UNIVERSIDAD DE VALLADOLID

ESCUELA DE INGENIERIAS INDUSTRIALES

Grado en Ingeniería Eléctrica

Planta fotovoltaica flotante

Autor:

Martín Delgado, Carlos

Responsable de Intercambio en la Uva:

Santiago Cáceres Gómez

Universidad de destino:

Novia University of Applied Sciences

Valladolid, Mayo 2019

TFG REALIZADO EN PROGRAMA DE INTERCAMBIO

TÍTULO: Floating solar panel park

ALUMNO: Carlos Martín Delgado

FECHA: 14 de mayo de 2019

CENTRO: Novia University of Applied Sciences

TUTOR: Mikael Ehrs

Resumen del trabajo:

El objetivo de este proyecto era proponer un diseño de una planta fotovoltaica flotante no solo funcional, sino también económicamente rentable en un país con unas condiciones climáticas adversas para la energía solar como es Finlandia.

En esta memoria se pueden encontrar los principales hallazgos en múltiples campos como localización, tipos de paneles, diseño de la estructura flotante o técnicas para mejorar el rendimiento de los paneles. A continuación se presenta un diseño final al que se ha llegado mediante un proceso iterativo en el que se descartan las opciones que presentan mayores complicaciones o son sencillamente inviables. En la parte final, se exponen un estudio económico y un estudio medioambiental que concluyen que el diseño es viable en ambos aspectos. Por tanto, la energía fotovoltaica instalada en la superficie de lagos puede ser de ayuda en la transición a un modelo energético limpio y renovable en Finlandia.

Palabras clave:

Fotovoltaica, flotante, solar, renovable, Finlandia

Floating Solar Panel Park

Final Project Report

Floating Ideas Team

Team Members:

Carlos Martin Delgado, Laura Ripoll Albaladejo, Stephan Fischer,
Elizabeth Larsen, Amber Kauppila

Novia University of Applied Sciences
European Project Semester

May 14, 2019

Abstract

This Final Report is the culmination of a four month long design study on floating solar panel park feasibility in Vaasa, Finland. The *Floating Ideas Team* was tasked with coming up with a design that would not only work, but also make a profit. The team focused a lot of time on initial research, an iterative design process, and experiments to gather information that could not be found during the research phase.

In this report, one can expect to find the major findings from research in many different areas such as location, panel design, flotation design, cooling techniques, and efficiency adding techniques. The first takeaway is that implementing floating solar parks in Finland would require adding efficiency techniques such as mirrors or concentrators. Second, how the panels are placed means a lot in a location so far north. Placing the panels far away from each other and horizontally will reduce the negative impact of shadows. And third, the rotation of the structure is important in increasing efficiency. Multiple axis tracking is not necessary, but tracking in the vertical axis can add a 50% increase in power generated.

This research then lead into the defining of four initial designs which were eventually paired down into one. The largest factors leading to the change in design were the combination of rotation and anchoring methods, the flotation structure, and the structure required hold the panel modules together. In the end, the final design is a modular circular design with panels and mirrors to help add efficiency, approximately 37%.

From there, an economic and environmental feasibility study was done and for both, this design was deemed feasible for Finland. With the design, detailed in this report, it would be possible to implement this and make a profit off of it, leading the team to believe that this should be implemented in places looking for alternatives for renewable energy production.

Table of Contents

List of Figures

List of Tables

1. Introduction

1.1 European Project Semester (EPS)

The European Project Semester (EPS) program is offered in eighteen universities throughout Europe and is a one semester project-based learning program designed for engineering students. Throughout the duration of 15 weeks, multinational teams are to work on an assigned project subject. This program allows students to improve their intercultural communication and teamwork skills while being challenged to solve real multidisciplinary problems.

For this report, the EPS is hosted at Novia University of Applied Sciences. The *Floating Ideas Team* has been assigned to the Floating Solar Panel Project to investigate the feasibility of a floating solar panel park in Finland. An introduction to the project, objectives, and more detailed information about the project and end results will be elaborated in the report.

1.2 The Floating Ideas Team

The *Floating Ideas Team* is composed of five team members from different nationalities and fields of study. An introduction of each team member is given below.

Carlos Martin Delgado

I am an electrical engineering student at Valladolid College of Industrial Engineering. I have taken this EPS as a way to do my Final Degree Project at my university. My field of study is electricity in every phase: generation, transportation and use of it.

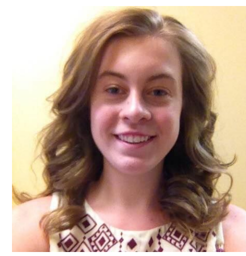
Laura Ripoll Albaladejo

My name is Laura Ripoll and I am from Sitges, a nice town near Barcelona. I study Mechanical Engineering in UPC Vilanova. After this project I will get my degree and I am looking forward to work on new sustainable and ecological projects.

Stephan Fischer

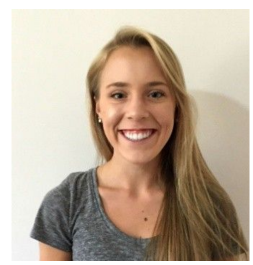
My name is Stephan Fischer from Kiel, Germany and I am earning my Bachelor's Degree in International Sales and Purchase Engineering. After the mechanical engineering fundamentals my degree program focuses on strategic and operational activities in the commercial sector.

Elizabeth Larsen



My name is Elizabeth Larsen. I study Civil, Environmental, and Sustainable Engineering. I am originally from Minnesota, but study at South Dakota School of Mines and Technology in Rapid City, South Dakota. I will be earning my Bachelor's Degree after the completion of this project.

Amber Kauppila



My name is Amber Kauppila and I am earning my Bachelor's Degree in Environmental Engineering. I am from Marquette, Michigan in the United States. Major focuses in my studies include waste to energy technology, sustainability, and remediation.

1.3 Introduction to the Project

The main content of the EPS program is the Floating Solar Panel Park project performed by the *Floating Ideas Team* throughout the semester. In addition to the project, the EPS program consists of supplement courses focused on teaching and improving technical, teamwork, and cross-cultural skills. The Project Management course concepts have been deeply integrated into the project work, project planning, time scheduling, budgeting, and risk assessment done by the team. An overview of the group work and practical tasks completed by the team is discussed in the Project Management Review section of the report.

A brief introduction to project objectives and project goals are discussed below. The research, simulation, and testing have been conducted over the semester in reference to the main interested party Wärtsilä. Other interested parties could include energy companies, and countries with low solar radiation.

1.3.1 Wärtsilä and The Customer

Wärtsilä is a Finnish company that was founded in 1834 with locations in Helsinki, Vaasa, Turku, and other European locations. Wärtsilä is a world leader in smart technologies and product lifecycle solutions for the marine and energy businesses. The goal of Wärtsilä is to sustainably meet the world's increasing energy demand through maximizing the environmental and economic performance of customers vessels and power plants (Wärtsilä, 2019). The *Floating Ideas Team* is fortunate to have Sören Hedvik, a current employee of Wärtsilä and sustainability enthusiast, to serve as a contact for the company and to help assist with the Floating Solar Panel Park project.

1.3.2 Project Scope

Floating solar panels are an emerging technology that is becoming increasingly popular amongst countries that are shifting to renewable energy options. As the material for solar technology is rapidly dropping in price level and developing worldwide, it is becoming possible to engineer the technology to make it feasible for locations with low solar energy potential. Due to the country's northern location, Finland is currently considered a country with low solar energy potential. However, as a result of Finland's cooler climate and landscape with over 180,000 lakes, floating solar technology still has the potential to be feasible in Finland.

The purpose of the Floating Solar Panel Park project is to determine, and verify the feasibility of floating solar technology in Finland. The project will design and a floating solar panel park that will be analyzed in terms of its final energy estimation, its economic feasibility, ant its environmental impact. The project will estimate the yearly power output and efficiency of the panels in regards to interested parties such as energy companies and other countries with low solar energy potential. These concepts will be further built upon throughout the project through research, simulation, and testing.

1.3.3 Mission and Vision Statements

The mission statement for the project is as follows:

"Create an economically, socially, and environmentally feasible floating solar energy source for Northern Europe first concentrated in Vaasa, Finland and then extend it to other locations with similar latitudes."

The vision statement for the project is as follows:

"Design a sustainable and economically successful floating solar park technology that is adaptable for areas that are not yet energy efficient in reference to solar energy."

2. Background Information and Research

Solar photovoltaic (PV) is a type of renewable, green technology that directly transform solar energy into electrical energy. The sun is a powerful energy source that has the ability to meet the global energy demands of Earth for an entire year with only an hour of sunlight. However, solar energy technology by today's standards is only able to utilize 0.001% of the energy given off by the sun (Oni, B., 2017). By effectively and efficiently harnessing the sun's radiation, solar PV systems present unique advantages and have a large potential to become an advantageous, renewable, and clean energy source.

2.1 How Solar Panels Work

Solar PV systems work by absorbing photons of light and releasing and separating electrons from their atoms. This physical and chemical phenomenon is called the photoelectric effect. Smaller units called PV cells contained in the solar panel are responsible for directly converting the energy of light into direct current (DC) electricity by capturing the free electrons (Knier, 2008). The DC electricity produced from solar panels must be converted into a more stable, and safer alternating current (AC) electricity by a PV inverter before use in a national or local grid. Figure 1 below shows a schematic of the operation of a basic PV cell.

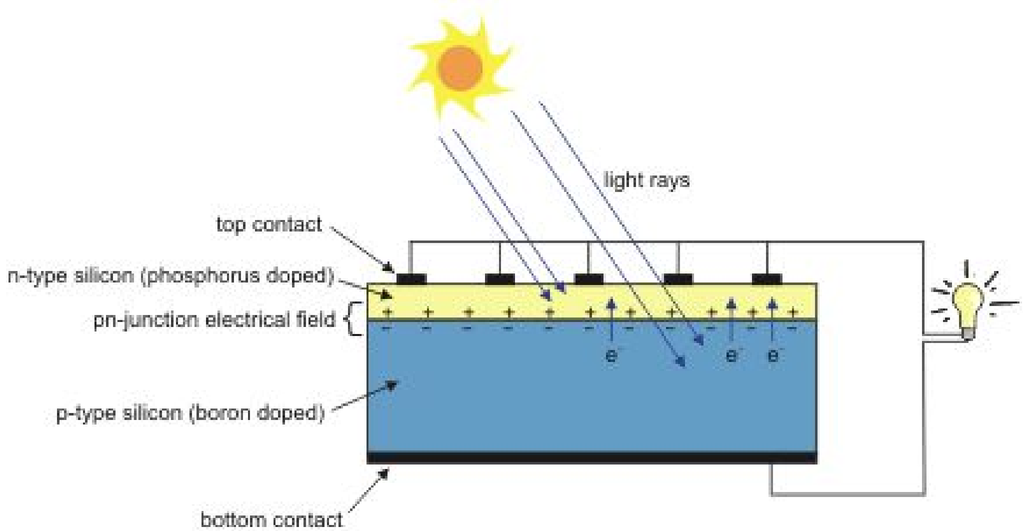


Figure 1. *Diagram illustrating the operation of a PV cell (Lighting Research Center, 2006).*

PV cells are composed of specially treated semiconductor material that share properties of both metal and insulators in order to convert sunlight into electricity. Light that is absorbed by a semiconductor is transferred as energy to electrons. This allows the electrons to freely flow through the material as electrical current. The direction of electron flow is controlled by the positively and negatively charged electric fields in the PV cells. By drawing the current off of the PV cell, the power produced by the solar cell can be used for external use (Kneir, 2008).

Silicon is the most common semiconductor material used in solar cells. Infact, ninety percent of solar panels sold today use silicon as a semiconductor material (Solar Energy Technologies Office, 2013). Silicon's marketability is contributed to it's crystal lattice structure of the atom that makes it capable of providing solar cells with a higher efficiency, lower cost, and a longer lifetime. Silicon is doped with phosphorus resulting in n-type silicon, and doped with boron resulting in p-type silicon to increase the conductivity of it's crystal lattice. The increase in conductivity helps to move electrons across the positive-negative junction and create electric current flow and voltage in the PV cell, thus, producing power. Other semiconductor materials used in solar cells include thin-film photovoltaics, organic photovoltaics and concentration photovoltaics (Solar Energy Technologies Office, 2013).

An assembly of PV cells electrically connected together form a photovoltaic module, also known as a solar panel. The typical solar panel consists of approximately 40 PV cells. Solar panels can be further wired together to form a solar array. The electrical energy produced will increase with increasing area size of solar panel or solar array. According to the National Renewable Energy Laboratory (NREL), an array of between 10 to 20 solar panels is required in order to provide enough electricity to power the average home (Solar Research, 2018).

The amount of electrical energy produced by a PV cell is dependent on the intensity and wavelength of the light source, and various performance characteristics of the PV cell. Significant parameters affecting PV cell performance include the maximum current and voltage, efficiency, characteristic and parasitic resistance, temperature, diode ideality factor, and the band gap energy (Alternative Energy Tutorials, 2019). Out of all factors, temperature and solar irradiance have the largest influence on PV cell performance. A graph showing the current and voltage (I-V) characteristics of a PV cell operating under normal conditions is shown in Figure 2 below. PV cell I-V characteristic curves are significant for determining the relationship between the current and voltage at present temperature and solar irradiance conditions. Information provided by the I-V characteristic curves yield necessary information for designing a solar system to operate as close to the PV cell's optimal peak power point (MPP) as possible (Alternative Energy Tutorials, 2019).

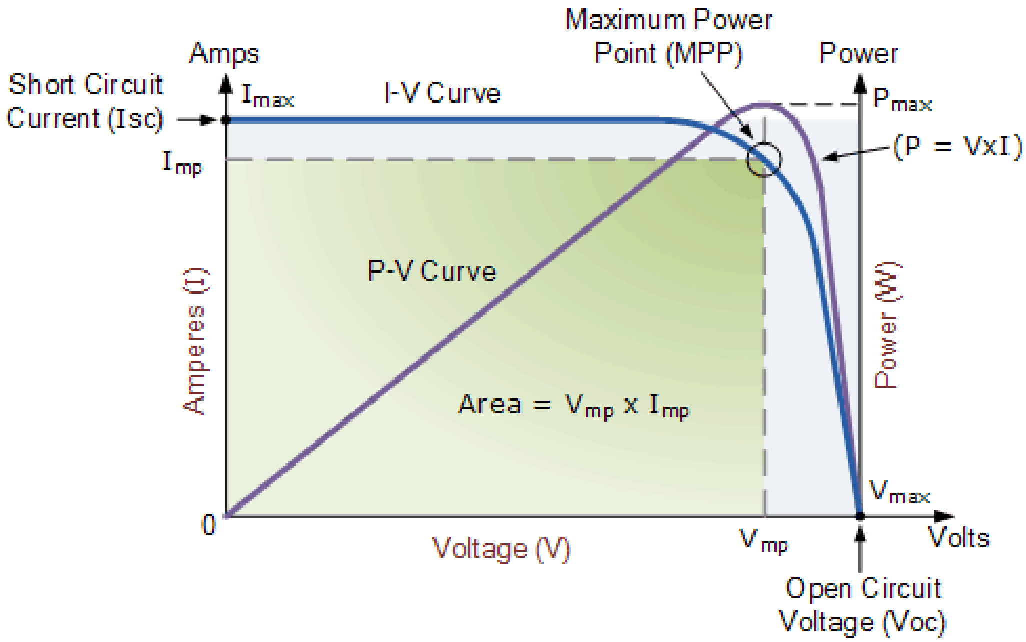


Figure 2. *PV cell I-V characteristic curve (Alternative Energy Tutorials, 2019).*

The efficiency of each PV cell determines the total efficiency produced from the solar panel. Solar panel cell efficiency can be defined as the ratio of electrical power produced from the PV cell to the amount of sunlight captured by the PV cell (Solar Energy Technologies Office, 2013). Simply stated, the efficiency of a solar panel determines how much of the energy captured by the PV cell will be converted into electrical energy. Solar panels are tested at Standard Test Conditions (STC), an industry-wide standard, to compare, rate, and determine the efficiency and performance of solar panels. These conditions correspond to a clear, sunny day with the incident light hitting a sun-facing 37 degree-tilted surface with the sun at an angle of 41.81 degrees above the horizon. Standard test conditions are displayed in Table 1 below.

Table 1. *Standard Testing Condition specifications*

Standard Testing Conditions	
Cell Temperature	25 °C
Solar Irradiance	1000 W/m^2
Air Mass	1.5

It is important to note that STC is not a sufficiently accurate standard to stimulate a panel's real world operation and performance due to major climatic and geographic conditions on Earth. Regularly occurring deviations in lamp spectrum, module and environment temperature, and solar irradiation are examples of sources that cause panel's of manufacturers to not effectively meet STC, resulting in incorrect output data. Today, the typical efficiency of commercially available PV panels is 7 to 17%, with the most efficient solar panels on market today having efficiency ratings as high as 22.2%. Efficiency values of panels and cells will vary with each manufacturer and panel type.

2.2 Progress of Floating Solar Park Technology Today

In today's society and growing population, 80% of the world's current energy demand is produced using fossil fuels. Fossil fuels not only pose grave environmental consequences, but are nonrenewable resources that will eventually be exhausted. Thus, the need for, and transition to renewable, green energy sources are becoming more and more dire. Solar power is a type of green energy that is growing fast in recent years as a result of technological advancement, solar PV capacity growth, significant cost reduction in material, and worldwide need for green, renewable energy sources.

Floating solar, also known as a floating photovoltaic, is a relatively new solar energy technology that consists of a solar array that floats on top of a body of water. From the design, this technology is able to take advantage of unutilized water spaces and convert them into profitable and eco-friendly energy generating areas. Due to the rapid drop in the price of solar PV modules, and factors of land encroachment and increasing purchasing cost of acquiring land have helped to aid the floating solar industry in becoming a popular alternative to traditional solar methods. According to NREL, floating solar park technology is estimated to save 2.1 million hectares of land saved if solar panels were installed on top of water bodies instead of on the ground (DOE/NREL, 2019).

Although the solar PV industry has been around and developing for over one hundred years, the first floating solar panel systems installation was in 2007. After the Fukushima nuclear disaster that occurred in 2011, Japan was one of the first countries to heavily invest in the floating solar industry as an effort of energy transition. Since then, Japan has experienced enormous benefits that has helped put the country in a better economic and environmental state. From Japan's success with their floating solar projects, the floating solar market is growing more popular and is being developed worldwide as other countries are following in pursuit (Thi N., 2017). Floating solar has predominantly been installed in China, Japan and the UK, but the technology is expanding to the US, South America, China, South Korea, ASEAN countries, Latin America, and Asia (DOE/NREL, 2019). Floating solar is projected to continue to be adopted by developed countries, and especially amongst island nations with land-scarce regions. In fact, the use of floating solar has grown more than a hundred-fold in less than four years, from a worldwide installed capacity of 10 megawatts at the end of 2014 to 1.1 gigawatts by September 2018 according to the World Bank Group and the Solar Energy Research Institute of Singapore (SERIS) (The World Bank, 2018). The democratization of floating solar takes time, which is why some nations have yet to adopt the technology. However, with greater awareness and increasing need for renewable energy sources, floating solar panels have a bright future and the rapid adoption of floating solar technology can be expected.

2.3 Floating Solar Park Examples

Many countries have been developing floating solar park technology within the last decade. Japan has nearly 50 floating solar facilities of more than 1 MW and plans to install several dozen more.The country’s largest farm (13.7 MW) was opened in March 2018 in Chiba, near Tokyo, where it supplements the output of the hydroelectric dam on the same site.

Following the steps of Japan, China is developing floating solar PV farms on a gigantic scale as a result of the country’s variety in landscape. The Huainan farm in Anhui province is now operational, with a capacity of 40 megawatts (MW), and another 150 MW facility is planned for the same region by 2019. A leading Saudi developer and operator ACWA Power has announced it has won the right to develop the first utility-scale renewable energy project in Al Jouf region in Saudi Arabia, the 300 megawatt Skaka IPP PV solar project, at a record-breaking tariff of 2.34 US-cents per kilowatt-hour. In addition, India, has announced an ambitious floating solar program supported by the public authorities. India is home to a huge number of irrigation reservoirs (36,000 in the state of Karnataka alone). Australia has also started to move into the solar PV market.

However, apart from the United Kingdom, which has two of the world's ten largest floating solar farms (the Queen Elizabeth Reservoir near London and the Godley Reservoir near Manchester), European countries such as Belgium, Denmark, Italy and Portugal have so far opted for sites with capacities of less than 1 MW. In France, discussions have been ongoing for several years for an ambitious project in a former aggregates quarry in Piolenc, Vaucluse. If it goes ahead, the floating solar farm should be ready in 2019. In the Alsace region, a small site on a lake in the Strasbourg suburb of Illkirch-Graffenstaden is being finalized for use by the local authorities, but is facing opposition from environmental activists.

2.4 Location and Climate

Vaasa is located on the West Coast of Finland, right on the Bothnian Bay. With the sea being so close, Vaasa, Finland is a more temperate place in the summer, while being very cold in the winter. Over the course of the year, the temperature ranges from -10ºC to 20ºC (Average Weather…). In addition to the temperature, Vaasa, Finland is also very cloudy and has a lot of precipitation.

Clouds

Vaasa, Finland's weather can be described as cloudy/overcast for most of the year. On average, it is cloudy 46% of the day. Most days bounce between 46% cloudy and 76% cloudy. The cloud cover is generally worse from October until April making it slightly more difficult to produce energy during this time. Because of this, it might not be worth it to collect energy during this period of time.

Precipitation

Precipitation takes the form of both rain and snow. Rain alone is very common for 9.7 months out of the year (Average Weather…). This means that the weather will be overcast for this portion of the day as well. There are also parts of the year that commonly have mixed snow and rain and then further, parts of the year that are completely snowy. The snow is common for 6 months out of the year, October to April (Average Weather…). This again, might mean that neglecting the panels in between October and April might be the best option. Snow can be hard to remove from panels and would require added effort and cost when designing the solar park.

Wind

According to WeatherSpark.com, the wind in Vaasa, Finland blows from the South for almost 11 months out of the year, with the wind coming from the North for the last month of the year (Average Weather…). This means that the wind will most likely come at the panel park and hit it straight on possibly creating a large wind sail that could affect the placement of the solar panel park. Since the panel park is going to rotate from side to side, this might not be as large of a problem as once thought. More research will need to be done to rule this out as a possible issue.

During the windier part of the year, September 15th to March 28th, the average wind speeds are more than 12.7 km/h (Average Weather…). This type of wind does not pose a threat to the panels themselves, but when the panels are put into a large formation could cause a wind sail effect and want to move more due to the wind.

Wind can also be directed and used for cooling, if designed correctly. More about this will be talked about later.

Sun

With Vaasa being so far in the north, the day lengths range dramatically throughout the year. In the summer, the sun shines for about 20 hours, 23 minutes (Average Weather…). In the winter, the sun shines for only about 4 hours, 40 minutes on and near the shortest day of the year, December 22nd (Average Weather...).

With all of this in mind, WeatherSpark.com also detailed the best times in the year for daily incident shortwave solar energy. They took into account seasonal variations in length of day, elevation of the sun, and absorptions by clouds when calculating these values. The following figure shows the average daily shortwave solar energy reaching the ground for all parts of the year.

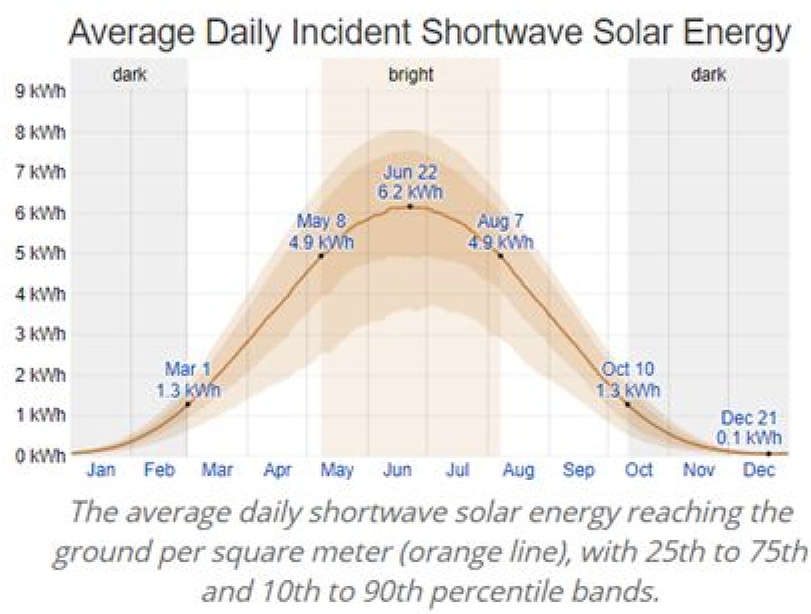


Figure 3. *Average Daily Shortwave Solar Energy to Reach the Ground in Vaasa*

As one can see, the brightest period of the year lasts about 3 months, from May 8th to August 7th (Average Weather…). It will be imperative that the solar panels are functioning properly in this time period as the most amount of solar energy can be gained then. Additionally, it seems that adequate amounts of solar energy reach the ground in between March 1st and October 10th. This means that making sure the panels are active during this time is also important when trying to get as much energy out of them as one can.

With all this information about the weather, it can be concluded that putting in the extra effort to clean the panels in the winter would be useless. The sun does not shine enough in the winter to warrant the extra task of cleaning off the snow. The best time to get energy from the sun is from March until October and that is when the conditions are the clearest as well as has the least amount of snow. This means that during the winter, if the panels are covered in snow, that is okay. However, in the summer months, it will be imperative that they are working to their best ability.

Additional Locations

For this project, Vaasa, Finland is going to be the main focus for research and design purposes. Solar panel park technology, however, it viable in many locations across Europe and across the world. The Idea of a floating solar park can be seen as an addition to the possibility of wind energy in Vaasa.
(Agbavor, 2015) Relating to the research on the Correlation between Sun Light Intensity and Wind Speeds of a Coastal Location done by David Etse Yao Agbavor in 2015 “Sea breeze occurs in Finland especially strongly in spring and early summer (March/April till July), and some later in the summer (August) but practically non-existent in September-February” (Agbavor, 2015, p. 19). This means, especially in the summer month, energy harvesting by wind- and also by photovoltaic parks can be a big influence in the renewable energy proportion of Finland.
Other countries nearby have already started wind farms and have gotten renewable energy from the wind, but this takes up a lot of land and concerning the lower amount of landmass in Finland due to more than 180.000 lakes, land area is a high value. According to the figure below, near Vaasa, Finland, the solar electricity is estimated to be about 850 kWh/kWp. This is a little bit on the lower scale and that is why making sure that the final design is as efficient and as well-equipped to collect solar radiation as possible, is a must before integrating this into Finnish bodies of water.

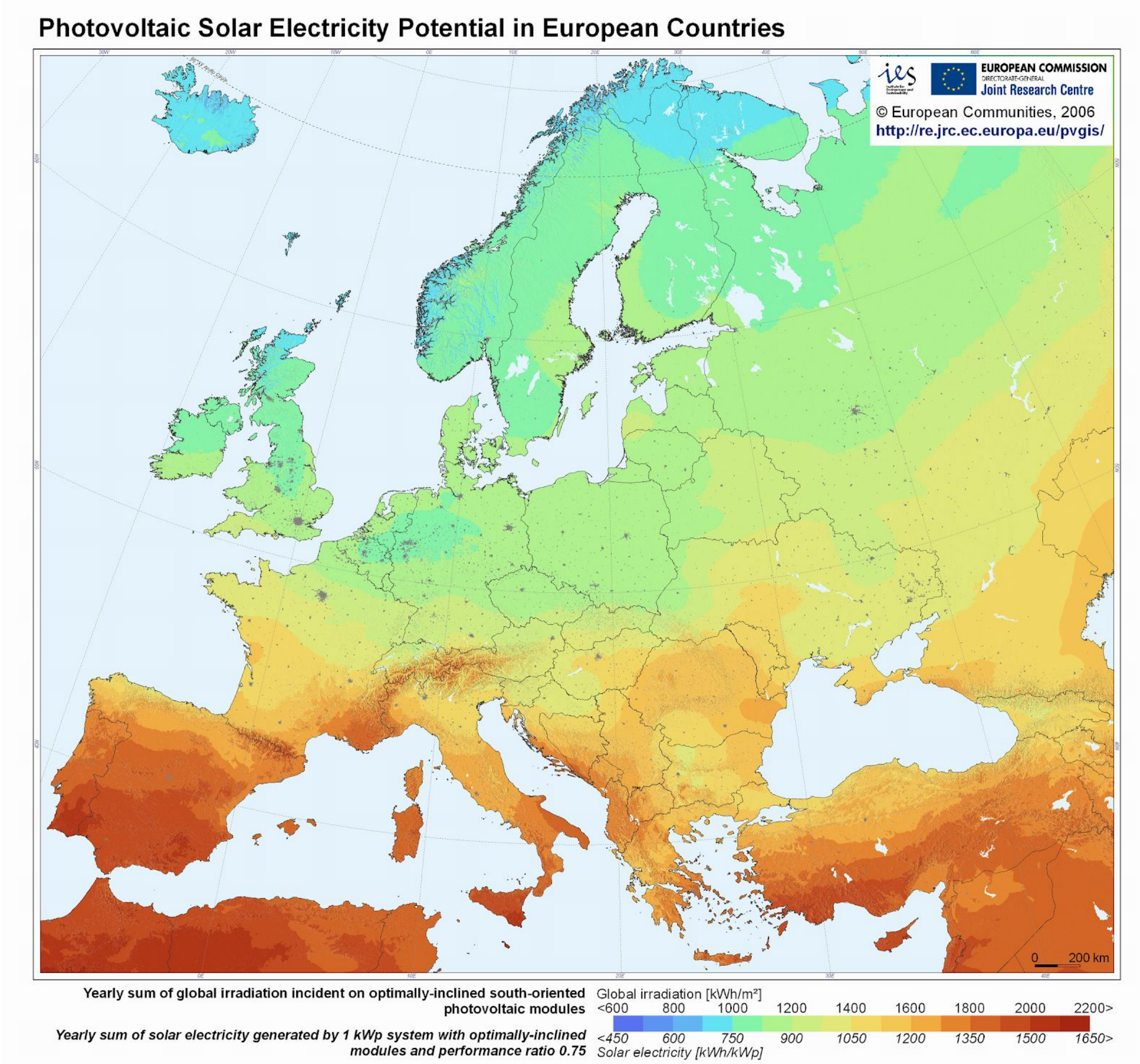


Figure 4. *Yearly Solar Irradiation and Energy Output for Europe (Photovoltaic Solar Electricity Potential in European Countries)*

Vaasa, Finland does not have the highest potential for solar energy, but does provide a sufficient amount of energy if given the right circumstances. With that being said, other locations in northern Europe are also viable options for a solar panel park. Locations in Sweden, Norway, The Netherlands, Denmark, and the United Kingdom, etc. would all have similar potential to Finland and would be good locations for a solar park such as this one.

2.5 Types of panels

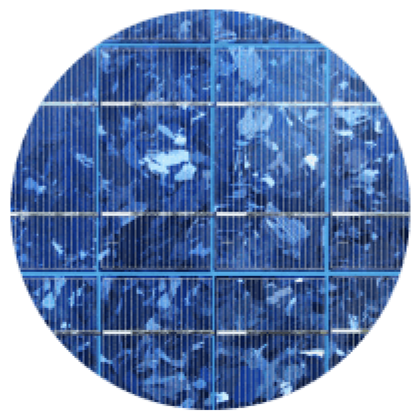
2.5.1 Monocrystalline Solar Panels (Mono-SI)

This type of solar panels (made of monocrystalline silicon) is the purest one. They can be easily recognised from the uniform dark look and the rounded edges. The silicon's high purity causes this type of solar panel has one of the highest efficiency rates, with the newest ones reaching above 20% (Askari Mohammad Bagher).

Monocrystalline panels have a high power output, occupy less space, and last the longest. Of course, that also means they are more expensive. Another advantage to consider is that they tend to be slightly less affected by high temperatures compared to polycrystalline panels.

They have been used in the solar industry for many years, which means that the manufacturing process is very optimized and the prices are very competitive.

2.5.2 Polycrystalline Solar Panels (Poly-SI)



These panels can be quickly distinguished because this type of solar panels has squares, its angles are not cut, and it has a blue, speckled look. They are made by melting raw silicon, which is a faster and cheaper process than that used for monocrystalline panels.

This leads to a lower final price but also lower efficiency (around 15%), lower space efficiency, and a shorter lifespan since they are affected by hot temperatures to a greater degree. However, the differences between mono- and polycrystalline types of solar panels are not so significant and the choice will strongly depend on your specific situation. The first option offers a slightly higher space efficiency at a slightly higher price but power outputs are basically the same.

2.5.3 Thin-Film Solar Cells (TFSC)

Thin-film solar panels are manufactured by placing one or more films of photovoltaic material (such as silicon, cadmium or copper) onto a substrate. These types of solar panels are the easiest to produce and economies of scale make them cheaper than the alternatives due to less material being needed for its production.

They are also flexible, which opens a lot of opportunities for alternative applications, and is less affected by high temperatures. The main issue is that they take up a lot of space, generally making them unsuitable for residential installations. Moreover, they carry the shortest warranties because their lifespan is shorter than the mono- and polycrystalline types of solar panels. However, they can be a good option to choose among the different types of solar panels where a lot of space is available.

This type of cells are mainly used for photovoltaic power stations, integrated in buildings or smaller solar power systems.

There are some different types of thin-film panels:

- Amorphous Silicon Solar Cell (A-Si) are the most used of this type because they are the cheapest, although the efficiency is very low, around 7%.
- Gallium arsenide cells have good resistance against temperature and can reach an efficiency around 32%. They are quite expensive because the materials are rare.
- Cadmium telluride cells are cheap to manufacture but the efficiency is low, around 11%. Moreover the materials needed are rare.
- CIS cells (Copper and indium selenide alloy) have efficiencies around 12% and the output is quite constant.

2.5.4 Bifacial panels

Bifacial modules produce solar power from both sides of the panel. Whereas traditional opaque-backsheeted panels are monofacial, bifacial modules expose both the front and backside of the solar cells. When bifacial modules are installed on a highly reflective surface some bifacial module manufacturers claim up to a 30% increase in production just from the extra power generated from the rear.
Bifacial modules come in many designs. Some are framed while others are frameless. Some are dual-glass, and others use clear backsheets. Most use monocrystalline cells, but there are polycrystalline designs. The one thing that is constant is that power is produced from both sides. There are frameless, dual-glass modules that expose the backside of cells but are not bifacial. True bifacial modules have contacts/busbars on both the front and back sides of their cells.

2.5.5 Conclusion

As the purpose is to design a big solar park, it should be more appropriate to use crystalline silicon panels because the prices are more competitive when comparing euros/Wp. There is not a big difference between monocrystalline and polycrystalline, monocrystalline are slightly more expensive but require less space.

However the other types of panels can be useful for special conditions. For example, thin film cells are better for concentration systems because they are less affected by temperature and bifacial panels could be appropriate with the light reflecting on the water. Specially the bifacial panels will still be considered an option as a way to increase the energy output of the park.

2.6 Placement of panels

The objective of this analysis is studying how different distributions of panels work and try to find the best of them; this means the one that produces more energy output.

It is necessary to choose one model to do the simulations and compare different situations so the chosen panel is the model BMO-290 made by BISOL with 290 Wp of power. Nevertheless, this is not the panel that will be chosen for the final design, it has only been used in this section and the final decision will be made at the end of the report.

2.6.1 Fixed or rotating panels

To do a first approach to this topic an online tool provided by PVgis has been used in order to simulate the energy output of a solar park placed in Vaasa during a year. To compare the different options we will use the specific production, which is the relation between the energy produced and the power installed in the park. It is measured in KWh/KWp and is useful to compare panels and parks with different assigned power.

2.6.1.1 Totally fixed

The results are shown in Figure 5 below.

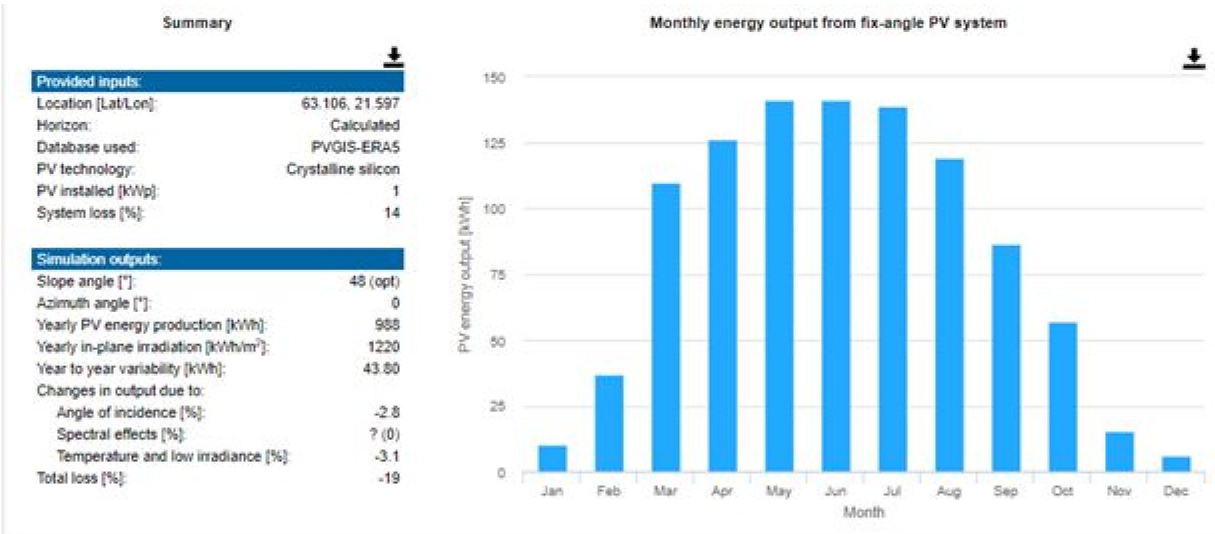


Figure 5. *Total fixed panels' energy production for every month according to simulation*

2.6.1.2 Rotating

There are three different options for rotating the panels: on a vertical axis, on an inclined axis or on two axes. The three of options are compared in Figure 6 below.

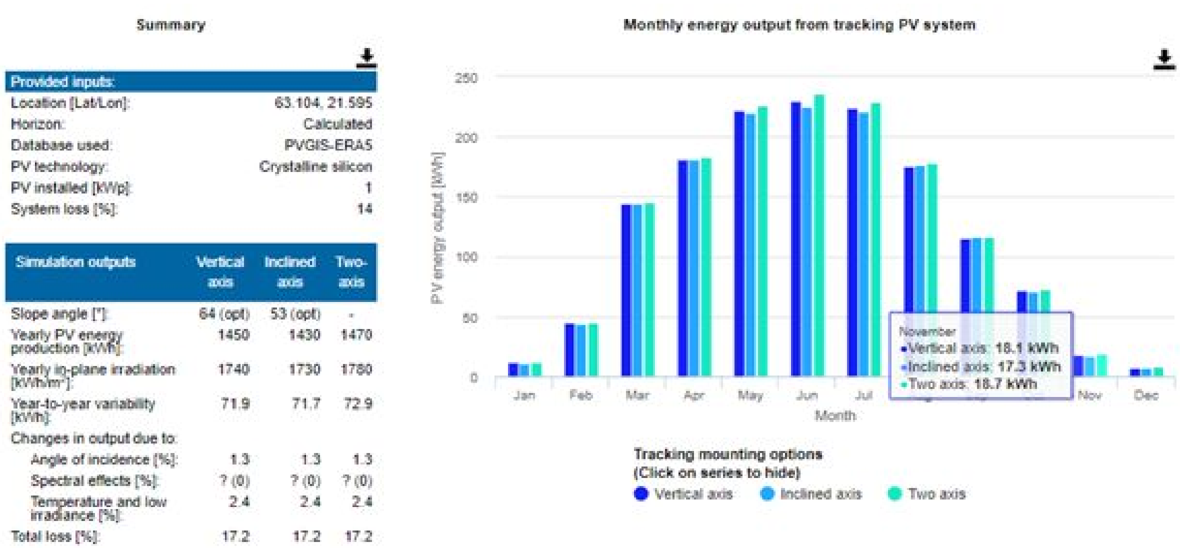


Figure 6. *Different rotation methods' energy production for every month according to simulation*

2.6.1.3 Comparison and Conclusion

Table 2. *Comparison between fixed and rotating panels*

Type of rotation	Optimum angle(s)	Specific production	Comparing percentages
Fixed	48º slope, 0º azimuth	988	100%
Vertical axis	64 slope	1450	146.8 %
Inclined axis	53 slope	1430	144.7%
Two axis	-	1470	148.9%

As it can be seen from Table 2, there is a big difference between fixed panels and rotating panels, near to 50% of efficiency gain when rotating. However the energy production of the different rotating methods is very similar. Considering that the panels will be mounted on a floating structure it seems that the natural way of rotating would be on a vertical axis. A second axis could be added too but would require another system which would increase the cost and require more moving parts that can originate maintenance problems. It is not worth it for such a small amount of extra energy, so we can state that a vertical axis is the best option.

Another important conclusion from these simulations is the energy production during the winter months. From November to February only a little amount of energy is produced comparing to summer months. This result opens the possibility of turning off the power plant during the winter. Keeping the panels free of ice and snow would require a an extra system to heat the panels in order to melt them or some kind of mechanical device that could remove them from the panel surface. Any of these solutions would increase remarkably the cost of the park, would need energy to work and still would not success on having the panels totally clean to get the maximum energy output. For all these reasons it is very unlikely that the extra energy and money invested on keeping the panels working during the winter will be recovered with the energy that it would generate during those months. Moreover it is not a good idea either to let the panels work without cleaning the snow in order to get some little energy without any expense; the inverter and some control devices will consume energy and the energy balance would probably be negative.

The best solution will be turning on off the whole system when the snow starts to fall in November, make sure that the ice does not cause any damage and turn it on in March when the temperatures start to be above zero degrees.

2.6.2 Shadows

In northern locations like Vaasa, shadows caused by panels will generate important energy losses because the sun is usually very low and the angle of the panels is quite big. Therefore is very important to consider how the shadows affect our solar park and try to find the best disposition for the panels. To know how big energy losses due to shadows are, we will use a software called PVsyst to simulate the energy production in a year. The panel used will be the one chosen above and the inverter is just one that fits the panel. As the purpose of this is comparing the inverter model is not important.

The solar cells forming a solar panel are connected in series. When several cells are connected in series they may experiment mismatch effects. Mismatch happens when cells connected in series are under different conditions, if one of the cells is producing less current because of shadows or degradation all the other cells will produce less too. To avoid this loss of energy, panels have bypass diodes; these are connected in parallel to a cell to allow the current generated by other cells flow through them when the cell is not working properly (PV Education. (o.D.). Bypass Diodes | PVEducation. Retrieved March 10, 2019). Connecting a diode for each cell would be expensive so they usually use only three diodes in this kind of panels. The diodes are connected as shown in Figure 7.

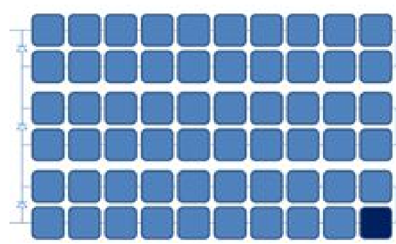


Figure 7. *Connection of solar cells and bypass diodes in a standard solar panel*

Based on this, the panels must always be placed in horizontal way because that way, when the shadows cover the lowest part of the panel, only a part of the energy will be lost. Some different options will be analysed to understand how the shadows affect the energy production depending on how the panels are placed.

2.6.2.1 First Situation: No Shadows

As it was found before, the optimum angle to rotate on vertical axes is 64º. The specific production calculated by simulating this situation on PVsyst is 1377 KWh/KWp. As we are also considering turning off the power plant from November to February, also the specific production from March to October will be calculated. In this case it is 1250 KWh/KWp.

2.6.2.2 Second Situation: Sun angle 10º

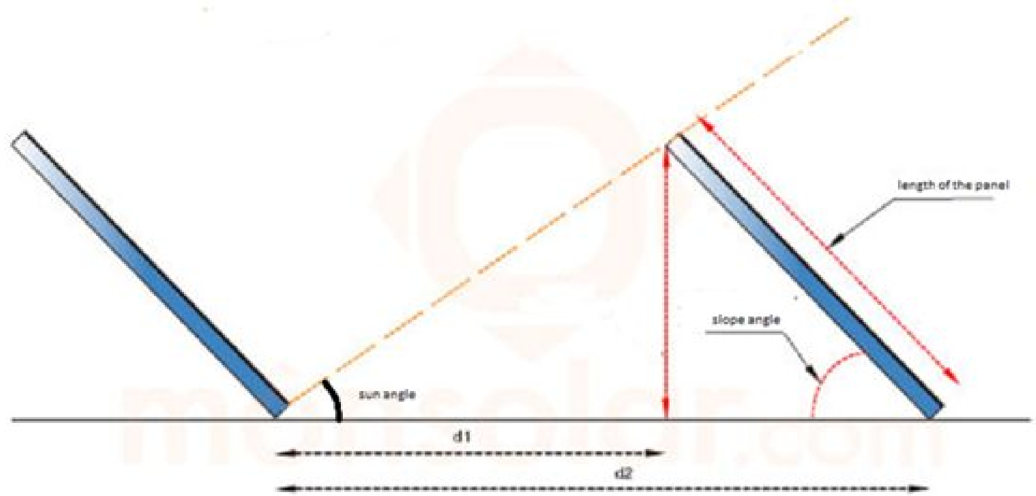


Figure 8. *Diagram of position of panels*

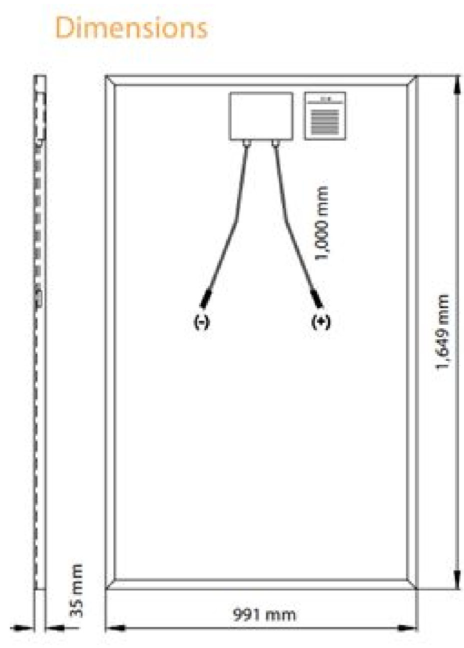


Figure 9. *Dimensions of the chosen solar panel*

The specific production during the whole year in this situation is 1169 KWh/KWp. During the best 8 months it is 1104 KWh/KWp. Knowing that the length of the panel is 991 mm we can calculate the necessary distance (d_2 in figure 22) to get a sun angle of ten degrees. That is 5.5 meters. However, thinking about it, it is easy to realize that the shadows do not allow the panels to generate when the sun is low and therefore a smaller slope angle may be better. By trying different angles it is found that the maximum output is got when the slope angle is 53 degrees.

The specific production is 1183 KWh/KWp but the specific production decreases very slowly when decreasing the angle. This means that it can be worth it to lose a little energy in order to make the distance between panels shorter and, in consequence, the area of the park smaller.

Table 3. *Raw calculation data for 10 degrees sun angle*

Slope angle (degrees)	Specific production (KWh/KWp)	Specific production Mar-Oct (KWh/KWp)	Distance between panels (m)
53	1183	1121	5.08
50	1181	1120	4.94
47	1176	1116	4.79
45	1172	1112	4.67
43	1166	1107	4.56
40	1155	1098	4.37

It has also to be consider to put one row of panels in top of the other and separating them a longer distance. The space needed would be the same for the same number of panels and the energy output in this situation would be slightly higher because the panels on the top would get more sunlight. However doing this also means that the wind force is doubled and, as the park is floating, it may not stay in its place.

2.6.2.3 Third situation: Sun angle 15º

In order to decrease the size of the park we will see how it works with more shadows. A similar process will be followed; finding the optimum angle and see how the output and distance change when the angle decreases. The optimum angle in this case is 47º.

Table 4. *Raw calculation data for 15 degrees sun angle*

Slope angle (degrees)	Specific production (KWh/KWp)	Specific production Mar-Oct (KWh/KWp)	Distance between panels (m)
47	1046	1008	3.38
45	1044	1007	3.32
43	1042	1005	3.25
40	1036	1000	3.14

2.6.2.4 Fourth situation: Sun angle 20º

The optimum angle in this case is 42º.

Table 5. *Raw calculation data for 20 degrees sun angle*

Slope angle (degrees)	Specific production (KWh/KWp)	Specific production Mar-Oct (KWh/KWp)	Distance between panels (m)
42	910	884	2.56
40	909	883	2.51
37	905	880	2.43
35	902	877	2.37

2.6.2.5 Fifth situation: Sun angle 5º

The optimum angle in this case is 56º

Table 6. *Raw calculation data for 5 degrees sun angle*

Slope angle (degrees)	Specific production (KWh/KWp)	Specific production Mar-Oct (KWh/KWp)	Distance between panels (m)
56	1290	1195	9.45
53	1287	1193	9.64
50	1280	1189	9.31
47	1271	1182	8.96

Figure 10 shows the relation between distance (y axes) and sun angle (x axes). For sun angles higher than 20º, the distance decreases very slowly and for angles lower than 10º the distance increases very fast. This probably means that the best options will be around those angles, between 5º and 25º.

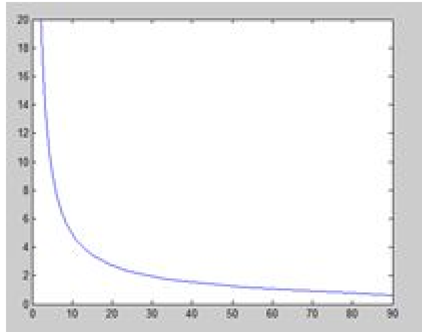


Figure 10. *Plot showing the relation between distance between panel and sun angle*

2.6.2.6 Comparison

It is now quite complex to know which the best option is, so we are going to use an extra measurement to help us to compare. The purpose is designing a power plant of about 1 MW, which means that we will need 3448 solar panels of 290 W. The idea is calculating how big a power plant on a square shape would be having around 3448 panels. Once we know this we can calculate how much energy we get per square meter to give us and idea of how exploited is the area. It will be referred as energy density since this point.

Table 7. *Comparison of raw calculation data for different sun angles and slope angles.*

Sun angle (degrees)	Slope angle (degrees)	Sp. Prod. Mar-Oct (kWh/kWp)	Sp. Prod. Mar-Oct (kWh/kWp)	Relative product.	Relative product. Mar-Oct	Energy density (kWh/m^2)	Energy density Mar-Oct (kWh/m^2)
5	53	1287	1193	93,5%	95,4%	24,46	22,67
5	47	1271	1182	92,3%	94,6%	25,94	24,13
10	53	1183	1121	85,9%	89,7%	42,19	39,98
10	47	1176	1116	85,4%	89,3%	44,45	42,18
10	40	1155	1098	83,9%	87,8%	47,77	45,41
15	47	1046	1008	76,0%	80,6%	55,75	53,73
15	40	1036	1000	75,2%	80,0%	59,41	57,34
20	42	910	884	66,1%	70,7%	63,84	62,02
20	37	905	880	65,7%	70,4%	66,86	65,01

From Table 7 we can see that the losses due to shadows are lower if comparing the energy output only from March to April, this gives us another reason to believe that it is not worth it to keep the park working during the winter months.It is not so easy to get some conclusions from the sun and slope angles analysis. Here are the results plotted to see them better:

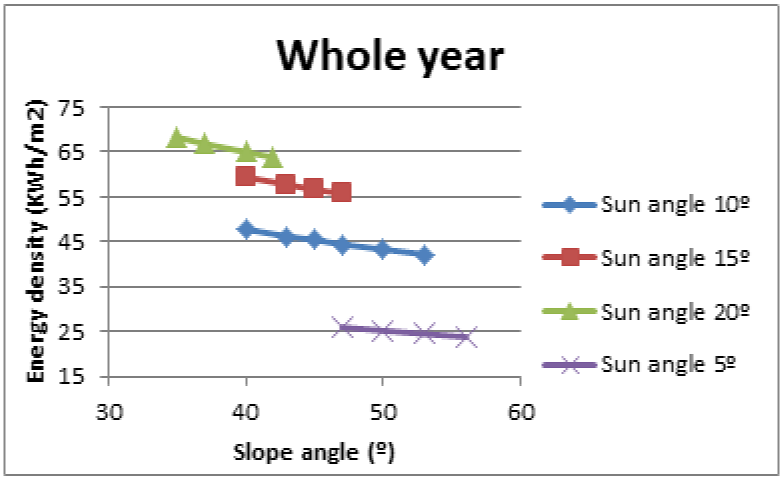


Figure 11. *Graph representing the variation of energy density depending on sun angle and slope angle*

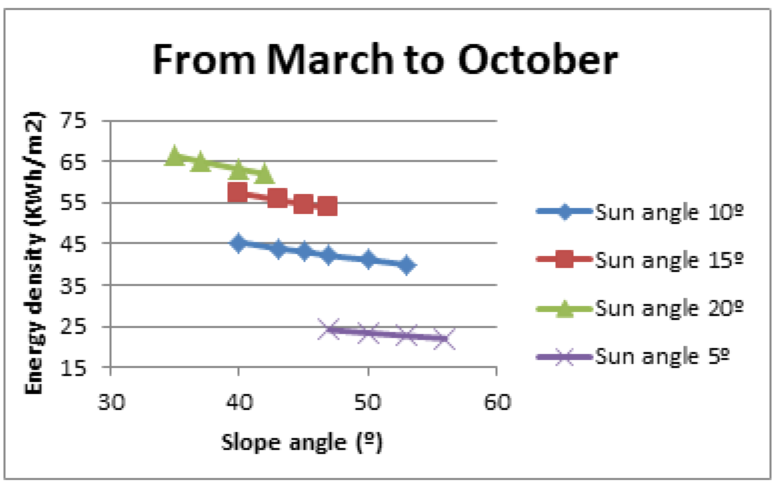


Figure 12. *Graph representing the variation of energy density depending on sun angle and slope angle*

The energy density keeps growing in a linear way when decreasing the slope angle so the important factor when deciding about it is the price of the land (or water) and the price of the panels and the structure. For example if the land is very cheap it would be better to use a slope angle near to the optimum although it will use more space. If the panels and the structure are very cheap it can be afforded not to get the maximum power from them and save space using a lower slope angle.

The sun angle seems to work in a similar way but from the plots it can be guessed that it approaches to a maximum point when going higher than 20 degrees. To see this, energy density has been calculated for different sun angles at its optimum slope angle. Plotting them (Figure 13) we can see there is a maximum point around 25 degrees, so it is never worth it to further than that.

However it is still impossible to know which angle between 0 º and 25 º is the best. Again, it will depend on the prices of the land and the panels. One of the reasons to make the park float instead of just putting it on land is that nobody uses the water areas for any other purpose so the price should be lower than the land's price. It's difficult to check this assumption as nobody owns a lake. Based on this, a low sun angle will be better, probably between 5 and 15 degrees.

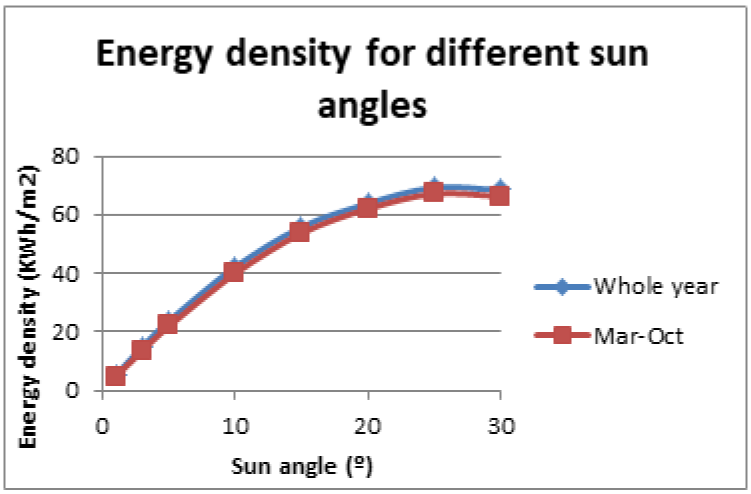


Figure 13. *Graph showing energy density for different sun angles with the optimus slope angle*

2.6.3 Conclusion

After all this analysis, we can understand much better how shadows affect the energy production but it is also needed some information about the costs about other elements of the park, that is why, at first, three different options were considered.

Table 8. *Parameters of 3 different options for placing the panels*

	Compact	**Medium**	**Spaced**
Sun angle (degrees)	25	10	6.5
Slope angle (degrees)	37	40	53
Distance between panels (m)	2.07	4.37	7.54
Sp. Production, whole year (KWh/KWp)	799	1155	1263

	Compact	Medium	Spaced
Energy density, whole year (KWh/m2)	69.19	47.77	30.55
Sp. Production, Mar-Oct (KWh/KWp)	775	1098	1179
Energy density, Mar-Oct (KWh/m2)	67.11	45.41	28.52
Area required for 1 MW approx. (m2)	11537	24386	41292
Square side length (m)	107.64	157.32	203.58
Columns	65	94	123
Rows	53	37	28

It has been found that the price to buy the area needed for the park is going to be low compared to the price of the panels so, from this point, the spaced design will be used so that we can get the most from each solar panel, which will be the most expensive component of the park.

2.7 Efficiency Improvement Techniques

A number of associated challenges still exist that make the technology financially impractical and an inadequate power source for meeting current global energy needs.

2.7.1 Solar Tracking

A solar tracking system tracks the position of the sun and maintains the solar photovoltaic modules at an angle that produces the best power output. Several solar tracking principles and techniques have been proposed to track the sun efficiently. The idea behind designing a solar tracking system is to fix solar photovoltaic modules in a position that can track the motion of the sun across the sky to capture the maximum amount of sunlight. Tracker system should be placed in a position that can receive the best angle of incidence to maximize the electrical energy output. Designing such device to produce electrical energy is interesting and important. However, it requires extensive mathematical calculations and detailed measurements of different solar parameters. One of the most important parameters is the daily average solar irradiance. The daily average solar irradiance ranges from 4-7 kilowatt-hour (KWh/m2) worldwide (M.K.M., 2018).

Tracker systems track the position of the sun, thereby increasing the input of solar radiation and electrical energy output. However, designing, implementing, and installing these systems are difficult for different reasons. Multiple amount of measurement results are required before employing tracker systems. These results are collected during a relatively long period time to be used when installing solar cells to track the sun. The collected results are used to identify the best technique for tracking the position of the sun. Following the position of the sun is performed to obtain the optimal output of solar energy in all situations (ICRERA, 2012). Different environmental pressures and different parameters, including panel direction, angle of photons incidence, time to measure the results, material of solar cells, and conductivity of photovoltaic modules, may affect the output of the solar panel cells (Aust Economy Rev., 2006).

Considering the first aspect of increasing efficiency, solar tracking can be condensed to a few details. A distinction must be made between active and passive solar tracking, as well as between one-axis and two-axis tracking of the solar panels.

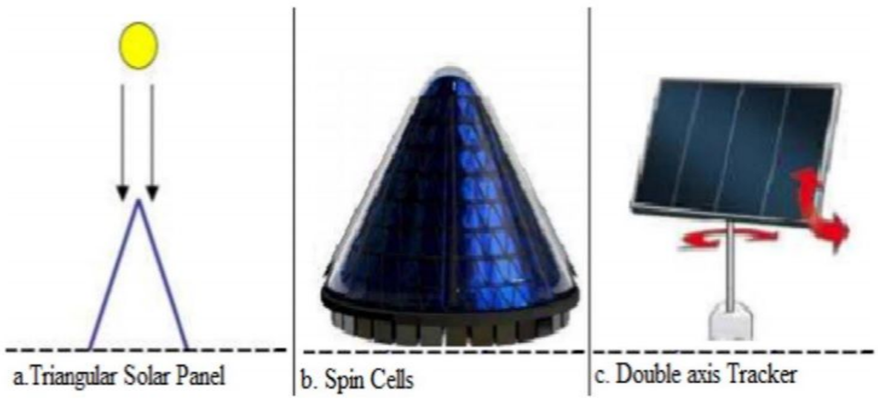


Figure 14. *Triangular Solar Tracker, spin cell, double solar tracker*

In addition to the mechanical tracking of the above-mentioned aspects, there are also specially designed solar panels, which have, to some extent, integrated the solar movement in their construction. These include Spin Cells or Triangular Solar Panels. Both cases are not suggested for northern latitudes due to the energy loss by non-utilization of the entire panel area at any time (M.K.M., 2018).

2.7.2 Mirrors and Concentrators

Known variants of solar power bundling have been around for some time in the field of solar thermal power plants. The best known are the parabolic troughs, the paraboloid and the solar tower, but these are difficult to apply to the photovoltaic technology, as they are concave mirror constructions designed for maximum temperature output, similar to the burning glass (Wikimedia Commons, 2011).

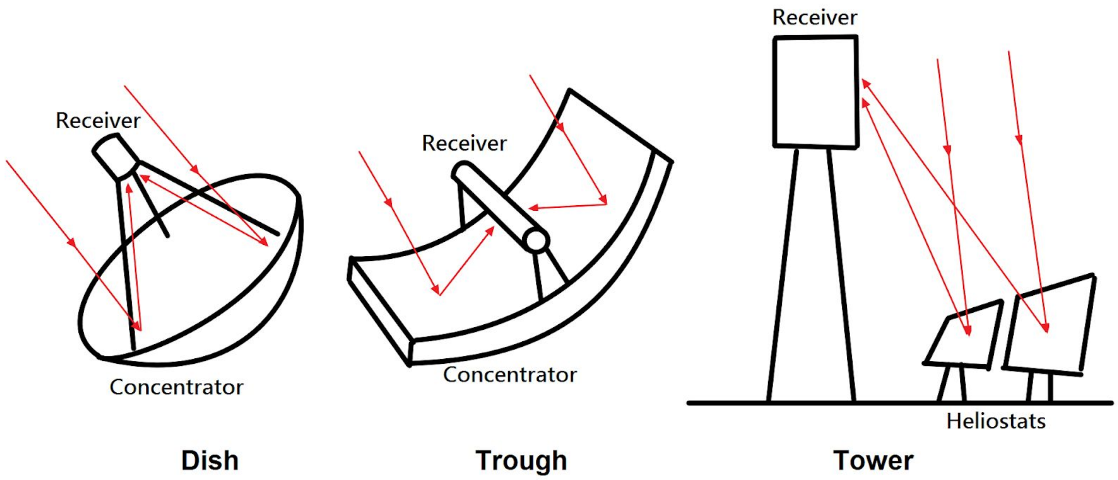


Figure 15. *Types of concentrated solar power solutions*

Nonetheless, there are now techniques for solar power bundling in the field of photovoltaic systems.

One way to increase the output from the photovoltaic systems is to supply concentrated light onto the PV cells. This can be done by using optical light collectors, such as lenses or mirrors. The PV systems that use concentrated light are called concentrating photovoltaics (CPV). The CPV collect light from a larger area and concentrate it to a smaller area solar cell.

The company Concentrix, for example, relies on Fresnel lenses that can concentrate sunlight almost 500 times, and the high-efficiency solar cells developed at ISE (III-V stacked solar cells made of gallium indium phosphide, gallium arsenide and germanium),(Fedkin, M.F.(o.D.)). As shown in Figure 29, Fresnel lenses concentrate incident light onto a central solar cell. These cells are specially designed for concentrated radiation, have a diameter of 2 mm and an efficiency of up to 32%. When soldered to copper sheets, they are glued to a glass plate so that they are always in the focus of a Fresnel lens, see Figure 16.

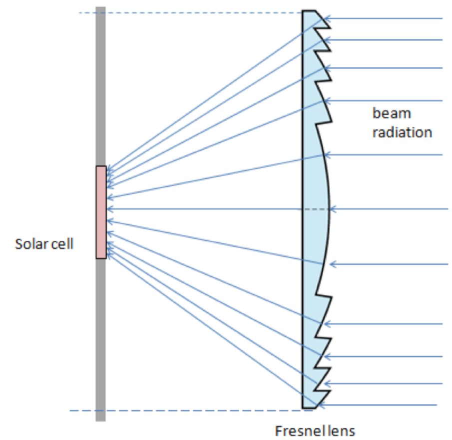


Figure 16. *Processing of Fresnel lenses* **Figure 17.** *Fresnel lens*

Disadvantages of this efficiency enhancement variant are the high manufacturing costs for the special solar cells and the need for a minimum one-axis tracking of the sun so that the focal point of the lens at all times meets the active area of the solar cell.

Figure 18. *Archimedes V-Trough PV Concentrator*

Another variant of the increase in efficiency are mirrors. One variation was already mentioned with the solar thermal power plants, the Heliostats. The Heliostats are a combination of mirrors combined with solar tracking. Heliostats could work for solar energy plants, but they would need a big amount of space and therefore will not be considered further.

The so-called V-trough concentrators are a better space saving solution. The V-trough concentrator is formed by two flat reflector benches, which are attached to the side of the photovoltaic with an angle of 60 ° and can result in a construction just like Figure 18 or Figure 19. This results in a geometric concentration factor of C = 2 (Klotz, F. H. K. (o.D.), 1996).

The geometric concentration factor C is defined as the ratio of the radiation-receiving aperture area of a concentrating collector to its absorber area. The irradiance in the module level depends on the reflector quality and the direct radiation drive. On clear days, irradiation intensities of up to 2000 W / m² can be achieved with good reflectors. The V-Trough solution can achieve an energy gain of 58% compared to conventional solar cells with the same size (measured in Central Europe) . This reduces the proportion of expensive solar cells. The mirror surface is significantly cheaper than the module surface (Archimedes Solar GmbH, 2008).

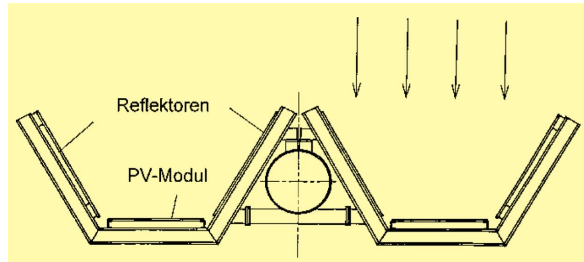


Figure 19. *Cross-section V-Trough*

Generally, efficiency increasing methods in the solar sector are divided into 3 groups. Solar tracking systems, mirrors and concentrators.

Coming to the topic of Mirrors it has been proven that the Attachment of Heliostats to the solar cells would not be efficient after all. Additionally, it can be seen a change in the last years related to the V-Trough concentration method. Looking at the sources of the known efficiency enhancement measures for solar energy systems, it is noticeable that V-trough technology has hardly received any attention for some time (Powalla, 2019). According to an email conversation with Dipl. -Phys. Dirk Stellbogen from the Zentrum für Sonnenenergie- und Wasserstoff-Forschung Baden-Württemberg (ZSW), the V-Trough technology, especially the refinement of photovoltaic elements by mechanical and/or optical elements, isn’t feasible anymore due to dropping performance- as well as area-related prices. The only feasible solution left, would be a very simplified, cost optimized, one-axis tracking, bifacial module which is worked on in this project.

Among the concentrators there are various variants of special cells. The Fresnel lenses, tandem solar cells or fluorescent cells are only a few variants and types of different lens and cell types. The Fresnel lenses have the highest efficiency with respect to the problem of photovoltaic use in Finland and have therefore been considered in more detail.

The focus will be set on bifacial panels combined with the V-Trough Technology, in form of adding mirrors in a 60° angle to the panels.

In addition to the research which was done on panels and efficiency increasing methods, another interesting aspect was the creation or the composition of the already mentioned mirrors.

It is an advantage that mirrors for photovoltaic systems do not require highly specialized and expensive materials. However, the mirrors must be resistant to all weather conditions for a period of at least ten years and have a total photon reflectance of wavelength intervals of about l = 300-1100. The mirrors use a wide variety of materials (Almeco Group).

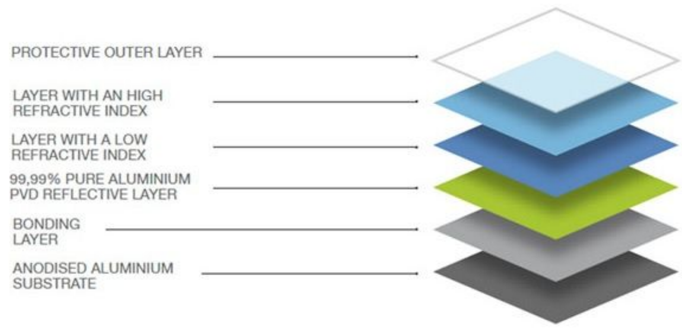


Figure 20. *Vega Energy WA layers*

The differentiation goes from commercially available glass mirrors, simple thin glass mirrors with a reflectance of 92%, or aluminum and silver based mirror surfaces in general, to more complex variants. For example, the mirror surfaces of the Almeco Group are made of pre-anodized aluminum with a thin, PVD-coated multiple coating of up to 99.99% pure aluminum or silver and ceramic protective layers.

Generally, mirrors can be made out of:

- ❏ a rolled stainless steel plate with a special surface coating
- ❏ a rolled aluminum plate with a polymer coating that protects against the effects of the weather (PVF protection)
- ❏ a silver-coated acrylate film
- ❏ an aluminum-coated acrylate film

2.7.3 Cooling Systems

A main advantage of FPV systems is their capability to utilize the water body as a source to cool the PV panels appropriately. Proper cooling is important to solar systems and it can significantly increase performance and the energy harvested from the sun. The increase in efficiency by cooling results from two different sources.

1. The water refraction index of 1.33 which helps reduce the reflection effects of solar radiation when water flows over the solar panel. This effect gives a gain of about 2% if radiation is perpendicular to the panel (Rosa-Clot M., Tina G. M., 2018).
2. The loss of efficiency as the temperature increases. For every 1 ^{o}C increase in surface temperature on the PV module will cause a reduction in efficiency of 0.5% (Rosa-Clot M., Tina G. M., 2018). This is most significant during the intense radiation hours and is further enhanced if mirrors or other concentration devices are utilized.

Various cooling techniques have been investigated, but for the purposes of this project have been narrowed down to the following cooling systems below. Each cooling technique listed gives an overall operational description, and their capability of addressing undesirable influence of temperature on PV efficiency in terms of their advantages and disadvantages.

Water Veil Cooling System

The Water Veil Cooling (WVC) system consists of a pump and an irrigation system made of polyethylene pipes positioned on the top of each solar panel. This technique includes a temperature control system that switches on when the solar panel temperature exceeds a fixed threshold, typically the maximum temperature for solar panel is 30 °C (Siecker J., Kusakana K., Numbi B. P., November 2017). A low pressure, submersible water pump is used to move the water through the pipes to the top of the panel. Figure 21 below shows a typical layout of a WVC system.

A WVC system utilizes a uniform water layer to lower PV cell surface temperature and create a refractive layer to decrease the solar radiation reflected by the glass. For reference, the refractive index is 1.3 to water and 1.5 to glass (Castanheira A., Fernandes J., Branco C., 2018). A WVC system is estimated to increase the efficiency of a solar panel by 10% on an annual basis to 15% output at peak radiation conditions. There is also potential for panel surface cleaning caused from the irrigation system water flow. Key disadvantages of a WVC system include a large power requirement to circulate the cooling water, and water blockage that is caused by dust or dirt deposition on the panel. It is significant to note that this cooling technique may compete with other non-solar, conventional energy supply systems as a result of this system's higher operating costs.

Figure 21. *Diagram of a WVC system (Rosa-Clot M., Tina G. M., 2018)*

Water Sprinkler Cooling System

A water sprinkler cooling system is a simpler alternative to a WCV system. Instead of irrigation pipes, the system utilizes high-pressure sprinklers that operate at a pressure of 2 to 3 bar. As a result, the cost of cooling is much less than the WCV system while still increasing the power output by 10% on an annual basis. A issue that may become a concern is the shadowing effect caused from the water jet. Although this can be limited by the amount of time spent spraying. Spray time can be planned for a very short amount of time to maintain a low panel temperature without waste of pumping energy and loss of solar radiation (Siecker J., Kusakana K., Numbi B. P., November 2017). Therefore, major disadvantages of this cooling system are water and heat wastage. Visuals of a high-pressure sprinkler attachment and layout of water sprinkler cooling system is shown in Figure 22 and 23 below.

Figure 22. *Visual of high- pressure sprinkler head for solar panel cooling system (Castanheira A., Fernandes J., Branco C., 2018)*

Figure 23. *Visual layout of water sprinkler cooling system (Castanheira A., Fernandes J., Branco C., 2018)*

Forced Water Circulation Cooling System

The forced water circulation cooling system has thermal collecting pipes mounted to the back of the solar panel. Water is used as the working fluid that circulates through the thermal collecting pipes by a DC pump. The heat generated from the PV cells is transferred to the circulating water in the thermal collecting pipes and the recycled flow goes back to a hot water insulated collecting tank for other uses (Siecker J., Kusakana K., Numbi B. P., November 2017). A major disadvantage associated with this system is that the operation of the DC pump and water tube network are expensive to run, making this system the most high-costing. Another issue of concern is that the system is incapable of reaching optimal efficiency due to the constant flow rate of the system. On the other hand, the system is capable of the greatest drop in operating PV cell temperature as well as the highest increase in power output. Depending on other environmental and economical factors, this system may not be a feasible cooling technique for this project.

Forced Air Circulation Cooling System

The forced air circulation cooling system is designed so that the PV module is placed on top of a support structure with an air channel underneath. A fan powered by the PV module will force the air acting as the cooling fluid through the channels. The width of the channel has significant effect on the PV cell temperature, or the natural cooling due to convection. As the width of the channel increases, the cavity velocity and size of the heat exchanging surface increase. This allows the heat from the solar panel to transfer to the air in the channels via convection and reduce in surface operating temperature, therefore reaching a higher electrical efficiency (Siecker J., Kusakana K., Numbi B. P., November 2017). Depending on the size availability for the location design area, this relationship could work positively or negatively in favor for the project.

This cooling technique is not as efficient as the other cooling techniques listed above and is only economical for large-scale PV systems. Another issue of concern is that the temperature controller is required to adjust the air flow rate which adds additional costs. However, forced air circulation systems are very effective in cold climatic conditions compared to hot climatic conditions making this more favorable for Finland. The system is additionally one of the lesser energy intensive cooling techniques available.

Transparent Coating (Photonic Crystal Cooling)

This cooling system technique incorporates a transparent coating (photonic crystal cooling) based on silica photonic crystals. The coating creates a new material atop the solar cells enabling the PV cells to reflect generated heat in the form of infrared light under solar irradiance back into space (Siecker J., Kusakana K., Numbi B.P., November 2017). The transparent coating is capable of keeping PV cells cooler even though the PV cell absorbs the same amount of sunlight. In fact, researchers predict the transparent coating could help solar cells turn approximately 1% more sunlight into electricity (*Li W., Shi Y., Chen K., Zhu L., Fan S., 2017*). Although this amount may seem insignificant, it is in actuality a significant increase in efficiency for such a small addition to the system. By using the sky as a heat sink to eliminate unwanted generated heat, the cooling material is capable of lowering the cell temperature and eliminating the problem entirely. Like the forced air circulation cooling system, the transparent coating also works better in a cooler climate such as Finland.

Disadvantages of the material is that it needs to be replaced as the coating degrades with time and will no longer work as effectively. Another issue this cooling technique is that some of the heat generated will be wasted when it could be utilized for energy. Figure 24 below shows a typical diagram of the transparent coating material.

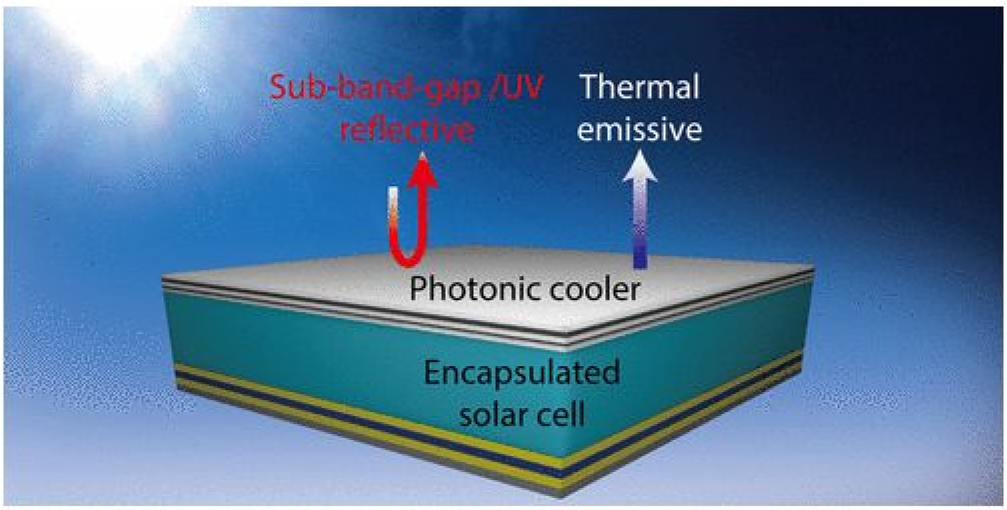


Figure 24. *Diagram of Photonic Crystal Cooling Material (Li W., Shi Y., Chen K., Zhu L., Fan S., 2017)*

2.7.3.1 Solution to Calcite Formation

For water cooling techniques that utilize water for cooling by exposing water to the solar panel surface, certain precautionary steps can be taken in order to prevent the formation of calcite formation. To avoid calcite formation suction pipes with a non-return strainer and, or a strainer/filter attachment can be utilized before water enters the pipes to prevent unwanted particles from entering the system. A pre-water treatment system could also be another option but it should be kept in mind that this would drastically increase the cost of the cooling system.

2.7.3.2 Conclusion

As of today, economical and technically viable design options along with effective cooling system information are still in early development. As a result, only a limited amount of data is currently available (Castanheira A., Fernandes J., Branco C., 2018). Therefore generating numbers regarding energy intensitivity for cooling and quantity of PV cell electrical output for each cooling technique is hard to determine and compare at this point. Moving forward, the team has determined the water sprinkler cooling technique to be the best option in terms of increased performance and energy gain, durability and the minimal maintenance required to upkeep the system.

2.8 Other Design Components

2.8.1 Floating Structure

The structure is an important part of the project and, due to the location chosen, ice and corrosion are two of the hardest inconveniences. To find a good material for the floating structure, the research has to be focused on the next chart.

Table 9. *Required characteristics of a floating material*

Corrosion resistance	high
Impermeability	high
Floatage / Buoyancy	high
Density	low
Rigidity	medium / low
Traction resistance	high
Bending resistance	medium
Deformation	low
Ice compressión resistance	high

Many materials have been considered such as wood, stainless steel, PVC, and other composite materials with fibers and special finishing treatments.

PVC, PE polyvinyl chloride (PVC) and polyethylene (PE-HD, PE-LD) belong to the plastics. In a study on the topic of corrosion in water pipes, the material plastic is generally classified as harmless (Förstner, 2012). There is no influence of the water on the plastic (corrosion), nor of the plastic on the water. For cable insulation often a so-called soft PVC is used, which is also used in the underwater cables. This PVC plasticizer (phthalates) are added, which are not bound to the plastic and thus easily escape (Umweltbundesamt, 2017). These can accumulate in 40 sediments and accumulate in the food chain via enrichment in fish. The effects of phthalates on humans are not fully understood. Due to controversial opinions, there are now also alternative plasticizers such as adipates, adipic acid polyesters or citrates. Hexamol® DINCH and citrates in particular have been scientifically studied and approved as plasticisers in toys and food contact. With these phthalate alternatives, there are no indications to date of negative health and environmental effects (Windsperger und Tuschel, 2007).

PE-HD is considered to be very resistant to diluted acids, alkalis, alcohol, gasoline, water, fats and oils. Solar radiation affects PE-HD, as well as most plastics, in its mechanical properties and in its color. Antioxidants or active carbon black are often used as UV protection.

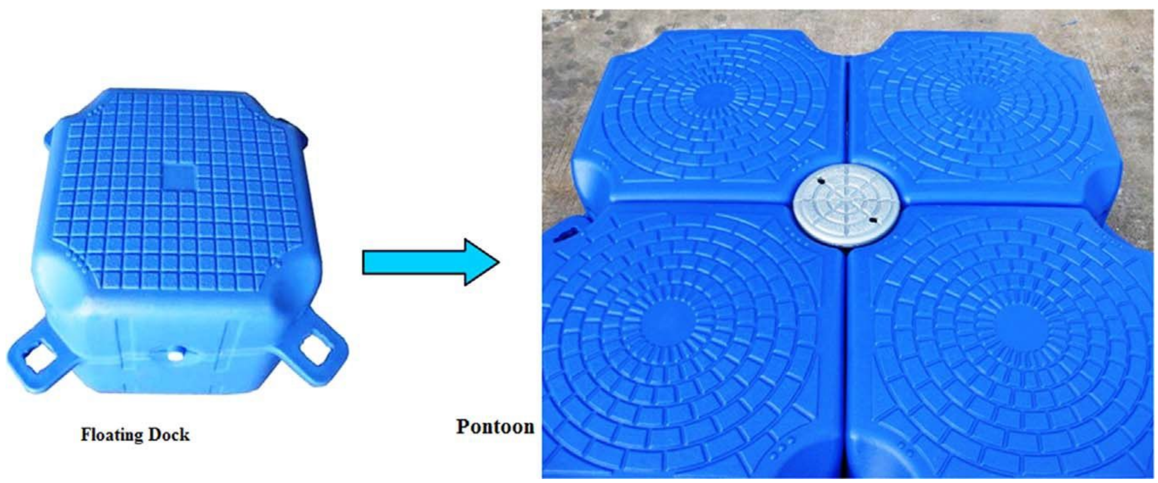


Figure 25. *PE-HD Floating photovoltaic power plant parts*

Polyethylene is water-repellent and does not swell when stored in water. Due to its resistance to chemicals, PE-HD has been the preferred material for drinking water pressure pipes and sewage pipes for more than 40 years. From the food and pharmaceutical perspective, there are no concerns about the use of PE in the water and it is a non-dangerous variation for the platform building in floating solar park foundations (Domininghaus, 2012).

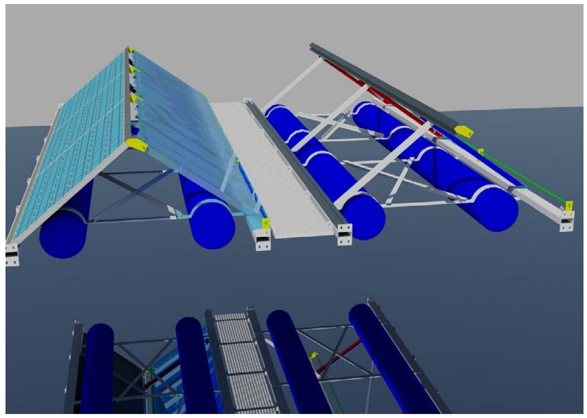


Figure 26. *Submerged & floating photovoltaic systems*

Nowadays there are some floating platforms in the freshwater area. Several test basins were installed in Singapore in 2016 in cooperation with the Solar Energy Research Institute of Singapore (SERIS). Ciel et terre, a French company, which is the leader in floating freshwater technology. Similar to floating footbridges in bathing lakes, Ciel et terre has developed a modular plug-in system consisting of polyethylene pontoons on which solar modules are mounted (Ciel et terre 2017). In 2017, 4CSolar built a first floating prototype of tubes, also made of PE-HD, in the Maldives (Smadja and Smadja 2017).

Kyocera, a Japanese company, is installing floating equipment in Japan using the polyethylene substructure of Ciel et terre and its own solar modules (Kyocera 2017). There is also a development concept of Swimsol in the freshwater area, in which polysurf pontoons are used instead of the polystyrene floats. This has the advantage that the entire construction manages with fewer components and as a result, the assembly is also less expensive. Larger systems can be installed in less time and installation costs are minimized. The French company Ciel et terre uses a custom pontoon type to mount their solar modules directly on top. These are also characterized by a very fast installation time (Ciel et terre 2017). In the new development concept of Swimsol, the floats originally made of styrofoam are exchanged for blow-molded polyethylene floats.

Nevertheless, there are other methods of building swimming platforms which are being tested just as a swimming solarpark in Albania by Statkraft shows.

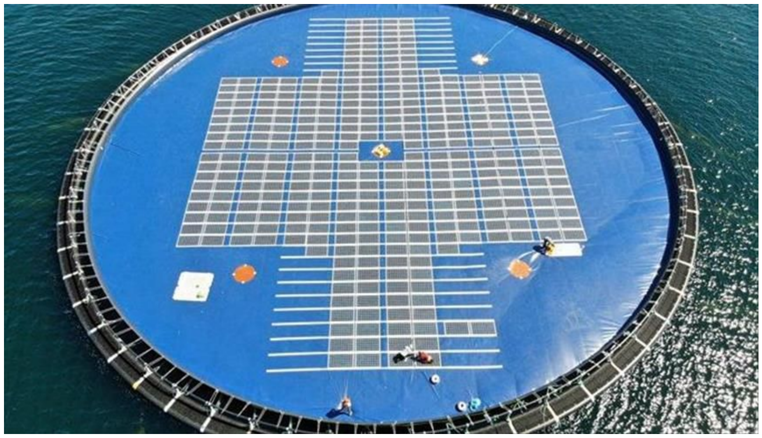


Figure 27. *Swimming Solar Park by Statkraft, Albania*

The PV Cells are mounted on a flexible membrane which is an effective barrier against the waterbody, carefully designed to withstand mechanical stress and sun exposure. This solution is a great alternative for more southern regions, but due to the fact that the angle to the sun can not be adjusted, the non-permeable membrane is not a solution for solar parks in Finland (Ocean sun, 2018). When you take all this in consideration, the most efficient way in building foundations for swimming solar platforms are the polysurf pontoons by Swimsol and the PE-HD variations, which capture the least cost and are easy to assemble.

2.8.2 Anchoring

Since many options for floating systems are available there are also many options for anchoring systems. Most of the anchoring systems consist of an anchor, being attached to a fixed object, or a combination of the two. Fixed objects include the land, a driven pile and pole, or something in the environment that is going to stay fixed.

After further research and a discussion about the structure type, it seems like the best options are to either anchor the structure straight down from the bottom and have another fixed point off to the side to limit the structure from rotating all the way around or to anchor the structure at points diagonal to each other and either cross the anchors inward or place the anchors farther apart to hold them in place. The following figures detail the two ways anchors could be placed.

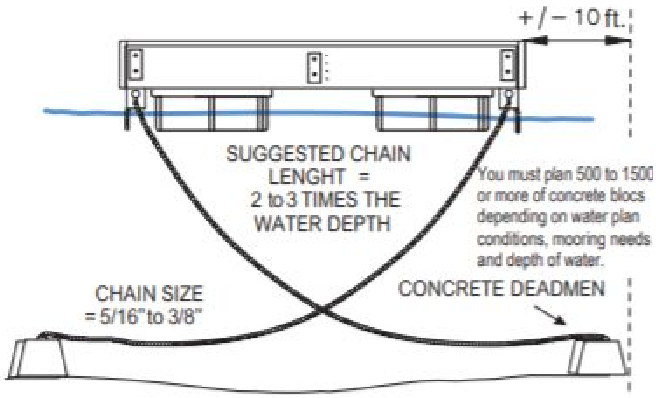


Figure 28. *Chains Crossed Inwards* (How to Anchor a Dock System)

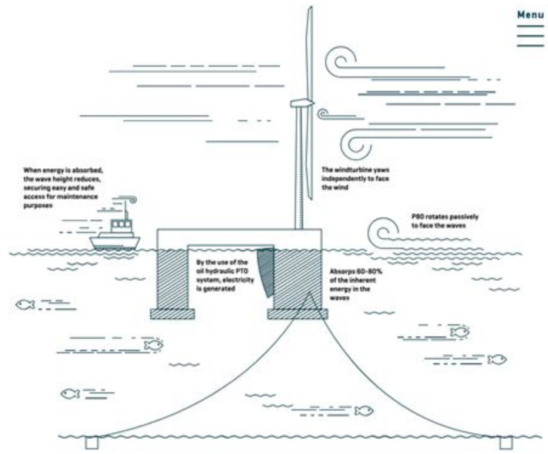


Figure 29. *Chains Going Outwards* (Floating Power Plant…)

These anchors can be dredge-anchors that will stick into the ground further as the platform moves around a little bit or can be a simple concrete block that is of enough weight to hold the structure in place.

2.8.3 Rotation

As for rotation, there seems to be two ways main ways to rotate the panels. One way is above water, which includes gear-like movement, and another way is under water where motors or propulsion machines would be necessary to move the platform.

Rotating underwater might be less accurate, but would require less of an exact design up front and would possibly require better solar tracking in the end. For below water rotation, there are many “motor-like” options. The best design seems to be to attach two motors to the outside edges of the floating platform and have them be able to spin both directions to rotate the platform back and forth to follow the sun. Options for motors could be an electric outboard motor, a pump that expels water quicker on one side that the other, or an electric propellor motor generally used for trolling. The final design will have to take into account the energy used to run these motors to see which one is the most feasible.

Besides the “motor-like” options, rotation above the water is also possible. This can be done in the form of a gear system on top of the floating platform that would be able to rotate as it tracked the sun. This could take the form of a singular rotating system is in the middle of multiple platforms holding panels and all rotating at the same time or a rotating system could be put in the singular structure, row, or panel even making everything more modular when it came to rotation. With this option, a more static anchoring system would be required. This type of rotation may also be more exact and could warrant better efficiency values, but could also incur a higher energy cost to run. More research will be needed to produce a full energy analysis for the rotation system.

3. Design Process

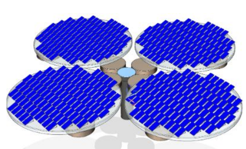
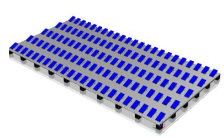
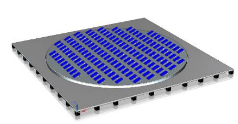
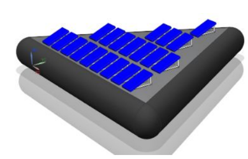
3.1 Four Initial Designs

To start, four initial designs were compiled. They were originally designed to try out multiple shape combinations. The design process started with these four different design configurations and through discussing and clarifying details the design was narrowed down into one final design. The following sections detail each design iteration and the process taken to narrow the design down further.

3.1.1 Details

The following table, Table 10, details the basic designs first mentioned in the Midterm Report. These designs come from compiling all of the basic background information collected into basic options and have since been dialed down into one final design.

Table 10. *Four Initial Design Ideas*

	Design 1: Rotating Circular Structures	**Design 2: Rectangular Structure**	**Design 3: Square with Circular Rotating Platform**	**Design 4: Triangle Shaped Inflatable Structure**
Shape and Structure	Four equal-sized circles around a smaller center circle, designated for rotation. Panels placed on the four larger circles. Structure is held up by a pole fixed in the lakebed. Stationary, doesn't need flotation device.	Panels are placed in straight columns and rows to form a rectangular shape structure.	Square structure with a circular inset that holds the panels. The square will be stationary, while the circular inset will rotate the track the sun.	Triangular in shape, this structure can easily be placed near other triangles to form different shapes.
Design Drawing				

	Design 1: Rotating Circular Structures	Design 2: Rectangular Structure	Design 3: Square with Circular Rotating Platform	Design 4: Triangle Shaped Inflatable Structure
Flotation	Not Needed.	Four HDPE platforms are used at the corners to support the weight. HDPE comes in many sizes and can be adjusted for the weight.	(See Left)	Outside consists of an inflatable inner tube. Tube rests on the outside, while structure for panels is housed on the inside.
Rotation	The center circle rotates around with gear-like pegs on the outside. The outside circles rotate accordingly in a gear-like motion around the center.	Two electric propeller motors rotate this structure. The two motors placed across from each other can propel the structure in two directions allowing it to rotate back and forth.	The square floating structure will stay in place, while the inset circle will rotate around within the square. This can be done with a gear system situated above water.	One anchoring point and two piston locations are used as anchoring points, panel can be attached to a post with the piston arm. With these piston arms, the triangle can be moved back and forth to rotate.
Anchoring	This structure is being held up by a singular pole in the middle. The anchoring method for this is simply the driven pile and pole holding up the structure. This pile and pole will need to be concrete or metal so that it does not disintegrate in the water.	The HDPE platforms will have anchors attached to the bottoms. Chains will come down to a point where all meet and go to one chain attached to the anchor at the bottom of the lake. Another anchoring point off to the side will keep the park in place.	The four HDPE platforms will each have their own chains attached to anchors. These chains will be placed in diagonal locations to ensure the platform does not move out into the middle of the lake.	The anchoring system and rotation system are one in the same. This includes poles or other nearby landmarks for anchoring and piston arms to hold the triangular shape in place. Land is also a viable option for anchoring in this case.
Cooling Systems	A coating could be used on the panels to reduce the heating effect they will receive from being used all day.	Forced air is a possible method for cooling the panels down. This would mean that the air blowing past the panel would be directed to help cool each panel.	A water spraying system would be established near the front of every row in an attempt to cool down the panels.	A water trickling system works best for this design as not all panels are in a straight row. The trickling method allows each panel to be cooled down directly without needing to put them around a central cooling system.

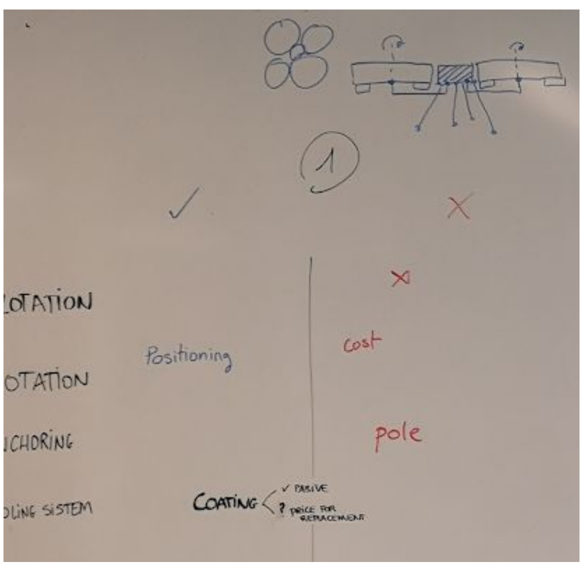
3.1.2 Discussion

The first four drafts presented in the midterm report were a compilation of all the different research done over the first month and a half. The objective was to visualize all the possibilities available so the team could discuss one by one the pros and cons of the different options. This last process has been done after the midterm presentation. In the next paragraph the conclusions are explained, giving as a result three new optimal designs. The costs and the feasibility of each component were studied so only the best design would be chosen to develop, test, and finally analyze.

The aspects discussed are the following: flotation structures, rotation systems, anchoring, and cooling systems.

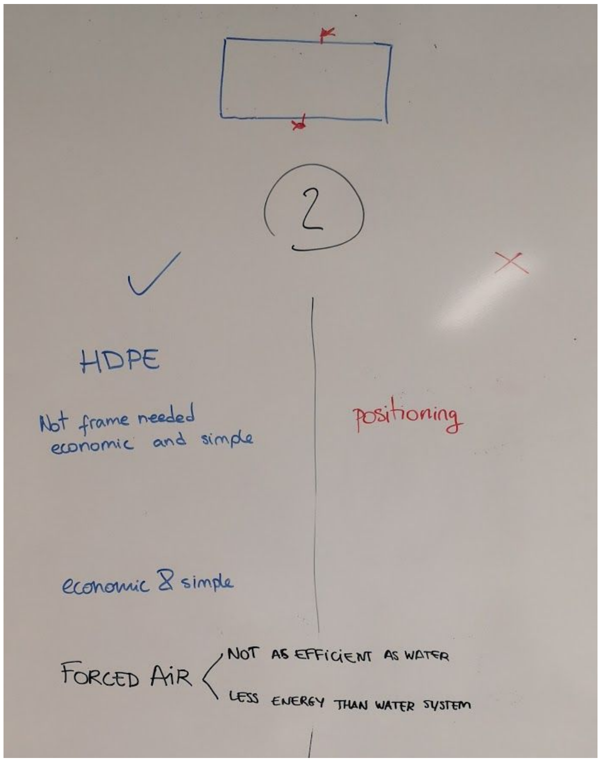
3.1.2.1 First Design

- No floating structure was considered in this design. The main structure was a pole or a rigid structure coming from the bottom of the lake/sea. This option seemed to very costly and did not utilize the biggest factor in this project description.



- Gears as a rotation system is a good solution to achieve high precision. Motors are controlled by encoders to have a precise positioning. On the other hand, price and maintenance are big inconveniences.
- The anchoring system, as mentioned before, is based on a main pole and is not what the floating solar park design should focus on.
- The cooling system established in this design was a coating method. This is a passive method that means no extra energy is required for cooling down the panels. The principal inconvenience is the cost to replace them when the coating is degraded from the sun's radiation.

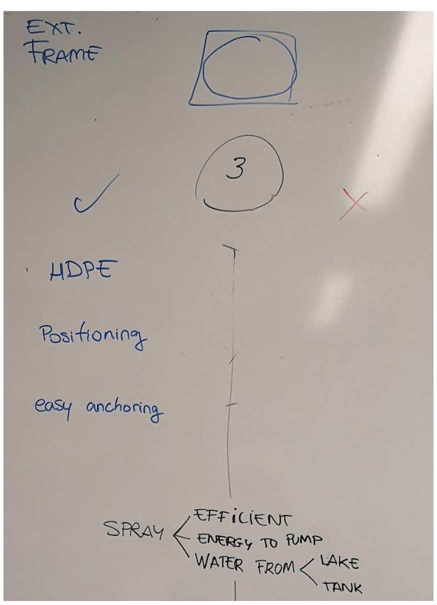
3.1.2.2 Second Design



The second model is the simplest one. It consists of a rectangular or square shaped platform so space is better used to fit the most panels.

- HDPE blocks are the main component of the floating structure. These are plastic boxes that resist water, are good in low temperatures, and resist high tensions. This material is commonly used to make floating platforms, docks, or support boats or other big machines in water.
- There is no fixed structure in this design so the material needed will come from the structure needed to support the panels. No external or central frame is needed but that means there is not a consistent reference point so positioning is not as precise as in the first design. This rotation system is quite cheap but the efficiency of the park will decrease.
- The anchoring system is economical and simple, but again, positioning is not accurate enough and the connection to the grid can generate problems while rotating this structure.
- Forced air is the cooling system proposed here. Cooling with air is less efficient than cooling with water but it requires less energy which is a major advantage.

3.1.2.3 Third Design



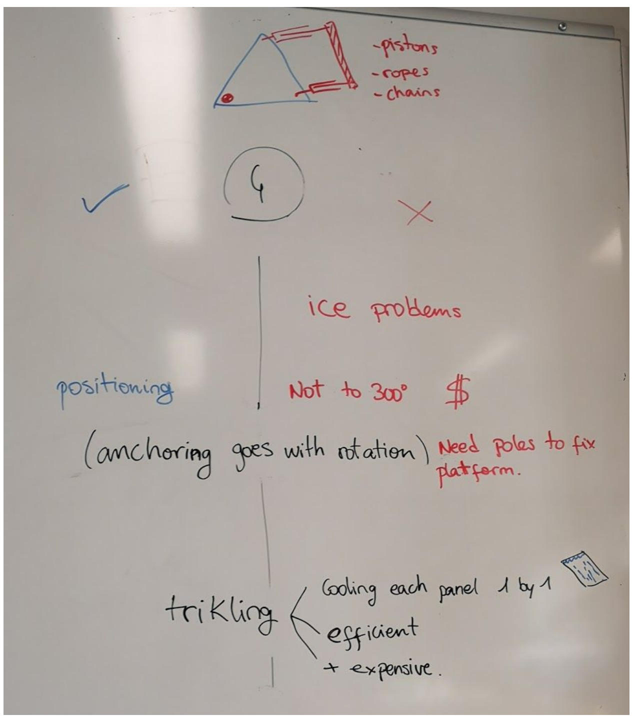
The third design has an external frame, first detailed as a square frame, but during discussion evolved into a ring shape frame. The main structure in the middle is where the panels will be placed. The outside frame is a fixed structure and the inside is the rotating structure.

- The floating system is the same as the second design. HDPE cubes will be the base and support the whole structure on top. It’s possible that too many cubes will be needed to make it cost efficient, so the weight of this structure will be important.
- The rotation can be done in many different ways such as using gears, chains, or other methods. Positioning is going to be precise because the frame will work as a fixed reference and encoders can control the motors’s movement.

- The anchoring in this design is easy and cheap. Only the outside frame has to be anchored. As this is going to be static, the chains connected to the anchors will not interlace.
- Spray could be the best cooling system for a floating solar panel park. As said before, cooling with water is more efficient than cooling with air. For spraying, a pump is needed to spray the water, but it only requires a low amount of water because it combines it with air in high pressure. The water used can come directly from the lake or from a tank on the structure. Additionally, the same spray system can reach more than one panel which saves on cost, maintenance, and initial construction.

3.1.2.4 Fourth Design

The final design is more unique and required extra discussion. The triangular shape was not easy to initially work with. Pistons, as rotation, also adds complexity.



- The floating structure has rubber components that may have problems with ice and corrosion because of the water and air beating on it.
- Rotation can be very precise because one of the three edges of the structure is fixed and pistons, ropes, or chains pull or push the other two edges to move the platform. The main disadvantages are that a fixed system is needed. With a fixed system, the design is not taking advantage of the floating ability of the design. This system is also not able to turn the platform 300º as needed.
- The anchoring system goes with the rotation system. Poles are needed to fix the edges and that is an expensive solution especially in water.
- Water trickling is the most efficient cooling system for panels but also the most expensive. Water falls down from all of the panels so tubs, valves, and sensors would be required for each panel set.

3.1.3 Decisions

After discussing these designs, the team found that some of the solutions were clearly worse than others so the next step was narrowing down the options by getting rid of them. The eliminated solutions are explained below.

- The next designs will all be floating since that way it can take advantage of placing the solar park on the water. The pole option is also more expensive and does not offer any added advantages compared to placing the park on land.

- The way to make the structure float will be by using HDPE pipes or blocks because inner tubes can break easily.

- In the case of having a static frame, the best rotation system is one based on gears because it allows the platform to turn 360º and it is made of resistant materials. It also allows the rotation to be very precise.

- The platform structure will be made only of the rows that hold the panels instead of it being covered completely between the rows. Full coverage would be an extra cost that is unnecessary.

There was not a decision related to the cooling system as the relevant information to make that decision comes from the energy balance and the working temperature of the panels. Any of the options can be added to the final design if it is considered appropriate.

3.2 Three Detailed Designs

These three designs are not as detailed. This is because there was less time to go so in depth into the way they would work and because they are mostly just a stepping stone used to establish general ideas in the effort to keep narrowing the path towards the final design. These ideas are mainly about the structure, the rotation system, the anchoring, etc. but not about the kind of panels and systems added to increase the efficiency. Those can be added to any of the designs later.

3.2.1 Details

3.2.1.1 First Design

The first design is quite simple, it is essentially a floating platform that holds all the panels and can rotate to track the sun by using some kind of outboard system, either motors or jet skis. As this rotating system does not need a immovable part, this design will not have any kind of frame, which implies that the anchoring point must be in the center of the platform so that it can rotate. As there is not any limitation about the shape of the platform a square shape has been chosen because it allows for the most efficient use of space.

Figure 30 below shows a sketch of the design where all the panels are fitted onto one platform to create a 1 MW park. However, the panels can easily be divided into smaller platforms if it is convenient. Also, the structure under the rows of panels that help to keep the structure rigid may vary in case the calculations reveal that this is not the optimal way to configure them into a square.

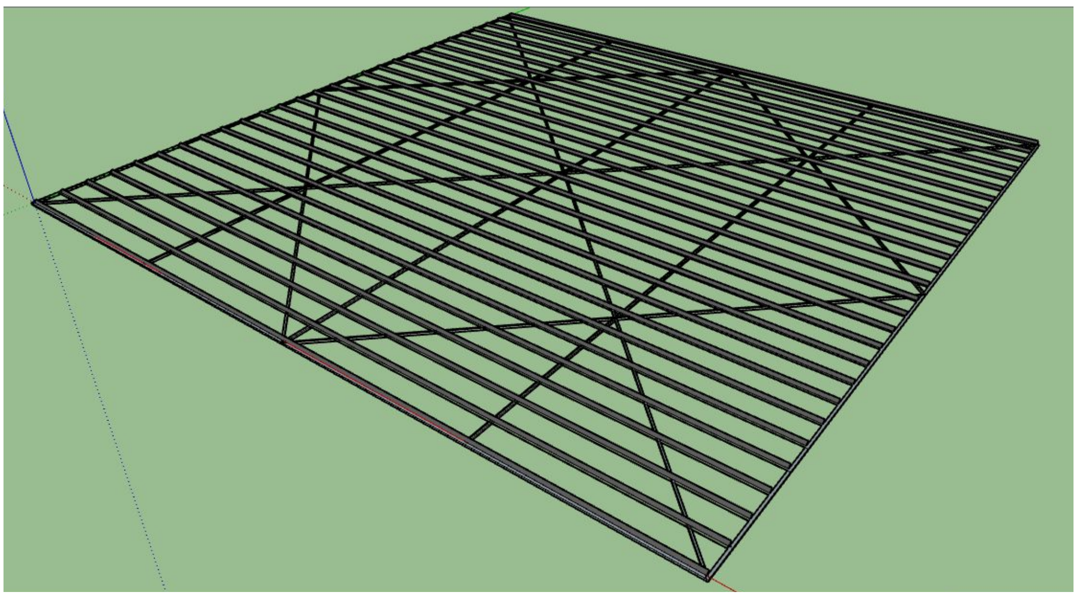


Figure 30. *Sketch of First Design*

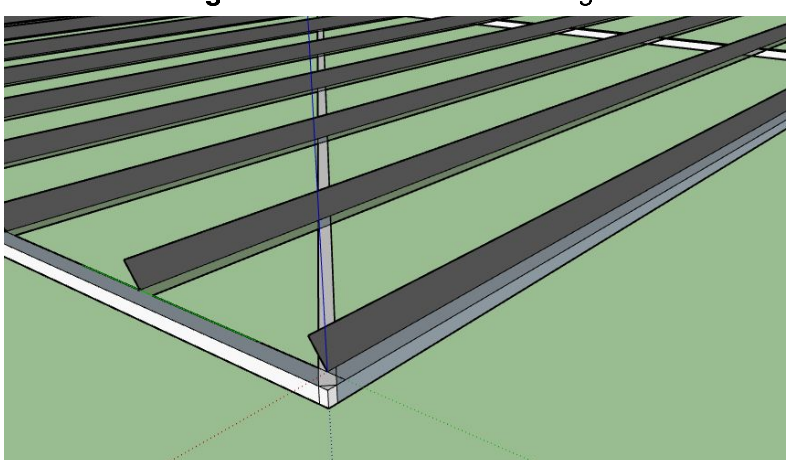


Figure 31. *Closer View of the First Design*

3.2.1.2 Second Design

The second design is based on having a steady, immovable platform that allows multiple anchoring points to be possible and gives a stationary supporting point for the rotation system. This stationary platform is in the middle of the park and the panels are placed on four circular rotating platforms situated around the central one. The rotating platforms are linked to the central platform by one beam under the water that allows them to rotate without separation. The design is shown below in Figure 32. As it is shown, the motors are situated either on the tip of the beam connected to the rotating platform or on the edge of the steady platform, provide the rotation.

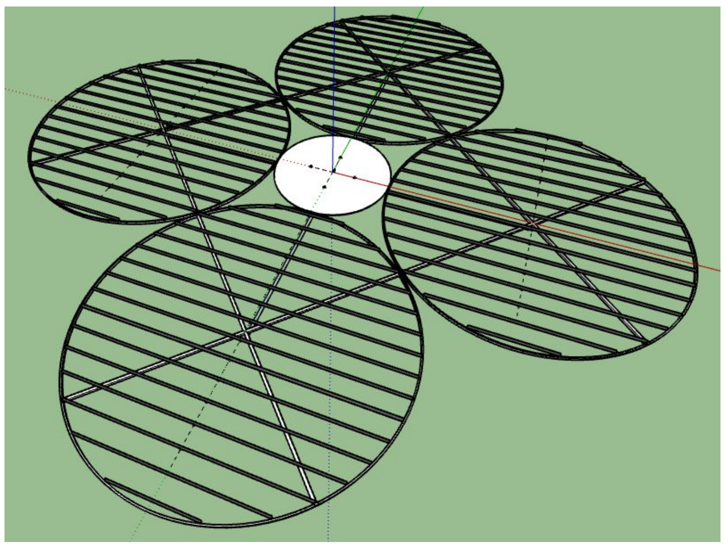


Figure 32. *Sketch of Second Design*

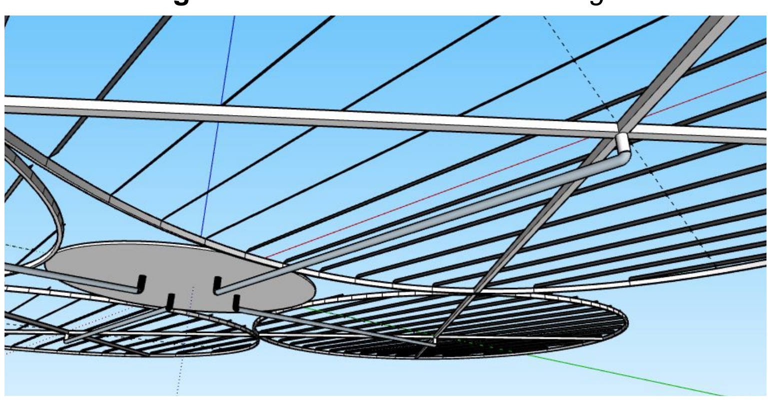


Figure 33. *Detail of the Beams Connecting the Center Platform with the Rotating Platforms*

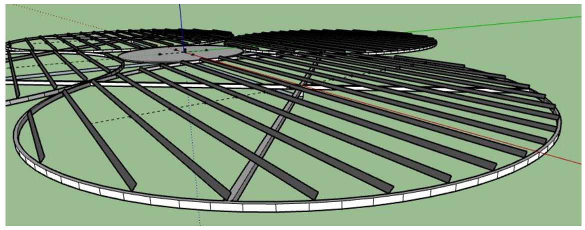


Figure 34. *Closer View of the Second Design*

In a similar way as in the first design, this can be divided in multiple smaller modules and even the number of rotating platforms per steady platform could vary.

3.2.1.3 Third Design

This design has a stationary frame around a rotating platform that holds the solar panels. This frame can be anchored easily and gives a supporting point for the rotation. In this case, only normal motors are needed. They would be attached to the frame and something like a wheel or a gear, on their axes, would be touching the side of the rotating platform so that when the motors run the platform turns. Also some kind of bearings will be needed to keep the moving platform in its place.

More than one of these structures will be needed to have a 1MW park, doing it in only one structure would result in a huge platform that would experience many problems.

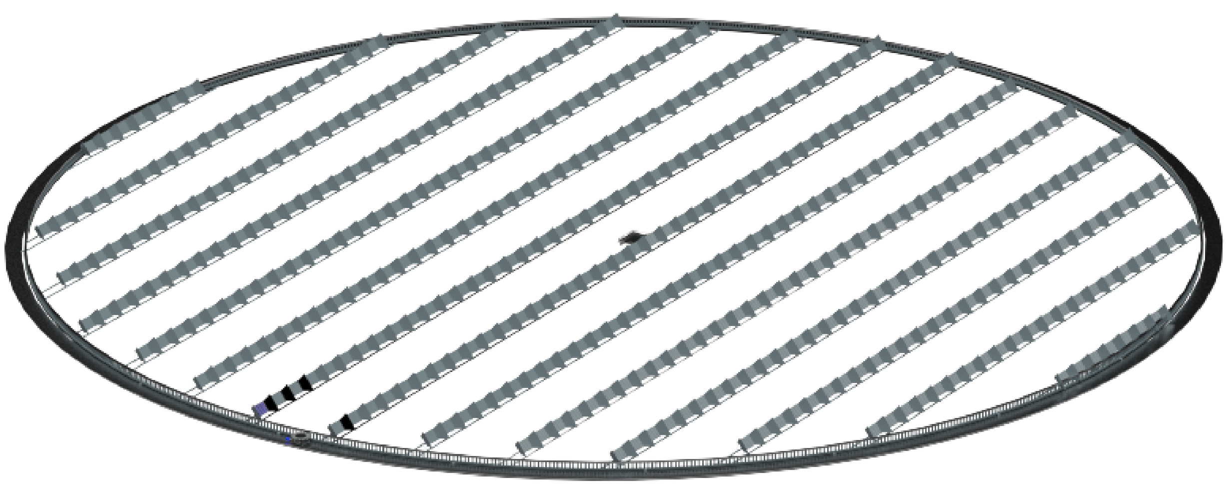


Figure 35. *Sketch of Third Design*

3.2.2 Discussion

For this iteration, strengths and weaknesses of the designs were discussed. Table 11, 12, and 13 below present the strengths and weaknesses about each design.

Table 11. *Strengths and Weaknesses of Design One*

Design One	
Strengths	**Weaknesses**
No frame	More difficult access
Best use of space	Rotation is not so accurate
Easy modularity	Difficult to connect to the grid
Easy to manufacture	Anchoring from center leads to the most movement

Table 12. *Strengths and Weaknesses of Design Two*

Design Two	
Strengths	**Weaknesses**
Small frame	Large beams to keep everything together
Fixed part can be anchored directly	Not very efficient rotation system
	Modularity is not easy to accomplish
	Many movable parts that can break

Table 13. *Strengths and Weaknesses of Design Three*

Design Three	
Strengths	**Weaknesses**
Very easy to anchor	Large and expensive frame
Easy access	Ice can cause problems between platform and frame
Simple and accurate rotation system	Many movable parts that can break
Easy modularity	

3.2.3 Decisions

The first design has a significant issue caused by forces of the wind and waves. As the anchoring has to be done from a central point, the platform can not be prevented from rotating when it is not desired. The outboard motors would need to be working almost all of the time to correct the position, which would consume a lot of energy and would still be very far from a perfect tracking system. Due to this, and considering that the other two designs solve that problem easily by having a stationary part, this design was discarded.

The second design looks better, but there is something that may not be totally realistic: the very long beams that keep the platforms together. The forces on the rotating platforms will probably be too high to be resisted by only these long beams. However, the third design looks more realistic in the way that it keeps everything together and, in general, is more feasible even though the price may be slightly higher because the frame will have to be bigger.

To be more sure about this decision, all the designs should be studied more deeply and smaller details should be analyzed. That would require a significant amount of work and time that is not available, so the final decision was to go ahead with the third design. This will be the only design that will be totally developed.

3.3 One Final Design Option

Finally, after several design discussions, one unique design was developed. This design combines the best technology for all of the park components. The panels that are going to be used are bifacial solar panels with mirrors attached and the platform structure will be based on the previous design iterations Design Three. Each section going forward will explain the design and the reasons behind the decisions made.

3.3.1 Energy Increasing Systems and Estimation of Energy Production

In this section, different possibilities to increase the energy output will be discussed to help decide what the best combination is and, along with an estimation based on climate and surrounding conditions of the park, a final energy estimation will be calculated. But first, it is necessary to gather information about how the bifacial panels and mirrors could work by doing some testing.

3.3.1.1 Testing

For the testing phase of this project two multicrystalline silicon panels were used.

Table 14. *Specifications of the Panels used for Testing*

Peak Power (W)	10
Maximum Power Current (A)	0.57
Maximum Power Voltage (V)	17.49
Short Circuit Current (A)	0.61
Open Circuit Voltage	21.67

3.3.1.1.1 Test on Bifaciality

The objective of this test was to determine how much extra energy could be produced by installing bifacial panels instead of conventional ones. As bifacial panels were not available for this testing, the two panels described above were used. The experiment was done in different locations in order to determine the difference in power output depending on the surface the panel were placed on.

Description of the Test

To imitate the performance of a bifacial panel, the two panels were placed one behind the other so that the one in the front was pointing to the sun (simulating the front side of the bifacial panel) and the one in the back was pointing to the opposite direction (simulating the back side of the bifacial panel). In addition to the panels, two multimeters and a decade resistor have were used; the multimeters were used to measure current and voltage in order to know the power generated by the panel and the decade resistor was used to set the resistance that allowed the panel work at its maximum power point.

The electric components were set up as follows:

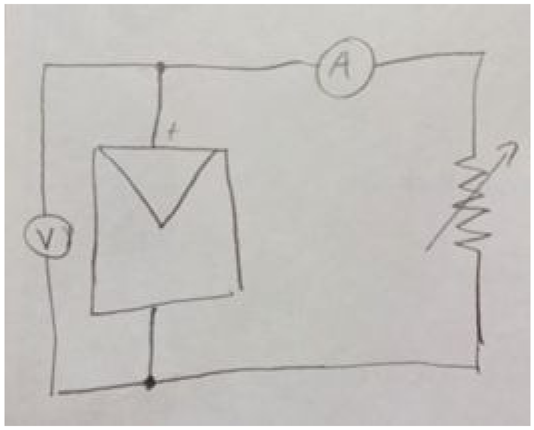


Figure 36. *Electrical Scheme of the Test on Bifaciality*

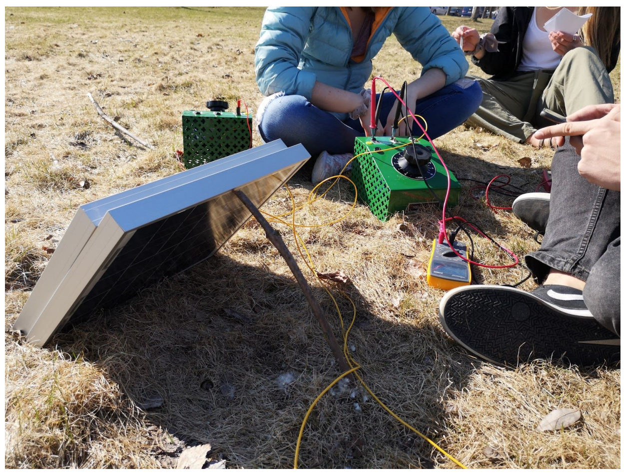


Figure 37. *Test on Bifaciality Setup*

The electrical assemblage shown in Figure 36 was repeated for each of the two panels. Figure 37 shows one of the real-time tests being done.

Results

The following table details the results from testing the bifaciality in the multiple locations. The voltage and current were collected during testing and the power and extra power gained were calculated.

Table 15. *Results Obtained in the Bifaciality Test*

		Voltage (V)	Current (mA)	Power (W)	Extra power
Grass	Front	17,25	657	11,33	4,26%
	Back	17,23	28	0,48	
Snow	Front	17,79	649	11,55	7,15%
	Back	17,94	46	0,83	
Water	Front	17,94	475	8,52	3,59%
	Back	13,9	22	0,31	
Mirror	Front	14,44	447	6,45	8,79%
	Back	15,33	37	0,57	
Cloth	Front	14,44	447	6,45	4,71%
	Back	16	19	0,30	

Analysis

The first conclusion of this test is quite obvious: the surface is relevant to determining how much energy can be produced by the back side; the more light that is reflected by the surface, the more energy will be generated. The capacity of a surface to reflect light is measured by the albedo coefficient. This coefficient gives the relation between the amount of light reflected and the amount of light striking the surface. The values of the albedo coefficient for different surfaces have been measured in numerous studies and the results are quite different. However, it is still easy to see the correlation between the albedo coefficient and the results of this test. For instance, the highest results correspond to mirrors and snow, which also have the highest albedo coefficients.

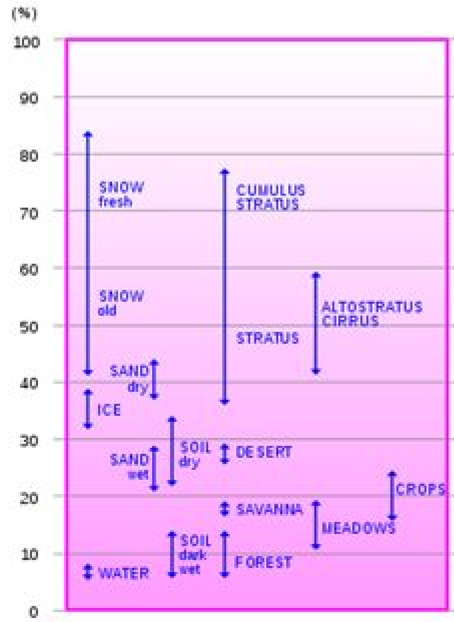


Figure 38. *Percentage of Diffusely Reflected Sunlight Relative to Various Surface Conditions*

The above figure shows the differences in albedo coefficients.

Conclusion

As the solar park will be on the water, it is important to know how it influences the performance of the bifacial panels. Water's albedo coefficient depends on the angle the light strikes the surface. The more perpendicular it is, the less light is reflected; that could be a good advantage in such a northern location where the sun is usually very low in the sky. However, the back side of the panels will not be pointing to the sun, but the opposite and, therefore, the light used to generate electricity is diffuse irradiation coming from everywhere. In Figure 38 it is shown that the percentage of diffuse light reflected by water is quite low compared to other surfaces. Also found in the results of the testing, the relation between the back side and front side's power outputs on water (3.59%) is the lowest of them all.

Nevertheless, panel manufacturers claim that up to 30% more energy can be generated by using bifacial panels and some studies show that these panels can produce between 10% and 20% more energy even on low albedo surfaces (Castillo-Aguilella & Hauser, 2016). Moreover, this testing was done on sunny days where the fraction of diffuse irradiation compared to the total irradiation was low; on cloudier days, the power generated by the back side will be closer to the power generated by the front side.

As an estimation of the energy production increase is needed to decide about the bifacial panels, a medium point between the diverse results will be considered: 6%.

3.3.1.1.2 Test on Mirrors

Another method to increase the efficiency is the use of mirrors. They increase the surface where the panel can receive light from the sun. As it is not clear what the real energy gain by using a system of this kind is, a test has been done to find it out. The test is divided in three phases: (1) a panel without mirrors is tested in the lab with a powerful lamp; (2) the same panel with mirrors is tested under the same conditions; and (3) the results are analyzed and compared.

Materials used on the test include:
- 10 W solar panel
- 1000 W lamp
- Arduino uno board
- 2 arduino voltage sensors
- Resistor (26.8 Ω)
- Variable resistor
- Optical thermometer

Procedure

The following schematic shows how the test was set up.

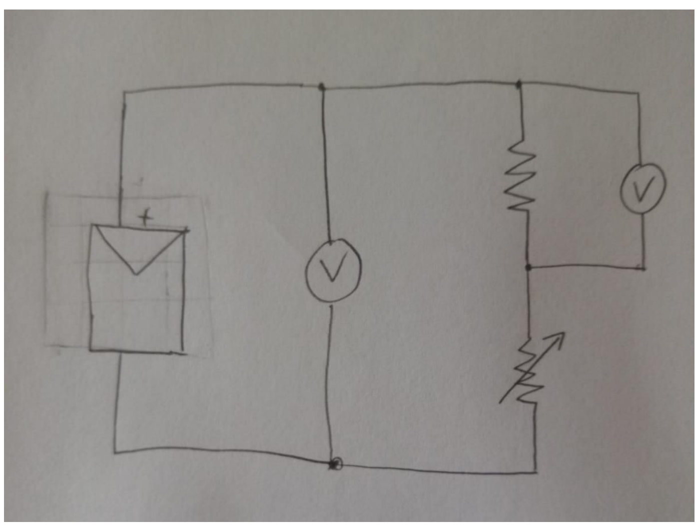


Figure 39. *Electrical Scheme for Mirrors Test*

As a current sensor accurate enough to measure such small currents was not available, a voltage sensor was used to calculate the current by connecting it to a resistance whose value is known by applying Ohm's law. Another voltage sensor measured the voltage generated by the panel and a variable resistance was used to reach the maximum power point. Both sensors are connected to the arduino board, which was programmed to take measurements every second and store the data on an SD card.

To measure the temperature, an optical thermometer was pointed to the center of the panel with a variable frequency depending on the moment of the test and the measurements were noted down manually. To make sure that the time the temperature measures were taken was registered, a switch connected to the arduino was switched on every time the temperature was measured and an indication of it is included in the data stored on the SD card. When the experiment was done, all the data was analyzed using MatLab in order to draw plots and calculate results.

Test Without Mirrors

The figure below shows both the power of the panel over time as well as the temperature of the panel over time.

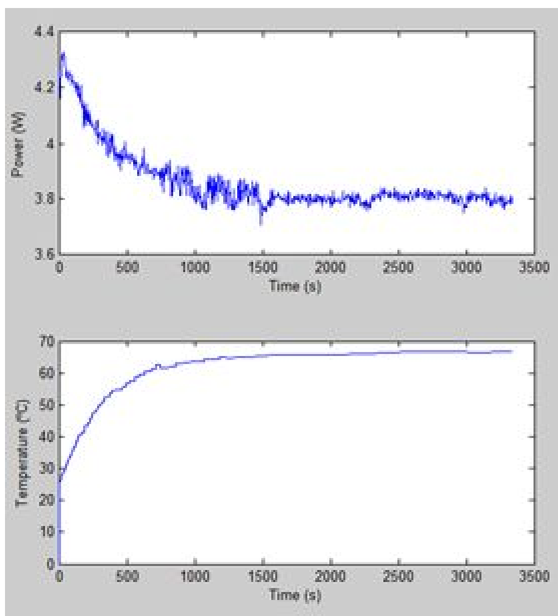


Figure 40. *Plots Showing the Power and the Temperature During the Test Without Mirrors*

As shown in Figure 40, the efficiency decreases as the panel heats up. The test was started at 25.8 ºC, where the panel was generating around 4.3 W, and the highest temperature reached, when the temperature stabilized, was 66.7 ºC, and at that time the panel was only generating around 3.8 W.

Test With Mirrors

The mirrors were set up as shown in Figure 41, forming an angle of 60º with the plane of the panel. This way to set the mirrors was not chosen randomly, geometric calculations were done to find out that, when the total surface of the mirrors is the same as the surface of the panel (as it is in this case), the right angle to distribute all the reflected light equally on the panel is 60º. Thus, each mirror reflects the light to one half of the panel and the total surface perpendicular to the light beams is increased by 50%. This also means that the amount of light which can be converted to energy is increased by 50%.

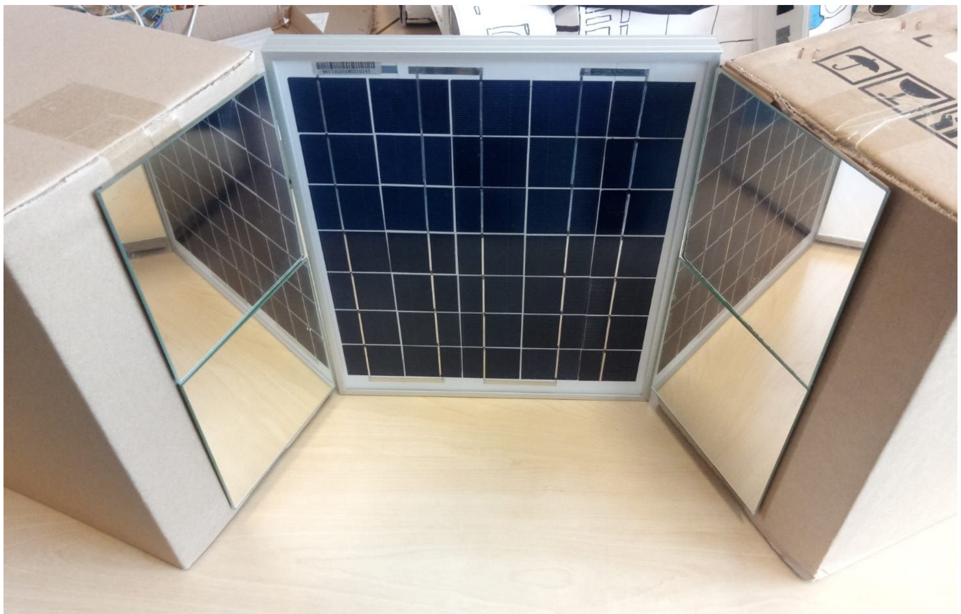


Figure 41. *Setup of the Mirrors for the Test*

Again, the following figure details the power and the temperature of the panels during testing.

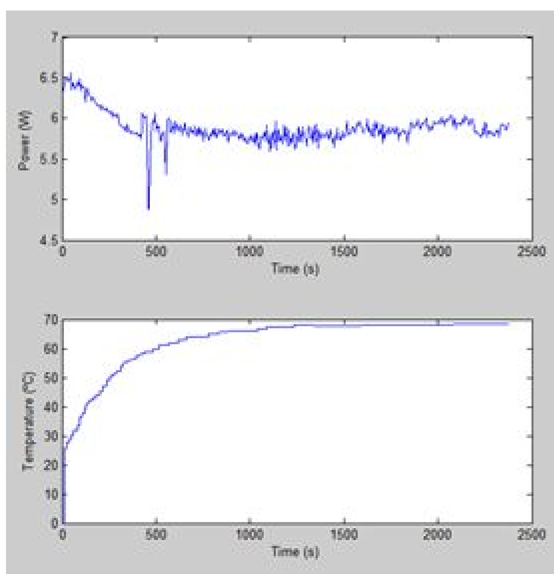


Figure 42. *Plots Showing the Power and the Temperature During the Test with Mirrors*

Despite some fluctuations caused by an adjustment of the variable resistor, performance of the panel (Figure 42) is quite similar to the test without mirrors described above. Starting at 25.8 ºC, the panel generates around 6.5 W and as the temperature increases, the efficiency decreases until the thermal balance is reached, at that point the temperature is at a maximum of 68.5 ºC, and the power generated is 5.8 W.

Comparison

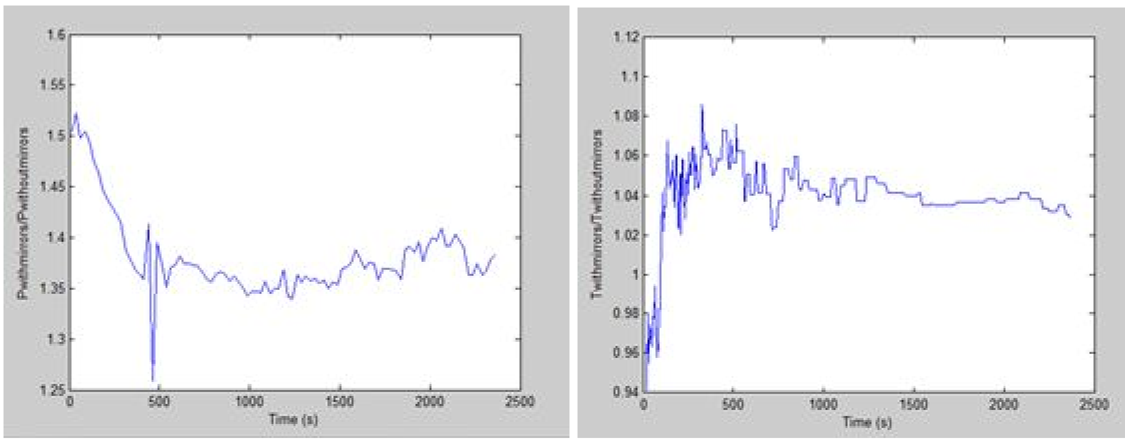


Figure 43. *Plots Comparing Power and Temperature in Both Tests by Showing the Relation Along the Time*

In Figure 43, the beginning of the test is shown to generate 50% more power from the panel with the mirrors. As the figure also shows, as the panels heat up the power gain will start to decrease. This is because the panel with mirrors receives more light and, therefore, it gets hot faster and reaches a higher maximum temperature, which reduces the efficiency of the panel.

To make an estimation of the extra energy that can be generated by using mirrors, a medium increase of power was calculated. The data used to do this is the relationship between power with and without mirrors but only from 1000 seconds until the end. After that point the temperature is stable and that state can be considered as normal when the panel is working in a real situation. The result is a 36.99% energy gain which will be the estimation used to decide on the use of mirrors in this design.

It is also important to note what the temperature increase was when mirrors were used because very high temperatures can reduce the life expectancy of the panels. The same way the extra energy output was calculated above, it was found that the medium temperature increase when the thermal balance was reached was a 3.88% increase. The actual difference between maximum temperatures in both tests was only 1.8 ºC, which means that adding mirrors to the solar panel park will not increase the temperature enough where a cooling system would be required.

3.3.1.2 Energy Estimation

Conventional Park

The first step is calculating an estimation of the energy output without considering the effects of installing the park on the water and the extra energy output coming from the bifacial feature of the panels and the mirrors installed. In order to do this a PV system was used. In this software it is possible to introduce the characteristics of the solar power plant and climate data so that it can simulate the performance during one year.

Table 16. *Specifications in the Simulation of a Conventional Park*

Characteristics	
Panel Type	Panda bifacial 60 CL (without bifaciality) (330Wp)
Inverter	Ingecon Sun 1000TL U X400 Outdoor (1 MW)
Distance Between Panels	7.54 m (corresponding to spaced design)
Slope Angle	53º
Modules in Series	22
Number of Strings	138
Total Power	1002 kWp
Number of Panels	3036

Table 17. Results of the Simulation of a Conventional Park

Results	
Total Production (MWh)	1297.8
Specific Production (KWh/KWp)	1295.2
Production Mar-Oct (MWh)	1212.4
Specific Production Mar-Oct (KWh/KWp)	1210.0

These results are better than the ones obtained in the section called “Placement of the Panels” because in this case a bigger inverter of 1 MW was used instead of a small inverter for only one panel. The more powerful inverters are usually more efficient because they are designed for large solar power plants where the smallest difference in efficiency matters. As an effective method to keep the plant working during the winter has not been found, the production from March to October will be considered henceforth.

Cooling Effect of Water

The humidity around the lake and the temperature of the water, which will be lower than the air during the summer, will have a cooling effect on the solar panels that will increase their efficiency. This is one of the main reasons to build a solar park on a body of water and it could work especially well in Finland where there is still ice in the water during March and April so the water stays cold for longer.

There is not information about the energy gain due to this effect specifically in Finland but, in other locations, it is usually estimated that 10% more energy is produced due to the cooling effect of the water (Rosa-Clot, M., Tina, M. G., 2018).

Bifacial Panels

As noted in the testing section, the estimation for the energy gained when using bifacial panels is 6%, which is not so significant. Moreover, bifacial panels are more expensive than normal ones, around 30% more depending on the quality. However, the cost of the panels usually represents between 30% and 50% of the total cost and it could be even less in this case because the floating structure will probably be more expensive than the structure of a traditional solar power plant.

Thinking about it from that point of view, it is still not a good idea to increase the cost by around 9% (30% of 30%) to increase the income by only 6%. Nevertheless, there is an extra function that could be utilized by using the bifacial panels that may make it worth it to have them instead of conventional panels. During the winter months when ice does not allow the platform to turn and snow may cover the panels, the park could be pointed to the north so that the back sides of the panels can receive light, either directly from the sun or reflected off the ice (which has a quite high albedo coefficient) or reflected off of the water (which also has a very high albedo coefficient when the light is striking it forming a low angle which happens in the winter).

Working this way, the panels would generate some energy and would also heat up and possibly help to melt some snow and ice so that the park can start to work normally earlier in the year. This is a very innovative idea, so there is no information about how well this could work or how much energy the park could generate by doing it. Therefore, as there is no way to make an estimation of the energy produced, it will not be included in the energy estimation.

Mirrors

Unfortunately, it is not easy to find information about how much energy can be gained by using mirrors and the studies are always done with setups that are not applicable to this project. A specific test was done for this specific project and the results look quite reliable. In the test, the energy gain by using mirrors was 36.99% and this will be, going forward, the estimation in this project.

The set up will be very similar to the one used for testing: one mirror of half the size of the panel on each side of the panel, forming a 60º angle with it and reflecting the light of each mirror to one half of the panel. The difference in shape comes in because the sun's height varies over the length of a day but the panels are not following that movement. Because of this, square mirrors would not catch all the light when the sun is too high or too low for the panels. To make sure that all the light coming from the sun, at any time, will be reflected on the mirrors a trapezoidal shape has been given to the mirrors as shown in Figure 44.

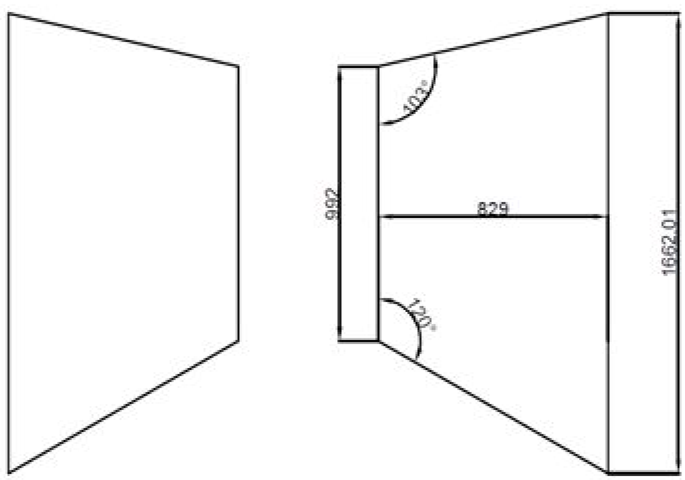


Figure 44. *Shape and Dimensions of the Mirrors*

The area of one of these mirrors is 1.1 m^2, so the surface of mirrors needed for each panel is 2.2 m^2. The price of the mirrors is \$2.2/m^2, so the price of the mirrors for one panel would be \$4.84. The price of a panel is \$66 so adding mirrors would add an extra 7.3% cost but almost an extra 37% more of income, which make this option very convenient for this project. Adding mirrors will also add costs to the structure but the margin is so wide that we can assume that it will still be worth it to do so.

Cooling Systems

Cooling systems are also a way to keep the panels colder and increase their efficiency, but, although they can be very profitable in hot climates for conventional solar power plants, they are not so beneficial in this case. The reasons are two: Finland already has a cold climate that will not allow the panels to heat up much and the water under the panels already has a cooling effect. This implies that the panels could not be kept much colder by adding cooling systems and, considering the high energy consumption of this kind of system, it is very unlikely that it makes the park produce an extra significant amount of energy.

To prove this, extra testing would be necessary. The team does not have the time nor the resources for that, so it will not be considered in this project.

Conclusion
The following table summarizes the estimated energy outputs for the different design options.

Table 18. *Specific Production of the Park for Different Setups*

Setup	Sp. Production (kWh/kWp)
Only Normal Panels	1210
Panels on Water	1331
Bifacial Panels on Water	1410.9
Panels with Mirrors on Water	1823.5
Bifacial Panels with Mirrors on Water	1932.9

Even though the gain due to the bifacial feature is not much, it will be added to the park because of its added winter function, explained above. On the other hand, mirrors are proven to be worth it and will be added to the panels. By including all of these improvements the energy production is 59.7% higher than in a normal rotating solar park on land. Comparing it to a solar power plant without any solar tracking systems (energy production of around 865 KWh/KWp), the efficiency gain is huge, 123.4%. This addition is in response to the necessity of getting the maximum power from the panels in a place where the sun does not shine as much.

3.3.2 Frame and Structure to Hold the Panels

As explained in the previous chapter, bifacial panels are a great option for this floating solar panel park. One of the first things to define is the way the panels will be fixed on the structure. A frame is needed to hold the panels and also a resistant and stable structure is required to hold them in position. The principal objective is to use as less material as possible, making sure the structure is resistant enough to support winds of 140km/h and rigid enough to guarantee the correct position of the panels.

The structure is composed of an aluminium frame set all the way around the panel without covering any part of either side so that the panel can obtain as much light as possible. Four tubular legs follow from the corners of the frame to the base and a rectangular flat bar is shaped to fix the legs to the floating pipes and cross-brade in case of wind or waves. The possibility of using two legs per panel instead of four was discussed but stability is an important point since the structure will lay on the water and will be in constant movement. After discussing and calculating the shear stress and buckling potential with only two legs, it was determined that using four legs is the best option.

The following figure shows the frame, legs, and attaching structure.

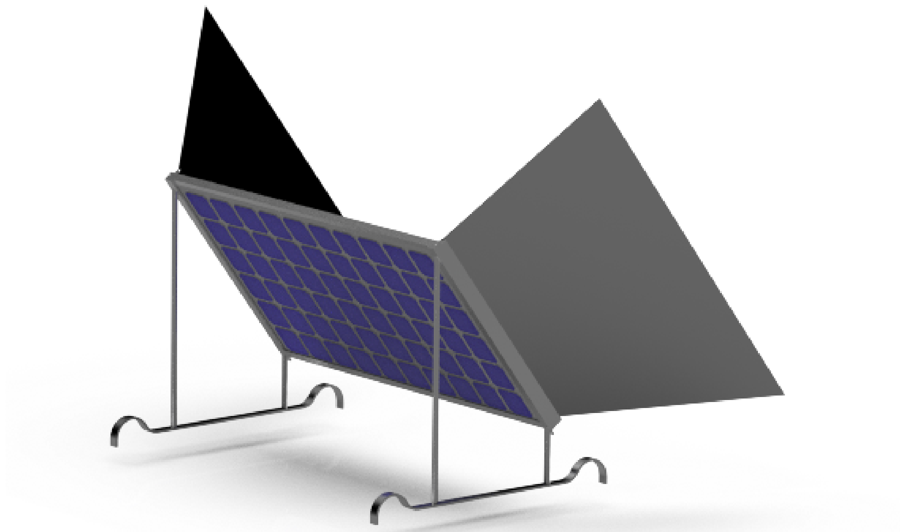


Figure 45. *Diagram Showing the Leg Structure Supporting the Solar Panel*

Mirrors are also added to the basic support structure. The principal idea is to attach them to the panel frame so they can be as close to the panel as possible. To save material, mirrors will be held up by the same legs as the panels, so as a result this structure will hold the panel and two mirrors.

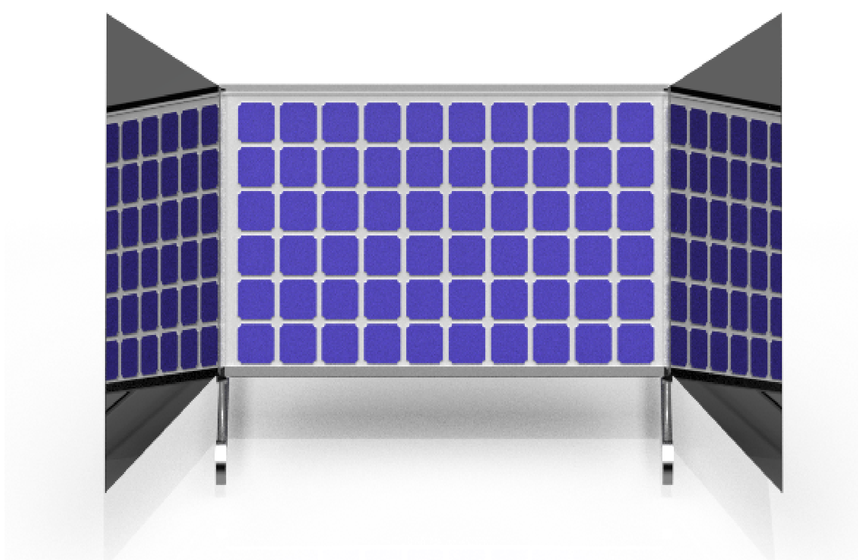


Figure 46. *Diagram of Mirror Attachment to Panel Structure*

To calculate the dimensions of the legs, the total weight of one panel and two mirrors was considered as well as the force of the wind blowing at 140km/h towards that surface. This was done to determine the proper leg size in the case of a large storm or other such forces acting upon this structure.

According to Engineering Toolbox's Wind Velocity and Wind Load calculation webpage, the equation to calculate wind load on a surface is $F_w = ½ ρ v^2 A$, where F_w is the wind force (N), ρ is the density of air (kg/m^3), v is the wind speed (m/s), and A is the surface area (m^2) the wind is blowing on (Wind Velocity and Wind Load). For these calculations, a maximum wind speed of 140 km/hr was used and converted to 39 m/s to fit the equation's unit requirements. This maximum wind speed was determined by looking at the research done in Marco Rosa-Clot's book, *Submerged and Floating Photovoltaic Systems*, and taking the maximum wind speed they predicted for floating solar parks on open bodies of water would experience (Rosa-Clot, 2018). This maximum speed should never be exceeded and that's why a maximum of this magnitude was used. Using this equation, a wind force of 2270 N was calculated. This was calculated by using the above mentioned wind speed, the full area of the panel, 2.487 m^2, to make sure that a factor of safety was included in the calculations, and a density of 1.2 kg/m^3. This 2270 N wind force was then projected horizontally at the panel and split into x and y components within in the plane of the panel (tilted to 53°). In addition to the wind load on the panel, the weight of the panel and mirrors also had to be taken into account. The weight of the panel and mirrors themselves is 45 kg. To convert that to a force, that weight was multiplied by 9.81 m/s^2. This produced a downward force, due to weight, of 441.45 N. This force was also then split into x and y components in the 53° angle plane of the panel. The following figures show the forces acting on the panel and consequently its four legs. Figure 47 shows the wind and weight forces, Figure 48 details their total combined components and the supporting reactions, and Figure 49 shows the consequent forces acting upon each leg.

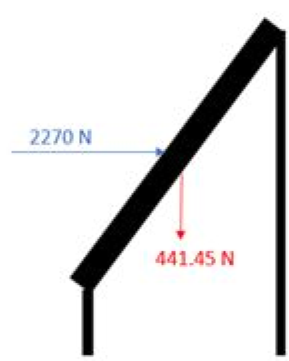


Figure 47. *Wind and Weight Forces on the Panel and Mirror Structure*

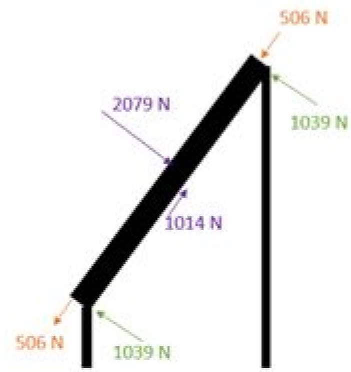


Figure 48. *X and Y Components on the Panel and Mirrors and Supporting Forces in All Four Legs*

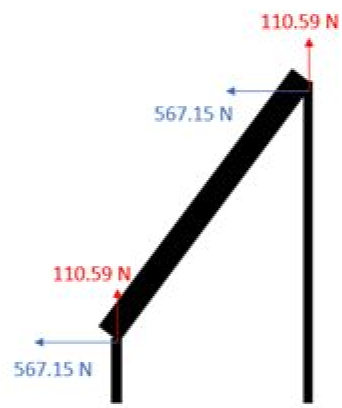


Figure 49. *Forces on Each Leg from Wind and Weight of Panels and Mirrors*

All design calculations were checked with MechaniCalc's Beam Analysis Software (Beam Analysis).

To complete these calculations, fixed ends were assumed, since the panel will be situated in a frame which will then be welded onto the legs below it. Welds can generally be assumed to be fixed ends in the case of static beam design. In total, there will be four legs, one on each corner of the panel, to help stabilize it and hold it at the correct angle. With the given angle of 53^{o}, the relative height of the panel is approximately 0.8 m. For ease in construction and to allow some air to flow beneath the panel, the front two legs will be 0.2 m in height and the back legs 1 m in height. These leg heights were chosen rather arbitrarily, but are used in the following structural analysis and work in the overall design.

Knowing the forces in the legs, the following structural analysis was done. Shear strength, deflection, and buckling were checked in this analysis. The metal of choice for this design is aluminum due to it being lightweight, yet strong. To start, the characteristics of aluminum were researched. The following table details the most important characteristics used in the analysis.

Table 19. *Aluminum Alloy 6061 Characteristics*

Aluminum Alloy 6061-T6		
Characteristic	**Value**	**Unit**
Modulus of Elasticity (1)	69	GPa
Ultimate Shear Strength (2)	1.86×10^8	Pa
Density (2)	2700	Kg/m^3

References: (1) (Modulus of Elasticity for Metals), (2) (TellSteel)

The first iteration of analysis was done on a 50 mm outside diameter (OD) hollow aluminum pipe. Once the first check, shear strength, was done, it was clear that this pipe was over designed for its use. With this knowledge, the second iteration was done with a 25 mm OD pipe and this analysis is shown below.

Shear Strength

To check the shear strength, the shear due to the pressure on the leg must be less than the ultimate shear strength of aluminum. This value would also, preferably, be around half of the ultimate shear strength, meaning it has a factor of safety of 2. Shear stress is calculated by dividing the vertical pressure by the area. The following MathCad screenshot details the calculations done to calculate the shear stress.

$$r_1 := 12.5\ mm \qquad P_1 := 110.59\ N$$

$$r_2 := 10.5\ mm \qquad E := 69 \cdot 10^9\ Pa$$

$$A := \pi \left(r_1^2 - r_2^2\right) = 144.513\ mm^2$$

$$stress_{ult} := \frac{P_1}{A} = \left(7.653 \cdot 10^5\right)\ Pa$$

Figure 50. *Shear Strength Calculations*

As one can see, the maximum shear that these legs are going to experience is 7.653 x 10^5 Pa, which is significantly lower than the ultimate shear strength of aluminum. This means then that this is a safe size for the leg in terms of shear strength. If one were to continue to iterate, one could find an even smaller pipe that could be used, but considering availability and price, pipes much smaller than 25 mm OD are generally for specialized use and are not worth considering in this analysis. The next two design checks are also done with the 25 mm OD hollow aluminum pipe. This pipe has a wall thickness of 2 mm and is the piping that was chosen to be used for this design.

Deflection

The maximum deflection in both directions in both the short legs and the long legs was calculated next. The equation to calculate deflection is $\delta = \frac{PL}{AE}$, where P is the pressure (N) exerted in the axial direction, L is the length (m) of the leg, A is the cross-sectional area (m^2) of the pipe, and E is the modulus of elasticity (Pa) of the material. The following MatchCad screenshots detail the calculations done to estimate the maximum deflections of each leg in both directions.

$r_1 := 12.5\ mm \quad P_1 := 110.59\ N \quad L_1 := .2 \cdot m \quad L_2 := 1 \cdot m$

$r_2 := 10.5\ mm \quad E := 69 \cdot 10^9\ Pa \quad P_2 := 567.15\ N \quad k_1 := 1$

$$A := \pi \left(r_1^{\,2} - r_2^{\,2}\right) = 144.513\ mm^2$$

$$def_{yshort} := \frac{P_1 \cdot L_1}{A \cdot E} = 0.002\ mm$$

$$def_{xshort} := \frac{P_2 \cdot L_1}{A \cdot E} = 0.011\ mm$$

$$def_{ylong} := \frac{P_1 \cdot L_2}{A \cdot E} = 0.011\ mm$$

$$def_{xshort} := \frac{P_2 \cdot L_2}{A \cdot E} = 0.057\ mm$$

Figure 51. *Deflection Calculations for Panel Legs*

From this analysis, one can see that the maximum deflection in the x-direction is 0.057 mm and in the y-direction 0.011 mm. These both come from the longer back leg, which is understandable. To make sure that these deflections are acceptable for aluminum, the equation L/150 is used (The Aluminum Association). This equation comes from The Aluminum Association's Aluminum Design Manual. This value, L/150, is the maximum deflection that would be acceptable for an aluminum member. The following table, Table 20, details the possible deflections, the ultimate deflections allowed, and if they pass the analysis.

Table 20. *Maximum Deflection Check*

Member	Possible Deflection (mm)	Maximum Allowable Deflection (mm)	Pass?
Short Leg – X Direction	0.011	1.33	✓
Short Leg – Y Direction	0.002	1.33	✓
Long Leg – X Direction	0.057	6.67	✓
Long Leg – Y Direction	0.011	6.67	✓

The size of the legs will be sufficient when it comes to the possibility of deflection. The legs should not deflect past a recoverable amount. This, again, confirms that the chosen 25 mm OD aluminum pipes will be sufficient for the possible loads the legs could experience.

Buckling

This factor is arguably the most important when designing a column or leg such as this. The following math details the calculations done to estimate the critical pressure that would make the legs buckle and fail. The critical pressure, P_{cr}, is defined as $P_{cr} = \frac{\pi^2 EI}{(kL)^2}$, where E is the elastic modulus (Pa), I is the moment of inertia (m^4), which is defined for a circle as $I = \frac{1}{4} \pi r^4$, k is the column effective length factor, which in this case is 0.5 due to both support ends being welded, fixed ends, and L is the length of the column (m).

The moment of inertia for this size of pipe is 1.917×10^4 mm^4 or 1.917×10^{-8} m^4. With this calculation done, the critical pressure is easy to calculate. The critical pressure for the short legs is 1.305×10^6 N, which is more than the 110.59 N being exerted on them, meaning the short legs will not buckle. The critical pressure for the long legs is 5.22×10^4 N, which is also more than the 110.59 N force acting on them, meaning they will also not buckle with the proposed load.

With these three main structural analyses done, one can see that using a 25 mm OD hollow aluminum pipe with a wall thickness of 2 mm will be sufficient for all four legs of this structure. Like mentioned before, going smaller would increase the price and would not be as common of a pipe size, leading to this being the final design choice even though it is fairly overdesigned.

Once the structure to hold the panel was designed, it was clear that four legs were better than two, meaning the final design would need to include two beams underneath the panels to span the width of the circular park. Using structural steel for the beams would be the only option to hold that much weight, but would also add a very significant amount of weight to the structure as well. Since weight was going to be an issue, floating pipes were designed to hold up the panel structure instead. The design of these pipes will be detailed later. The two pipes, however, will float freely if not attached to one another, so a cross-bracing system was designed to keep the two floating pipes per panel row together.

As mentioned previously, Finland houses many lakes of different sizes and shapes. It is common, though to not have large waves on these lakes and it will be even less likely if a large floating structure is to be put in it. The largest forces creating these waves are wind and change in depth. With most lakes in Finland being shallow in nature, average depth is 7 m, this, again, decreases the likelihood of experiencing large waves (Finnish Lakeland, 2019). The significant wave height for most lakes is approximately 1.4 m, which will be decreased by the factors mentioned above (Finnish Lakeland, 2019).

Overall, waves are not going to create a large force against the structure of the panel park. The outside frame should act as a buffer to most of the waves. However, cross-bracing will be added in between the two floating pipes to make sure that those lines stay rigid and hold the panels in place. The cross-bracing will look as follows:

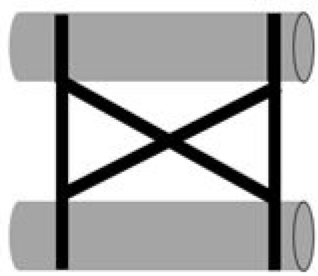


Figure 52. *Cross-Bracing Design*

This design comes from the book *Submerged and Floating Photovoltaic Systems* (Rosa-Clot, 2018). Many designs that utilize two floating pipes like this design does, also utilize cross-bracing such as this. The authors of *Submerged and Floating Photovoltaic Systems* used this cross-bracing setup after designing for small waves in open bodies of water (Rosa-Clot, 2018). Due to this, it is the team’s belief that this will also work for this design. Wave dynamics is beyond the scope of the team’s knowledge and is something that will need to be researched and referenced separately, hence the use of the cross-bracing design from the *Submerged and Floating Photovoltaic Systems.*

In addition, this cross-bracing will also help with wind bracing. The best three forms of bracing for wind are (1) knee bracing, (2) k-braces, or (3) cross-bracing (Wind Bracing). The design incorporates the third form, cross-bracing, which means that this structure will be able to withstand moderate amounts of waves and very strong wind.

This cross-bracing will be constructed out of aluminum, just as the frame is to make sure that consistency is had. This also keeps the structure as light as possible and allows it to all be welded together. The cross-bracing size will be 40 mm by 3 mm and will span the lengths shown in Figure 52 above (Gah-Alberts…). This length, in total, is approximately 5.4 m. This is a common aluminum flat bar size and will be sufficient to withstand waves on lakes. This would not be transferable to the sea, however.

The following figure shows the entire panel and mirror set as well as the structure needed to hold it up and in place.

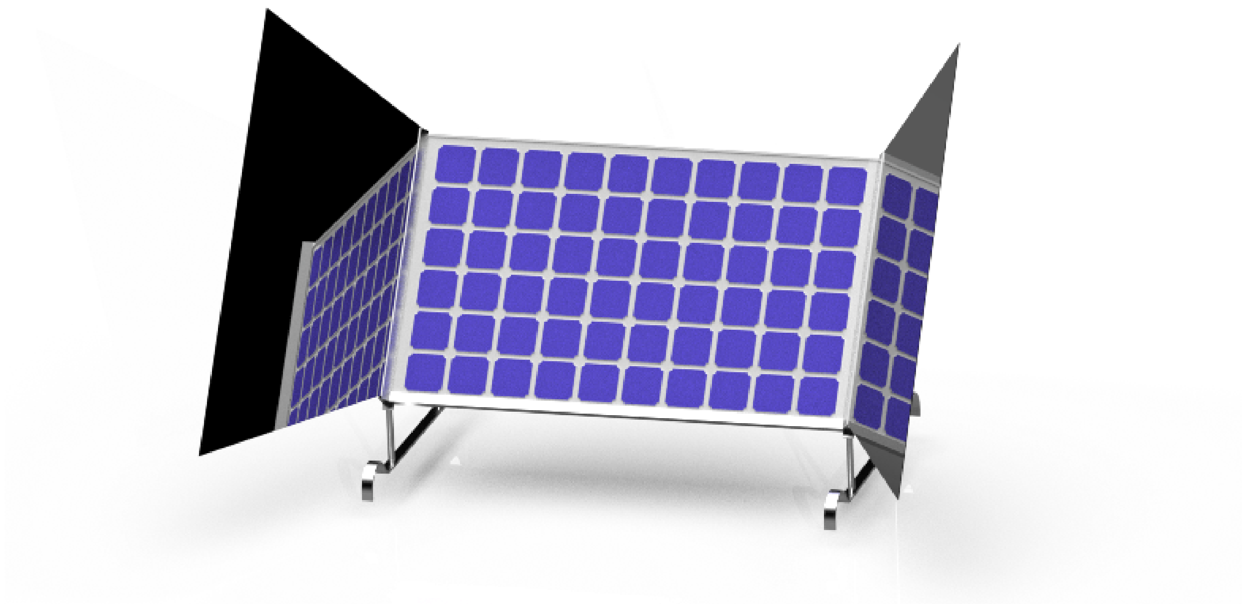


Figure 53. *Diagram of the Solar Panel, Support Structure, and Mirror Attachment*

With the panel support structure designed, a final weight and buoyancy requirements could be calculated.

3.3.3 Floating Structure and Calculations

With all of the above components included, the total weight of the structure was calculated. This “structure” is defined as a 100 m diameter modular circular design. The idea was to make a 100 m (a size that seemed manageable) diameter design that is modular and can be used in multiple locations across Finland. In the case of a 1 MW park, eight of these circular modules would be needed to produce slightly more than 1 MW. All of the design parameters have been sized to this modular 100 m size. One 100 m module holds 417 solar panel and mirror combinations on it, with each row holding a different amount as you start in the front and go back. The number of panels per row is as follows:

Table 21. *Panel Row Dimensions*

Row	No. of Panels	Row Length
14	8	23.50
13	22	56.95
12	29	74.33
11	34	85.29
10	37	92.82
9	39	97.50
8	40	99.72
7	40	99.70
6	39	97.37
5	37	92.58
4	34	84.92
3	29	73.51
2	22	56.07
1	7	20.86

In total, there are 14 rows. The number of panels per row and the row lengths were calculated to optimize as much area as possible. Like mentioned, this design can hold 417 panel and mirror sets. More of these modular structures can be added to increase the amount of energy produced. For the design calculations, only one modular structure is modeled. All modular structures would be a copy of this design.

The following table details the weights of the major components per set. A "set" is defined as one solar panel and mirror pairing. In total, there are 417 "sets" on each park structure.

Table 22. *Weight of Components of Structure per Set*

Component	Weight (kg)
Panel	23
Mirrors on Both Sides	22
Weight of the Frame for Each Panel Set	2.68
Panel Structure Legs	0.94
Cross-Bracing Between Panel Floats	1.75
Total	**50.37**

The table above, Table 22, details the weight of each panel set, so to find the entire weight for the panels, mirrors, and support structure, the total weight needs to be multiplied by 417. In total, the entire weight of the panels, mirrors, and support structure is 21,001 kg or 21 tonnes.

To make the structure float, HDPE cubes were also considered during the initial research, but due to the cost and the enormous amount of cubes that would be needed, the final design uses an alternative. Long pipes that can be directly extruded on top of the water, made with the same material, HDPE (High-density polyethylene).

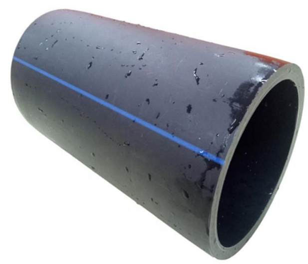


Figure 54. *HDPE Pipes Used in the Construction (Alibaba, 2019)*

The quantity of pipe needed for one platform is calculated using the Archimedes' principle and the buoyancy force.

$$F_B = m\,g = \rho_f\,g\,V_d$$

F_B: Buoyancy force.
m: Mass of the element.
ρ_f: Fluid density. (Water at 4ºC has a ρ_f = 1g/cm^3 = 10^{3}kg/m^3)
V_d: Displaced fluid volume.

The total weight of the panels is 9,519 kg and the weight for the mirrors is 9,174 kg. The aluminium structure, in total, weights 2,236.14 kg.

To know the weight of the pipes, first of all, an estimation of the volume is needed. A tubular section of r_{ext} =0.28m and r_{int} =0.2586m is considered. The perimeter of the rotating platform is 2πR = 2*π*50 = 314.2 meters. The panels will be placed in 14 rows of different lengths as shown in table 21, with a total of 1,047.535 meters of pipe.

The total volume of pipe used in one of the platforms is:

$$V = A * L = \left[\pi R_{ext}^2 - \pi R_{int}^2\right] * \left[L_{perimeter} + L_{rows}\right] = 0.036192 * [314.2 + 1,047.535] = 49.284 m^3$$

The density of the HPDE is 960 kg/m^3

$$m_{HDPE} = 49.284 * 960 = 47,312.64\ kg$$

The mass of structure is 47,668.03 kg, that can be approximated to 50 tonnes.

$$V_{displaced} = V_{pipe\ air} = \frac{m}{\rho_w} = \frac{50,000}{1,000} = 50m^3$$

$$V_{pipe\ air} = \pi R_{int}^2 * L = \pi 0.2586^2 * 1,361.735 = 285.94m^3$$

The volume of air in the pipes for this estimation is way larger than the volume needed for buoyancy. Due to this fact, the cross-section of the row pipes can be reduced. For the perimeter pipe only, the volume of air in the pipes is:

$$V_{pipe\ air} = \pi R_{int}^2 * L_P = \pi 0.2586^2 * 314.2 = 65.977m^3$$

That is enough to make the platform float. Finally the panel rows will have two pipes with an inner diameter of 0.15m. The same calculations have been done for the longest row of panels to check buoyancy.

$$V_{displaced} = \frac{m}{\rho_w} = \frac{1,945}{1,000} = 1.945m^3$$
$$V_{pipe\ air} = \pi R_{int}^2 * L = \pi 0.15^2 * 100 * 2 = 14.13m^3$$

As it is shown in the previous equations, the volume of air in the pipes is 7 times larger than the needed for buoyancy and it guarantees the water will not cover the whole pipe so the aluminium structure will be always above the water level.

The final weight needed to then be calculated for the entire structure. The floating piping going around the entire structure will be 280 mm OD HDPE pipe. This is going to be used to hold the structure up as well as be the outer ring that is being rotated. This same kind of pipe will be used on the outside ring of the structure and act as the frame, but is not included in the weight calculations here since it does not affect the weight of the main structure. In total, this outside pipe weighs 34.74 kg/m. With this being the outside pipe, the length of this will be 314.16 m long. In total, this outside pipe will weigh 10,915.25 kg or approximately 10.9 tonnes. This pipe adds significantly to the total weight of the structure.

The piping being used to hold up each row of panels is also going to be made out of HDPE, but will have a 180 mm OD. Each row is made of two floating pipes and consequently, the meters needed for each row is double the length of each row, shown in Table 21. The total meters needed for the whole structure is 2110 m. With this in mind, the weight for the floating pipes is 15,752 kg or approximately 15.75 tonnes. This, again, adds a significant amount of weight to the total weight of the structure. Together the floating piping weighs 26,667 kg or 26.7 tonnes.

Adding the weight of the floating pipes and the weight of the structure together, the total circular structure weighs 47,668 kg or 47.7 tonnes. With this weight, the buoyancy can be calculated and checked. If the buoyancy is not enough, the floating pipes will need to increase in size to accommodate the weight of the structure.

3.3.4 Anchoring

The anchoring system for such a large structure also has to be quite large. According to multiple different sources (Rosa-Clot, 2018 and How to Anchor a Dock System) stringing anchors from the sides of the structure outwards will keep the structure in place most securely. With a large percentage of Finland's land being organic in nature and another large portion being peat or clay, it is likely that the anchor will sink deep into the soil and hold the structure securely (Ministry of Agriculture and Forestry of Finland). This means that most anchor options would be acceptable for use. To save on cost, a basic concrete block anchor will be used.

In doing research on common offshore anchoring systems, it is clear that a triangular shape anchoring method that spans outward is common. This is also seen in the book *Submerged and Floating Photovoltaic Systems*. This type of anchoring is practical in many situations since it is usable when water depths vary, when there are large horizontal forces such as wind, and is very precise since it keeps the structure pulling on multiple chains to help keep it in the right spot (Rosa-Clot, 2018). The following figure, Figure 55, details the idea.

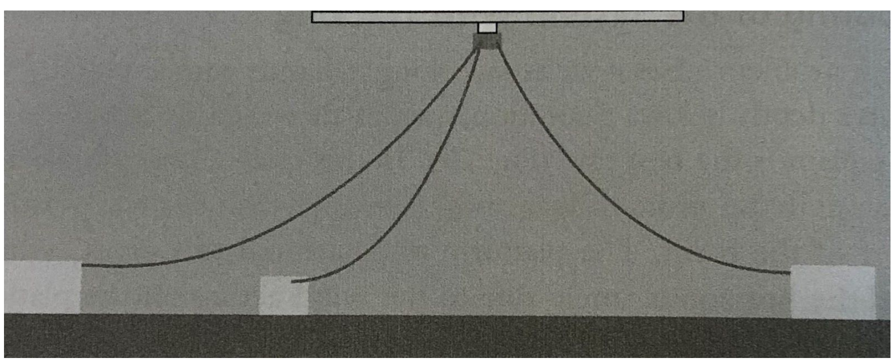


Figure 55. *Anchoring System Design*

According to a service provider at ChainsRopes&Anchors.com, the basic guide for sizing an anchor is that 1.5 kg is needed for every meter in length that your boat is. Since this is not a regular boat shape, it was advised to multiple this 1.5 kg/m rule by both dimensions of the structure (Chains, Ropes, and Anchors). This would mean multiplying 1.5 by 100, twice. This was not all, however. Since this structure is also (1) heavier than an average boat, (2) wider than normal, (3) blunt in shape, not streamline, (4) will be held in the water for an extended period of time, and (5) is utilizing an old anchor design the basic guide should be increased (Chains, Ropes, and Anchors). For each added design "flaw", in this case 5, the guide should be increased by 0.25 kg/m (Chains, Ropes, and Anchors). So the guide for a structure with our characteristics would be 2.75 kg/m. With this in mind, that guide number was them multiplied by 100 m and by another 100 m to account for the circular shape. In total, the structure would need

27,500 kg of weight below the surface. Additionally, when weights are put into the water, they "lose" approximately ⅓ of their weight meaning the total weight needed for this structure would, in fact, be 36,667 kgs (How to Anchor a Dock System). Dividing this by three, since a triangular shape anchor system was tested to be the best design, the weight per anchor would need to be 12,222 kgs (Rosa-Clot, 2018).

To calculate an approximate size for the concrete anchors, the required weight was divided by the density of a normal concrete, 2300 kg/m^3, to get an approximate volume of concrete needed. In this case, the required volume would be 5.314 m^3 per concrete block. Any number of shapes could be done to make a concrete block of this size, but an easy size that would give a volume over the requirement would be a 2 m x 2 m x 4 m block. With three of these concrete block anchors, the structure should stay in place even with strong winds. And like mentioned above, the anchors will be able to hold better as time goes on.

An anchoring system is not just the anchor, though. To hold the concrete blocks to the chains being used and to hold the chain to the floating structure, six carabiners will be used. The chain being used is a Nickel Chromoly Steel Alloy. This steel is being used because it is a common chain type and is very good in water (Nickel Alloys). Chain length for anchoring should be approximately 2-3 times the depth of the water. The average depth of lakes in Finland is 7 m, so for an average lake, the length of chain needed would be approximately 17.5 m and 52.5 m when considering all three chains being used (Finnish Lakeland, 2019). The deepest lake in Finland is Päijänne, with a depth of 95.3 m, which would require a chain length of approximately 238 m and 715 m in total (Finnish Lakeland, 2019). For further estimates, a smaller chain length will be used, since an average lake is a likelier location for this solar panel park than the deepest lake in Finland.

To determine the chain strength that is needed, the wind force will again be considered. The wind force pushing on one panel was 2270 N. If that is multiplied by 40, the largest possible panel area the wind would hit, the total force on the structure due to wind would be 90.8 kN. There will likely not be a time that one chain should be holding the whole structure in place, since the anchors will be placed in a triangular formation, but in that case each chain will be sized to approximately a 90.8 kN strength. This gives the entire structure a factor of safety since one chain will not be doing all of the holding all of the time.

3.3.5 Rotation system

The solar panel park is designed on a tracking system to face the panels directly to the sun for every moment of the day. The platform of 100 meters diameter will rotate with the same angular speed as the earth's rotation ($\omega = 7.26 * 10^{-5} rad/s = 4.16 * 10^{-3} m/s$). The rotation system is based on a gears connection where a hydraulic motor, because of the low speed and high torque needed, will impulse a worm gear that will move a bigger gear in touch with the external perimeter of the rotating platform.

To determine the exact motor and the gear dimensions it is important to know the torque needed to rotate the platform. To do this, the body of inertia of the platform, the friction resistance with the water and the possible inertia of added mass, have to be considered.

As a simple approximation, the rotating platform as a whole is a cylinder of 100 meters diameter and 50 tonnes of weight. The inertia of the platform would be the following:

$$I_z = \frac{1}{2}mR^2 = \frac{1}{2} * 50,000 * 50^2 = 62,500,000\ kg\ m^2/\ rad^2$$

To calculate the friction resistance between the structure and the water a flux analysis was done. The calculation will consider the friction on the outer perimeter of the rotating structure, simulating again the structure as a big cylinder. Every 10 meters of the perimeter surface can be considered as a flat plate sliding over a fluid.

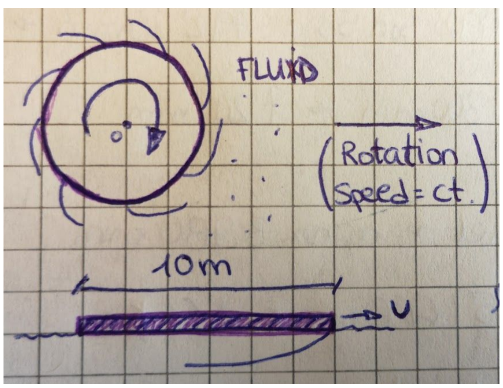


Figure 56. *Flux Analysis Sketch*

The speed of every plate will be the linear speed of the external points of the cylinder due to the rotation:

$$U = 7.26 * 10^{-5} * 50 = 3.63 * 10^{-3} m/s$$

$$\rho_w = 10^3 kg/m^3 \qquad \nu_w = 10^{-6} m^2/s$$

The Friction resistance equation for a flat plate sliding over a fluid is the following:

$$F_F = A_{plate} * C_D * \frac{1}{2} * \rho_w * U^2$$

The sheet area is $15m^2$ and the only variable left to calculate is the drag coefficient (C_D). This value depends on the type of surface layer created. It can be laminar or turbulent and that is determined by the Reynolds Number:

$$Re = (U * L)/\nu = 3.63 * 10^4 < 3.2 * 10^5 \rightarrow Laminar\ layer$$

$$C_D = 1.3/Re^{\frac{1}{2}} = 0.00682$$

With all of these values, the friction force between the platforms surface and the water can be calculated:

$$F_F = 15 * 0.00682 * 10^3 * (3.63 * 10^{-3})^2 * \frac{1}{2} = 6.7 * 10^{-4} N$$

This value is rather insignificant compared to the inertial moment calculated previously.

The added mass of a body moving in a fluid is a common issue to consider because the object and surrounding fluid cannot occupy the same physical space simultaneously. For simplicity this can be modeled as some volume of fluid moving with the object, though in reality "all" of the fluid will be accelerated, to various degrees. In our case the rotating speed is so low that it makes this phenomenon disregardable.

To summarize, the total torque needed to turn the platform is mainly the torque due to the inertia, this will be called as M_{out}.

$M_{out} = M_{in} * i * \eta \qquad M_{in} \rightarrow input\ torque\ given\ by\ the\ gears\ system \qquad i = \frac{R_{driven}}{r_{conductor}}$

$\eta \rightarrow depends\ on\ the\ friction$

Usually mechanical systems have a rendiment around 45%. In this case, having a floating platform on the water considerably reduces friction in the system. The rendiment considered for the following calculations is 75%.

The ratio i is given by the relation of the radius between the platform and the conductor gear that will have a primitive diameter of 0.6m. The resulting relationship is:

$i = \frac{50}{0.3} = 166.66$

The torque needed to rotate the platform is:

$M_{in} = \frac{62{,}500{,}000}{166{,}6 * 0{,}75} = 500,000\ Nm$

And the rotation speed of the conducting gear in rpm has to then be:

$n_{in} = i * n_{out} = 166.6 * 6.93 * 10^{-4} = 0.1155\ rpm$

To generate this torque and speed a slew drive system will be installed with a hydraulic motor. A slew drive is a gearbox that can safely hold radial and axial loads, as well as transmit a torque for rotation. The rotation can be in a single axis, or in multiple axes together. Slew drives are made by manufacturing gearing, bearings, seals, the housing, the motor and other auxiliary components and assembling them into a finished gearbox. Figure 57 shows how a slew drive looks inside the housing.

Figure 57. *Slew Drive with an Open Housing.*

The outside ring of the slew drive should provide a torque value of 500 kNm and a rotation speed of 0.12 rpm. From the catalogue of the company TBG, the next model can be determined to be a TGE1050 with a gear ratio 150:1, and efficiency 40%. In this case, the motor should provide the following torque and speed:

$$M_{motor} = M_{in} / (i * \eta) = 500,000 /(150 * 0.4) = 8,333.33\ Nm$$

$$n_{motor} = n_{in} * i = 0.12 * 150 = 18\ rpm$$

The type of motor that will be used is a hydraulic motor. Electric motors can generate tremendous amounts of torque without the losses associated with torque-multiplying gear systems. The problem is, however, that the size of these high-torque electrical motors is impractical for use on construction equipment. Hydraulic motors can generate equally tremendous amounts of torque at a fraction of the size. Hydraulic motors can work in places that electric motors cannot. They are ideal for many of the rugged environments and working conditions faced by construction, mining, and agricultural equipment on a daily basis. Under certain conditions, hydraulic motors are even considered much more efficient than electrical motors. This is explained by Dr. McCaslin in Heavy Equipment 101, 2018.

The next figure shows the entire rotation system for the structure.

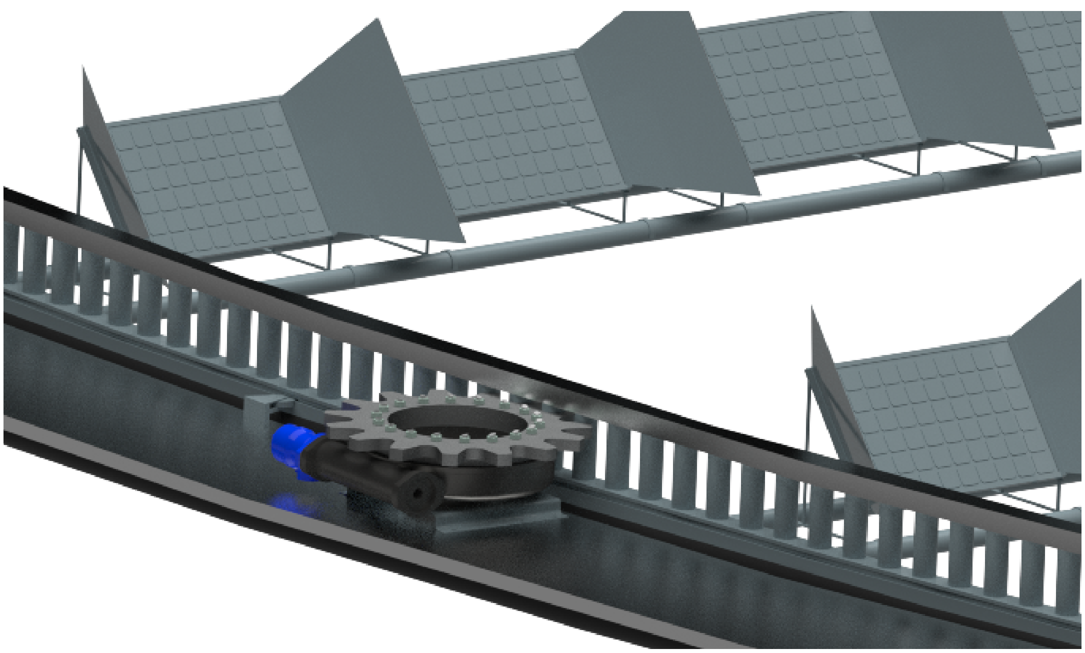


Figure 58. *Rotating System.*

To power the motor, a hydraulic group is needed. This is a pump moved by an electrical motor that puts pressure on the hydraulic fluid so that it can move the motor. The power of this machine will not be as high as the motor's because its maximum power will never be needed as the movement required is really slow. To make sure it is not affected by changes in the production of the plant, the electrical connection will be done on land to the electrical grid instead of to the output cables of the park. This connection will be done through cables under the water along with the power cables coming from the panels to the inverter.

A control system based on a Programmable Logic Controller (PLC) will be needed to make sure that the motor moves in a way where the panels follow the sun. This will also be placed on land and connected to the motor with subaquatic cables.

3.3.6 Connection to the grid

The inverter needed to connect the park to the electrical grid will not be part of the modular design but will chosen depending on the actual size of the whole park. This is because it is cheaper and more efficient to have only one (or a few if the park is so large that there is not as powerful of an inverter) and it will be placed on land. Having the inverters on the floating platform would add a significant amount of weight and would require more buoyancy.

Some cables will connect the panels inside the platform in a way that the maximum voltage fits with the inverter. This connection will be made using combiner boxes, which will include switches that allow the disconnection of the plant and protect the installation in case of a short-circuit. They also may include some monitoring features, if it is appropriate. The boxes will be placed in the center of the platform and, from there, one cable will transport the electricity under the water to the inverter.

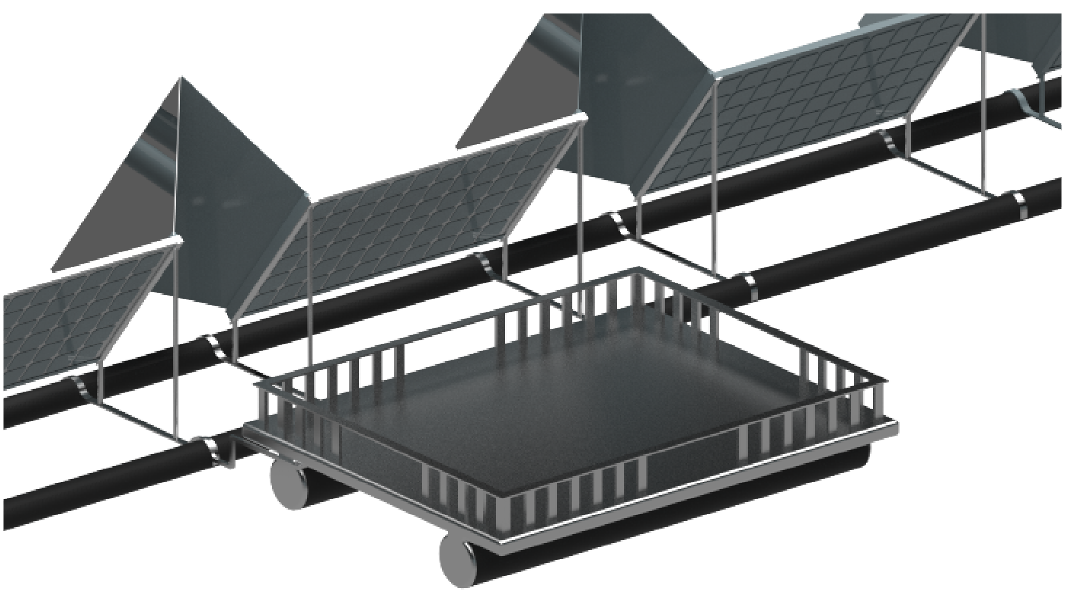


Figure 59. *Platform for Combiner Boxes.*

Depending on the location, if there is not access to the low voltage grid, it may be necessary to have a transformer that increases the voltage to that of a high voltage grid and even a short power line if the connection point is far from the power plant. This extra cost will not be considered in this project due to the fact that there is not a chosen location. This is an important factor, though, when deciding about the best place for the power plant since the cost could be significant.

3.4 Final Design Conclusions

Concluding the design of the floating solar panel park, the main structure will be based on a circular platform of 100 meters in diameter surrounded by a second pipe structure that acts as a frame. The frame will be anchored and has the purpose of being a fixed base for the main platform to rotate within. The anchoring system is basic in that three blocks are to be used. The chains will start from the sides of the frame and span outwards creating a triangular pattern. The rotating equipment will be placed on the outside frame structure. This includes a slew drive system, a hydraulic motor, and many gears to get the required torque and speed.

The inner platform will be formed by a perimetral structure of pipe and steel. This will be in contact with the gears from the rotating system. Bifacial panels will be used to increase efficiency, most specifically in the winter. There will be 417 panels on each circular module and each panel will have two trapezoidal mirrors on each side of it. The panels will be placed in 14 rows, each one 7.54 meters away from the next one. Rows will have two lines of pipe and panels will be placed on top with an aluminium structure with 4 legs. The aluminum legs holding up the panels will be 25 mm in outside diameter and will be 0.2 m tall in the front and 1 m tall in the back. In addition, aluminum flat bar, size 40 mm x 3 mm, will be used as cross-bracing to hold the two lines of pipes together. Mirrors will be added to the panel structure with a special frame designed to position them at the correct angle. The pipes on the perimeter of both structures will have an outside diameter of 0.28m and the pipes in the rows will have an outside diameter of 0.18m.

In the middle of the rotating structure there will be a small platform connected to the row of panels in front. This platform will contain all of the electronics that the panels need and will connect all of the rows with the grid.

To guarantee that both platforms work concentrically, several wheels that come out from the frame will be in constant contact with the perimetral inside structure.

All the renders have been done with the modeling program *NX12* from *SIEMENS*. The figure below (Figure 60) shows the complete design.

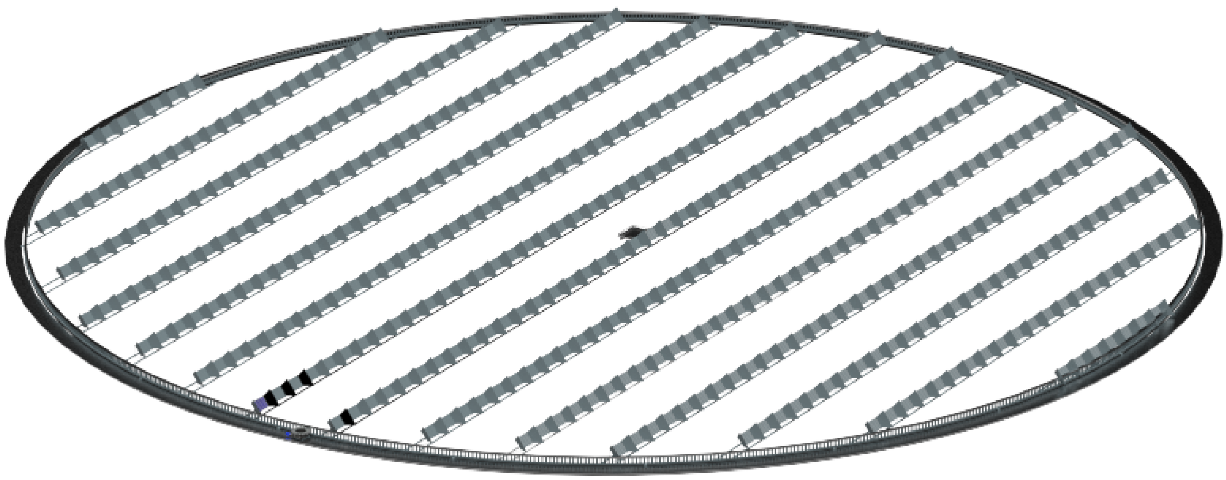


Figure 60. *Floating Solar Panel Park Design*

And the following figure shows the complete design in more detail.

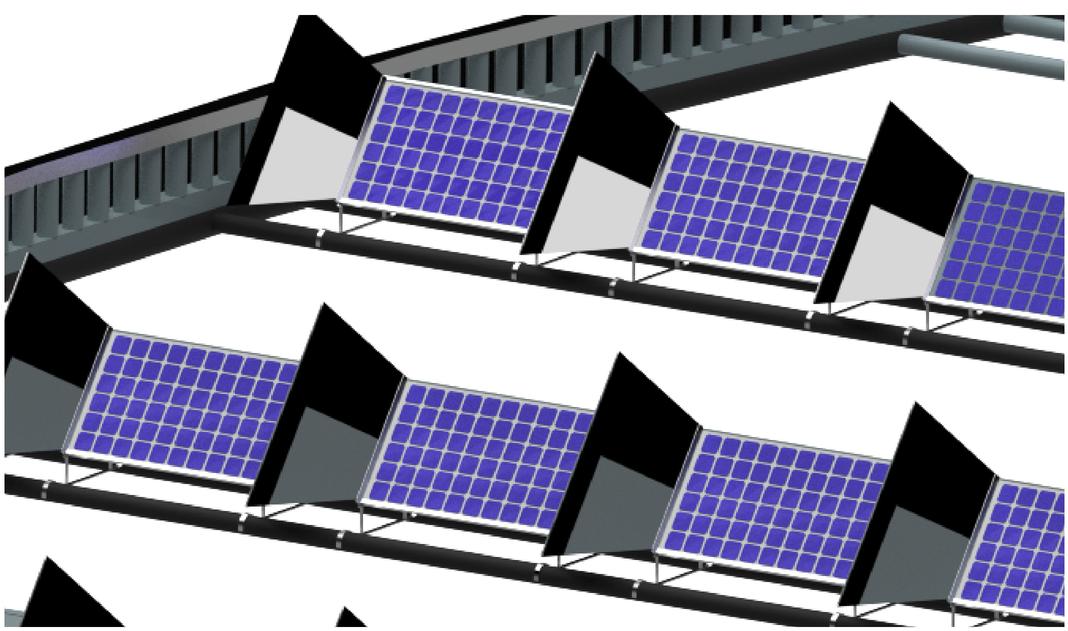


Figure 61. *Floating solar panel park detail*

Now that a design has been chosen, multiple feasibility studies were done to prove the design will work.

4. Feasibility Studies

4.1 Economic Analysis

Long-term investment decisions are always exposed to high risk in a nowadays highly disruptive world with tremendous technological advances. Similar to the deflationary behavior, you will never know if a more effective, cheaper solar panel will be released tomorrow, based on the record-breaking news on the efficiency of solar cells. We are now living in a time when every investment consideration should include the aspect of sustainability and moral acceptance. Nevertheless, the salvation of the planet must still be reconciled with the profitability of a venture.

Based on the technology, functionality and design of the solar park, it has been demonstrated that it is technically sensible to focus on renewable energies in Finland, especially photovoltaic technology. The question, which still has to be answered is the one about the feasibility of the project. For this purpose, the investment theory, including the meaning and purpose of the calculation interest rate, opportunity costs and the types of advantageousness will be briefly explained.

Subsequently, basic data necessary for further calculations are presented and the calculation methods which were used are explained more specifically. The comparisons will be based on the net present value method, the dynamic amortization calculation, the return of investment and return of equity. The various options for raising capital will not be discussed in the further course, since it depends heavily on the respective company and the team was not provided with any detailed data in this regard.

While financing-theory sheds light on how to raise funds, investment theory analyzes the use of finance. An important aspect in the investment theory, which will lead us to the advantage of investment projects, is the calculation interest rate. (Konstantin, 2017) The calculation interest rate is determined in this case with the WACC, the weighted average cost of capital method, and uses values which are common in the energy sector in the field of renewable energies. (WKO, 2019) According to the WKO the income tax rate for Finland is 20%.

Table 23. *Weighted Average Cost of Capital for the floating Solar Park (based on Konstantin, 2017)*

Weighted Average Cost of Capital			
Position	**Unit**	**conventional**	
		Equity	**Loan**
capital shares	**%**	**20**	**80**
Interestrates & Surcharges			
risk-free return/ Interest rate	% /a	3,0%	3,0%
Investment risk-premium *)	% /a	5,0%	1,0%
Technology risk-premium	% /a	1,0%	1,0%
Region risk-premium **)	% /a	0,0%	0,0%
Subtotal after taxes	**% /a**	**9,0%**	**5,0%**
Income tax rate Finland 20%	% /a	3,2%	0,0%
Capital costs before taxes	**% /a**	12,2%	5,0%
Weighted Av. Cost of Capital (WACC), nominal	**% /a**	**6,44%**	
./. Inflation	% /a	2,00%	
WACC adjusted for inflation, before taxes	**% /a**	**4,44%**	
*) depending on the state of development of the technology			
**) takes land risks into account, for most industrialized countries it's zero			

Another known method is the opportunity-cost-principle (Wirtschaftslexikon, 2019), which basically has the same ulterior motive. Opportunity costs are costs that did not arise due to the decision for another project. Investment projects with a positive net present value thus generate a return that is above the minimum return expected by investors or above the return of an alternative project. If there are no alternative projects, one uses investment options such as average returns of stock indices or industry-standard values, if they exist.

The net present value is the monetary value which, after taking into account all deposits, disbursements and the minimum return on investors (according to Table 23 adjusted for inflation) at the end of the project life cycle.

This brings us to the already mentioned advantages of investment projects. If the net present value of an investment is positive, this is called absolute advantage. This means that the investment itself is worthwhile in principle. However, in order to make an informed statement or decision, one should compare its investment plans with other investment alternatives. If the capital value of the planned investment is the highest value in comparison, this is called relative advantage.

4.1.1 Basics of Upcoming Calculations

The basics of the following calculations, comparisons and values provide the total investment costs of the project, as well as the fixed operating costs, which can change depending on the investment choice by interest on borrowed capital and the yield of the solar power plant.

Another point of discussion was the question of the lake area. However, the decision between leasing and the purchase of the required area in *ha* was cleared very quickly, as it could be shown that after 7 years, leasing would be more expensive than the purchase of the area for the rest of the life cycle of the park. (Stewart, 2018) Based on the lack of information in relation to the costs of the lake, the comparison was made with the farmland area in Finland which, according to C. Stewart and A. D'Amore stated in the press release from eurostat in 2018 is 10.000€ /ha to buy and 225€ /ha for leasing.

Table 24. *Material & cost list of the floating solarpark*

Material & Cost List for 1MW Park					
Building Materials	**Material**	**Amount**	**Unit**	**Price**	**Total**
Structure					**120.843,12 €**
HDPE Pipes (bigger rings)	HDPE	5.040,00	m	0,84 €	4.233,60 €
HDPE Pipes (Cross pipes)	HDPE	16.881,92	m	0,84 €	14.180,81 €
security mirrors	Glass, Vinyl backside	7.339,20	m²	7,42 €	54.456,86 €
Aluminium frames	Aluminium	17,92	t	2.677,00 €	47.971,84 €
Panels					**341.272,80 €**
Monocrystalline Panels (360W)	-	1.100.880	W	0,24 €	264.211,20 €
Bifacial Panels (315W)	-	1.100.880	W	0,31 €	341.272,80 €
Anchoringsystem					**14.764,88 €**
Alloy chain (13mm)	Ni-Cr-Mo Alloy steel	800,00	m	17,89 €	14.312,00 €
Concrete Blocks 2'x2'x4' Standard	Concrete	24	pc	17,87 €	428,88 €
Carabineer	Stainless Steel	48	pc	0,50 €	24,00 €
Trackingsystem					**599,52 €**
TFT LCD Display for Arduino	-	8	pc	7,15 €	57,20 €
Arduino	-	8	pc	26,80 €	214,40 €
PIR motion sensor	-	128	pc	1,24 €	158,72 €
waterproof electric Control Cabinet	Stainless Steel	8	pc	21,15 €	169,20 €
Rotationsystem					**12.000,00 €**
Electromotor	cast iron	8	pc	200,00 €	1.600,00 €
hydraulic pump with e-motor	-	8	pc	700,00 €	5.600,00 €
PLC	-	8	pc	100,00 €	800,00 €
gears & pipes & cables	-	8	pc	500,00 €	4.000,00 €
Seacosts for 1MW Park		/			**90.000,00 €**
Engineering & building performance *)		/			**150.000,00 €**
Electronical components **)		/			**100.000,00 €**
unforeseen Costs (15%)		/			**124.422,05 €**
					953.902,36 €

*) engineering & building performance costs 100.000€ after speaking to Sören H.

**) electronical equipment & parts (like Converter, Switches, etc.) 150.000€ after speaking to Sören H.

Table 25. *Fix operating costs*

linear Depreciation 3,33%	31.796,75 €
fix Operating Costs²	
O&M	20.000,00 €
Insurance	2.000,00 €
fixOperating Costs	**22.000,00 €**

Table 26. *Proceeds per Year*

Proceeds bifacial²	
kW/h per Circle	265.986
kWh per Year (8 Circles)	2.127.888
MWh per Year	2.128
per MWh	42,77 €
Proceeds per Year	**91.009,77 €**

In order to have a rough comparative value, the coming capital values are compared not only with each other, but also with the Return of Investment (RoI) from the investment in conventional bank accounts with an inflation-adjusted interest rate of currently -1,52% consisting of - 0,40% ø deposit rate (Suomen , 2019) and 1,12% inflation (Triami, 2019).

In order to take into account the performance of the money in the 30-year life cycle, the pure investment costs are compounded using the following formula.

$$K_n = K_0 * (1 + i)^n$$

K_0	Initial investment	i	Inflation-adjusted rate of interest
K_n	Net value	n	Project lifecycle in years

The annual charges are compounded and summed up according to the following formula.

$$K_n = g * \frac{(1+i)^n - 1}{i}$$

g	Yearly Disbursements

The sum of these two values is the monetary value at the end of the project term and corresponds to a RoI of - 30% compared to the total investment.

The net present values, which are compared below, are calculated according to the following formula:

$$C_0 = -A_0 + \sum_{t=1}^{n}(E_t - A_t) * \frac{1}{(1+i)^t}$$

C_0	Net present value	E_t	Deposits
A_0	Initial investment	A_t	Disbursements
n	Project lifecycle in Years	i	Calc. interest rate

Furthermore, it is calculated from when the respective variant of the investment pays off, i.e. has repaid itself. As a rule, in projects, payback periods are specified by the management in the context of which the project must be at the end. On the basis of the dynamic amortization calculation, the loss of value can be included in long-term projects. The amortization in this case is calculated as follows.

$$t_d = Years_{compl} + (Investment - Returns_{cumulated}) * \frac{Years_{started} - Years_{compl}}{Surplus_{start} + (Investment - Returns_{cumulated})}$$

Before we come to the comparisons, we look at the calculation of the return on investment and return on equity.

RoI related to the complete Project Duration: $RoI = \frac{Net\ Present\ Value}{Costs\ of\ Investment\ within\ 30\ Years}$

RoI within 1 Year: $RoI = \frac{Revenue - Depreciation}{Costs\ of\ Investment}$

RoE within 1 Year: $RoE = \frac{Revenue - Depreciation - Dept\ costs}{Equity}$

In the following, a pure equity financing, as well as a pure debt financing, a mixed financing of equity and debt in order to use the leverage effect and financing with the help of subsidies will be closer illuminated.

4.1.2 Equity Financing

The advantage of equity financing is a low risk of over-indebtedness, no interest and repayment installments, and the financial independence from credit institutions (Exporo, 2019). The problem with equity financing, on the other hand is, that normally a high risk premium will be demanded by the equity holders and the equity ratio drops sharply. Furthermore, the fixed assets should be permanently covered by equity in a company. Equity financing should ideally be made possible through internal financing, i.e. through the retention of profits, since external equity capital increases often produce a negative signal effect on the equity investors.

Due to the presumably higher risk premium for equity financing, the actual capital value would be lower than stated here. The amortization would be in this case 21,90 years, as can be seen in the second graph.

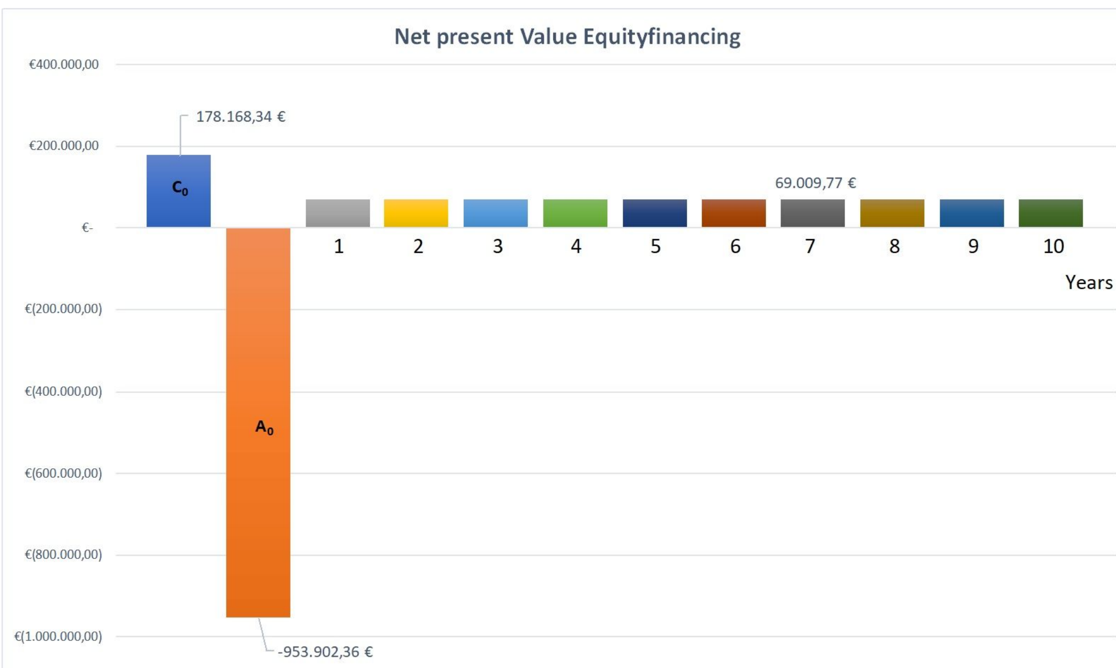


Figure 62. *Net present Value of Equity financing*

Based on the net present value of 178.168,34€ the RoI related to the complete project duration, the yearly RoI and the RoE are as follows.

RoI (project) 18,68%
RoI (yearly) 7%
RoE 6%

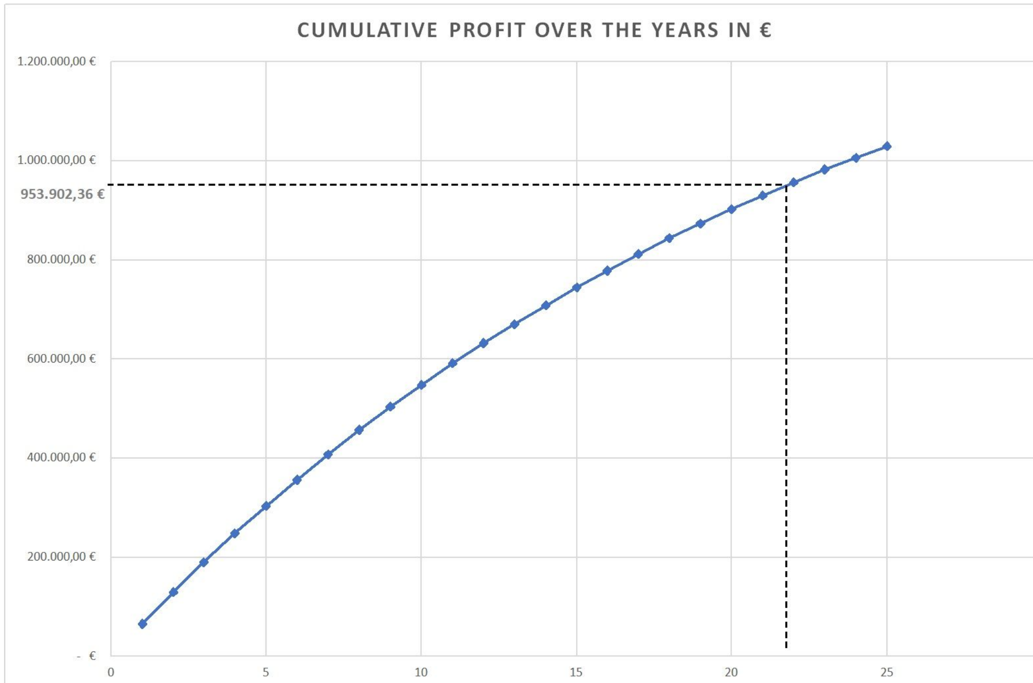


Figure 63. *Dynamic Amortization on pure Equity Financing*

4.1.3 Debt Capital Financing

(Noreisch, n.d.) In pure debt financing, the investor is not involved in the profit and is only interested in the payment of interest. Thus, debt capital contains a decision independence in comparison to the equity financing with participating equity holders.
Borrowed capital is limited-term capital and therefore limited in time, but the borrowing costs can be deducted for tax purposes.

The following charts show how pure debt financing affects the net present value and the amortization.
Calculated in the way above mentioned, the RoI related to the 30-year lifecycle and the RoI per Year are as follows.

RoI (project) 10,01%
RoI (yearly) 6%

As in the Figure 65 can be seen, the payback time for this variant is 24,97 Years. The net present value is compared to the equity financing with 95.489,67€ already lower but still bigger than 1, which means, the investment is still be placed in the section of absolute advantages.

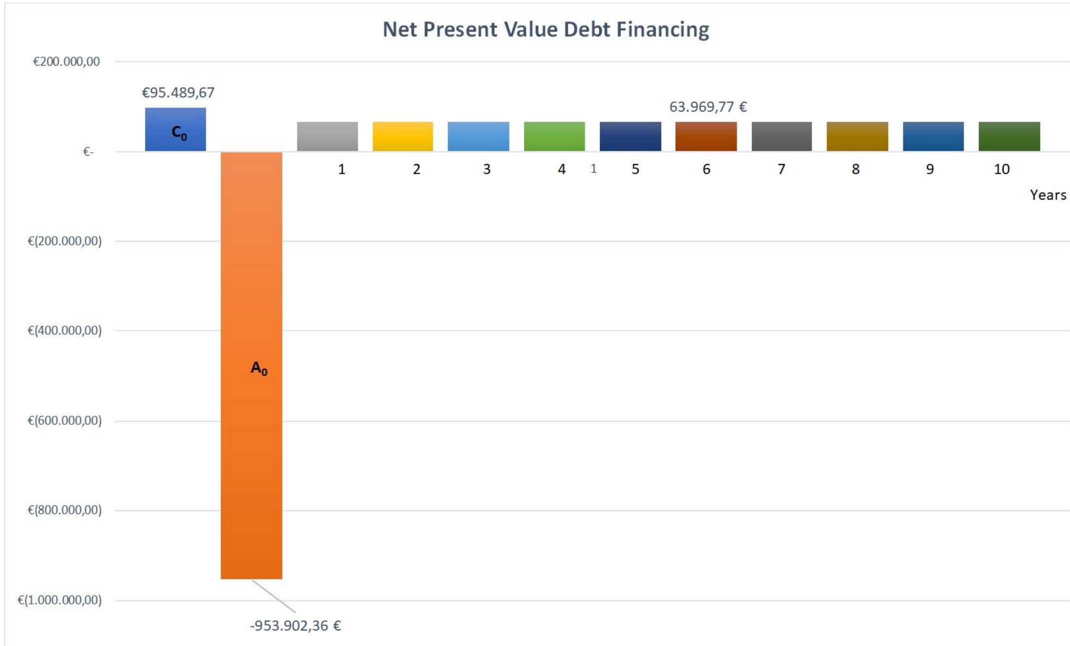


Figure 64 . Net present Value of pure Debt financing

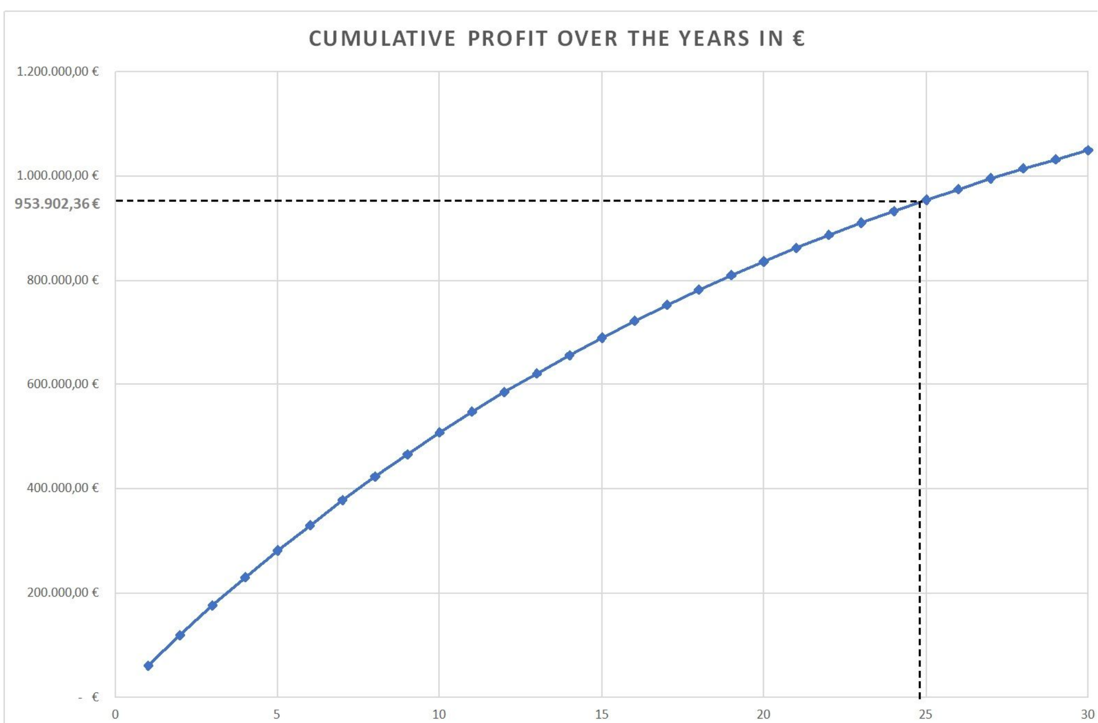


Figure 65 . *Dynamic Amortization on pure Debt Financing*

4.1.4 Mezzanine Financing

The biggest advantages of mixed financing or mezzanine financing are the avoidance of the negative influences of the previous financing options and in particular the utilization of the leverage effect. As long as the RoI is higher than the debt interest rate, it is worthwhile to finance with higher debt to increase the equity ratio for the owners and thus the potential payout. (Konstantin, 2017) In the renewable energy sector, equity requirements for loans vary between 20% - 30%. In the following calculations 30% Equity was used. RoI and RoE are as follows.

RoI (project)	11,44%
RoI (yearly)	6%
RoE	19%

The following two figures below show the net present value and the payback time of the mezzanine financing and the difference to pure equity and debt financing can be seen.

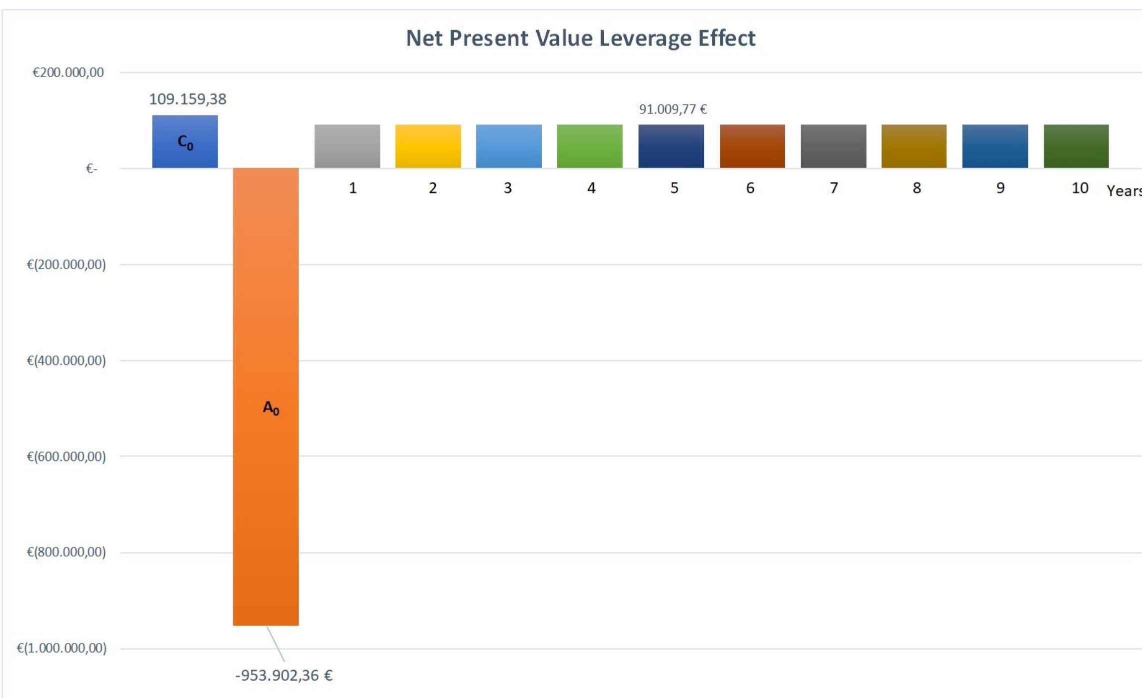


Figure 66 . *Net present Value of Mezzanine Financing*

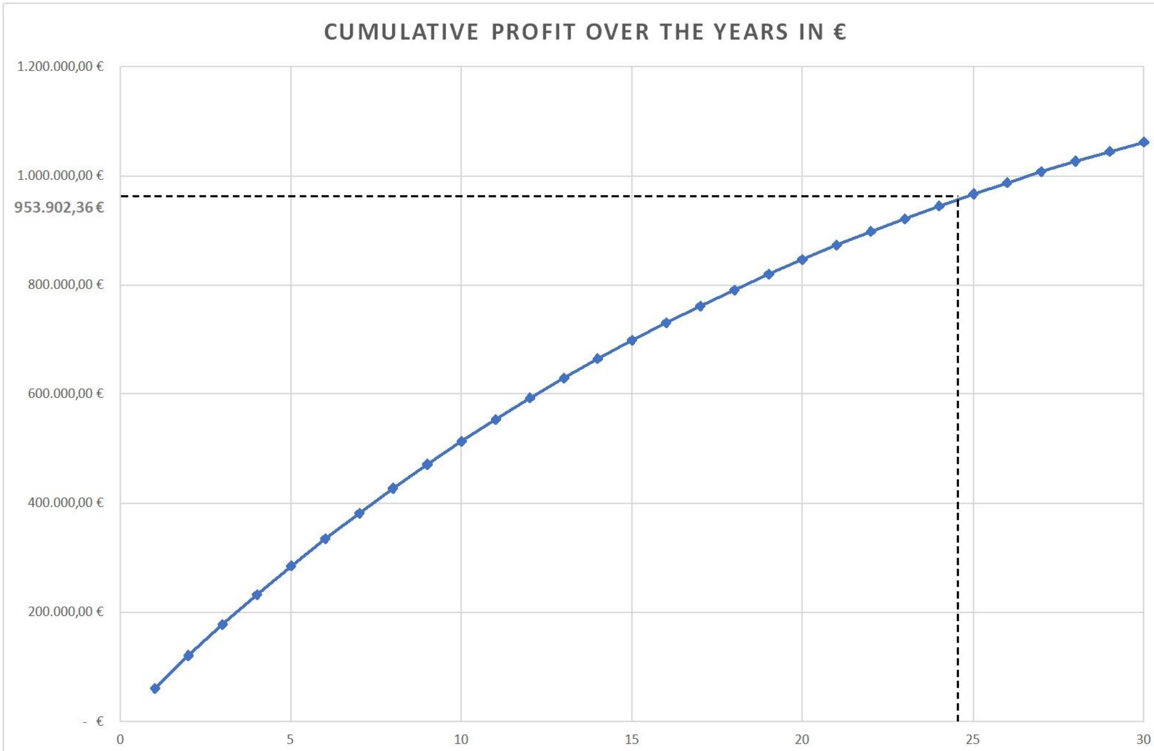


Figure 67. *Dynamic Amortization on Mezzanine Financing*

4.1.5 Financing with Subsidies

Finally, the renewable energy sector allows us to count on possible state subsidies, which makes investment projects even more interesting. In Finland, subsidies of up to 30% can be expected in the renewable energy sector (IEA, n.d.). To make the influence of subsidies clear, this value was chosen below. Due to the requirements of 20% - 30% Equity, 30% Equity and 40% debt capital were used in the calculation. The final results will probably lower due to subsidies below 30%. Due to the subsidies, the starting investment is 30% lower compared to the financing methods before. This leads to an impressive change in the RoI and the RoE.

RoI (project)	63,63%
RoI (yearly)	14%
RoE	31%

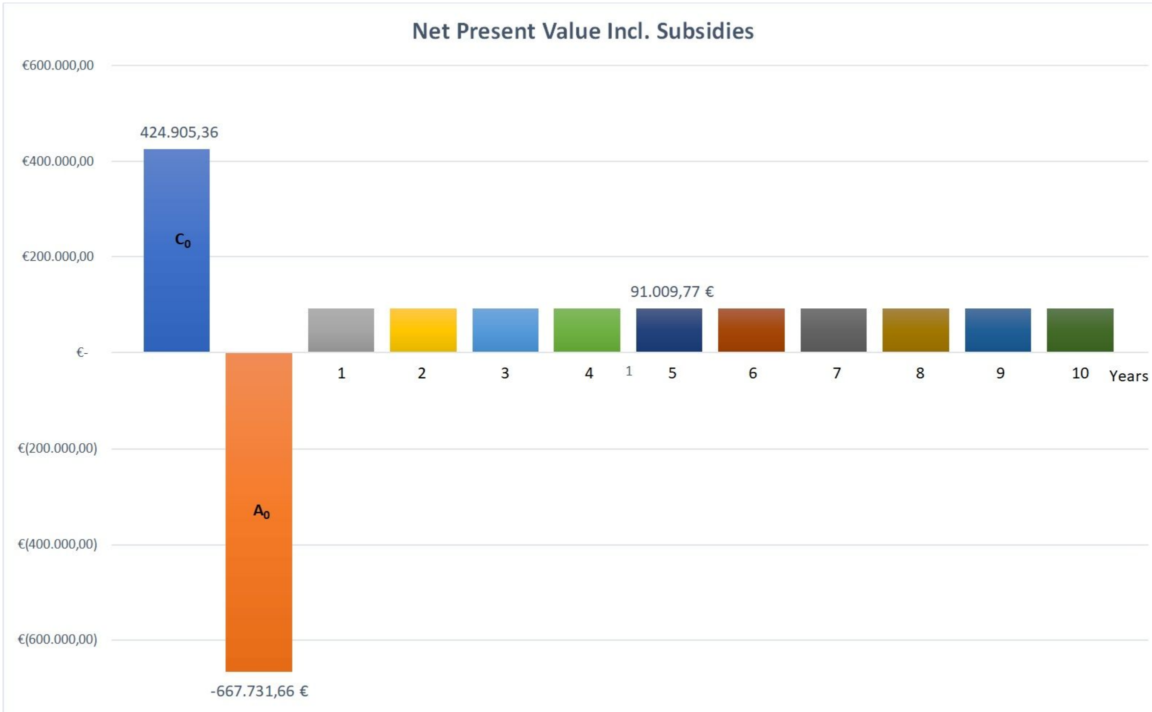


Figure 68. *Net present Value of Mezzanine Financing*

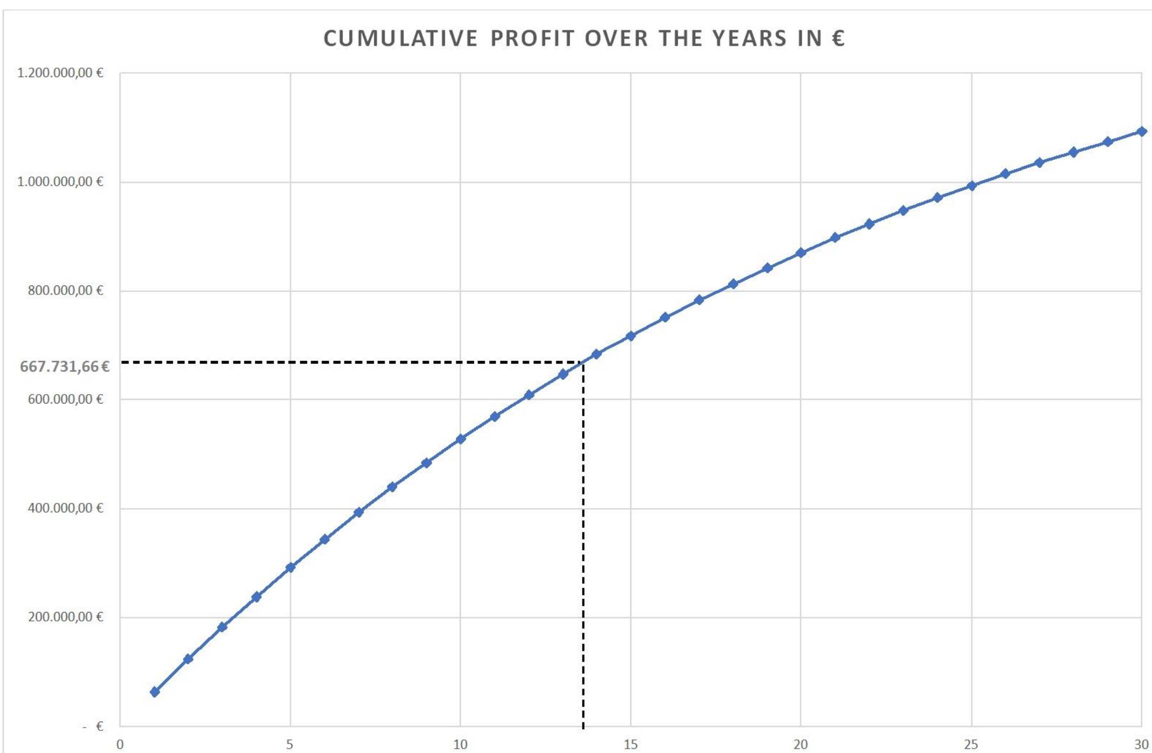


Figure 69*. Dynamic Amortization on Mezzanine Financing*

4.1.6 Conclusion

On the basis of the table below, it can be seen how the type of financing affects which aspect. Based on the financial decision criteria of profitability, independence, liquidity and security, different financing strategies can thus be developed for further strategic management decision making. Based on the formula $r = \frac{C_{i1} * i_2 - C_{i2} * i_1}{C_i - C_{i2}}$ the internal rate of return, which could be expected, is also added in the table below.

Table 27. *Influences by financing options to different key figures*

Financing Variation	Net Present Value	Payback Time	RoI (Project)	RoI (Yearly)	RoE	Int. rate of return
Equity Financing	178.168,34€	21,90 Years	18,68%	7%	6%	5,96%
Debt Capital Financing	95.489,67€	24,97 Years	10,01%	6%	-	5,27%
Mezzanine Financing	109.159,38€	24,41 Years	11,44%	6%	19%	5,39%
Financing with Subsidies	424.905,36€	13,56 Years	63,63%	14%	31%	9,28%

As expected, investing in combination with subsidies is the most feasible way. Related to the RoI and the RoE, preferences of the company will be decisive according to Equity or Mezzanine financing.

4.2 Environmental Assessment

4.2.1 Introduction

To overcome negative impacts of flexibility, deforestation and land requirements posed from conventional photovoltaics, floating photovoltaic (FPV) systems have been emerging as a new concept in renewable, electricity generation. Successful experimental FPV plants have been developed in countries such as Korea, UK, USA, Italy, Spain, and Japan. However, FPV systems have limited history since the first FPV plant installation was in 2010 (Silva, G. D. P., Branco, D. A. C., 2018). Studies today have focused primarily on weather-related environmental conditions, with a concentration on evaporation control. However, there is still little information regarding FPV ramifications and benefits, and studies have yet to access the potential impacts of floatovoltaics deployment on lake ecosystems and the surrounding environment area.

The surface water coverage caused by FPVs alters the amount of sunlight and wind received by the water body, thus affecting the physical, chemical, and biological water quality parameters. Consequently, it is reasonable to assume FPV technology is not completely environmental-impact free. Legislation on the protection of water and the sea by the European Environmental Agency and the Finnish Ministry of the Environment require an environmental impact assessment prior to the introduction of FPV technology in Finland. This is important in protecting and ensuring that the water quality, and the surrounding environment is not compromised by the FPV technology and installation area. This study will analyze how the FPV system affects the natural equilibrium of the water body in areas of carbon footprint, water quality, aquatic ecosystem, materials of construction, and pollution risks. The environmental assessment findings will be used to determine the feasibility of FPV technology in Finland.

4.2.2 Floating Photovoltaic Plant Installation Location

4.2.2.1 Summary

Finland's geography provides several water body categories where FPV plants can be installed. When determining a location for FPV plant installation, it is important to consider the water body's surface use and inhabitants, surrounding soil quality, and climate. The surface use is largely related to hydrography of the water body, water supply, fishing, and human recreational activities. The characteristics of water bodies and their corresponding location are important to account for as they have differences in the extremity of hydraulic conditions (storms, waves, currents), water level fluctuations, weather adaptations and surrounding urbanization.

4.2.2.2 Area Installation Classifications

Finland is known as the land of the thousand lakes having over 180,000 lakes and ponds of more than five hundred square metres. Approximately 56,000 lakes with a surface area of over one hectare and 2,600 lakes larger than one square kilometre. In addition, the Finnish coast is heavily embayed and fringed with 73,000 islands and inlets (Finnish Environment Institute, 2013). Therefore there is a great opportunity to install FPV systems on an abundant amount of water environments in Finland.

The different location categories for FPV installations are presented below. The categories discuss water body characteristics and their corresponding advantages and disadvantages specific to Finland. For the purposes of this project, a 100 m FPV structure diameter is considered when deciding on an location for FPV installation. The quantity of FPV structures implemented per water body will depend upon the usable water surface area available and the resulting environmental impact from the FPV plant.

Industrial Basin

These basins hold non-drinkable water for industrial purposes only. The quality of the water held in these basins are poor, thus no aquatic or plant life exists. Therefore the full coverage of the water body surface by FPV plants are allowed as a result of basin use. Examples of industrial basins include sand pit mines, cooling basins, and wastewater treatment basins.

Irrigation Basin

Irrigation basins are formed from flooding an embankment enclosure with water. The water is held for irrigating various types of crops. There is a smaller water surface coverage allowed for FPV installation compared to an industrial basin due to basin function. The area equipped for irrigation for 20 regions in Finland derived derived from the European Union farm structure survey 2003 is shown in Table 28.

Table 28. *Finland irrigation areas (Global Map of … 2016)*

Region	Area equipped for irrigation (ha)
Ahvenanmaa	2 150
Etelä-Karjala	2 600
Etelä-Pohjanmaa	5 350
Etelä-Savo	3 840
Itä-Uusimaa	4 470
Kainuu	470
Kanta-Häme	6 640
Keski-Pohjanmaa	1 360
Keski-Suomi	2 250
Kymenlaakso	4 260
Lappi	250
Päijät-Häme	4 990
Pirkanmaa	8 150
Pohjanmaa	4 210
Pohjois-Karjala	1 690
Pohjois-Pohjanmaa	5 590
Pohjois-Savo	5 040
Satakunta	9 440
Uusimaa	9 160
Varinais-Suomi	21 890
Finland total	**103 800**
with groundwater	15 570
with surface water	88 230
Area actually irrigated (ha)	15 000

Water Reservoirs

A water reservoir is an artificial lake created by the damming of rivers to collect, store, and draw off water to serve purposes such as hydropower production, water supply for drinking, irrigation, and flood protection. These basins have the potential to be very large in area and thus allow a larger area of water surface coverage by FPV plants. In addition, water reservoirs used for hydropower production are also advantageous to FPV systems as the reservoir is already is connected to a grid. By generating extra income, an FPV gives the water body additional purpose and can be a secondary use of water real estate. On the other hand, water reservoirs have complex aquatic ecosystems and large fluctuations in water levels as a result of changes in weather that affect the natural flow of streams and rivers. The environmental impact resulting from these factors is important to consider when designing and selecting a installation location for the FPV system.

Natural Lakes

FPV system installation in natural lakes is the most sensitive and dependent on the natural landscape and environmental impact. This is impart from the complexity of the aquatic ecosystem, surrounding urbanization and human settlement, and recreational activities of the water body such as fishing. There is an abundance of freshwater, natural lakes in Finland. In fact, 10% of Finland's total land area is covered by lakes (Freshwater - State..., 2015). Although the lake area size, and consequently FPV installation area, will vary, there are approximately 56,000 lakes with a surface area of over one hectare and 2,600 lakes larger than one square kilometre. Therefore there is still potential to install and cover larger areas of water body surface by FPV systems.

The water quality of Finnish inland waters improves from south to north, and from west to east. Water quality is the poorest in coastal areas in the south, southwest, and west. The waters of Finnish lakes are mainly soft and often humic. In general the water quality of lake area is mostly good, having a ecological quality status of good or high. The water quality status of lakes is worse and more prone to eutrophication for small and medium-sized lakes in agricultural areas. Finnish lake depth is shallow having an average depth of about 7 m (Finnish Environment Institute, 2013). As a result of the shallow lake depth and the relatively low discharges of rivers with long period of ice cover, inland waters are highly sensitive to pollution. The aquatic ecosystems can also be disrupted from relatively low concentrations of excess nutrients, acidic deposition, or contaminants *(Freshwater - State..., 2015)*.

A map of the ecological state of Finland's surface waters is shown in Figure 70 below. The water bodies are ranked by the quality of their ecological state from monitoring data compiled over the period 2000-2007 *(Freshwater - State..., 2015)*.

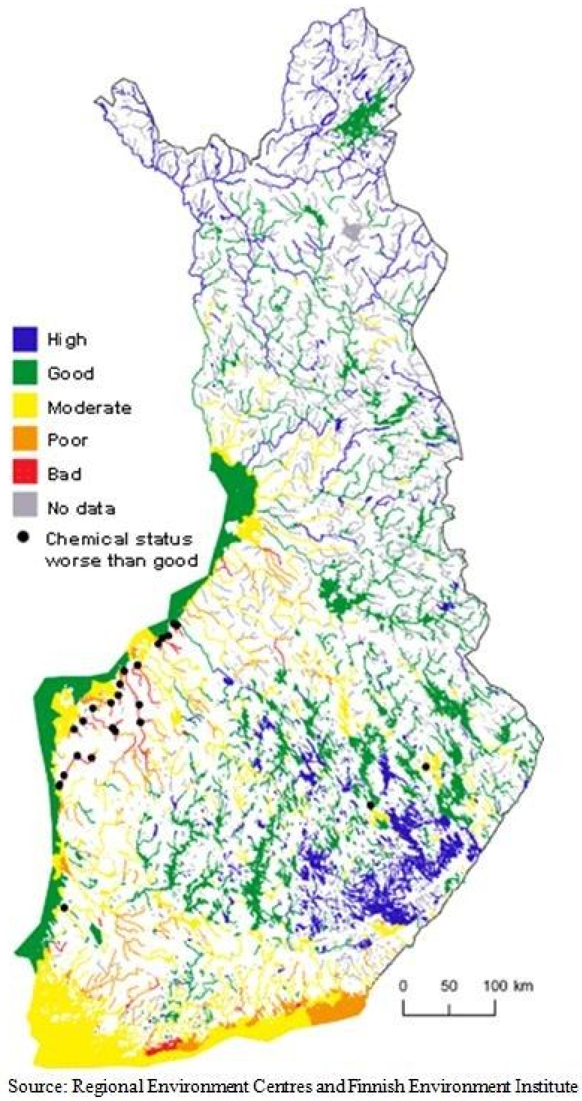


Figure 70. *The ecological status of Finland's surface waters (Freshwater - State..., 2015)*

Figure 71 shows the ecological status of surface waters by proportion of total river length or surface of water area. As shown by Figure 71 river and coastal water quality is much poorer than inland lake water quality with many rivers in Finland ranking in a poor or passable state. This is a result of the relatively low discharge rate of rivers and problems of diffuse loads of nutrients from farmland, and constructions such as dams along watercourses.

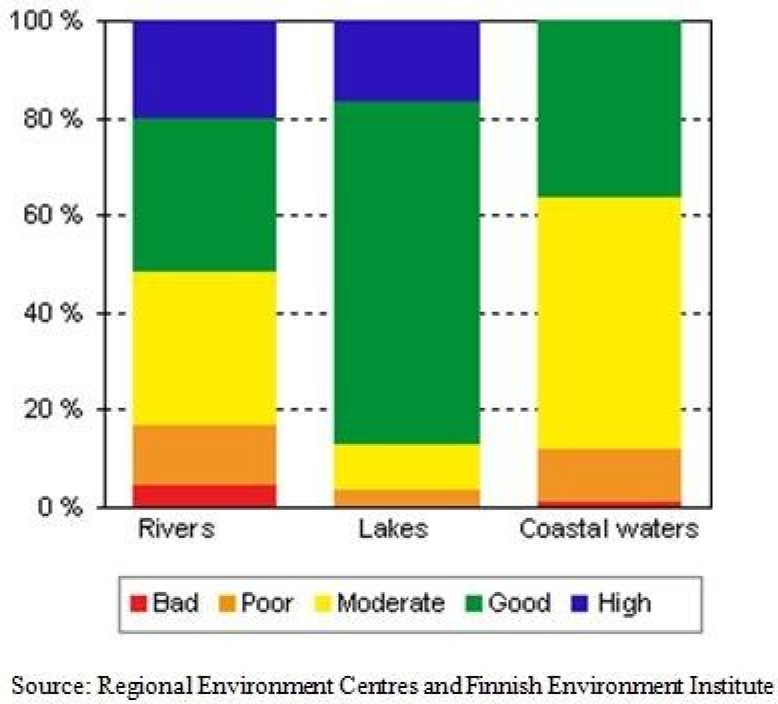


Figure 71. *Ecological status of surface waters by proportion of total length or surface area (Freshwater - State..., 2015)*

The impact potential of FPV deployment on lake ecosystems and the surrounding environment area is influenced by the water quality of the water body. Table 29 displays the general water quality classifications in Finland with their corresponding criteria descriptions. A detailed discussion of how the FPV structure affects the physical, chemical, and biological water quality parameters will be elaborated in a later section of the study.

Table 29. *Criteria for the general water quality classification in Finland (Finnish Environment Institute, 2013)*

Criteria	Description
High	Natural, freshwater state. The water is usually oligotrophic, clear, or with some humus. The water use is not restricted by algae occurrence and is highly suitable for all modes of use.
Good	Near-natural freshwater state. The water is slightly oligotrophic, or clearly humic. Locally restricted algal blooms can occur occasionally. The water is still suitable for most modes of use.

Moderate	Water is slightly affected by wastewaters, diffuse loading, other changing activity, or is appreciably eutrophic or humic due to natural causes. Algal blooms can occur repeatedly. Concentrations of harmful substances in water, sediment, or biota can be slightly higher in pristine conditions. The water is usually satisfactory for most modes of use.
Poor	Water is strongly affected by wastewaters, diffuse loading, or changing activity. Algal blooms are common and may restrict water use for a long period. Concentration of harmful substances in water, sediment, or biota can be clearly higher than in pristine conditions. In catchments with Littorina Sea clay deposits, the pH of water can be very low for short periods and fish die-offs caused by the acidic conditions can sometimes occur. The water is suitable only for modes of use having few water quality requirements.
Bad	Water is extensively polluted by wastewaters, diffuse loading, or changing activity. Algal blooms occur frequently and are often abundant, restricting water use for a long period. Oxygen concentrations are clearly affected by eutrophication. Concentrations of harmful substances in water, sediment, or biota can be at levels that cause clear risk to use of water or biota. In catchments with Littorina Sea clay deposits, the pH of water can be very low for long periods and fish die-offs cause by acidic conditions occur repeatedly. The water is poorly suitable for any mode of use.

.

Sea Surfaces

The Finnish coast is heavily embayed and fringed with 73,000 islands and islets on the Baltic Sea. The Baltic Sea is shallow with a mean depth of only 55 m and is mostly closed, shallow and cold brackish basin. These conditions make the Baltic Sea highly vulnerable to pollution as harmful substances degrade slowly under cold conditions. In addition, the winter ice coverage prevents oxygen being transferred from the air to the surface water creating oxygen deficient conditions. From Figure 71, Finnish coastal waters are classified as satisfactory, passable, or poor. Today, eutrophication continues to be a concern in Baltic Sea and is causing more abundant blue-green algae blooms in the summertime. Eutrophication in the Baltic Sea is caused by nutrient loads from land areas and the release of phosphorus from the sea bottom sediments (Finnish Environment Institute, 2013).

Currently, FPV installations are primarily designed for inland freshwater water bodies as installation on seawater is more complex and demanding. Off-shore, oceanic FPV systems present more challenging conditions including increased movement and and vibration caused by larger waves, salt water traces on the glass surface of the panel, any extra electrical losses through long cable runs, and corrosion and degradation management to construction materials caused by the aggressive high salt content (Riding the Wave… , 2018). Shallower seawaters are preferred due to the limited proximity of electrical connections with the grid network.

4.2.2.3 Finland Soil Quality

Coarse mineral and organic soil types are common in Finland. Consequently, the concentrations of inorganic substances in Finnish surface waters are low. Likewise, the concentrations of dissolved organic substances can be high in surface waters since bogs cover about 30% of land area in Finland (Finnish Environment Institute, 2013). In Finland, the pH levels of topsoil acidity are naturally low everywhere, making Finnish soils vulnerable to acidification. Many inland lakes in Finland have characteristically been undergoing a slow process of acidification that is harmful to numerous plants and aquatic species. Even at relatively low concentrations, excess acidic deposition can disrupt aquatic ecosystems.

Finland's soil quality is considered in this study as the quality of the soil can influence the water quality and thus, the potential impact of FPV deployment on the corresponding water body. Soil can regulate the drainage, flow and storage of water and solutes which includes nitrogen, phosphorus, pesticides, and other nutrients and compounds dissolved in water. From the above paragraph, Finnish soil can be summarized to be predominantly humic, high in organic matter, and consequently, more acidic content. In fact, the soil pH has dropped low enough that there are a few lakes in Southern Finland in which there are no fish at all (Tikkanen, M., 2002).

Runoff flow can also affect water quality for two reasons. Firstly, the water runoff carries sediment with the flow that contributes significantly to increased water turbidity levels and soil erosion. Secondly, the sediment that travels with the water comes from many sources such as agricultural fields, woodlands, highway road banks, and mining operations. The sediment often carries organic matter, animal or industrial wastes, nutrients, and chemicals depending on the source the water flows from. As a result, the sediment can affect water quality physically, chemically, and biologically. Depending on the soil and water quality of a water body location, FPV deployment has the potential to positively impact the environment by decreasing organic matter content and restricting algae growth. The level of potential impact will also depend on location, lake size, climatic conditions, and solar irradiation.

4.2.2.4 Conclusion

The Floating Solar Panel Park project will primarily target natural lakes as a FPV installation area due to the abundant amount of natural lakes in Finland. However, from the combination of factors including shallow lake depth, low river flow rates, diffuse nutrient loads, and long periods of cold weather and ice coverage, Finland's inland waters are highly sensitive to pollution. Consequently, it is important to take precautionary methods to avoid eutrophication, and excess nutrient loading. The shading of water surface that results from FPV deployment has the possibility to provide a solution to these water quality issues in Finland. Other FPV plant installation areas that are mentioned above will also be considered if they fit area size requirements and are deemed to be more economically and environmentally favorable.

4.2.3 Impact Assessment

The amount of sunlight and wind received by a water body will be disrupted by the water surface coverage caused from FPV system deployment. The fraction of water surface area covered will depend on the location, and water body chosen for FPV installation. When conducting the assessment, it is significant to consider FPV design, construction, implementation, use, and end use processes that have the potential to impact water quality of the utilized water body and the surrounding environment. In the impact assessment, factors of carbon footprint, water quality, aquatic ecosystem, materials of construction, and pollution and risk of contamination will be analyzed to determine impact extent to the environment and the physical, chemical, and biological water quality parameters in Finland.

Carbon Footprint

The carbon footprint of a FPV system is the amount of carbon dioxide released into the atmosphere as a result of the power output generated. Carbon dioxide (CO_2) production is a concern worldwide as CO_2 emissions contribute to global warming and climate change. Fossil fuel power plants that generate electricity are currently one of the biggest contributors in CO_2 emissions. Thus, the development and continuing advancement of solar panel technology provides a solution in terms of a renewable, green energy source with a drastically better environmental impact. In principle, solar energy creates no CO_2. However, the various processes of solar panel technology does produce CO_2 emissions. This section will discuss the feasibility of FPV systems in terms of CO_2 emissions and how the technology compares to conventional photovoltaic systems.

In general, the manufacturing, installation, transportations and recycling of PV modules generates CO_2 emissions. Throughout the duration of a solar installation however, the technology will produce CO_2 emissions on a magnitude of 30 times less than fossil fuel plants. On average, it will take 3 years time before solar panel technology create as much as energy as what was consumed in the initial production and installation. Although 3 years is not a realistic, or economic timeframe, the CO_2 emissions for all life-cycle stages of solar panel technology is predicted to continue to decrease in the future due to improvements in manufacturing processes as well as greater efficiency of electricity production, greater durability, and more effective recycling.

Differences in total carbon footprint have been determined comparing the FPV system to conventional photovoltaic systems. FPV systems have predominantly proved to have less of a carbon footprint over conventional photovoltaics in comparison of construction, operation, and decommissioning impact phases. A considerable difference is the improved yield performance that is gained by the FPV cooling effect from the water. Water acts as a natural coolant lowering the operating temperatures of PV modules and allowing more efficient operation. Consistent temperature differences exist between land and water, with a maximum temperature of 70℃ reached on conventional photovoltaics compared to a maximum temperature of 60℃ reached on FPV systems (Riding the Wave…, 2018). In this way, FPV systems have advantageous conditions compared to conventional photovoltaics that are critical to achieving higher energy yields and performance gains. It is significant to note that the impact of water cooling will depend on ambient temperature and humidity, as well as the design and carbon footprint of the FPV system (Riding the Wave…, 2018).

Another concern with conventional photovoltaics is the scale of land involved with their deployment and the change of land use involved. Conventional photovoltaics require large land areas that will destroy forests and cause deforestation. Forests act as a carbon sink and emit CO_2 into the atmosphere once cut down which becomes harmful to the climate. Deforestation and forest degradation present a large concern as the CO_2 emissions are estimated to be between 15 percent and 20 percent of annual global emissions from all sources (Ragazzi, S., 2016). Not only does deforestation resulting from conventional photovoltaic system installation contribute to CO_2 emissions, but it causes other adverse environmental problems including unsustainable resource use, erosion problems, and water depletion. FPV systems avoid the problem of deforestation by utilizing unoccupied, available water bodies and therefore do not contribute additional CO_2 emissions from their installation.

Water Quality

The floating array of a FPV structure will naturally cause shading to the water surface that will alter the amount of sunlight and wind received by the water body. As a result of this new interaction between the atmosphere and water surface, this section will assess how various water quality parameters may change, and to what extent. Water quality parameters that will be analyzed include water level, algal growth, temperature, dissolved oxygen (DO), turbidity, pH, total suspended solids (TSS), and chlorophyll.

The conducted studies on FPV shading effect have determined the drop in water temperature does indeed act as a form of evaporation control. This is advantageous for drought prone areas and local populations alike by conserving the water level of inland lakes rather than evaporating into the air. In fact, more water evaporates from reservoirs than is consumed by humans (Riding the Wave…, 2018). In addition, the FPV structure prevents and reduces wave action which helps slow water from evaporating. Thus, standing water helps lower evaporation rates as well as limiting the erosion of reservoir embankments.

However, the amount of water that does or does not evaporate will depend on the location and the local climate of the given installation area. Evaporation rate can also be lowered with the addition of a cooling system to the FPV system design. Countries with a higher radiation will have the greatest potential to save water through evaporation control. Finland has a background radiation that ranges from 0.05 to 0.30 microsieverts per hour (Stuk, 2019). The regional radiation variation in Finland depends on differences of uranium concentration in rock and soil . Figure 72 shows the radiation map for Finland. Data was obtained from STUK, the Radiation and Nuclear Safety Authority in Finland. The map suggest that Finland has low radiation values with radiation increasing towards the south. It is reasonable to conclude that evaporation control as a result of FPV system deployment would be minimal in Finland due to low levels of radiation.

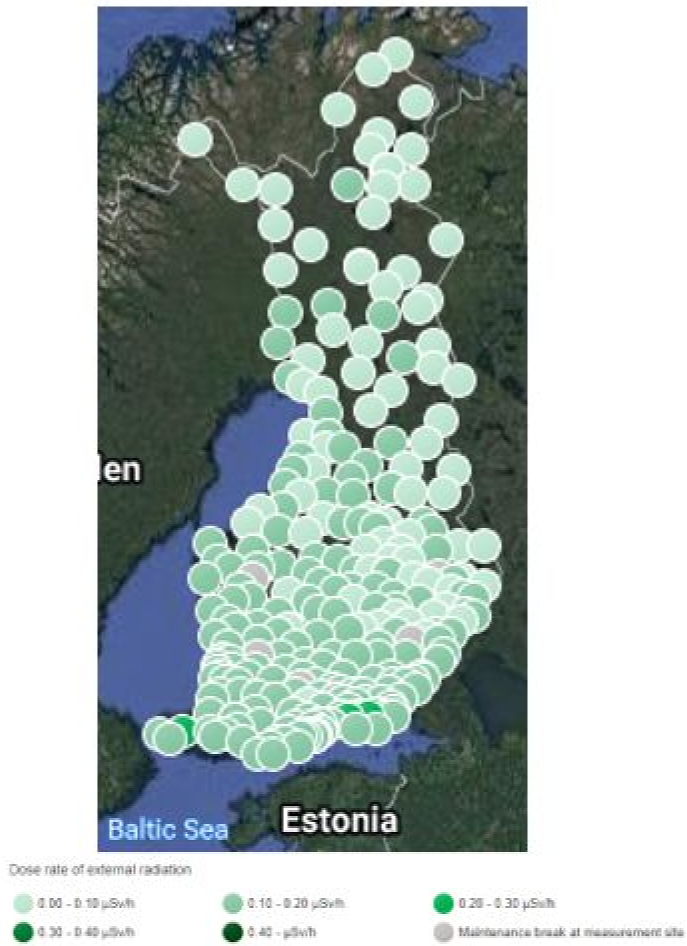


Figure 72. *Radiation map for Finland (Stuk, 2019)*

As mentioned previously, Finnish inland lakes are highly sensitive to pollution. Therefore, precautionary methods need to be taken to avoid problems of eutrophication. Eutrophication causes dense growth of plant life such as algal blooms that limit growth of plants and oxygen production by restricting light penetration through the water. Algal blooms can benefit water ecosystems, but are becoming an increasing planetary pollution problem due to climate changes and excess of nutrients in water from different origins such as agricultural, recreational, and inadequate wastewater treatment sources (Riding the Wave…, 2018). Algal growth is further increased in the summertime due to increases in solar radiation. Furthermore, algae is short lived and algae decay consumes dissolved oxygen in the water resulting in hypoxic conditions and toxic product production. In summary, algal blooms are a risk to human health, impact plant and animal ecosystems, and impact tourism and recreational use of coastal areas.

FPV systems create less favorable conditions for algae growth that would help to counteract the problem of eutrophication in Finland. By limiting the amount of sun needed for algae growth, FPV systems are capable of acting as a control for algal blooms and biological fouling. With less algae present it in turn reduces the need for maintenance, cleaning and replacement of FPV parts. In addition to restricting algal growth, FPV systems have further operation benefits by maintaining, and potentially increasing DO levels in the water. DO is one of the most important water quality indicators and is vital to aquatic ecosystems. Aquatic life is put under stress DO concentrations below 5.0 mg/L. DO concentrations under 5.0 mg/L increases the stress intensity and if severe enough, can result in large fish kills (EPA, 2012).

Other water quality parameters of turbidity, pH, TSS, and chlorophyll will additionally be affected by the sunlight and wind variation caused by FPV system installation. The water temperature can also be anticipated to be lower with the FPV system compared to natural conditions impart from the shading imposed by the FPV structure. However, due to the natural convection cycles of a water body, the warmth from the sunlight and the water's oxygen levels should still be distributed evenly (Riding the Wave…, 2018). In addition, the Floating Solar Panel Park project design incorporates space between the solar panels where light is able to reach the water. Thus keeping the impact of widespread shading to a minimum. Therefore, it can be reasonably concluded that the changes in water quality parameters of turbidity, pH, TSS, chlorophyll, and temperature will not change significantly enough to negatively impact the aquatic ecosystem or surrounding environment. It is still important that these parameters are still monitored if an FPV system is deployed to ensure significant changes do not occur.

Aquatic Ecosystem

Similar to the quality of the water, sunlight blockage and wind alteration caused by the FPV structure has the potential to impact the aquatic ecosystem. In general, the amount of shading an ecosystem receives is an important determinant of primary productivity which influences species diversity and nutrient cycling. A major concern is the direct relationship between the amount of sunlight received by the water body and the overall productivity of an ecosystem. For example, decreasing the amount of sunlight received by a water body will decrease the biomass of filamentous algae and organic matter that feeds fish stocks and other organisms of the aquatic ecosystem. Therefore, an aquatic ecosystem that becomes excessively shaded will alter the ecology of the floral and faunal communities in reservoirs and effect the reservoir's biodiversity. Other issues presented by the FPV system include the potential for bird mortality caused by water birds being attracted to the solar panels, and changes in fish habitat as fish may prefer to reside under the FPV structure where there is no direct sunlight.

The design of the Floating Solar Panel Park project design considers the resulting impact to aquatic ecosystems by incorporating space between the solar panels where light is able to reach the water. Thus, the FPV structure does not completely cover the water surface area which minimizes the shading impact to the aquatic ecosystem. It can be assumed that the biological integrity of the water body will become influenced by the FPV system, but the extent of impact will be very minimal.

FPV Construction Materials

Apart of the impact assessment includes checking the compatibility of materials used in the manufacturing of the FPV system. Factors of material lifetime, resistance, durability, and potential leaching to a given water body must be analyzed to verify the impact an individual material has on the local environment and the quality of water. For this project, materials of construction in contact with, or submerged in water include high-density polyethylene (HDPE), galvanized steel, aluminum, concrete, and alloyed metals made up of Nickel, Chrome, and Molybdenum.

Table 30 below lists each material, their role in FPV design, issues of concern, and compatibility with freshwater environment.

Table 30. *FPV construction materials in contact with or submerged in water*

Material	FPV Design Role	Issues of Concern	Compatibility with Freshwater Environment
HDPE	Pontoon structure	HDPE is used for drinking water pipes thus there is no concern regarding the material's effect on freshwater quality.	Very compatible
Galvanized Steel	Bracing and support structures	Galvanizing steel provides protection against corrosion caused by exposure to freshwater	Compatible in hot and cold domestic, industrial, river, lake and canal waters

Material	FPV Design Role	Issues of Concern	Compatibility with Freshwater Environment
Aluminum	Bracing and support structures	Alkalinity and pH of freshwater increases aluminums potential to react which could negatively affect terrestrial and aquatic life in different ways.	Compatible
Nickel	Alloyed chain for anchoring system	Under normal conditions nickel does not react with freshwater.	Compatible
Chrome	Alloyed chain for anchoring system	Chromium polluted discharges in freshwater can cause environmental disasters.	Compatible
Molybdenum	Alloyed chain for anchoring system	Naturally-occuring metal in water. At low concentration levels is not known to be harmful	Compatible
Concrete	Anchoring blocks	Underwater concrete (UWC) must be used	Compatible

From further research, it has been concluded all materials in the construction of the FPV system that are submerged in water or have the potential to contact water are compatible with a freshwater environment. The only minor concern to be aware of is the potential for algae to concentrate and grow on the FPV pontoon structure that is in contact with the water body.

Pollution and Risk of Contamination

As concluded above, all FPV materials for the Floating Solar Panel Park project that are in contact with or that are submerged in water do not pose risk of contamination to water quality. As the solar panels themselves should not come in contact with the water, there is limited to no risk of contamination to the water or surrounding environment. Moreover, careful consideration of the FPV system design and construction protects against any leakage or contact between the current-carrying components and any humidity (Riding the Wave…, 2018). The largest issue of concern in regards to potential pollution and risk of contamination for the FPV structure involve the interaction the FPV system has when it comes in contact with the water.

Overall the FPV system has minor pollution or contamination risks. The minor contamination risks that do exist include contaminant spills from lubricants and oils and possible battery leakage. The potential pathways these contaminants may get into the water include through rain events, and increased fluctuations in water level. A solution to this problem would be to use a environmentally friendly, biodegradable lubricant with a low operating temperature. In addition, special precaution should be taken to protect against any leakage from the battery.

4.2.4 Conclusion

FPV systems are a new, emerging technology that is becoming increasingly popular to conventional solar systems in response to issues of deforestation, flexibility, and land area requirements. Currently, the information available regarding the ramifications and benefits of FPV systems are limited due to the technology's recent development. Therefore an environmental impact assessment was conducted for the Floating Solar Panel Park project to verify that the FPV design proposal met the legislation and regulation requirements of both the European Environmental Agency and the Finnish Ministry of the Environment. In addition, this study was carried out to determine all potential impacts of FPV deployment to lake ecosystems and environment in Finland with respect to differences in location, lake size, climatic conditions, and solar irradiation.

From the study, the environmental impact of FPV systems is negligible, and even a possible advantageous energy solution for Finland. In general, FPV systems have been predominantly proven to have a lower carbon footprint than conventional photovoltaics in areas of yield performance, and conservation of forested areas. Likewise, the FPV system is designed in a way that the structure does not completely block all sunlight that is to be received by the utilized water body which thereby minimizes any impact imposed by shading. Actually, FPV system deployment can counteract the high pollution sensitivity problem experienced in Finland by partially managing and controlling algal blooms and maintaining adequate DO levels. The aquatic ecosystem additionally can be assumed not to be perturbed by PV installation as the impact is insignificant.

In conclusion, the findings from the environmental feasibility study have determined the installation of the FPV project design to be in compliance with environmental legislations and regulations relevant to Finland. The FPV system will vary in environmental impact depending on various factors so it is important that these factors are taken into account for each water body utilized, and that water quality parameters are continuously monitored. Current studies, and further research conducted in this study have found minimal to no observable changes to water body water quality and significant impact on the surrounding wildlife upon the deployment of FPV systems in Finland.

4.3 Feasibility Review

In summary, both feasibility studies of economic and environmental impact analysis conclude the feasibility of the Floating Solar Panel Park project design in Finland.

From the economic analysis it is understood that the yearly RoI will decrease over time due to the inflation. Another topic which has to be mentioned is the loss of energy which isn't included. Within 30 years the panels can lose up to 15% of their energy output compared to the given figures in their description. That will reduce the calculated amounts and figures as well. Sensitivity Analyses will have to be added in the future to check how the financing decisions react to changing inputs. As well as the implementation of assessments of uncertainty for future natural events and failures by using the Bayes-Rule or the μ-σ-principle (based on the Bayes-Rule).

With regard to the absolute and relative advantages discussed previously, and having the mentioned influences in mind, it can thus be concluded that the project makes both economic and environmental sense. FPV systems become more economically favorable when the possibilities for subsidies exist, however the type of financing must be decided by the respective company. In addition, differences in location, lake size, climatic conditions, and solar irradiation experienced by FPV installation area will determine the extent of environmental impact and whether or not the FPV system will be advantageous to the water quality and surrounding environment. Currently there are issues at hand relevant to both economical and environmental sectors such as high costs for solar panel materials, the carbon footprint required for FPV installation process, and the recyclability of solar panel materials in the end use phase. Fortunately, with continuing development and advancement of FPV technology these issues are expected to be overcome in the future.

5. Project Management Review

The following section provides information pertaining to the group work and practical tasks completed by the *Floating Ideas Team* as part of the Project Management course. Only newer and more relevant, project-related topics will be discussed in detail. Appendix A contains all other work performed throughout the semester duration.

5.1 Risk Analysis

Risks are a daily companion in project work and especially in project management. To not be unprepared when risks occur, there are several ways and methods to handle potential risks in the first place and prioritize them. With regard to the risk management, the main focus was laid on the 9 most probable risks. In the figure below the risks were listed and their monetary influence was defined by which work packages would be most affected and disturbed or annihilated. Furthermore was defined whether the risks can be prevented or have to be mitigated and how to handle those risks when they finally occur.

Risk Management

Risks	Probability 1 - 5	Impact in €	Total		how to prevent/ mitigate	when occurs
1. Bad basis due to bad Research	3	108.000,00 €	324.000,00 €	Prevent	- get lots of feedback by Supervisors - use reliable Sources	- define useful Research and use time buffer for additional
2. No testing due to lack of Ressources	5	42.000,00 €	210.000,00 €	Prevent	- organize resources in the beginning of the project	- Consultation with supervisor, eventually donation from client
3. Broken Research Panel	4	42.000,00 €	168.000,00 €	Prevent	- define Testing Area and Security for Panel	- Consultation with supervisor, eventually donation from client
4. Motivation Loss & Disagreements	3	46.680,00 €	140.040,00 €	Mitigate	- add Teambulding Activities - Define Communication Standards	- Teambuilding Activities - problemsolving Communication
5. uneffective Tutoring due to communication issues	1	116.700,00 €	116.700,00 €	Prevent	- Communication Standards - arrange Feedback Sessions - defining weekly meetings	- problemsolving communication - clear goal definition of the project
6. Quality of work doesn't lead to 30year life cicle park	4	23.340,00 €	93.360,00 €	Prevent	- Feedback on Quality of work	- integrate determined solarpark life cycle into report
7. Development of cheapest possible solarpark already done	5	15.560,00 €	77.800,00 €	Mitigate	- Compare prices with existing Solarparks	- compare and integrate Investment results into report
8. Investment Budget for Solar Park in Finland too high	5	11.670,00 €	58.350,00 €	Mitigate	- Compare prices with existing Solarparks	- defined as part of the project, integrate into report
9. Knowledge issues lead to time delay	2	23.340,00 €	46.680,00 €	Prevent	- integrate time buffer	- use integrated time buffer and consult supervisors immediately

Figure 73. *Risk definition, calculated impact and ways for prevention and occurring.*

In addition, the impact of the risks were compared to their probability and were assigned to the corresponding area by means of points. In the matrix you see for example, that misleading tutoring has the most financial impact, but due to defined project goals and created communication standards, the probability was kept very low. (Communication Management, see Appendix A). The most critical part in the risk analysis was the research aspect, due to the risk of misleading information and the basis it built for the project.

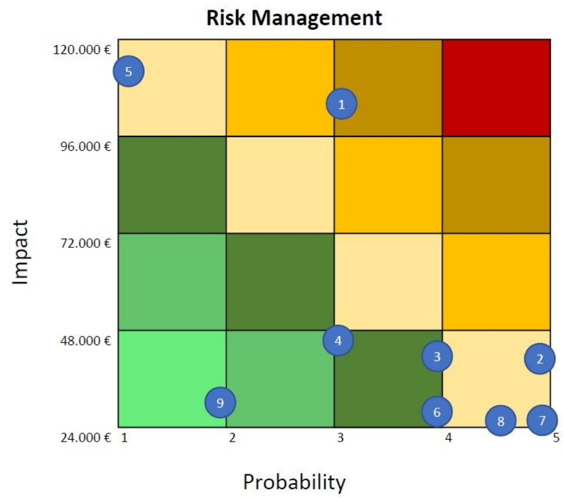


Figure 74. *Risk management matrix, relation between impact & probability.*

5.2 Teaming Review

As discussed in the previously done Midterm Report, each team member brings a different set of skills to the team. To first realize what each member could bring to the team, the Belbin Role test was done. Each member took the test and the results can be found in Appendix A, Section 2.2. It was was very interesting throughout the whole semester to see how each team acted in a real team scenario versus how their Belbin role predicted they would.

For most of us the Belbin team roles were not far off. They depicted a lot of our personalities and teaming skills accurately. Some things of note are that some individuals held the same roles as other people on the team and balancing some of those skills with the roles' skills we didn't have was important to the team's success. In the end, it is our opinion that all roles were filled by team members when they needed to be filled. We did not have such a specific set of roles as other teams might have, which made it so when a new role needed to be filled, it was easy for someone to step in a fill it. The team leader switched hands multiple times and it usually came down to who knew the most about the subject and whose subtask it was. Instead of having one group leader, we elected to follow the leader who was in charge of the specific task. This sometimes could be confusing as many tasks overlapped, but we also had members who would keep everyone on task, so that the confusion did not last long.

Overall, the organization of our team was not so strict as many teams before us have been. This had some very obvious positives and negatives as the project went along, but in the end, it worked out in our favor to have people working on many different things at once and it helped to have multiple points of view come in when things became confusing. As a team, we worked well together and not only got to focus on the things that we each as individuals care about, but we also got to learn a lot from the other members of our team to learn more about other engineering disciplines.

5.3 Schedule Review

An updated schedule, updated on May 8th, 2019, can be viewed in Appendix B, Figure 2. The schedule, as one can see is coming quickly to an end. The team had worked diligently to get everything done, but with every project, the time ran out to complete some of the lesser of the important subtasks and some have yet to be done.

Tasks Not Going to Be Done

Like mentioned, there are frequently times when parts of a project are not finished on time. With this being a rather short project and one with a definite deadline, there is not any room to extend the project and continue to research and test. With that being said, the main things that, according to the schedule, are not going to get done include making a 3D printed structure for testing. Ultimately, this was seen as a less important task and left out due to the approaching deadline. In addition, the testing of the floating structure as well as the rotation and tracking systems is also not going to be fully completed. Again, these two tests were seen to be less important than the testing of the efficiency improvement techniques and consequently were not completed due to time constraints. These things could be done in the future if more time allowed, but were not seen as vital to the project and thus not completed.

Tasks Yet to Be Done

The tasks that have yet to be done include creating a video and website, which is still currently in the works to get done as well as completing the final report and the final presentation, both of which will get done after the updating of this schedule.

Conclusion

Overall, the schedule was not followed as closely as the team should have been following it, but for the most part, the tasks were completed and completed within the time range given. The task orders changed slightly as the team figured out what they needed to focus on and how much time each task would really take, but in the big picture, the schedule was followed and helped the team to make sure they got done what they had set out to accomplish.

5.4 Cost Review

For the Final Report the Cost Analysis has been reworked and is now more related to the Work Breakdown Structure and the several Work Packages it contains. The complete table of Work Packages including planned costs, actual costs, and progress can be seen in the Appendix B.
For the calculation of the planned Costs, the specified days from the agile schedule was used and multiplied with an amount of 80€/h per Person. One day was estimated to be a 7.5h workday. For the actual costs, on the other hand, the continuously being worked on timesheet was used, to have the actual working time for the different topics and to calculate more precise. The complete budget (BAC), you will see in the upcoming table, is the budget for the complete project work and is not related to the costs of the solar park. The Earned Value (EV) is the actual value which was accomplished until today and is calculated by using the planned costs multiplied with the percentage of completion of the specific tasks.

As shown in the figure below, there are several key figures which are used in the cost calculation. The Cost Variance (CV) is the difference between the EV and the actual costs (AC) and is also explained as the Cost Performance Index (CPI) being a key figure which can be relied on in terms of cost performance and is calculated by dividing the EV through the AC. The SPI is the schedule performance index, calculated in the same way, like the CPI but using the planned costs (PV). The CPI is the key figure to the difference of the EV and the planned costs. In "A Guide to the Project Management Body of Knowledge" (Project Management Institute, 2008) it is stated, that an CPI and SPI beneath 1 would be a significant goal for Project Management.

BAC Complete Budget		233.400,00 €
PV Planned till today		177.600,00 €
AC Actual till today		130.160,00 €
EV Earned Value till today		129.180,00 €
Cost Variance (CV)	-	980,00 €
Cost Performance Index (CPI)		0,99
Schedule Variance (SV)	-	48.420,00 €
Schedule Performance Index (SPI)		0,73

Figure 75 . *Project Costs comparisons between planned and actual costs and earned value*

The figures for the above mentioned table and the graph below, showing the correlation between planned costs, actual costs and the earned value were taken on the 1st of may 2019 and therefore can be slightly different due to the finalizing of the project on the 10th of may.

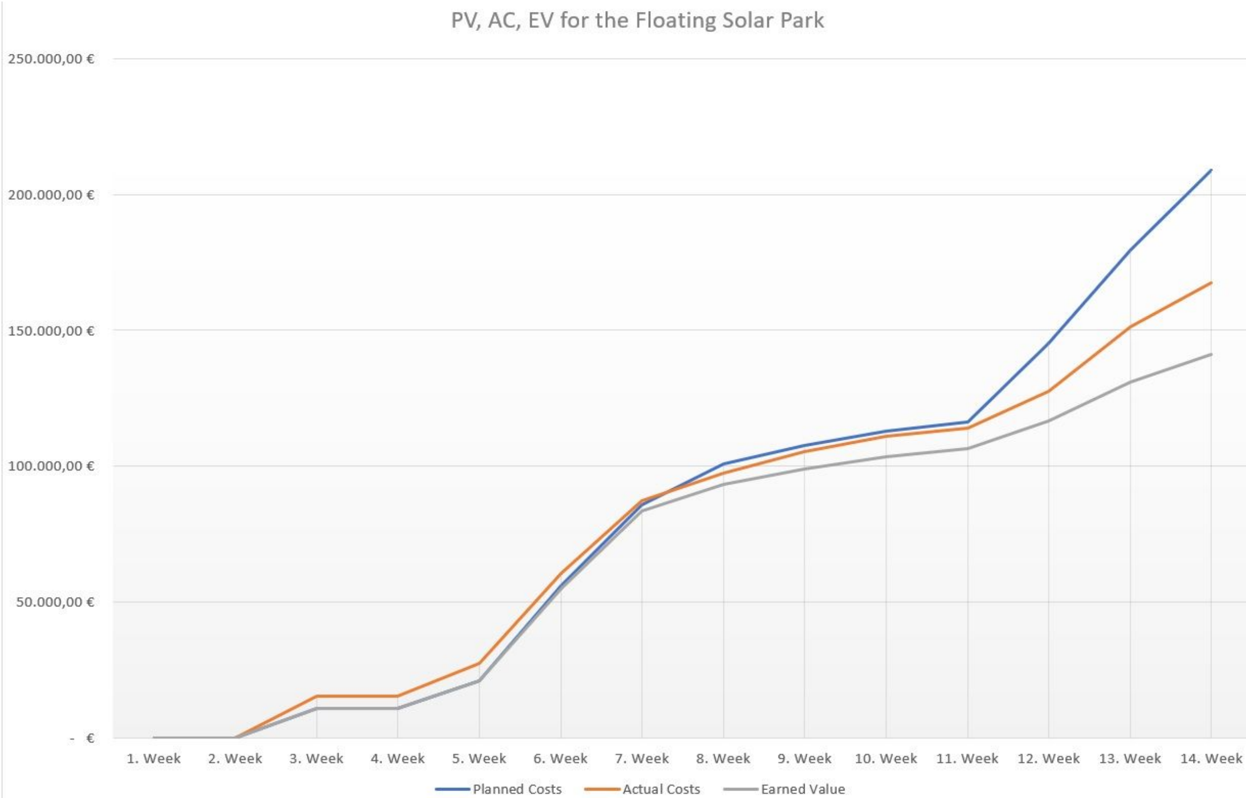


Figure 76. *planned and actual costs and earned value comparison related to the project time scale*

6. Conclusion

6.1 Lessons

Floating solar panel parks are becoming more popular as societies continue to need energy, but are running out of land space to keep up with the energy demand. Because of this, floating options are on the rise. It is common to see offshore windfarms and is becoming more common to also utilize offshore solar or floating solar. In most cases thus far, they are in very sunny areas and are also used to help conserve water in basins. In the case of Vaasa, Finland, it is not as necessary to conserve water in basins, but is highly efficient to have a floating park since Finland has over 180,000 lakes within its borders.

Floating solar is becoming more popular, but it is still something that is not very developed. Not many “perfect solutions” have been found and many parks are still being tested for efficiency. With this, there was not an easy place to start. Lots of research needed to be done to even begin to start designing a park of this size for a place so far from the equator. In this research phase the team learned a lot of things about solar energy, Finland, and what kinds of components can increase the efficiency of a solar park.

The biggest takeaways from starting this project consisted of learning that Finland is simply not the best place to put a solar park, but it can be done and can be done with a profit in the end. Vaasa, Finland is cloudy for a large portion of the year, leading one to believe that it would not be an ideal place for a solar park, but with the use of mirrors and concentrators, one can increase the efficiency by a lot.

With the help of mirrors the efficiency of a panel can increase by 36.99%. This is a significant amount of energy being added by a relatively cheap efficiency component. Systems like concentrators add efficiency as well, but were not as cheap and thusly could not compete with the use of mirrors. These efficiency adding techniques are only as beneficial as they are when combined with a tracking system. Another major lesson learned was that tracking the sun is very important and can increase the efficiency of the panel park by almost half (it produces 46.8% more energy than a park without any tracking), but does not require the most expensive and advanced system to do so. Adding only tracking in the vertical axis increases the energy output by half and adding more tracking, like two axis tracking, does not add a significant amount more energy for the added cost and energy used to track the sun. This was a large takeaway as most would assume the best systems will produce the best outcome, but in the case of tracking, one axis tracking in the vertical axis is enough.

In addition, another large takeaway is that solar panel parks can be used just about anywhere. If a solar panel park can be made efficiently and produce energy and a profit in Vaasa, Finland, it shows that many other places equally as far north and certainly south of here can use solar to reduce their CO_2 emissions without limiting their energy consumption. Societies continue to require more and more energy and with this project and others like it, one can see that floating solar is an option for many places around the world.

6.2 Summary

The Floating Ideas team learned a lot about solar panels through their research, but the most important parts of this project were the designs and the design process that the team went through to get to a final feasible floating solar panel park design.

Starting the project with solely research, the team learned a lot about solar parks and what are required to make them work and be feasible in Finland. After detailing many components that could possibly work, the team set out to create a final design and through many design iterations came upon a final design that is feasible in Finland.

The final design utilizes various methods researched and tested throughout the semester. The figure below shows the final design in detail and the table below summarizes the final design components for the floating solar panel park.

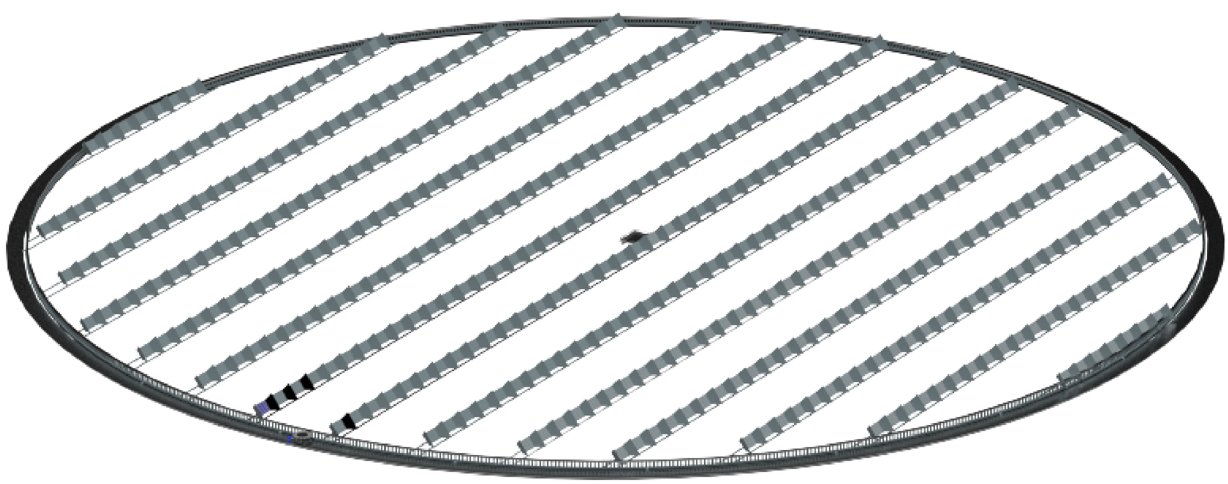


Figure 77. *Final Design Drawing*

Table 31. *Summary of Final Design Components*

Component	Basic Design Description
Panel Type	Bifacial panel (417 per circular module)
Placement	The panel are placed horizontally to avoid losing efficiency from shadows. They will be fixed in the vertical direction at a 53^{o} angle while rotating on the xy-plane to track the sun
Shape and Structure	The shape of this park is a circle. This is done with an outside ring being anchored down, holding an inside ring in the middle which holds the panels and mirrors
Panel Frame and Structure	Panels will be held in place with an aluminum square frame and held up above the water with 25 mm outside diameter aluminum round pipe. Since every row will have two floating pipes associated with it, cross-bracing will be needed in between the pipes to hold it in place. This cross-bracing is also made out of aluminum and will be 40 mm x 3 mm thick flat bar
Mirrors	Two mirrors will be on each side of a single panel. They are trapezoidal in shape to catch more rays from the sun
Flotation	Each row of panels, in addition to the outside ring of the module, will be hollow round HDPE pipe that floats. The outside pipe is 280 mm outside diameter and the row piping is 180 mm outside diameter
Rotation	Rotation will be achieved with a slew drive system and a hydraulic motor. This system will give a lot of torque at a slow speed
Anchoring	The anchor will be a 2 m x 2 m x 4 m concrete block attached to a Nickel Chromoly Steel Alloy chain. Three of these will be necessary to anchor this structure
Cooling Systems	No cooling system is going to be added, but being on the water and having wind blow around the structure will add natural cooling
Connection to Grid	A floating platform will be added to the center of the modular structure to house the inverter and other electronics needed to run the park and connect the energy back to the grid
Cleaning	Cleaning will need to be done annually as part of the maintenance schedule as rain is not sufficient for cleaning

This final design is a compilation of a four month long design study and can now be put into use if chosen to be used. With the feasibility studies done, it is clear to see a lot has to be considered before implementing a project. This design is indeed feasible economically with various different financing options. The best financing option would be financing the project with subsidies for help, but this cannot always be assumed, so it is good that all other options are likely to be feasible as well, most namely equity financing especially with the focus on the return on investment and the mezzanine financing with focus on the return on equity, respectively.

In addition, an environmental assessment was done, which considered many things. Finland's lakes are prone to pollution since the water bodies have slow-moving inlets and outlets. This was one major area of concern. It was determined, however, that the floating solar panel park will not have a major impact on Finland's water quality and might actually improve water bodies since less algal blooms will be able to grow. Keeping a close eye on how floating solar will affect Finland's environment is a must as the design is implemented. It does, however, reduce the amount of CO_2 being produced and is consequently recommended over conventional energy methods.

6.3 Continuation of Work

Even with all of the work that has been done on this project, more research and testing could be completed before making a final working version of this design. If more work were to be done, it would be focused on testing different parts of this design to produce an accurate representation of the added efficiency one can get from having a rotation tracking system. Testing on the floating structure could also be done, but would be of lesser importance compared to the efficiency techniques. Additionally, further research into where this floating panel park could be placed would be good. Currently Poland is looking to add more coal-fired power plants to their economy to fill the demand in energy needed there. It would be ideal to further this study with Poland in mind and estimate the energy they would gain from a design like this as well as note how much cleaner this design would be rather than adding more coal-fired power plants to their country.

In the end, more work could always be done to continue this study, but with the design detailed in this report, floating solar could soon be feasible in Finland and most certainly in more locations with even more sun.

REFERENCES

Belis G., Cortes Martin A., De Oliveira M., Vrignon P., Winters R. (May 18, 2018) *Floating Solar Panel Final Report.* Vaasa: Novia University of Applied Sciences.

Rosa-Clot, M., Tina, M. G., (2018) *Submerged and Floating Photovoltaic Systems.* London: Academic Press.

Oni, B. (February 9, 2017) *Solar a Energy: Advantages And Disadvantages.* Tile Energy. Retrieved from https://www.tileenergy.uk/solar-a-energy-advantages-and-disadvantage

Lighting Research Center. (July, 2006), *"How do PV panels or PV cells work?"* Rensselaer Polytechnic Institute. Retrieved from https://www.lrc.rpi.edu/programs/nlpip/lightinganswers/photovoltaic/04-photovoltaic-panels-work.asp

Alternative Energy Tutorials. (2019), *"Solar Cell I-V Characteristic,"*. Retrieved from http://www.alternative-energy-tutorials.com/energy-articles/solar-cell-i-v-characteristic.html

Knier G. (August 6, 2008), "*How Do Photovoltaics Work?"* Retrieved from https://science.nasa.gov/science-news/science-at-nasa/2002/solarcells

Agbavor, D. A. (2015). *Correlation between sunlight intesity and wind speeds of a coastal location* (School of Technology). Retrieved from https://www.theseus.fi/bitstream/handle/10024/103987/My%20thesis%20pdf.pdf?sequence=1&isAllowed=y

Solar Energy Technologies Office. (August 16, 2013), *"Solar Photovoltaic Cell Basics,"* U.S. Department of Energy. Retrieved from https://www.energy.gov/eere/solar/articles/solar-photovoltaic-cell-basics

Solar Research. (2018), *"Solar Grid and Systems Integration,"* The National Renewable Energy Laboratory. Retrieved from https://www.nrel.gov/solar/index.html

DOE/NREL. (January 8, 2019), *"Great Potential for Floating Solar Photovoltaics Systems,"* Science Daily. Retrieved from https://www.sciencedaily.com/releases/2019/01/190108125422.htm

Thi N. (July 16, 2017), *"The Evolution of Floating Solar Photovoltaics,"* Research Gate. PDF.

The World Bank. (October 30, 2018), *"Growing Exponentially, Floating Solar Opens Up New Horizons for Renewable Energy: Report,"*. Retrieved from https://www.worldbank.org/en/news/press-release/2018/10/30/floating-solar-opens-new-horizons-for-renewable-energy

Average Weather in Vaasa Finland Year Round. (n.d.). Retrieved from https://weatherspark.com/y/87765/Average-Weather-in-Vaasa-Finland-Year-Round

Best Way to Clean Solar Panels. (n.d.). Retrieved from https://energyinformative.org/solar-panel-cleaning/

Cleaning and Maintenance Tips for Solar Panels. (n.d.). Retrieved from https://www.greenmatch.co.uk/blog/2016/04/cleaning-and-maintenance-tips-for-solar-panels

Floating Power Plant - Invest in the future of energy. (n.d.). Retrieved from http://www.floatingpowerplant.com/

How to Anchor a Dock System [Review]. (n.d.). *Home Depot.* Retrieved March 10, 2019, from https://images.homedepot-static.com/catalog/pdfImages/7b/7b3ad166-3238-478e-9405-ae8e4ac2666b.pdf

Stapleton, G., & Neill, S. (2012). *Grid-connected solar electric systems: The Earthscan expert handbook for planning, design and installation.* Abingdon, Oxon: Earthscan.

Prouvost B. (September 25, 2017), *"Inside the World of Floating Solar Technology,"* Distributed Energy. Retrieved from https://foresternetwork.com/distributed-energy-magazine/solar/flotovoltaics/

Wärtsilä. (2019), *"Wärtsilä in Finland,".* Retrieved from https://www.wartsila.com/fin

Honsberg, C. H., & Bowden, S. B. (n.d.). Shading | PVEducation. Retrieved March 19, 2019, from https://www.pveducation.org/pvcdrom/modules-and-arrays/shading

Bagher, A. M. (n.d.). Types of Solar Panels (2019) | GreenMatch. Retrieved March 20, 2019, from https://www.greenmatch.co.uk/blog/2015/09/types-of-solar-panels

Rosa-Clot M., Tina G. M., (2018), *"Submerged and Floating Photovoltaic Systems,"* Elsevier Inc. Retrieved from https://books.google.fi/books?id=OOLWDgAAQBAJ&pg=PA110&lpg=PA110&dq=water+veil+cooling+system&source=bl&ots=8q5tHaS1SI&sig=ACfU3U079xe5xBUzDeI9EYrZrDEECY8cnQ&hl=en&sa=X&ved=2ahUKEwiz1pPYp5HhAhVD2aYKHcFQAQUQ6AEwBnoECAgQAQ#v=onepage&q=water%20veil%20cooling%20system&f=false

Siecker J., Kusakana K., Numbi B. P., (November 2017), *"A review of solar photovoltaic systems cooling technologies,"* ELSEVIER. PDF document.

Photovoltaic Solar Electricity Potential in European Countries [Photograph]. (n.d.).

Li W., Shi Y., Chen K., Zhu L., Fan S., (2017), *"A Comprehensive Photonic Approach for Solar Cell Cooling,"* ACS Photonics. Retrieved from https://pubs.acs.org/doi/abs/10.1021/acsphotonics.7b00089

Alfons Oebbeke, A. O. (2008, 23. Juli). Fluoreszenzkollektoren: Mit Weltrekord zurück aus der Mottenkiste. Retrieved on March 11, 2019, from https://www.baulinks.de/webplugin/2008/1241.php4

Altmeppen, K. D., Zschaler, F., Zademach, H. M., Böttigheimer, C., & Müller, M. (2017). Nachhaltigkeit in Umwelt, Wirtschaft und Gesellschaft: Interdisziplinäre Perspektiven. Wiesbaden, Deutschland: Springer Fachmedien Wiesbaden.

Apex IT Group. (o.D.). Optimierungs- und Verstärkungstechniken. Retrieved March 10, 2019, from http://www.apex-portal.com/ecosolutions/analyse-derexergie/sonne_verstaerkungstechnik.php

Esolutions Company. (o.D.). Solar Konzentratoren | Solar trackers | Beiderseitige Solarplatten | Mobiles Fotovoltaiksystem. Retrieved March 9, 2019, from http://www.solar-trackers.com/de/solar-concentrators.asp

Fraunhofer ISE. (o.D.). Current Status of Concentrator Photovoltaic (CPV) Technology. Retrieved March 9, 2019, from https://www.ise.fraunhofer.de/content/dam/ise/de/documents/publications/studies/cpv-report-ise-nrel.pdf

Konstantin, P. (2017). Praxisbuch Energiewirtschaft: Energieumwandlung, -transport und -beschaffung, Übertragungsnetzausbau und Kernenergieausstieg (4. Aufl.). Berlin, Deutschland: Springer Berlin Heidelberg.

Kyocera. (o.D.). KYOCERA TCL Solar Begins Construction on 13.7MW Floating Solar Power Plant; Company's fourth floating solar project, world's largest, will be built on Japan's Yamakura Dam reservoir | News Releases | KYOCERA. Retrieved March 19, 2019, from https://global.kyocera.com/news/2016/0102_knds.html

Powalla, M. P. Prof. Dr.-Ing.. (o.D.). ZSW: Dünnschichtsolarzellen und -module. Retrieved March 19, 2019, from https://www.zsw-bw.de/forschung/photovoltaik/themen/duennschichtsolarzellen-und-module.html

PV Education. (o.D.). Bypass Diodes | PVEducation. Retrieved March 10, 2019, from https://www.pveducation.org/pvcdrom/modules-and-arrays/bypass-diodes

Miloni, R. P. M. R.P.. (2014, 1. März). Adaptive Photovoltaik. Retrieved March 6, 2019, from http://www.solventure.ch/adaptive_photovoltaik.pdf

Rolf Hug, R. H. (o.D.). Solar-Report | Konzentrator-Photovoltaik bringt die Sonne auf den Punkt - SolarServer. Retrieved March 10, 2019, from https://www.solarserver.de/solar-magazin/solar-report/konzentrator-photovoltaik-bringt-die-sonne-auf-den-punkt.html

Stefan Glunz, S. G. (o.D.). Stand und Perspektiven der Photovoltaik. Retrieved March 9, 2019, from http://www.fze.uni-saarland.de/AKE_Archiv/DPG2005-AKE_Berlin/Buch/DPG2005_AKE4.3Glunz_Stand%20und%20Perspektiven%20der%20Photovoltaik_final.pdf

Sven Vörtmann - Internet und IT Service, TYPO3, S. V. (o.D.). Konzentrator. Abgerufen March 8, 2019, von https://www.energie-experten.org/erneuerbare-energien/solarenergie/solarzelle/konzentrator.html

Wesselak, V., & Voswinckel, S. (2012). Photovoltaik: Wie Sonne zu Strom wird. Berlin, Deutschland: Springer Berlin Heidelberg.

Domininghaus, Hans. 2012. Kunststoffe. Herausgegeben von Peter Elsner, Peter Eyerer, und Thomas Hirth. Berlin, Heidelberg: Springer Berlin Heidelberg

Förstner, Ulrich. 2012. Umweltschutztechnik. Berlin, Heidelberg: Springer Berlin Heidelberg.

Umweltbundesamt. 2017. „Phthalate: PVC-Weichmacher mit Gesundheitsrisiko“. Retrieved March 19, 2019. http://www.umweltbundesamt.at/umweltsituation/schadstoff/pvcweichmacher/.

Windsperger, Andreas, Brigitte Windsperger, und Richard Tuschl. 2007. „Die aktuelle Situation des Werkstoffs Weich-PVC in den relevanten Themenbereichen“. PVC Heute. Institut für industrielle Ökologie

Smadja, Judith, und Paul Smadja. 2017. „4cSolar - Floatracker, Water treatment, Nearshore, Open sea“. 4csolar. Retrieved March 08, 2019. https://www.4csolar.com

Ciel et terre. 2017. „Ciel et terre“. Ciel & Terre. Retrieved March 06, 2019. http://www.ciel-et-terre.net/.

Cogley, J. Graham. 1979. „The Albedo of Water as a Function of Latitude“. Monthly Weather Review 107 (6): 775–81

Kyocera. 2017. „KYOCERA TCL“. Retrieved March 08, 2019. http://global.kyocera.com/news/2016/0102_knds.html.

Heliofloat GmbH. (o.D.). Heliofloat Platform Technology. Retrieved March 14, 2019, from https://www.heliofloat.com/index.php?id=17

Kriechhammer, S. K. (2017). Master Thesis Technikfolgenabschätzung von schwimmenden Solaranlagen (Eine energetische und ökologische Betrachtung). Abgerufen von https://zidapps.boku.ac.at/abstracts/download.php?dataset_id=17079&property_id=107

Ocean Sun. (o.D.). Products | Ocean Sun. Retrieved March 19, 2019, from https://oceansun.no/products/

Statkraft picks Ocean Sun for €2.3M solar park in Albania. (o.D.). Retrieved March 18, 2019, from https://www.aa.com.tr/en/energy/general/statkraft-picks-ocean-sun-for-23m-solar-park-in-albania/23816

Nadia AL-Rousan, AL-Rousan Mohammad, Shareiah Adnan, Hazem AL-Najjar. Choosing the efficient tracking method for real time tracking system in Jordan and it's neighbors to get maximum gained power based on experimental data. In: Proceedings of international conference on renewable energy research and applications (ICRERA); 2012. IEEE.

Birol F. World energy prospects and challenges. Aust Econom Rev 2006;39(2):190–5.

Smith CL. The energy challenge. Appl Petrochem Res 2012;2(1-2):3–6.

Jazayeri K, Uysal S, and Jazayeri M. MATLAB/simulink based simulation of solar incidence angle and the sun's position in the sky with respect to observation points on the Earth. In: Proceedings of international conference

Duffie JA, Beckman WA. Solar engineering of thermal processes 3. New York: Wiley; 2013https://books.google.com.my/books?hl=en&lr=&id=Q1tjDQAAQBAJ&oi=fnd&pg=PR17&dq=Solar+engineering+of+thermal+processe&ots=Zj8QiteyOC&sig=iPL_N9_McVorH__5Rl5AMPj4c4&redir_esc=y#v=onepage&q=Solar%20engineering%20of%20thermal%20processe&= false

Al-Naima, F., & Yaghobian, N. (1990). Design and construction of a solar tracking system. Solar & Wind Technology, 7(5), 611-617. https://doi.org/10.1016/0741-983x(90)90072-a

AL-Rousan, N., Isa, N. A. M., & Desa, M. K. M. (2018). Advances in solar photovoltaic tracking systems: A review. Renewable and Sustainable Energy Reviews, 82, 2548–2569. https://doi.org/10.1016/j.rser.2017.09.077

Rosa-Clot, M. R. C., Rosa-Clot, P. R. C., Tina, G. M. T., & Ventura, C. V. (2017, 1. Oktober). RAST: RoundAbout Solar Tracking. Retrieved March 18, 2019, from https://www.sciencedirect.com/science/article/pii/S1876610217347082

Tharamuttam, J. K. T., & Ng, A. K. N. (2017, 1. Dezember). Design and Development of an Automatic Solar Tracker. Retrieved March 19, 2019, from https://www.sciencedirect.com/science/article/pii/S1876610217365025

Askari Mohammad Bagher, Mirzaei Mahmoud Abadi Vahid, Mirhabibi Mohsen. Types of Solar Cells and Application. American Journal of Optics and Photonics. Vol. 3, No. 5, 2015, pp. 94-113. doi: 10.11648/j.ajop.20150305.17

Castillo-Aguilella, J. E., & Hauser, P. S. (2016). Multi-Variable Bifacial Photovoltaic Module Test Results and Best-Fit Annual Bifacial Energy Yield Model. IEEE Access

Silva, G. D. P., Branco, D. A. C. (May 28, 2018). *Is floating photovoltaic better than conventional photovoltaic? Assessing environmental impacts.* [PDF file] Retrieved from https://www.researchgate.net/publication/325404421_Is_floating_photovoltaic_better_than_conventional_photovoltaic_Assessing_environmental_impacts Accessed on May 2nd, 2019

Freshwater - State and Impacts (Finland). (March 21, 2015). European Environment Agency. Retrieved from https://www.eea.europa.eu/soer/countries/fi/freshwater-state-and-impacts-finland-1 Accessed on May 2nd, 2019

Finnish Environment Institute. (2013). *Water Quality of Lakes, Rivers and Sea Areas in Finland in 2000-2003.* [PDF file] Accessed on May 2nd, 2019

Global Map of Irrigation Areas (GMIA). (2016). Food and Agriculture Organization of the United Nations. Retrieved from
http://www.fao.org/nr/water/aquastat/irrigationmap/FIN/ Accessed on May 2nd, 2019

Riding the Wave of Solar Energy: Why Floating Solar Installations are a Positive Step for Energy Generation. (December, 2018). REC. [PDF file] Accessed on May 2nd, 2019

Tikkanen, M. (2002). *Long-term changes in lake and river systems in Finland.* FENNIA. [PDF file] Accessed on May 2nd, 2019

Ragazzi, S. (2016). *New energies against deforestation.* Afrikan Sarvi. Retrieved from
https://afrikansarvi.fi/issue11/117-artikkeli/300-new-energies-against-deforestation Accessed on May 2nd, 2019

Stuk. (2019). *Radiation Today.* Retrieved from
https://www.stuk.fi/web/en/topics/environmental-radiation/radiation-today Accessed on May 2nd, 2019

EPA. (2012). *Dissolved Oxygen and Biochemical Oxygen Demand.* Retrieved from
https://archive.epa.gov/water/archive/web/html/vms52.html Accessed on May 2nd, 2019

Pictures

Chris, A. (o.D.). Type of concentrated solar power – Wikimedia Commons [Bild/Grafik]. (2011,24. November). Retrieved March 10, 2019,
https://commons.wikimedia.org/wiki/File:Type_of_Concentrated_solar_power.png

Fedkin, M. F. (o.D.). 5.1. What are concentrating photovoltaics? | EME 812: Utility Solar Power and Concentration [Bild/Grafik]. Retrieved March 9, 2019, from
https://www.e-education.psu.edu/eme812/node/537

Rolf Hug, R. H. (o.D.). Solar-Report | Konzentrator-Photovoltaik bringt die Sonne auf den Punkt - SolarServer [Bild/Grafik]. Retrieved March 8, 2019, from
https://www.solarserver.de/solar-magazin/solar-report/konzentrator-photovoltaik-bringt-die-sonne-auf-den-punkt.html

Archimedes Solar GmbH (o.D.). Solar-Report | Konzentrator-Photovoltaik bringt die Sonne auf den Punkt - SolarServer [Bild/Grafik]. Retrieved March 8, 2019, from
https://www.solarserver.de/solar-magazin/solar-report/konzentrator-photovoltaik-bringt-die-sonne-auf-den-punkt.html

Klotz, F. H. K. (o.D.). Querschnitt des PV V-Troges [Bild/Grafik]. Retrieved March 10, 2019, from
http://www.fvee.de/fileadmin/publikationen/Themenhefte/th1996/th1996_02_07.pdf

Vega Energy. (o.D.). Alluminio - ALMECO GROUP [Bild/Grafik]. Retrieved March 7, 2019, from http://www.almecogroup.com/uploads/1011-tinox_energy_WR__0002_schema_vega_energy_wr_eng.jpg

Sahu, A. S., Yadav, N. Y., & Sudhakar, K. S. (2015) [Bild/Grafik]. Floating photovoltaic power plant: A review. Renewable and Sustainable Energy Reviews, , 6.

Rosa-Clot, M. R. C., & Tina, G. M. T. (2018) [Bild/Grafik]. The Floating PV Plant. Submerged and Floating Photovoltaic Systems, 89–136. https://doi.org/10.1016/b978-0-12-812149-8.00005-3

Ocean Sun. (o.D.). Statkraft picks Ocean Sun for €2.3M solar park in Albania [Bild/Grafik]. Retrieved March 20, 2019, from https://www.aa.com.tr/en/energy/general/statkraft-picks-ocean-sun-for-23m-solar-park-in-albania/23816

RAST: RoundAbout Solar Tracking [Bild/Grafik]. (2017, 1. Oktober). Retrieved March 16, 2019, from https://www.sciencedirect.com/science/article/pii/S1876610217347082

AL-Rousan, N., Isa, N. A. M., & Desa, M. K. M. (2018b) [Bild/Grafik]. Advances in solar photovoltaic tracking systems: A review. Renewable and Sustainable Energy Reviews, 82, 2548–2569. https://doi.org/10.1016/j.rser.2017.09.077

Castanheira A., Fernandes J., Branco C., (February 1, 2018). *"Demonstration project of a cooling system for existing PV power plants in Portugal,"* ScienceDirect. Retrieved from https://www.sciencedirect.com/science/article/pii/S0306261917316859

Record-Low Solar Bid From ACWA Power For 1st Utility-Scale Renewable Energy Project In Saudi Arabia. February 6th, 2018 by Joshua S Hill https://cleantechnica.com/2018/02/06/acwa-power-develop-first-ever-utility-scale-renewable-project-saudi-arabia-record-breaking-tariff/

Bi-facial Solar Panels, By Kelly Pickerel, April 2, 2018. https://www.solarpowerworldonline.com/2018/04/what-are-bifacial-solar-modules/

Test to compare of snow-shedding rates between tilt angles and study the bifacial advantage. St Lawrence College Project, 2017. http://www.silfabsolar.com/the-bifacial-advantage/

Solar works in cold weather. By Manish Nayar, CEO, OYA Solar, By SPW | February 5, 2019. https://www.solarpowerworldonline.com/2019/02/solar-works-in-cold-weather/

Huainan, the Largest Floating Solar Farm in the World, 11 JUL. 2018. https://www.planete-energies.com/en/medias/close/huainan-largest-floating-solar-farm-world

Architecture and constructions in extreme climate zones, F. Pfenniger http://www.arquitecturaenacero.org/uso-y-aplicaciones-del-acero/soluciones-constructivas/arquitectura-y-construcciones-en-zonas-de

Konstantin, P. (2017). Praxisbuch Energiewirtschaft: Energieumwandlung, -transport und -beschaffung, Übertragungsnetzausbau und Kernenergieausstieg (4th ed.). Berlin: Springer Berlin Heidelberg.

WKO (n.d.). Steuersätze in den EU-Ländern. Retrieved May 6, 2019, from https://www.wko.at/service/steuern/Steuersaetze_in_den_EU-Laendern.html

Kalkulationszinssatz - das Wirtschaftslexikon.com. (n.d.). Retrieved May 6, 2019, from http://www.daswirtschaftslexikon.com/e/kalkulationszinssatz/kalkulationszinssatz.htm

Stewart, C. S., & D'Amore, A. D. (2018). Erhebliche Unterschiede bei den Preisen für Agrarland zwischen den und innerhalb der Mitgliedstaaten. eurostat - Pressemitteilung, , 1–3.

Triami Media, T. M. (n.d.). Inflation Finnland - aktuelle Finnische inflationsraten. Retrieved May 6, 2019, from https://de.inflation.eu/inflationsraten/finnland/inflation-finnland.aspx

Suomen Pankki, S. P. (n.d.). Interest rates. Retrieved May 6, 2019, from https://www.suomenpankki.fi/en/Statistics/interest-rates/

Exporo AG, Eigenkapital einer Unternehmung | Wiki. (n.d.). Retrieved May 6, 2019, from https://exporo.de/wiki/eigenkapital/

Dr. Bernhard Noreisch, B.N. (n.d.). Eigekapital- versus Fremdkapitalfinanzierung. Retrieved May 6, 2019, from https://www.lutzabel.com/download/Eigenkapitalfinanzierung-versus-Fremdkapitalfinanzierung.pdf

Hydraulic Motors vs Electrical Motors: Why Hydraulic Wins. Dr McCaslin | Jan 18, 2018 | Heavy Equipment 101 | http://info.texasfinaldrive.com/shop-talk-blog/hydraulic-motors-vs-electrical-motors-why-hydraulic-wins

International Energy Agency (IEA) - Finland. (n.d.). Retrieved May 6, 2019, from https://www.iea.org/policiesandmeasures/pams/finland/name-20994-en.php

The Aluminum Association. (n.d.). *Aluminum Design Manual* (Publication).

Beam Analysis. (n.d.). Retrieved from https://mechanicalc.com/calculators/beam-analysis/#divResults

Chains, Ropes, and Anchors. (n.d.). Retrieved from https://chainsropesandanchors.co.nz/what-size-anchor

Finnish Lakeland. (2019, January 08). Retrieved from https://en.wikipedia.org/wiki/Finnish_Lakeland

Gah-Alberts 469917 Flat Profile - Untreated Aluminium - 1,000 x 40 x 3 mm. (n.d.). Retrieved from https://www.amazon.co.uk/Gah-Alberts-469917-Flat-Profile-Untreated/dp/B008GZN5GW?ref_=fsclp_pl_dp_2

Ministry of Agriculture and Forestry of Finland. (n.d.). *Soil*. Retrieved from https://mmm.fi/en/rural-areas/agriculture-and-the-environment/soil

Modulus of Elasticity for Metals. (n.d.). Retrieved from https://www.amesweb.info/Materials/Modulus-of-Elasticity-Metals.aspx

Nickel Alloys. (n.d.). Retrieved from https://www.nickel-alloys.net/nickelalloys.html

TellSteel. (n.d.). Aluminum Pipe. Retrieved from https://www.tellsteel.com/AluminumPipe.html

Wind Bracing. (n.d.). Retrieved from https://www.dlsweb.rmit.edu.au/Toolbox/buildright/content/bcgbc4010a/04_struct_members/03_wind_bracing/page_001.htm

Wind Velocity and Wind Load. (n.d.). Retrieved from https://www.engineeringtoolbox.com/wind-load-d_1775.html

James Maktelow, J.M. (n.d.). Plan-Do-Check-Act (PDCA) Continually Improving, in a Methodical Way. Retrieved May 1, 2019, from https://www.mindtools.com/pages/article/newPPM_89.htm

Hdpe Rohr Preise - Buy Hdpe Rohr,Vertrauen Hdpe Rohr,Hdpe Rohr Preise Product on Alibaba.com. (n.d.). Retrieved May 8, 2019, from https://german.alibaba.com/product-detail/hdpe-pipe-prices-60776520701.html?spm=a2700.md_de_DE.maylikeexp.3.3c176fa8cOR2KO

Siecker J., Kusakana K., Numbi B. P., (November 2017), *"A review of solar photovoltaic systems cooling technologies,"* ELSEVIER. PDF document.

Castanheira A., Fernandes J., Branco C., (February 1, 2018). *"Demonstration project of a cooling system for existing PV power plants in Portugal,"* ScienceDirect. Retrieved from https://www.sciencedirect.com/science/article/pii/S0306261917316859

Li W., Shi Y., Chen K., Zhu L., Fan S., (2017), *"A Comprehensive Photonic Approach for Solar Cell Cooling,"* ACS Photonics. Retrieved from https://pubs.acs.org/doi/abs/10.1021/acsphotonics.7b00089

APPENDICES

Appendix A: Project Management

1. Quality Management

In terms of quality management, the team decided to rely on the PDCA cycle, popularized by Dr. William Edward Deming in the 1950s and the Fishbone Diagram or Ishikawa Diagram, which was invented by Kaoru Ishikawa in the 1960s to break down root causes that potentially contribute to a particular effect.

The phases of the PDCA cycle (Manktelow, 2016) are PLAN, DO, CHECK and ACT, where the first one concentrates on identifying the problems which have to be worked on. The DO aspect is focused on potential solutions, which have to be studied in the third stage whether they are usable or have to be reworked, tested again. In the last stage, the ACT stage, the best solution which was worked out will be implemented. Every team meeting was build upon those stages, by first defining the problems which were worked on, then explaining the research results and possible solutions being tested or outlined. The Act of CHECKing was done by the whole team within the team meetings to come to a final implementation of the best solution the team figured out.

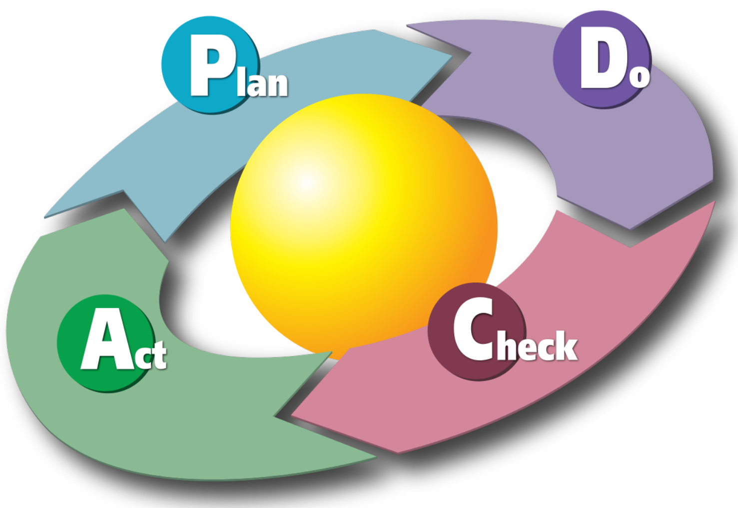


Figure 1. *PDCA cycle by William Edward Deming (Wikipedia, 2008)*

The Fishbone Diagram was especially used to define aspects of problems which occurred within the process of finalizing the Design and to be able to work in the most effective way in terms of problem solving. The Fishbone Diagram used for the floating ability problem can be seen in the following figure.

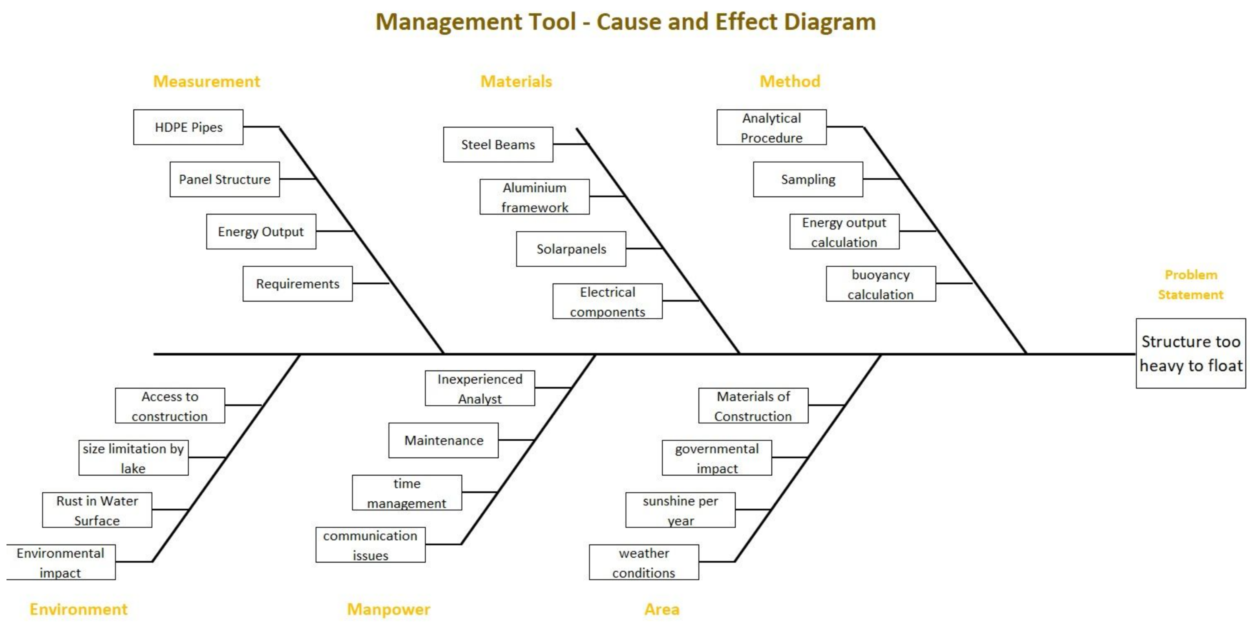


Figure 2. *Fishbone Diagram of the Floating Ability Issue*

2. Human Resource Management

Human Resource Management is a big part in succeeding within a project, especially in multinational team constellations. Under several tools for the project management tasks, the team decided to work with a RACI Matrix, which will be explained further on, and the Belbin Test, which was already an essential part of the team building process in the beginning of the project.

2.1. RACI Matrix

Human Resource Management is a large part of Project Management. Because of this, the team developed an RACI Matrix to help divvy up tasks as well as ensure that each task had an owner or someone who would be responsible for checking up on its progress and completion. This matrix also helped making sure that the team was not all devoting time to the same task when they could be productively splitting up the work and kept people not involved in each task informed about what was being done. An RACI Matrix does this by simplifying every person's role for a given task into four categories. RACI stands for Responsible, Accountable, Consulting, and Informing. These four words detail what each role is for the task.

Responsible - Who is responsible for this activity? This individual is in charge of checking up with others to see what work is being done and to ensure that the task will get done on time. These individuals are also tasked with informing the individuals who are not involved, how everything is going.

Accountable - Who is also accountable for this task? These individuals are also working on the given task, but are not in charge of ensuring its completion. These members are completing the tasks alongside the “responsible” individual.

Consulting - Who should be we consulting with for this task? These individuals are not doing the actual work on the task but help in the form of giving advice through consultation. These individuals are not needed at every meeting about this task but are asked to help when needed or when a large decision needs to be made.

Informing - Who has to be informed about this task? These individuals are being informed about the progress and completion of these tasks only. They are not working on the project nor being consulted for help.

Figure 3, below, is the working RACI Matrix for this project team. The tasks from the Work Breakdown Structure are featured to the left in this table. It is color-coded by job type with a key to the right.

	Stephan	Laura	Carlos	Amber	Elizabeth	Mikael	Soren
Research							
Finish Previous Project Report	A	A	R	A	A	C	C
Research Types of Panels and Efficiency Improvement Techniques	A	A	R	A	A	I	C
Define Assumptions and Create Final Project Plan	A	A	A	A	R	C	C
Research Tracking, Rotation, Tilting, and Floating Structure	A	R	A	A	A	I	I
Finish Plans for Efficiency Methods	R	A	A	A	A	I	I
Any Additional Research Needed after Testing							
Design							
Compile all Ideas into a few Working Options	A	A	A	A	R	C	C
Initial Sketches of Designs	C	A	C	R	C	I	I
Create 3D Printed Structure for Testing	A	R	A	C	C	C	C
Add Rotation System to Design	R	A	A	A	A	C	C
Add Efficiency Influences to Design	A	A	R	A	A	C	C
Design a Final Protopype	A	R	A	A	A	I	I
Simulate Energy Production for Final Design	A	C	R	A	A	I	I
Testing							
Start Hypothesizing and Plan for Testing	A	A	A	R	A	C	C
Do a Control Test on the Solar Panel	C	A	R	A	A	C	C
Test Floating System	A	A	A	A	R	C	C
Test Tracking and Rotating System	R	A	A	A	A	C	C
Test Efficiency Influences	R	A	A	A	A	C	C
Summarize Conclusions Gained from Testing	C	C	A	C	R	C	C
Test Again if Required							
Managerial Tasks							
Start Adding Researched Information to Midterm Report	A	A	A	R	A	I	I
First Draft of Midterm Presentation	A	A	A	R	A	I	I
Finalize PM Requirements for Midterm Report	A	A	A	A	R	I	I
Final Edits to Midterm Report	A	A	A	R	R	I	I
Turn in Midterm Report	I	R	I	I	I	I	I
Review Comments from Midterm Report	R	A	A	A	A	C	C
Finalize Midterm Presentation and Practice	A	A	A	R	A	I	I
Make a Video and Website	R	A	A	A	A	I	I
Start Final Report	A	A	A	R	A	I	I
Finalize Final Report	A	A	A	R	R	I	I
Turn in Final Report	I	R	I	I	I	I	I
Create Final Presentation and Practice	A	A	A	A	R	I	I
Final Presentation	A	A	A	A	R	I	I

R	Who is Responsible?
A	Who is being held Accountable?
C	Consulting with this person
I	Informing this person

Figure 3. *RACI Matrix*

As one can see from the RACI Matrix, every task has one, and in some cases two, responsible parties. This was to ensure that the task got done and one person was able to communicate with everyone else about its progress. In most cases, everyone in the team wanted to be involved with every task. Usually, this wouldn't be the case in design projects elsewhere, but with this being a multicultural and multidisciplinary team, everyone wanted to try to be involved to learn from one another. Additionally, the supervisors for this project were included. The team consulted with them regularly, but mostly informed them about progress for some of the more basic, non-design, tasks.

2.2. Belbin Test

The Belbin Test helps individuals in identifying their specific, different role or roles they contribute to a team setting. This is significant in enabling team members to understand and discuss differences and similarities about their behavioural strengths in a productive, safe, and non-confrontational way. By having a greater self-understanding of each team member's strengths and weaknesses can result in more efficient and successful working team. The Belbin team roles are categorized as follows: Shaper, Completer-Finisher, Implementer, Plant, Monitor-Evaluator, Specialist, Team worker, Coordinator, and Resource Investigator. Each team member's Belbin Test results are shown in Table 1 below.

Table 1. *Belbin Test results*

Team Members	Belbin Roles	Role Description
Laura	Plant	Creative, imaginative, good at solving problems in unconventional ways
	Implementer	Practical, helps in planning a workable strategy and carrying it out efficiently
Carlos	Team worker	Cooperative, helps the team to work together effectively and efficiently
	Specialist	Dedicated, brings in-depth knowledge of a key area to the team
Stephan	Plant	Creative, imaginative, good at solving problems in unconventional ways
	Shaper	Thrives on pressure, provides the necessary drive to ensure the team keeps moving and doesn't lose focus or momentum
Elizabeth	Shaper	Thrives on pressure, provides the necessary drive to ensure the team keeps moving and doesn't lose focus or momentum
	Coordinator	Confident, helps team to clarify goals, delegates work to team members and keeps everyone on track
Amber	Coordinator	Confident, helps team to clarify goals, delegates work to team members and keeps everyone on track
	Resource Investigator	Outgoing, uses inquisitive nature to find ideas to bring back to the team

3. Communication Management

The communication management mainly deals with the interaction of the project team and every stakeholder who is involved. From defining the stakeholder by a stakeholder analysis and prioritization related to the influence and interest of the stakeholders in the actual project to creating a communication plan and drawing up the needed documents for the project time, well done communication management can have a big impact on the project result when it is done right.

The stakeholder who were involved in the project can be seen in the following stakeholder influence chart, as well as their impact on the work of the project team.

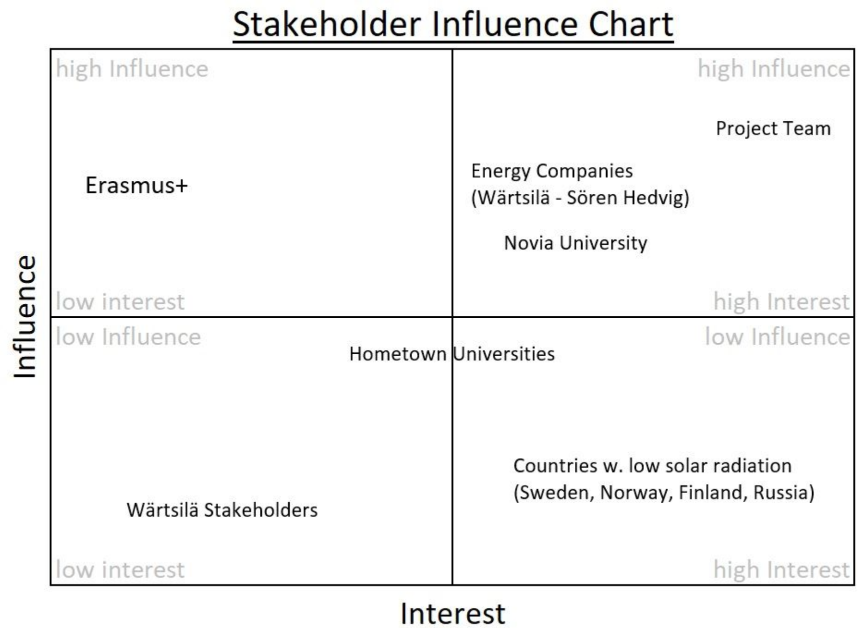


Figure 4. *Stakeholder Influence Chart*

As in the influence chart can be seen, the most impact to the project work had the team itself and an employee from Wärtsilä who as well worked as a supervisor for the Project Team together with the Novia University supervisor Mikael Ehrs. High influence but low interest had the Erasmus program which was responsible for 3 out of 5 students to be able to work in the project in the first place.

To answer the question about a functional report performance one has to look at the documents needed as well as other aspects of the Project Management. The risk management which was updated throughout the project process and the automated cost calculation which can also be seen in Appendix A are as important as the Human Resource Management when it comes down to prezise reports for the stakeholders.

In clarifying the stakeholders expectations the team concentrated on those stakeholders who are involved in the project in one way or another:

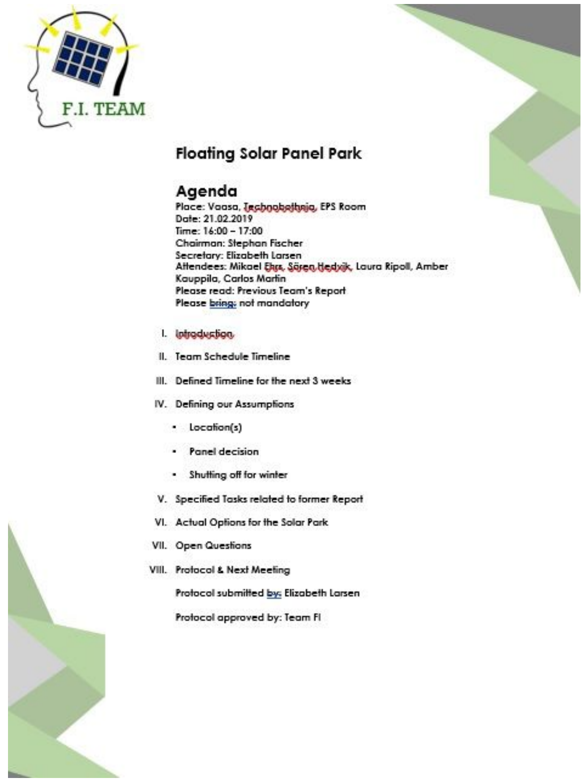
Wärtsilä – Study for a feasible, swimming, solar park in Finland for commercial use
Project Team – Further education, multinational team working experience, good grades
Novia University – Representable Erasmus project studies for further projects
Home Universities – Representative work of the outgoing students

This finally leads to the documentation which had to be prepared for the project time and the used documentations for report and structural work are as follows.

Which Documentations were needed for good communication management?

- Time Sheet
- Team Contract (find attached)
- Assignment
- Project Meeting Notes
- Agile Schedule
- Project Agendas
- Designs (stated under chapter 3)
- Continuous updated Report (final report)

On the right side one of the first agendas can be seen with which was worked for every Meeting.



F.I. TEAM

Floating Solar Panel Park

Agenda

Place: Vaasa, Technobothnia, EPS Room
Date: 21.02.2019
Time: 16:00 – 17:00
Chairman: Stephan Fischer
Secretary: Elizabeth Larsen
Attendees: Mikael Ehrs, Sören Hedvik, Laura Ripoll, Amber Kauppila, Carlos Martin
Please read: Previous Team's Report
Please bring: not mandatory

I. Introduction
II. Team Schedule Timeline
III. Defined Timeline for the next 3 weeks
IV. Defining our Assumptions
   - Location(s)
   - Panel decision
   - Shutting off for winter
V. Specified Tasks related to former Report
VI. Actual Options for the Solar Park
VII. Open Questions
VIII. Protocol & Next Meeting

Protocol submitted by: Elizabeth Larsen

Protocol approved by: Team FI

Figure 5. *Team Project Meeting Agenda*

TEAM CONTRACT

Project: Floating Solar Panels

Group members: Carlos Martin Delgado, Laura Ripoll Albaladejo, Stephan Fischer, Elizabeth Larsen, Amber Kauppila

Valid dates: February to May (both included)

PROJECT VISION

We want to learn in this project as much as possible, in our fields and outside of them.
We expect to do our best, keep the project interesting during all the semester.
The final grade we get is not the most important part of the project if we did our best.

ELEMENTS OF EFFECTIVE TEAMWORK

Communication

1. Free ideas. Everyone can express her/his idea without been judge.
2. listening to each other. When someone is speaking we have to listen to her/him and pay attention (don't be looking at the phone)
3. Try to make an effective non judgmental feedback.
4. No "cross talking" is allowed. This means not interrupting when someone else is talking.
5. In the event that a group member or members are dominating the group, it's the time keeper's job to politely interrupt them (this is when you can interrupt) and ask that someone else speak.
6. Keeping the other team members informed.
7. First understand, and then be understood to apply to all team members.
8. Use visual means like drawings, charts, as well as tables in order to facilitate discussion. (Good when we present each others the work we have done).

Participation

1. initiative in participating in the group tasks, especially in areas where they may have strengths.
2. Ask for help when needed and if you can help someone because of your strengths you should do it.
3. members need to make concerted efforts to be available for meetings.
4. Each team member needs to be honest as well as open.
5. Encourage a diversity of opinions on all topics.
6. Everyone given the opportunity for equal participation in whatever type of work, not only in her/his specific field.
7. Focus on what is best for the team as a whole. The team has to be bigger than an individual team player. The interests of the team have to come first. Besides, care has to be taken that the interests of the team and the team players are in synergy and do not clash.

Organization

1. All the group work will be shared in Google Drive.
2. We will use Trello to organize our work.

Procedure

1. Each group member agrees to show up to class and to outside group meetings on time. If someone is late more than 5 minutes will have to bring coffee/tee for the rest of the members.
2. Group members can be late (like 30 minutes or 1 hour) to a meeting if it was noticed before or it can be justified. If a group member is late without notifying will have to prepare dinner for all the group next weekend.
3. All members have to respect deadlines.
4. Everyone should be accountable with her/his work.

WORK PLANNING

1. We will meet every morning during the week at school to work in the project.
2. We will share and explain what we have been doing for the project at least once a week. We will choose

TEAM ACTIVITY PLAN

We will do an activity together once a week like having dinner, going to ice hockey or bowling.

CRITICAL REVIEW DATES

21/03/2019 - Send midterm report to Mikael and Sören
26/03/2019 - Midterm presentation

09/05/2019 - Send final report to Mikael and Sören
14/05/2019 - Final presentation

CONTRACT AGREEMENT

This is an official contract. Once you have signed it you are accountable.

Name: *Carlos Martin Delgado*	Date: *08/02/2019*
Name: *Laura Ripoll Albaladejo*	Date: *08/02/2019*
Name: *Stephan Fischer*	Date: *08/02/2019*
Name: *Elizabeth Larsen*	Date: *08/02/2019*
Name: *Amber Kauppila*	Date: *08/02/2019*

4. Change Management

The Occurrence of Changes within a project is a normal part of the processes the project walks through. To ensure the quality of the work, the team can rely on the “Iron Triangle” which graphically reveals the correlation between scope, time, and cost.

Within a change, one of these three aspects will apparently change and its mandatory to rearrange the other two aspects to keep the quality of the work on the same level as before.

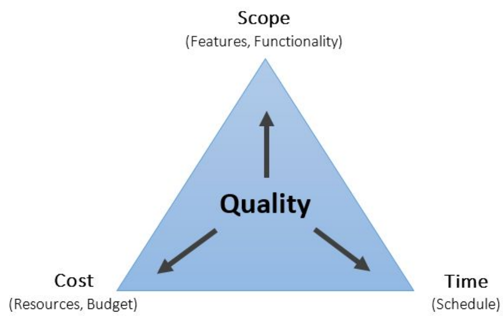


Figure 6. *Iron Triangle – triple constraints of project management (Dhillon, 2018)*

The way to manage changes of the Floating Solar Park Project Team was by using a change log in which the influence to the aspects was noted in the comments section. Every change request got a change number and a change type, was described and tracked by including the submitted and approved date and the actual status the change request presently has. As you can see below a variety of changes occurred during the project time.

Table 2. *Change Log of the Floating Solar Park Team*

Change Log							
Project: Floating Solar Panel Park							Date: 03.05.2019
Change No.	Change Type	Description of Change	Requestor	Date Submitted	Date Approved	Status	Comments
Each change request is assigned a reference number	This may be a design, scope, schedule or other type of change	What is the requested change about?	Who initiated the change request?			Open, closed or pending? Approved, denied or deferred?	This section may describe status or provide any useful information
CS01	Schedule	Change request calls for new scheduling of Research Task. 5 more days.	Stephan F.	02.03.2019	03.03.2019	Approved	Cost Aspect went up by ~ 5.000€, Scope stayed the same
CD01	Design	This request calls for changing monochristalline Panels to bifacial panels	Carlos D.	11.03.2019	14.03.2019	Approved	More expensive than monochrystallin, Functionality increased due to usability in Winter (Reflection)
CD02	Design	This request calls for design changes into smaller solarpark circles for more modifiability	Carlos D.	03.04.2019	10.04.2019	Approved	Modifiability and usage possibilities, Cost stayed the same, time increased for testing & calculation
CS02	Scope	This request calls for a 3D printed Prototype for additional presentation method	Laura A.	13.04.2019	01.05.2019	Denied	The Idea was approved but Time aspect would have been protracted too long
CD03	Design	This request calls for a Cooling system, to get the panels under 60°C	Amber K.	22.04.2019	26.04.2019	Deferred	Change of Scope not necessary, big cost & time influence

Appendix B: Large Figures

1. Hours Worked and Cost Associated with Working

Work Packages	Responsibility	Planned Cost	Actual Cost	% Progress	Earned Value	Start Day	End Day	relating Date	Duration	HR Costs 80€/h
Research								**30.04.2019**		
Finish Previous Project Report	ALL	3.000,00 €	3.200,00 €	100%	3.000,00 €	18.02.2019	18.02.2019	71 Days	1 Days	3.000,00 €
Research Panels and Efficiency Impr.	Carlos, Stephan	4.800,00 €	9.720,00 €	100%	4.800,00 €	18.02.2019	21.02.2019	68 Days	4 Days	4.800,00 €
Assumptions and Final Project Plan	ALL	3.000,00 €	2.280,00 €	100%	3.000,00 €	21.02.2019	21.02.2019	68 Days	1 Days	3.000,00 €
Research Tracking, Rotation and Floating	Laura	10.200,00 €	11.960,00 €	100%	10.200,00 €	22.02.2019	10.03.2019	51 Days	17 Days	10.200,00 €
Finish Plans for Efficiency Methods	Stephan	11.400,00 €	14.280,00 €	90%	10.260,00 €	22.02.2019	12.03.2019	49 Days	19 Days	11.400,00 €
Any Add. Research Needed after Testing	ALL	12.000,00 €	13.400,00 €	50%	6.000,00 €	27.04.2019	30.04.2019	0 Days	4 Days	12.000,00 €
Design										
Compile all Ideas into a few Working Options	ALL	12.000,00 €	9.000,00 €	100%	12.000,00 €	13.03.2019	16.03.2019	45 Days	4 Days	12.000,00 €
Initial Sketches of Designs	Laura	5.400,00 €	4.640,00 €	80%	4.320,00 €	14.03.2019	22.03.2019	39 Days	9 Days	5.400,00 €
Create 3D Printed Structure for Testing	Laura	7.200,00 €	5.520,00 €	25%	1.800,00 €	17.03.2019	28.03.2019	33 Days	12 Days	7.200,00 €
Add Rotation System to Design	Stephan	2.400,00 €	2.880,00 €	70%	1.680,00 €	01.04.2019	04.04.2019	26 Days	4 Days	2.400,00 €
Add Efficiency Influences to Design	Carlos	3.000,00 €	3.760,00 €	80%	2.400,00 €	08.04.2019	12.04.2019	18 Days	5 Days	3.000,00 €
Design a Final Protopype	Laura	8.400,00 €	9.640,00 €	50%	4.200,00 €	28.04.2019	11.05.2019	-11 Days	14 Days	8.400,00 €
Simulate Energy Production for Final Design	Carlos	4.800,00 €	5.520,00 €	100%	4.800,00 €	28.04.2019	05.05.2019	-5 Days	8 Days	4.800,00 €
Testing										- €
Start Hypothesizing and Plan for Testing	Amber	2.400,00 €	2.480,00 €	100%	2.400,00 €	01.04.2019	04.04.2019	26 Days	4 Days	2.400,00 €
Do a Control Test on the Solar Panel	Carlos	1.800,00 €	2.280,00 €	100%	1.800,00 €	05.04.2019	07.04.2019	23 Days	3 Days	1.800,00 €
Test Floating System	Elizabeth	- €	- €	-	-	29.03.2019	01.04.2019	29 Days	4 Days	7.200,00 €
Test Tracking and Rotating System	Stephan	2.400,00 €	2.000,00 €	80%	1.920,00 €	05.04.2019	08.04.2019	22 Days	4 Days	2.400,00 €
Test Efficiency Influences	Stephan	3.600,00 €	3.120,00 €	90%	3.240,00 €	13.04.2019	18.04.2019	12 Days	6 Days	3.600,00 €
Summarize Conclusions Gained from Testing	Elizabeth	3.600,00 €	3.920,00 €	70%	2.520,00 €	26.04.2019	27.04.2019	3 Days	2 Days	3.600,00 €
Test Again if Required	Carlos	7.200,00 €	6.560,00 €	80%	5.760,00 €	28.04.2019	09.05.2019	-9 Days	12 Days	7.200,00 €
Managerial Tasks										
Adding Researched Info to Midt. Report	Amber	11.400,00 €	10.160,00 €	100%	11.400,00 €	22.02.2019	12.03.2019	49 Days	19 Days	11.400,00 €
First Draft of Midterm Presentation	Amber	4.800,00 €	2.320,00 €	100%	4.800,00 €	13.03.2019	20.03.2019	41 Days	8 Days	4.800,00 €
Finalize PM Requirements for Midterm Report	Elizabeth	16.800,00 €	18.200,00 €	100%	16.800,00 €	21.02.2019	20.03.2019	41 Days	28 Days	16.800,00 €
Final Edits to Midterm Report	Elizabeth, Amber	2.400,00 €	1.360,00 €	100%	2.400,00 €	21.03.2019	22.03.2019	39 Days	2 Days	2.400,00 €
Turn in Midterm Report	Laura	600,00 €	160,00 €	100%	600,00 €	22.03.2019	22.03.2019	39 Days	1 Days	600,00 €
Review Comments from Midterm Report	Stephan	4.200,00 €	1.680,00 €	100%	4.200,00 €	25.03.2019	31.03.2019	30 Days	7 Days	4.200,00 €
Finalize Midterm Presentation and Practice	Amber	3.600,00 €	3.040,00 €	100%	3.600,00 €	21.03.2019	26.03.2019	35 Days	6 Days	3.600,00 €
Make a Video and Website	Stephan	10.200,00 €	480,00 €	20%	2.040,00 €	28.04.2019	14.05.2019	-14 Days	17 Days	10.200,00 €
Start Final Report	Amber	17.400,00 €	4.560,00 €	20%	3.480,00 €	01.04.2019	29.04.2019	1 Days	14,5 Days	17.400,00 €
Change Management	Elizabeth, Amber	8.400,00 €	1.680,00 €	20%	1.680,00 €	22.04.2019	28.04.2019	2 Days	7 Days	8.400,00 €
Risk Management	Stephan	4.200,00 €	2.480,00 €	20%	840,00 €	22.04.2019	28.04.2019	2 Days	7 Days	4.200,00 €
Quality Management	Stephan	4.200,00 €	2.080,00 €	20%	840,00 €	22.04.2019	28.04.2019	2 Days	7 Days	4.200,00 €
Communication Management	Stephan	4.200,00 €	1.840,00 €	20%	840,00 €	22.04.2019	28.04.2019	2 Days	7 Days	4.200,00 €
Cost Management	Stephan	4.200,00 €	1.680,00 €	80%	3.360,00 €	22.04.2019	28.04.2019	2 Days	7 Days	4.200,00 €
Finalize Final Report	Elizabeth, Amber	13.200,00 €	- €	0%	- €	30.04.2019	10.05.2019	-10 Days	11 Days	13.200,00 €
Turn in Final Report	Laura	600,00 €	- €	0%	- €	10.05.2019	10.05.2019	-10 Days	1 Days	600,00 €
Create Final Presentation and Practice	Elizabeth	10.800,00 €	- €	0%	- €	28.04.2019	15.05.2019	-15 Days	18 Days	10.800,00 €
Final Presentation	Elizabeth	600,00 €	- €	0%	- €	15.05.2019	15.05.2019	-15 Days	1 Days	600,00 €

BAC Complete Budget	230.400,00 €
PV Planned till today	162.600,00 €
AC Actual till today	132.280,00 €
EV Earned Value till today	120.180,00 €

Cost Variance (CV)	- 12.100,00 €
Cost Performance Index (CPI)	0,91
Schedule Variance (SV)	- 42.420,00 €
Schedule Performance Index (SPI)	0,74

2. Updated Schedule