Floating Solar Panel
Final Report

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Pascal Vrignon, Rick Winters
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Abstract of the report of the Floating Solar Park project, as part of the EPS spring 2018.

Five European students have been gathered in Novia University to make a project thanks to Erasmus. Wärtsilä, one of the main company's in Finland, asked us to study the feasibility of a floating solar park in order to diversify its activities.

This project involves the creation of a solar park on the water surface in order to win efficiency and save money compared to the land parks. The goal of this project is to design a concept idea of a floating solar park system, estimating the yearly power output and having built and tested prototype design to study the feasibility and advantage of a floating solar park. After the study of the technology and physics of solar panels, factors that affect the efficiency of solar panels have been identified. Some designs have been imagine to answer all the problems. For example, in Finland, there is ice and snow that can make the panels inefficient. In addition, an Excel table can be found to have an idea of the price of the floating solar park designed. The results of this research bring a better understanding of why it is difficult to build a floating solar park in Finland.

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Chapter 1

Introduction

1.1 The EPS project

The report here presented analyses the profitability of the construction of an offshore solar power plant and proposes some designs for its realisation. This study was done as the main part of an European Project Semester carried out at Novia University of Applied Sciences in Vaasa. It was done commissioned by Wärtsilä company. In this first chapter a brief introduction of the involved parties will be shown. Thereafter, the subject, goal, and mission and vision of this project will be explained. At the end buildup of the report is detailed.

1.1.1 Novia University of applied sciences

Novia University of Applied Sciences is a university acting along the west coastline, the Swedish speaking part of Finland. Novia is the largest Swedish speaking university of applied sciences in Finland with over 4000 students. Their vision is stated as "Novia UAS is an important developer of working life and industry near-by the campuses. In our strategic focus areas we are among the top of the nation and internationally recognised." Source: [NoviaUAS, 2015]

1.1.2 Wärtsilä

Wärtsilä is a world leader in smart technologies and lifecycles solutions for the marine and energy markets. Their goal is to maximise the environmental and economic performance of its costumers' vessels and power plants by emphasising on sustainable innovation, total efficiency and data analytics. The cornerstone to their commitment to sustainability is meeting the world's increased demand for energy in a sustainable way. Sören Hedvik, employee of Wärtsilä, has commissioned this project and is the contact person from the company. Source: [wärtsilä, 2018]

1.1.3 The team

The team consists of five members of which a short introduction is given now.

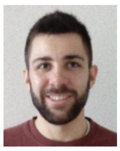
Gilles Belis

I am an electro-mechanical engineering student at Artesis Plantijn university of applied science. I live in Belgium and I am in Finland for his final semester of my bachelor degree. I chose to do it abroad for the full experience. Working in a group with students from other countries is a good way to learn new competences. And also a good way to become independent and living on your own.

Gilles

Andrés Cortés Martín

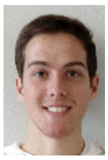
I am a mechanical engineer student at Valladolid College of Industrial Engineering. I have taken this EPS as a way to do my Final Degree Project at my university, the last step to get the degree. My role was to be responsible for the design of the models and for finding ways to increase the efficiency of solar panels by cooling them and by using flat mirrors. I was the team manager for the second halve of the project. My speciality is design in CATIA V5, thermodynamics calculations and doing mechanics designs.



Andrés

Mathieu de Oliveira

I am Mathieu, I am from France and I am studying Mechanical and Industrial engineering at the ENIT university. I am in the same school as Pascal, at team member. I chose to do the EPS because I thought it would be very interesting to work with foreign students in a project and I am very satisfied of this choice. With

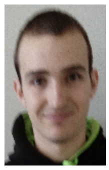


Mathieu

this experience, it allows me to discover different cultures and adapt to work with the others.

Pascal Vrignon

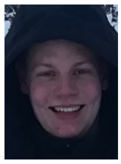
My name is Pascal Vrignon. I am a french student of engineering school in Tarbes named ENIT. I study mechanical and industrial engineering. I chose to do the EPS project because I thought it will be very interesting to work on a project with different nationalities and cultures. I preferred to go in Finland because of the very good life conditions, beautiful landscape and happy people.



Pascal

Rick Winters

I am an Applied Physics student at Saxion University of applied Sciences working on my bachelor's degree. I am taking the EPS as extra curriculum as it is my opinion that the experience will be great. My is to be responsible for the reporting of the project and i have been the team manager for the first halve of the project. Next to that his major tasks were the numerical simulation and research. His speciality is programming in Matlab for numerical simulations.



Rick

1.2 Subject

The subject of this project is to design a concept for a floating solar park for its use in Finland and verify its feasibility by testing a solar panel in the surroundings of Vaasa. One advantage of a floating solar park compared to a common solar park is that no ground has to be used, so no nature has to be taken. Another advantage is that if the solar panels get to hot, it is easier to cool them with the water.

The mission of this project is to gather information on the generation of energy using floating solar parks and build a prototype to test it. The vision is to have designed a concept idea of a full floating solar park system and to have build a prototype with the necessary experiments done.

1.3 Project Goal

The goal of this project is to design a concept of a working floating solar park system, estimating the yearly power output and building and testing a prototype design to study the feasibility and advantages of a floating solar park.

1.4 Buildup of this report

This report consists of four major parts with chapters dividing. Firstly all the literature and background information is described in multiple chapters starting with the history of solar parks and their technology. Next, the factors that can affect the efficiency of panels are shown and how to use them to improve their efficiency. The next part of the report describes the design process. This describes how the team came up with several designs. This part also includes a numerical simulation showing the importance of having the panel rotate and tilt with the sun, as this is a major point in designing. The third part describes the management of the project, a report of who is accountable and responsible for which tasks and why and shows the Belbin personality tests results. The last part of the report is a short summary of the results so far, looking back to the goals set, and describing the plan for the next part of the project.

Part I

Research and background information

Chapter 2

History and examples of solar parks

2.1 Introduction

Floating Solar Parks are being developed all around the world. Because of the decrease of available area appropriate for the construction of Solar Systems, since 2014 countries are deciding to create offshore solar parks. As there are many lakes and other water surfaces in Finland, it is possible to use these areas for solar parks.In Figure 2.1 a map of the world is shown where the countries that have developed or are developing floating solar parks are marked.

Figure 2.1: Floating Solar Parks in the World

2.2 First Floating Solar Park in the world (Korea)

The company Solkiss built in Geumgwang reservoir in Anseongthe Korea the first Floating Solar Plant in the world. It is composed of 1.600 modules in 7.500 m^2 and it can deliver 465 kilowatts of electricity, enough for up to 250 households. This particular system can rotate the complete deck instead of each panel separately, in order to gain more energy. It can be seen in Figure 2.2. This system generates 22 % more energy compared to a local ground mounted system that does not rotate. Source: [english.donga.com, 2014]

Figure 2.2: Korea First Floating Solar Park in the World

2.3 Yamakura Dam reservoir (Japan)

The construction of the Yamakure Dam reservoir (see Figure 2.3) began in 2014 and will finish in 2018. The plan is to have 50.904 panels in an area of 180.000 m^2, generating 16.170 MWh annually which serves up to 5.000 houses. This project offsets 8170 tons of CO_2 production reducing the environmental impact and pollution. When the construction is finished this will be the biggest floating solar park in the world. For now the biggest floating solar park is the Tames Water Floating Solar Park in London.
Source: [Kyocera, 2016] .

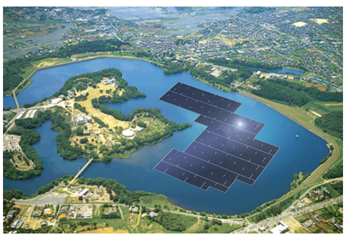


Figure 2.3: Yamakura Dam largest Floating Solar Park in the World

2.4 The Tames Water Floating Solar Park (London UK)

This park is currently the biggest one. The Tames Water Floating Solar Park, is located is the Queen Elizabeth II reservoir approximating eight football fields in size. It consists of 23.000 panels generating 6.3 MW in total, which is enough for 1.800 homes. This park is made to supply the local water treatment plants with electricity. A picture of this park can be seen in Figure 2.4. Source: [thegaurdian.com, 2016]

Figure 2.4: The Tames Water Floating Solar Park

2.5 Jamestown Floating Solar Park (Australia)

Australia decided to create its first Floating Solar Park in Jamestown and Gladstone (see Figure 2.5). This project covers five basins of water, generating 4 megawatt with 3.576 panels for a cost of 12 million dollars in total. The panels in the water follow the sun allowing them to increase the production in a 15%. The advantage of putting panels in the water is that they can cool themselves. This installation in particular can generates 57% more power than land solar park in the same circumstances, and it also reduces evaporation by up to 90%, so they are specially appropriate for dry areas. The Solar Park is expected to produce more than enough energy to power the entire waste-water treatment facility. It will also help to facilitate the treatment of water, save water from evaporation and reduce the local authority's reliance on fossil fuels and treatment chemicals. Source: [reneweconomy.com.au, 2015]

Figure 2.5: Jamestown Floating Solar Park

2.6 Balbina Floating Solar Park (Brazil)

As Brazil often experiences a drought it was decided to develop a floating solar park on top of the reservoirs for the hydroelectric plants. This also diversifies Brazil's energy production. The plan is to eventually produce 10 MW of power, however, they have started in 2016 with a project if just 1 MW. This was done in order to evaluate the performance of arrays. The plan is to put these arrays on top of the reservoirs to decrease the evaporation of the water reservoirs in time of drought, while generating power. A picture of this park can be seen in Figure 2.6. Source: [pv magazine.com, 2016]

Figure 2.6: Brazil Floating Solar Park

2.7 Conclusion

In this chapter, multiple examples of existing floating solar parks have been discussed. All of these examples are closer to the Equator than Finland is, which means a more constant power production throughout the year. Each example discussed shows a gain in energy production or other benefits compared to solar parks on land.

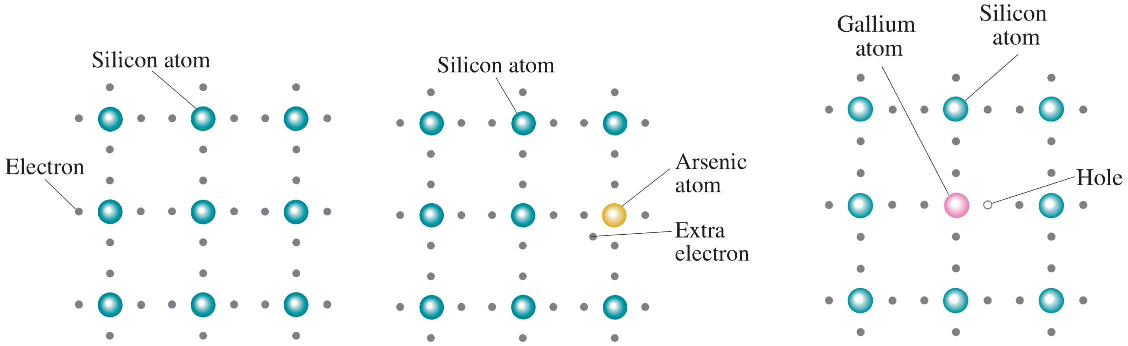
Chapter 3

Solar panel technology

3.1 From light to electricity

To gather electrical power from a solar panel, an array of photovoltaic cells is used. Photovoltaic cells are made up of two types of semiconductors. A side view schematic can be seen in Figure 3.2. The semiconductors are made up of an a lattice of atoms, most commonly silicon or germanium is used. In Figure 3.1a, a 2D representation of such a lattice can be seen. At room temperature and with only 1 in 10^9 electrons in such a lattice is free floating, meaning it can conduct electrical energy. By applying a process called 'doping' it is possible to increase the conductivity of such a lattice.

When doping a semiconductor, another atom is added to the lattice to either add or remove electrons. In Figure 3.1b, an example is shown of n-type (negative) doping. Here an extra atom of arsenic is added. This causes a free electron to be present which does not fit in the lattice structure and as such is free to move around. Doping a semiconductor can increase its conductivity 1000 to 10.000 times. Another type of doping is p-type (positive). Instead of adding electrons to the lattice an atom is used that misses an outer-electron, creating a gap in the lattice. In this configuration electrons can jump to the other gap leaving a gap behind them. This also increases the conductivity of a lattice. Source: [Giancoly, 2009]



(a) Four (outer) electrons surround each silicon atom.

(b) Silicon Crystal doped with a small percentage of arsenic atoms: the extra electron doesn't fit into the crystal lattice and so is free to move about. This is an n-type semiconductor.

(c) A Gallium doped silicon lattice. Gallium only has three outer electrons, and as such one connection will leave a gap. This is a p-type dope.

Figure 3.1: Two-dimensional representation of a silicon crystal.

Source: [Giancoly, 2009]

Figure 3.2 shows a schematic side view of Solar Panels. As it is particularly shown, this panel has a n-type semiconductor and a p-type semiconductor layered on top, creating an electrical field. When a photon hits the surface, it might knock an electron out of its bounds so that the electron is flowing free. This causes an electrical current when the two sides are connected to a circuit. The power output depends on the amount of sunlight hitting the surface, and on the efficiency and area of the solar cell.

[www.solo labs.com, 2014]

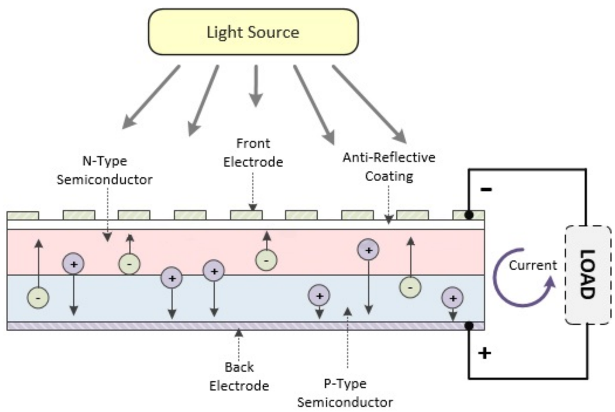


Figure 3.2: Side view schematic of a photovoltaic cell

Source: [www.solo labs.com, 2014]

3.2 Solar efficiency

Solar cell efficiency refers to the portion of energy in the form of sunlight that can be converted via solar panel into electricity. The efficiency of the solar cells used in a photovoltaic system, in combination with factors such as latitude and climate, determines the annual energy output of the system.

3.2.1 Solar panel efficiency

The efficiency of a solar panel is baseline value describing how much of the energy falling on the panel is converted into electrical energy. Solar panels are far from converting all the sun energy that falls on them into electricity. A lot of this energy is converted to heat energy. Generally a panel has an efficiency between 15% to 22%.

To determine the efficiency, the panels are tested at Standard Test Conditions. STC specifies a temperature of 25°C and an irradiance of 1000W/m2. This is the equivalent of a sunny day with the incident light hitting a sun-facing 37°-tilted surface. Under these test conditions, a solar cell of 15% efficiency with a 100 cm2 surface area would produce 1.5 W. Apart from the STC, solar cells are tested for performance in other conditions:

- Hail impact
- Wind, snow, ice load
- Exposure to humidity
- Thermal cycling (exposure to temperatures between -40°C to +85°C)
- UV degradation
- Insulation resistance
- Chemical exposure

3.2.2 Panel and cell efficiency

As explained in Section 3.3, solar panels are usually made up of multiple cells. Panels and cells can have a different efficiency value from the manufacture. For example, a technical specification sheet can say that a specific cell inside a panel has an efficiency of 15.9%, while the panel itself has an efficiency of 14.8%. The efficiency of a panel is a more realistic value. A significant improvement of efficiency by 19% of solar panels over water has led to the construction of large scale floating solar farms in China, India, UK and Japan. Source: [greenmatch.co.uk, 2018]

3.3 Types of panels

There are multiple types of solar panels, which are developed for different purposes. The way they produce electricity is practically the same. However, the buildup of the panels is different. There are four main kind of solar panels.

The first technology discussed is called amorphous or thin-film. This is the cheapest photovoltaic technology but also the least efficient. This technology can convert up to 6-8% of the sunlight energy received to electrical energy. Diffuse solar radiation (radiation from the sun that e.g. gets reflected from a cloud) is converted with a higher efficiency than other technologies. One advantage of this technology is that amorphous panels can be manufactured in a curved manner.
Source: [Boxwell, 2017]

Another kind of technology is called polycrystalline. This technology is about 20-30% more expensive than the amorphous panels, but it comes with an efficiency increase. These panels convert up to 16% of the solar energy. The panels are made from multiple cells, which consist of multiple layers of silicon wafers. Source: [Boxwell, 2017]

Next to polycrystalline there is monocrystalline. This technology is fairly similar to polycrystalline, the difference being the solar cells are made from only one silicon wafer. This increases the efficiency even more up to 19%. It does, however, cost more, as it is much more difficult to separate single silicon wafer. Source: [Boxwell, 2017]

The last type of panels is a hybrid technology. These panels are made by piling thin film cells between monocrystalline cells. This brings together the high efficiency of monocrystalline with direct radiation and the higher performance with diffuse radiation of amorphous cells. This kind of panel can reach up to 22% in efficiency in perfect conditions, but their real benefit is when working on sub-optimal real world conditions, where they can produced about 10-20% more than the other technologies. These panels, however, can cost up to twice as much an monocrystalline panels. For most cases these panels are ignored out of economic regards due to the high cost. Source: [Boxwell, 2017]

3.4 Advantages and disadvantages of solar energy

Solar energy has a lot of advantages over other sources of energy. Some of the advantages of solar energy are:

- Solar panels produce clean energy without polluting the environment directly. No gases are released and there is no radioactive waste produced.
- Solar energy is inexhaustible. Fossil fuels such as coal or oil will be exhausted eventually.
- The solar panels remain silent and non-disturbing for neighbouring residents, which is not the case for all energy sources.
- Solar panels, once installed, require very little maintenance and energy is produced without human action.
- For isolated places or small installations, solar panels are better at providing local electrical power.

Next to advantages, there are disadvantages as well, which can explain why solar energy is not massively employed

- Solar energy is not competitive when it comes to high energy production. Energy sources such as nuclear power are more profitable financially. All global energy needs can not be provided by solar energy.
- A solar panel has a lifetime of about 25 years. Beyond that, the efficiency decreases rapidly. In addition, it takes 3 years for the panel to produce the energy that was used for its construction.
- Due to the weather and day-night cycle, the energy production is irregular. Next to that the power production can not be scaled up or down depending on the energy requirements of the community.
- The high cost of solar panels and necessary facilities as the means of energy storage.
- The size of the installation: it takes large areas of solar panels to produce energy.

3.5 Summary of technologies

In this chapter it is explained how solar panels work on a molecular level. This part concerned the doping of silicon lattices. With this theory it was explained how the silicon lattices are applied in a solar panel and how electricity is created

This was followed by a discussion of four types of solar panels, namely amorphous or thin-film, polycrystalline, monocrystalline and hybrid panels. These 4 technologies were compared in prices and efficiency of power production.

Solar Efficiency is discussed next and advantages and disadvantages of solar energy are discussed at the end.

Chapter 4

Effects on the efficiency

4.1 Introduction

Having explained how solar panels work and different photovoltaic technologies, it must be considered that the technology used is not the only factor on the efficiency of the panel. There are multiple external factors that can change the efficiency no matter what technology is used. In this chapter some of these factors are explained, including the temperature of the panel, the solar position with regard to the horizon, the local weather and lastly the solar irradiance.

4.2 Effects of temperature on solar panels

Temperature can have a big effect on the efficiency of solar panels. The efficiency can drop drastically with an increase in temperature. As solar panels usually have glass panels on top for protection they absorb a lot of energy which gets converted into heat. In hot environments this can cause the panels to heat up to 90 °C. Source: [Boxwell, 2017]

The Wattage rating given to a solar panel is tested at 25 °C with a 1.000 W/m^2 light source. With an increase of temperature the energy produced with the same radiation energy will be lower, and the other way around. A solar panel manufacturer usually gives a value for change in efficiency per degree change in temperature, called the temperature coefficienct of power. Typical values are in the range of -0.5% per °C increase. Table 4.1 shows the effect of the temperature on a 100 W rated panel. This also shows that if it is possible to cool the panel to below 25 °C, it is possible to produce more power than the panel is rated for, which can be beneficial if cooling costs less power than the efficiency increase produces. Source: [Boxwell, 2017]

Table 4.1: Effect on the efficiency of the temperature, considering a coefficient of -0.5% / °C

Source: [Boxwell, 2017]

	5 °C 41 °F	15 °C 59 °F	25 °C 77 °F	35 °C 95 °F	45 °C 123 °F	55 °C 131 °F	65 °C 149 °F	75 °C 167 °F	85 °C 185 °F
Panel output for a 100 W solar panel	110	105	100	95	90	85	80	75	70
Percentage gain loss	10%	5%	0%	-5%	-10%	-15%	-20%	-25%	-30%

4.3 Solar position

A major influence on the efficiency of the solar panels is the sun itself. The most amount of energy is produced if the sun is on the normal axis of the panel, i.e. facing the panel directly. But the sun, relative to the panel, moves through the sky. When doing calculations on the energy produced over a year this has to be taken into account. To take this into account one could track the time of day and apply a factor, however the sun does not move the same way through the sky every day. Apparent Solar Time (AST) is used to express the time of the day according to the sun, this can be calculated by offsetting the clock time with a few minutes. This correction is called Time correction. Another correction to be made is the Longitude correction. As the sun does not rise at the same clock minute in the area covered by one time zone, a correction has to be made for the exact longitude position in that timezone. This correction is called a Longitude correction.

Time correction

As one rotation of the earth is not exactly 24 hours. This is partly because the earth does not spin exactly ones every 24 hours, and because the earth moves around the sun at the same time. This movement around the sun changes in velocity due to earth's slightly elliptical orbit around the sun. Due to these factors the time correction varies each day. In Figure 4.1 the minutes offset from the LST (Local Standard Time) to the AST can be seen. Source: [Kalogirou, 2009]

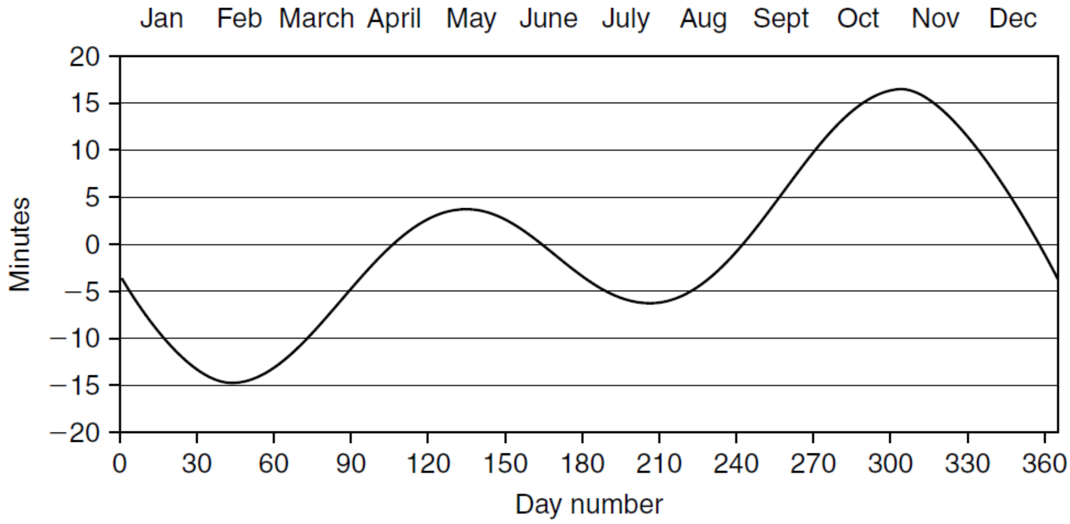


Figure 4.1: Chart showing the correction in minutes depending on the day of the year

Source: [Kalogirou, 2009]

Longitude correction for Vaasa

As the sun does not rise at the same time throughout one time zone, a correction based on longitude is required. The earth spins at 1 °per 4 minutes. The time meridian for UTC+2:00 (the timezone where Vaasa is) is located on 30 °E, while Vaasa is located at 21°37́longitude. Calculating the difference of these longitude coordinates, and multiplying this by 4 minutes is the correction to the clock time needed. As Vaasa is west of the UTC+2 meridian, this value has to be subtracted.

Solar angles

Another factor to take into consideration is the elevation of the sun. If it is possible to tilt the solar panel maximum efficiency can be reached throughout the day. In Finland the sun does not rise up high during winter, but during summer the sun will be above the horizon for a long time. This makes it necessary to know at which elevation the sun will be during the day.

Source: [Kalogirou, 2009]

The solar altitude is the angle that the sun takes with respect to the horizon. This is also called the elevation angles. Due to the inclination of the earth and the changing of seasons throughout the year the elevation of the sun changes every day. The average angle in Vaasa is 27°, which is the altitude angle of the sun during the solar midday on the equinox.

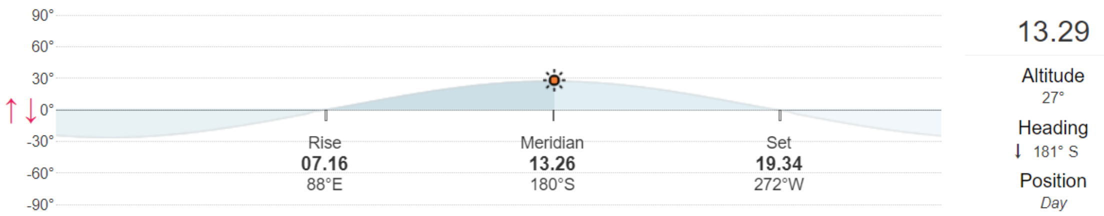
Source: [Kalogirou, 2009, timeanddate.com, 2018]

The hour angle is the angle on a compass that points straight to the sun. This means that when the hour angle is 90 °, the sun is facing east. This hour angle varies everyday as well due to the inclination of the earth. If the solar panels are to rotate without a tracking device this angle can be used in order to rotate the panels in the correct way.

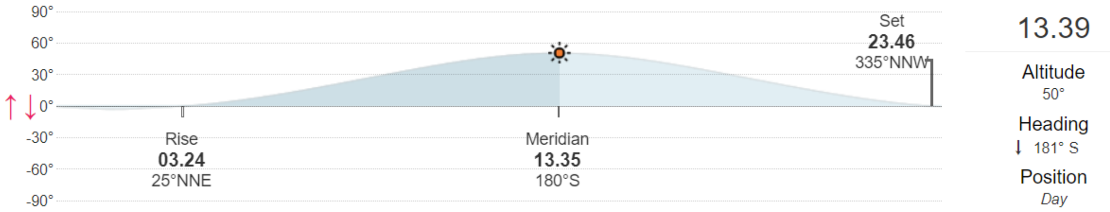
Source: [Kalogirou, 2009]

In Figure 4.2 the elevation angle of four days is shown over time. Next to that these figures show the time of sunset and sunrise together with the hour angle of the sun at that time. The highest point is also shown with information about the time this occurs, the altitude angle and hour angle. It can be seen that, in Vaasa, during winter solstice the sun rises in the South-South East (148°) and sets in South-South West (212°). In the summer however, the sun rises in the North-North East (25°), going through the south setting in the North-North West (335°).

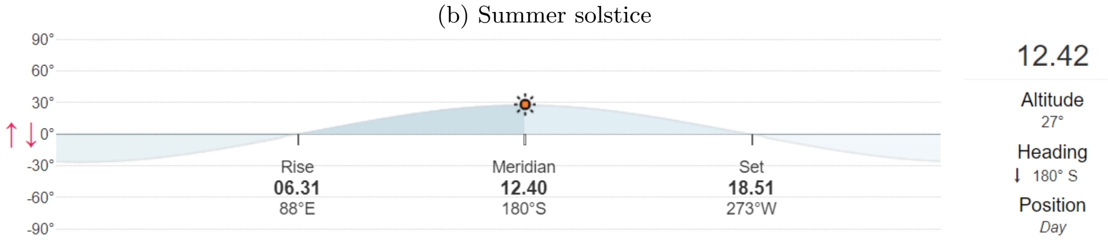
Source: [timeanddate.com, 2018]



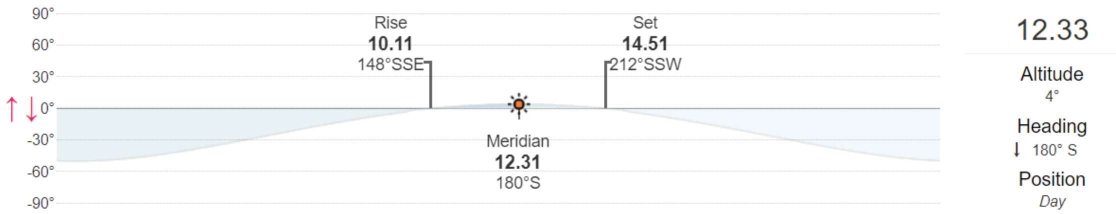
(a) Spring equinox



(b) Summer solstice



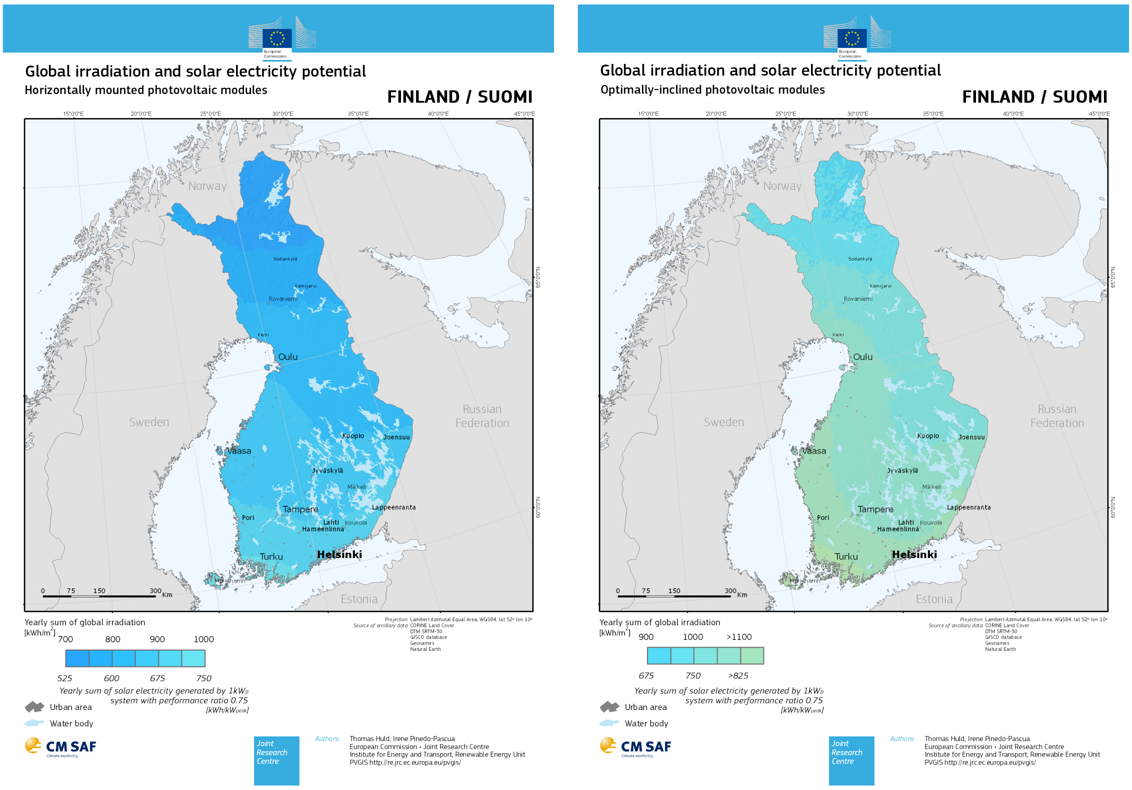
(c) autumn equinox



(d) winter solstice

Figure 4.2: Elevation paths of the sun during several days, with the compass heading of the sun at sunrise and sunset with additional information on the highest point of the sun

Source: [timeanddate.com, 2018]



(a) Panels placed horizontally

(b) Panels placed in optimal angle

Figure 4.3: Solar energy per year and square meter in Finland

Source: [re.jrc.ec.europa.eu, 2017]

In Figure 4.3 the electricity potential for panels placed in Finland can be seen, both when mounted horizontally and mounted with an optimal fixed angle. Both figures show that in the area near Turku the most electricity can be produced, reaching up to 1200 kW/m^2 yearly production on optimal tilt. Also the further more north the less energy is produced.

4.4 Weather in Vaasa

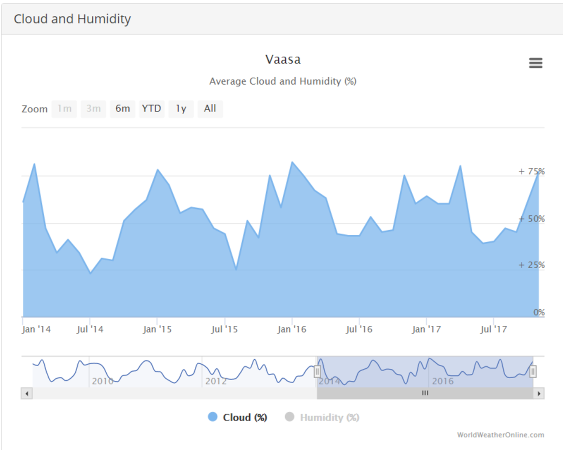
To study the profitability of the installation of a solar panel, the local weather needs to be considered. To see if it is feasible in Vaasa, the weather is quickly detailed in this section. This information can also be used in a simulation of total power generation of a panel for a more precise simulation.

The graph in Figure 4.4a shows the average cloud coverage in Vaasa for every month over the past 4 years. This shows that the average cloud coverage does not go lower than 25% and with some peaks just above 75% cloud coverage.

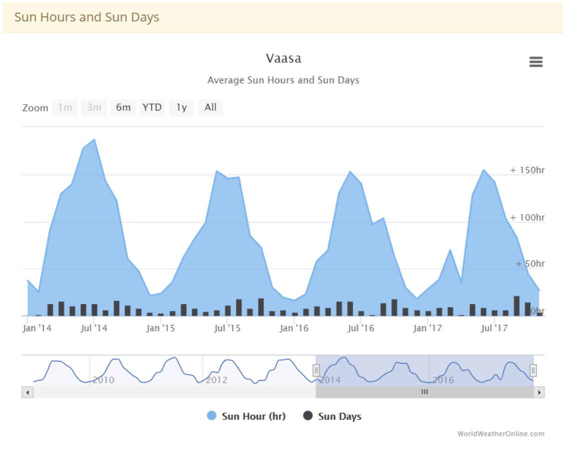
The next Figure (Figure 4.4b) shows the amount of sun hours per month over the past years. It can be seen that during summer there are about 150 sunny hours per month, though in the winter this goes as low as merely 25 hours. In 2017, there was 1747 hours of sun in Vaasa. The map 4.3b shows the total radiation in Finland during a year.

If a panel is covered by a few centimetres of snow, it will not work as efficiently or not at all. Snowfall is, as such, also an important factor. The average amount of snow and snow days of every month can be seen in Figure 4.4c). It shows that during winter, there will be always some snow in Vaasa. This means in order for the floating solar park to work properly the panels need to be cleaned of snow.

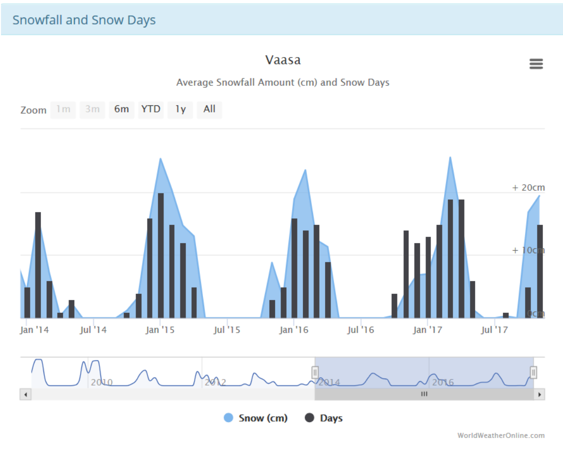
The wind can also be a decisive factor when choosing the location of the solar park. Firstly because wind speeds the heat transfer of the panel, affecting its efficiency but mostly because it can damage the panel structure. It can be seen in Figure 4.4d that the maximum sustained wind speed is about 32 Km/h, with gusts reaching over 40 Km/h. This has to be taken into consideration when conceiving the idea in an open area susceptible to wind.



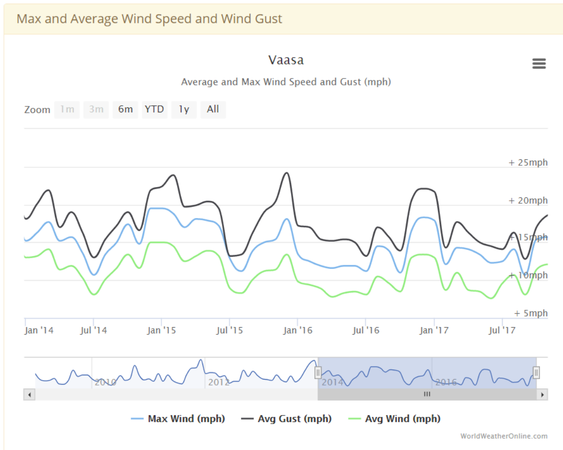
(a) Clouds



(b) Sun hours and days



(c) Snow fall and snow days



(d) Wind-and-gust

Figure 4.4: Average weather data in Vaasa

Source: [worldweatheronline.com,]

4.5 Difference between direct and diffuse radiation

There is a big difference in efficiency for most panels if this energy comes from diffuse radiation or direct radiation, so it is an important matter to know the difference.

Direct radiation happens when the photons reach the solar panel directly from the sun. In this case the photons radiated from the sun reach the solar panel directly. This type of radiation gets converted the electrical energy the more efficient than diffuse radiation.

Diffuse radiation is where the beam of photons has been redirected by e.g. clouds or buildings. This type of radiation on the solar panel is usually very inefficiently converted to electrical energy. One advantage of diffuse radiation over direct radiation is that there are not shadows, since diffuse radiation comes from all directions.

Reflected radiation occurs when the radiation that strikes the solar panels is reflected from an object. This can be important as snow can reflect up to 90% of the radiation striking it.

The total amount of radiation, which is the sum of these three types is called total radiation or global radiation.

The distribution of these types of radiation changes over the day. When the sky is clear and the sun is high in the sky, about 85% of the solar radiation is direct. As the sun goes down the amount of diffuse radiation goes up as more light is reflected from the atmosphere down to the ground. When the sun is about 10 °above the horizon diffuse radiation is about 40% of the total radiation. In order to get the most direct radiation it is best to tilt the panel towards the sun, to get the most diffuse radiation over a day however it is best to mount the panels horizontally.

4.6 Effects of clouds on solar panels

Some research in books and internet were made to find out how each type of clouds affect the panel. But, only few information has been found. During a cloudy day, the solar panel output has only an efficiency between 10% and 25%. Therefore, 75 to 90% of electricity is lost compared to a sunny day. This numbers were the same as in our experiments in Chapter 10. Source: [SolarPowerRock.com,]

On the other hand, electrical performance can be seen in the Graph 4.5, which shows the voltage, current and power generated by a panel under different solar irradiation. It can be seen that the energy production varies in a complex way with the illumination and the tension produced by the panel. For each illumination value the energy output has a maximum (from 142 to 290 watts) for a fairly precise voltage between 32 and 35 volts.

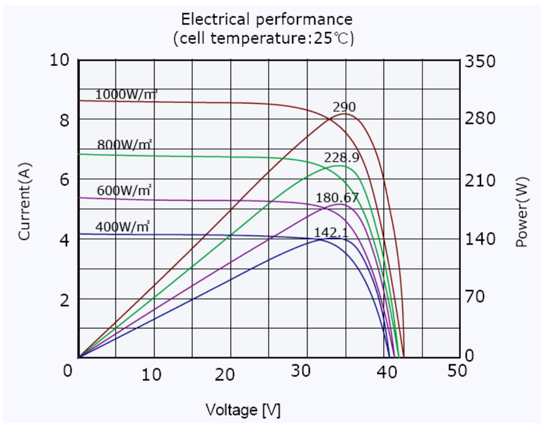


Figure 4.5: Electrical performance

Source: [tilikum and Robert, 2012]

4.7 Conclusion

This chapter presented some elements which affect solar panels. A few of these elements are the temperature of the panel, the position of the sun and the local weather. A higher temperature has a negative impact on the power output, generally by 0.5% per degree. A change in the position of the sun changes the angle of incidence of direct radiation which has an effect on the efficiency as well. At last, the effects of clouds have been discussed.

Chapter 5

Improving the efficiency

5.1 Introduction

In Chapter 4, multiple factors that can affect the efficiency of panels were discussed. In this chapter some ideas will be discussed to counteract or to use these factors in order to increase the efficiency of the panels. Increasing the efficiency might result in less panels used for the same energy production, lowering the cost of a system.

5.2 Cooling

As was said before in 4.2, the efficiency of solar panels increases with the lower temperature. That is why taking in consideration the possibility of implementing a cooling system for the installation is a task that has to be done.

In all methods considered some assumptions are made to do the calculations. First, the temperature of the water in the sea in Vaasa is no higher than 18ºC in summer. For the upcoming calculations this value will be considered the temperature of the cold focus, and therefore, the coldest temperature reachable. In Vaasa the average temperature for July, the hottest month, is 20ºC and 76% of relative humidity. An average wind speed of 3 m/s will be considered. Regarding to the characteristics of the panel, they are usually made up of glass, so for the calculations the material properties of glass will be taken. The predictions will be done considering a plate of 6 millimetres of thickness, one square meter of area, with a density of $2500Kg/m^3$. A value of 837 J/Kg °C will be considered for the specific heat (Cp), and a value of $0.8W/m^2$ for the thermal conductivity (K). The temperature coefficient of power rating considered for the panel is 0.45%.

5.2.1 Heat flow of the panel

For this, first we have to know how hot the panels get. At was said before, in solar panels about 10-15% of the energy received is converted into electrical power. A 10% of the energy is considered to be reflected, and the remaining 75-80% is converted into thermal energy. Due to this, solar cells can reach temperatures as soaring as 30ºC higher than the temperature of the surroundings, which implies a decrease in efficiency between 9-15%. Source: [Sánchez, 2004]

Also, the heating net flux on the solar panel has to be found. For that, we used a isothermal model from solar panels. It considered the radioactive and convective heat flux, as can be seen in Figure 5.1. Source: [Romero, 2002]

The flux for temperatures from 20°C to 50°C , in 1°C intervals was calculated and then plotted. A regression was done to know the equation which relates the heat flux with the temperature of the panel, and the Equation (5.1) was generated:

$$W = -31.594T_p + 1496.9 \tag{5.1}$$

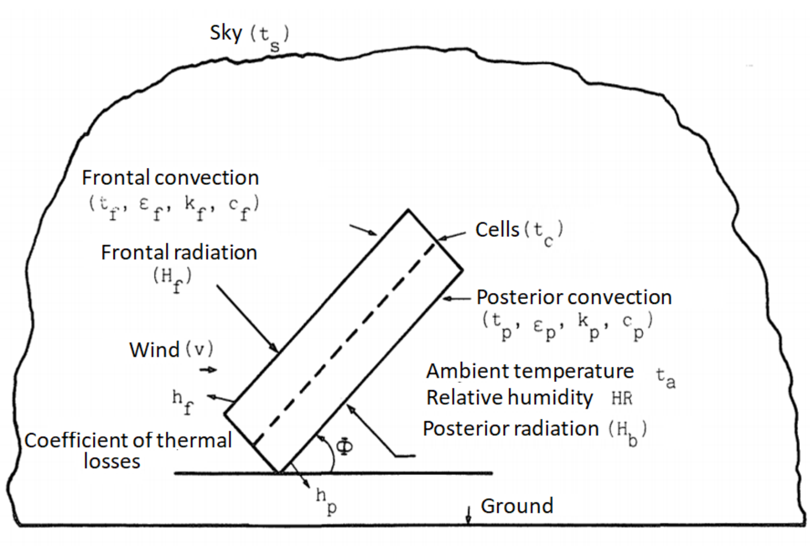


Figure 5.1: Schematics of the heat heat flows parameters in a solar panel

Source: [Romero, 2002]

According to this Equation (5.1), the net heat flux is zero at a value of 47.22 °C degrees, which is when the thermal equilibrium is reached without cooling. This temperature is similar to the one that the bibliography specified and is the one that will be considered in the following calculations.

5.2.2 Cooling

Commonly used cooling systems such as an expansion refrigeration system or a peltiers system is not profitable with this solar panel temperature. However, due to the special circumstances of this project, the implementation of cooling with water may be possible. The first method of cooling is by plunging the solar panel in water to cool it down. In this method the efficiency gain due to cooling will be compared to the efficiency lost of the panel being underwater. The next method considered is by pouring streams of water on top of the panel and thus forcing a heat flux. In this method the efficiency gained has to be compared to the energy cost of pumping water.

5.2.3 Plunging cooling

In this situation the main way of heat transfers would be natural convection. The heat flow per square meter Q is described by Equation (5.2), where h convective coefficient, T_p is the temperature of the panel and T_w is the temperature of the water.

$$Q = h(T_p - T_w) \tag{5.2}$$

Radiation heat transfer under water will be disregarded, as well as the cooling due to the evaporation of the remaining water on the panels after returning to theyr normal position. As such, in this method, a hot flat surface being submerged in water is considered. Also no water flow lateral to the surface is considered.

To calculate the convective conductance h in Equation (5.2), Equation (5.3) is used. Here N_u is the Nusselt Number, K is the thermal conductivity of the water and L is the length of the panel. The Nusselt Number can be calculated by using Equation (5.4), where C and m are coefficients dependant on the Rayleight Number (R_a). Table 5.1 shows the empirical values of these coefficients.

$$h = \frac{N_u K}{L} \tag{5.3}$$

$$N_u = C * R_a^m \tag{5.4}$$

Table 5.1: Values of C and m dependent on the Rayleigh Number

R_a	C	m
$10^4 - 10^7$	0.54	1/4
$10^7 - 10^{11}$	0.15	1/3

The Rayleigh Number is described by Equation (5.5) where G_r and P_r are the Grashof and Prandtl numbers. The Prandtl Number is a property of the water, depending on temperature. The Grashof Number can described by Equation (5.6) respectively. Where g is the gravity force in m/s^2, β the coefficient of volumetric expansion, T_p the temperature of the panel, T_w the temperature of the water, L the length of the panel and ν the kinematic viscosity in m^2/s.

$$R_a = G_r * P_r \tag{5.5}$$

$$G_r = \frac{G\beta(T_p - T_w)L^3}{\nu^2} \tag{5.6}$$

Replacing h in the Equation (5.2) the heat flow while cooling can be calculated. The lost on efficiency in this way of cooling is due to the fact that when the panel is underwater, no power is generated. To calculate the time needed to reach a certain colder temperature from a certain hotter temperature Equation (5.7) is used, where C_p is the specific heat capacity of the panel, $(T_h - T_c)$ is the difference between the hot and cold temperature and Q is the energy flow.

$$t = \frac{C_p(T_h - T_c)}{Q} \tag{5.7}$$

While t is the time, C_p the specific heat of the panel, T_h the temperature before cooling, and T_c the temperature after cooling. The convective heat flux changes with the temperature of the panel, which varies over the time. This means that Q has to be expressed in function of time. Doing this we can get the expressions shown in Equation (5.8)

$$t = \frac{C_p(T_h - T_C)}{h(T_p - T_w)}$$

$$= \frac{C_p(T_h - T_C)}{\frac{K_f N_u}{L}(T_p - T_w)}$$

$$= \frac{C_p(T_h - T_C)}{\frac{K_f 0.15 R_a^{1/3}}{L}(T_p - T_w)}$$

$$= \frac{C_p(T_h - T_C)}{\frac{K_f 0.15 R_a^{1/3}}{L}(T_p - T_w)}$$

$$= \frac{C_p(T_h - T_C)}{\frac{K_f 0.15 (G_r * P_r)^{1/3}}{L}(T_p - T_w)}$$

$$t = \frac{C_p(T_h - T_C)}{\frac{K_f 0.15 P_r^{1/3}}{L}\left(\frac{g\beta(T_p - T_w)L^2}{\nu^2}\right)^{1/3}(T_p - T_w)} \tag{5.8}$$

By simplifying and integrating the temperature of the panel T_p from T_h to T_C in Equation (5.8), Equation (5.9) comes up. With this it is possible to calculate the time needed to cool down to a certain temperature. The plot in Figure 5.2 shows how long it takes for the panel to cool down one degree at each temperature. In Appendix B the time it takes from each temperature to each temperature is shown.

$$t = \int_{T_C}^{T_h} \frac{C_p(T_h - T_c)}{K_f * 0.15 * P_r^{1/3} * \left(\frac{g*\beta}{\nu^2}\right)^{1/3} * (T_p - T_w)^{4/3}} dT_p \tag{5.9}$$

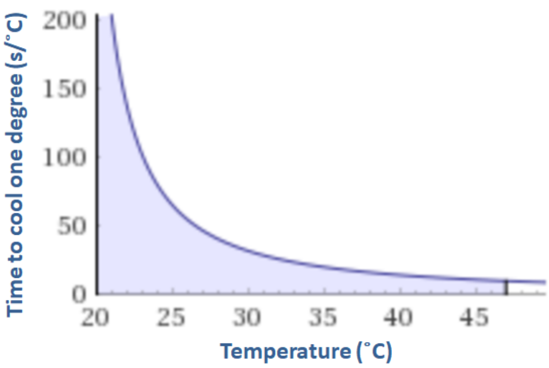


Figure 5.2: Seconds needed to cool one degree

The results gotten for each temperature ranges are in the Appendix B. Now we have to find the time that it takes to heat up again the panel. The sum of the time that it takes to heat and the time that it takes to cool will be the time of one cycle. Heating time is calculated on a similar way as cooling time. As can be seen in Equation (5.10).

By calculating how long it takes for the panel to reach T_h from T_c from the sunlight the time that power is generated is known. This is necessary to calculate how much power is generated while heating up, so that this can be compared by the power loss due to being submerged. The heating time is calculated in much the same way. Equation (5.10) shows the time it takes. By integrating the temperature of the panel T_p from T_c to T_h this time can be calculated. This is shown in Equation (5.12). The results of the integral for each temperature range is shown in Appendix B. Figure 5.3 shows the number of seconds needed for the panel to heat up one °C at a certain temperature.

$$wt = C_p(T_h - T_c)$$

$$t = \frac{C_P(T_h - T_c)}{-31.594T_p + 1496.9} \tag{5.10}$$

$$wt = c_p(t_H - T_C)t = \frac{wt(C_p - T_c)}{-31.594T_p + 1496.9} \tag{5.11}$$

$$\int_{T_c}^{T_h} \frac{C_p(T_h - T_c)}{-31.594T_p + 14969} dT_p \tag{5.12}$$

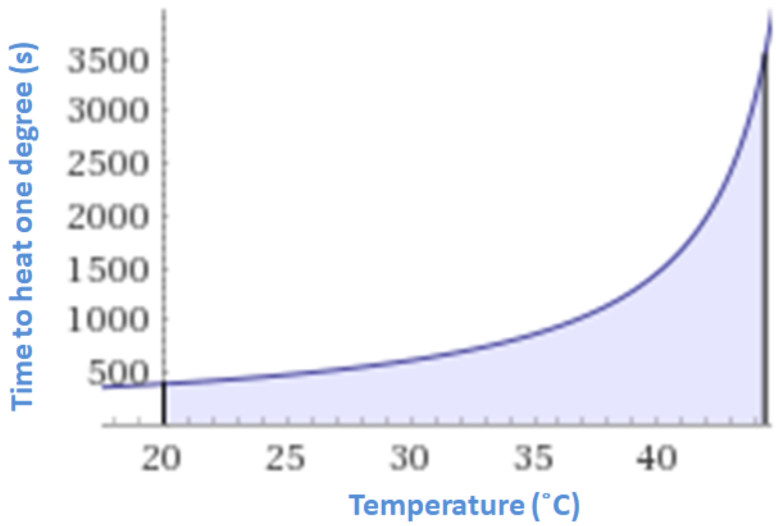


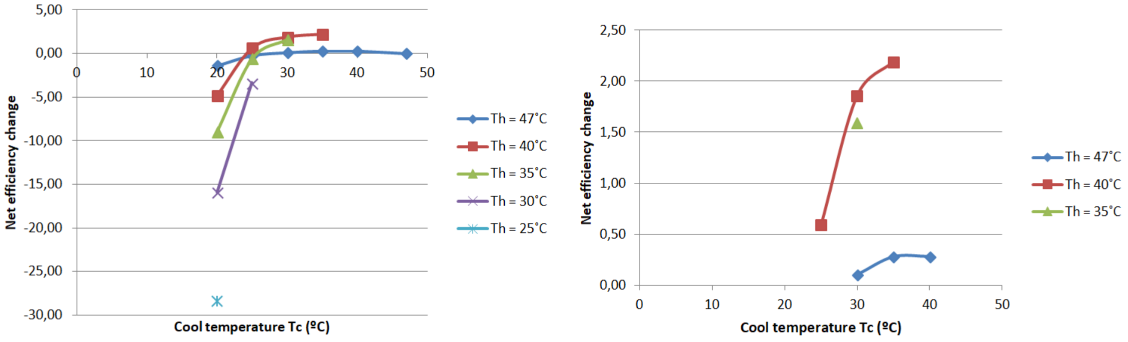
Figure 5.3: Seconds needed to heat one degree

Now, in order to calculate the increase of efficiency, the average temperature during the heating time has to be calculated. This point is the temperature in which the vertical line divides the area under the graph in two sides with the same area. These results are shown in the Appendix B.

$$\int_{T_c}^{T_{average}} \frac{C_p(T_h - T_c)}{-31.594T_p + 1496.9} dT_p = \int_{T_{average}}^{T_h} \frac{C_p(T_h - T_c)}{-31.594T_p + 1496.9} dT_p \tag{5.13}$$

For calculating the efficiency drop, the time needed to cool the panel was multiplied by 100%, which is the efficiency drop assumed. For calculating the efficiency gained, the time needed the heat again the panel was multiplied for the temperature coefficient of power rating considered, and for the difference between 47 °C, which is the temperature that the panel would have without cooling, and the average temperature of the panel during the heating process. For the measuring of the efficiency change the sum of the efficiency increase and drop was done, and then divided by the total cycle time. This way the results are obtained in terms of percentage. All these results are shown in the Appendix B .

In Figure 5.4a the net efficiency gain is plotted for multiple T_h values cooling to T_c. As it can be seen, most of the situations lead to a decrease in the total efficiency. If just the positive data are isolated (Figure 5.4b), some cases where the efficiency is improved can be detected. The graph shows that the situation with the highest increase in efficiency is when the panel is cooled to 35 degrees every time that the panel reaches 40 ºC. This way an improvement in the efficiency of 2.19% could be achieved.



(a) Efficiency - Temperature of the panel (b) Positive results

Figure 5.4: Net efficiency change of different T_h cooling the panel to T_c

5.2.4 Conclusion

All the calculations done lead to the conclusion that a tight improvement in the efficiency can be achieved by this method, and that it can be even higher than the one found if the water were colder or the panel hotter.

5.2.5 Validity of the results

When considering the validity of the results, it has to been observed that for doing the calculation some assumptions were made. Also, the calculations were done just for one specific ambient situation. This means that all the calculations should not be perceived as hard truths but as a first hint about the possibility of cooling the panels using this method and therefore, practical study should be done to effectively prove the method.

5.2.6 Forced flux

Another method to cool the panels is by pouring water on top of them to dissipate the heat away. This process will be profitable, and therefore feasible, if the energy gained due to the increase in efficiency is higher than the energy cost of pumping the water. This time in order to maintain a constant temperature in the panels; the water will be pumped all the time, generating a cooling heat flux determined by Equation 5.1. The water flow needed to cool the panels can be calculated with the following equation:

$$q = \frac{W}{C_p(T_w - 19)} \tag{5.14}$$

Where q is the water flow in m^3/s, w the heat flow to dissipate, Cp is the specific heat of the water, and Tw the temperature of the water after the cooling. In the calculations, we supposed a heat exchange rate of about 0.5, which means that the heat exchanged is half of the maximum heat that could be transmitted. With this rate the temperature of the water after the cooling can be calculated, and thus the water flow. The power needed to pump water is the multiplication of the flow and the pressure given to the water. Assuming a pressure drop of one meter (9806 Pa), the energy that the water need to be pumped can be calculated. For this neither the efficiency of the pump or the installation were considered. It is also assumed that one square meter of solar panel provides 187.5W. Knowing all of this we can calculate how much energy is lost by pumping the water and how much energy is gained due to the cooling. Subtracting the first from the second and dividing the result by 187.5, we can calculate the change in the efficiency. These results are plotted in the Chart 5.5 and displayed in Appendix B.

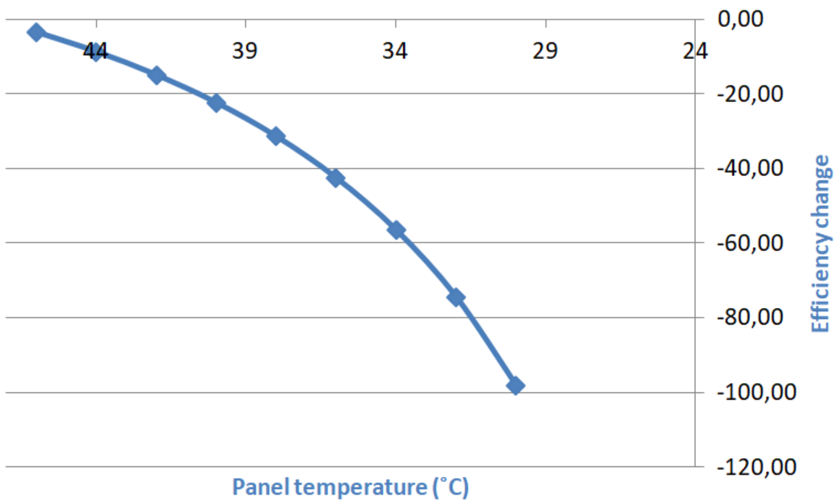


Figure 5.5: Chart Efficiency - Panel temperature

As it can be seen, the chart shows a clear inefficiency in the process of cooling by pumping water, being necessary to spend even all the energy generated by the panel to cool it down to 30 °C. The calculations done indicate that cooling by pumping water is not profitable in any case.

5.3 Solar Tracking

5.3.1 Theory

In Section 4.3, the effect of the position of the sun has been discussed. One important thing to note is that when the sun is not facing the panel directly, the panel will produce less power. Figure 5.7 shows a graph on how the efficiency of the panel relates to the angle of the sun to the normal of the panel. At a 45°angle, the panel only produces about 30% of the maximum power. This graph shows that the larger the angle to the normal, the less efficient the power production. This relation can be described Equation 5.15, where x is the efficiency factor and α is the angle of incidence.

This shows that if it is possible to track the sun throughout the day, it should be possible to generate more electrical power. In a study done in 2008 with a simple solar panel and a tracking setup, the researchers have achieved a 30% increase in total energy production during a day by tilting the panel compared to a horizontally fixed panel. Source: [Rizk and Chaiko, 2008]

$$x = 1 - cos(\alpha) \tag{5.15}$$

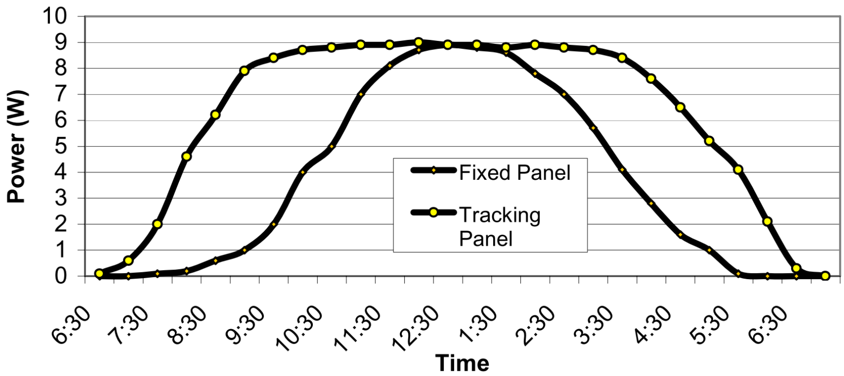


Figure 5.6: Power output during the day of a tracking panel compared to fixed panel

Source: [Rizk and Chaiko, 2008]

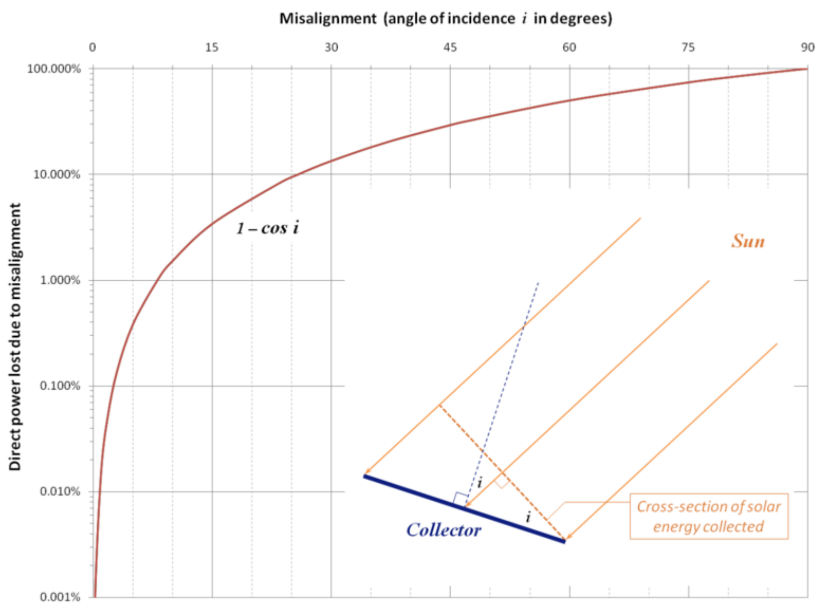


Figure 5.7: A graph and drawing showing the effect of the angle of incidence of the light on the panel

Source: [Wikipedia, 2017]

5.3.2 Numerical simulation

Introduction

In order to see if applying solar tracking in Finland is beneficial, a numerical simulation has been made with solar data in Vaasa. A few assumptions are made in this simulation. The first assumption is that no clouds will affect the efficiency. In real life, cloud coverage will block direct radiation decreasing the power production. Another assumption made is that the temperature of the solar panel does not affect the efficiency either. As shown in Section 4.2 that a higher temperature affects the power production in a negative way.

To find the position of the sun, a table has been found of the elevation and azimuth angle of the sun. This source can be used to find the position of the sun every minute of every day for a year long, and as such find the angle of incidence from direct radiation if the angle of the solar panel is known. Source: [sunearthtools.com, 2018]

Figure 5.7 shows that if the angle of incidence gets smaller the efficiency of the panel decreases significantly. In this case an angle of 90 °means that the direct radiation is parallel with the panel surface's normal. The efficiency of the panel due to the angle of incidence can be described by Equation 5.15.

Method

The software used for this numerical calculation is Matlab R2017B. Multiple situations were simulated. The first situation is that the solar panel is rotating with sun's position, but that the tilt is fixed. The code for this simulation can be seen in Appendix A.1. The next situation simulated is the solar panel facing south and on a fixed tilt angle, this code is shown in Appendix A.2. With both of these simulations the best fixed tilt angle was found by looping over the tilt, starting at 0 (flat on the ground) and going to 90 (on the side) with steps of 1 degree tilt. The last situation is where the solar panel is tracking and tilting with the sun. The Matlab code for this is shown in Appendix A.3. This situation can be compared to optimal angle of both other situations. In all situations the panel's rated wattage is set to 75 W.

Results

- Facing south, fixed tilt

In Figure 5.8 the total power generation from one year is plotted versus the tilt angle when the panel is facing south. It is shown that at 67 °tilt the most energy gets produced over a whole year. This amount is 285 million Joules. Figure 5.9 shows the power generated for every day in the year with this maximum angle. To generate the most amount of power, one has to balance tilting the panel in so that energy can be created in the winter, and having the panel plat so that power is generated in the summer when the sun is right above. As can be seen, the most power generation happens in the months of March and at the end of September. In Figure 5.10 the total energy production over the year for 0° and 90° tilt is shown for comparison.

During the summer the total power generation is less because as the sun rises in the morning the azimuth angle of the sun is more north than the panel is facing, meaning that the direct radiation is hitting the backside of the panel. The same thin happens in the afternoon. Another factor in the summer is that the sun is higher than the panel is facing, so the energy production is not optimal. If it is possible to rotate the panel to face the sun, energy can be produced in these hours where the sun is 'behind' the panel. This could increase the total yearly energy production.

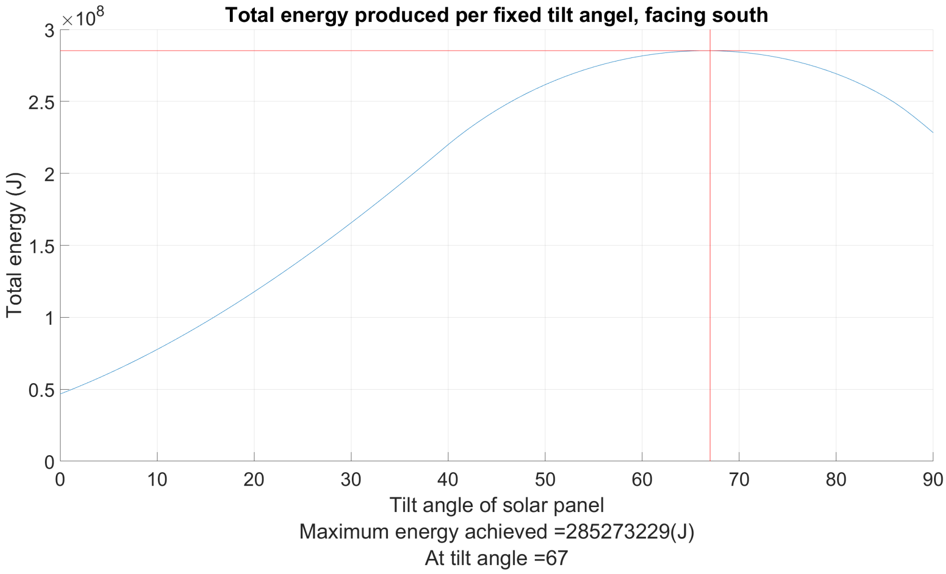


Figure 5.8: Total power (J) of a 75 Watt solar panel at 100% efficiency at different tilt angles

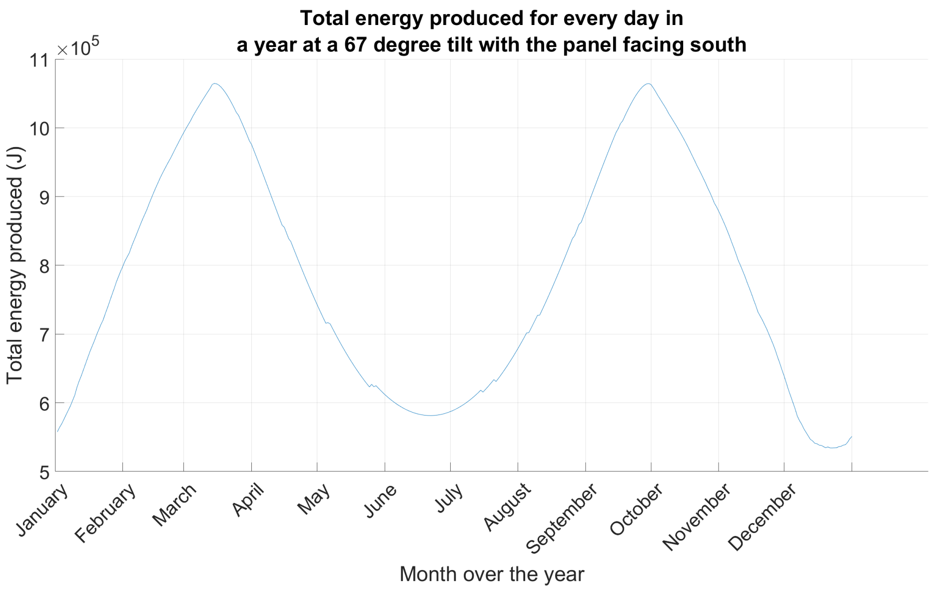
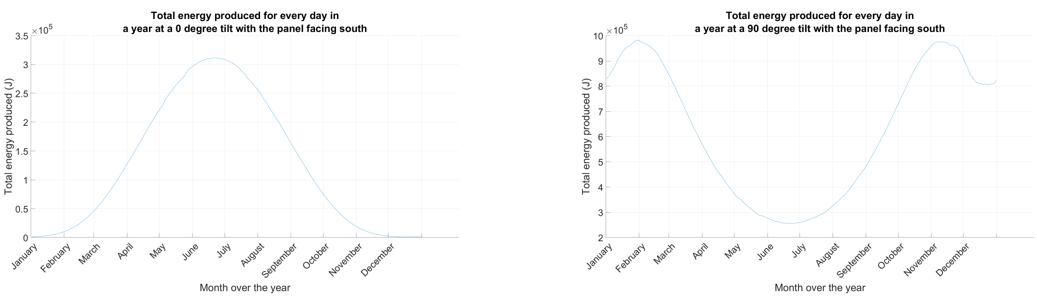


Figure 5.9: Total energy (J) created at each day of the year at a tilt of 67 °



(a) At 0° tilt (b) at 90° tilt

Figure 5.10: Total energy creation at each day of the year

- Rotating with the sun, fixed tilt

Figure 5.11 shows the total amount of energy produced for every tilt angle of the panel when the sun is rotating. In this case the optimal angle is 73°, which a total amount of 952 million Joules of electrical energy produced. This is around 3.3 times as much energy than when the panel is only facing south. This huge increase in power production can be explained by the fact that the panel is generating energy when the sun would be behind the panel if it does not rotate. Looking at the power production of every day across a year, which can be seen in Figure 5.12, there is no dip in power production in the during the summer. This fact further supports the idea that, if the panel is facing south a lot of energy is lost due to the sun being behind the panel. In Figure 5.13 the total power production per day for the angle tilted 0° and 90° is shown for comparison.

Another way to improve power production is if the panel is tilting with the sun. This way it is possible to increase the overall efficiency of the panel, as the effective cross-sectional area will be 100% for most of the times.

- Rotating with the sun, tilting with the sun

In Figure 5.14 the total energy produced per day over a year when the panel is rotating and tilting with the sun. The graph has a shape which you would expect of the sun hours in Vaasa. [something about linearly going up and then down, as do the sun hours]. The total energy produced in this case is 1.204 million Joules. This is assuming perfect weather conditions and with a tilt tracking where the panel can go from 90 to 0 degrees tilt. This is an increase of 252 Million Joules compared to only rotating with the sun.

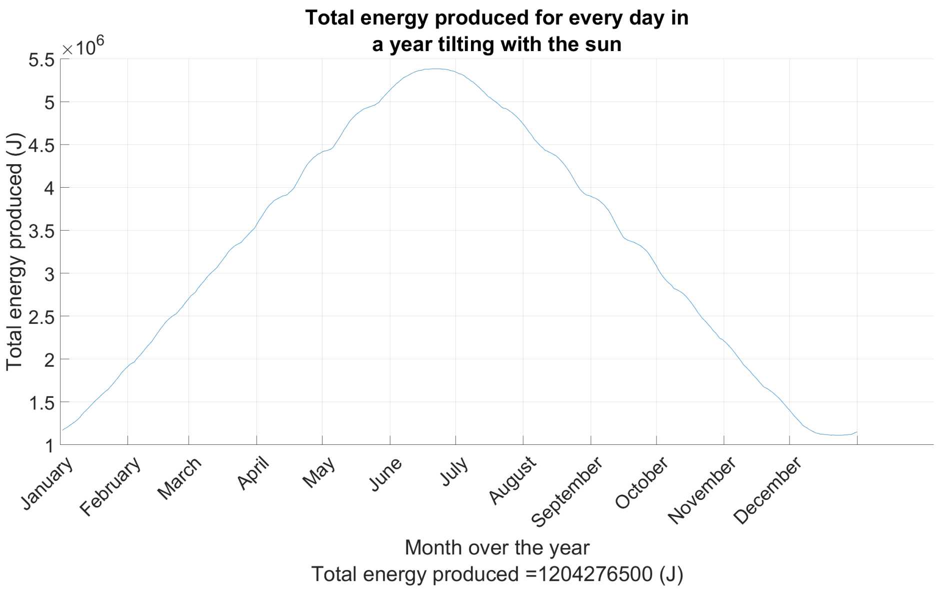


Figure 5.14: Total energy production over a year when the panel is rotating and tilting with the sun

Conclusion

In Table 5.2 the total energy produced in the 3 situations is compared to each other, where the fixed solar panel is taken as a base value. It can be seen that only rotating the panel already increases the total power output by 3.34 times. Tilting the panel as well increases the total power output to 422% of the base value. As such it can be concluded that, regarding the assumptions and simplifications used in this simulation, it is beneficial to use rotation and tilting to track the sun.

Table 5.2: Comparison of total power output during the year

Name	Facing south, fixed tilt	rotating, fixed tilt	rotating, tilting
Joules in million	285	952	1204
Percentage	100	334	422

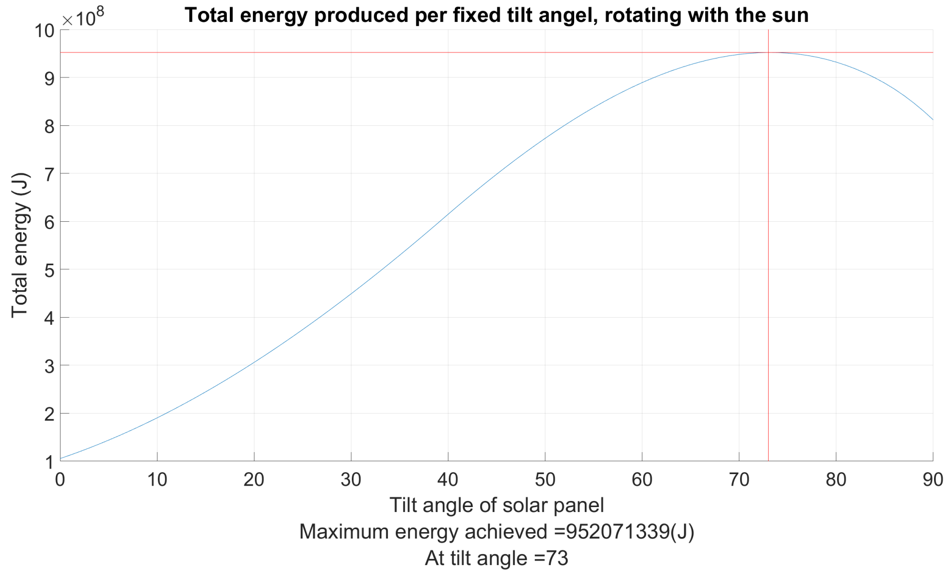


Figure 5.11: Total power (J) of a 75 Watt solar panel at 100% efficiency at different tilt angles

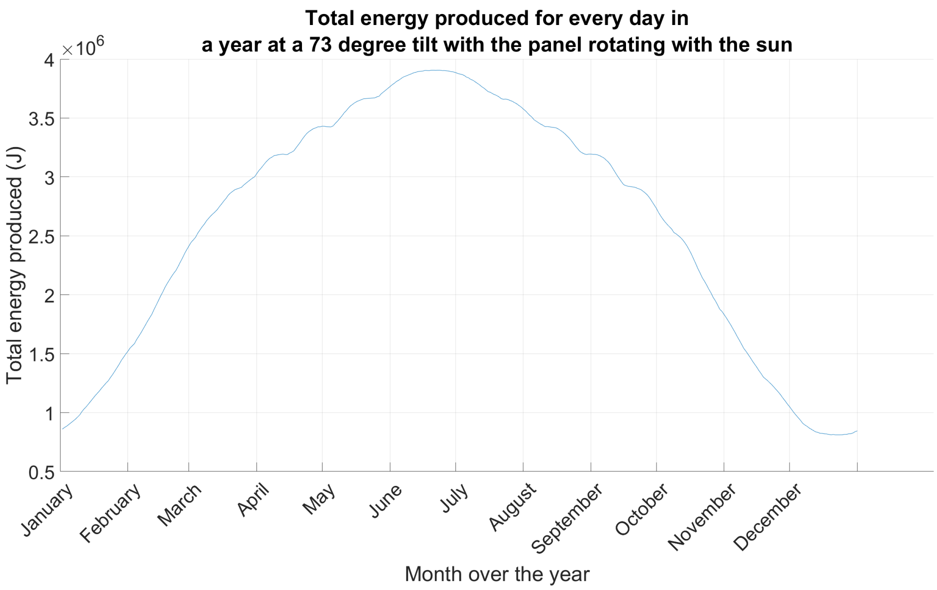
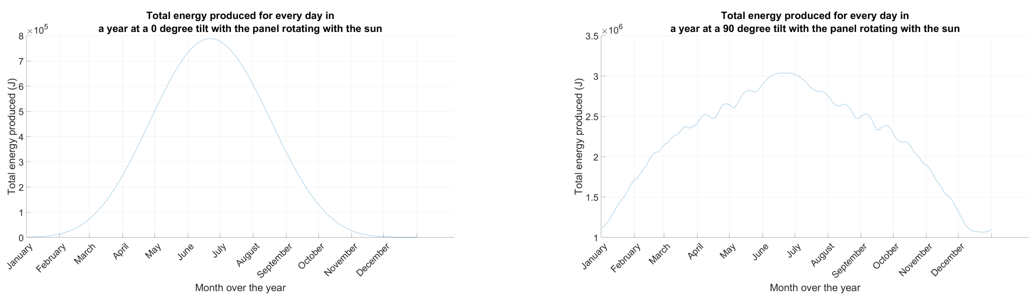


Figure 5.12: Total energy (J) created at each day of the year at a tilt of 73 °



(a) At 0° tilt

(b) at 90° tilt

Figure 5.13: Total energy creation at each day of the year

Discussion

In the numerical simulations some assumptions have been made that can influence the result. The most important is that the weather has not been taken into account. Cloud coverage can severely lower the instantaneous power output of a solar panel as the direct radiation is blocked, resulting in less energy produced throughout the day. The temperature of the solar panel is disregarded as well, as it is too complicated to calculate at the moment. Next to that, the power efficiency calculation of the base line might be wrong. This is calculated by using Equation 5.15 for the elevation angle difference and for the azimuth angle difference separately, than multiplying both values and as such calculating the total efficiency. It might be possible that the actual efficiency in certain situations is higher than calculated. Next to that, the power needed to rotate and tilt the solar panel is not calculated and subtracted from the power generation. If it happens that rotating costs more power than will be got, it is not beneficial to rotate. This has to be investigated. However more details should be known about the prototype or concept design.

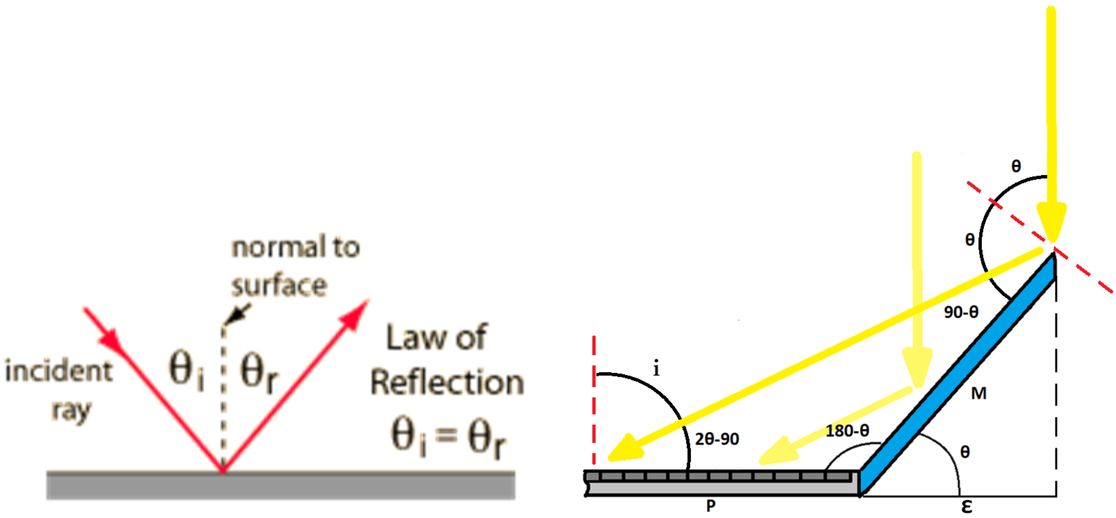
5.4 Mirrors

In environments where the solar radiation is not specially intense, it could be interesting to concentrate the light in the panels with the aid of mirrors. In this section the usage of mirrors to gather more light is explored. For that, calculations were made in the situations of flat and parabolic mirrors reflecting the sunlight into the panel

5.4.1 Flat mirrors

The law of reflection states that on a flat mirror, the angle between the incident light to the mirror's normal and the angle between the reflected light, when all are in the same plane, is the same. This is illustrated in Figure 5.15a. For reflecting the light uniformly along the panel, the light from the border of the mirror must be reflected to the centre of the panel. This way two mirrors can be placed on both sides covering all the surface of the panel. This is illustrated in Figure 5.15b, where the light hitting the mirror on the outer edge is reflected to the panel's centre. In this figure only half of the panel is shown. Here P is half the panel's length, M is the length of the mirror,i is the angle of the reflected ray to the normal of the panel, Θ is the angle of the mirror to the horizon and ϵ is the length of the mirror projected to the horizon. The effective area of the panel in the case that there were two mirrors in opposite laterals can described by equation (5.16), where A_f is the effective area. Source: [Olmo and Nave, 2018]

$$A_f = 2 * (P + \epsilon) \tag{5.16}$$



(a) Law of reflection (b) Schematic of mirror added to panel

Figure 5.15: Law of reflection in combination with a flat mirror angled to the side of a panel.

Considering a triangle with three sides $[a, b, c]$ and three angles $[A, B, C]$, and where angle A is opposite side a, angle B opposite side b and angle C opposite side c, the Sine Law (Equation (5.17)) can be used to find the relationship between the length of the sides and the angles. By taking sides P and M and their corresponding angles, the length of the mirror needed to reflect light up to the centre of the panel can be calculated for each angle. If M is known ϵ can be calculated and from that the effective area of the panels.

$$\frac{sin(A)}{a} = \frac{sin(B)}{b} = \frac{sin(C)}{c} \tag{5.17}$$

$$\frac{sin(90 - \theta)}{P} = \frac{sin(2\theta - 90)}{M}$$

$$sin(90 - \theta) * M = sin(2\theta - 90) * P$$

$$M = \frac{sin(2\theta - 90) * p}{sin(90 - \theta)} \tag{5.18}$$

The results for solving Equation (5.18) for $P = 0.5$, which is a one meter panel, is shown in Figure 5.16 It is shown that an angle of more than 45 °is needed to reflect light to the panel. Next to that the bigger the angle the longer the mirror has to be for the previously explained condition to be met. The increase of efficiency is directly linked with the effective length of the mirrors, which is the area of the mirror which receives sunlight, referred as ϵ in the Figure 5.15b.

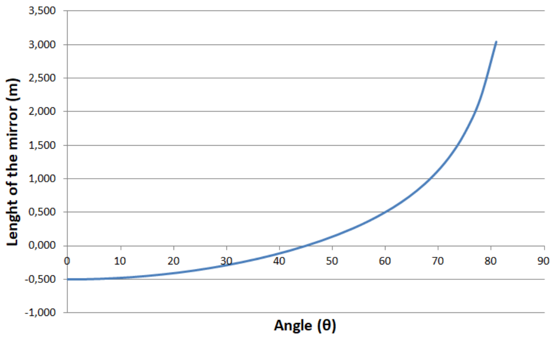


Figure 5.16

The next step for calculating the efficiency of the mirrors is adding efficiency lost due to the misalignment of the solar rays reflected. For this the equation shown in the Figure 5.7, will be used. Also, a efficiency of a 95% will be considered for the mirrors. The efficiency lost due to the heating is not considered.

Applying all these considerations, the Chart 5.17 is generated. In the graphic it also can be appreciated that the mirror length increases sharply, so for achieving an increase in efficiency of about ninety percent huge mirrors would be needed.

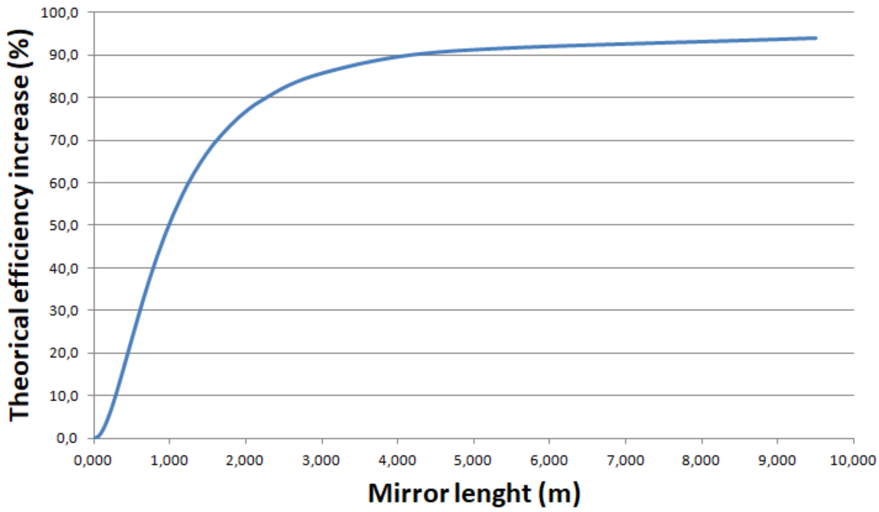


Figure 5.17

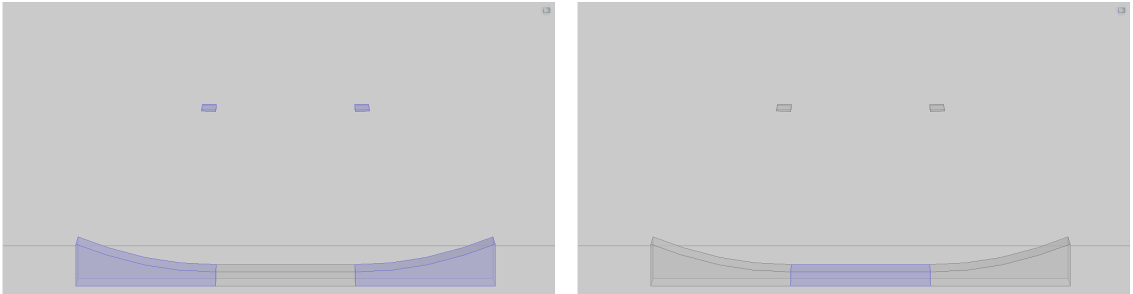
It is important to remark that for taking advantage of the mirrors it is mandatory to do a full solar tracking, since otherwise the mirrors would shade the panels most of the time. Also, the mirrors would only work properly in an ambient with a high percentage of direct solar radiation, since diffuse solar radiation comes from every direction and would not be reflected into the panels. The shadow that the mirrors of one panel can cause in other panels also has to be taken in consideration.

5.4.2 Conclusion

As a conclusion, empirically in the tests done, our solar panel rated for 100 watts, it was measured that it was providing a power of about about 40-45 watts when it was tilted toward the sun in sunny conditions. This mean that for achieving the power which it is rated, twice as much sunlight has to be reflected into the panels. It is not possible to gather such an amount of sunlight by using flat mirrors, so facing the conditions that we have witnessed in Vaasa it would not be possible to reach the rated power. However, by using mirrors of just of one meter of length, an theoretical increase of efficiency of a 53% could be achieved. So the usage of flat mirrors is one boost that should be considered if the proper circumstances, and when solar tracking is going to be done anyway.

5.4.3 Parabolic mirrors

A second idea for placing mirrors is to use parabolic mirrors as in a telescope. To test if this is geometrically possible, a Comsol Multiphysics model was created for ray tracing. In Figure 5.18 the geometry of this model can be seen, detailing the mirrors and panel separately.

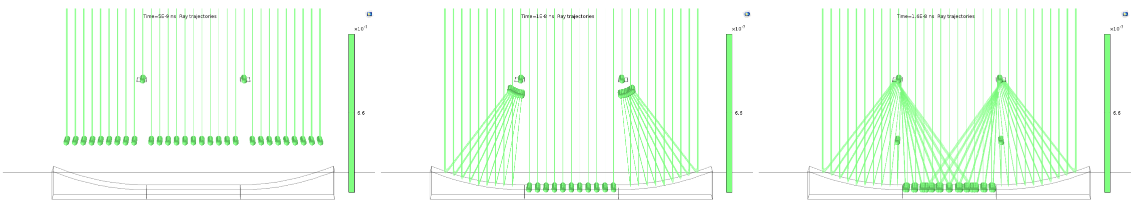


(a) mirrors (b) solar panel

Figure 5.18: Geometry of the parabolic mirrors setup, with separate figures detailing which part is mirror and which part is panel

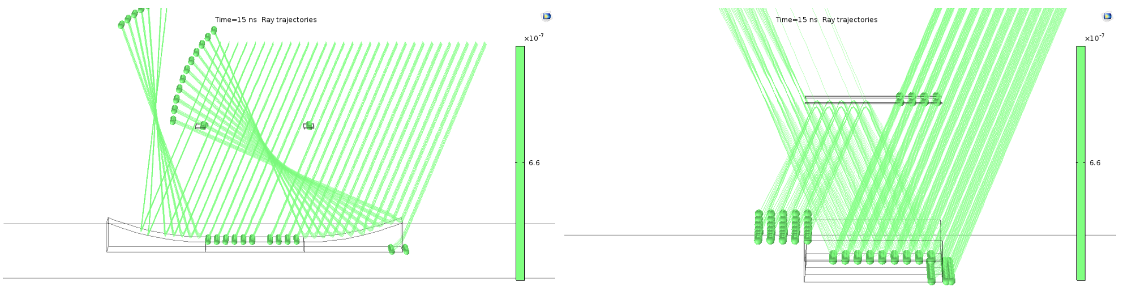
The lower mirrors are parabolic with a curvature that can be described by $a * x^2$, where a is a coefficient, and x is the distance away from the mirror. The higher mirrors have a curvature of $2a * x^2$, and are placed at the focus point of the first mirrors. This way the light collected from the first mirrors gets reflected back to the solar panel but equally spread out across the solar panel. The equal spread guarantees that there are no hotspots of light where excessive heat is generated.

The goal of this model was to do a ray-tracing study in order to get the correct geometry. In Figure 5.19 three time intervals of the ray tracing are shown. It can be seen in Figure 5.19b that the big mirrors focus the incoming light towards the top mirror. This is what happens in a telescope as well. Figure 5.19c shows that the reflected light is now spread out on the solar panel. This geometry only reflects the light to the panel if the light is coming straight from above. In practice this means that the setup needs to rotate and tilt. Figure 5.20 shows two situations where the light is not coming directly from above. This shows that the design can only work if it can rotate and tilt with the sun.



(a) 5 nanoseconds (b) 10 nanoseconds (c) 15 nanoseconds

Figure 5.19: Ray tracing of light at different times



(a) Light coming from the side, front view (b) Light coming from behind, side view

Figure 5.20: Two situations where the light is not coming straight from above, showing that solar tracking is necessary with this design

5.4.4 Inconvenience

Mirrors can be efficient if the panel and mirror structure is faced directly towards the sun in order for the light to be reflected correctly. Therefore the structure has to rotate, requiring a mechanical structure and a solar tracking system. If no rotation or tilt is done, it is cheaper to settle more solar panels instead of mirrors. Moreover, solar panels get hotter with more sunlight and they can lose efficiency without a cooling method. Even if it is possible to maintain a constant temperature, the lifetime of a PV cell can decrease. Cooling systems also cost electrical power and money. In a majority of solar park projects it is less efficient to put mirrors than to add more panels.

As mirrors focus the light, this means that the panel also heats up more. When a semiconductor gets hot, charge carriers are excited in the conduction band. With more electrons free floating the conduction band, electrical charge leaks. This is a negative effect on the efficiency of the solar panels. To explain with simple images, a dam is the junction. The water of the lake is charge carriers and the sun is the energy needed to carry water from above the dam to the lake. The mirrors heat affects water and create waves in the lake where sometimes go below the dam.

Next that, the power output of a panel is limited by the cell generating the least amount of current. This means that the reflected light has to be reflected equally across the surface. Equal reflection on the panel also ensures that no hot spot is created locally burning the panel or melting the soldering.

5.5 Cleaning solar panels

5.5.1 Introduction

In this chapter different methods of cleaning, and their advantages and drawbacks will be discussed. First, the necessity of cleaning the dust in Finland will be argued. And a secondly, the snow coverage of the panels will be examined.

5.5.2 Dust and snow state of Finland

Cleaning the solar panels in Finland is not necessary if regarding to the environment. In Finland there is enough rain to clean the solar panels from dust. Also Finland is not a deserted area, which means that the amount of dust on the solar panels will be low. On the other hand, during winter, snow and ice will be problematic.

Source: [evergreensolar.com, 2017]

5.5.3 Solar panels in cold climates

Cold and sunny weather is actually very appropriate for panels. Winter months are good for solar energy production, as long as the panels are not covered by snow. Like most electronics, solar panels function more efficiently in cold conditions than in hot. This means that the panels will produce more power for each hour of sunshine during the short days of winter.

Regarding to the effect of snow, all solar panels are designed to bear a certain amount of weight, and snow will usually be light enough to not cause any issues. All solar panels undergo pressure tests to assess their durability and quality. Ratings vary by panel, with higher pressure ratings indicating that the panel can withstand more pressure. If snow covers the panels, they will not be able to produce power, but it is simple to clean them off with the right equipment. Most panels are tilted at an angle, so snow will slide off on its own accord, but that process can be slow. Control of the situation can be taken by getting a solar panel snow rake or similar tool made for solar panel snow removal that will not damage the panels.

Source: [evergreensolar.com, 2017]

Figure 5.21: The impact of passive cleaning on solar panels

Source: [skyfireenergy.com, 2015b]

5.5.4 Snow on the solar panels

A heating system attached on the solar panel can melt the snow, insuring the proper functioning of the photovoltaic cells. Carbon fibre heating system, working with electricity, can heat the solar panel and consequently melts the snow that may accumulate over the panel allowing it to operate normal and correct. After the fall of snow, the heating system is turned on and in the next 15 minutes the surface of the photovoltaic panel will be 30 °C: The required functioning time (to release all the snow from the surface) is determined by the amount of snow and the outside temperature. The system can function during all winter, but at temperatures above 0 °C the device is not necessary. Source: [evergreensolar.com, 2017]

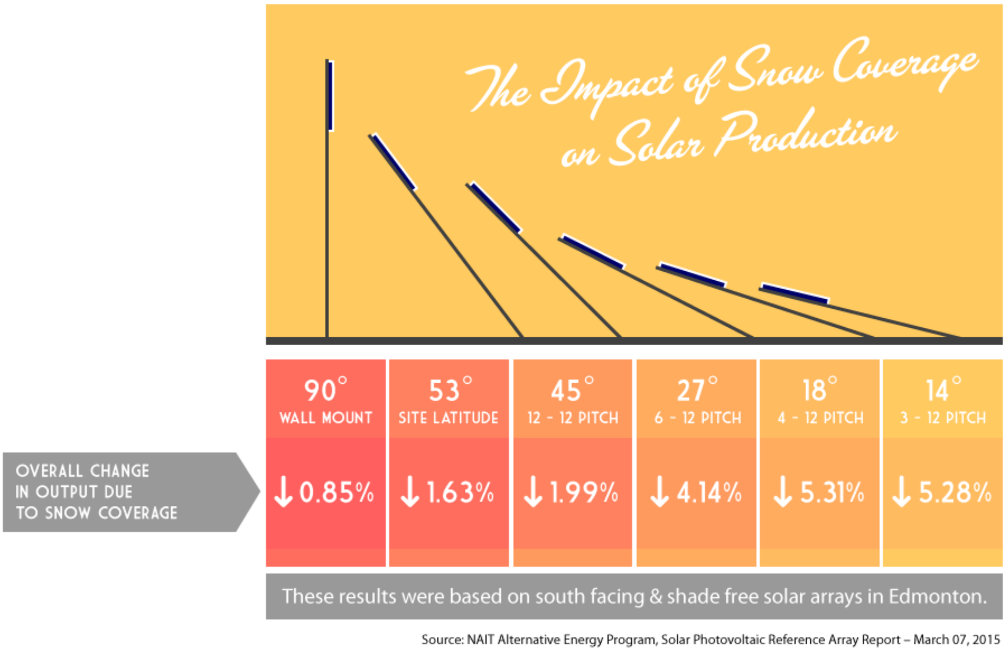


Figure 5.22: The impact of snow coverage dependent of the angle

Source: [skyfireenergy.com, 2015a]

5.5.5 Second method

Another option to keep panels ice free is the following. During the day panels stand under their fit angle. When it snows they will be covered and they will not produce any electricity. And this is exactly the same during the night. When this happens the panels are brought up to 90° during the night time with a piston. This way the snow will fall off. Then when the sun is about to come up the panels will be brought up again to their fit angle. The only problem not solved by this method is the ice. To prevent forming ice, an anti-freeze system which would spray anti-freeze liquid on the panels could be installed. Source: [evergreensolar.com, 2017]

5.6 Conclusion

This chapter relates the various elements discussed in the Chapter 4 for possible improvements. At first, multiple methods of cooling the solar panel to increase the efficiency were studied. It has been found that with the assumptions made, an increase in efficiency of just above 2% can be made if the panel is submerged in water to cool it down. However, practical experiments should be done to find exact numbers and to check the feasibility. The next method of cooling, pouring water onto the panel to keep it at a fixed temperature, is found to be not feasible.

Solar tracking is discussed afterwards. A numerical simulation is executed in three situations. Where the panel is facing south, rotating on a fixed tilt and rotating and tilting. In these simulations, the effects of clouds have not been considered. It is found that rotating with the sun increases the total power generated in Vaasa with 230 % and tilting with the sun improves power generation another 90%. These numbers are for solar panels located in Vaasa.

Following solar tracking the usage of mirrors to increase the light gathered on the solar panels is discussed. This is started with flat mirrors placed on the side of the panels. It is found through numerical analysis that about 80 % more light can be gathered and more energy can be produced, without getting into too big mirrors. However, in this analysis, the effect of increased temperature is not considered. Next to this, parabolic mirrors have been discussed in order to collect light to the panels as in telescopes. It is shown with a ray-tracing study that it is possible to collect light. However, it is also shown that for this setup to collect light correctly the panel must be facing the sun directly. Otherwise, the rays will not hit the panel correctly. As such this idea has been deemed unfeasible.

At last, the cleaning of solar panels is discussed. It is shown that keeping the panels cleaned during winter is highly important for energy production.

Chapter 6

Main components of a solar park

In this chapter the building blocks of a solar park are discussed. This concerns parts that every solar park has, which includes the solar cells, any structure to keep them floating and the electrical connection to the power grid. Then, the cost of all this elements will be calculated in Chapter 9.

- Solar PV modules

Solar PV modules are made up of a series of panels which in turn are made up of cells. This is the most important part of a solar park, since these are the devices which generate the power. The role of the photovoltaic module is to generate power from sunlight.

Figure 6.1: Solar panels

- Floating platform

For a floating solar park a structure or platform has to be designed that keeps the modules floating on the water. This can be a modular structure or a structure for the whole park. It needs either pontoons, floaters or other material that cause a buoyancy force. For designing such a structure one should keep in mind that not only it has to float, but also hold the weight of all the solar panels. If such a structure is made on sea this should also be able to withstand the waves and other forces. If the floating solar park is located in a cold environment, the structure must also be able to withstand the pressure of the ice generated around it, if there is not any antifreeze system.

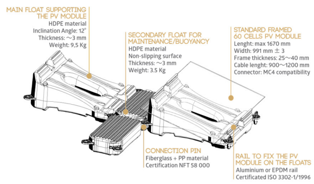


Figure 6.2: Floating platform

- Cables and connectors

Cables and connectors are needed to connect the solar panels together in an electrical circuit and to connect the park to the grid network. The cables have to be resistant to high mechanical loads for when different modules are moving relative to each other. Next to that a high temperature resistance is required. The connectors need to be sturdy enough to keep everything together and require a high current resistance.

Figure 6.3: Cables and connectors

- Mooring arrangement

This arrangement is to keep the floating structures in place. If a floating solar park is made on water with several modules connected together, an arrangement has to keep these modules on the same spot. Wind might otherwise push the solar panels to the side and possible severely damage the park. When building on sea an anchoring arrangement must done. An example of such an arrangement can be seen in Figure 6.4.

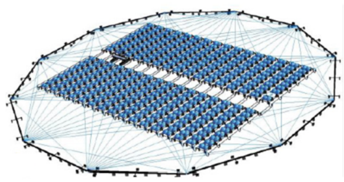


Figure 6.4: Mooring structure

- Access walkway

An access walkway is necessary to clean and maintain the solar panels. If the panels are not easy to reach the cost of maintenance is much higher and this will lengthen their amortisation time. Next to that, access walkways in between the modules make it easier to dissipate excessive heat.

- Electrical installation

An electrical instillation is needed to transform the generated power to be suitable for the power grid. In Figure 6.5 a schematic can be seen detailing the connection of the solar panels to the grid. As can be seen the most important components are the inverters, circuit breakers and cables.

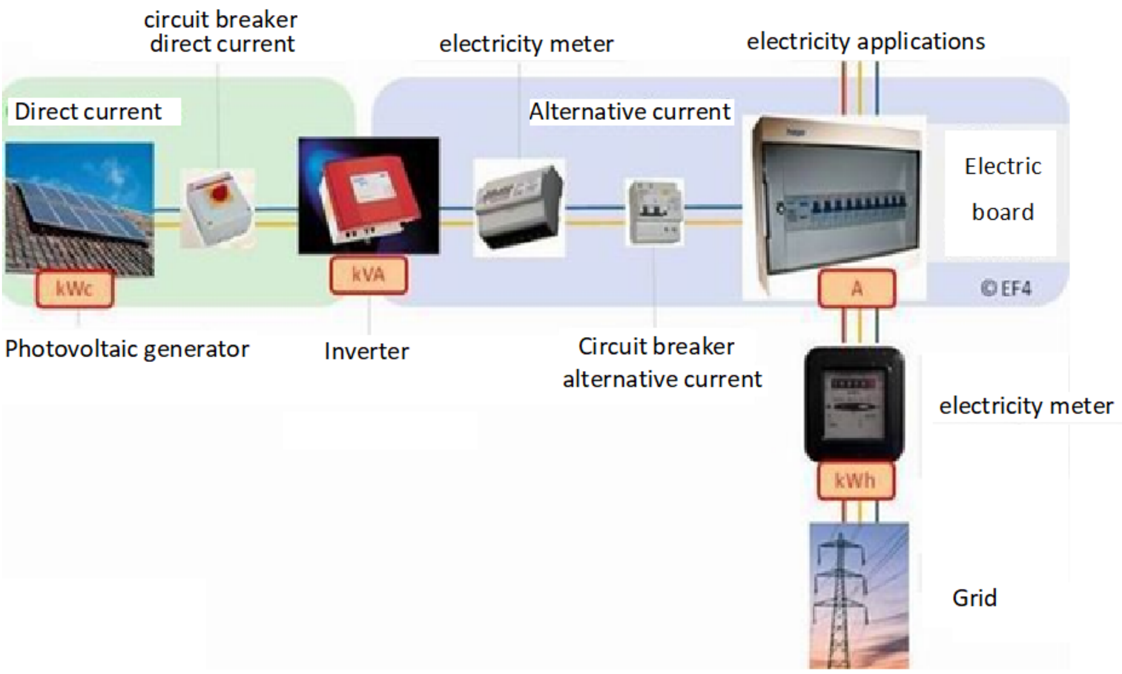


Figure 6.5: Electrical diagram

Source: [eF4.be,]

- Circuit breaker

There are different kind of circuit breakers. In Figure 6.5 the DC circuit breaker only disconnects a module of panels when the inverter is malfunctioning. However the AC circuit breaker disconnects the complete park from the grid if something is wrong. These circuit breakers can function automatically to prevent major damage to the park in case of an emergency. They can be switched manually if maintenance is needed.

(a) Circuit breaker direct current (b) Circuit breaker alternating current

Figure 6.6: Circuit breakers

Source: [Legrand.fr, 2018]

- Inverter

An inverter is a device that converts direct current to alternating current. There is either a central inverter or a micro inverter. A central inverter is connected to a series of solar panels and converts the combined DC of these panels in one device. This costs more efficiency than micro inverters, but has a drawback that if one panel has a problem the complete series of panels can not be used. Micro inverters are used to connect each panel separately. This is more costly but it has the advantage that if a panel gets damaged, only the damaged panel reduces the power production. Mostly only small installations use this solution. Source: [QuelleEnergie.fr, 2014]

(a) Central inverter (b) Micro-inverter

Figure 6.7: Inverters

Source: [Almasolar.fr, 2018]

- Electricity meter

In the schematic in Figure 6.5 two electrical meters are shown. The first one is located after the inverter and calculates the power generated from the solar panels. This can be used to generate a number of 'green certificates', which is a document a power company can use to show they produce green energy. The other electrical power meter is placed before the grid, counting up all the electrical power put into the power grid. This can be used to see if there is any error in the solar park or send messages to maintenance when something is wrong.

- Electric board

This is the main component of the installation. Here all the different modules are connected and rewired to the grid. It also serves as a central access point to the power grid making it easier the maintenance.

6.1 Conclusion

In conclusion, panels, structure for the panel and the floating platform are the principal components for building a solar park. Then, the electrical installation has to be added in order to recover the electricity and get it into the grid.

Part II

Product Design and testing

Chapter 7

Design Considerations

7.1 Introduction

In this chapter multiple design considerations will be discussed, such as some examples of floating structures, location of the park and the ice issue. All these information will be used in the next chapter for doing a morphological overview where all different ideas are shortly explained. Later this, multiple designs will be discussed following the morphological overview.

7.2 Different floating structures

There multiple possibilities to have solar panels floating. In this section, these structures will be discussed.

One example of a floating structure is the solar park in Far Niente (California). In this structure, pontoons made of floating foam, bound together with pipes, are used as a floating structure. The pontoons are bound together by stainless steel pipes.

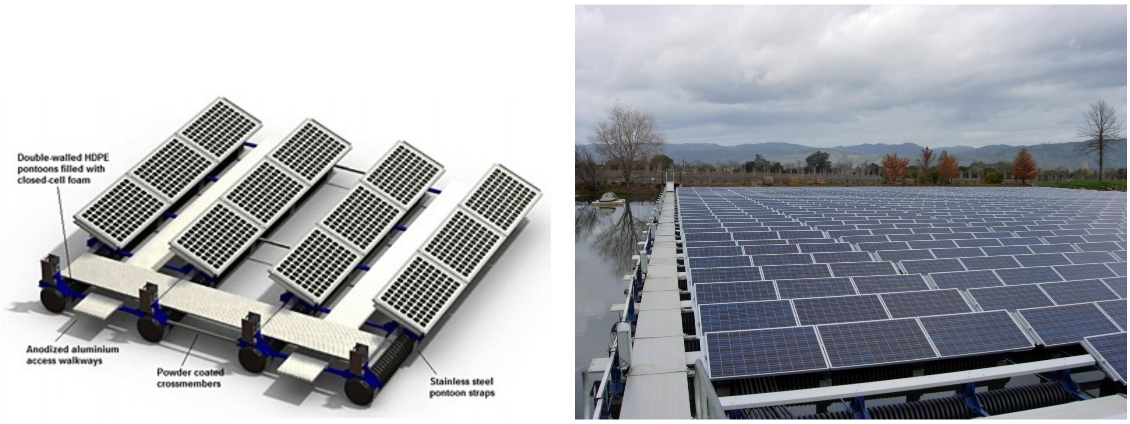
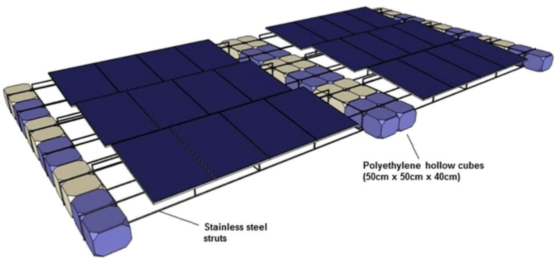


Figure 7.1: Floating solar construction in Far Niente, California using foam filled pontoons bound by stainless steel pipes

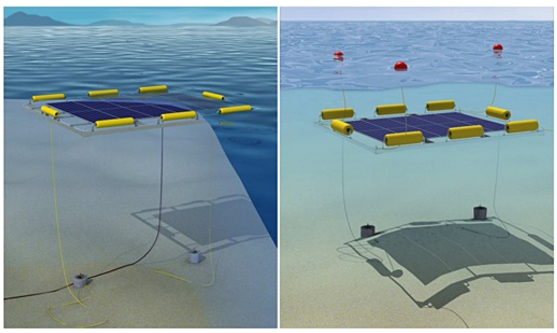
Source: [Trapani and Redon Santafe, 2014]

Another way to have the construction floating on water is to use floaters made by polyethylene hollow as can be seen in Figure 7.2a. These floaters are easy to install, cheap and lightweight.

The concept of submersible panels is to put thin film panels with some floaters and fix them with an anchor. This solution eliminate the problems of maintenance but the panel cannot rotate and it is sentenced to be horizontal.



(a) Schematic design of the Bulbanos installation
Source: [ipannellifotovoltaici.com,]



(b) Submersible floating PV concept

Figure 7.2: Two more possible designs for floating structures

Source: [Andrews et al., 2015]

7.3 Localisation

In order to construct and develop a solar park, a location must be found, preferably in Finland and somewhere else in the world, to meet criteria. Some of the criteria are for instance the area available for the installation, the cost of the land on sale, and the local weather. Price of water area cannot be found in literature. Local authorities have to be contacted to have information about the renting of the lake or of the sea. Therefore, price of lands are detailed to have an idea of comparison.

7.3.1 In Finland

Finland is a territory composed of many lakes, seas and forests with climatic differences between the north and south. The cold months are many, lasting this season between 105 to 120 days in a year (longer in north). In comparison, the south has a continental climate with short autumn and spring seasons. In summer, the temperature raises and it is warmer. In Finland, a difference in industrialisation and advanced technologies can be noticed. All these elements must be taken into account in order to define the best place to develop a floating solar park.

To have an idea about the cost of land, Table 7.1 shows the price in €$/m^2$ all over the world. These prices are a compilation of selling and renting offers scanned on the internet.

Table 7.1: Prices per square meter of land all over the world (in €$/m^2$)

Country	Price	Country	Price
Monaco	44.52	Luxembourg	4.61
UK	20.19	Spain	4.38
France	12.80	Germany	4.33
Russia	11.87	Denmark	4.28
Austria	11.56	Czech Rep	3.83
Switzerland	11.48	Portugal	3.83
Italy	8.44	Malta	3.58
Sweden	7.00	Slovak Rep	3.10
Netherlands	6.90	Belgium	3.02
Finland	6.61		

Source: [property guide, 2018]

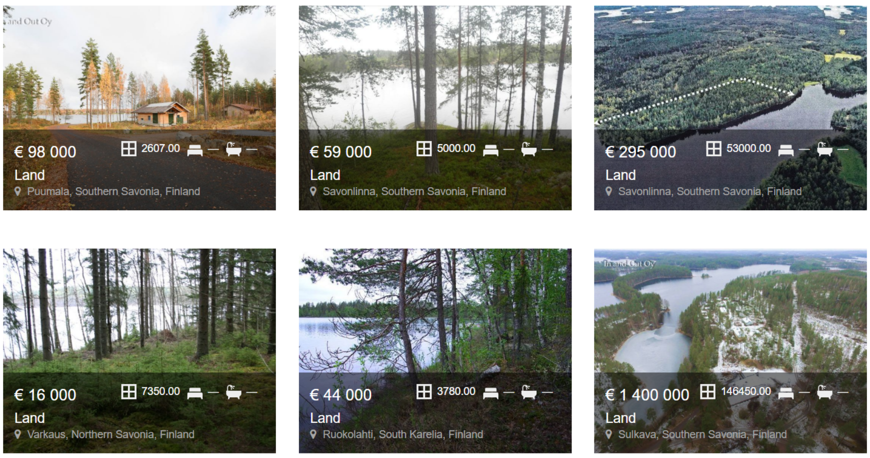
For comparing with Finland, Table 7.2 shows the prices of different locations in Finland. This table shows the total available area and total price for that area. Not counting the outliers, the average price in these locations is 8 €$/m^2$. Some examples of these locations can be seen in Figure 7.3a.

Table 7.2: Price land in Finland

Location	Area m^2	Price	Price €$/m^2$
Koli	1240	40000	32,26
Enonkoski	1300	13000	10
Jousteno	1379	24549	17,80
Sulkava	3001	69500	23,16
Savonranta	3160	79000	25
Savonranta	3500	75000	21,43
Ruokolahti	3780	44000	11,64
Vuontisjärvi	5000	29000	5,80
Savonranta	5000	49000	9,80
Savonlinna	5000	59000	11,80
Savonranta	5280	79000	14,96
Puumala	5900	24000	4,07
Ruokolahti	6000	85000	14,17
Savonlinna	6300	76500	12,14
Varkaus	7350	16000	2,18
Iskmo	10000	150000	15
Savonlinna	13150	69000	5,25
Kerimäki	18600	450000	24,19
Savonlinna	53000	295000	5,57
Ruokolahti	63700	390000	6,12
Sulkava	146450	1400000	9,56
Punkaharju	180000	1990000	11,06
Mikkeli	687000	1575000	2,29
Vuontisjärvi	820000	120000	0,15
Turku	1300000	555000	0,47
Kuusamo	2100000	1390000	0,66

Source: [ee24, 2018]

The Figure 7.3b shows the different places where lands are located, cited before in the Table 7.2, which shows also their price.



(a) Examples of land in Finland

(b) Land on sale found in Finland

Figure 7.3: Examples of land on sale with a corresponding map

Source: [ee24, 2018]

7.3.2 In the World

To find other locations besides Finland, locations were chosen based on the yearly solar radiation. In Figure 7.4 the yearly average solar radiation can be seen. Spain and California, USA have been chosen to compare with Finland.

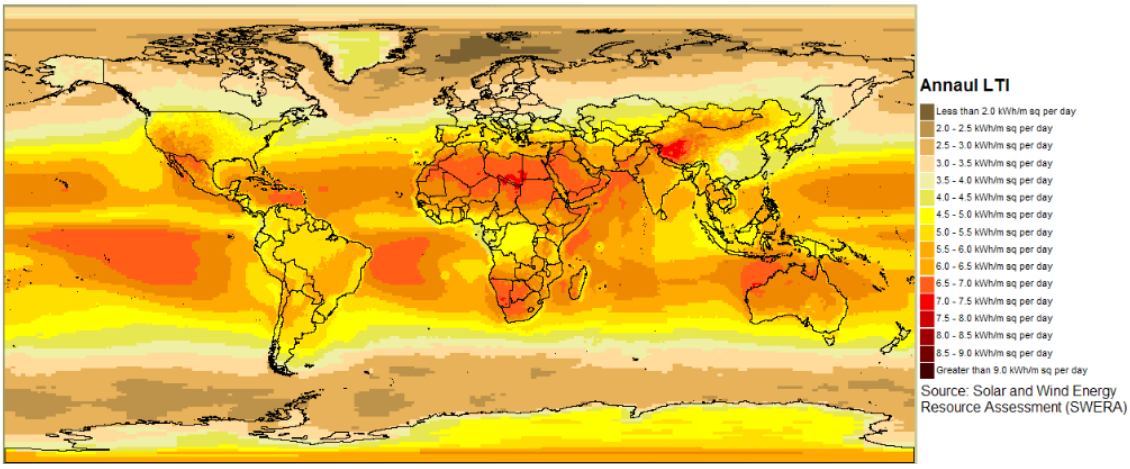


Figure 7.4: Sun radiations in the World

Source: [Eskom, 2018]

Spain is an interesting place to place a solar park. The daily solar radiation is about 6 KWh/m^2. In Andalusia the average temperature during summer is around 33 °. There are about 260 sun days whereas there are only 110 sunny days in Vaasa. The amount of sunny hours in Andalusia is about five times more than in Vaasa.

The prices of land in Spain is also cheaper than in Finland. Table 7.3 shows the price of land in Spain.The difference in prices are due to the location of the area, if it is near the sea or with a good views this will increase the price. Next to that some lands spoken are farmland and others building land. This will affect the price as well.

Table 7.3: Price land in Spain

Location	Area (m^2)	Price	Price €/m^2
Begur	1600	235000	146,88
Vejer de la Frontera	10000	115000	11,50
Felanitx	21450	212500	9,91
Nijar	10000	72000	7,20
Estepona	7077	2830000	399,89
Coín	275000	60000	0,22
Lorcha	1260	380000	301,59
Marbella	4000	3360000	840,00
San Pedro de Alcántara	6058	4450000	734,57
Casares	1000000	5000000	5,00
Estepona	7830	6000000	766,28
Marbella	28500	6600000	231,58
Mijas Costas	194000	12000000	61,86
Marbella	23375	15000000	641,71

Another place considered is California, USA. California has problems with evaporating water lakes and droughts. Placing floating solar parks on top of water reservoirs might slow down the evaporation. In Figure 7.5 the testing of black balls to prevent evaporation is shown. This is a current solution California is testing.

Next to the prevention of evaporation the weather is better as well. On average there are 325 days of sun shine, far more that in any place of Finland. Next to that the price for 10.000 m^2 is about 40.000 €.

Source: [Wikipedia, 2018b]

Figure 7.5: California black ball water reservoir

7.4 Freezing of the water

The problem during winter in the northern countries like Finland is the cold temperature. The water will freeze, and the ice will expand. This can damage the structures. To prevent the water from freezing, it can either be heated up or kept moving. One idea to keep the water moving is to have a hollow tube around the structure acting like a sprinkler. This design will be explained in Section 9.4. Figure 7.6 shows an example of such a system.

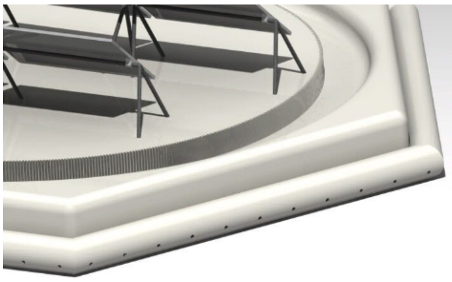


Figure 7.6: leaky pipe sketch

To estimate the cost of using a pump to move the water in each module, the power consumption of a pump is calculated and then multiplied by the time that it will be operating. It is estimated that six months per year the water will be frozen, so the pump is needed. This means that the total energy used for the pump for one module is 10951,2 kWh. As the cost per kWh in Finland is 0.114 Euro, a total cost is estimated of 1448,44€. This is, however, only for one module and has to be multiplied by the number of modules each design needs for 1 MW.

7.5 Conclusion

Before started to think into a design, some considerations were studied like the floating platform. An other important aspect is the location. Finland has lots of lakes but not so much sun comparing with Spain or California. To finish, an antifreeze system is necessary to avoid the breakage of the structure. This will cost about 1450 Euros each year for an utilisation of six month.

Chapter 8

Morphological overview

8.1 Introduction

This chapter lays out the morphological overview created in pursuit of designing concept ideas for a floating solar park. The idea behind it is that a module or park has multiple separate parts, where for each part a different solution can be found. Combining these solutions into an overview makes it possible to combine these into product designs. The overview will be shown first with each solution quickly explained.

In total seven design categories were made, with different ideas for each category. This morphological overview can be seen in Table 8.1.

Table 8.1: Morphological overview

Rotation	***Anchoring***	***Solar Panel Structure***	***Mechanical Structure***	***Anti Freeze***	***Solar Tracking***	***Cleaning***
Gears & zip actuated by a stepper-motor	Chains sideways (R)	Chicken hen (R)	Hexagonal Circle	Roped air tube (R)	Solar Tracking Cells (R)	Wipers
Jetski (A)	Concrete & chains on bottom lake (A)	Mounted in the middle (A)	Floaters (A)	Sprinkler (G)	Solar position equation (A)	Heat resistor + 90 °tilt
Engine & gear for the structure or all the modules (M)	Literal Anchor (R)	1 side fixed & piston (R)	Wood(A)	Sprinkle deep water (P)	LDR & shader (R)	Sprinkle panel
	Poles & Chains (P)	Rope balance (A)		Heat resistor (R)		
		Chains balance / 1 axel				

8.2 Rotation

As has been discussed in Section 5.3, tracking the sun by rotating the panels can increase the total power output across a whole year. In this section multiple ideas are discussed in order to rotate the solar panels.

Gears and zip actuated by stepper motor

A small stepper motor on top of the floating structure rotating a module. With enough gears rotation doesn't need a huge motor, it will just go slowly. This can be seen Figure 8.1.

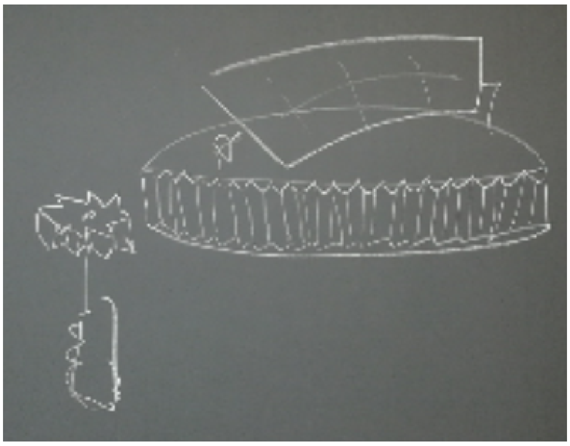


Figure 8.1: Electrical engine with gearing for rotating one module of panels

Engine and gear for all the structure or all the module

It is the same idea as above, but applied to the complete floating structure instead of an engine per module.

Pro: One engine can rotate all the panels, reducing the cost of production.

Con: A complex gearing system has to be designed which will increase cost of production.

Jetski / Motorboat outside

This is using water jet motors as in a jetski or outboard engines from a speedboat on the sides of the structure. Placing this engines on the side of a module or structure while it is anchored in the middle means that a torque can be generated in order to rotate the structure.

Pro: A lot of torque can be generated to rotate large and heavy structures.

Con: High power required. Also keeping the rotation constant would be more difficult than with a stepper motor.

8.3 Anchoring

Chains sideways

This consists on chains or cables tightened from poles or rocks on the side of the lake. The idea is to tighten the floating park from all sides to keep it from going ashore due to the wind. This is only possible for relatively small parks.

Pro: Very cheap and easy to maintain.

Con: Not possible for parks meant to produce more than 1 MW of power.

Poles and chains

Instead of trees, poles are settle in the lake ground right next to the structure with a ring and a chain keeping the floating structure in place. This allows the structure to rise and fall with the water, while the chains do not loosen up or get strained. This can be seen in Figure 8.2.

Pro: It is simple and cheap.

Con: It only works in relatively small areas.

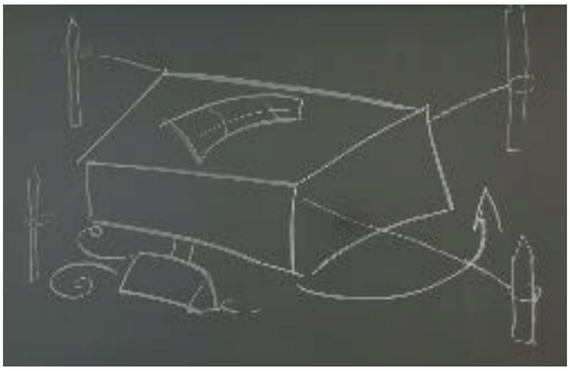


Figure 8.2: On the 4 edges of the block poles are drawn. The module is tightened in place with chains going from the edges to the poles.

Concrete and chains on bottom lake or literal anchor

Anchoring the floating structure with chains that connect it to a heavy weight at the bottom of the lake. This can be a block of concrete. A drawing of this can be seen in Figure 8.3.

Pro: It is simple and cheap.

Con: The floating structure might move around due to wind.

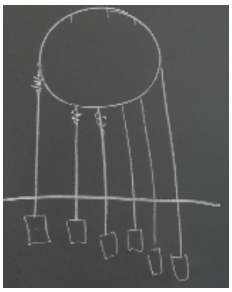


Figure 8.3: Concrete and chains

8.4 Solar panel structure

Chicken hen

It is a simple rectangular structure with a tilted roof. This structure can be on top of the floating structure and can be made so that the panel is in the perfect angle. This can be seen in Figure 8.4

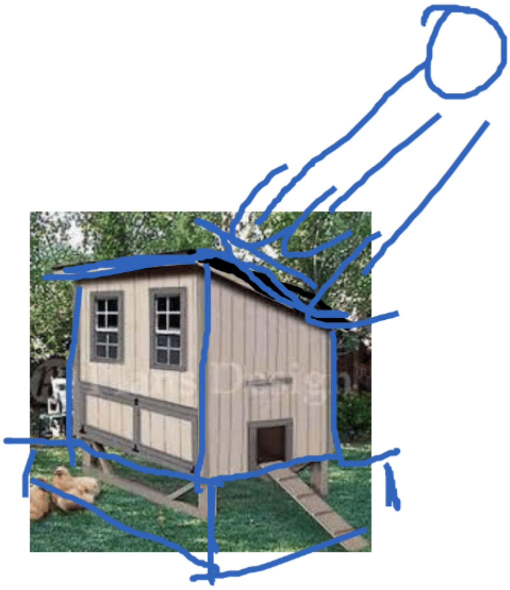


Figure 8.4: Chicken Hen

Pro: Simple, cheap and sturdy.
Con: Solar panels are rigidly fixed.

Mounted in the middle

This idea consists on panels mounted on an axle that can rotate. This axle is in the middle of the panels in a horizontal position. With an electrical motor coupled in to the axle it is possible to rotate the solar panel. This can be made for each panel, or one axle for multiple panels in series.
Pro: If all the panels are in the same axle, all can be tilted with one engine.
Con: If the engine breaks, the whole module will not be able to tilt.

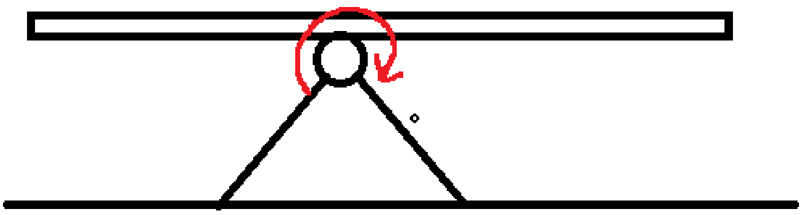


Figure 8.5: mounted in middle

One side fixed and piston

In this case one side of the solar panel is fixed at a certain height and the other is connected to an actuator which allows the module to tilt. It is possible to connect each panel to a separate actuator or use a framework to connect multiple panels in series on one actuator. Figure 8.6 shows a drawing of this idea. Multiple types of actuator can be used.
Pro: Multiple panels can be tilted simultaneously.
Con: Actuators can break down and are more difficult to maintain. Depending on the type of actuator a tank of oil or compressed air is needed.

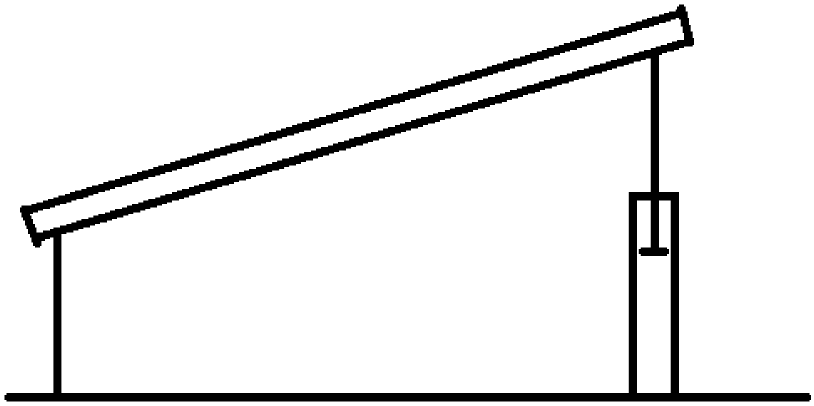


Figure 8.6: One side fixed and piston

Rope balance

This idea is a system with a pivot point in the middle. One one side a mass is suspended and the other end is connected with a rope coiled around on a coil. An electrical motor can unwrap or coil up this rope in order tilt the panel.

Pro: Cheap system to construct and to control. If balanced correctly not much electrical energy is needed.

Con: A structure has to be build to support the pull of the rope and weight on both sides. Connecting both ends to a solar panel might break the panel. This will increase cost of construction.

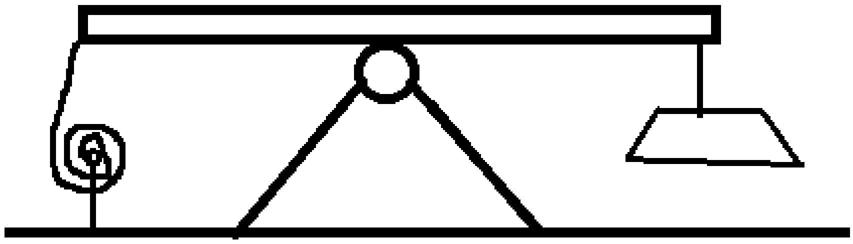


Figure 8.7: Rope balance schematic functioning

Chain balance

This idea consists on a chain connected to both ends of the panel. With the electric motor on one side the panel can be pulled, allowing it to tilt.

Pro: The system can be balanced, requiring then a less powerful engine.

Con: Expansive with gearwheels.

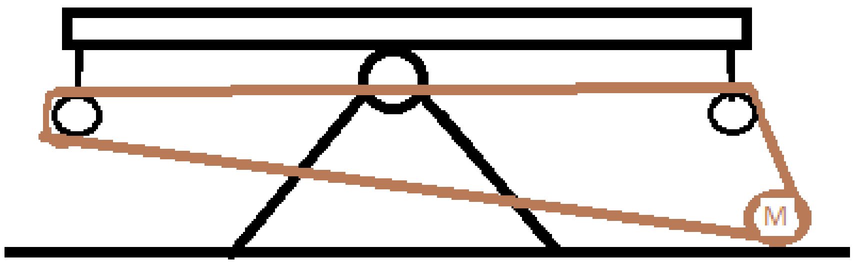


Figure 8.8: chain balance

8.5 Antifreeze system

If the floating structure is located in a cold country a system has to be developed around the floating solar panels in order to stop the ice from crushing the structure. When water freezes the ice expands with that much force that it could break structures. One way to prevent the water from freezing is to keep it moving. On this principle multiple ideas were thought of.

Roped air tube

This idea is based on having an airtight rubber tube around the structure where at multiple position a rope is wound around the tube. With a small electric motor one rope can be tightened. This will push the air to the side and expands the tube at other places. If first the odd numbered wires are tightened and than the even numbered, a movement of air is created inside the rubber tube pushing out the water to keep it moving.

Pro: It is cheap and use less electrical energy to keep water moving.

Con: Rubber might freeze, creating holes. Not appropriatee for modular design

Sprinkler

This system is based on a garden sprinkler system where a tube with small holes is laid down. By pumping water through this tube some small streams of water are created. This idea can be used in order to keep the water around the structure moving. If the water is pumped from the bottom of the lake, this is water will be above freezing temperature, at about 4°. This can also help in keeping the ice from crushing the structure. A sketch can be seen in Figure 8.9.

Pro: It requires less energy.

Con: Multiple pumps system might be required.

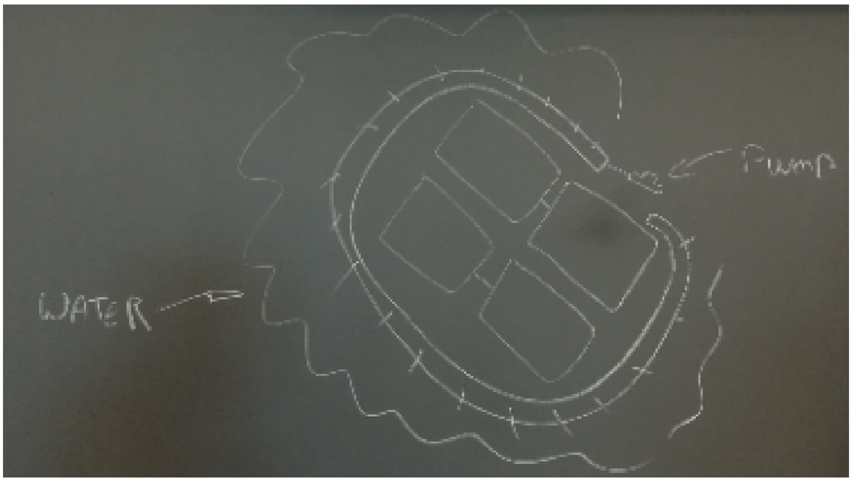


Figure 8.9: Schematic draw of the sprinkler system

Heat resistor

One other way to keep the water from freezing is by heating it up. This would be done with a heater. This heating element can be a high power resistor drawing electrical energy from the solar panels. This will however cost a lot of energy which can not be used for the electrical power production. In the winter this idea will probably cost more power in total than it will be generated.

Solar tracking system

In order to increase the total power output even more, as discussed in Section 5.3, the panels can rotate. Three ideas were thought of to do this.

Solar tracking cells

This system consists of 2 single cells setup in a triangular structure, with the bottom parallel to the panel. If the sun is shining directly on to the panel, these two cells will produce the same voltage. If however the sun is not directly shining on the panel, one cell will produce a higher voltage than the other. This voltage difference can be used as a direct control signal for a microprocessor. Figure 8.10 shows a schematic drawing.

Pro: Only one tracking setup is needed for a structure. Control signal is very accurate. As control signal is a voltage difference, the electronics can be all analogue.

Con: It takes up a bit of space for a solar panel. Can get damaged. Without backup system, there is no control system for tilt.

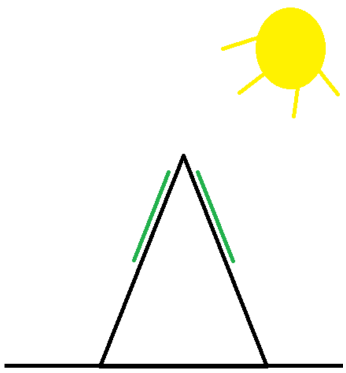


Figure 8.10: tracking cell

Solar position equations

With astronomical data,some equations can be fitted to the solar elevation and angle for the whole year. This data can be used in a micro controller to steer the panel.

Pro: As long as the micro controller is working, the equations can be calculated.

Con: Without sensors such as a compass and accelerometer no feedback signals are generated to check the tilt and rotation of the panels, so no auto-correction of the position can be done.

LDR and Shader

Two light dependent resistors with a shader in between can be used as a control signal as well. This shader can be any piece of construction material that blocks the light. If two LDR's are set up on a plane parallel to the solar panel with the shader standing up in between, one LDR will be in shade if the sun is not directly shining on the panel the resistance will be different. Using voltage dividers with both LDR's this difference can be directly used as a control.

Pro: It is cheaper than using two cells and less prone to damage.

Con: LDRs only have a limited range in signal. They need to stay clean to have a valid control signal.

8.6 Cleaning

To protect against dust in desert areas or snow in cold countries, panels need to be cleaned to stay efficient.

Wipers

A basic system of car's wipers where a broom clean the surface of panel could be use for the task.
Pro: Simplicity.
Con: It is useless against ice.

Heat resistor and panel 90 degrees

If the panel can tilt 90°, it can be in the vertical position during snow days. To ensure the cleaning when the wind sticks snow on the cells, heating elements can be implemented in the solar panels to melt the snow.
Pro: It is simple and effective against ice.
Con: Heat can make cells less effective. Energy consumption.

8.7 Conclusion

After a careful consideration of all the ideas, some design concepts have been thought of by combining the ideas together. An example of this can be seen in Table 8.2. This example led to the design discussed in Section 9.4. Multiple designs have been brought up like this and will be discussed in Chapter 9.

Table 8.2: Morphological overview

Rotation	***Anchoring***	***Solar Panel Structure***	***Mechanical Structure***	***Anti Freeze***	***Solar Tracking***	***Cleaning***
Gears & zip actuated by a stepper-motor	Chains sideways (R)	Chicken hen (R)	Hexagonal Circle	Roped air tube (R)	Solar Tracking Cells (R)	Wipers
Jetski (A)	Concrete & chains on bottom lake (A)	Mounted in the middle (A)	Floaters (A)	Sprinkler (G)	Solar position equation (A)	Heat resistor + 90 °tilt
Engine & gear for the structure or all the modules (M)	Literal Anchor (R)	1 side fixed & piston (R)	Wood(A)	Sprinkle deep water (P)	LDR & shader (R)	Sprinkle panel
	Poles & Chains (P)	Rope balance (A)		Heat resistor (R)		
		Chains balance / 1 axel				

Chapter 9

Designs

9.1 Introduction

In this chapter multiple designs will be discussed with the advantages and disadvantages of each. Next to that, a cost estimation is made for a solar park able to produce 1 MW. The cost of the electronics for each design is based on the cost of the prototype (See Chapter 10). At the end, all the designs will be compared, including the efficiency benefits of for example rotating and tilting with the sun. This should result in a clear choice of design.

9.2 Electronics

In every design, the electronics needed to measure power output and control the tilt and rotation of panels will likely be the same. Therefore, it is beneficial to calculate the cost of the electronics seperately. Table 9.1 shows the cost of the electronics for the prototype. Shipping costs are not counted in this table, and for each element the cost is only counted once. This table can be used for estimating the cost of the electronics for every design. This might change a bit as some designs will not be able to rotate or tilt, or need more than one electric engine to tilt.

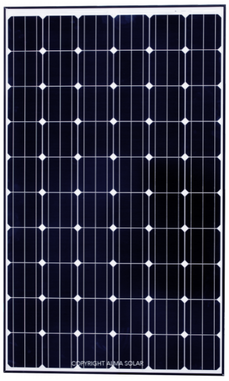
Table 9.1: Cost estimation of the electronics parts, derived from the prototype.

Prototype pieces	Costs
3 volt 13100 Rpm DC Motor kit	16,26 €
12V DC 6800mAh Super Rechargeable Li-ion Battery	44,52 €
ACS712 Current Sensor Hall Module	8,52 €
Solderless Prototype Breadboard	5,12 €
Data Logger Module Logging Recorder Shield	5,40 €
Arduino Voltage Sensor Detector	8,55 €
DC 12V/24V Mini Brushless Food Grade Hot Water Pump	15,12 €
LM2596 Radiator DC-DC 4.5 - 40V Adjustable Power SupplyModule	15,73 €
Relay Board Module Optocoupler LED for Arduino	3,55 €
10 pcs Thermistor Temperature Sensor	32,50 €
Solar cell 3v 450mA with wire	2,00 €
UNO R3 clone development board	4,99 €
100w Flexible Solar Panel Charging Kit	148,36 €
Total	310.62 €

9.3 Electric grid connection

The cost of each design to connect to the power grid will the same. With some calculations the necessary elements and the amount of each element is found. The calculations and method is explained in this section as well as the final cost estimation.

Figures 9.3 and 9.6 show the panel and inverter used in the cost estimation of the electronics. The amount is calculated for 1 MW.



(a) Panel 300 W

Voltage (Voc)	39.9 V
Current (Ioc)	9.8 A
Height X Length X Depth	1649 X 991 X 40 mm
Max yield :	18.35 %
Power	300 W
Cells	Monocristalline
Tolerance	3%
Frame colour	Black
Background Colour	White
Panel Brand	BISOL
Yield	17.19 %
Product warranty	10 years
Place of manufacture	Europe

(b) Technical properties of solar panel

Figure 9.3: Panel and technical information used in cost estimation of prototype

Source: [Almasolar, 2018]

(a) Inverter 500Kw

MPPT range	570 - 900 V
Starting Voltage	670 V
Input current max	90 A
Height X Length X Depth	760 X 500 X 425 mm
Max yield	98.3 %
MPPI tracker	1
Injection	three phase
Input power min panel	45000 W
Panel input power max	55000 W
Internet connection	Ethernet
Inverter brand	KACO NEW ENERGY
product warranty	5 years
Place of manufacture	Europe
Inverter Type	Network UPS

(b) Technical properties of the Inverter

Figure 9.6: Inverter used in cost estimation

Source: [Almasolar, 2018]

With these two elements it is possible to calculate how many parallel chains of panels can be made, and how many panels in series within each chain. The total number of panels in total can be calculated by dividing 1 MW by 300 W. As such 1000000/300 = 3334 panels are needed in total.

The nominal input current of each circuit breaker is (I_n) for the circuit breaker is maximum of 90 A. This has to be bigger than the short circuit current of each panel (I_sc) times the number of parallel chains ($N_{parallel}$) connected to this circuit breaker, with a safety factor of 1.25. As such equation (9.1) is set up. This is rewritten to equation (9.2) to figure out the parallel lines. This shows that $N_{Parallel}$ is less than 7.27. As such a maximum of seven parallel chains is allowed for each inverter.

$$I_n > I_{cc} * 1.25 * N_{parallel} \tag{9.1}$$

$$N_{parallel} < \frac{I_n}{I_c c * 1.25} => N_{parallel} < \frac{90}{9.9 * 1.25} \tag{9.2}$$

To calculate the number of panels in each series. The highest point in the MPPT range of the inverter is divided by the the MPP Voltage of the panels, which is 31.6 V. This is 900/31.6 = 28.48. As such a maximum of 28 panels are allowed in series. This means that $28 * 7 = 196$ panels are connected per inverter. As 3333 panels are needed this means that 3333/169 = 17 inverters are needed in total.

Circuit breakers that fit this power requirement need to be found. The circuit breakers just below have been used in the cost estimation of the electric grid connection. These are however quite small and not made for a 1 MW park. A DC circuit breaker and an AC circuit breaker are calculated in accordance to Figure 6.5.

(a) Circuit breaker DC
Source: [myshop, 2018]

(b) Circuit breaker AC
Source: [manomano, 2018]

Figure 9.7: Circuit breakers

Table 9.2 shows the prices of the different circuit breakers and inverters per item and the total price for 1 MW. The maximum power for both circuit breakers is stated as 6 kW. This means for each of them 167 circuit breakers are needed, as such the price per unit is multiplied by 167. The price of each inverter is multiplied by 17, as is calculated before.

Table 9.2: Prices for circuit breakers and inverter, per module and per 1 MW

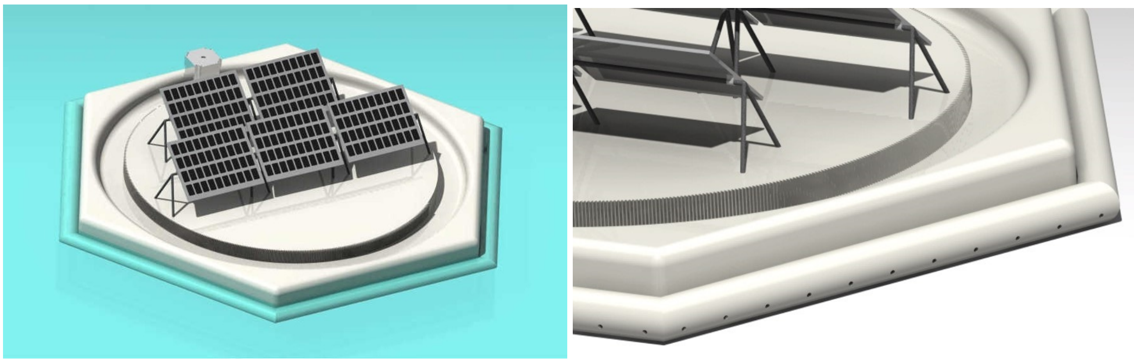
	Price unit	Price 1MW
Circuit breaker DC 6000W	245 €	40915 €
Inverter 50000W	4590 €	78030 €
Circuit breaker AC 6000W	312 €	52104 €
TOTAL		**171049 €**

9.4 Design 1: Floating Platform

The first design that was created is called the Floating platform. This design consists of a hexagonal support structure that floats on the water. Within this hexagonal structure, a circular structure is mounted on an axis that can rotate. The hexagonal outer structure makes it easy for modules to be mounted together, making this design modular. In Figure 9.8a and overview of this design is shown. On the outside of the hexagonal structure a tube is placed with small holes in it. Water is pumped through this tube in order to spray water around to keep it from freezing. This is detailed in Figure 9.8b.

The advantages of this design is that it is modular and that the panels can rotate and tilt. Due to the anti freezing mechanism this design should be able to operate during the winter.

The disadvantages of this design is that a lot of space is used for the structure itself and not for the panels. This means that there is no optimal use of area. Next to that, the estimated cost of the material will be fairly high compared to other designs.



(a) Overview (b) Detail

Figure 9.8: Isometric view of the floating platform design, consisting of a hexagonal shape to make the structure float and a circular platform that can rotate

It is estimated that with a radius of 3 meter, 12 panels of 300W can fit on a module. This will produce in total 3.6Kw. In Table 9.3 the costs of this design can be seen. For the cost estimation some pipes are taken as the hexagonal structure, totalling 21 meter. For a simple construction a plastic drum is considered to act as a floater, with one on each side. To anchor the design, steel chains are considered of 4 meter long anchored to the bottom. With one on each corner of the hexagon, this totals $4 * 6 = 24$ meter. The cost of anchoring depends on the height of the lake. It is estimated that assembling this design will take around 50 hours, where a well paid engineer costs around 50 Euros per hour. The total estimated cost of this assembly for 3.6 KW is 7,845 €. To go to 1 MW this means that 278 modules are needed ($\frac{1000}{3.6} = 277.78$). This will mean that the price for 1 MW is estimated to be 2.2 million Euro's.

Table 9.3: Price estimation of Floating Platform design, per module

material	estimated price per item	amount	total price
300W solar panels	190 €	12	2,280 €
alluminium circle plate	2000 €	1	2000 €
alluminium pipe	5 € per meter	21	105 €
electronics	360 €	1	360 €
plastic drum (flotations)	40 €	6	240 €
anchoring chains	15 € per meter	24	360 €
subtotal price			5,345 €
Working hours	50 € per hour	50	2,500 €
Total price per module			7,845 €
Total price for 1 MW	(7845 ∗ (1000/3.6))		2,179,167 €

9.5 Design 2: Off-board engine

This design is a modification of the floating platform design. The biggest change is that the rotation in this design is not done by an electromotor and a circular platform but by using an off-board engine. The advantage of this is that these engine can be used to keep the water from freezing as well. Another advantage is that it is easier to install, as no gearing system is needed for rotating the platform. The structure can be a complete solid structure. Modularity is still possible with this design, if all the modules are rotated as if it is one complete structure. The disadvantage is that rotational control is more difficult to control and will cost more energy. Figure 9.9 shows a sketch of this design.

When it comes to cost estimation, the difference is that no electrical engines are needed to rotate the panels separately and the structure is also cheaper. However, off-board engines are needed. If every module would have their own off-board engine the price would probably be higher. However, if the complete structure is rotated as one only, the outer modules would require off-board engines. For this reason, it is estimated that the cost of the offboard engine design for 1 MW is equal to that of the floating platform.

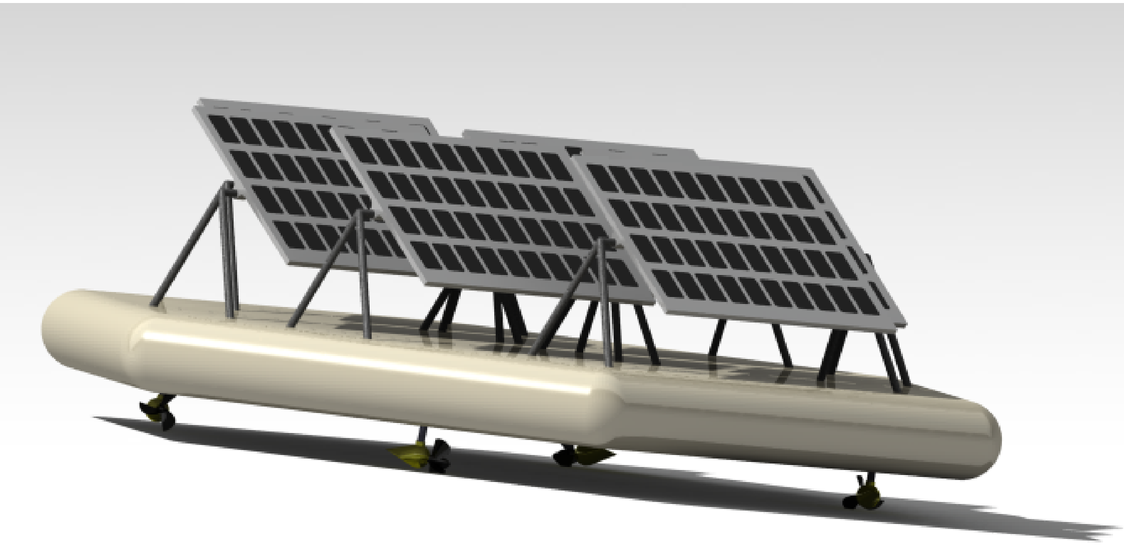


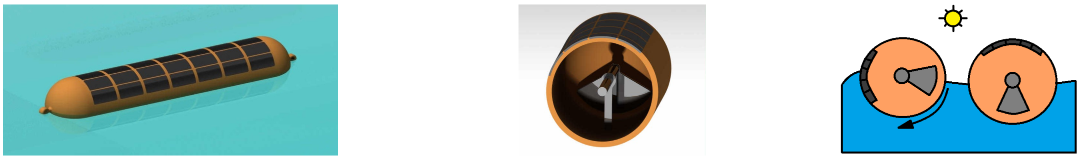
Figure 9.9: Modification of the floating platform design. There are offboard engines for rotation

9.6 Design 3: Cylindrical shape

This design consists of a cylindrical case with semishpe

rical ends. Within this casing an axis is placed with weights on the bottom. By rotating the weights to one side, and due to gravity forces, it is possible to rotate the cylindrical shape around its axis. This is demonstrated in Figure 9.10c. This allows for solar tracking in one axis only.

One benefit that this design presents is ease of rotation and solar tracking. Also the cleaning and cooling of panels can be done easily with this design by simply submerging the panels. Moreover, as this design does not rise up high above the water wind will not affect this design as much as others. Due to the circular design this concept is more resistant against forces from waves.



(a) Sketch of the overview

(b) Inside detail sketch of the balancing weight

(c) Rotating system graphic explanation

Figure 9.10: Overview and detail sketch of the cylindrical design

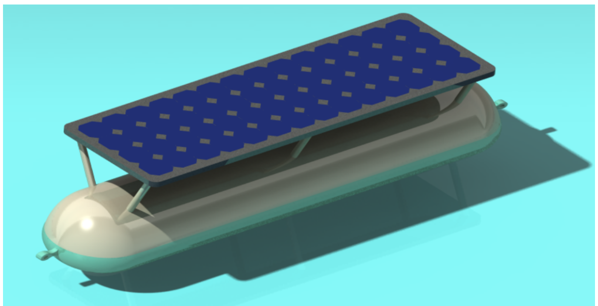
The approximate cost of making one module is shown in the Table 9.4. For the cost estimation of the pontoon, the cost of a marine rubber airbag of two meters of diameter and twenty of effective length was taken. The room available for flexible solar panels was considered to be one third of the cylinder surface, so 59 panels of $0.7m^2$ can be placed in each module. This panels provide 120 watts each, so each module would be able to provide 7,13kW. Therefore 140 modules would be required to construct a 1MW solar plant, with an approximated cost of about 1.79 million Euros.

Table 9.4: Cost of a singular module

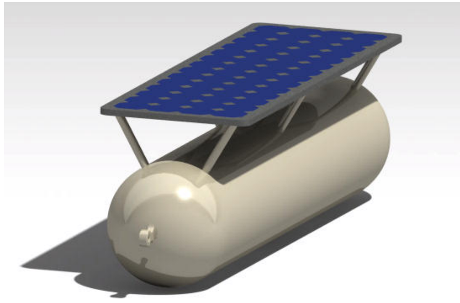
Material	Estimated price per item	Amount	Total price
Pontoon	4867 €	1	4867 €
Solar panel	107 €	59	6365 €
Motor	406 €	1	405 €
Counterweight	50 € (per m^3)	1.5	75 €
Electronics	311 €	1	311 €
Subtotal			12,023 €
Working hours	50 € (per hour)	15	750 €
Total price per module			12,773 €
Total price for 1 MW	$(12773 * (1000/7.13))$		1,791,445 €

9.7 Design 4: Adapted Cylindrical shape

The adapted cylindrical design is a different version of the cylindrical design. Instead of putting bendable solar panels on top of the cylinder, this design has flat panels supported by a structure placed on top of the cylinder. The benefits of this are that more panels can be placed on the same area and that tilting has a better effect. A downside is that a heavier counterweight is needed in order to keep the design in the correct tilt. This also requires more power to turn.



(a) In water



(b) Overview

Figure 9.11: Sketch of the adapted cylindrical design, in water and without water

The approximately cost of each module can be seen in the Table 9.5. For cost estimation the same pontoon as before is used. As no bendable panel is needed, the 300 W non-bendable panels are used to estimate the cost. On the flat surface 26 of these panels can fit, which totals a power of 7.8 kW per module. This means that 129 modules are needed for 1 MW. To the cost estimation the cost of the structure is added and the increase in manual labour hours.

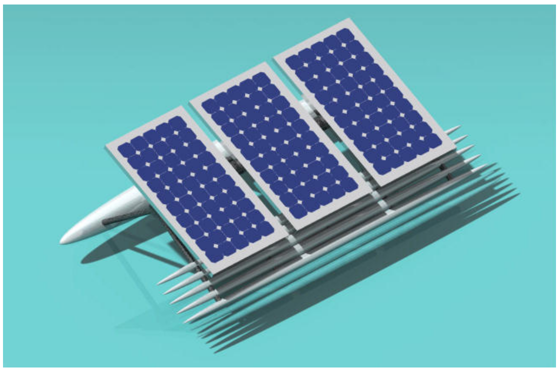
Table 9.5: Estimated cost of the alternate cylindrical design per module

Material	Estimated price per item	Amount	Total price
Pontoon	4867 €	1	4867
Solar panel	198 €	26	5,148
Motor	406 €	1	405
Counterweight	50 € (per cubic meter)	2	100
Structure	19 €	26	494
Electronics	311 €	1	311
Subtotal			11,325
Working hours	50 € (per hour)	15	750
Total price per module			12,075
Total price for 1 MW	(12075 ∗ 129)		1,557,675

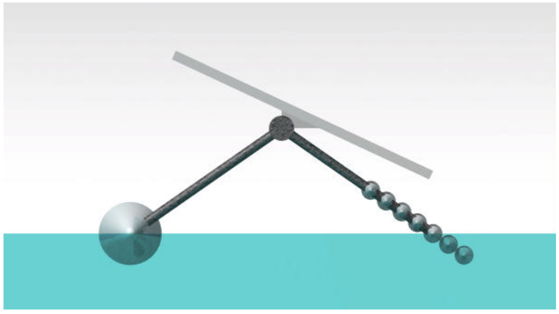
9.8 Design 5: Biflotant Design

This design consists of one big floater on one side and multiple smaller ones on the other, connected with a frame which holds the panels. A sketch can be seen in Figure 9.12a. Rotation of this design is possible by pumping water in or out of one of the smaller floaters, sinking one side of the structure in the water. This can be seen in Figure 9.12b. These modules can be put in a park next to each other with the panels connected in series, building up 1 line. With each module having three panels totalling 900 W, a total of (1000/0.9 = 1111.1) 1112 modules are needed.

The advantage of this design is that it only needs a pump and valve system to tilt. This can be the same pump used for an anti-ice sprinkler system. The structure is also fairly simple with rods and floaters. The disadvantage for this design is that there are only a small number of tilt-positions.



(a) Overview sketch



(b) Profile sketch

Figure 9.12: Sketch of the Biflotant design

For the cost estimation, the cost of one module is estimated and then multiplied by the number of modules.

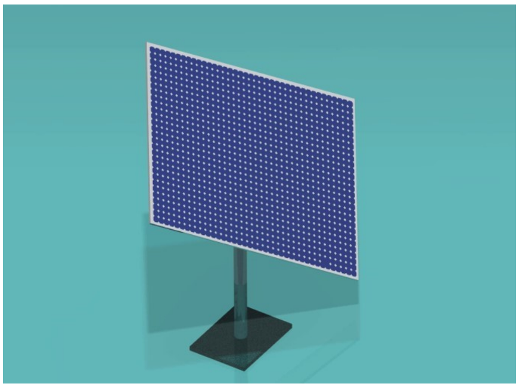
Table 9.6: Estimated cost of biflotant design for 1 MW

Item	estimated price per item	amount	Total price
Pipes floater	6 €	7	42 €
Aluminium pipe	5 €/ meter	4.5	22.5 €
Solar panel 300W	220 €	3	660 €
Electronics	310 €	1	310 €
Anchoring	15 €/meter	4	60 €
subtotal			1,094.5 €
working hours	50 €/hour	10	500 €
total price per module			1,594.5 €
total price for 1 MW	$(1594.5 * 1112)$		1,773,084 €

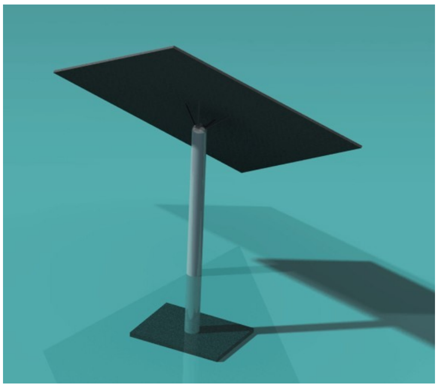
9.9 Design 6: The pole

This is called the pole design, the idea is to put a big surface of solar panels on a pole that keeps them above the water. The pole is anchored in concrete on the bottom of the lake, to make sure it keeps his position. On the top end of the pole there is a mechanism that makes the solar panels move so they can follow the sun. The idea is to put multiple poles near to each other.

The idea is to form a surface of 100 m^2, which would be a square of 10m x 10m. One panel has a surface of 1,6m^2 so we will need 62 solar panels. Panels of 300W were considered, which means that 3336 panel will be needed to reach 1 megawatt. After calculations it was found out that 54 poles are required to make solar park of 1 megawatt.



(a) As seen from the front



(b) As seen from the back

Figure 9.13: Sketch of the pole design for the solar

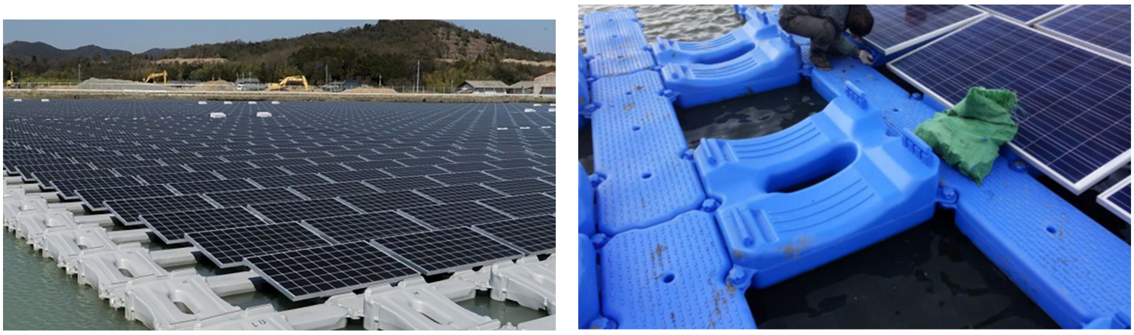
The Table 9.7 shows the cost of each module, and the cost of a 1MW park.

Table 9.7: cost estimation of pole design

Item	estimated price per item	amount	total price
Anchoring	400 €	1	400 €
Pole	600 €	1	600 €
Solar panels	190 €	62	11,780 €
electronics	310 €	1	310 €
subtotal			13,090 €
work hours	50 €	5	250 €
total price per module			13,340 €
total	$(13340 * 54)$		720,360 €

9.10 Reference: Classical floating solar park

To compare the designs discussed to existing floating solar parks, a cost estimation has been made on the same way. In Figure 9.14 an existing floating solar park, consisting of pontoons with solar panels on top, is estimated.



(a) Classical floating solar park (b) Plastic solar panel floaters

Figure 9.14: Classical floating solar park and module

Table 9.8: Estimated cost for classical floating solar panel for 1 MW

Item	Estimated price per item	Amount	Total cost
Plastic solar panel floater	60 €	3333	200000 €
Solar panel 300W	220 €	3333	733260 €
Anchoring	15 €/meter	100	1500 €
Subtotal			934,760 €
Work on	50 €/hour	500	25000 €
Total			959,760 €

9.11 Comparison

In Table 9.9 the different designs are compared with the cost of a 1 MW park. Next to that the possible efficiency increases are estimated. These factors include rotation and tilting of the panels as discussed in Chapter 5.3.2. Rotation and tilt is estimated to increase the power generated per year by 230% and 90% respectively. For cooling and mirrors an increase of 20% and 30% is assumed. These increases are tallied up and an estimated output with these factors taken into consideration is given.

Rotating and tilting however is only useful when there are no clouds. According to the weather data in Section 4.4 there are only 106 days on average with sunny days in Vaasa. Assuming that 10% during cloudy days, rotating and tilt has no affect, the efficiency gains are valid only 109/365 = 29.86% of the days. This means that rotation and tilt only offer an efficiency gain of 68.75% and 26.87% respectively on average during a year.

It can be seen that the most expensive design for 1 MW of power is the floating platform design. This one does however have the most benefit as well

Table 9.9: Comparison of the designs, with estimated efficiency increases and estimated actual output in MW for each design

Design	Cost for 1 1 MW (Million €)	Rotation	Tilting	Cooling	Mirrors	Total efficiency increase	Estimated output
Floating platform	2.2	x	x	x		+116 %	2.16 MW
Off-board engine	2.2	x	x	x		+116 %	2.16 MW
Cylindrical shape	1.79		x	x		+47 %	1.47 MW
Adapted cylindrical	1.56		x	x	x	+77 % - 97 %	1.77 - 1.97 MW
Biflotant design	1.78		x	x	x	+77 % - +97 %	1.77 - 1.97 MW
Pole	0.72	x	x			+96 %	1.96 MW
Reference	0.98					+0 %	1 MW

9.12 Land price

The ten biggest lakes of Finland are listed in Table 9.10. It shows that there are several lakes with an area big enough for a 1 MW solar park. However, it is not known if it is legal to build on these lakes and how much it would cost. As it is always possible to build a solar park on land, the cost is estimated to build the designs on land as well to get an idea of the total cost.

Table 9.10: Largest lakes in Finland

Name	Area (km3)
Saimaa	1377,05
Päijänne	1080,63
Inari	1040,28
Pielinen	894,21
Oulujärvi	887,09
Pihlajavesi	712,59
Orivesi	601,30
Haukivesi	562,31
Keitele	493,59
Kallavesi	472,76

Source: [Wikipedia, 2018a]

In Table 9.11, the price of the area needed for installing a 1MW solar park is shown. This area is an estimation based on the area of one module multiplied by the number of modules needed. The price of land is taken as 8 €/m^2, calculated in Section 7.3.

Table 9.11: Meter square per design for 1 MW

	Area for 1 MW	Price
Design 1	10.000 m^2	80.000 €
Design 2	10.000 m^2	80.000 €
Design 3	9.555 m^2	76.440 €
Design 4	9.555 m^2	76.440 €
Design 5	10.000 m^2	80.000 €
Design 6	15.000 m^2	120.000 €

The Table 9.12 shows the total price of every design accounting for the price of the land, the electrical installation and a 1Km long grid connection. The price of the land comes from Table 9.11. The electrical installation costs are taken from Table 9.2. The grid connection cost is taken as 100.000 € per Km, multiplied by the number of inverters needed.

Table 9.12: Price for each designs

	Price **Installation**	**Price Land**	**Electrical Installation**	**Grid connection connection**	**Total**
Design 1	2.200.000 €	80.000 €	171.049 €	1.700.000 €	4.151.049 €
Design 2	2.200.000 €	80.000 €	171.049 €	1.700.000 €	4.151.049 €
Design 3	1.790.000 €	76.440 €	171.049 €	1.700.000 €	3.737.489 €
Design 4	1.660.000 €	76.440 €	171.049 €	1.700.000 €	3.607.489 €
Design 5	1.073.360 €	80.000 €	171.049 €	1.700.000 €	3.024.409 €
Design 6	706.980 €	120.000 €	171.049 €	1.700.000 €	2.698.029 €

Clouds consideration

The price of the installation for 1 MW in Table 9.12 was calculated without any negative effects, such as cloud coverage or high temperature, neither with any positive effects, such as rotation or cooling. As clouds do have quite a negative effect on the power production, this should be taken into account in the price estimation. According to the weather data discussed in Section 4.4, there are 106 sun days on average in Vaasa. Assuming a 10% power efficiency during cloudy days.

Equation 9.3 calculates an efficiency factor of clouds. This is done by multiplying the number of sunny days with 100% and adding the number of cloudy days multiplied 10%, and dividing this total by 365 days. To account for this, the solar parks need to be increased by a factor of $1/0.36 = 2.8$ for an average power production of 1 MW.

$$\frac{(106 * 100) + (259 * 10)}{365} = 36.14\% = 0.36 \qquad (9.3)$$

Table 9.13: Influence of clouds on the price

	Price withouth clouds	**Price with cloud considered**
Design 1	4.151.049	11.530.691
Design 2	4.151.049	11.530.691
Design 3	3.737.489	10.381.913
Design 4	3.607.489	10.020.802
Design 5	3.024.409	8.401.136
Design 6	2.698.029	7.494.525

9.13 Final prices including bonuses

The prices in Table 9.13 are based on the price for a 1 MW solar park, placed on land, taking clouds into consideration. However, the base price is for 1 MW per design without taking the benefits. Dividing the prices per MW without benefits by the efficiency gained it will result in the price per MW with gains. This can be seen in Table 9.14

Table 9.14: Prices per MW, accounted for bonuses

	Price per MW without gains	**Price per MW with gains**
Design 1	11.530.691	5.338.282
Design 2	11.530.691	5.338.282
Design 3	10.380.913	7.069.328
Design 4	10.020.802	5.661.470
Design 5	8.401.136	4.746.404
Design 6	7.494.525	3.823.737

9.14 Different Regions in the world

Because clouds are often present in Finland, other destinations with less clouds, like Spain or California, were checked to see if it is more profitable to place solar parks in other countries.

9.14.1 Clouds in Spain

In Spain, the weather is more appropriate than in Finland regarding to solar energy. In fact, there are about 206 sunny days in Spain as was said before in Section 7.3. In order to have an idea for comparison the same calculation which was done before for Finland is made now for Spain and shown in the Table 9.15. The price per MW without gains is generally lower as there are more sunny days. As such a park for an average of 1 MW does not have to be that big.

Table 9.15: Clouds effects in Spain

	Price per MW without gains	Price per MW with gains
Design 1	5.609.526	2.597.003
Design 2	5.609.526	2.597.003
Design 3	5.050.661	3.435.824
Design 4	4.874.985	2.754.229
Design 5	4.087.039	2.309.062
Design 6	3.645.985	1.860.196

In conclusion, it seems to be more interesting, if we take in consideration clouds effects, to put a solar park in Spain than in Finland because there are more sunny days.

9.14.2 Clouds in California

In California, sun days are even more common than in Spain. Indeed, there are around 325 sun days in this country. The calculation in the Table 9.16 shows the same calculation that was made before for Finland and Spain.

Table 9.16: Clouds effects in California

	Price per MW without gains	Price per MW with gains
Design 1	4.612.277	2.135.313
Design 2	4.612.277	2.135.313
Design 3	4.152.766	2.825.011
Design 4	4.008.321	2.264.588
Design 5	3.360.454	1.898,562
Design 6	2,997,810	1,529,495

To conclude,it is seen that the price is lower than in Spain and Finland because there are more sunny days. It seems to be the best place among the considered to install a solar park according to the cost calculation. But other aspects have to be taken into account, such as the temperature on the panels, the price of land or the area available. In fact, a cooling system will have to be added if the temperatures get too high.Also the price of land could be more expensive than in other countries.

9.15 Conclusion

In this chapter multiple designs were discussed. For each design a cost estimation per module is made together with the cost for 1 MW. In this initial cost estimation, no negative effects or positive effects are considered. The first two designs are build up of a hexagonal floating structure with an array of panels on top, with the only difference being the method of rotation. Both designs are estimated to cost around 2.2 million euros. The next two designs are based on a cylindrical floater, one with the panels bend on top of the cylinder and the other with the panels on a structure. These two designs cost around 1.7 and 1.6 million euros respectively. The last two designs are also in the same price range.

After discussing all the designs, they were compared to each other in Table 9.9. Each of the possible benefits are totalled for each design to show the possible power production for the price stated.

The feasibility of putting the designs on land is also discussed by looking at the land price, connection to the power grid, etc. These figures can be seen in Table 9.12. However, the prices were calculated without taking the clouds in consideration. The Table 9.13 takes this into consideration and notices that Finland is not the most appropriate country to develop the idea of solar parks. At last the price per MW for each design when the possible bonuses were taken into consideration were calculated and displayed in Table 9.14. This shows that Design 6, the pole design, is the cheapest to build a 1 MW solar park.

Chapter 10

Experiments

10.1 Introduction

In this chapter the experiments that have been done will be discussed. Firstly the general measurement setup is explained. This is the electrical schematic and Arduino code. After the general measurement each experiment is laid out and discussed. The goal for this project was to build a prototype for testing. However, due to time constraints, it was not possible to build a prototype able to tilt and rotate. The best thing possible was to create a measurement setup measuring the power produced from a panel.

10.2 General measurement setup

10.2.1 Electronics

The electronics in the measurement setup are relatively simple. The goal of the setup is to measure the power output of the solar panel at any given moment. The circuit consists on a power supply, which is the solar panel, with a load resistor (Figure 10.2a) connected to it. In series with this load is an ampere-meter (Figure 10.2b) connected to an Arduino. Parallel to both, the ampere-meter and the load is a voltage divider (Figure 10.2c). The code that is running on the Arduino can be seen in Appendix C.

The current sensor is powered through an Arduino Uno (Figure 10.3a 5V supply and has a signal cable to the A1 pin of the Arduino. The voltage divider is only connected to the Arduino by the signal pin to A0. On top of the Arduino is an SD card shield (Figure 10.3b) and an SD card for data logging. The Arduino is programmed to do a measurement on both devices and calculate the power with a certain time interval in between. This data gets stored on the SD card as raw numbers.

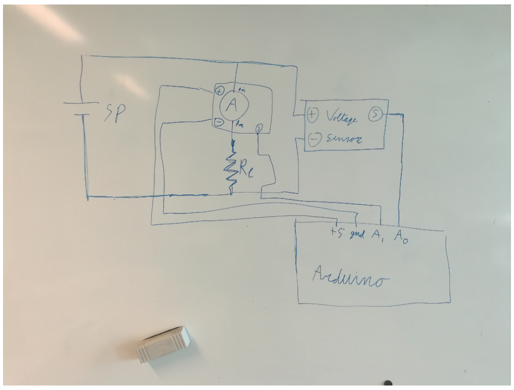
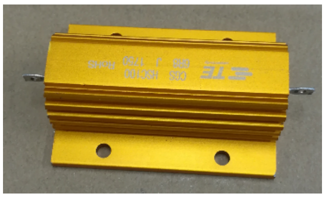
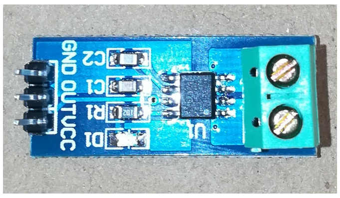


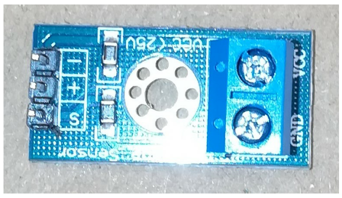
Figure 10.1: Schematic of the electronics used to measure the power output



(a) 100 Watt resistor

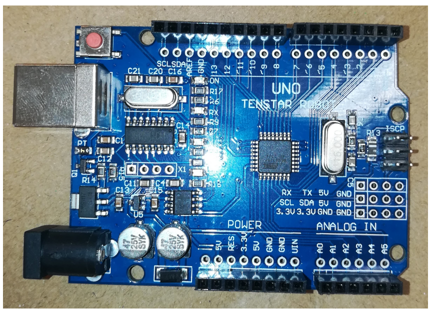


(b) Ampere sensor

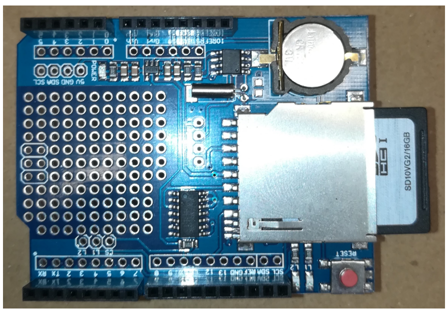


(c) Voltage divider

Figure 10.2: Electronics parts



(a) Arduino Uno



(b) SD card and shield for arduino

Figure 10.3: Microcontroller and data logger setup

All the measurements have been done on the roof of the Technobothnia building.

10.3 Measurements

10.3.1 Sunny with one cloud

In Figure 10.4 a graph of the power output of the panel can be seen. At first, the sun was shining directly on the panel. But between 18 and 240 seconds the sun was covered by a cloud. As soon as the cloud covered, the sun the power output dropped from 15 to 10 Watts. After the cloud moved away, the power output fluctuated between 15 and 25 Watts. The cause of this fluctuation could be some very small or light clouds. These simple measurements show that cloud coverage reduces the power output of a solar panel significantly.

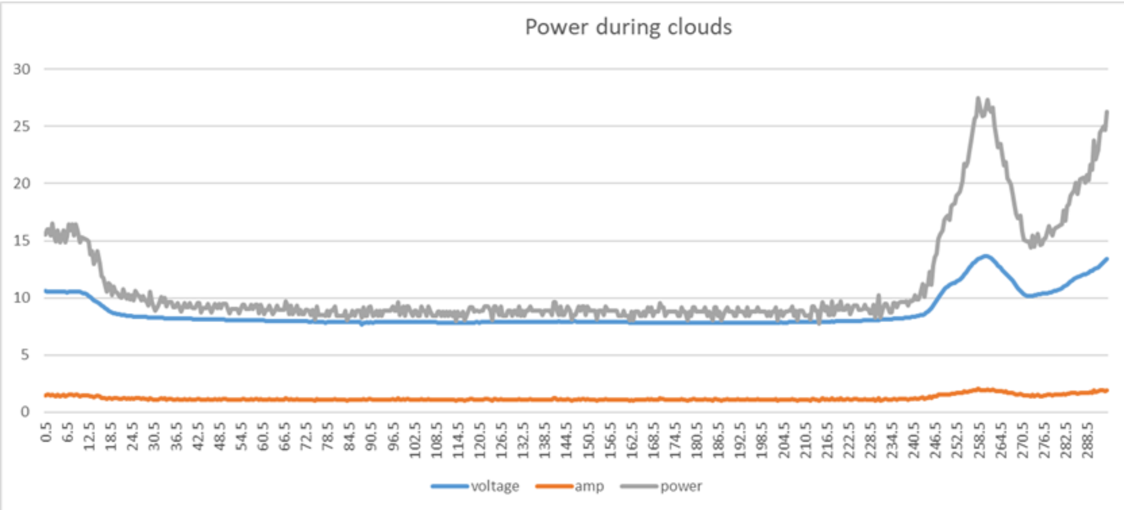
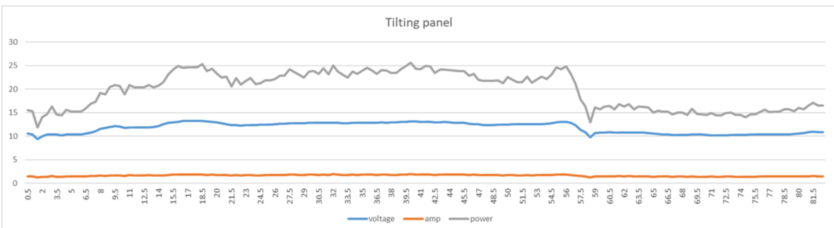


Figure 10.4: Power graph during a could covering the sun, in otherwise sunny weather

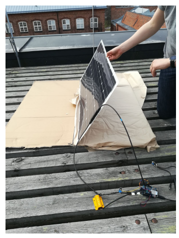
10.3.2 Tilting the panel

Continues measurement

The second measurement is done during tilting of the panel. Figure 10.5b shows the panel being tilted towards the sun. This quick measurement was done by hand and no angle was measured. In the graph in Figure 10.5a it can be seen that while tilting the power output is somewhere between 20 and 25 Watt but after putting it down, the power only reaches 15 Watt. This shows that decreasing the angle incidence has a positive effect on the power generation. This is however expected from the theory explained in Section 5.3



(a) Power graph of tilting the panel



(b) Tilting the panel towards the sun

Figure 10.5: Tilting panel

Multiple tilts

With another measurements, three tilts were measured seperataly for 10 seconds. An average is taken and the standard deviation from this measurement was calculated. During the 10 second measurement and assumption can be made that external situations have not changed, and as such the power output follows a normal distribution. From this a 95% range can be calculated to see where the output will be if the test is repeated. If, with a different tilt, these ranges do not coincide, it can be concluded that tilt does affect the power production.

In Table 10.1 a table can be seen where the panel is tilted in three angles. Looking at the 95% max for the 0 °tilt and the 95% min for the 12 °tilt, it can be concluded that a better tilt towards the sun increases the power output. The same can be said for 12°and 30 °tilt.

Table 10.2 shows the same values but just for the current. The Voltage levels are shown in Table 10.3. There you can see that the current draw from the barely increases. The mean current at 12°tilt is within the 95% range of the current at 30°tilt. As such it can not be stated that this increase in tilt has increased the current output. The voltage however shows a very distinct increment when tilting towards the sun. This explains the power raise.

Table 10.1: Wattage average and 95% normal distribution range

	Mean	**Standard deviation**	**95% min**	**95% max**
0	37.95	0.68	36.59	39.31
12	43.04	0.86	41.32	44.76
30	46.89	0.87	45.16	48.62

Table 10.2: Amperage average and 95% normal distribution range

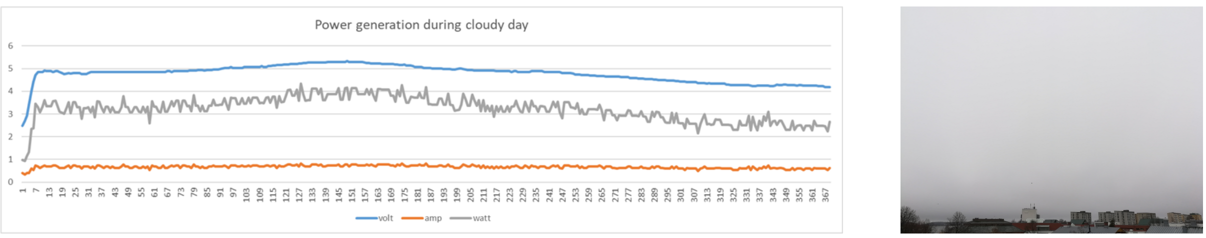
	Mean	**Standard deviation**	**95% min**	**95% max**
0	2.31	0.04	2.23	2.39
12	2.47	0.05	2.37	2.57
30	2.57	0.04	2.47	2.67

Table 10.3: Voltage average and 95% normal distribution range

	Mean	**Standard deviation**	**95% min**	**95% max**
0	16.37	0.02	16.33	16.41
12	17.39	0.02	17.36	17.42
30	18.22	0.05	18.13	18.31

10.3.3 Cloudy day

This measurement was a quick test to see if during a cloudy day some power could be generated. As can be seen from the graph in Figure 10.6a, the power generation during the 3 minutes measurement did not go higher than 5.5 Watts. This shows that during complete clouds barely any power is generated.



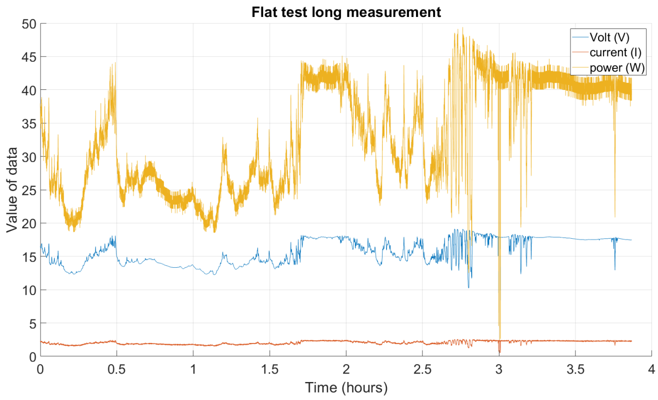
(a) Power graph during a cloudy day

(b) Weather at the cloudy day

Figure 10.6: Simple measurement setup during a cloudy day

10.3.4 Long test

As part of the experiments, a four hours long measurement has been taken. In the graph in Figure 10.7a it can be seen that even during a sunny day, the power produced varies a lot. This might be due to tiny clouds or a shadow passing over the panel. As the panel is made up of two parallel series of cells, if one cell is covered with a shadow only half the power will be produced. Looking at the power produced, this varies between 20-25 watt to 40-45 watt.



(a) Measurements from the nearly 4 hour continuous measurement of the current, voltage and wattage

(b) The weather at that day

Figure 10.7: Results of the measurement

10.3.5 Mirrors test

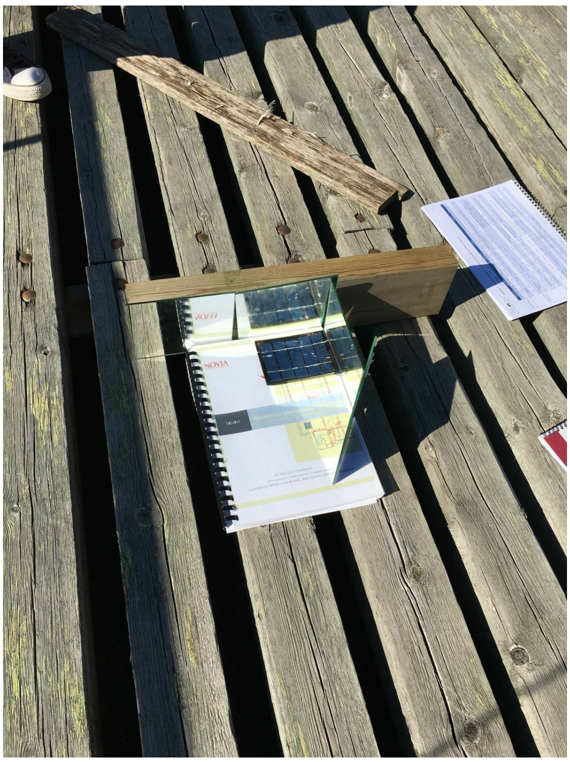


Figure 10.8: mirrors test

To test the effect of mirrors in the photovoltaic cell, we placed four reflecting surfaces in order to concentrate the sun rays on the cell, like Picture 10.8 shows. After one hour, a normal cell in the sun direction was at 39° Celsius whereas the testing cell with mirrors was at 91°C.This is 52°C of difference, which implies a drop in efficiency of about 25%. We could see at the end of the experiment that the plastic frame of cell was curved by the heat, but no other damages were observed. However, it is recommended to install a cooling system when mirrors are added to counteract the huge drop of efficiency due to the additional heat.

10.4 Conclusion

In this chapter the measurement setup is discussed as well as the measurements taken. At the end of the project there was not enough time to set up all the experiments desired, but a few results were extracted. First of all, it has been found that mirrors, while being able to increase power production, require both a solar tracking device and a cooling system for working properly without damaging the panels. The experiments described in Section 10.3.2 showed that orienting the panels towards the sun positively affects the power production. These measurements coincide with the theory discussed. One long time measurement was done with sunny weather.It showed that the power production during a long time varies severely. Next to that, mirrors were placed around a solar cell in order to compared its performance with a cell without mirrors.

Part III

Project management and accountability report

Chapter 11

Project Management

11.1 Introduction

In this chapter different elements of Project Management will be discussed. This work done helped us to schedule the project, assign tasks to team members and overall development. Some tools that have been helpful will be discussed.

11.2 Project Management overview

In appendix D.1 an overview of the Project-management schedule can be seen. If a person has worked on a particular task, the working hours are shown as well. The resources used for this task are shown in the next column. The resources include not only the material and software used but also the people who had worked on the task. Recurring tasks, such as the weekly meetings are also shown up in the schedule.

Next to that the individual worksheets of every teem member are shown in appendix D.2. Each group member has around 300 hours of planned work. Of course in reality we worked more hours on this project because it is impossible to plan every single hour of every person. The main tasks of the project do represent these 300 hours.

11.2.1 RACI Matrix

The first thing that is discussed is the RACI matrix. This is a table which shows who is Responsible, Accountable, Consulted or Informed of each task. This matrix makes it easier for team management to know as a person which task is your responsibility.

The team members that are responsible for a task are those that have to execute it. They can get this task from the person that is accountable for this task.

The accountable team member for a certain task is the person who manages that specific tasks and makes sure it is finished on time. This person has to work on it as well but can ask other team members to help them.

The consulted role is for people who's opinion is of importance to a certain task. These people need to be consulted before important decisions on that task are taken.

Informed team members are the least important for a task. Those team members are just kept up to date on a certain task.

IN Figure 11.1 the RACI matrix is shown. It can be seen that every task at least one person who is Accountable and one responsible. Depending on the task the other teammates are either informed are consulted.

RACI matrix	Mathieu	Rick	Pascal	Andres	Gilles	Mikaël
Gather data	R	R	R	R	A	I
Investigate location	A	I	R	I	I	C
Gather local weather	I	I	A	R	I	I
Create design	R	C	C	A	C	I
Calculate cost + energy budget	A	I	I	I	R	I
Create a prototype	R	C	C	A	C	C
Create simulation of design	I	R	A	I	I	I
Establish baselines values	I	R	I	I	A	I
Create a report	R	A	R	R	R	I

R	Responsible
A	Accountable
C	Consulted
I	Informed

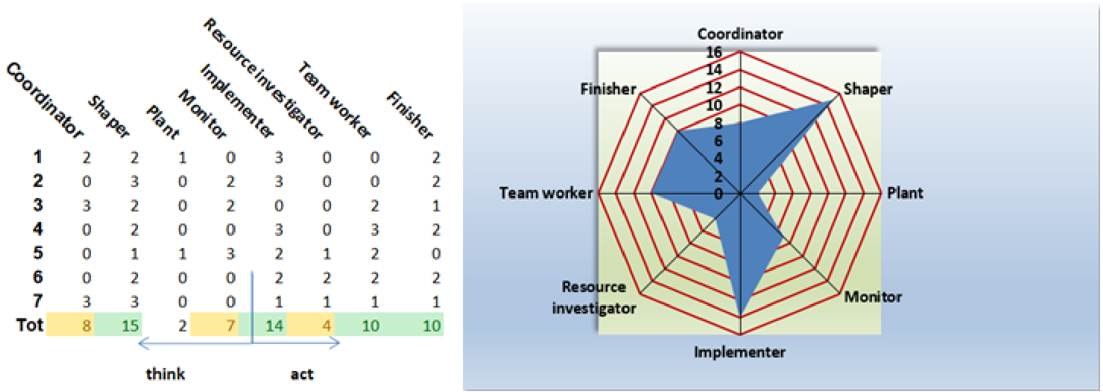
Figure 11.1: Raci Matrix

11.2.2 Belbin Tests

The Belbin Test is a good tool to get an idea of which kind of roles the team members can best fulfil. This test consists of a questionnaire which will result in a spiderweb plot of certain personality types. This will allow to discover the potential strengths and vigilance of team members.

Let's read the description of each people of the FloSoP Team :

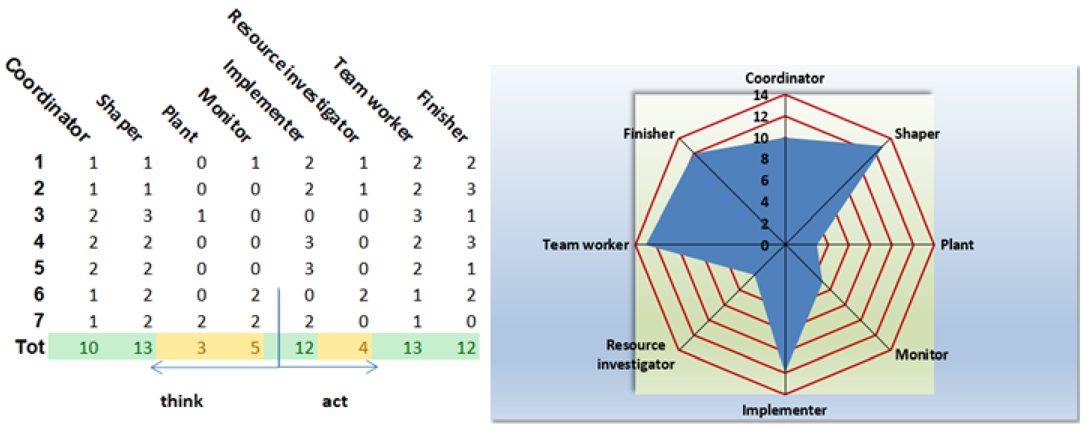
Gilles Belis: My biggest role will be shaper. I can provide the necessary drive to ensure that the team keeps moving and does not lose focus or momentum. I can be prone to provocation, and may sometimes offend people's feelings. My second role is implementer, so I need to plan a workable strategy and carry it out as efficiently as possible. My strength here is that I turn ideas into actions and organises work that needs to be done. My third role is team worker, using their versatility to identify the work required and completing it on behalf of the team.



	Coordinator	Shaper	Plant	Monitor	Implementer	Resource investigator	Team worker	Finisher
1	2	2	1	0	3	0	0	2
2	0	3	0	2	3	0	0	2
3	3	2	0	2	0	0	2	1
4	0	2	0	0	3	0	3	2
5	0	1	1	3	2	1	2	0
6	0	2	0	0	2	2	2	2
7	3	3	0	0	1	1	1	1
Tot	8	15	2	7	14	4	10	10

Figure 11.2: Gilles Belbin test

Mathieu de Oliveira: My best strength role is as team worker because I find it very interesting to work in a team, listen the ideas of each people, compare and look for the best one. Also, when you have a problem, different people' skills can help you to solve it in order to do not stay alone in front of the problem. After, I have 3 others main competences which are finisher, shaper and implementer. I like to organize, plan my work and I need to have a clear idea of the project and know what people are going to do.



	Coordinator	Shaper	Plant	Monitor	Implementer	Resource investigator	Team worker	Finisher
1	1	1	0	1	2	1	2	2
2	1	1	0	0	2	1	2	3
3	2	3	1	0	0	0	3	1
4	2	2	0	0	3	0	2	3
5	2	2	0	0	3	0	2	1
6	1	2	0	2	0	2	1	2
7	1	2	2	2	2	0	1	0
Tot	10	13	3	5	12	4	13	12

Figure 11.3: Mathieu Belbin test

Pascal Vrignon: I am relatively versatile with a tendency to shaper. I am a task-focused people who pursues objectives with vigor and who is driven by tremendous energy and the need to achieve. Two other skills also characterize me: coordinator and plant. I can be stepping back to see the big picture. I recognize abilities in others and delete tasks to the right person for the job. More, like plants, I am creative, unorthodox and generators of ideas but tend to ignore incidentals. The Plant often has a hard time communicating ideas to others. Many ideas are generated without sufficient discernment or the impetus to follow the ideas through to action.

	Coordinator	Shaper	Plant	Monitor	Implementer	Resource investigator	Team worker	Finisher
1	1	1	1	2	3	0	0	2
2	1	1	0	0	2	1	3	2
3	0	2	1	1	1	2	2	1
4	2	8	2	1	1	1	0	2
5	3	0	3	1	1	0	1	1
6	2	0	2	2	0	1	2	1
7	2	2	2	0	1	2	0	1
Tot	11	14	11	7	9	7	8	10

think act

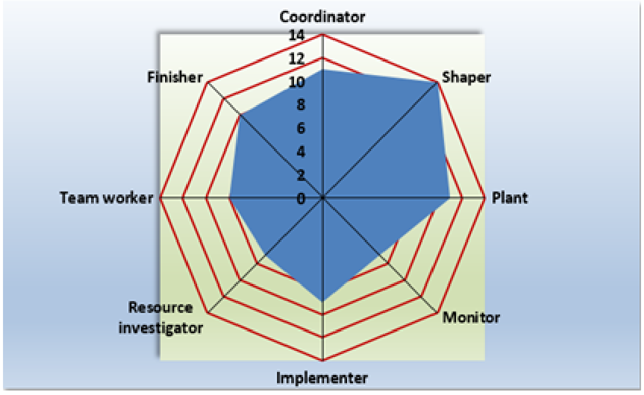


Figure 11.4: Pascal Belbin test

Andrés Cortés Martín: My characteristic role is resource investigator, this means that I am enthusiastic and outgoing, and that I can find new ideas for the project. But this also means that I may be over-optimistic in some situations, and eventually losing the interest. My second role is plant; this implies that I am a creative person, good at solving problems by lateral thinking, but that I can be forgetful, and that I can worry too much about how to communicate effectively.

	Coordinat(	Shaper	Plant	Monitoı	Implemente	Resou	Team worker	Finisher
1	0	1	2	0	2	2	1	2
2	2	1	3	2	0	1	0	1
3	1	0	2	1	1	2	3	1
4	1	1	1	1	1	2	0	3
5	1	0	3	1	0	3	0	2
6	1	2	2	2	3	0	0	0
7	2	2	0	0	0	5	1	0
Tot	8	7	13	7	7	15	5	9

think act

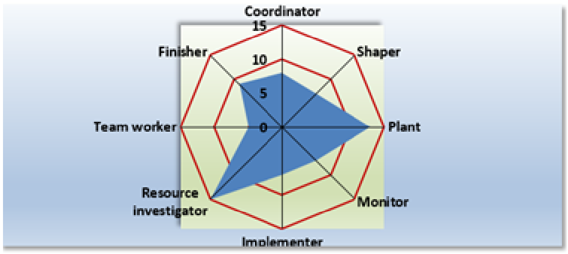


Figure 11.5: Andrés Belbin test

Rick Winters: Looking at the spiderweb plot in Figure 11.6, the two personalities that pop up are a finisher and implementer. This I can recognise from previous projects. A finisher is very recognisable as i always spend a lot of time on the final report of a project, making as perfect as can be. An implementer is also recognisable as i have done a lot of side projects in programming and automating things. Next to that i have also implemented quite a few algorithms in Matlab to do a certain kind of data analysis, which is my speciality.

	Coordinator	Shaper	Plant	Monitor	Implementer	Resource investigator	Team worker	Finisher
1	1	1	2	2	1	0	1	2
2	1	2	1	0	2	0	1	3
3	1	2	0	2	1	2	1	1
4	1	2	0	1	2	1	0	3
5	2	1	1	1	2	1	1	1
6	0	1	2	3	2	2	0	0
7	0	0	2	1	3	0	2	2
Tot	6	9	8	10	13	6	6	12

think act

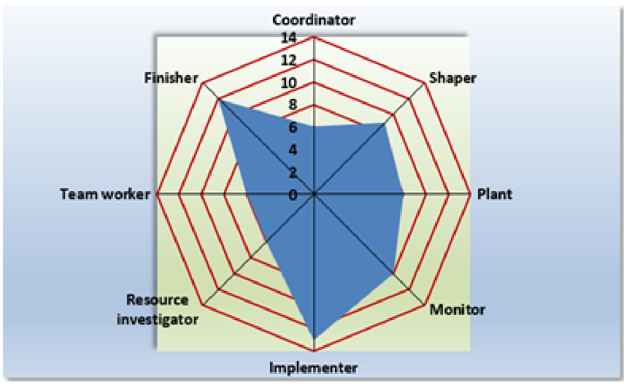


Figure 11.6: Rick Belbin test

11.3 Logo

For the task of designing both the logotype and the brand image of the project, we wanted to reflect the union between solar panels and water, which is inherent to our project. Firstly, we started proposing complex and overloaded designs, such as the shown in the image 11.7, but eventually we change our mind to focus on more simple and discreet design, reaching the chosen logo. In the logo is described a solar panel emerging among the waves, accompanied by the acronym FloSoP, standing for "Floating Solar Park" in a black and blue typography. The final logotype can be seen in the front page.

Figure 11.7: First logos designed

11.4 Project cost

To calculate the cost of the project an hourly rate of 50 €/h was considered. The calculated hours are the minimum done, only the hours filed to a task were registered. This means that more time was actually spent on the project. In Table 11.1 a total of the work hours can be seen. This means that the project would have costed 75,300 €. Including a prototype the cost would go to 75,654 €.

Table 11.1: Total working hours of each team members and a total

Name	Hours
Gilles	303
Mathieu	299
Pascal	301
Andres	299
Rick	304
Total	1,506

Figure 11.8 shows a block diagram of the hours worked per month of every person for each month. The work hours in February are less because there were lectures to be attended. May has less hours as well as the project had to be delivered half of May, so there was less working days.

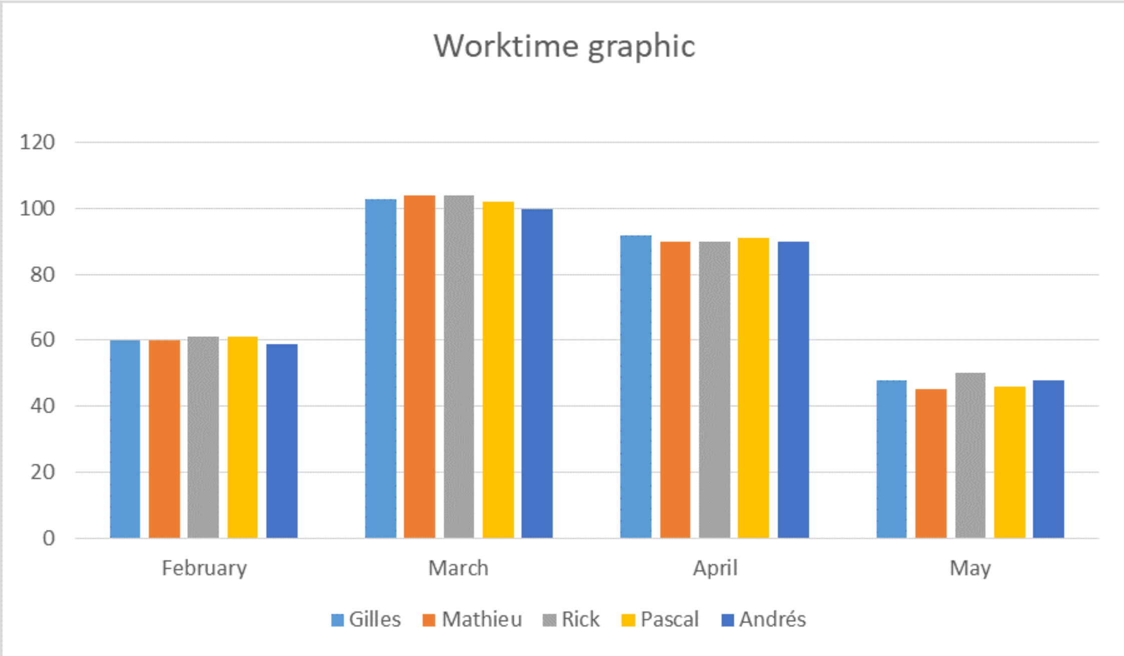


Figure 11.8: Block diagram of hours worked per person and month

Part IV

Conclusion

Chapter 12

Conclusion and Discussion

12.1 Introduction

Throughout the entire present project, many ideas have been proposed in order to design and study the profitability of an offshore solar plant. In this chapter, a small summary will be given of the complete report. Each part is briefly discussed, together some results. At the end, the results that are gathered are compared to the goal of the project in order to see if the goal has been met or not.

12.2 Research and background information

At the beginning of the report (Chapter 2), the current situation of solar floating parks was studied. It was found that some floating solar parks already exist and there are more plans to build these parks. Chapter 3 discusses the technology of solar panels and the physics on how it works.

On the following chapter (4), the factors which affect the solar panels were discussed. First of all, the influence of temperature was studied. The higher the temperature is, the lower the efficiency. This effect is important, since it can be used in a positive way. Next to that, the effect of the position of the sun relative to the panel's angle is discussed which is followed by weather. The chapter ends by discussing the effects of clouds on the power production.

Knowing the factors that influence solar panels efficiency, work has been done to try and use these effects favourably to increase the power output of the solar panels. This is discussed in Chapter 5. First, an analysis of the cooling was done. A detailed analysis of cooling the panels by submerging was done, reaching the conclusion that theoretically submerging the panels for a certain time can improve the overall efficiency by a small amount. However, these results should be considered as a first hint about the possibility of cooling the panels and therefore, practical study should be done to effectively prove this. Next to this, an analysis of forced water cooling was done. This resulted in an always negative result, meaning that this method is inappropriate to improve the efficiency.

Another way of improving solar panel performance is by making them follow the sun. This way the panels will produce the maximum power output when the sun is up. This was analysed by numerical simulations which determined that there is a huge increase in efficiency, especially in higher latitudes where the days are long in summer and short in winter. These numerical simulations, however, did not take cloud coverage into consideration. Next to this, the usage of mirrors to increase efficiency was examined. First, flat mirrors were studied. The study revealed that theoretically performance could be increased up to a 80% according to Figure 5.16. However, this figure also shows that very large mirrors are needed. It is necessary to have a full solar tracking system when mirrors are used and a cooling system to counteract the additional heat generated is recommended. Next, a simulation with Comsol Multiphisycs was done to analyse the possible usage of parabolic mirrors. The results achieved shown that mirrors require full solar tracking in order to work properly. Otherwise, they would have a counter-productive effect.

Finally, the effect of dust and snow over the solar panels was studied. With a minimum of snow coverage, the panels produce zero output. So, cleaning the snow of the panels, either on a passive or an active way, is mandatory in Finland.

In Chapter 6, the last chapter of the Part I, a brief study of the main components of a solar park is discussed.

12.3 Design ideas

Part II started with some design considerations. Different topics were discussed such as different kind of floating structures or the best location of the solar farm. Regarding to weather data, it seems not very interesting to install a park in Finland due to very little sun hours and a big maintenance against ice and snow. Two other places were investigated, Andalusia in Spain and California in USA, where the amount of sun is high.

The necessity of keeping the water ice free was also studied. A design based on a sprinkler system was thought of. However, the energy cost of preventing the ice is too high and it would make the installation unprofitable in energy and financial terms.

A morphological overview is discussed in Chapter 8. This discussion started with a matrix with ideas for rotation, anchoring, structure, antifreeze system, solar tracking and cleaning. Next to that, all of the ideas were discussed. This overview was the basis for several designs the team came up with over the course of the project.

These designs were displayed on the following chapter (Chapter 9) with advantages and disadvantages of each one. Firstly, the devices present in every design were described in order to start later explaining the particularities of each.

Six designs were described. After calculating the cost of each design for 1 MW production, taking into consideration the positive effects of,, for example, rotation and tilt or cooling, the designs could be compared to each other. Table 9.14 shows the price of each design located in Finland. This shows that the third design (discussed in Section 9.6) is the most expensive and the last design (discussed in Section 9.9) is the cheapest to build.

12.4 Measurements

The next chapter (Chapter 10) of the report discusses the measurements taken at the end. This chapter starts with the measurement setup. Multiple measurements are discussed showing similarities to the theoretical background.

12.5 Project management

Finally, the report finished with the explanation of how the project management was done. The Work Breakdown Structure was the first part of our project. After finishing the WBS, the planning was started. Microsoft office Projectmanager was used as task planner. In this tool, all the tasks per people in the team were filled. Moreover, an hour planning in time was made to know the tasks which has to be made during the 4 months. This way, the plan was followed during whole the project. A cost calculation is also present. Also, the work hour cost of the 5 team members and the cost of the prototype were calculated. The cost is €75.654. To finish this chapter, a work time graphic which shows the work hours of every group member divided over the 4 months is shown.

12.6 Goal

The goal of this project was to design a concept of a working floating solar park system, estimating the yearly power output, building and testing a prototype design to study the feasibility and advantages of a floating solar park.

This goal can be divided into multiple part. Designing a concept park, estimating the power output and testing a prototype. Multiple concepts have been designed and discussed, as such this part of the goal is reached. A single module for each design has an estimated power output. However, for cost estimations, a solar park of 1 MW power output has been used. As such this part of the goal is reached as well. A measurement setup was made and some measurements have been done. However, a prototype able to tilt and rotate was not made. This part of the goal is not reached.

12.7 Conclusion

Gathering all the data and research collected during this project, it is concluded that building a floating solar park in Finland is not feasible. The reason for this is that powering a system that keeps the water from freezing is in terms of energy and financially unprofitable. Other factors such as low sun days make it difficult as well. However, creating a floating solar park in other locations closer to the equator is feasible though a practical test and deeper study should be done before a commercially viable plant is constructed.

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Appendices

Appendix A

Matlab scripts

A.1 Numerical simulation of solar panel, rotating with the sun, fixed tilt

```
clear all
close all
clc
warning off
load elevationangles
% Load in the elevationangles data
elevationangles = angles;
% Put the values in the 'elevationangles' variable
folder = 'C:\Dropbox\Saxion\4e jaar\EPS finland Floating Solar Park\EPS Floating Solar Park\numerical s

basepower = 75;
% Watt
timestep = 1;
% In minutes
minutes = 1:1/60:24;
% Array of minutes troughout the day
SPangle = 0:1:90;
% Array of tilt-angles of the solar panel
tic
% Start timer

yearlyplot = 0;

parfor u = 1:91
    % Parallel loop over all tilt angles, Multiple proceses get started
    % where each process calculates this loop iindependently of the other
    Totalenergy(u) = 0;
    % Create an array of Totalenery
    maxpower = [];
    % Set maxpower to an empty array, this gets added to the cell-matrix
    Maxpower{u} = [];
    % Create a cell-matrix entry that is an empty array.
    Totaldailyenergy{u} = [];
    % Set the cell-matrix entry to an empty array
    totaldailyenergy = [];
    % Create an ampty array representing the total powergenerated for each
    % day in the month.
    for i = 2:366
        % Loop over all days in the year
        strcat('current: ',num2str(SPangle(u)),' deg    days',num2str(i),'/365')
        % Update the user through command window

        % Calculate efficiencies based on elevation angles
        angles = elevationangles(i,:);
        % Load in elevation angle data of this day
        weights = (angles > -1);
        % Find which values of the angles are used to fitting the curve
        fitted = fit((1:1:24)',angles','cubicinterp','weight',weights);
        % Fit the angles of the sun with a cubic interpolated fit
        minuteangles = fitted(minutes);
        % Apply the fit to find the angles per minute
        ind = minuteangles < 0;
        % Find where the sun hasnt risen yet
        SPangles = minuteangles + SPangle(u);
        % Apply the rotation of the solar panel
        SPangles(SPangles>90) = 90 - (SPangles(SPangles>90)-90);
        % Make sure the angle goes down again
        SPangles(ind) = 0;

        %from here we calculate the energy produced per minute assuming
        %perfect weather condition
        efficiencies = 1 - cosd(SPangles);
        % Calculate the efficiency of the panel regarding the angle of the
        % sun on the panel
        power = basepower .* efficiencies;
        % Multiply with base power to get power for every minute
        output = power .* 60;
        % Calculate total output
        Totalenergy(u) = Totalenergy(u) + sum(output);
        % Summarize total output
```

```
        totaldailyenergy = [totaldailyenergy, sum(output)];
        maxpower = [maxpower, max(power)];
        % Remember the max power output of this day
    end
    %After a year, plot the maximum power output vs of each day
    if yearlyplot == 1
        figure('units','normalized','outerposition',[0 0 1 1])
        grid on
        hold on
        plot(1:365,maxpower)
        xlabel('days')
        ylabel('Maximum power output')
        legend('power (W)')
        title(strcat('Maximum power output of panel rated at 75W, each day of the year, at ',num2str(SP
        saveas(gca, strcat(folder,'\Max_power_over_time_at_angle_',num2str(u),'_rotational_tracking'),'
        close all
    end
    Maxpower{u} = maxpower;
    Totaldailyenergy{u} = totaldailyenergy;
end

ind = find(Totalenergy == max(Totalenergy));

%after looping over the SP angle the total power generated over a year gets
%plotted vs the angle
figure('units','normalized','outerposition',[0 0 1 1])
grid on
hold on
plot(SPangle,Totalenergy)
line([SPangle(1),SPangle(end)],[max(Totalenergy),max(Totalenergy)],'Color','r')
Ylim = get(gca,'ylim');
line([SPangle(ind),SPangle(ind)],[Ylim(1),Ylim(2)],'Color','r')
xlabel({'Rotation (deg)',' ';
    'Max power generation at angle: ',num2str(SPangle(ind))})
ylabel('Total power generation (J)')
legend('power generated')
title('Total power generated of a solar panel at a certain angle')
saveas(gca, strcat(folder,'Yearly_energy_creation_per_angle'),'png')
toc
save('Max_power_per_day_per_angle_rotational_tracking','Maxpower')
save('Total_daily_energy_per_day_per_angle_rotational_tracking','Totaldailyenergy')
```

A.2 Numerical simulation of solar panel, not rotating with the sun, fixed tilt

```
clear all
close all
clc
warning off

load elevationangles
% Load in the elevationangles data
load azimuth.mat
% Load in the azimuthangles data
elevationangles = angles;
% Put the values in the 'elevationangles' variable
folder = 'C:\Dropbox\Saxion\4e jaar\EPS finland Floating Solar Park\EPS Floating Solar Park\numerical s

basepower = 75;
% Watt
SPazimuth = 180;
% Angle on a compass of the solar panel face
timestep = 1;
% In minutes
minutes = 1:1/60:24;
% Array of minutes throughout the day
SPangle = 0:1:90;
% Array of tilt-angles of the solar panel
tic
% Starts timer
dailyplot = 0;
```

```
yearlyplot = 1;

parfor u = 1:91
    % Parallel loop over all tilt angles, Multiple processes get started
    % where each process calculates this loop independently of the others
    % and at the same time, speeding up the process
    Totalenergy(u) = 0;
    % create an array of Totalenergy
    Maxpower{u} = [];
    % Create an cell-matrix of MaxPower
    maxpower = [];
    % Set maxpower to an empty array, this array gets added to the cell
    % matrix
    totaldailyenergy = [];
    % Create an empty array representing the total power generated for each
    % day in the month
    Totaldailyenergy{u} = [];
    % Set the cell-matrix entry to an empty array
    for i = 2:366
        % Loop over all days in the year
        strcat('current: ',num2str(SPangle(u)),' deg    days',num2str(i),'/365')
        %Update the user through command window

        %calculate efficiencies based on elevation angles
        angles = elevationangles(i,:);
        % Load in elevation angle data of this day
        weights = (angles > -1);
        % Find which values of the angles are used to fitting the curve
        fitted = fit((1:1:24)',angles','cubicinterp','weight',weights);
        % Fit the angles of the sun with a cubic interpolated fit
        minuteangles = fitted(minutes);
        % Apply the fit to find the angles per minute
        ind = minuteangles < 0;
        % Find where the sun hasnt risen yet
        SPangles = minuteangles + SPangle(u);
        % Apply the rotation of the solar panel
        SPangles(SPangles>90) = 90 - (SPangles(SPangles>90)-90);
        % Make sure the angle goes down again
        SPangles(ind) = 0;
        elevation_efficiencies = 1 - cosd(SPangles);
        % Calculate the efficiency of the panel regarding the angle of the
        % sun on the panel

        %calculate efficiencies based on azimuth angle differenc
        azimuth_current = azimuth(i,:);
        % Load in azimuth angles of the sun this day
        weights = azimuth_current > 0;
        % Only take the azimuth of the sun into consideration where it has
        % risen to fit it for every minute
        fitted = fit((1:1:24)',azimuth_current','d.*x.^3+a.*x.^2+b.*x+c','weight',weights);
        % Fit the azimuth with a cubic fit
        azimuth_fitted = fitted(minutes);
        % Evaluate fit
        azdifference = abs(azimuth_fitted - SPazimuth);
        % Calculate difference in azimuthe angle
        azdifference(azdifference > 90) = 90;
        % If its bigger than 90 degrees, set it to 90 degrees
        azimuthefficiencies = 1-sind(azdifference);
        % Calculate efficiency in the same way elevation efficiency is
        % calculated. as a first assumption this should do

        efficiencies = azimuthefficiencies .* elevation_efficiencies;
        % Multiply elevation and azimuth together to get total efficiency
        power = basepower .* efficiencies;
        % Multiply with base power to get power for every minute
        output = power .* 60;
        % Calculate total output
        Totalenergy(u) = Totalenergy(u) + sum(output);
        % Summarize total output
        totaldailyenergy = [totaldailyenergy, sum(output)];
        % Remember total daily output in array
        maxpower = [maxpower, max(power)];
        % Remember the max power output of this day

        if dailyplot == 1
            % This plot is used for debugging purposes
```

```
            figure('units','normalized','outerposition',[0 0 1 1])
            grid on
            hold on
            plot(minutes,azimuthefficiencies.*100)
            plot(minutes,elevation_efficiencies.*100)
            plot(minutes,efficiencies.*100)
            plot(minutes,azdifference);
            plot(minutes,SPangles);
            plot(minutes,power);
            xlabel('Hours')
            ylabel('data')
            legend('azef','elef','eff','azdiff','SPangles','power')
            title('eu')
        end
    end

    %After a year, plot the maximum power output of each day
    if yearlyplot == 1
        figure('units','normalized','outerposition',[0 0 1 1])
        grid on
        hold on
        plot(1:365,maxpower)
        xlabel('days')
        ylabel('Maximum power output')
        legend('power (W)')
        title(strcat('Maximum power output of panel rated at 75W, each day of the year, at ',num2str(SP
        saveas(gca, strcat(folder,'Max_power_over_time_at_angle_',num2str(u),'_no_rotational_tracking')
        close all
    end
    Maxpower{u} = maxpower;
    % Save max power output per day in cell-matrix, so that Matlab main
    % process can acces it
    Totaldailyenergy{u} = totaldailyenergy;
    % Save totaldailyenergy to cell-matrix, so that main process can acces
    % it
end

ind = find(Totalenergy == max(Totalenergy));
% Find the index of the maximum total energy, this is also the optimum
% angle

%Plots total energy output vs solar panel angle, with crossing lines at
%optimum place
figure('units','normalized','outerposition',[0 0 1 1])
grid on
hold on
plot(SPangle,Totalenergy)
line([SPangle(1),SPangle(end)],[max(Totalenergy),max(Totalenergy)],'Color','r')
Ylim = get(gca,'ylim');
line([SPangle(ind),SPangle(ind)],[Ylim(1),Ylim(2)],'Color','r')
xlabel({'Rotation (deg)',' ';
    'Max power generation at angle: ',num2str(SPangle(ind))})
ylabel('Total power generation (J)')
legend('power generated')
title('Total power generated of a solar panel at a certain angle')
saveas(gca, strcat(folder,'Yearly_energy_creation_per_tiltangle_no_rotational_tracking'),'png')
toc
save('Max_power_per_day_per_angle_facing_south','Maxpower')
save('Total_daily_energy_per_day_per_angle_facing_south','Totaldailyenergy')
```

A.3 Numerical simulation of solar panel, rotating and tilting with the sun

```
clear all
close all
clc
warning off
load elevationangles
% Load in the elevationangles data
elevationangles = angles;
% Put the values in the 'elevationangles' variable
```

```
folder = 'C:\Dropbox\Saxion\4e jaar\EPS finland Floating Solar Park\EPS Floating Solar Park\numerical s

basepower = 75;
% Watt
timestep = 1;
% In minutes
minutes = 1:1/60:24;
% Array of minutes in a day
tic
% Start timer
mintilt = 0;
% Minimun tilt of solar panel
maxtilt = 90;
% Maximum tilt of solar panel
yearlyplot = 1;
dailyplot = 0;

maxpower = [];
% Create an empty array of max power production per day
totaldailyenergy = [];
% Create an empty array of total energy production per day
Totalenergy = 0;
% Set Totalenergy to 0
for i = 2:366
    % Loop over all days of the year
    strcat('current: ',num2str(i-1),'/365')
    % Update user over command window
    angles = elevationangles(i,:);
    % Load in elevation angle data of this day
    weights = (angles > -1);
    % Find which values of the angles are used to fitting the curve
    fitted = fit((1:1:24)',angles','cubicinterp','weight',weights);
    % Fit the angles of the sun with a cubic interpolated fit
    minuteangles = fitted(minutes);
    % Apply the fit to find the angles per minute
    ind = minuteangles < 0;
    % Find where the sun hasnt risen yet
    SPangles = 90 - minuteangles;
    % Inverse the angles so that 0 degree tilt is the panel on its side,
    % facing the horizon, which coincides with 0 degree elevation of the
    % sun
    SPangles(SPangles ≥ maxtilt) = maxtilt;
    % Limit the tilt of the panel to the maxtilt
    SPangles(SPangles ≤ mintilt) = mintilt;
    % Limit the tilt of the panel to the mintilt
    angledif = invangles - SPangles;
    % Calculate the difference of the SPnormal and SUN, there might be a
    % difference because of tilt limitations
    angledif(ind) = 90;
    % Set the diff to 90 degrees when the sun hasn't risen yet, because
    % cosd(90) = 0,

    %from here we calculate the energy produced per minute assuming perfect
    %weather condition
    efficiencies = cosd(angledif);
    % Calculate the efficiency of the panel regarding the angle of the sun
    % on the panel
    power = basepower .* efficiencies;
    % Multiply with base power to get power for every minute
    output = power .* 60;
    % Calculate total output
    Totalenergy = Totalenergy + sum(output);
    % Summarize total output
    totaldailyenergy = [totaldailyenergy, sum(output)];
    % Keep track of totaldaily energy
    maxpower = [maxpower, max(power)];
    % Remember the max power output of this day
    if dailyplot == 1
        figure('units','normalized','outerposition',[0 0 1 1])
        grid on
        hold on
        plot(minutes,efficiencies.*100)
        plot(minutes,SPangles);
        plot(minutes,angledif);
        plot(minutes,power);
        xlabel('Hours')
```

```
        ylabel('data')
        legend('eff','SPangles','angledif','power')
        title('eu')
    end
end
%After a year, plot the maximum power output vs of each day
if yearlyplot == 1
    figure('units','normalized','outerposition',[0 0 1 1])
    grid on
    hold on
    plot(1:365,totaldailyenergy)
    xlabel({'days';
        strcat('Total energy produced = ',num2str(Totalenergy),' (J)')})
    ylabel('Total energy produced')
    title(strcat('Total energy creation of panel rated at 75W, each day of the year, rotating and tilti
    saveas(gca, strcat(folder,'Total_power_per_day_yearly_rotational_tracking_tilt_tracking'),'png')
    figure('units','normalized','outerposition',[0 0 1 1])
    grid on
    hold on
    plot(1:365,maxpower)
    xlabel('days')
    ylabel('Max power output per day')
    title('Max power output per day of panel rated at 75W, each day of the year, rotating and tilting w
    saveas(gca, strcat(folder,'Maximumn_power_output_per_day_rotational_tracking_tilt_tracking'),'png')
end

save('Total_daily_energy_per_day_rotational_tracking_tilt_tracking','totaldailyenergy')
save('Max_power_per_day_rotational_tracking_tilt_tracking','maxpower')
```

Appendix B

Heat calculation results

Th (°C)	Tc (°C)	Energy disipated Cp(Th-Tc) (W/m²)	Time to cooling (s)	Efficiency lost over time	Time to heat (s)	Average temperature (°C)	Efficiency Improve (%)	Efficiency gained over time	Cicle time (s)	Net efficiency (%)
47	47	0	0,00	0,00	0,00	47,0	0,00	0,00	0,00	0,00
47	40	87885	24,95	2495,40	8234,81	45,7	0,58	4817,36	8259,76	0,28
47	35	150660	87,75	8774,70	16583,00	45,2	0,81	13432,23	16670,75	0,28
47	30	213435	228,46	22845,80	25784,00	44,8	0,99	25526,16	26012,46	0,10
47	25	276210	502,57	50256,90	35577,80	44,4	1,17	41626,03	36080,37	-0,24
47	20	338985	1220,41	122041,00	45826,90	44,3	1,22	55679,68	47047,31	-1,41

Figure B.1: Results achieved for the case of cooling the panels by plunging them directly into the water. Starting at 25°C.

Th (°C)	Tc (°C)	Energy disipated Cp(Th-Tc) (W/m²)	Time to cooling (s)	Efficiency lost over time	Time to heat (s)	Average temperature (°C)	Efficiency Improve (%)	Efficiency gained over time	Cicle time (s)	Net efficiency (%)
40	35	62775	19,62	1962,00	1027,59	37,8	4,14	4254,22	1047,21	2,19
40	30	125550	101,82	10182,00	3403,04	36,1	4,91	16691,91	3504,86	1,86
40	25	188325	330,70	33070,00	6611,55	34,5	5,63	37189,97	6942,25	0,59
40	20	251100	1212,83	121283,00	10417,90	33,1	6,26	65163,96	11630,73	-4,83

Figure B.2: Results achieved for the case of cooling the panels by plunging them directly into the water. Starting at 30°C.

Th (°C)	Tc (°C)	Energy disipated Cp(Th-Tc) (W/m²)	Time to cooling (s)	Efficiency lost over time	Time to heat (s)	Average temperature (°C)	Efficiency Improve (%)	Efficiency gained over time	Cicle time (s)	Net efficiency (%)
35	30	62775	31,82	3181,84	673,93	32,8	6,39	4306,41	705,75	1,59
35	25	125550	185,81	18581,30	2352,52	30,9	7,25	17044,01	2538,33	-0,61
35	20	188325	885,77	88576,70	4730,62	29,0	8,10	38318,02	5616,39	-8,95

Figure B.3: Results achieved for the case of cooling the panels by plunging them directly into the water. Starting at 35°C.

Th (°C)	Tc (°C)	Energy disipated Cp(Th-Tc) (W/m²)	Time to cooling (s)	Efficiency lost over time	Time to heat (s)	Average temperature (°C)	Efficiency Improve (%)	Efficiency gained over time	Cicle time (s)	Net efficiency (%)
30	25	62775	62,71	6270,54	502,3	27,7	8,69	4362,72	565,03	-3,38
30	20	125550	548,43	54843,2	1805,9	25,6	9,63	17390,72	2354,32	-15,91

Figure B.4: Results achieved for the case of cooling the panels by plunging them directly into the water. Starting at 40°C.

Th (°C)	Tc (°C)	Energy disipated Cp(Th-Tc) (W/m²)	Time to cooling (s)	Efficiency lost over time	Time to heat (s)	Average temperature (°C)	Efficiency Improve (%)	Efficiency gained over time	Cicle time (s)	Net efficiency (%)
25	20	62775	220,217	22021,7	400,6	22,6	10,98	4398,75	620,83	-28,39

Figure B.5: Results achieved for the case of cooling the panels by plunging them directly into the water. Starting at 47°C.

Panel temperature (˚C)	Increase in efficiency (%)	Output water temperature (˚C)	Heat flow	Water flow (m^3/s)	Power gained (W)	Power used (W)	Net energy (W)	Efficency (%)
46	0,45	32,5	43,576	0,001	0,84	7,05009	-6,21	-3,31
44	1,35	31,5	106,764	0,002	2,53	18,5527	-16,02	-8,54
42	2,25	30,5	169,952	0,003	4,22	31,8957	-27,68	-14,76
40	3,15	29,5	233,14	0,005	5,91	47,5592	-41,65	-22,21
38	4,05	28,5	296,328	0,007	7,59	66,2063	-58,61	-31,26
36	4,95	27,5	359,516	0,009	9,28	88,779	-79,50	-42,40
34	5,85	26,5	422,704	0,012	10,97	116,663	-105,69	-56,37
32	6,75	25,5	485,892	0,015	12,66	151,983	-139,33	-74,31
30	7,65	24,5	549,08	0,020	14,34	198,17	-183,83	-98,04

Figure B.6: Results achieved for the case of cooling the panels by pouring water over them.

Appendix C

Arduino code

```
    // This is the code used for data logging in the measurement setup
// of the Floating solar park module.

#include <SPI.h>
#include <SD.h>

//values that CAN be changed
bool outputtofile = true;
//if you want to output the measurement data to a file or not.
bool givetitle = false;
//if you want to give a title to the document or not.
int waittime = 500;
//number of milliseconds between measurements.
float voltmultiplier = 1;
//multiplies the measured voltage by this number. the voltage sensor
/ used in the prototype multiplies the actual voltage with (7/37).

//values that CAN NOT be changed
bool cardpresent = false;
  //tracks if a card is present or not
bool titlegiven = false;
  //tracks if a title is given or not
int mVperAmp = 100;
  // 185 for the 5 A, 100 for the 20 A, 66 for the 30 A.
int ACSoffset = 2500;
  //offset in millivolt for the ampmeter
const int chipSelect = 10;
  //which pin the sd card communicates to
String filename = "";
  //filename for the datalogging

// the setup routine runs once when you press reset:
void setup() {
  // initialize serial communication at 9600 bits per second:
  Serial.begin(9600);
    // set the builtin led to output, this will turn on when data is
    // being written to sd card
  pinMode(LED_BUILTIN, OUTPUT);
  if (outputtofile) {
    while (!cardpresent) {
        //if the card is not present, and a title must be given
      if (!SD.begin(chipSelect)) {
          //if beginning the SD card is not possible, print
          // error message
        Serial.println("Card failed, or not present, trying again in 5s");
          // don't do anything more:
        delay(5000);
      }
      else {
          //if sd card is found
        cardpresent = true;
        if (givetitle) {
            //if a title must be given ...
          Serial.println("card initialized. waiting for filename input");
          while (!titlegiven) {
              // wait for a serial data string to be present and set
              // that as title
            if (Serial.available()) {
              filename = String(Serial.readString());
              filename = filename + ".txt";
```

```
              titlegiven = true;
              Serial.println(filename);
            }
          }
        }
        else {
            // otherwise set "datalog.txt" as filename
          filename = String("datalog.txt");
          Serial.println("filename set to \"datalog.txt\" ");
          File datafile = SD.open(filename, FILE_WRITE);
          datafile.println("starting new measurement on this line");
          datafile.close();
        }
      }
    }
  } // end of setting up sd card
  // normalizing amp sensor
  int ACSoffset = analogRead(A1);
}

// the loop routine runs over and over again forever:
void loop() {
  int voltValue = analogRead(A0);
  float voltage = voltValue * (5.0 / 1023.0) * voltmultiplier;
  int ampValue = analogRead(A1);
  float ampvoltage = (ampValue / 1024.0) * 5000;
  float amp = ((ampvoltage - ACSoffset) / mVperAmp);

  if (outputtofile) {
    String datastring = String(voltage) + "," + String(amp) + "," + String(voltage
    File dataFile = SD.open(filename, FILE_WRITE);
    if (dataFile) {
      digitalWrite(LED_BUILTIN, HIGH);
      dataFile.println(datastring);
      Serial.println("printing " + String(datastring) + " to sd card");
      dataFile.close();
      digitalWrite(LED_BUILTIN, LOW);
    }
    else {
      Serial.println("error opening datalog.txt");
    }
  }
  else {
    Serial.print(voltage);
    Serial.print("\t");
    Serial.print(amp);
    Serial.print("\t");
    Serial.println(voltage * amp);
  }
  delay(waittime);
}
```

Appendix D

Project Management overview

D.1 Gantt diagrams

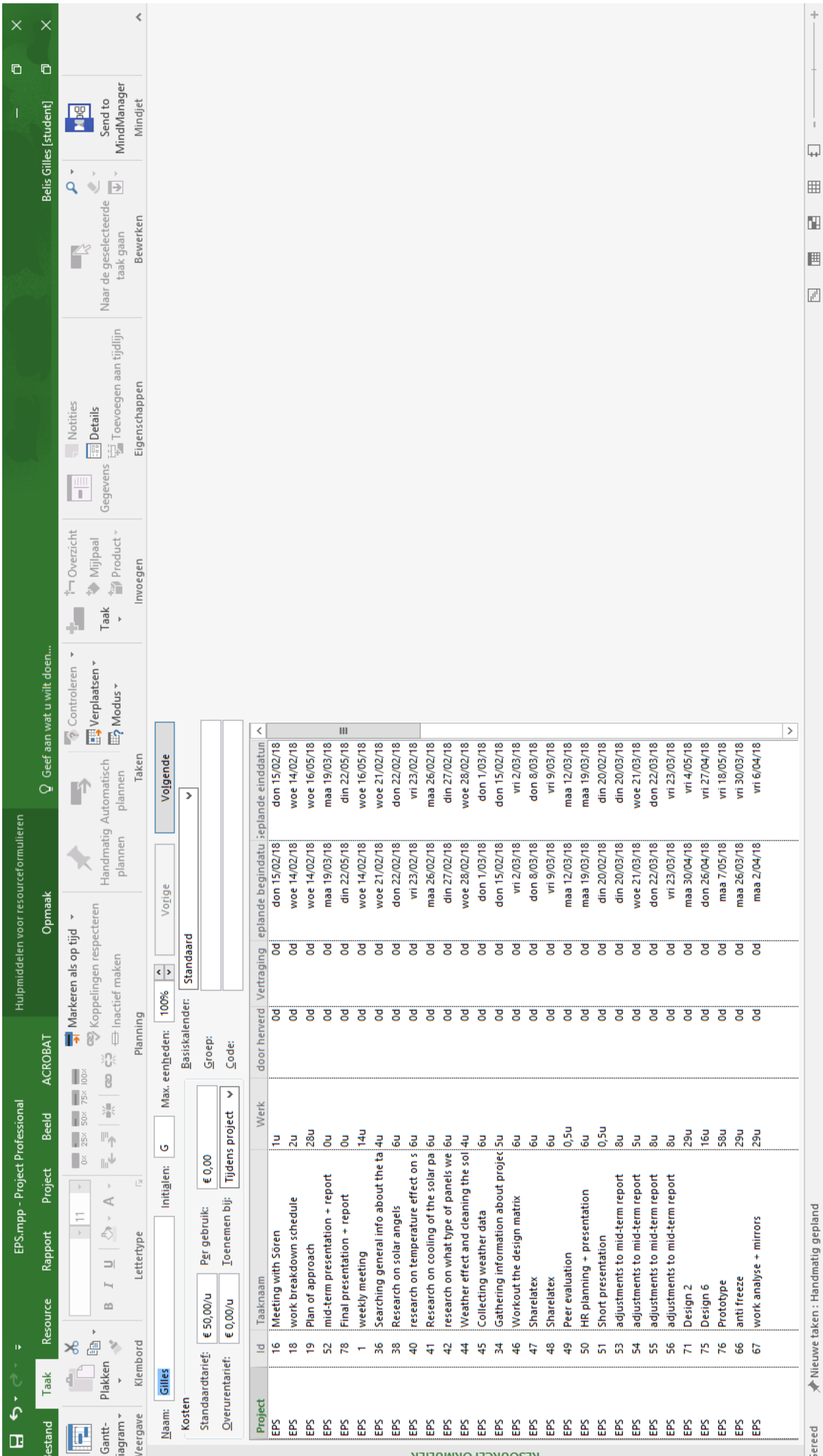
Id		Taakmodu	Taaknaam	Duur	Begindatum	Einddatum	Voorafgaande taken	Resourcenamen
1			**weekly meeting**	**66 dagen**	**woe 14/02/1**	**woe 16/05/1**		**Andrés;EPS Room[14];Gilles;Mathieu;Mikael;Pascal;Rick**
16			Meeting with Sören	1 uur	don 15/02/1	don 15/02/1		Andrés;Gilles;Mathieu;Mikael;Pascal;Rick;Sören
17			Powerpoint for first presentation	2 uur	woe 14/02/18	woe 14/02/18		Andrés;Pascal
18			work breakdown schedule	2 uur	woe 14/02/18	woe 14/02/18		Gilles;Office Powerpoint[1]
19			**Plan of approach**	**65,25 dagen**	**woe 14/02/1**	**woe 16/05/1**		**Gilles;ProjectManager[28]**
34			Gathering information about project	5 uur	don 15/02/18	don 15/02/18		Andrés;EPS Room[1];Gilles;Mathieu;Pascal;Rick
35			Firts presentation	0 dagen	vri 16/02/18	vri 16/02/18		Andrés;EPS Room[0];Mathieu;Mikael;Office Powerpoint[0
36			Searching general info about the task	5 uur	woe 21/02/18	woe 21/02/18		Andrés;EPS Room[1];Gilles;Mathieu;Pascal;Rick
37			Numerical simulation	6 uur	don 22/02/18	don 22/02/18		EPS Room[1];Rick
38			Research on solar angels	6 uur	don 22/02/18	don 22/02/18		Andrés;EPS Room[1];Gilles;Mathieu;Pascal
39			Numerical simulation	6 uur	vri 23/02/18	vri 23/02/18		EPS Room[1];Rick
40			research on temperature effect on solar panels	6 uur	vri 23/02/18	vri 23/02/18		Andrés;EPS Room[1];Gilles;Mathieu;Pascal
41			Research on cooling of the solar panels	6 uur	maa 26/02/18	maa 26/02/18		Andrés;EPS Room[1];Gilles;Mathieu;Pascal;Rick

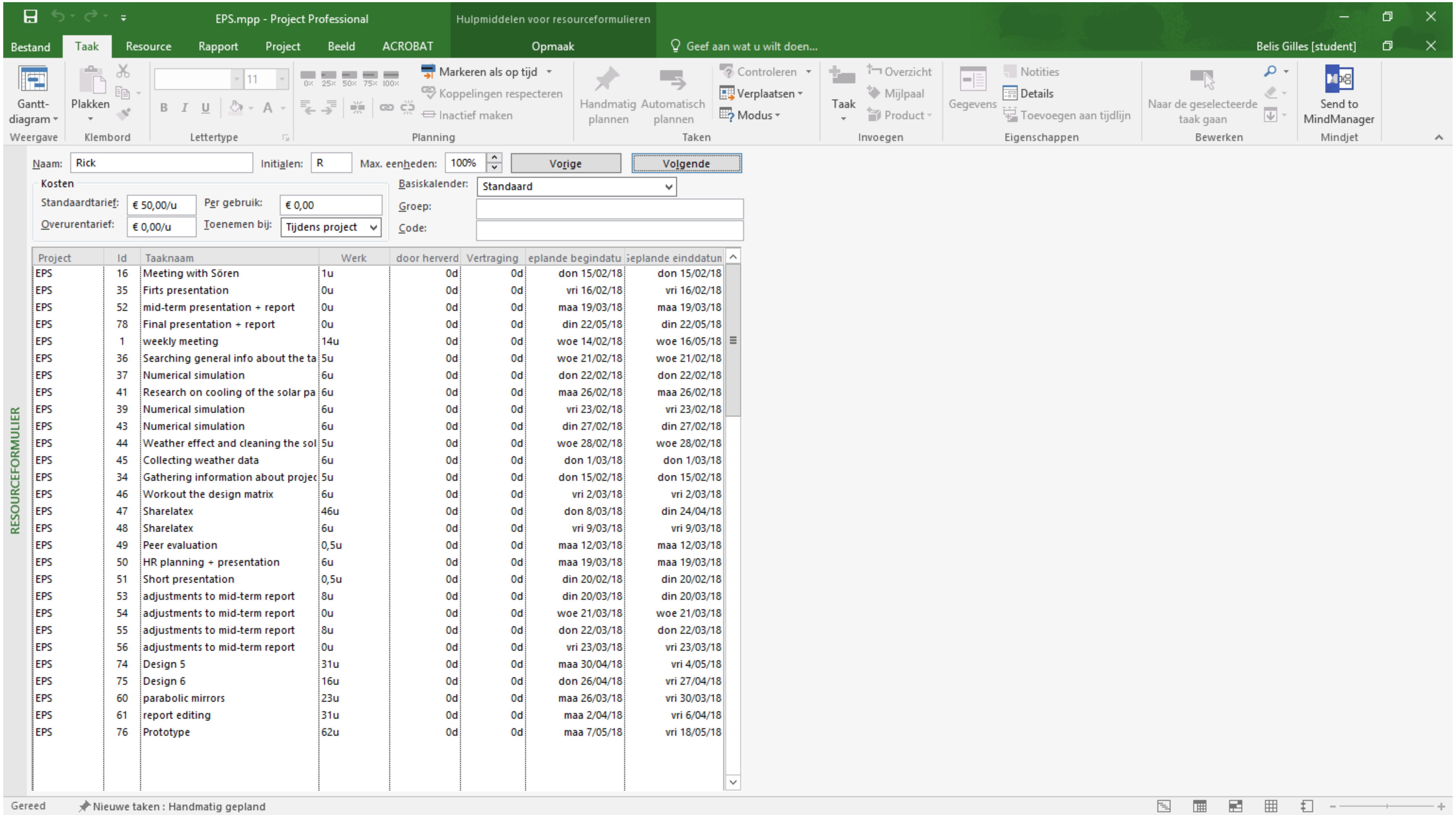
Id		Taakmodu	Taaknaam	Duur	Begindatum	Einddatum	Voorafgaande taken	Resourcenamen
42			research on what type of panels we use	6 uur	din 27/02/18	din 27/02/18		Andrés;EPS Room[1];Gilles;Mathieu;Pascal
43			Numerical simulation	6 uur	din 27/02/18	din 27/02/18		EPS Room[1];Rick
44			Weather effect and cleaning the solar panels	5 uur	woe 28/02/18	woe 28/02/18		Andrés;EPS Room[1];Gilles;Mathieu;Pascal;Rick
45			Collecting weather data	6 uur	don 1/03/18	don 1/03/18		Andrés;EPS Room[1];Gilles;Mathieu;Pascal;Rick
46			Workout the design matrix	6 uur	vri 2/03/18	vri 2/03/18		Andrés;EPS Room[1];Gilles;Mathieu;Pascal;Rick
47			Sharelatex	126 uur	don 8/03/18	woe 16/05/1		Andrés;EPS Room[1];Gilles;Latex[1];Mathieu;Pascal;Rick
48			Sharelatex	6 uur	vri 9/03/18	vri 9/03/18		Andrés;EPS Room[1];Gilles;Latex[1];Mathieu;Pascal;Rick
49			Peer evaluation	0,5 uur	maa 12/03/1	maa 12/03/1		Andrés;EPS Room[1];Gilles;Mathieu;Pascal;Rick
50			HR planning + presentation	6 uur	maa 19/03/18	maa 19/03/18		Gilles;Rick;Andrés;Mathieu;Pascal;ProjectManager[1];EPS Room[1];Excel office
51			Short presentation	0,5 uur	din 20/02/18	din 20/02/18		Andrés;EPS Room[1];Gilles;Mathieu;Pascal;ProjectManage
52			mid-term presentation + report	0 dagen	maa 19/03/18	maa 19/03/18	50	Andrés;EPS Room[0];Gilles;Latex[0];Mathieu;Mikael;Office Powerpoint[0];Pascal;Rick
53			adjustments to mid-term report	8 uur	din 20/03/18	din 20/03/18		Andrés;EPS Room[1];Gilles;Latex[1];Mathieu;Pascal;Rick
54			adjustments to mid-term report	5 uur	woe 21/03/18	woe 21/03/18		Andrés;EPS Room[1];Gilles;Latex[1];Mathieu;Pascal;Rick

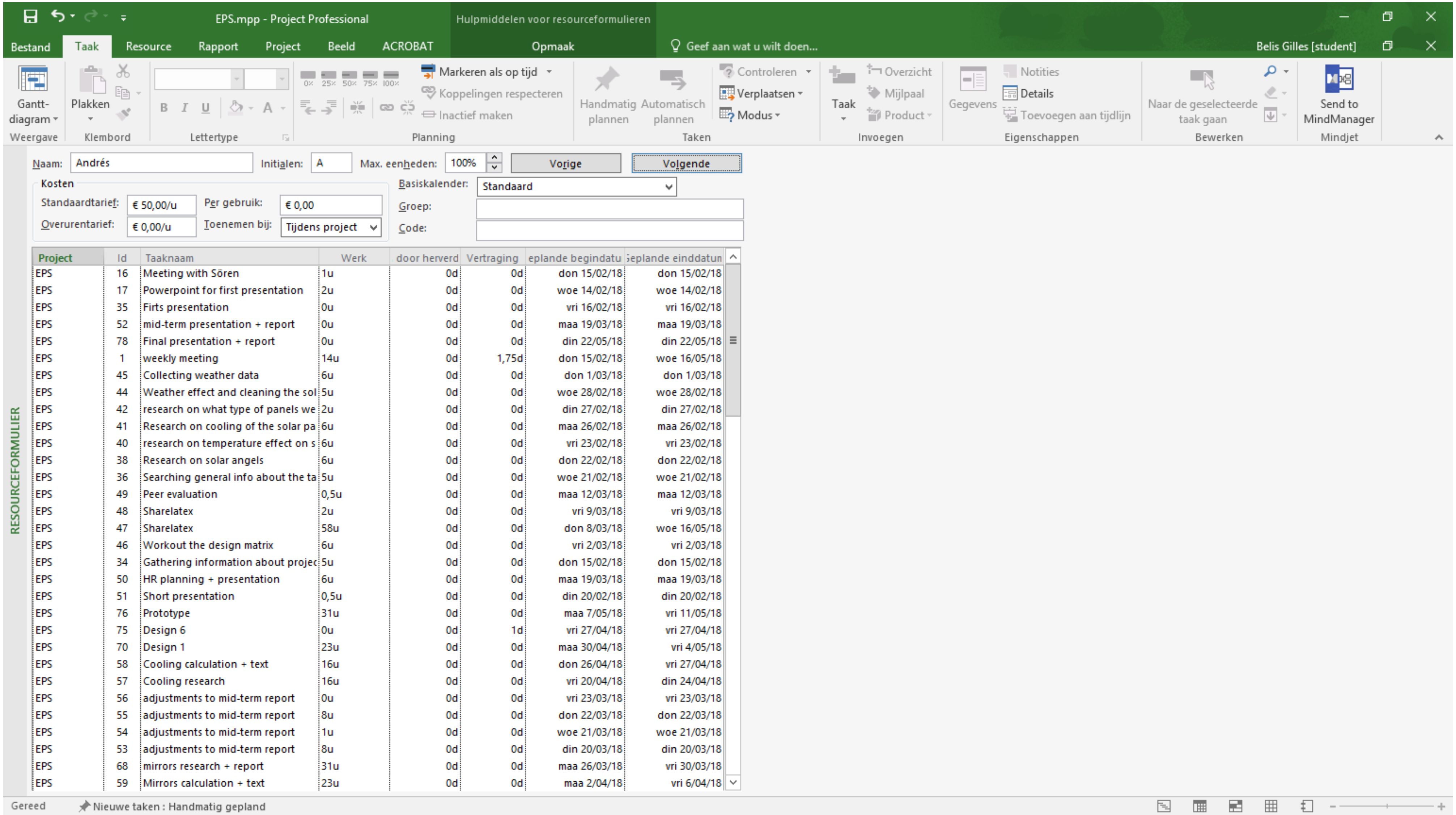
Id		Taakmodu	Taaknaam	Duur	Begindatum	Einddatum	Voorafgaande taken	Resourcenamen
55			adjustments to mid-term report	8 uur	don 22/03/18	don 22/03/18		Andrés;EPS Room[1];Gilles;Latex[1];Mathieu;Pascal;Rick
56			adjustments to mid-term report	8 uur	vri 23/03/18	vri 23/03/18		Andrés;EPS Room[1];Gilles;Latex[1];Mathieu;Pascal;Rick
57			Cooling research	24 uur	vri 20/04/18	din 24/04/18		Andrés[92%];EPS Room[1]
58			Cooling calculation + text	16 uur	don 26/04/18	vri 27/04/18		Andrés;EPS Room[1]
59			Mirrors calculation + text	40 uur	maa 2/04/18	vri 6/04/18		Andrés;EPS Room[1]
60			parabolic mirrors	40 uur	maa 26/03/1	vri 30/03/18		EPS Room[1];Rick
61			report editing	40 uur	maa 2/04/18	vri 6/04/18		EPS Room[1];Rick
62			weather effect on panels	40 uur	maa 26/03/18	vri 30/03/18		EPS Room[1];Pascal
63			locations in the world	40 uur	maa 2/04/18	vri 6/04/18		EPS Room[1];Pascal
64			locations in the world	40 uur	maa 26/03/18	vri 30/03/18		EPS Room[1];Mathieu
65			electronic components	40 uur	maa 2/04/18	vri 6/04/18		EPS Room[1];Mathieu
66			anti freeze	40 uur	maa 26/03/1	vri 30/03/18		EPS Room[1];Gilles
67			work analyse + mirrors	40 uur	maa 2/04/18	vri 6/04/18		EPS Room[1];Gilles
68			mirrors research + report	40 uur	maa 26/03/18	vri 30/03/18		Andrés;EPS Room[1]
69			Mirrors research					

Id		Taakmodu	Taaknaam	Duur	Begindatum	Einddatum	Voorafgaande taken	Resourcenamen
70			Design 1	40 uur	maa 30/04/1	vri 4/05/18		Andrés;EPS Room[1]
71			Design 2	40 uur	maa 30/04/1	vri 4/05/18		EPS Room[1];Gilles
72			Design 3	40 uur	maa 30/04/1	vri 4/05/18		EPS Room[1];Mathieu
73			Design 4	40 uur	maa 30/04/1	vri 4/05/18		EPS Room[1];Pascal
74			Design 5	40 uur	maa 30/04/1	vri 4/05/18		EPS Room[1];Rick
75			Design 6	16 uur	don 26/04/1	vri 27/04/18		Andrés;EPS Room[1];Gilles;Mathieu;Pascal;Rick
76			Prototype	80 uur	maa 7/05/18	vri 18/05/18		Andrés;EPS Room[1];Gilles;Mathieu;Pascal;Rick
77			<Nieuwe taak>					
78			Final presentation + report	0 dagen	din 22/05/18	din 22/05/18		Andrés;EPS Room[0];Gilles;Latex[0];Mathieu;Mikael;Office

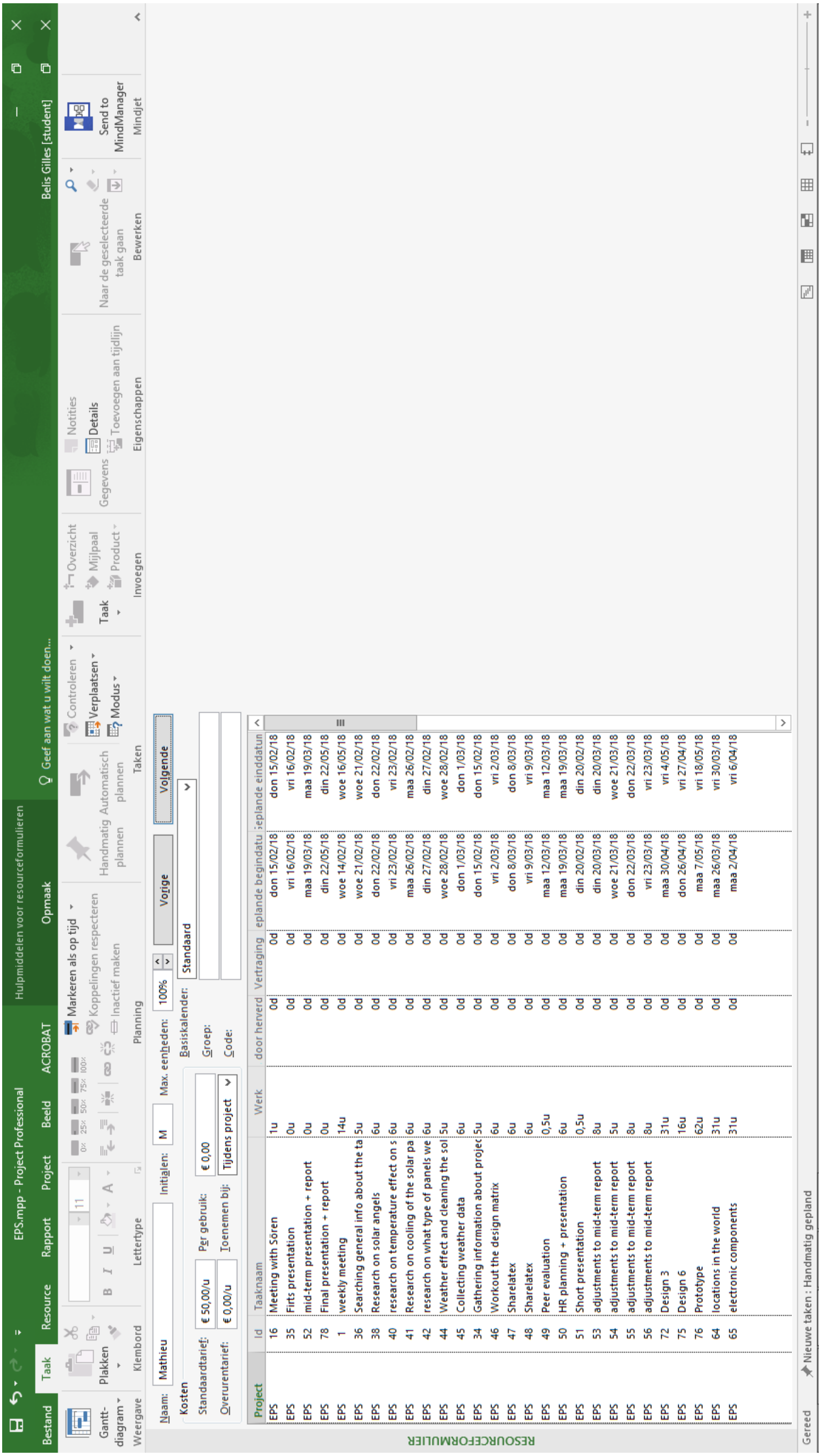
D.2 Individual Worksheets




EPS.mpp - Project Professional
Hulpmiddelen voor resourceformulieren
Bestand Taak Resource Rapport Project Beeld ACROBAT Opmaak
Geef aan wat u wilt doen...
Belis Gilles [student]
Gantt-diagram Plakken Markeren als op tijd Koppelingen respecteren Inactief maken Handmatig plannen Automatisch plannen Controleren Verplaatsen Modus Taak Overzicht Mijlpaal Product Gegevens Notities Details Toevoegen aan tijdlijn Naar de geselecteerde taak gaan Send to MindManager
Weergave Klembord Lettertype Planning Taken Invoegen Eigenschappen Bewerken Mindjet
RESOURCEFORMULIER
Naam: Rick Initialen: R Max. eenheden: 100% Vorige Volgende
Kosten
Standaardtarief: € 50,00/u Per gebruik: € 0,00
Overurentarief: € 0,00/u Toenemen bij: Tijdens project
Basiskalender: Standaard
Groep:
Code:
Project | Id | Taaknaam | Werk | door herverd | Vertraging | eplande begindatu | eplande einddatun
EPS | 16 | Meeting with Sören | 1u | 0d | 0d | don 15/02/18 | don 15/02/18
EPS | 35 | Firts presentation | 0u | 0d | 0d | vri 16/02/18 | vri 16/02/18
EPS | 52 | mid-term presentation + report | 0u | 0d | 0d | maa 19/03/18 | maa 19/03/18
EPS | 78 | Final presentation + report | 0u | 0d | 0d | din 22/05/18 | din 22/05/18
EPS | 1 | weekly meeting | 14u | 0d | 0d | woe 14/02/18 | woe 16/05/18
EPS | 36 | Searching general info about the ta | 5u | 0d | 0d | woe 21/02/18 | woe 21/02/18
EPS | 37 | Numerical simulation | 6u | 0d | 0d | don 22/02/18 | don 22/02/18
EPS | 41 | Research on cooling of the solar pa | 6u | 0d | 0d | maa 26/02/18 | maa 26/02/18
EPS | 39 | Numerical simulation | 6u | 0d | 0d | vri 23/02/18 | vri 23/02/18
EPS | 43 | Numerical simulation | 6u | 0d | 0d | din 27/02/18 | din 27/02/18
EPS | 44 | Weather effect and cleaning the sol | 5u | 0d | 0d | woe 28/02/18 | woe 28/02/18
EPS | 45 | Collecting weather data | 6u | 0d | 0d | don 1/03/18 | don 1/03/18
EPS | 34 | Gathering information about projec | 5u | 0d | 0d | don 15/02/18 | don 15/02/18
EPS | 46 | Workout the design matrix | 6u | 0d | 0d | vri 2/03/18 | vri 2/03/18
EPS | 47 | Sharelatex | 46u | 0d | 0d | don 8/03/18 | din 24/04/18
EPS | 48 | Sharelatex | 6u | 0d | 0d | vri 9/03/18 | vri 9/03/18
EPS | 49 | Peer evaluation | 0,5u | 0d | 0d | maa 12/03/18 | maa 12/03/18
EPS | 50 | HR planning + presentation | 6u | 0d | 0d | maa 19/03/18 | maa 19/03/18
EPS | 51 | Short presentation | 0,5u | 0d | 0d | din 20/02/18 | din 20/02/18
EPS | 53 | adjustments to mid-term report | 8u | 0d | 0d | din 20/03/18 | din 20/03/18
EPS | 54 | adjustments to mid-term report | 0u | 0d | 0d | woe 21/03/18 | woe 21/03/18
EPS | 55 | adjustments to mid-term report | 8u | 0d | 0d | don 22/03/18 | don 22/03/18
EPS | 56 | adjustments to mid-term report | 0u | 0d | 0d | vri 23/03/18 | vri 23/03/18
EPS | 74 | Design 5 | 31u | 0d | 0d | maa 30/04/18 | vri 4/05/18
EPS | 75 | Design 6 | 16u | 0d | 0d | don 26/04/18 | vri 27/04/18
EPS | 60 | parabolic mirrors | 23u | 0d | 0d | maa 26/03/18 | vri 30/03/18
EPS | 61 | report editing | 31u | 0d | 0d | maa 2/04/18 | vri 6/04/18
EPS | 76 | Prototype | 62u | 0d | 0d | maa 7/05/18 | vri 18/05/18
Gereed
Nieuwe taken : Handmatig gepland



Project	Id	Taaknaam	Werk	door herverd	Vertraging	eplande begindatu	eplande einddatun
EPS	16	Meeting with Sören	1u	0d	0d	don 15/02/18	don 15/02/18
EPS	17	Powerpoint for first presentation	2u	0d	0d	woe 14/02/18	woe 14/02/18
EPS	35	Firts presentation	0u	0d	0d	vri 16/02/18	vri 16/02/18
EPS	52	mid-term presentation + report	0u	0d	0d	maa 19/03/18	maa 19/03/18
EPS	78	Final presentation + report	0u	0d	0d	din 22/05/18	din 22/05/18
EPS	1	weekly meeting	14u	0d	1,75d	don 15/02/18	woe 16/05/18
EPS	45	Collecting weather data	6u	0d	0d	don 1/03/18	don 1/03/18
EPS	44	Weather effect and cleaning the sol	5u	0d	0d	woe 28/02/18	woe 28/02/18
EPS	42	research on what type of panels we	2u	0d	0d	din 27/02/18	din 27/02/18
EPS	41	Research on cooling of the solar pa	6u	0d	0d	maa 26/02/18	maa 26/02/18
EPS	40	research on temperature effect on s	6u	0d	0d	vri 23/02/18	vri 23/02/18
EPS	38	Research on solar angels	6u	0d	0d	don 22/02/18	don 22/02/18
EPS	36	Searching general info about the ta	5u	0d	0d	woe 21/02/18	woe 21/02/18
EPS	49	Peer evaluation	0,5u	0d	0d	maa 12/03/18	maa 12/03/18
EPS	48	Sharelatex	2u	0d	0d	vri 9/03/18	vri 9/03/18
EPS	47	Sharelatex	58u	0d	0d	don 8/03/18	woe 16/05/18
EPS	46	Workout the design matrix	6u	0d	0d	vri 2/03/18	vri 2/03/18
EPS	34	Gathering information about projec	5u	0d	0d	don 15/02/18	don 15/02/18
EPS	50	HR planning + presentation	6u	0d	0d	maa 19/03/18	maa 19/03/18
EPS	51	Short presentation	0,5u	0d	0d	din 20/02/18	din 20/02/18
EPS	76	Prototype	31u	0d	0d	maa 7/05/18	vri 11/05/18
EPS	75	Design 6	0u	0d	1d	vri 27/04/18	vri 27/04/18
EPS	70	Design 1	23u	0d	0d	maa 30/04/18	vri 4/05/18
EPS	58	Cooling calculation + text	16u	0d	0d	don 26/04/18	vri 27/04/18
EPS	57	Cooling research	16u	0d	0d	vri 20/04/18	din 24/04/18
EPS	56	adjustments to mid-term report	0u	0d	0d	vri 23/03/18	vri 23/03/18
EPS	55	adjustments to mid-term report	8u	0d	0d	don 22/03/18	don 22/03/18
EPS	54	adjustments to mid-term report	1u	0d	0d	woe 21/03/18	woe 21/03/18
EPS	53	adjustments to mid-term report	8u	0d	0d	din 20/03/18	din 20/03/18
EPS	68	mirrors research + report	31u	0d	0d	maa 26/03/18	vri 30/03/18
EPS	59	Mirrors calculation + text	23u	0d	0d	maa 2/04/18	vri 6/04/18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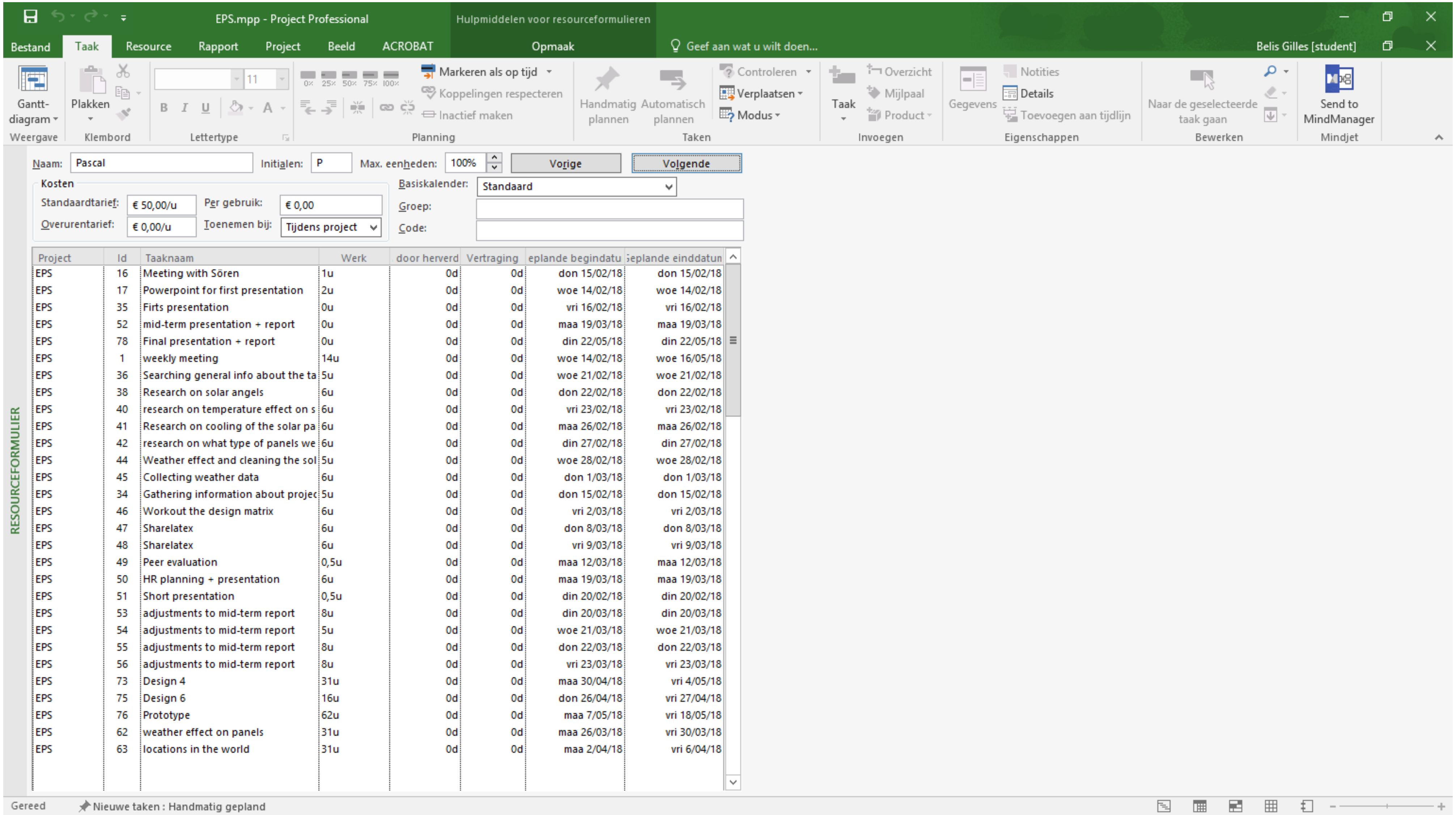
Weergave Klembord Lettertype Planning Taken Invoegen Eigenschappen Bewerken Mindjet
Naam: Mathieu Initialen: M Max. eenheden: 100% Vorige Volgende
Kosten
Standaardtarief: € 50,00/u Per gebruik: € 0,00
Overurentarief: € 0,00/u Toenemen bij: Tijdens project
Basiskalender: Standaard
Groep:
Code:
RESOURCEFORMULIER
Project | Id | Taaknaam | Werk | door herverd | Vertraging | eplande begindatu | eplande einddatun
EPS | 16 | Meeting with Sören | 1u | 0d | 0d | don 15/02/18 | don 15/02/18
EPS | 35 | Firts presentation | 0u | 0d | 0d | vri 16/02/18 | vri 16/02/18
EPS | 52 | mid-term presentation + report | 0u | 0d | 0d | maa 19/03/18 | maa 19/03/18
EPS | 78 | Final presentation + report | 0u | 0d | 0d | din 22/05/18 | din 22/05/18
EPS | 1 | weekly meeting | 14u | 0d | 0d | woe 14/02/18 | woe 16/05/18
EPS | 36 | Searching general info about the ta | 5u | 0d | 0d | woe 21/02/18 | woe 21/02/18
EPS | 38 | Research on solar angels | 6u | 0d | 0d | don 22/02/18 | don 22/02/18
EPS | 40 | research on temperature effect on s | 6u | 0d | 0d | vri 23/02/18 | vri 23/02/18
EPS | 41 | Research on cooling of the solar pa | 6u | 0d | 0d | maa 26/02/18 | maa 26/02/18
EPS | 42 | research on what type of panels we | 6u | 0d | 0d | din 27/02/18 | din 27/02/18
EPS | 44 | Weather effect and cleaning the sol | 5u | 0d | 0d | woe 28/02/18 | woe 28/02/18
EPS | 45 | Collecting weather data | 6u | 0d | 0d | don 1/03/18 | don 1/03/18
EPS | 34 | Gathering information about projec | 5u | 0d | 0d | don 15/02/18 | don 15/02/18
EPS | 46 | Workout the design matrix | 6u | 0d | 0d | vri 2/03/18 | vri 2/03/18
EPS | 47 | Sharelatex | 6u | 0d | 0d | don 8/03/18 | don 8/03/18
EPS | 48 | Sharelatex | 6u | 0d | 0d | vri 9/03/18 | vri 9/03/18
EPS | 49 | Peer evaluation | 0,5u | 0d | 0d | maa 12/03/18 | maa 12/03/18
EPS | 50 | HR planning + presentation | 6u | 0d | 0d | maa 19/03/18 | maa 19/03/18
EPS | 51 | Short presentation | 0,5u | 0d | 0d | din 20/02/18 | din 20/02/18
EPS | 53 | adjustments to mid-term report | 8u | 0d | 0d | din 20/03/18 | din 20/03/18
EPS | 54 | adjustments to mid-term report | 5u | 0d | 0d | woe 21/03/18 | woe 21/03/18
EPS | 55 | adjustments to mid-term report | 8u | 0d | 0d | don 22/03/18 | don 22/03/18
EPS | 56 | adjustments to mid-term report | 8u | 0d | 0d | vri 23/03/18 | vri 23/03/18
EPS | 72 | Design 3 | 31u | 0d | 0d | maa 30/04/18 | vri 4/05/18
EPS | 75 | Design 6 | 16u | 0d | 0d | don 26/04/18 | vri 27/04/18
EPS | 76 | Prototype | 62u | 0d | 0d | maa 7/05/18 | vri 18/05/18
EPS | 64 | locations in the world | 31u | 0d | 0d | maa 26/03/18 | vri 30/03/18
EPS | 65 | electronic components | 31u | 0d | 0d | maa 2/04/18 | vri 6/04/18
Gereed
Nieuwe taken : Handmatig gepland



Project	Id	Taaknaam	Werk	door herverd	Vertraging	eplande begindatu	eplande einddatun
EPS	16	Meeting with Sören	1u	0d	0d	don 15/02/18	don 15/02/18
EPS	17	Powerpoint for first presentation	2u	0d	0d	woe 14/02/18	woe 14/02/18
EPS	35	Firts presentation	0u	0d	0d	vri 16/02/18	vri 16/02/18
EPS	52	mid-term presentation + report	0u	0d	0d	maa 19/03/18	maa 19/03/18
EPS	78	Final presentation + report	0u	0d	0d	din 22/05/18	din 22/05/18
EPS	1	weekly meeting	14u	0d	0d	woe 14/02/18	woe 16/05/18
EPS	36	Searching general info about the ta	5u	0d	0d	woe 21/02/18	woe 21/02/18
EPS	38	Research on solar angels	6u	0d	0d	don 22/02/18	don 22/02/18
EPS	40	research on temperature effect on s	6u	0d	0d	vri 23/02/18	vri 23/02/18
EPS	41	Research on cooling of the solar pa	6u	0d	0d	maa 26/02/18	maa 26/02/18
EPS	42	research on what type of panels we	6u	0d	0d	din 27/02/18	din 27/02/18
EPS	44	Weather effect and cleaning the sol	5u	0d	0d	woe 28/02/18	woe 28/02/18
EPS	45	Collecting weather data	6u	0d	0d	don 1/03/18	don 1/03/18
EPS	34	Gathering information about projec	5u	0d	0d	don 15/02/18	don 15/02/18
EPS	46	Workout the design matrix	6u	0d	0d	vri 2/03/18	vri 2/03/18
EPS	47	Sharelatex	6u	0d	0d	don 8/03/18	don 8/03/18
EPS	48	Sharelatex	6u	0d	0d	vri 9/03/18	vri 9/03/18
EPS	49	Peer evaluation	0,5u	0d	0d	maa 12/03/18	maa 12/03/18
EPS	50	HR planning + presentation	6u	0d	0d	maa 19/03/18	maa 19/03/18
EPS	51	Short presentation	0,5u	0d	0d	din 20/02/18	din 20/02/18
EPS	53	adjustments to mid-term report	8u	0d	0d	din 20/03/18	din 20/03/18
EPS	54	adjustments to mid-term report	5u	0d	0d	woe 21/03/18	woe 21/03/18
EPS	55	adjustments to mid-term report	8u	0d	0d	don 22/03/18	don 22/03/18
EPS	56	adjustments to mid-term report	8u	0d	0d	vri 23/03/18	vri 23/03/18
EPS	73	Design 4	31u	0d	0d	maa 30/04/18	vri 4/05/18
EPS	75	Design 6	16u	0d	0d	don 26/04/18	vri 27/04/18
EPS	76	Prototype	62u	0d	0d	maa 7/05/18	vri 18/05/18
EPS	62	weather effect on panels	31u	0d	0d	maa 26/03/18	vri 30/03/18
EPS	63	locations in the world	31u	0d	0d	maa 2/04/18	vri 6/04/18