity		300	Ah
Capacity		7200	Wh
Depth of discharge		80	%
Usable capacity		5760	kWh
Price / Battery		5,700.00	euro
Battery converter	Sunny Island		SI-80H-10
Maximum Power In		11.5	kW
Maximum Power Out		3.3	kW
efficiency		94.5	%
price		3470	euro
Generator	Doosan		P222LE-S
Power Output		552	kW
Fuel use at 552 kW		130	L/h
Fuel price		1.35	Euro/L
Price		113980	Euro
maintenance cost		300	Euro/Year
Power Cable	Draka		TFXI
Diameter	3*120		mm2
maximum voltage		10000	V
Price		145	Euro/m
Costruction cost		28	Euro/m
total Cost		173	Euro/m

15.8 Appendix 8

Solar panel comparison table

#	Manufacturer	Model	Power (STC)	Price	Price per Watt
1.	Talesun	TP660P-235	235W	$183.30	$0.75
2.	Canadian Solar	CS6P-235PX	235W	$190.35	$0.81
3.	Eoplly	E156P/60-230W	230W	$204.70	$0.89
4.	Eoplly	E156P/60-240BB	240W	$213.60	$0.89
5.	Eoplly	E156P/72-280W	280W	$249.20	$0.89
6.	Talesun	TP660PB-240	240W	$220.80	$0.92
7.	Talesun	TP660PB-245	245W	$225.40	$0.92
8.	Suniva	MPV285	285W	$262.20	$0.92
9.	Jinko	JKM-235P	235W	$230.30	$0.98
10.	EcoSolargy	ECO230S156P-60	230W	$227.70	$0.99

15.9 **Appendix 9**

Barriers and possible solutions to increased capacities of Solar PV in Finland (Child, Haukkala, & Breyer, 2017)

	Barriers	Possible Solutions
Technological	- Lack of energy storage solutions in Finland - Grid and grid monopoly	- Lessons to be learned from solutions available in Germany, R&D allocated to storage solutions - Sufficient and efficient grid, easier to access for small-scale producers, compensation for the producers

Economic	- Competitiveness - Module prices - Price of the electricity in the Nord Pool Area - A need for new electricity markets and rules - Inefficient markets of storage systems - Support and high subsidies for conventional energy system	- Solar has reached grid parity in some market segments and will become more competitive on its own in the future - Module prices are falling continuously - Storage solutions are available at least in Germany—a need to export solutions - As long as electricity prices are lower in Finland than in other countries, Solar will not be as popular as elsewhere - Ideally there should be no support systems in the long run distorting markets - Subsidies for harmful emissions from conventional energy need to be eliminated - New business models
Institutional and political	- Current energy regime based on nuclear power, fossil fuels and bio energy - Vested interests - Path dependency - Lock-in - Incumbent electricity companies - Lack of support policy - Lack of powerful advocacy coalitions - Fossil fuels lobbying - Failure to overcome existing subsidies	- A possibility to build a more distributed energy regime - New business models - Some support policy seems to be needed in the beginning phase but type is less significant - More established and powerful Solar energy advocacy coalition
Behavioural	- General attitudes - Psychological resistance - Political will	More information and practical examples of successful installations provided