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Sustainably scaling up the operations of Kelp Blue in Lüderitz, Namibia

A consultancy report

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1 Preface

We are a group of five students of the Delft University of Technology, who did a research for a Dutch company that is partly situated in Namibia. We are all doing a different Master of Science for the TU and this ‘Multi Disciplinary Project (MDP)’ is an elective part of it. Since we all study in distinct fields, the process of this project, where different kinds of knowledge are put together to do research, has been enlightening and informative. We were asked to perform a consultancy project on an engineering level by a Dutch start-up that tries to cultivate Giant Kelp. According to the company, it was essential that we would analyze the overall setup of their farms and operations at the location where the company’s first farms are installed. This paper is a scientific report about the company and the consultancy project that we did for them. In this paper we assume that the reader has knowledge about engineering at an academic level.

We refer readers that are particularly interested in the company to chapter 6, readers that are interested in designing a new module for the company to part I and readers that are interested in improving the energy system to part II.

We would like to thank our supervisors and the MDP coordinators for their advice on organizing and setting up the project. Furthermore we would like to thank Kelp Blue for inviting us to Namibia to participate in their interesting and sustainable purpose.

2
Abstract

Kelp Blue is a company whose top priority is the well-being of the planet. Through the cultivation of giant kelp on offshore farms, they create several sustainable products, new job opportunities in regions where they are needed, enhance biodiversity in the water, and above all, sequester tons of CO_2 from the air.

The start-up is still in its research and development phase, but plans to be building farms on a large scale in just a few years. Despite their knowledge in engineering, the company still needs consulting on certain elements. Therefore the company invited a group of students from the Delft University of Technology to Lüderitz, Namibia for a consultancy project. The project involved creating a procedure for the company to scale up in a sustainable manner. The students decided that this complex problem should be divided into sub-problems. One workstream focused on reducing the carbon emissions during upscaling, while the other workstream focused on analyzing and improving the company's current design and installation of the farms. Following, both parts of the project are shortly summarized:

Part I: Improving the company's current design

Kelp Blue is currently in the pilot phase, in which they're installing their first large giant kelp farms. Before, they were focusing on the complete installation, including planting the kelp on the submerged netting structure, and the review of this. For the company's commercial phase, where they want to be able to place farms daily on a large scale, designs were still developed and analyzed. For the commercial phase, this workstream made a new design and installation method. It required an installation where buoys would need to be submerged, the structure locked in place at the desired depth, without the use of scuba divers or remote operated vehicles. Despite the fact that these requirements were challenging, an outstanding result was achieved. The main problem was divided into subproblems, and for each of those a suitable solution was created. Hopes are that the company will consider the given advice as helpful and maybe implement some parts of (or the whole) new design.

Part II: Reducing carbon emissions during upscaling

First, interviews and desk research were conducted to get a good idea of the challenge of sustainability. This included reading reports, speaking with employees, policy makers and experts with experience within the area. With this information, the challenge could be mapped out and the solution space became clear in terms of legislation and technical possibilities. Climate information was also requested that could later be used to run simulations. During the determination of the possible solutions, research was done on the realistic possibilities, where eventually the use of either solar or wind energy was most appropriate. After conducting a multi-criteria analysis that was put together with the management of Kelp Blue, investing in a solar plant proved to be the most appropriate solution.

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3 Introduction

Climate change has a major impact on the lives of everyone on Earth, and this impact is only going to get bigger in the future. The amount of greenhouse gas emissions in the atmosphere is increasing day by day, which has an accelerating effect on the occurring changes. Although there is a lot of concern for the environment at the international level, in practice it often fades away in society. There are many reasons for this. Sometimes it is a natural phenomenon and a natural disasters occur, sometimes it is for survival and trees have to be cut down to make way for fields of crops in poor countries to combat famine, but most often it is to increase the economic activity of rich countries. Kelp Blue is a company whose top priority is the well-being of the planet. Through the cultivation of giant kelp on offshore farms, they create several sustainable products, new job opportunities in regions where they are needed, enhance biodiversity in the water, and above all, sequester tons of CO_2 from the air. Kelp Blue's vision is clear, however, the road towards it is still unclear.

The objective of this research is to provide an actionable and suitable consultation on the research question "How can Kelp Blue sustainable scale up its operations in Lüderitz, Namibia"? The multi-disciplinary project team approached this task and broke down this question into workable sub-questions, eventually arriving at an overall recommendation. From the company's point of view, it is important that this advice can actually be implemented, so it must fit within the technological, financial and legal frameworks that have been set.

As the main question is very broad, it was decided to divide this into several sub-questions which are easier to solve. The report is divided in line with the sub-questions: in Part I, the challenges of scaling up are solved, and in Part II, the objective is to minimize emissions of the Namibian operations.

4
Problem scope

Before the project, Kelp Blue had defined the following problem scope:

"How can Kelp Blue sustainably scale up their operations in Lüderitz, Namibia?"

In assessing the problem scope, it was determined this main problem scope needed to be divided to make it more approachable. An analysis of the company was performed in the first week, which revealed several aspects. It was found that Kelp Blue currently faces a set of problems during preparation and installation of their main operations. Proceeding with these current operations will make them unable to upscale successfully and reach their targets. In addition, it was also desired for Kelp Blue to become carbon neutral. With supporting operations such as their office and the future processing plant in mind, it became clear that a plan needed to be written to compensate for the generated emissions. By establishing this, it was possible to write specific subscopes per component.

The following scope has been established for the main operations:

"Design a modular array structure that can be placed under tension at a desired depth, without the use of divers or work-class ROVs."

Through a quick analysis of this scope, the main goal was divided into 3 sub-challenges:

1. How to descend the array structure down to the desired depth of 15 [m] from the water surface, without the use of divers or work class ROVs?
2. How to lock the system in place at the desired position, without the use of divers or work class ROVs?
3. How can the operations team continue the installation, after they have been absent from the installation site for an indefinite period?

Besides these challenges, it was also identified that in order to achieve the desired goal, Kelp Blue needs to use excessive material in order to put the array structure under tension.

The following scope has been established for the supporting operations:

"How can Kelp Blue reduce the carbon emissions of their operations."

5 Methodology

To answer all of the questions mentioned in Chapter 4, the thesis is separated into two different parts. The first part focuses primarily on the structural problems associated with scaling up the company. The second part focuses on the carbon emissions of Kelp Blue and sustainable energy sources Kelp Blue can utilize.
The methodologies that were applied throughout the course of this project are presented in this section. Utilizing a variety of measuring techniques is necessary to have a deeper knowledge of the environment in which Kelp Blue operates.

The first scope presented in Chapter 4 requires a new designs for specific parts of the system, as well as a new design for the whole system itself together with a new installation procedure. In this report, designs of prototypes and explanatory overviews of systems were made in 2D and 3D design software. These were respectively Google draw and SolidWorks. These programs were chosen based on their accessibility research group, as well as their compatibility with the desired outcomes.

The designs were evaluated through a Multi Criteria Analysis based on criteria discussed with Kelp Blue. This was necessary to ensure that company standards and values were met. Subsequently, several designs were built by companies that were locally available. The goal was to understand parameters leading to improper installation or failure of the element. Therefore, to understand the physical and structural parameters leading to failure, physical tests were applied and failure can be visually observed.

Subsequently, in the second part of this report, the second scope; ”How can Kelp Blue reduce the carbon emissions of their operations”, is answered.

Weather data was collected and analyzed to assess the potential for solar and wind energy at the site. The data was sourced from the Meteonorm 8 database, which provides high-resolution weather data for over 6,000 locations worldwide. The data was analyzed to determine the average solar radiation and temperature for the site, as well as the distribution of solar radiation and wind speed throughout the year. This information was used to inform the design of the solar and wind energy systems and to estimate the potential energy yield.

Matlab was used to evaluate the weather conditions gathered from Meteonorm and to implement temperature of module model. This helped to estimate the energy yield and losses of the proposed renewable energy systems.

The SolarEdge Designer tool was then used to design and optimize a solar energy system for Kelp Blue’s processing site. The tool takes into account the site’s weather data and energy consumption to determine the optimal system size and configuration.

The current energy consumption of Kelp Blue’s processing site was determined by analyzing electricity bills, but since the bills were not sufficient and full of errors, the devices and employee growth were analyzed. This data was used to inform the design of the renewable energy system and to estimate the potential savings from the implementation of such a system.

Additionally, measurements were made to calculate the current and projected energy loads for Kelp Blue's office spaces, taking into consideration the expansion of the team and their workplace.

A site survey was conducted to gather information on the physical characteristics of Kelp Blue's properties, including its location, size, and topography. Drone position surveys were carried out to have a better grasp of Kelp Blue's whereabouts and its surroundings, this will aid the analysis of the behavior of developed renewable energy.

The future energy consumption of Kelp Blue's processing site was estimated based on projected growth and changes in operations. Water usage of Kelp Blue's processing site was also analyzed to determine the potential for implementing a water conservation system.

The System Advisor Model (SAM) was used to model the energy yield and losses of the proposed renewable energy system. This helped to estimate the performance and the design parameter of the solar and wind solutions.

For financial analysis and evaluation, Excel was used to build a financial dashboard. This dashboard will be sent separately from the report.

Finally, a multi-criteria model was developed to evaluate the potential of the proposed renewable energy systems in terms of their environmental, economic, and social impacts. This model was used to compare the proposed systems to alternative energy options and to identify the most cost-effective and sustainable solution for Kelp Blue's operations.

6 Introduction to the company Kelp Blue

In this chapter, an overview of the company Kelp Blue is given. They have a wide variety of goals besides their objective of rewilding the oceans and sequestering CO_2 and are, for example, actively involved in increasing prosperity for the local society. The company also thinks about solutions for the purpose of kelp after it is harvested, so they create value throughout their whole value chain. All these aspects of the company are highlighted in the following sections.

6.1. Kelp Blue's vision

Kelp Blue is a company founded by Daniel Hooft and Caroline Slootweg. Their purpose is to re-wild the oceans and simultaneously safely sequester CO_2. During Daniels' 20-year career in the fossil fuel industry, he has often been exposed to the direct consequences of extracting these resources. This has made him realise that the world is severely out of balance. This balance is of great importance for the survival of all life on earth, making it imperative to restore this balance.

While looking for a new career opportunity, his wife Lucy attended a conference about the giant kelp and its excellent benefits to nature. Daniel was so impressed by this, he started figuring out how to farm giant kelp and make a viable and feasible business with this. Once proven everything, they set out to find the best location to start testing and building the first farm.

Because giant kelp can only grow at certain locations in the world due to water temperature, nutrients and current direction, they were already limited in their operation locations. From an economic and legal perspective, it was finally decided to start in Lüderitz, Namibia.

Kelp Blue currently has two sites at which they plan to grow giant kelp. One site is 10 nautical miles Northwest of Lüderitz.This is the pilot site, which has water characteristics more comparable to the final offshore site. The other site is located in Shearwater Bay and is called the BTP (Biosystem Testing Program)/Shearwater Bay site. At this site, the water depth is only 10 m and the netting modules, on which the kelp grows, are installed at 5 m below the surface. The site is suited for installing new designs and analyzing the strengths and weaknesses of new concepts.

At the Shearwater Bay site, there is already a module, a grid of ropes of 10x10 meters, installed and in use. The object of this project is to install a second module without the use of divers or ROVs. If possible, the module should be made in such a way that a third or fourth module can be easily added to the second module without the use of divers or ROVs. The use of divers is cost intensive, dangerous and adds up to the total carbon emissions of Kelp Blue.

Kelp Blue is a company that does multiple things. First, it is an international company with its first hub in Lüderitz, Namibia, and are currently working on obtaining licenses to start and grow Giant Kelp in New Zealand and Alaska. The first hub is in Lüderitz because of the easily obtainable licences and the upwelling of the Benguela current near the coast. This current contains lots of nutrients and cold water, which creates an essential environment for growing giant kelp.

Right now, Kelp Blue is developing the farms and is exploring different ways to structure and install them. It is a very complex engineering problem as this has never been done before. The goal is to have 4 ha of installed netting at the end of 2023.

Next to its economic and ecological ambitions, Kelp Blue also focuses on its social impact. They aim to be a worldwide sustainable business and create long lasting jobs through their timeless value chain. They also create a source of education, local capability, and skills development through their side projects. For the latter, they invested in the Blue School, a primary school part of the All-Atlantic Blue Schools Network (BlueSchool, 2022). The school integrates ocean learning into the curriculum, recognizing the critical role formal education plays in fostering an ocean-literate society.

6.2. Benefits of Macrocystis Pyrifera

Giant kelp is the largest breed of kelp in the world. There are only certain places in the world where the growing conditions are optimal for giant kelp. In these places, giant kelp can grow as much as 50 cm a day, up to 60 m total in length, making it the fastest-growing organism in the world. Besides these incredible attributes, giant kelp has extraordinary potential in sequestering CO_2. There are estimates that giant kelp can sequester 5-10 times more CO_2 than a typical tropical rainforest (Hurlimann, 2019). Like all plants, giant kelp grows and sequesters CO_2 from the water through photosynthesis. Eventually, when the plant dies, or parts break off due to e.g. current, it moves with the ocean currents to deep ocean sediment deposits. Where the seabed is more than 500 meters deep and the pressure is high, the risk of disturbance is so low that the kelp can slowly transform into fossil fuels over a course of millions of years. Therefore, the sequestration can assumed to be permanent.

The giant kelp farms also stimulate biodiversity. The kelp forests provide much shelter for small animals and organisms from the current and predators, making it an ideal habitat for shelter. Ultimately, this also attracts predators, allowing the creation of whole new ecosystems and niches. More than 800 species are known to take shelter in kelp forests (NationalParksService, 2016), so artificially creating these forests will affect some of them anyway.

Besides these growing and sequestering capabilities, giant kelp can also be created into biomass. From the harvested kelp, biostimulants can be crafted that have proven to have great stimulating effects on plant growth, such as increasing the resilience of plants and increasing the crops yield rate (KelpBlue, 2022a).

As shown, giant kelp has beneficial attributes throughout its whole life cycle, making it a great organism to cultivate.

6.3. Cultivating Macrocystis Pyrifera

Nowadays, some companies extract wild-grown kelp from the sea and use it to produce specific products. Kelp Blue is the first company in the world that wants to cultivate giant kelp in the ocean, making their idea the first of its kind. They plan to build farms in the ocean where the kelp grows on a horizontal placed grid op ropes. A schematic overview of the farms can be seen in figure 6.1, (KelpBlue, 2022b). In the figure some important aspects of farming the kelp are depicted.

The farms will have the following basic characteristics:

1. The farm is a few kilometers away from the shore.
2. At the location, the nutrients from the Benguela current and the cold water are optimal for the giant kelp to grow.
3. In the figure, the grid on which the kelp grows is submerged at 15 meters below the ocean surface. Each grid is attached to a big weight that rests on the ocean floor.
4. Unique vessels will harvest the top parts of the kelp plants. The processing of the giant kelp starts on this vessel.
5. The harvesting vessels will only reach till 1.5 m below the surface, meaning they will only harvest the canopy of the kelp. This will be done 4 times per year.

6. Kelp can easily regrow after being harvested and generally lives between 7 and 20 years before the holdfast becomes to weak to anchor the plant.

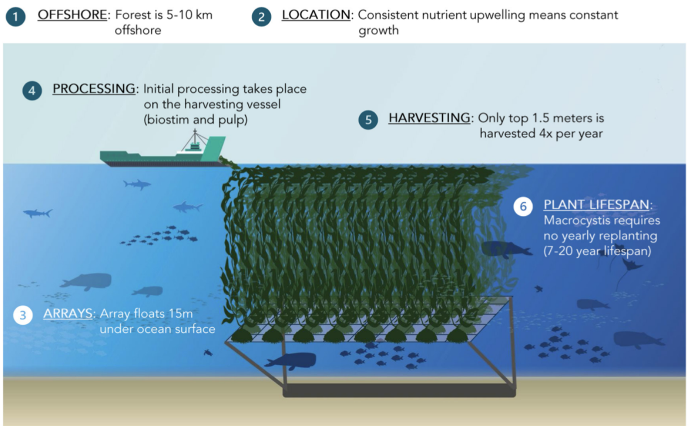


Figure 6.1: A schematic overview of the Kelp Blue's farms, (KelpBlue, 2022b)

6.4. Future goals of Kelp Blue

Although the principles of growing giant kelp are clear, there are still enough obstacles ahead to actually carrying out the operations. Right now, it takes too much time to install one module. A method has to be designed to deploy module after module without the use of divers or work class ROVs. The aim is to be able to install 4 ha/month, which is impossible under the current design. As the Lüderitz Hub is the first one, it will be the hub where the wheel needs to be invented. Kelp Blue aims to open hubs in New Zealand and Alaska in 2024, and it is expected that these hubs will be much quicker overall, as all the techniques are innovated in Lüderitz.

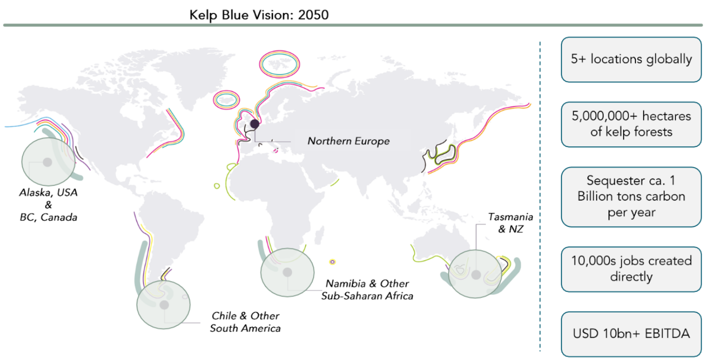


Figure 6.2: Vision of Kelp Blue operations by 2050, (KelpBlue, 2022b)

6.4.1. Upscaling operations: Daily installation of 4 ha/month in Lüderitz

In order for the business model of Kelp Blue to be viable, they calculated it is necessary to produce a certain amount of biofuel per month. By reverse calculating from this amount, they were able to identify how much m^2 is needed for this, and thus how much m^2 is needed to install per month. The conclusion of this calculation is that Kelp Blue needs to install 4 ha/month starting from Q3 2023, meaning they have to install rougly 1 ha/week. At this moment, with their current operations and array design this is not possible, which will be discussed in chapter 7.

6.4.2. Upscaling operations: Intercontinental hubs

Next to their ambitions of installing 4 ha/month, Kelp Blue also has worldwide ambitions. As stated in the introduction, the first Hub is situated in Lüderitz for both economic and legal reasons. But most importantly, they are situated here because of the Benguela current in the ocean. This current brings the necessary water temperature and minerals needed for giant kelp to grow. But as mentioned in Chapter 1, the coast of Namibia is not the only geographical position for kelp to grow. Kelp Blue thus aims to set up hubs in New Zealand and Alaska starting Q1 2024.

6.4.3. Limitations

As discussed in chapter 6.1, Namibia was partly chosen due to their regulations concerning licensing. But next to this advantage, Kelp Blue also experienced many disadvantages during their time in Lüderitz. First of all, there are not a lot of materials available apart from the essentials. In addition, the positioning of Lüderitz is unfortunate and it takes ~1 day to drive from Windhoek. This results in long delivery times and creative problem solving when it comes to prototyping. Third, for their operations Kelp Blue currently only has access to 3 small vessels. This makes performing their operations more difficult and therefore they aim to re-purpose a larger vessel for installation in the future.

Part I

Scaling up

7 Analysis of design of Kelp Blue's macrocystis farm

Kelp Blue started with large ambitions and large operations. Their current main focus is on installing a full array structure of their pilot design offshore of Lüderitz. Since they experienced multiple setbacks and delays before even installing the first module, they decided to also focus on creating a new design. The aim for this design, called the commercial design, is that it will be used in the future for all their operations. Therefore, it needs to be designed with as little to none flaws as possible. In this chapter, the gaps in the current design will be analyzed. Together with the analysis, preliminary solutions will be given for components which will be translated to boundary conditions that can be found in Appendix A.1.

7.1. The pilot design

In figure 7.1, the pilot design of Kelp Blue is shown. An amount of eight modules are connected to each other, of which one module has a surface area of 36 x 52 m. In total this netting spans a surface area of almost 15,000 m^2. The nettings are 15 m under the water surface in 55-60 m deep water and consist of polysteel ropes. The material of these ropes is a mixture of PP and HDPE plastics. On both ends of the total system, two drag anchors are connected by catenary chains. The drag anchors create tension in the array and therefore prevent motion in the north-south direction in the horizontal plane. The catenary chains meet with the bridles, which are connected to the first and last module. From the meeting point between chain and bridle, a vertical rope reaches to the surface connecting two surface buoys to the system at each end of the array. Each netting module is on both ends connected to a spreader bar. This spreader bar is a hollow steel bar sealed off at both ends, which creates an air pocket inside that allows the bar to have buoyancy. The spreader bars thus act as a floating device and also form a connection between each netting module. From the outer ends of each spreader bar, a pair of mooring lines are connected to the gravity anchor. These gravity anchors are installed at the bottom of the sea. They consist of a square steel frame filled with solid concrete and have a weight of 30 tonnes each and can be seen in Figure 7.1. Together with the spreader bar, these create tension in the mooring lines to prevent the system from movement in the vertical direction. Following, the installation procedure is given.

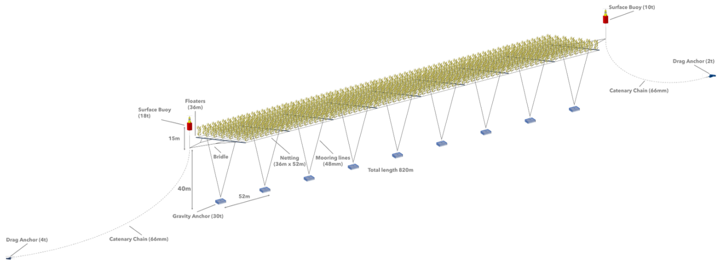


Figure 7.1: Pilot design of the first macrocystis farm

7.2. Installation procedure

The current installation procedure for the pilot design consists of multiple stages. Since the whole procedure consists of many steps, a brief summary is given below:

1. Installation of northern buoy mooring northeast of array location.
2. Gravity anchors with spreader bars attached are sequentially installed (N->S) (Requires the pre-assembly of the spreader bars to the gravity anchors)
3. Installation of netting modules (Requires installation of all gravity anchors/spreader bars)
4. Installation of (southern) buoy mooring southwest of array location

This installation procedure is already different from the initial final theoretical one. The changes were made due to failure of certain components as a result of directions of forces that had not been taken into account.

Since the gravity anchors are made of solid concrete in combination with steel, they are very heavy and thus hard to transport. Kelp Blue currently uses large air lift bags (see figure 7.2) to transport the anchors from the port to the pilot site. The air lift bag in combination with gravity anchor and the spreader bar in perpendicular orientation from the navigation direction (also held up by two smaller air lift bags), create an extremely large amount of drag force. Because kelp blue only has access to the two smaller boats indicated earlier (chapter 6.4.3), transport is very slow on itself. This also calls for optimal weather windows, which makes installation again very weather dependent. After the installation of the spreader bars, connected to the gravity anchors through mooring lines, netting modules can be installed.

Figure 7.2: Seaflex air lift bag

As of now, Kelp Blue has only installed 2 anchors at the pilot site, with the first one on September 14th. This shows how slow the current procedure is, and therefore is in need of drastic changes.

In chapters 7.3 till 7.6.2, the individual components that make up the pilot design are analyzed for their flaws, which will be taken into account for further designing.

7.3. Gravity anchors

7.3.1. Analysis

In figure 7.1 can be seen that on each corner of every netting module, one mooring line is connected to a square anchor at the seabed. These gravity anchors are concrete blocks in a steel frame that weigh 10 tons each. If each module would contain a netting module of 50x50 m, one module would have a surface area of 0.25 ha. Taking into consideration that Kelp Blue wants to start producing 4 ha/month, the following formula shows how much concrete would be used if the gravity anchors would still be applied in that phase with first the number of anchors and in the second formula is the total weight of these anchors:

$$\frac{4}{0.25} = 16 \tag{7.1}$$

$$16 * 10 = 160 tons \tag{7.2}$$

Using 160 tons of concrete per month just in Lüderitz is obviously not sustainable. Besides, the installation of the gravity anchors has been proven harder than expected and really weather dependent. Therefore, the gravity anchors need to be taken out of the current design and replaced by an alternative.

7.3.2. Preliminary solution

From the gap analysis, it was concluded that the gravity anchors need to be replaced by an alternative. For this alternative, a brief analysis has been performed of conventional and offshore anchoring methods. The later analysis showed multiple viable options, but for multiple reasons it was decided to make use of helical anchors. Thus, it is assumed that helical anchors will be used as anchoring techniques for the new design.

7.4. Spreader bar

7.4.1. Analysis

The spreader bar is a sealed off hollow tube containing air that is connected to each end of a module. Since the air is trapped inside, the bar wants to go to the surface. This generates tension on the net modules, which in turn are attached to spreader bars on both the north and south sides. Therefore, the spreader bars have a length of 36 meters (the width of one module) which make the spreader bar material-intensive and result in a cost and emission intensive product. Next the bars have proven to be relatively hard to assemble and to be really weather dependent to install. Adding these up has resulted in Kelp Blue deciding to eliminate the spreader bar from their current design.

7.4.2. Preliminary solution

In the gap analysis was concluded that the spreader bars need to be replaced by an alternative. For this alternative, a brief analysis is being performed of conventional and offshore flotation devices. An option could be using subsurface buoys, but this will be investigated further in the paper.

7.5. Drag anchors, lines and catenary

7.5.1. Analysis

In the current design of the pilot phase, there are two catenary chains connecting 8 modules to drag anchors, which can be seen in figure 7.1. Furthermore, you can also see that two lines connecting the pennant buoys at the surface to the same spot. When the ocean is rough, the pennant buoy lines can be under a lot of tension. But when the weather is still, both the lines and the catenary chains will be more loose and able to move around more. This creates a problem for marine animals.

Each year, a lot of marine animals get entangled in ropes, catenary lines, or other human waste (mainly from fisheries). Using a design with these consequences is really conflicting with Kelp Blue's goal to rewild the oceans. Therefore the catenary chains and ropes in question need to be taken out of the system and a new design has to be made.

As also can be seen in figure 7.1, the total of 8 modules will be connected via polysteel ropes to two large drag anchors at both the north and south side. They create tension in the horizontal axis, which prevents movement of the system. But, as the name implies, drag anchors drag over the ocean floor. Until the anchor is stuck, or if it is yanked loose, it can destroy a lot on the ocean floor. Because the drag anchors used here are really big, their negative effects will also be much bigger. Therefore Kelp Blue has also decided to subtract them from future designs and replace them with helical anchors, which will be explained in Chapter 8.1.1.

7.5.2. Preliminary solution

From the gap analysis it was concluded that the lines and catenary need to be minimized or replaced by an alternative. As stated before, it was decided that Kelp Blue will make use of helical anchors and buoys to fix and tension the future redesign. Using these methods will eliminate the need for drag anchors and catenary, but increase the amount of active lines. Nonetheless, it can be assumed that redesign will make sure that all the lines will always be under tension.

7.6. Divers and work class Remote Operated Vehicles (ROVs)

7.6.1. Analysis

Currently the Kelp Blue team in Lüderitz has a sub-team of 4 divers. These divers make the subsurface connections at the installation of new netting modules at both the Shearwater bay site and Pilot site. However, when scaling up to the commercial phase, it is not feasible to make use of divers. Using divers to make these subsurface connections is very time consuming, because of all the safety procedures that are involved. In addition to time, dangerous work environments is also a large obstacle for the operation. The divers need to make connection while the installation is under a lot of tension, which can have disastrous outcomes if something goes wrong. To minimize these risks, at this moment Kelp Blue only installs new modules when the weather is very calm. But with the future goal of installing 4 ha/month, they can't be so dependant of weather windows. A replacement for divers are remote operated vehicles (ROVs), and specifically (light) work class ROVs. They are used at moderate to very deep depths for difficult operations where divers can't be used, or there is a high risk of diver safety. Although this is a desirable outcome, the price of work class ROVs, together with it extending installation time due to preparation, relocating etc., leads them to be nonviable and -feasible. Therefore the use of divers or work class ROVs must be excluded for the final design.

7.6.2. Preliminary solution

From the analysis it was concluded why the use of divers or work class ROVs must be excluded. As stated before, excluding the use of divers and work class ROVs is part of the main scope of this project. Therefore, no preliminary solution has been stated and the solution will be discussed later on in the report.

8
Revision of Kelp Blue's macrosytis farm

In Chapter 7, an analysis of the current design was done, and some preliminary solutions were stated. These, together with the analysis of the problem scope mentioned in Chapter 4, and weekly meetings with the engineering team, were translated into boundary conditions and assumptions. The full list of boundary conditions and assumptions can be viewed in Appendix A.1. After determining these, the preliminary design is made and at last, the dimensions are scaled down for the Kelp Blue's test site Shearwater Bay. At this location, the company carries out their Research and Development operations.

8.1. Preliminary design

8.1.1. General concept of design

Figure 8.1 shows the basic idea of the future commercial design. It is important to note that this is a preliminary design and that this basic sketch incorporates some essential concepts. These concepts are decided based on the analysis explained in Chapter 7 and the related gaps. The concepts are a visualization of the boundary conditions mentioned earlier in this Chapter. Thus, the solutions to specific boundary conditions have not yet been worked out and are addressed in Chapter 9.

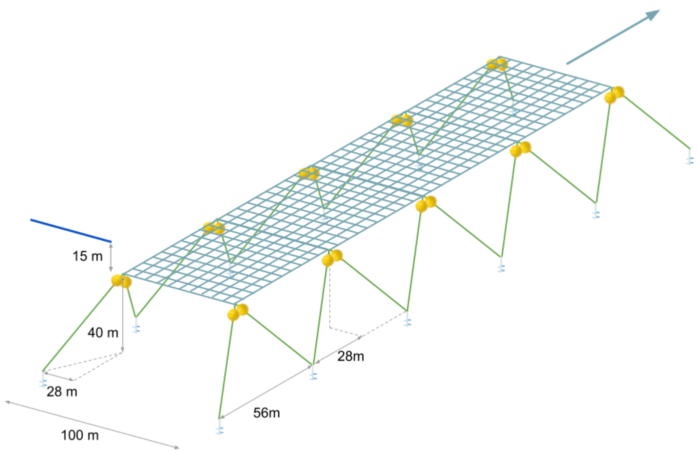


Figure 8.1: Preliminary design, the dimensions are given by Kelp Blue.

The first aspect of figure 8.1 that draws attention is the placement of the modules. The modules are situated next to each other, which implies that the installation of the modules is modular. Modules can be added to the already at-depth placed array structure in one pre-decided direction.

Second, the helical anchors can be placed without complications while the mooring lines and buoys are attached. This ensures no need for divers or ROVs for the installation since the mooring lines are reachable and need to be connected to the netting module. The buoy floats on the water surface with the mooring line going straight up.

The anchors are responsible for ensuring the module stays in place. From the anchors, mooring lines under tension are connected to the netting. The buoys that are attached to the end of the mooring lines are responsible for the stretching force and bring the whole structure under tension. The tension mitigates the risk of marine (whale) entanglement. From the netting grid, giant kelp will grow and exert an extra buoyancy force on the mooring lines and netting module.

Finally, figure 8.1 shows that the array structure underwater only consists of materials in use. No material is left in the water without a purpose. In the future, excess material used for installing the module can be retrieved. If some parts of the module need to be accessed from the water surface, retrievable lines connected to temporary buoys can be attached to the netting module. The buoys are only used if necessary to minimize the risk of marine entanglement.

It must be stated again that figure 8.1 is a basic design incorporating several ideas which are not yet explained in detail and will be discussed in Chapter 9. The preliminary design is used to make an initial calculation to determine the playing field, namely what forces are at play in the module and what materials will meet these forces.

8.1.2. R&D project

The design discussed previously in this chapter is aimed towards the commercial phase of the company. Before the design can be tested at the pilot site, which has the same depth and wave characteristics as the commercial location, it must be tested at a smaller scale. This is done to save time and prevent high costs when a failed installation occurs. In addition, the design can be tested in a more controlled environment. For instance, specific design elements can be tested separately without having to deal with the behavior of the sea from the commercial phase. The latter is also a limitation. Thus, after improving the design, tests in commercial phase conditions are essential.

As can be concluded from the previous part, it is essential to test the designs in the field. The first field tests of a design are conducted in a controlled environment. Shearwater Bay, located south from Lüderitz, is an excellent example of a calmer environment than the open sea. As figure 8.2 shows, Shearwater Bay is protected from currents directed northwards. The normative current for Lüderitz is the strong Benguela current flowing northwards (Hutchings et al., 2009).

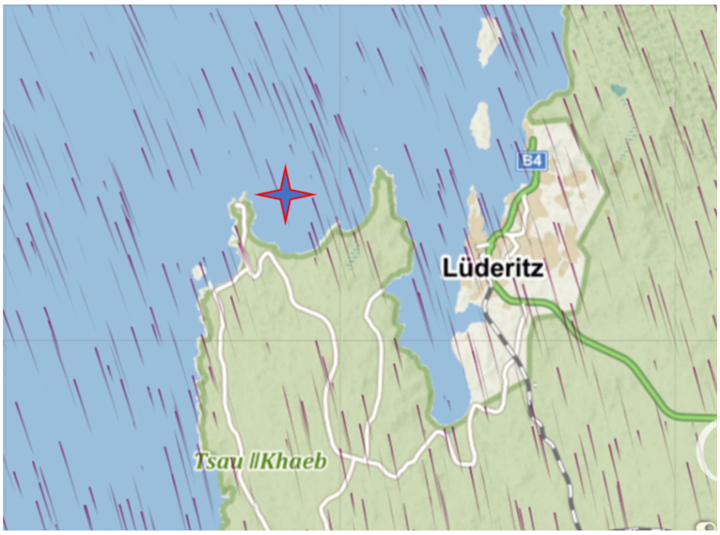


Figure 8.2: Oceanic flow Lüderitz, Shearwater Bay is marked with a star. (bron windy)

Moreover, Shearwater Bay is a good place for testing and analyzing first concept designs since it is shallow and sheltered. Therefore smaller horizontal forces due to waves or currents act on the system. In order to design a work plan for the installation of a netting module for the new design, all the dimensions from the Offshore pilot need to be scaled down for the Shearwater Bay area. Figure 8.3 shows a visualization of the dimensions of the preliminary design for the BTP area in Shearwater Bay.

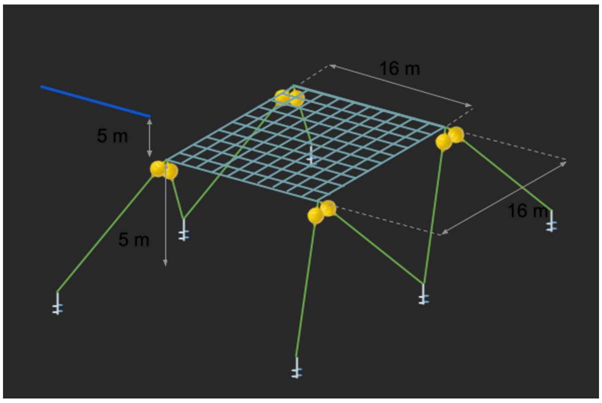


Figure 8.3: The dimensions of a single module.

8.1.3. Analysis of forces acting on netting module

The ocean can impose large hydrodynamic forces on the netting modules. These forces need to be calculated so that the module's structure can be designed with capacity large enough regarding strength and stiffness. They result in a balance of incoming forces and internal netting forces. The forces at play are essential characteristics by which the types of mooring lines, netting lines, and buoys can be determined.

So, to start the design project, it is essential to be aware of the forces acting on the modules. As this knowledge is vital to obtain before designing new modules, calculations were made on the basic design of the module in the Shearwater Bay site, shown in figure 8.4. The calculations include static and dynamic forces on the netting module. The figure is drawn in 2D to simplify the calculations. The basic design consists of a module with a width and length of 16 meters, with one anchor at each corner of the netting module. Using four anchors instead of six results from a normative force acting on the two anchors in the middle of one netting module shown in figure 8.3, which is equal to the forces in each anchor in the figure below.

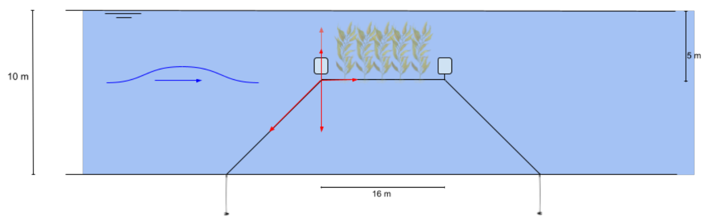


Figure 8.4: A schematic overview of wave forces on one netting module.

8.1.4. Calculation of forces acting on the netting module

It must be stated that the calculations discussed in this chapter are approximate. These calculations aim to determine the most extreme forces the mooring lines and netting should be able to handle. Some numbers, for example, the buoyancy of kelp, are assumed and are somewhat overestimated as a safety factor.

Other numbers, like the horizontal load, are calculated and multiplied by a safety factor of 2. This safety factor ensures that the modules can withstand the most severe oceanic forces that appear at the Shearwater Bay site. The forces working on the netting module are split up into two forces, horizontal and vertical, as figure 8.4 shows. This sub-chapter gives an exact overview of the forces at the end.

The buoyancy of kelp

Next to the ocean, that imposes large forces on the netting module, the giant kelp has a certain load on the netting module. Since giant kelp has oxygen bladders, which help the plant grow to the light coming from the water surface, the plant is buoyant. The bigger the plant grows, the more the plant becomes buoyant and the more upward pulling force the plant exerts on the netting module. From documents composed by Kelp Blue, the weight of a single plant can be found. For a water column length of 15 metres representing the commercial or pilot site, the plant has a length of 30 metres (canopy length added) and a total weight of 55 kg. The buoyancy force of the macrocystis plants is equal to 7,5% of the total weight of these.

Scaling it down for the Shearwater Bay site, where the plants grows in a water column of 5 metres, it is assumed that because the water column length is a third smaller than the pilot site, the weight of a plant of 55 kg can be divided by three. Thereby, the weight of a plant in a water column length of 5 metres becomes 55/3 = 18.33 kg. Since the buoyancy of a plant is a percentage of the total weight and the plant's total weight is rounded up to 20 kg, the buoyancy of a single plant in a water column of 5 metres becomes:

$$20 * \frac{7.5}{100} = 1.5kg \tag{8.1}$$

A module of 16 x 16 m has 17 lines in x- and y-directions, all one metre apart. Therefore, in x-directions there are 17*17 = 289 plants. The same applies to the other directions, resulting in a total of 289*2 = 578 plants. Applying the buoyancy force of a single plant to all the plants on one module results in a total buoyancy force of 578 * 1.5 = 867 kg on one netting module.

However, the plants are located in a water column where the load is applied to a vibrating system. This is known as dynamic loading because of the movement of the water. Therefore, since dynamic loading is more severe than static loading, a dynamic amplification factor needs to be applied to the buoyancy force of the kelp. In the documents provided by Kelp Blue, a dynamic amplification factor of 1.4 is found. This results in a total vertical buoyancy force of the kelp from one netting module of 867 * 1.4 = 1214 kg.

The total vertical buoyancy force of the kelp is distributed into four corners of the netting module, to which anchors are attached. Per corner point or anchor, a vertical force of 1214/4 = 303.5 kg is exerted. Multiplying this value by the gravitational acceleration of 10 m/s2, gives the value of the force in Newton.

$$303.5 * 10 = 3035N \tag{8.2}$$

Horizontal load

The waves and currents exert a horizontal drag force on the Giant Kelp. The maximum value of this force is calculated by multiplying the total vertical dynamic load with a specified horizontal ratio factor. For a plant length located in a water column of 5 meters, Kelp Blue estimated the total horizontal ratio to be 0.63.

The literature found that the biggest waves on a 5-10 meter depth are around 400 kg in force. (KelpBlue, 2022b). It is important to note that this force only acts on the netting module when the giant kelp has grown to the water surface.

Multiplying the total vertical dynamic load of 1210 kg by 0.63 gives a rounded-up value of the total horizontal load, 1210*0.63 = 800 kg. After applying a safety factor of two on the oceanic force, the total horizontal load becomes 1600 kg. The maximum horizontal load exerted by the ocean on the kelp is calculated to be 16.000 N, by multiplying the force in kg with the gravitational constant of 10m/s2. This force of 16.000 N acts in one direction. If the force acts from left to right, as seen in figure 9.5, the force is distributed through the two anchors on the left. The total horizontal load in one anchor becomes 8000 N.

It is assumed that the most optimal line configuration for the distribution of forces is chosen in the final design. Namely, to place the mooring lines at an angle of 45 degrees from the corners of the netting module. This results in the following calculation for an angled component of the oceanic force in the mooring line:

Force mooring line = 8000 N / sin (45 degrees) = 8000 * √2, which is equal to 11314 N, the force that the mooring lines should be able to withstand. A balance of forces is depicted in the figure below.

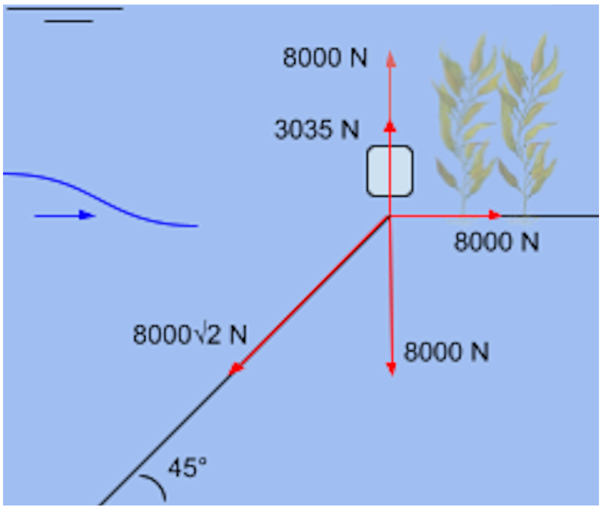


Figure 8.5: forces acting on corner of the module.

9

Exploring solutions

With a preliminary design based on the scope, sub-challenges, boundary conditions, and assumptions, it is now possible to focus on designing the different components. First, three structural concepts are made, exploring different ways to bring down the module 5 metres below the surface. Second, multiple designs are presented of self-locking systems that allow the module to be secured in the desired position. Third, a method is shown how to recover excessive material needed for installation, followed by designs of the necessary helical anchors and buoys. A multi-criteria analysis is performed to determine the most feasible and viable designs for the structural designs and self-locking systems.

9.1. Structural designs

In this part of the exploring solutions for the new design of the commercial phase, different solutions to structural challenges are determined. Most important is that a netting module can be winched down to a desired depth. The challenging element of this is that large buoyant buoys need to be submerged. This requires a large downward force, without the ability to let a diver install some device to execute this. Three concept designs are invented and through multicriteria analysis a final structural design is chosen.

9.1.1. Concept 1

In this first concept design, the whole system of netting and buoys will be submerged at the same time. When the screw anchors, mooring lines and buoys are installed, those buoys will be on the water surface. With the correct positioning of those buoys, mooring lines and anchors with regard to the netting, the corners of this netting and the buoys can be brought together at the desired depth. In figure 9.1 a 3D visualisation is given of winching down a netting module according to concept design 1. The different phases can be explained as follows:

Phase 0 - 1:
Six helical screw anchors are fixed in the sea bottom with two buoys at the surface per anchor attached via a mooring line. The netting is placed in the middle of the four buoys.

Phase 2 - 2.1:
In the second phase, working lines are connected to the corners of the netting. Each corner's other end of the workline is going through the corresponding buoy. This could be via some sort of device that is attached to the buoy. The working lines then come back to the vessel.

Phase 3 - 3.3:
In the last phase, the whole module will get submerged. The working lines will be pulled in from the vessel. Due to the positioning of the screw anchors in relation to the netting, the points where the buoys will meet with the corners, is at the desired depth of 5 meters. The final result is shown in phase

3.3.

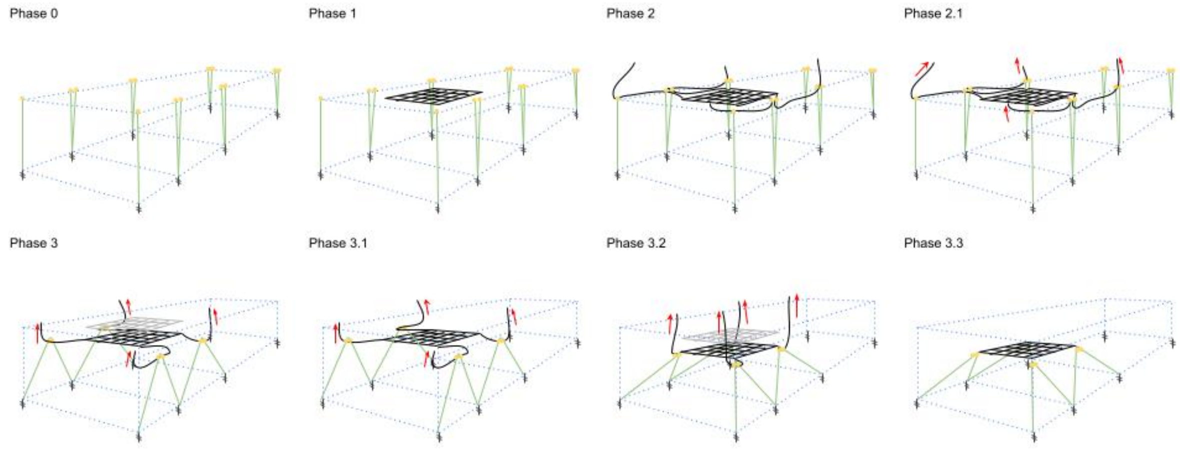


Figure 9.1: Overview of installation method of concept design 1

Pros:

- Only uses essential material
- Uses standardised material
- Mechanically easy to install

Cons:

- Friction can cause fractures in the working lines
- Installation material needs to be extracted

9.1.2. Concept 2

This second concept makes use of pulleys that are installed at the sea bottom. These pulleys are the device for the buoys to get submerged. In figure 9.2, a 2D visualization is given of the installation of a netting module corresponding to the second concept structural design. In the first phase of this visualization, some numbers relate to components of the structure. Table 9.1 shows what numbers relate to a certain element.

Number	*Description*
1	Pulley
2	Helical anchors
3	Rope clamp
4	Netting

Table 9.1: Numbers with description for figure 9.2

Phase 1:

The preparations for this concept are as follows. The six helical anchors are fixed in the ocean floor as in concept 1. In this concept, four pulleys are screwed inside the ocean bed. These pulleys will provide the action of submerging the buoys. The buoys' horizontal motion is provided by pulling a workline through a rope clamp[1] that is connected to a buoy. This horizontal workline is on the other side connected to the netting. There are also vertical working lines connected from the buoys to the vessels, through pulleys. This is shown in the top picture of figure 9.2.

Phase 2:

In this phase, the middle and bottom picture of figure 9.2, the module is brought to the desired depth. Pulling in the vertical working lines through the pulleys, submerges the buoys. At the same time pulling on the horizontal workline ensures that the corners of the netting eventually meet with the buoys.

Pros:

- Pulleys require less force to install
- Pulleys decrease risk of tear in working lines

Cons:

- Is dependant additional installation equipment
- Extra operation needed to install and retrieve installation equipment
- More expensive
- More difficult to install due to directions of lines

[1]The rope clamp is a device that ensures motion in one direction and blocks motion in the opposite direction. In chapter 9.2.1 a detailed explanation will be given about the rope clamp.

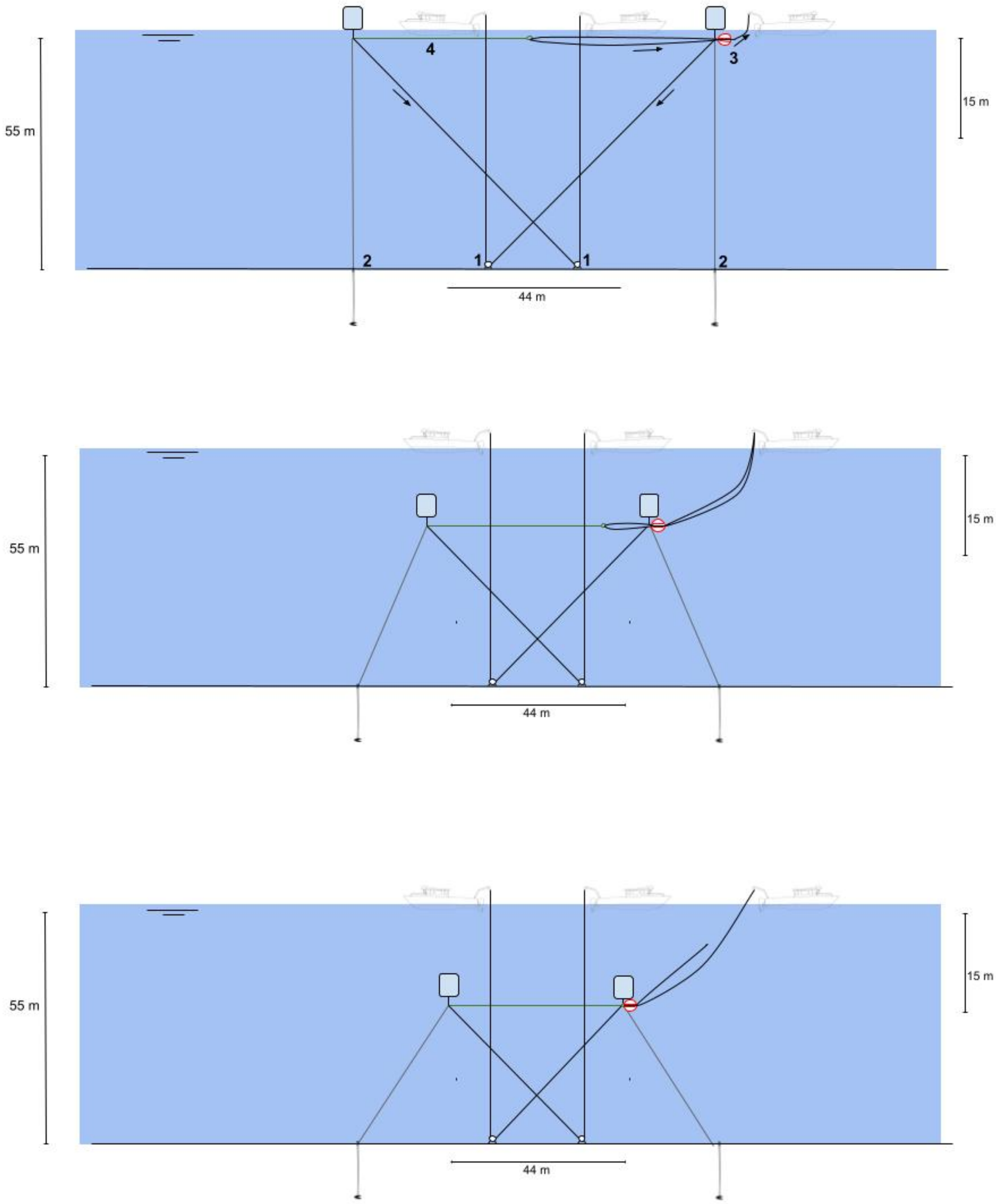


Figure 9.2: Overview of installation method of concept design 2

9.1.3. Concept 3

In this third and final concept for installing a netting module, again the rope clamp (or some other form of a self locking mechanism) plays an important part. This device is shown as the yellow sphere in the figure 9.3 below. This figure visualises the two phases of the installation method in one picture.

Phase 1:

The mooring lines are attached to a ring or a similar kind of connection mechanism. working lines that are attached to the buoy go through this connection mechanism to the vessels. Each of the working lines contains a rope clamp that is connected to the ring. It should be noted that in figure 9.3 this is not visualised correctly, and the “rope clamp” is called the tie wrap system. At the surface the netting is attached to all buoys. The setup of this structure is given with the number 1 in the figure.

Phase 2:

Pulling the working lines from the vessels in and/or sailing away from the structure will ensure that the buoys are submerged. Since the rope clamp and the ring are attached the line will go through the rope clamp and is obstructed by this mechanism to go back in the opposite direction. The working lines are pulled in until the desired depth of 5 metres is required. This installation method is visualised with the number two in figure 9.3.

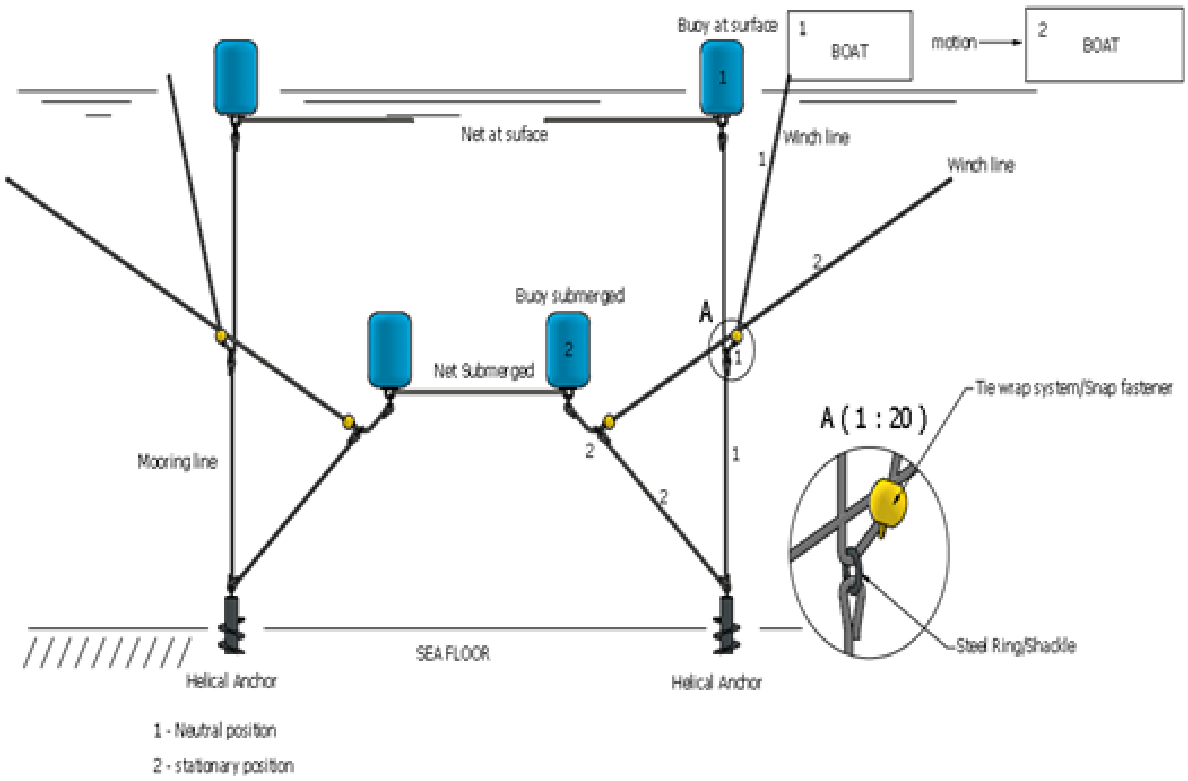


Figure 9.3: Overview of the installation method of concept design 3

Pros:

- All connections can be made on the surface

Cons:

- More material and connections needed than concept 1
- Working lines used for installation need to be retrieved

9.1.4. Multicriteria analysis

Now that the three concept designs are clear, a multicriteria analysis can be performed to determine the design that fits best. The criteria for analysing the concept designs are costs, mechanical simplicity, materials, durability, environmental impact, time consummation, and ease of use. The best design is rewarded with a one, and the worst with a three. The results are shown in the table 9.2 below.

Criteria	**Importance**	**Concept 1**	**Concept 2**	**Concept 3**
Costs	1	2	3	1
Mechanical simplicity	2	$1(=2)$	$3(=6)$	$2(=4)$
Materials	1	2	1	3
Durability	2	$1(=2)$	$2(=4)$	$2(=4)$
Environmental impact	3	$1(=2)$	$2(=4)$	$1(=2)$
Time consummation	3	$1(=3)$	$2(=6)$	$1(=3)$
Ease of use		$3(=9)$	$1(=3)$	$2(=6)$
Total score		**22**	**27**	**23**

Table 9.2: Multi-criteria analysis of the different design concepts

Looking at the multi-criteria analysis; there is one design which scores best. The first concept is mechanically-wise the most simple and also the most durable. As a result of the multi-criteria analysis, the first concept is the one which is elaborated in the rest of the research.

9.1.5. Concept 4

One final concept was designed for the company, which does not apply to all conditions but is highly recommended since it speeds up the installation process. This concept is shown in figure 9.4 below. The reason it is not further elaborated and not included in the multicriteria analysis either, is that this concept still needs the use of divers and is not modular. It cannot be extended with as many modules as one would want. As this is not compliant with some of the boundary conditions, it is not included but will be recommended for further research. In the installation method, multiple modules will be brought down to the desired depth at the same time. The amount of modules can be as high as the company wants, but is still doable regarding vessel power. In figure 9.4, four modules are submerged with this installation method.

Phase 1:
In the preparation phase, 12 helical anchors with mooring lines and buoys are installed. 6 on one side and 6 on the other. There needs to be a certain distance in between the third and fourth helical anchors, so that the modules are at the correct depth when brought to each other. The buoys and mooring lines are attached to the netting at the surface. Therefore the length of the mooring lines needs to be higher than in for example concept 2. Two of the modules are attached to each other on one side and two on the other side, as can be seen in figure 9.4 phase 1.

Phase 2:
In the second phase, working lines from the first pair of modules are connected to pulleys that are attached to the second pair of modules. Now on both sides a vessel pulls this workline in, bringing both pairs of modules closer to each other. Because of the certain distance in between the pairs, they will

meet at the desired depth.

Phase 3:
All four modules have met at the desired depth. Now a self-locking mechanism or diver locks the modules into place. In this design a lot of modules are installed at once. In that case not a lot of divers are needed per module installed, which could be acceptable for the company. Further research and development for self-locking mechanisms could be avoided.

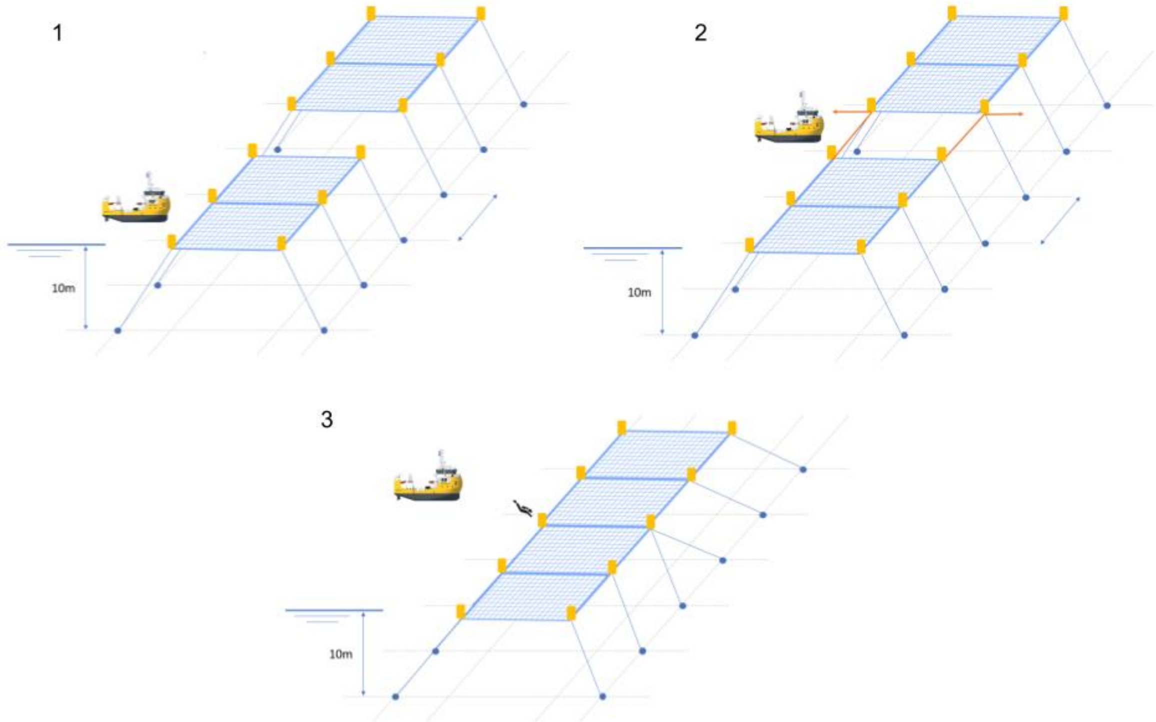


Figure 9.4: Overview of the installation method of concept design 4

9.2. Self-locking mechanisms

After exploring designs for the installation method of the module, one of the main problems that was constantly faced was a way to lock the module into place as soon as the desired depth was required. Without the use of divers, this has to be a mechanism that locks itself. In this subchapter, three different designed self-locking mechanisms are given and through multiple criteria analysed. The first mechanism considered is the rope clamp system, the second the latch lock system and the third the snap fastener.

9.2.1. The rope clamp

Inspired by rope clutches like in figure 9.5, a mechanism that prevents movement in one direction and can be pulled in the other direction, the rope clamp was designed. This spherical object can easily be manufactured and used in the eventual installation method. Combining this mechanism with the buoy, where the buoy is the yellow sphere in figure 9.6, is also an option.

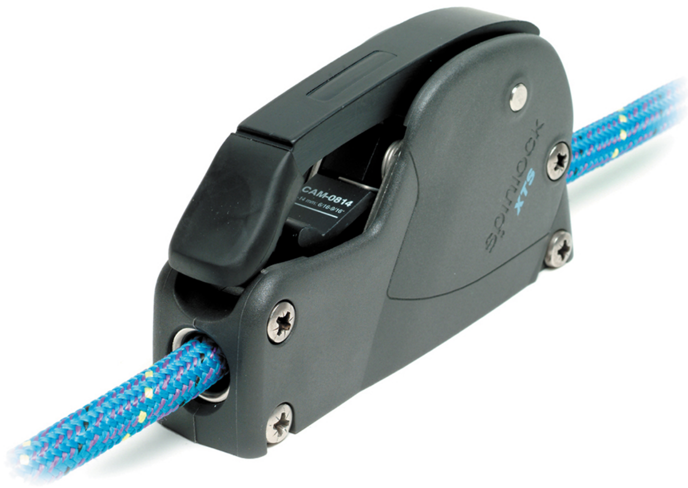


Figure 9.5: Rope clutch used on sailing boats (*Spinlock Powerclutch XTS1 single*, n.d.)

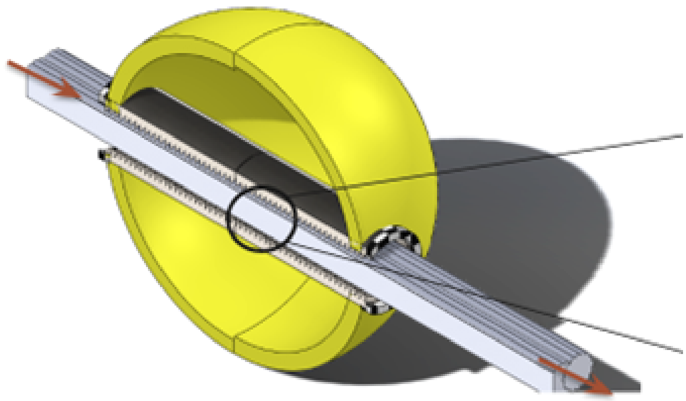


Figure 9.6: Design of rope clamp (own figure)

Inside the sphere, a hollow shaft is manufactured where working lines can move through in one direction. This so-called female part has inclined teeth in one direction that prevent movement in the opposite direction. A visualisation of this is given in figure 9.7.

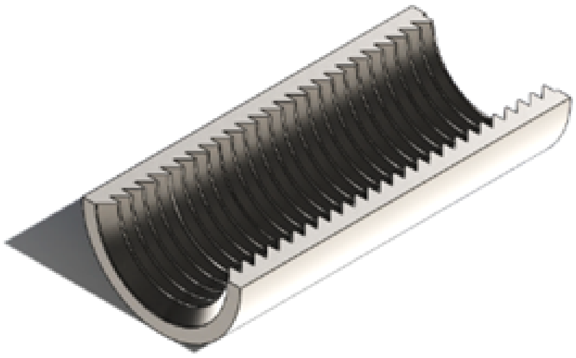


Figure 9.7: Clamp part of rope clamp design (own figure)

A problem with this mechanism is that it might fray the rope after some time, since the sharp inclined teeth will cut into the rope. Another problem might be that the teeth can not endure enough friction. A quick test also showed that current rope clamps do not work with polysteel ropes, because of the surface texture of the rope. Therefore a material needs to be found that solves this problem.
Pros:

- No active components are needed
- Can be easily produced
- Can be easily integrated into already existing buoys
- Further development can create a unlock mechanism

Cons:

- Perfect material must be found for hollow shaft and on the the polysteel rope
- Integration with marine hardware may cause problems
- Fatigue may play a role over time

9.2.2. The latch lock

The second self-locking mechanism is called the latch lock system, which is inspired by door latch mechanisms. It consists of two parts: a male part connected to each corner of a netting module (see figure 10.2), and a female part attached to a buoy (10.3). A rope of 20 m is connected to the front end of the male part and pulled through the female part on the surface. By pulling on this rope long enough, eventually the male part will slide in the female part. The spring loaded latches will snap into the slots of the male part , locking the entire system in place. A form of closure will prevent the male part from sliding all the way through, and the latches prevent motion in the opposite direction. Figure 10.1 shows the final position of the male and female part when installation has been performed successfully. The rings attached on both ends of the male part are used to attach other marine hardware onto, such as bow shackles or poly steel ropes.

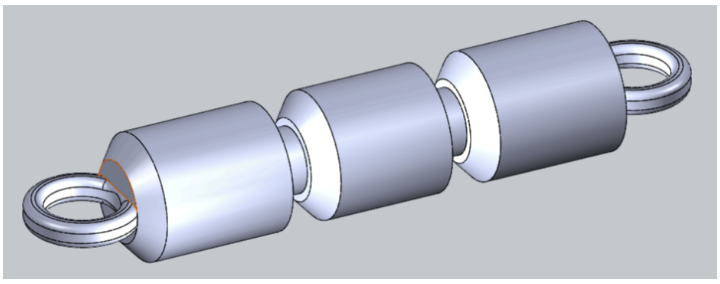


Figure 9.8: Male part (own figure)

9.2.3. The snap fastener

The final self-locking mechanism that was designed is called the snap fastener. Like the latch lock system, this system also uses a so-called male and female component. Apart from the overall form of the system, another major difference is that each netting module has two male and female parts connected to them. The female parts are located at the corners of an already installed module where a future module will be connected to, and the male parts are connected to the corners of the module to be installed.

Figure 9.9 shows a schematic overview of the system when the snap fastener has been installed. The gray object is the female part and the black half-circle is the male part. The yellow ropes connect the female part to the already installed netting module and the green ropes attach the male part to the newly installed module. The red rope running through the whole system is the working line that is used for pulling the system into place. It has a knot that can be slightly seen in the same figure that prevents the rope from going all the way through the male part. By implementing this, the rope can be pulled back through both the male and female part, while these are interlocked. The rope can be extracted to the surface and the male and female parts are left in the desired position.

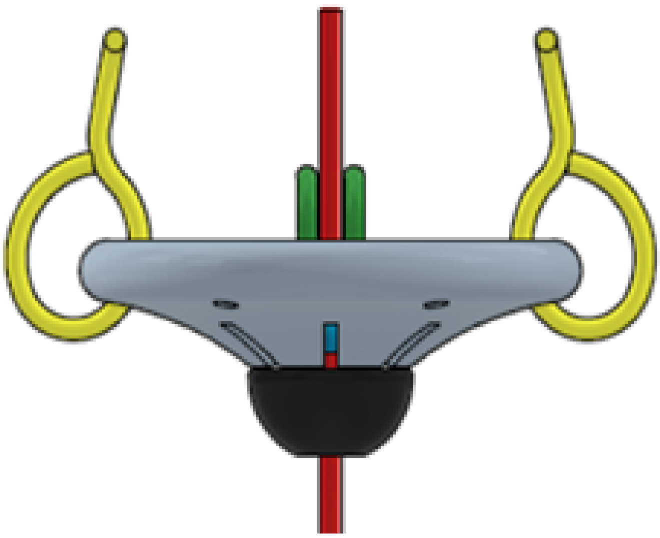


Figure 9.9: Side view of the snap fastener (own figure)

Pros:

- Solves problem of retrieving installation equipment
- Can be easily connected to existing marine hardware

Cons:

- Very precise dimensions are needed for best result
- Needs multiple materials
- Fatigue may play a role over time
- Needs very precise manufacturing
- Harder to integrate future unlock mechanism

9.2.4. Multicriteria analysis

Now that the three concept designs are clear, a multi-criteria analysis must be performed to determine the best design fits. The criteria for the concept designs that will be tested are costs, mechanical simplicity, materials, durability, environmental impact, time consummation, and ease of use. The best design is rewarded with a 1, and the worst with a 3. The results are shown in table 9.3 below.

Criteria	**Importance**	**Rope clamp**	**Latch lock**	**Snap fastener**
Costs	1	1	3	2
Mechanical simplicity	2	$1(=2)$	$2(=4)$	$2(=4)$
Materials	1	1	3	2
Durability	2	$1(=2)$	$2(=4)$	$3(=6)$
Environmental impact	2	$2(=4)$	$1(=2)$	$3(=6)$
Time consummation	3	$1(=3)$	$1(=3)$	$1(=3)$
Ease of use	3	$1(=3)$	$1(=3)$	$1(=3)$
Effectiveness	2	$3(=6)$	$1(=2)$	$2(=4)$
Total score	**22**	**24**	**30**	

Table 9.3: Multi-criteria analysis of the self-locking mechanisms (own table)

In the table, the rope clamp wins the multi-criteria analysis. However, one of the goals of this project is to realise as much as possible in real life. Meaning everything had to be produced locally here in Lüderitz. There was only a steel manufacturer in Lüderitz, so the latch lock system was the easiest choice. For this reason, the latch lock system is the concept design that is elaborated on in the report.

9.3. Retrieval system

Next to a self-locking mechanism, a second problem is to be analysed for the overall design, according to the boundary conditions. This challenge was mentioned in the problem scope and is about the retrieval of excess material in the installation of a giant kelp farm module. The designed element is called the retrieval system and contains one temporary buoy and a long thinner poly steel rope. Figure 9.10 shows a schematic overview of the retrieval system.

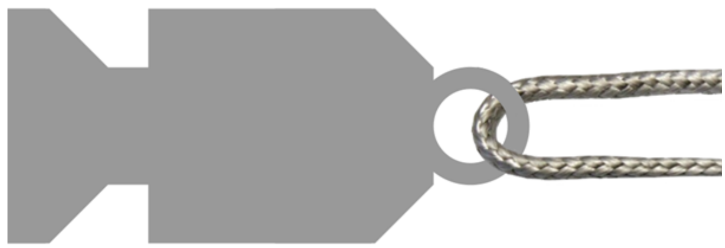


Figure 9.10: Schematic visualisation of the retrieval system (own figure)

The retrieval is simply a ring connected to a self-locking mechanism, in this case the latch lock system. Again, on an already submerged module, two female parts are connected to one side of this module. The module to be connected te the already submerged module, contains to male parts on the other side. In that way two corners of the new module will lock into place when they meet the two corners of the already installed module. The ring of the retrieval system will be attached to the male part. A line will loop through this ring and both sides of the loop will be pulled on until eventually, the male parts lock into the female parts. After this one side of the loop can be pulled in, so that all the worklines, used to pull the whole structure into place, are retrieved.

9.4. Helical anchor

9.4.1. Overview

As stated in the assumptions of appendix A, it was an assumption that helical anchors are used as the anchoring method for the final design. For the commercial design, Kelp Blue is still designing a final product that can be used for their purpose. Since the forces in the commercial site are of greater magnitudes, more elements must be considered when designing. Therefore, a new simplified design of a smaller helical anchor is made for the Shearwater Bay site. A schematic overview of the design can be seen in figure 9.11, and a detailed overview can be found in Appendix A.5.

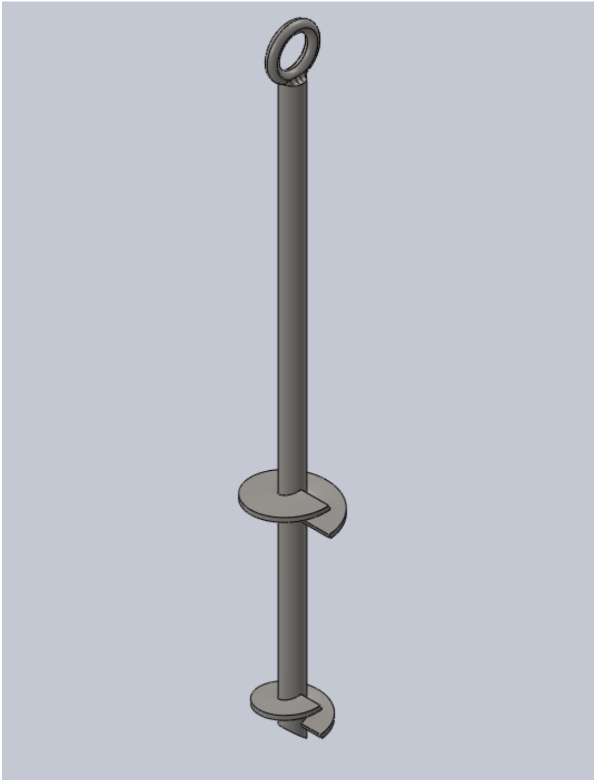


Figure 9.11: 3D visualisation of the screw anchor (own figure)

The helical anchor is a simple design consisting of four steel elements;

- A hollow bevelled circular shaft vertically goes into the ground and acts as the central attachment point.
- Two single helix plates allow the anchor to have its anchoring force. The helices are situated at the bottom and ⅔ of the total length of the shaft.
- A metal ring on top is used to screw the anchor in and acts as an attach point for the mooring lines.

Installing the helical anchor is done by a team of two divers. First, the bevelled end of the shaft is pushed into the ground until the lowest helix touches the soil. Then, the divers pass a solid steel rod through the ring on top. The anchor is slowly screwed into the seabed by turning the rod on both ends. Since the seabed soil at the Shearwater bay site primarily consists of sand, no problems are expected to screw the anchors into place.

9.4.2. Dimensions

Since there was no prior knowledge about helical anchors, research had to be done to determine the correct dimensions for them to be functional. (Watson, 2011) explains the fundamentals of helical anchors with accompanying rules of thumb, which are used to dimension the helical anchor. Prior to designing, two boundary conditions were set:

1. The length of the shaft is 1700 mm.
2. The helical anchor will use two single helices.

The length of the hollow shaft, 1700 mm, is derived from the physical height of the divers. Because they are the ones turning the rod, they need to be able to reach it and put force onto it. The bottom has a bevel of 39.8°, is 50 mm high, and meets the bottom of the lower helix. Both helices consist of one 360° rotation travelling over 75 mm in height and have a thickness of 13 mm, with the pitch being an industry standard. The lower and upper helix have a diameter of respectively 175 mm and 225 mm and are spaced 450 mm apart. These dimensions are determined through a combination of the boundary conditions and the following rule of thumb: “Helices are spaced on the shaft at a minimum distance of three times the diameter of the lower helix, if the spacing is greater than a distance of three times the diameter of the lower helix, the additional distance must be in 3” increments” (Watson, 2011). The distance from the upper helix to the ring is 1050 mm. The ring has an inner and outer diameter of 90 and 150 mm respectively.

9.5. Buoy design

9.5.1. Engineering

As stated in the assumptions in Appendix A.1, it is a boundary condition that subsurface buoys will be used to create tension for the final design. Kelp Blue now only uses regular secondhand mooring buoys for the Shearwater bay site, accompanied by fishnet floats. An illustration of these buoys can be seen in figure 9.12. These yellow spherical buoys have a buoyancy of 130 kg, and consist of a PE sphere filled with foam, with a steel rod going through. At both ends of the steel rod, a plate is attached with a large pad eye. For the buoys the same situation applies as with the helical anchors, being that smaller buoys need to be designed for the Shearwater bay site.

Figure 9.12: Mooring buoy (own figure)

Due to practical and economic reasons, it was decided to use oil drums as floatation devices as a temporary solution for the Shearwater bay site. Repurposing used oil drums to be used as buoys is a common practice. The drums will be sealed to minimise the chance of water getting in. Since the drums are not galvanised, corrosion is inevitable. Therefore, the lifespan of the buoys is short and they’re not feasible for operations in the long term.

Next to creating tension in the array structure, the buoys are the mounting point for the chosen self-locking mechanism. For the Shearwater bay design, this mounting point will be at the bottom of the buoy, next to the padeye. This makes the installation of the mechanism easier and allows the buoy to tilt if needed.

A 3D model of the buoy can be seen in figure 10.7 in chapter 10.1.3.

9.5.2. Position

Kelp Blue has thought of three different alternatives regarding the position of the buoy in comparison to the mooring lines and netting. These three are shown in figure 9.13.

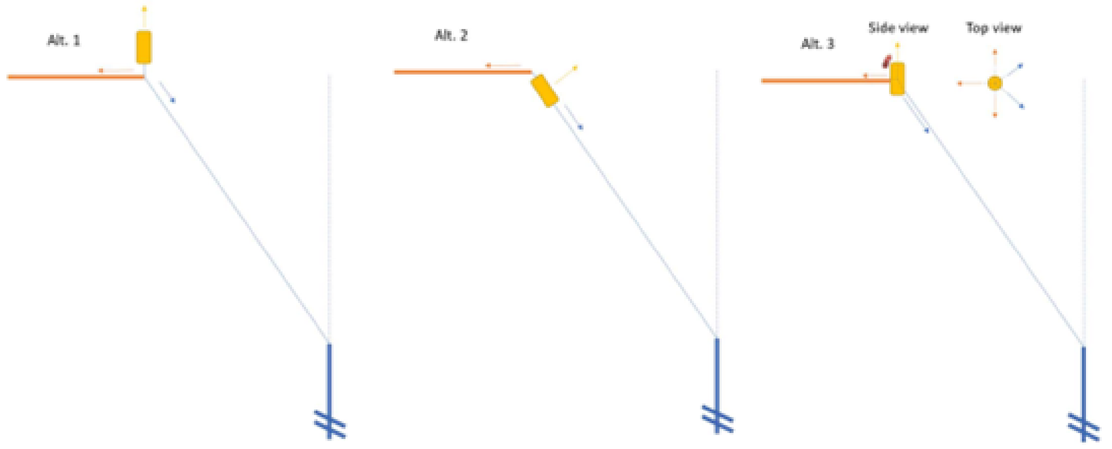


Figure 9.13: Buoy positioning (own figure)

Alternative 1 has a buoy above the node where the mooring line meets the netting. In alternative 2, the buoy is placed below the netting, and in alternative three the node is inside the buoy. Although the buoys are placed in different locations, they are of the same magnitude, which is a buoyancy force of 303.5 kg. In addition, the distribution of forces through the system is not affected by the different alternatives. Each alternative has its own advantages and disadvantages, which are listed below.

Alternative 1

- Advantages
  - \+ Installation
  - \+ Maintenance
  - \+ No difficult buoy design
  - \+ Best distribution of forces
  - \+ Buoy can move with current due to single connection
- Disadvantages
  - – Moving of buoy increases the risk of failure of connection
  - – Moving of buoy can cause damage to Kelp
  - – Moving of buoy can cause danger to wildlife

Alternative 2

- Advantages
  - \+ Fixed position decreases the risk of failure of connection
  - \+ Fixed position creates a low chance to damage Kelp
  - \+ Fixed position creates a low danger to wildlife
- Disadvantages
  - – Distribution of forces is not optimal
  - – Difficult to replace if maintenance is needed

Alternative 3

- Advantages
  + Combines the buoyancy and connection elements in one single point
- Disadvantages
  – Distribution of forces is not optimal
  – Difficult to replace if maintenance is needed

9.5.3. Dimensions

In chapter 8, it was found that the net buoyancy force of 303.5 kg is sufficient for the required horizontal tension in the array structure of 800 kg. According to the law of Archimedes (*Archimedes' principle*, n.d.), the amount of buoyancy force an object has, is related to the volume of water that is pushed away by the object. For a buoyancy force of 303.5 kg this means for the volume V:

$$F_b = V * g \tag{9.1}$$

For a cylinder, this means:

$$F_b = (\pi * r^2 * h) * g \tag{9.2}$$

The net buoyancy becomes:

$$F_{net,b} = (\pi * r^2 * h) * g - W = (\pi * r^2 * h - M) * g = 303.5kg \tag{9.3}$$

The repurposed oil drums used for the Shearwater bay design have standardised dimensions. These standardized oil drums have a net buoyancy of 190 kg, which is sufficient for the Shearwater bay design.

9.5.4. Materials

The standardised drums Kelp Kelp Blue make use as buoyancy devices for the Shearwater bay design are made of steel and will be airsealed. As stated before, the drums are not galvanized and will therefore corrode in time. Since corrosion can cause porosity, the drums have a risk of filling up with water. Therefore, Kelp Blue will fill up the barrels with larger plastic balls and PU foam in between. This not only minimises the risk of the barrels losing buoyancy when they have a leak, but will also create extra stiffness.

10

Prototyping and testing of concepts

10.1. Prototyping and testing of concepts

After exploring different design options within the overall design in chapter 9, the chosen elements need to be produced. Certain elements must be tested before implementing these in the commercial phase of farming kelp. In this chapter, the process of building and testing prototypes is described. First, the process of building the latch lock system is shown, then the helical anchors, and finally, the buoys.

Before starting with the production of the prototypes, a backup plan was made. This backup plan can be found in Appendix A.2. The backup plan describes different pathways to continue with the project if a core element cannot be delivered or an insufficient amount is delivered on time. Core elements of the design are helical anchors, the latch lock system, and buoys. Since limitations in the production phase occurred, none of the core elements could be delivered on time in the sufficient amount needed to install a whole netting module. Therefore, the pathway of testing a mechanism itself, rather than testing it while bringing a module to depth, has been chosen. Subsequently, when a sufficient amount of core elements can be delivered, Kelp Blue can bring a module to depth, together with the knowledge of the functionality of the core elements.

10.1.1. Latch lock system

The latch lock system was a challenging prototype to build. This element was a demanding obstacle since a locking mechanism like this is not yet developed in the maritime or offshore industry. Furthermore, the resources available in or around the town where the prototype was manufactured were minimal. The process of the latch lock system existed of 6 different phases:

1. Making technical drawings to hand out to different potential contractors.
2. Choosing a contractor based on costs, experience, and earlier collaborations with the company.
3. Let the contractor start with building the first prototype, getting familiar with the design, and finding its flaws.
4. Keep in close contact with the contractor to think about the adjustments of that the design needs.
5. Finalise a design and a prototype.
6. Test the functionality and the loading capacity of the prototype.

In Appendix A.3, a detailed description of the full development of the prototype of the latch lock system is given. This description includes difficulties and some pictures of the process among other things.

After some redesigning in phase 4 of the process, a final design was made and elaborated. The model of this design can be seen in figure 10.1. Kraatz Engineering started building on this design and after almost 7 weeks, the final prototype was delivered. Figures 10.2, 10.3 and 10.4 show pictures of this prototype.

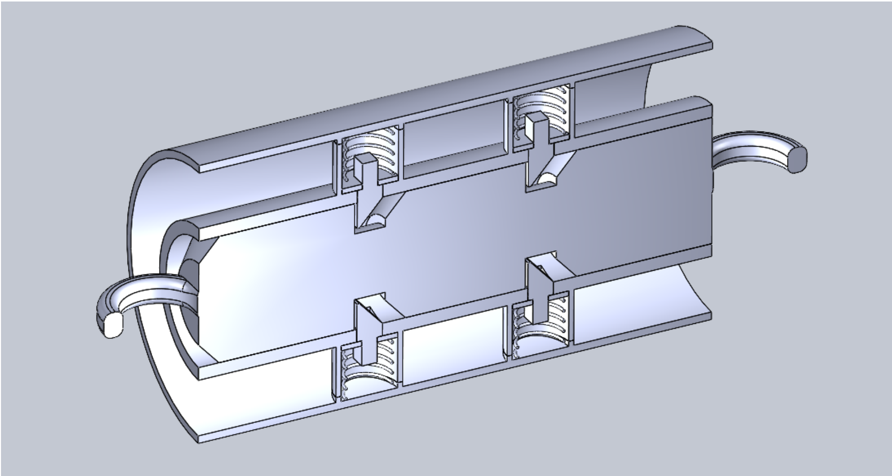


Figure 10.1: Section view of designed male and female part (own figure)

Figure 10.2: Male part

Figure 10.3: Female part

Figure 10.4: Inside view of female part

Next, the prototype was tested offshore. A detailed description and setup of the operation is shown in appendix A.3.

The test was performed to investigate whether the male part could make the desired turn and lock into place when only a vertical force was exerted. The test went perfect and proved our concept to perform as expected. Despite the fact that the helical anchor could not be installed, a temporary weight was used as a downward force. The male and female part locked in perfectly at the desired depth.

10.1.2. Helical anchor

For the convenience of the production of the helical anchors, it was again chosen to get inquiries from both Kraatz and Wesco. To increase the success rate, another inquiry from M.M.H Building Renovations was obtained. Based on the received quotas and passed experiences, it was decided to let Wesco manufacture the helical anchors.

Since no prior operational knowledge about helical anchors was present, it was necessary first to test the helical anchors on their yield strength. This was done through the use of a load cell shackle. The load cell is on one end attached to a polysteel rope connected to the helical anchor's ring, and on the other end to an air lift bag. Slowly filling the air lift bag with air allows it to increase the force on the helical anchor in a controlled manner. Due to the composition of the ground, the team failed to install a helical anchor. As a result, no tests were conducted that would have allowed the strength of the anchors to be measured. Kelp Blue has now set out to redesign the helical anchors so they can be properly tested. However, a schematic overview of the setup can be seen in figure 10.5.

Second, because the array structure will use mooring lines in an angle, it was also necessary to test yield strength of the helical anchor under an angle. This procedure was similar to the procedure mentioned before, but this time the air lift would be connected to one of the vessels of Kelp Blue. By positioning the boat further away from the installed screw anchor, the air lift bag can be positioned between the vessel and the helical anchor. A schematic overview of the setup can also be seen in figure 10.5.

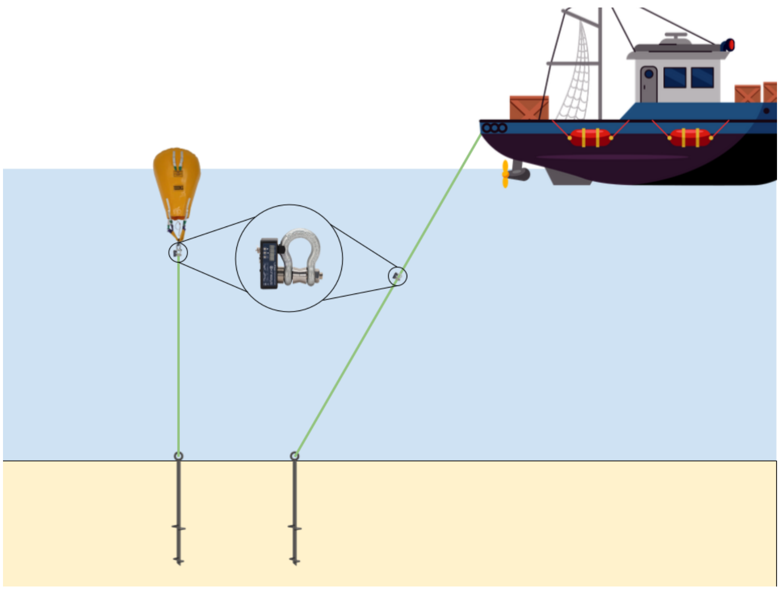


Figure 10.5: Schematic overview of the helical screw anchor capacity test

10.1.3. Buoys

The final element must be manufactured before the R&D module can be installed in the subsurface buoy. Manufacturing buoys on short notice is not feasible for the project. In Namibia itself, there are no buoy manufacturers. An option could be to find a manufacturer in South Africa. The company also has a manufacturer in the Netherlands, but the shipping costs are high, and it takes a long time for the buoys to arrive. Low-cost alternatives to the buoys that are readily available must be developed for Shearwater Bay. A solution for this that can be found and produced in Lüderitz is using oil drums filled with PU foam. As stated in Chapter 9.5.1, Barrels of 210 litres can be bought for a low price and picked up by the company for less than 20 US$.

The oil drums are filled with plastic balls. The space between the plastic balls is then filled with PU foam. The result is a filling of 60% of the volume of the oil barrel with the plastic balls and the remaining 40% with the PU foam. The barrels have a diameter of 580 mm and a buoyancy of 190 kg. A visualisation sketch can be found in figure 10.6.

The designed latch lock system could be dimensioned to this barrel, and the ends could be welded onto it. The cheapest but still efficient option for the position of the locking mechanisms on the oil drums is at the bottom of those. The pad eye should not be hindered since the mooring lines will eventually be connected to the buoys through these. Therefore the buoy design is shown in figures 10.7 and 10.8. Technical drawings of these are given in Appendix A.5.

Unfortunately, the manufacturing of the buoys could not be finished before the end of the field research. Therefore, they could not be tested.

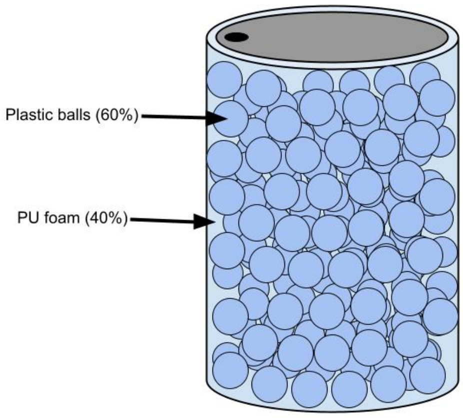


Figure 10.6: Schematic overview of oil drums with plastic balls and PU foam

Figure 10.7: Buoy design without locking mechanism

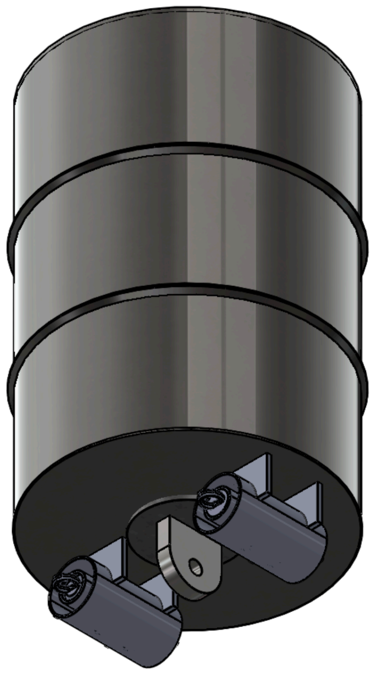


Figure 10.8: Buoy design with locking mechanism

11

Installation of final design

11.1. Installation of the module

After testing the different elements of the netting modules' new design, the final design's installation procedure can be developed. Knowing that buoys, helical anchors and now pulleys as locking mechanisms are readily available and can be used in the system, a complete plan can be generated regarding the installation of the module.

The installation procedure can be split up into five different phases. The first phase is onshore preparations, then anchoring, after the water surface installation, followed by the pulling down of the netting and ending with attaching a second module.

Kelp Blue's operations team was available to install the prototype module. In order to make clear to the team what the steps in the installation procedure were, a detailed manual was written. The full version of the manual can be found in Appendix A.4.

11.1.1. Onshore preparations

Onshore preparations are a vital part of the installation of a netting module. In this phase, the overview that is shown in figure 11.1 is laid out in the courtyard of the company's office. All the different combinations of connections are pre-assembled so that on-site, this is not needed anymore. This laying out of the total structure also gives a clear overview for everyone involved in the installation of the module.

Schematic overview of design

In figure 11.1, a schematic visualisation is given of the on-shore assembly of the installation of the prototype module. It is essential to do these on-shore preparations diligently, otherwise the whole operation might fail. The whole operations team can then be informed about the installation procedure, especially certain combinations of connections should be explained. Furthermore, in figure 11.2, the helical anchor alignment grid is given. This needs to be laid out in the courtyard as well. An explanation of the usage of the helical anchor alignment grid is given in chapter 11.1.2.

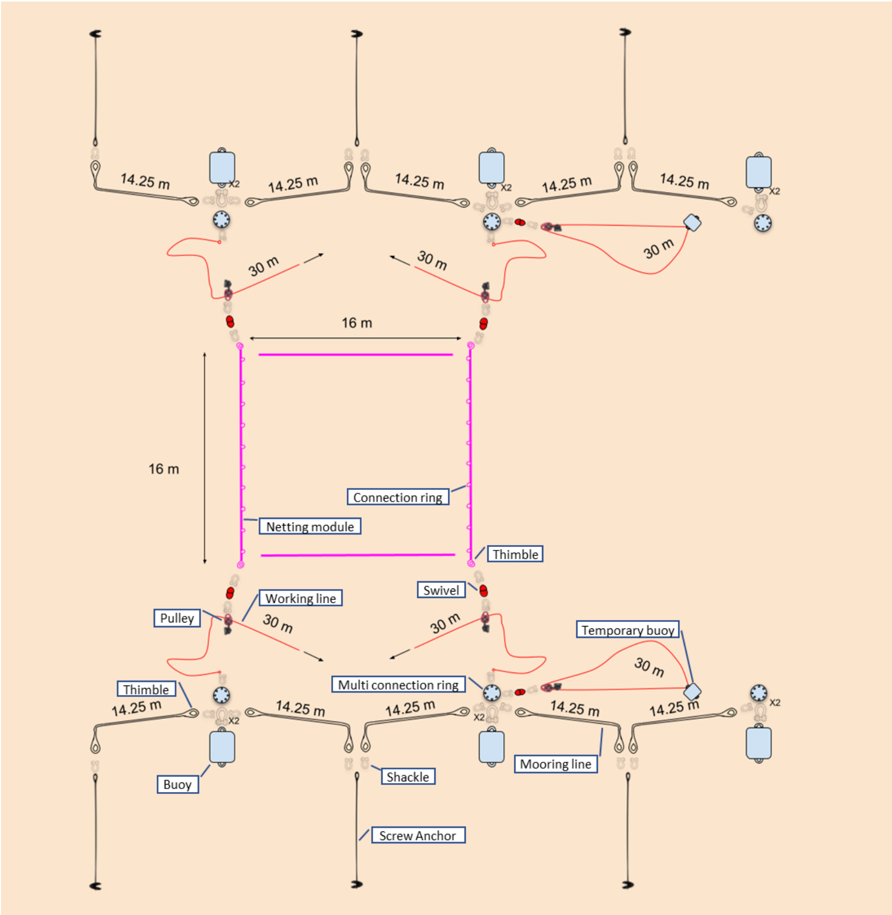


Figure 11.1: On-shore assembly overview (own figure)

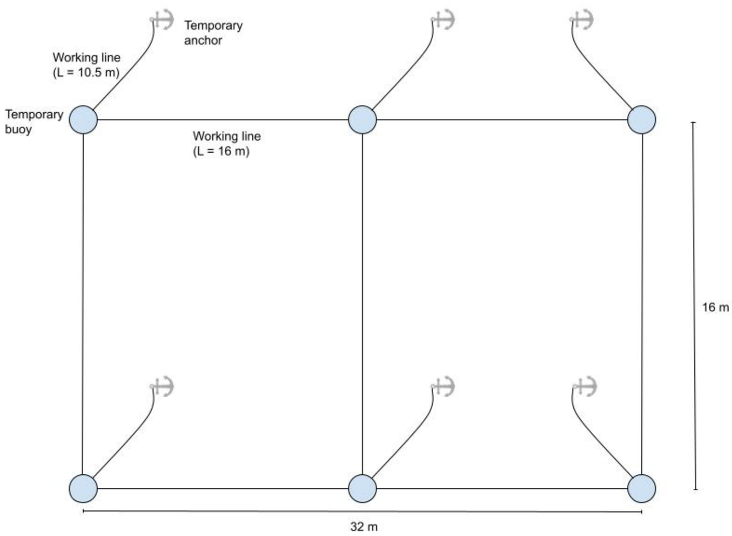


Figure 11.2: On-shore assembly helical anchor alignment grid (own figure)

Materials

In table 11.1 an overview can be found of all the materials needed for the installation of the R&D netting module.

Object	Amount
Helical anchor	6
Mooring lines	10
Multi connection plate	6
Subsurface buoy	6
Polyform buoy	2
Knotted netting outer line	2
Un-knotted netting outer line	2
Bow shackle (3.25t)	4
Bow shackle (6t)	48
Bow shackle (12t)	12
Galv swivel (5/8”)	6
Thimble (18mm rope)	24
Thimble (12mm rope)	6
Working line (12mm)	6
Connection line (18mm rope)	4

Object	Amount
Temporary anchor	6
Mooring line (18mm)	6
Polyform buoy	6
Line between anchors	5
Line between buoys	5

Table 11.1: Materials lists for R&D module (left) and installation (right) (own table)

An explanation of some of the materials that can be seen in figure 11.1 and table 11.1 can be found in Appendix A.4.

11.1.2. Anchoring

The second phase of the installation procedure is the anchoring phase. Here the helical anchors are placed at the correct location. If this part of the procedure is not performed accurately, the shape of the netting will not be squared. Minor errors are allowed but should be minimised. A sub-procedure is designed to be able to install the helical anchors as accurately as possible, without the use of precise GPS equipment.

Figure 11.4 gives a visualisation of this sub-procedure's design. This alignment grid is detached again and taken on the working vessel of the company. Each temporary buoy is attached to a temporary anchor. A helical anchor will be placed at each location of the temporary anchor. The temporary anchors and buoys are used to ensure that it can be seen from the surface that the anchoring positions have a space of 16 metres between them and an angle of 90/180°.

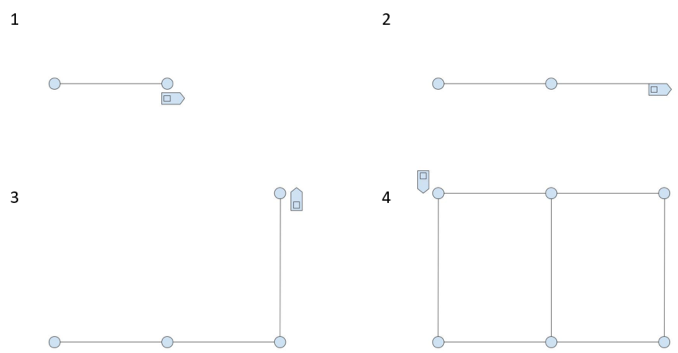


Figure 11.3: Installation grid helical anchor (own figure)

In figure 11.4 phase 1, the company's vessel drops a temporary anchor, attached to a surface buoy by a line. This line is about the length of the water depth (10.5 m) at the location. Connected to this first buoy is another line (16 m) that stays at the water surface. The vessel sails to the second position of the helical anchor grid. The direction does not have to be precise. When the line (16 m) is stretched under tension, the next combination of temporary buoy, anchor and line are installed, as can be seen in phase 1. Now, in phase 2, from the grid of buoys and lines the following position can be determined, which is 180° and 16 m further from the second buoy. In phase 3, the first three positions are determined and the vessel places the 4th buoy 90° and 16 m further from the 3rd buoy. These steps are repeated until a grid is obtained that can be seen in phase 4.

All the anchors have a third type of line (19.5 m) connected to them. Each time a temporary anchor is dropped, the other end of the line stays on the vessel and is attached to the next temporary anchor. This is repeated until there is a subsurface grid at the sea bottom as well. The reason for this is that the divers need a guiding line between the anchoring positions, due to limited visibility underwater.

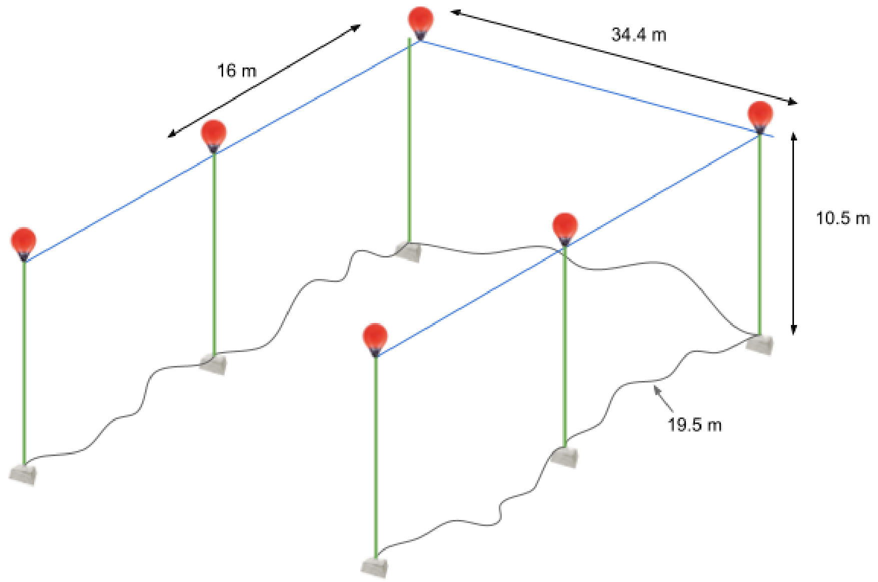


Figure 11.4: Installation grid helical anchor (own figure)

After the grid is installed, a pair of divers goes down to each anchoring position, at which they will install the helical anchor. When all six helical anchors are installed, the temporary anchors, buoys and lines (10.5 m, 16 m, 19.5 m) can be retrieved.

11.1.3. Water surface installation

The following phase in the installation procedure is the water surface installation. In this phase, all the different elements of the netting module are connected to each other at the water surface. Like explained in chapter 9.1.1, the corners of the netting are connected to the subsurface buoys, which are still on the water surface. working lines go from these buoys through the pulleys and back to the vessel. A visualisation of this is given in figure 11.5.

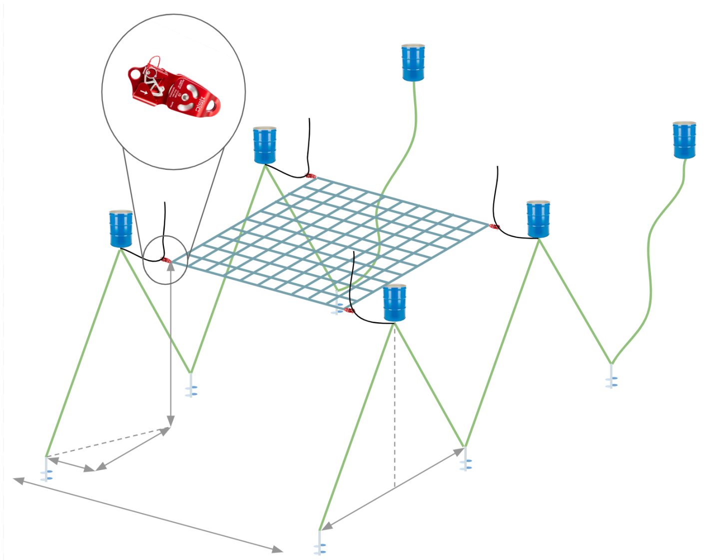


Figure 11.5: Preparation phase before installation (own figure)

11.1.4. Bringing down the netting

One by one, the working lines are pulled on through the pulley until the corner of the netting and the buoy meet. A visualisation of this is given in figure 11.6.

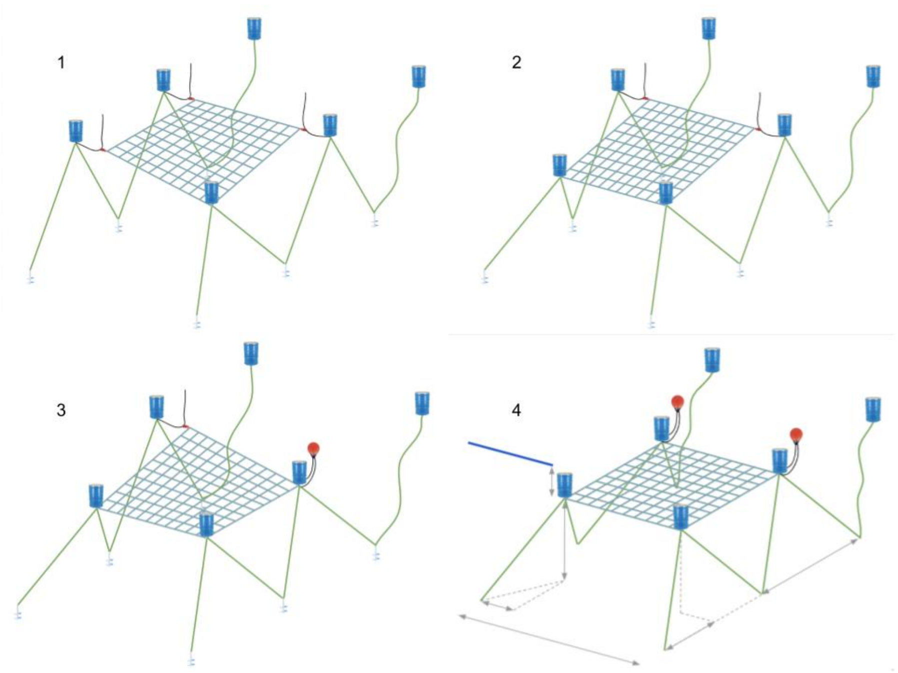


Figure 11.6: Installation steps of R&D module (own figure)

11.1.5. Attach an additional module

As can be seen in figure 11.6, there are two red temporary buoys connected to the two corners of the already installed module. Furthermore, there are two subsurface buoys connected to two of the helical anchors that were installed for the first module. In phase 5 of the installation procedure, these buoys are used to attach a second module. First the two working lines that are connected to the temporary buoys are pulled through two pulleys that are connected to the corners of the new netting. Two new working lines are connected to the new subsurface buoys, which are still on the water surface. These two working lines are pulled through the two pulleys on the other side of the netting. Now one by one the working lines are pulled in again until the corners of the new netting meets the corner of the already installed netting or the new subsurface buoys at the required depth.

11.2. Installation of the inner grid with twines

The twines on the module are pre assembled on shore. In the lab of the company the sporophytes are seeded on the polysteel ropes that will form the inner grid of the netting module. For the installation of the twines on the netting, a few possible options were considered. Following these options are considered with their pros and cons.

Option 1 - Install only the outer ropes of the grid. Install inner ropes with seeded twines later under water. This is the procedure Kelp Blue applies now already for the installation of the twines.

Pros	Cons
The installation method is safe regarding the vulnerability of the twines	Time consuming since the ropes with seeded twines need to be installed on another moment

Option 2 - Install the whole grid without seeded twines. A robot will seed the twines when the netting module lays on the water surface. Afterwards, the whole seeded netting module will be brought to the specific depth.

Pros	Cons
The whole grid is installed at once, making it the fastest option	Totally dependent on the functioning of the robot. When failure occurs, postponement of the activities is inevitable
More comparable to the commercial phase. (i.e. folding mechanism, bringing it to depth, etc)	The procedure of bringing the whole netting system with seeded twines down to a required depth has not been performed before, creating a a risk that this might fail

Option 3 - Connect only the outer ropes of the grid at the water surface to the buoys. When brought under slight tension, the inner grid with seeded twines will be connected to the outer ropes by hand. After assembly the whole netting system will be brought to the required depth.

Pros	Cons
Not dependant on the functioning of a robot	Time consuming since the seeded twines have to be connected at the water surface by hand
Connecting the seeded twines at the water surface increases the survival rate of the sporophytes since they are being kept wet throughout the process	The twines need to be installed carefully, high probability for inflicting damage

These pros and cons can now be processed into a MCA, which is given in table 11.2. The several MCA elements are arranged from 1 to 5, where 1 is ‘very bad’ and 5 is ‘very good’. Furthermore an important factor is applied in the MCA table as well.

	Importance	Option 1	Option 2	Option 3
Time consuming	1	2	4	2
Innovation	2	1	5	2
Chance of succeeding	1	5	4	4
Difficulty	2	4	2	4
Chance of damaging twines	3	4	2	2
Total score		**29**	28	25

Table 11.2: Multi Criteria Analysis of inner grid installation (own table)

The final scores of the MCA of the three different options are all really close. Option two has a very high potential. When the robot which seeds twines on the ropes is tested and proved to work, this installation method will be the most efficient. However, this test is purely focussing on getting one of the newly designed netting modules down without the use of divers or work class ROVs. Option 1 will be applied in the installation procedure.

12 Analysis and results

12.1. Conclusion

The current installation method designed by Kelp Blue for installing their Kelp farms is not usable on a larger scale. Currently, Kelp blue uses divers for attaching the seeded twines which is a time consuming job and poses great risks for the divers. Thus, if Kelp Blue wants to continue with their ambition to re-wild the ocean and sequester CO_2, a new installation method is of high importance for the company. Therefore, the goal of this research project is to design a new installation method by answer the following main question:

“Design a modular array structure that can be placed under tension at a desired depth, without the use of divers or work class ROVs.“

The main question is divided into three sub-questions after which a general conclusion is presented.

Starting with the first question: **‘How to descend the array structure down to the desired depth of 15 m from the water surface, without the use of divers or work class ROVs?’** The difficulty lies in submerging buoyant buoys that create the tension in the netting module . Three concept designs were made and through an MCA the best design was determined. In the first design, the netting and the buoys are submerged at the same time by pulling the corners of the netting module to the buoys. For the second design, pulleys need to be installed in the seafloor, from which lines can be winched in to get the netting module at the desired depth. The third design is similar to the first design, however, it is mechanically less simple. After comparison of the three designs through the MCA, the first design is chosen to be further elaborated on in this research. Points where this design excelled were: mechanical simplicity, durability, environmental impact and time consummation.

The second question reads: **“How to lock the system in place at the desired position, without the use of divers or work class ROVs?”** For this subject again, three so-called self-locking mechanisms were designed and through an MCA the best design was determined. The first design, called the rope clamp, is similar to a cable tie. This system is integrated in a buoy where a rope can be pulled in one direction, while it prevents movement in the other direction. A downside of this mechanism is the fact that the teeth can fray the rope and cannot endure enough friction. The second design is called the latch lock system and is inspired by door latch mechanisms. A male part will slide in a female part where spring loaded latches snap in the slots of the male part. The last design also consists of a male and female part, and is called the snap fastener. The male part slides into the opening of the female part, which bents open and closes as the male part slides through. Movement in the opposite direction is now blocked since the female part cannot bend the other way. From the three designs, the rope clamp system scored the best. However, due to local deficiencies, only steel manufacturers were present in Lüderitz. Therefore, the latch lock system is used in this report.

The third and final question is: **"How can the operations team continue the installation, after they have been absent from the installation site for an indefinite period?"** To answer this question, one must look at the design of an installed netting structure with the latch lock system integrated. A picture of this system is given below in figure 12.1

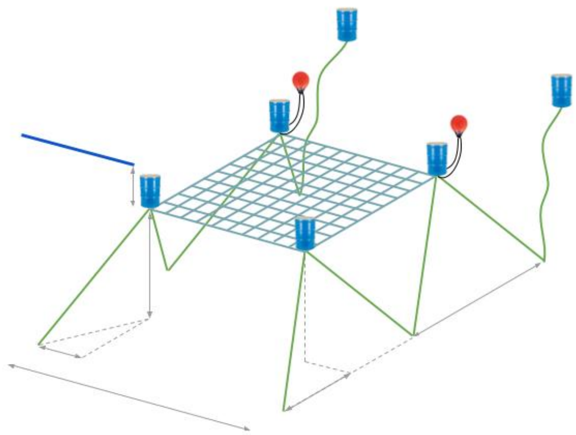


Figure 12.1: The installed phase of one netting module

As can be seen in the figure above, the netting module is now installed at the right depth, while four buoys float on the water surface. Underneath the bigger blue buoys, there are two locking systems assembled for two netting modules. The bigger buoys floating on the water surface will be connected to new anchors and brought under certain tension. Two corners of the new netting module will be connected to lines on the red buoys. These lines go through one of the locking mechanisms, so that the new netting module can be connected to the installed one. Subsequently, the other two corners will be connected with a line to the bigger buoys. After pulling the corners of the netting module through the locking mechanisms underneath the buoys, the two netting modules are installed at the desired depth.

To conclude, the designed installation method with the latch lock system meets the requirements of the main question of this report. The system is the first of its kind. A common practice with prototyping, the real flaws and areas for improvement become apparent only after testing the prototypes and systems. Unfortunately, due to time restrictions and local deficiencies, the whole system could not be tested. On the other hand, the latch lock system itself has been tested on some but not all parameters. Pulling the male into the female part from the water surface went perfectly. However, the strength of the latch lock system could not be tested due to anchor defects. Therefore, more tests should be conducted to determine the performance of the whole system. These topics will be covered in the next chapter.

12.2. Discussion and recommendations

In this chapter, uncertainties regarding the performed research, the performed tests, and future choices for Kelp Blue will be addressed. Eliminating specific uncertainties in further research should be done where possible. Other uncertainties can only be resolved by conducting more tests and putting the system into operation. Therefore, discussion points as well as recommendations are included in this chapter.

Passive variation of latch-lock system
As stated many times before, due to various reasons, it was chosen to prototype the latch lock system as a self-locking mechanism. Although tests show it works as desired, it is still recommended to do more research into other possibilities. Since the rope clamp system scored the best in the MCA, a combination of the rope clamp and latch-lock system is a promising option. This combines a male and female part with a passive locking mechanism. As a male part slides through the bendable female part, it locks itself in place. This eliminates moving parts from the system, lowering the likelihood of failure as well as material and assembly costs.

Long-term corrosion of metal parts
During this project, the latch lock system was manufactured in Luderitz. The design was successfully built after a couple of weeks. The only problem is that it is fully made out of steel. When exposed to seawater, this can corrode, in particular for such a long time.
There are two solutions for this problem. The first one is to create a non-corroding version of the latch lock system. For example, plastic will not rust under water. Another solution to the rust problem could be a closed shaft around the latch lock system, preventing water from entering the system and thus rusting. But to make something really waterproof, a much more professional company than Kraatz should be used.

Helix anchors design and installation
As displayed in chapter 10, the designed helix anchor failed to install properly. In addition, an installation on the beach showed that the anchor was installable, but still not flawless. A brief analysis showed that this could be due to a number of factors. First, the pitch of the helices was not constant and had large thicknesses, making installation more difficult. Second, no bottom or soil survey had been done at the installation site in Shearwater Bay. The divers may have been trying to install the anchor on a stiff or solid section. Third, the tube into which the helices were attached was hollow without a dense tip, which may also be a cause of problems. Fourth, the divers that were installing the anchor didn't have enough weight on their weight belts to put vertical force on the anchor. Therefore, it is recommended for Kelp Blue to do more research on helix anchors to come up with a new design and produce one that is easy to install for divers underwater.

Guiding form of female part

The latch lock system is now designed so that the rope is pulled through the female part until the male part is stuck in the female part. The female part will be attached to the bottom of the buoy, and therefore it will be perpendicular to the surface and to the direction of pulling the rope. This is illustrated in the following picture.

Figure 12.2: The opening of the female part where it guides the male part through

Due to the relatively sharp metal, the rope can fray due to movements induced by waves and eventually break. A solution for this problem could be designing some sort of mall that guides the rope through the female part without fraying.

Helical anchor installation framework

For the placement of helical anchors, a framework was designed to outline all the anchors with the correct dimensions. During the assembly and procurement of the installation procedure, it has proven difficult to successfully reach the precise placement of the anchors. This method relies on the eyes of those installing and, subsequently, the exact placement of the blocks. Relying on human factors has proven difficult in harsh environments like the sea. Since the exact placement is of great importance to the functioning of the whole system, designing a different or improved installation method can be a solution to certain problems. The anchors can be placed using precise but expensive GPS positioning systems. Second, tightness in the ropes of the framework above water ensures that the system is no longer dependent on the human eye. Pulling on four ropes at each corner of the system ensures its tightness. However, this method requires two more boats, which aren't available yet.

The use of divers for maintenance

The boundary conditions and assumptions for this project state that the maintenance part of the project should not be considered. Once the grid structure is installed at depth, it will not be retrievable without the use of divers. Therefore, Kelp Blue should prepare a maintenance plan that includes maintenance of the entire system as well as its specific components. To perform maintenance on the system at this point, divers will be required. If this goes against the guidelines of kelp blue, improvements must be made to the individual components in the design so that locked mechanisms can be unlocked and retrieved through more lines and buoys floating in the water.

Part II

Sustainable Energy

13

Analysis of environmental situation

13.1. Climate

Namibia's climate is described as hot and dry throughout the year (*Climate Change Knowledge Portal*, 2022). Over 90% of the country is classified as a form of arid. Average rainfall across the country covers about 285 mm. Average temperatures range from 16°C on the coast to 22°C inland.

From December to March, it is hot in the country, with the rainy season starting in January. During autumn, April and May, it can still rain and temperatures slowly start to drop. From June to August it is winter in Namibia, it stops raining in most regions, the days are moderately warm and the nights are very cold. In September there's a very brief spring in which the temperatures slowly start to rise. In October and November the temperatures rise again, and it begins to rain lightly, this is also called the minor rainy season. The summer lasts from October till March.

Namibia has three topographically and climatically distinct zones. These include the flat plains of the Caprivi strip and the Otavi mountains in the northern part of Namibia where it is most humid in the country. The low-lying and coastal Namib desert covers the western flank of the country with hot and dry conditions throughout the year; the Kalahari desert merges with the Namib in the central and south-western part of the country. The Namibian Highlands run through the middle of the country, through the capital Windhoek and these areas are generally a bit cooler during the year.

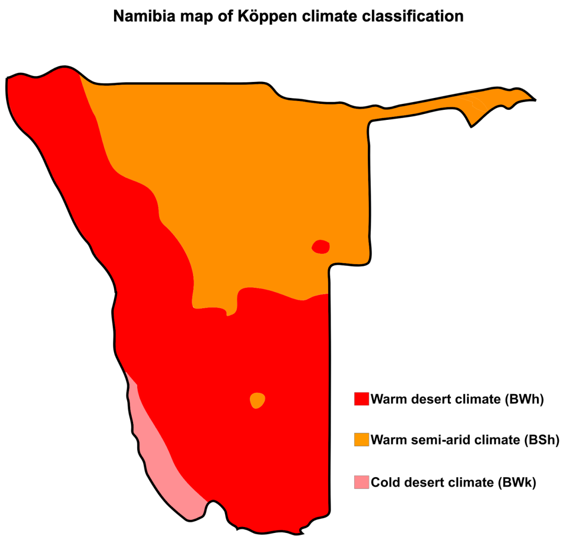


Figure 13.1: Köppen climate classification of Namibia

Lüderitz has a BWk desert climate with moderate temperatures throughout the year. The average precipitation is 17 millimetres and due to the South Atlantic current flowing along the coast, very windy and cold conditions can occur.

13.2. Solar Presence in Namibia and Lüderitz

The sun plays a major role in Namibia's climate, particularly in the dry and dusty regions such as Lüderitz. This section will explore various meteorological phenomena related to the sun in Namibia, starting with irradiance. The importance of the sun's height and hours will also be examined. Finally, the effect of the sun on temperatures in Namibia and Lüderitz will be discussed.

13.2.1. Irradiance

Namibia is known for its desert and savannah landscapes, which indicates that the solar irradiance in the country is above average. In fact, Namibia has the second highest solar radiation regime in the world, with a direct normal irradiation (DNI) ranging from 5.97-8.61 kWh/m^2 per day (*Global Solar Atlas*, 2022). This is due to Namibia's location within the Tropic of Capricorn, which allows for more solar radiation to reach the earth's surface compared to the average for the planet. Namibia receives approximately twice the amount of irradiance as the Netherlands (1000 kWh/m^2), with an average of 2319 kWh/m^2 per year. Solar radiation, or the amount of solar energy entering the earth's atmosphere at a particular location, can be converted into the amount of energy that can be produced over a specific period of time.

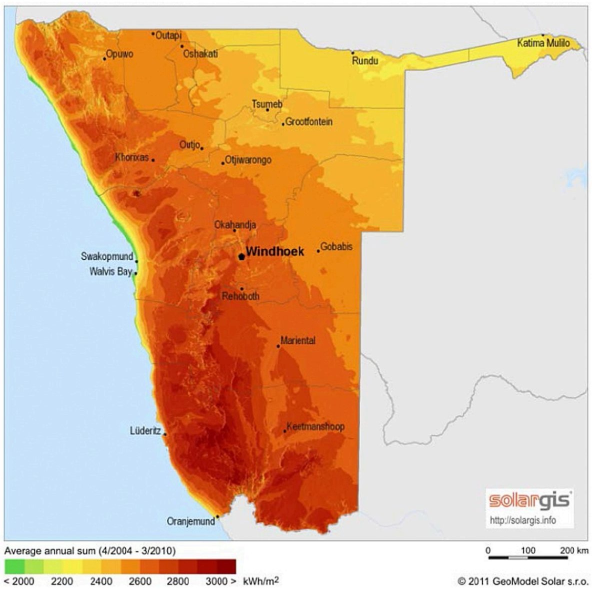


Figure 13.2: Irradiation map of Namibia (*Global Solar Atlas*, 2022)

As seen in Figure 13.2, Namibia's direct normal irradiation (DNI) is higher in the southern region compared to the north. There is a slight decrease in irradiance along the coastline, which may be due to the presence of clouds often found near shorelines. It's worth noting that the intensity of radiation is also seasonal, with the highest levels occurring during the summer months of October to March.

13.2.2. Solar Altitude

The height of the Sun, also indicated as the solar altitude, which is expressed in degrees, is the sun's angle with respect to the horizon of the Earth. In latitudes close to the equator, the height is zero at dawn and sunset and can be as high as 90 degrees during midday.

The distance that the radiation must travel through the atmosphere before reaching the earth's surface is determined by the sun's altitude, which influences the power of the irradiation at a specific location. Meteonorm simulates data on the solar altitude for every hour of the day over a full year. This data is used to determine the amount of irradiance at a specific area and its effect on the shape of shadowing. Figure 13.3 shows the solar elevation angles for Lüderitz and Delft.

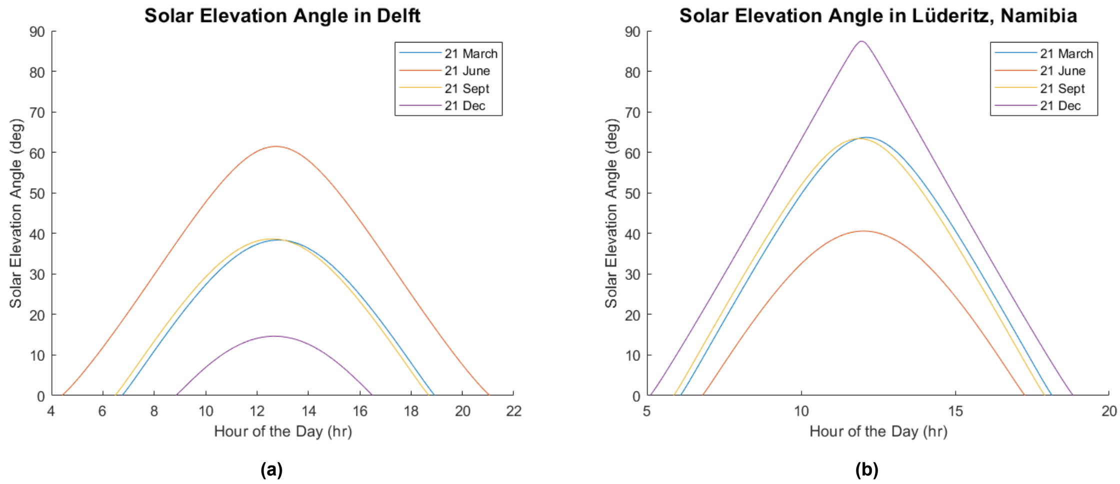


Figure 13.3: Solar Elevation Angle for different dates at (a) Delft, the Netherlands and (b) Lüderitz, Namibia

It can be seen that there is a difference in the solar elevation between the two locations. The highest position of the sun in Delft is around 60 degrees, which occurs on June 21st. When comparing the altitude of the sun in Lüderitz to Delft, it is clear that the angle of the sun relative to the earth's surface is much higher on average in Lüderitz. The high altitude of the sun is a major factor in the high levels of irradiance in Namibia. To design effective renewable energy systems, it is important to understand the path of the sun in Lüderitz.

The maximum height of the sun over a full year can be measured and displayed in a graph, as shown in Figure 13.4 for Lüderitz. The maximum altitude of the sun reaches 83.7 degrees in December, while the lowest maximum altitude on a single day is 39.4 degrees in June.

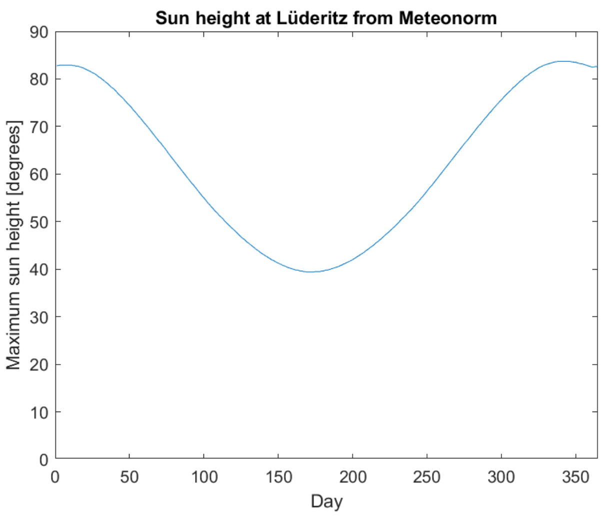


Figure 13.4: Sun height - Lüderitz, Namibia

13.2.3. Sun Hours

The amount of Sun hours is an important factor that influences irradiance. Lüderitz has a low cloud coverage, resulting in a significant number of Sun hours. Figure 13.5 shows the average number of Sun hours per week in Lüderitz.

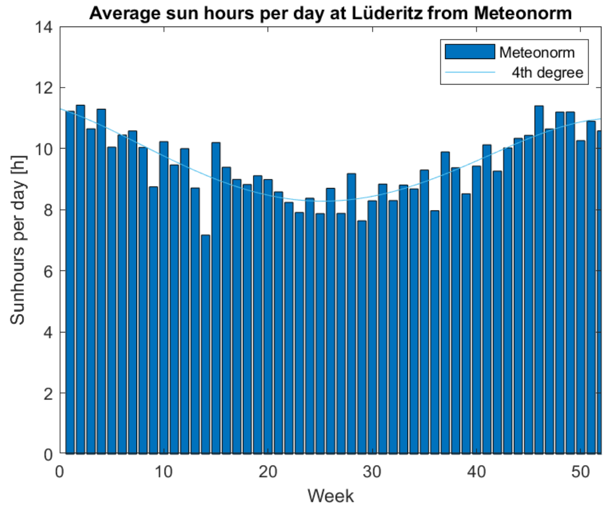


Figure 13.5: Average sun hours at Lüderitz, Namibia

According to the chart, the average number of Sun hours ranges from 7.4 to 11.4 hours and is related to the sun's height (as described in subsection 13.2.2). The data from Meteonorm shows minimal fluctuations, suggesting that the amount of solar radiation is stable. A fourth degree polynomial curve was fitted to the data, which had an r^2 value of 0.7351, indicating a strong correlation. This suggests that the fluctuations are not significant and the Sun hours follow the seasonal trend. The decrease in Sun hours from April to September may be due to the shorter days in winter. Overall, Lüderitz can be characterized as an extremely sunny town with an average of 9.4 hours of sunshine per day.

13.3. Temperature

The Sun also plays a role in determining the temperature experienced on Earth. Temperature is greatly influenced by latitude, and Lüderitz, located at a latitude of -26° 38' 53.02", experiences a range of temperatures. Figure 13.6 displays the temperature recorded at the Diaz Point Weather Station in Lüderitz from 2020 to 2021. These temperature readings differ significantly from the data provided by Meteonorm.

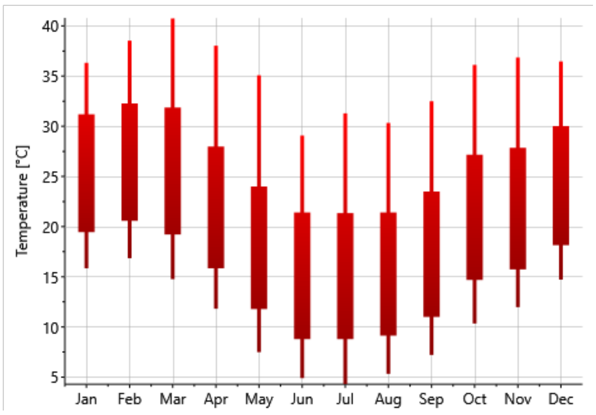


Figure 13.6: Temperature at Lüderitz, Namibia

Meteonorm provides estimates of climate data from the nearest weather stations, and it is important to consider the environment in which an energy system will operate when making recommendations for a system that will last for 25 years. Therefore, it was decided to use the Meteonorm data rather than the data from the two-year period at the Diaz Point Weather Station, as it may not accurately represent the average climate conditions over 25 years.

13.4. Wind

Lüderitz is known for the constant presence of high wind speeds. Since 2007, the Lüderitz Speed Challenge has been held where windsurfers reach speeds of 100 km/h. In this section, the wind speed and wind direction during the year and its statistical analysis are described.

13.4.1. Wind speed and direction

Wind speed and direction were measured using an anemometer attached to a weather station located at Diaz Point (26°37'58" S; 15°5'36" E), visible in Figure 13.7. The data is provided in hourly format and covers the period between 1 January 2020 and 28 July 2022. In addition to wind speed and direction, this dataset also includes atmospheric pressure and temperature.

Figure 13.7: The weatherstation at Diaz Point

The wind in Lüderitz originates due to two primary sources: The first primary source is cold front systems that originate from around 40-60 degrees south. Figure 13.8 provides a schematic example of such a low-pressure system that is always associated with a cold front. The proximity of the isobars generates high winds (directed parallel to the isobars due to the Coriolis effect – with deflection to the left in the southern hemisphere) that can blow over a significant fetch, often for days.

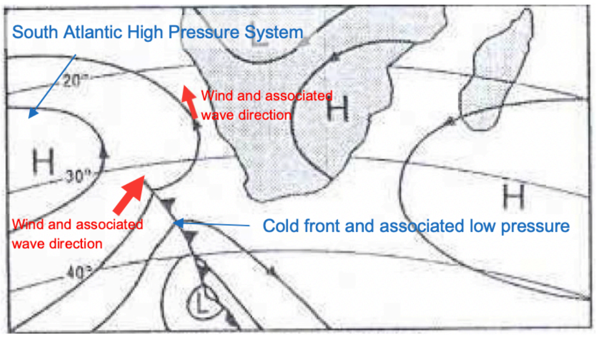


Figure 13.8: South Atlantic High-Pressure system

The second source of wind is attributed to the South Atlantic High-Pressure system. This high pressure cell is part of the discontinuous high pressure belt that circles the southern hemisphere at about 300° south with associated anticyclonic air flow. Wind is intensified in the Lüderitz region due to "the juxtaposition of this system with the continental heat-induced low pressure system over the land" (Peard, 2007). In addition, the land mass at Lüderitz extends westwards of the mean coastline orientation, thus being more exposed to the influence of the South Atlantic High Pressure system (Peard, 2007). Limited seasonal change is evident, with Spring and Summer winds only slightly stronger.

The South Atlantic High Pressure Cell shifts further south in summer. In combination with greater heat-induced low pressures over the land, this results in more intense southerly winds during this season. Conversely, the South Atlantic High Pressure Cell shifts northwards in winter allowing the frontal systems to shift northwards. The increased proximity to the African land mass results in intensified frontally generated wave action on the west coast shores. The more northerly position of the South Atlantic High Pressure system together with reduced continental land mass heating – results in slightly less intense winds from this source during winter. Figure 13.9 depicts the directional distribution of wind speed (wind rose) constructed using the data from the weather station at Diaz Point.

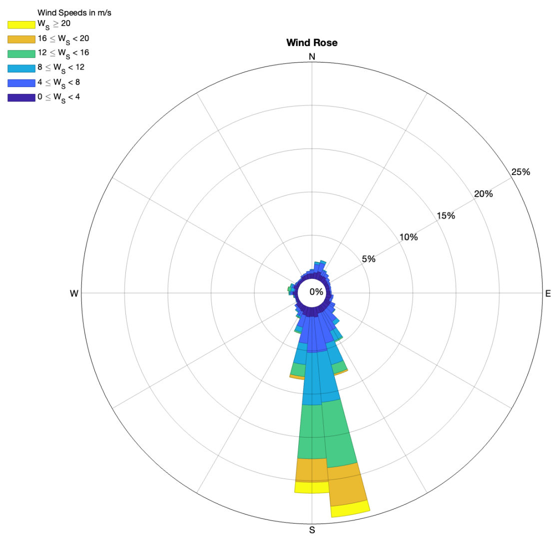


Figure 13.9: Wind rose at Diaz Point, Lüderitz

As shown, the offshore wind climate is dominated by winds from the southern direction. As the data was processed into daily and monthly averages, this along with the maximum speed and the spread of these speeds is shown in a box plot in Figure 13.10.

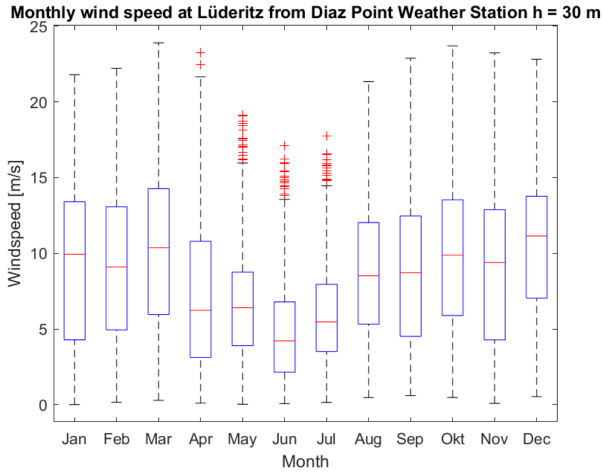


Figure 13.10: Division of wind speeds per month

One can see that the average wind speed varies between seasons, as mentioned earlier. It can be seen that in summer, October to March, it blows a bit harder with averages around 10 m/s. In the winter months of June to August, these averages are significantly lower.

13.4.2. Statistical analysis

To properly use the data obtained, it must be analysed statistically. That way, wind speed can be used to scale the estimated generation. The data was obtained from the weather station and these were then converted into histograms, showing which wind speed came from which wind direction how often. Then it was decided which method to use in this study, here it is a Weibull graph by visual fit.

A Weibull curve is a graph that translates a histogram into a probability density function. This function has two parameters, namely the shape parameter k and the scale parameter a. By varying these parameters, a curve is found that matches the histograms.

For wind distribution at 30 metres, the following parameters were established: the shape factor k equals 1.8 and the scale factor a equals 9.5. Furthermore, the average wind speed equals 7.94 m/s. These factors yield the following probability density function in Equation 13.1 and the cumulative distribution function in Equation 13.2

$$f(U) = \frac{k}{a}(\frac{U}{a})^{k-1}e^{-(\frac{U}{a})^k} \tag{13.1}$$

$$F(U) = 1 - e^{-(\frac{U}{a})^k}(= \int_0^U f(U')dU') \tag{13.2}$$

For both Equations is true that k is the shape parameter and a the scale parameter, f(U)dU is the probability that the wind speed occurs in the range (bin) dU and that F(U) is the probability that the wind speed is below U.

To make this data workable for scaling a wind turbine, wind shear is important. The surface roughness length indicates how much friction there is between the wind and the earth's surface. It has been calculated for Lüderitz that this coefficient is 0.0643. Using the following Equation 13.3 , the wind data can be extrapolated to the requested altitude and thus construct a Weibull distribution in the same way.

$$U(h) = U(h_{ref})\frac{ln(h/z_0)}{ln(h_{ref}/z_0)} \tag{13.3}$$

In this formula, h_{ref} is the reference height at which the wind speed is known, z_0 is the surface roughness length and h is the height at which the wind speed U is to be known.

These figures will be used in the SAM software and Excel dashboard to scale the appropriate wind turbine for the scope of this report.

13.5. Precipitation

The Benguela current, a cold ocean current offshore, and the dominant winds are the key factors affecting the pattern of rainfall (western and eastern winds). The average annual precipitation in Luderitz is around 50 mm, with variations between 15 to 17 mm. Most of it falls during the winter months between May and September. This amount of rainfall is relatively low compared to other parts of Namibia, and the town is prone to drought. Luderitz occasionally experiences strong storms and thunderstorms, which can bring heavy rainfall and strong winds. However, these events are not common and do not significantly impact the overall low levels of precipitation in the area.The majority of Namibia's rainfall is brought by cold fronts that originate from the Cape throughout the winter. Because of this, succulents, which are also adapted to the foggy circumstances, predominate in the vegetation.

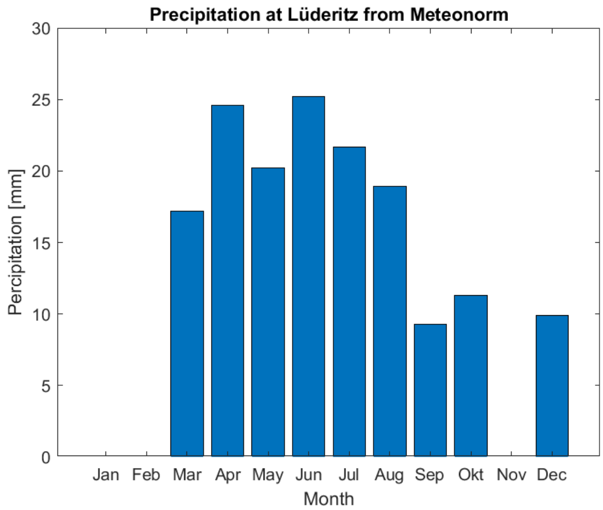


Figure 13.11: Precipitation at Lüderitz, Namibia

13.6. Ocean

13.6.1. Currents

The currents prevailing at Lüderitz are a consequence of large-scale oceanic circulations (Benguela Current), wind-driven flows over the continental shelf (as described in subsection 13.4.1) and, to a much lesser extent, tidal currents. It is only in the nearshore, specifically the surf-zone and just beyond, where wave-driven currents predominate. The Benguela Current is characterised as one of the coldest currents with strong coastal upwelling and high plankton production. It moves northward about 100 km from the coast, bringing Antarctic waters to subtropical regions. The current moves parallel to the coast at a speed varying between 10 and 30 cm per second, depending on the offshore location, wind direction and speed and the time of year. During the upwelling process, surface water is moved to the offshore direction by the effects of prevailing equatorial winds and the Coriolis force. Water from the nutrient-rich soil rises to the surface near the coast, creating an ideal environment for giant kelp to grow. This process is shown in Figure 13.12.

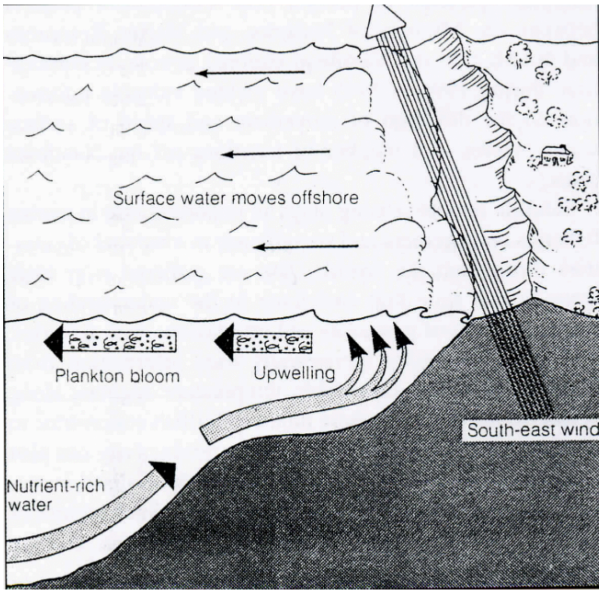


Figure 13.12: Ocean flow process

13.6.2. Water levels

Water levels at Lüderitz are primarily driven by tidal influences, with wind- and atmospheric pressure-driven variations occurring at times. The tidal levels, as obtained from the Lüderitz harbour, are as indicated in Table 13.1 below as delivered by the local harbor authorities.

Table 13.1: Water levels

Tide level	Value [m MSL]
Highest Astronomical Tide	0.935
Mean High Water Springs	0.595
Mean High Water Neaps	0.165
Mean Sea Level Datum	0
Mean Low Water Neaps	-0.115
Mean Low Water Springs	-0.405
Lowest Astronomical Tide	-0.825

13.6.3. Temperature

From the first descriptions of the Benguela current, it has been described as a cold current. This is in line with measurements made by *Seatemperature.net*, where water temperatures are measured over the years. The results of this can be seen in Figure 13.13. In this figure, the blue line represents the minimum temperature, the red line is the maximum temperature, and the yellow line is the average temperature, respectively.

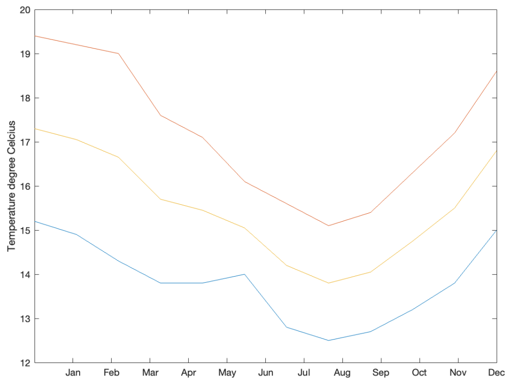
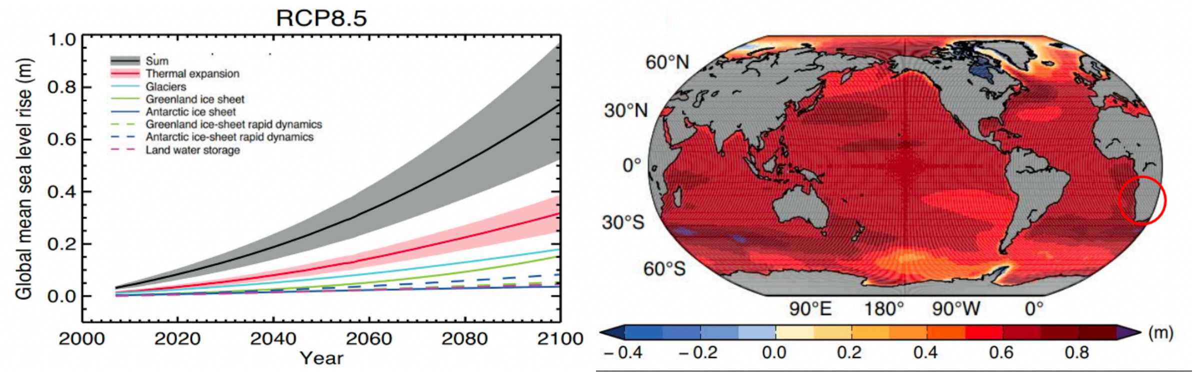


Figure 13.13: Water temperature

13.6.4. Ocean level rise

As described in the fifth Assessment Report (AR5) of the Intergovernmental Panel on Climate Change (IPCC, 2021), global warming and climatic change processes are well observed. Global mean surface air temperatures over land and oceans have increased over the last 100 years , and as a result, the sea level is increasing.

Estimated sea level rise is based on the AR5 report (IPCC, 2021) in which sea level changes were evaluated for a number of climate change scenarios, referred to as the Representative Concentration Pathway (RCP) scenarios, with each scenario accounting for relevant climate change impact factors such as greenhouse gases, carbon dioxide and the melting of ice sheets. Four scenarios were investigated, namely the RCP2.6, RCP4.5, RCP6.0 and RCP8.5 (the numbers after RCP refer to radiative forcing in W/m^2). RCP 8.5 is the most conservative of these scenarios, and represents the status quo or "do-nothing" scenario in terms of global interference. As such this is the recommended option for coastal projects. The predicted sea level rise for this scenario is shown in Figure 13.14a.



(a) (b)

Figure 13.14: Sea level rise scenario RCP8.5

Figure 13.14b provides some idea of regional variation in sea-level rise it may be noted, from the colour scale that the predicted sea level rise (from the baseline period near the turn of the century is 0.7 to 0.8, which concurs with the global predictions as per Figure 13.14. In other words, the sea-level rise at Lüderitz is similar to the global average.

13.7. Location Survey

In this section, the different locations of Kelp Blue's properties in Lüderitz, Namibia are described.First the building of the office space will be analysed which will be followed by the processing facility.

Lüderitz is located at latitude -26° 38' 53.02" S and longitude 15° 09' 33.98" E. It is important to have a thorough understanding of Kelp Blue's properties in order to assess and design their water and energy systems. The Bodikenhaus office building and the Lalandii workshop (which is the future site of the processing facility) are the two main properties that will be discussed in this chapter.

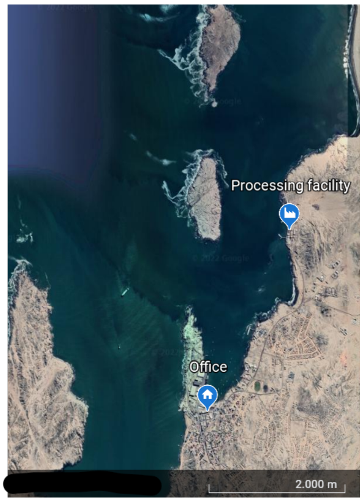


Figure 13.15: Location of the assets of Kelp Blue in Lüderitz

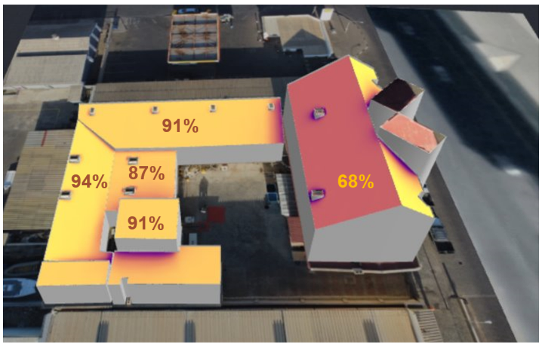
13.7.1. Bodikenhaus - Kelp Blue office

The office is located at 218 Hafen St, Lüderitz and serves as Kelp Blue's headquarters for their operations in Namibia. The building has two floors and an attic. The boardroom is located on the first floor, where the various work streams are located. Kelp Blue is currently expanding on the ground floor, which is being renovated, in order to increase their utilities. The management team anticipates that this will provide the necessary capacity to conduct all activities in Namibia for the foreseeable future. Figure 13.16 shows the front view of the Bodikenhaus, which was built in 1912. The building has a private courtyard that serves as a parking area for business vehicles. The operating hangar (OPS) and the kelp growing laboratory are located next to the courtyard, as shown in Figure 13.17a. The roof on the right is used by a butchery.

Figure 13.16: Front view of the Bodikenhaus

A compass was used to determine the azimuth of the front of the building, which is 275 degrees. Without access to blueprints, the dimensions of the building, including the roof, were determined using measuring devices. This information was used to create an irradiance map for a potential photovoltaic system, as shown in Figure 13.17b, using SolarEdge software.

(a) Overview of office areas



(b) Irradiation map of office spaces

Figure 13.17: Overview of 218 Hafen St, Lüderitz

Unfortunately, the main building's roof was constructed using asbestos, making it dangerous to install a solar system there. Therefore, the roof must be replaced with a material that can withstand the forces imposed during the installation of a solar system.

13.7.2. Processing Site - Lalandii Workshop

Kelp Blue is currently busy with the final agreements on renting a space for their to be built processing site for the processing of their harvested giant kelp into biostimulants. This site will have an estimated maximum processing yield of 20 ha giant kelp per month. In order to process all the kelp into biostimulants, it has to undergo a manufacturing process with a high energy demand. The utilities that will be installed have a cumulative maximum load capacity of 119.3 kW. This process will be the major electricity demanding process of Kelp Blue. Because Kelp Blue's mission is to decrease the amount of carbon dioxide out of the atmosphere, they are looking into renewable energy generating solutions to run the processing plant on.

The structure is made out of a steel frame, a concrete exterior and a fibre cement roof. The 380 m^2 interior floor space is broken down into 2 processing facilities, a lab, a cool room, and working space. The roof has a crest in the centre of the long side and a 25 degree slope. There are several vacant warehouses and workshops all around the structure. It was once the Pescanova fisheries workshop, but overfishing has rendered it obsolete. Figure 13.18 shows the different warehouses which are part of the workshop.

Figure 13.18: Overview different buildings of Lalandii workshop

The numbers indicate the different options for the location of the photovoltaic system:

1. Biostimulant production warehouse of Kelp Blue
2. Extra space that is currently empty and not in use, close to the biostimulant production.
3. Empty warehouse facing north
4. Empty warehouse facing north
5. Storage space for the devices used in Lalandii workshop
6. Ground area (not owned by Pescanova)

Warehouse 5 is not suitable due to weak strength of the building and is therefore excluded. The other warehouses needs to be analysed by an engineering company in order to make sure that the roof can bear the forces applied on the roof by the energy system.

The structure is located near to Lüderitz's harbour in a coastal area on the coastline. It is very accessible by both ship and car. Transporting items into and out of the facility is simple because of the sizable area in front of the building's entrance. The warehouse roof's backside and the seaside have azimuths of 85 and 265 degrees, respectively.

Figure 13.19: The Lalandii workshop from the sea

A more detailed view of the processing center and it’s operations and devices that are used in the biostimulants production can be found in section B.3

14

Analysis of Namibian Governmental and Social Situation

This chapter discusses the current governmental and social situation in Namibia, including an overview of the energy climate, key parties, the functioning of the energy sector, and relevant legislation.

14.1. Overview of Energy Climate

Namibia generates approximately 34.3% of its own energy needs at the Ruacana hydropower station, located in the north of the country. However, low energy yield from this station due to drought means that Namibia must also rely on other sources of energy. These include local generation from 135 MW solar parks, a 5 MW wind park, 145 MW from coal power plants, and imports of 380 MW from the South African Power Pool (SAPP), which is primarily generated by coal plants. This results in a total installed capacity of 632 MW. According to the National Integrated Resource Plan, Namibia's peak energy demand is 673 MW and is expected to increase to 931 MW in 2025 and 1,348 MW in 2030 ("Republic of Namibia Action Plan of the Namibian Government Towards Economic Recovery and Inclusive Growth II 3 HARAMBEE PROSPERITY PLAN II", n.d.).

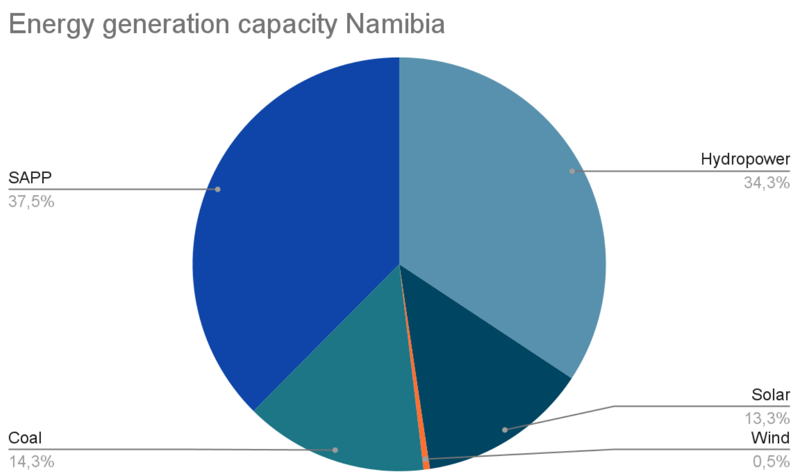


Figure 14.1: Energy generation capacity of Namibia

Despite having a wealth of renewable energy resources, Namibia imports around 60% of its electricity from the SAPP, mainly due to the low energy yield of the Ruacana hydropower plant. The SAPP is the first power pool in Africa and promotes competition in the energy market among southern African countries. It was originally a collaboration among South African electricity suppliers, but now serves multiple countries.

Access to power in Namibia is limited, with only 24.4% of the 544,655 households in the country (249,827 of which are rural) having access to grid, solar, or generator-powered electricity, according to the 2015/16 Namibia Household Income and Expenditure Survey.

The Namibian government has outlined a plan called Vision 2030 to transform the country into an industrialized nation by 2030. A reliable and sustainable electricity supply is necessary for this plan to be successful. To achieve this goal, the government aims to buy surplus electricity from neighboring countries and attract private investors to develop power plant projects, without providing investment funds (Simasiku, 2006).

Independent Power Producers (IPPs) have the opportunity to help fill the gap in sustainable energy generation by building solar and wind parks. These IPPs supplied about 7% of Namibia's annual energy consumption in 2020. The use of renewable energy presents good opportunities for investors, particularly since Namibia has the potential to become the first carbon-zero energy country in Africa due to its surplus capacity for producing green power.

14.1.1. Institutional Framework

This chapter has been constructed using interviews with officials in Namibia and the National Energy Policy (GOVERNMENT OF THE REPUBLIC OFNAMIBIA & ENERGY, 2017).

Stakeholders

The energy sector in Namibia involves four main groups of stakeholders: policymakers, regulators, licensees, and consumers.

14.1.1.1.1 Policymakers The government plays a key role in shaping the energy sector through the creation of laws and regulations that align with national policy. Four ministries in particular are responsible for various aspects of the energy sector in Namibia:

- The Ministry of Mines and Energy (MME) regulates energy and mining resources, and is primarily responsible for rural electrification.
- The Ministry of Environment and Tourism (MET) advances climate change initiatives in Namibia.
- The Ministry of Finance (MoF) provides funding for various projects and initiatives, including those supporting NGOs, SMEs, and local governments.
- The Ministry of Trade and Industry (MTI) has a department focused on attracting Foreign Direct Investment in energy projects in Namibia.

Together, these ministries contribute to the development of the National Energy Policy, which outlines the government's plans and projects to advance the energy sector in Namibia. The most recent published policy is the National IPP Policy of Namibia from 2018.

14.1.1.1.2 Regulators There are several parties with responsibilities in the regulation and operation of the energy sector, including:

- The Electricity Control Board (ECB) was established in 2000 and is responsible for regulating electricity generation, transmission, distribution, supply, import, and export in Namibia through the setting of tariffs and the issuance of licenses.
- The National Technical Committee on Renewable Energy (NTCRE) of the National Standards Institute (NSI) develops norms, standards, and codes of practice for the performance, manufacture, installation, and maintenance of renewable energy technologies.
- The Namibia Investment Centre (NIC) has a major role in attracting Foreign Direct Investment.
- The National Planning Commission is responsible for national planning and ensuring that climate change considerations are properly reflected in sector plans and budget allocations.

14.1.1.1.3 Power Producers Power producers in Namibia can be divided into three categories: on-grid government, on-grid Independent Power Producers (IPPs), and off-grid.

- On-grid government: NamPower is a state-owned enterprise that reports to the MME. It owns and operates most of the country's grid generation and all the transmission assets, as well as some distribution facilities in rural areas of central and southern Namibia. As a system operator and trader, NamPower plays a crucial role in balancing supply and demand and is the contracting party for imports. Regional Electricity Distributors (REDs) are state-owned entities responsible for supplying and distributing electricity in a specific region.
- On-grid IPPs: There are at least 14 IPPs that have been selected under the Namibia Renewable Energy Feed In-Tariff (REFIT) Program.
- Off-grid: There are three mini grids in Namibia, which are autonomous energy systems serving rural areas.

14.1.1.1.4 Private Companies and Research Institutions Several private companies also operate in the energy sector in Namibia, and there are a few research institutions, including the Namibia Energy Institute. Established by the government within the Polytechnic of Namibia in 2006, the institute disseminates research and information about renewable energy projects and programs including addressing barriers to renewable energy development.

14.2. Market Model

14.2.1. Single Buyer Model

Currently, NamPower serves as the sole buyer in Namibia's de facto Single Buyer Model (SBM) and is required to purchase electricity from all Independent Power Producers (IPPs). The current SBM in Namibia is illustrated in Exhibit 2. The National IPP Policy aims to address the shortcomings of the SBM and facilitate the adoption of a market model that is more conducive to the implementation of the policy.

In November 2000, the Cabinet of the Government of the Republic of Namibia adopted a plan for the reform of the Namibian Electricity Supply Industry (ESI). The establishment of a Single Buyer (SB) function within NamPower was a key component of the accepted concept. It was determined that the creation of an SB was the most effective way to oversee power trading agreements and contracts for new electricity investments. In order to more actively participate in Namibia's power market, the government has recognized the need to reevaluate the feasibility of an SB market model for Namibia based on feedback from stakeholders and best practices from around the world for establishing and operating an IPP regime.

Currently, small IPP projects are selling electricity to major energy consumers such as REDs, local governments, and mines within the ESI. The National IPP Policy aims to create a market system in Namibia that allows IPPs to generate and sell energy to specific off-takers other than the SB alone, within the current regulatory framework.

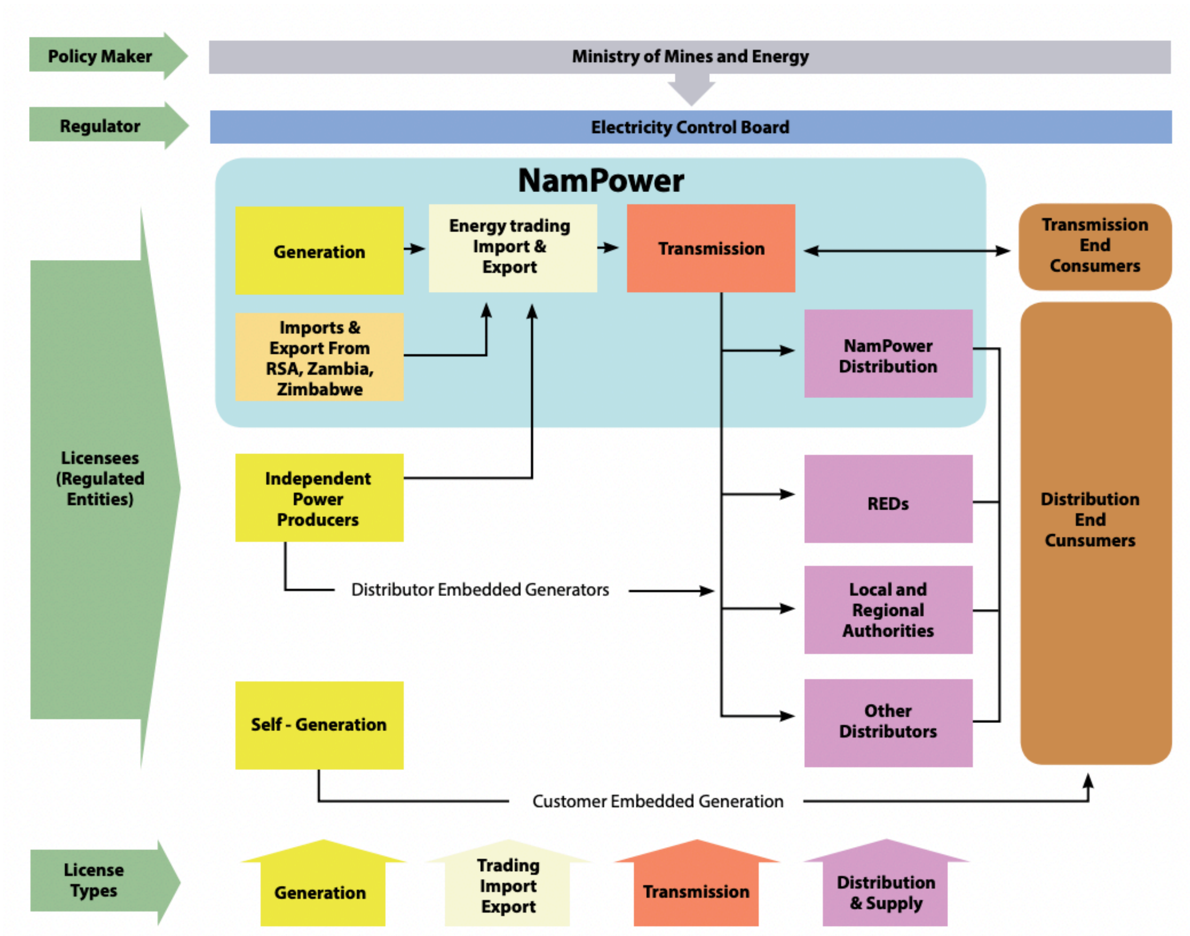


Figure 14.2: Energy framework of Namibia

14.2.2. Modified Single Buyer Model

The Government of the Republic of Namibia plans to modify the market model to allow for a wider range of transactions and power sources in order to better meet future electricity demand and incorporate new technology. These changes are necessary to bring the development of the ESI in Namibia in line with the various types of transactions currently being carried out between IPPs and REDs, including cross-border trade agreements. Under the revised model, such transactions would be officially recognized and generators would have the opportunity to sell directly to REDs and other major clients, rather than being required to sell their production exclusively through NamPower Trading.

The modified Single Buyer Model, facilitated by the National IPP Policy, will allow for competition among IPPs at the supplier level and balanced competition at the off-taker level for NamPower, REDs, municipalities, and major industrial off-takers such as mining.

14.3. Lüderitz Specific Regulations

According to local authorities, national regulations also apply in Lüderitz. In terms of energy generation, they indicated that obtaining a license for a solar panel installation is easier than for a wind turbine due to the more extensive process for obtaining an Environmental Impact Assessment (EIA) for wind turbines.

The local authorities also expressed frustration that local bodies prefer to generate their own energy rather than purchasing it from the Lüderitz Town Council, the local licensee. They see this as a loss of investment money. It is important to consider ways to incentivize local authorities during negotiations, as this can facilitate the process for obtaining larger installation and consumption capacities.

Regarding wind turbine projects near the coast in the region, the present understanding of the flyways of sea and shorebirds points to the minimum distance from the coast that could be safe should be between 2 and 3 km (depending on the shape and orientation of the coast). The present 3 wind turbines in Lüderitz are situated at 2.0, 2.2 and 2.6 km respectively from the nearest shore. Four other sites proposed for this development (on Nautilus Hill) were rejected as they were deemed too close to the shore (two at 0.6 km and 1.4, and 1.5 km respectively). Another turbine was proposed near the shore of the second lagoon at the old power station (Luderitz Waterfront phase two) was also rejected for the same reason.

The coastline is a very important migratory corridor for many sea and shore-birds including Sandwich and Common terns, many species of waders etc. Locally also teals and shellducks using the shores throughout the year. In addition the regional population of flamingos (both Lesser and Greater flamingos) make extensive use of the pan at the back of Agate beach and commute along the shore daily to their feeding sites in Luderitz Bay, and Shearwater Bay. These can count several thousands of birds outside the breeding season. The birds are very important to protect because very special bird species have a significant amount of their world population in and around Lüderitz.

15

Analysis of water system

15.1. Technical specifics

Water for Lüderitz is supplied by NamWater, the state-owned water supplier, and pumped from the Koichab Pan, via a well-field of 9 boreholes. The aquifer below the pan is a fossil reserve, and is therefore recharged at a slow rate. Water is abstracted from 9 boreholes in the Koichab Pan Aquifer and is collected in a reservoir. Water is transferred from the collector reservoir to the Lüderitz terminal reservoir by means of a 120 km long gravity pipeline and 5 Pressure Break Tanks (PBT) along the route. The Koichab area was proposed as early as 1914 as the most suitable source of water supply for the growing town of Lüderitz, however a water supply scheme was only established in 1968. Radiocarbon analyses show that the groundwater in the Koichab River aquifer is fossil water some 5000 - 7000 years old. It is of Group A quality and one of the best waters found in Namibia regarding NamWater.

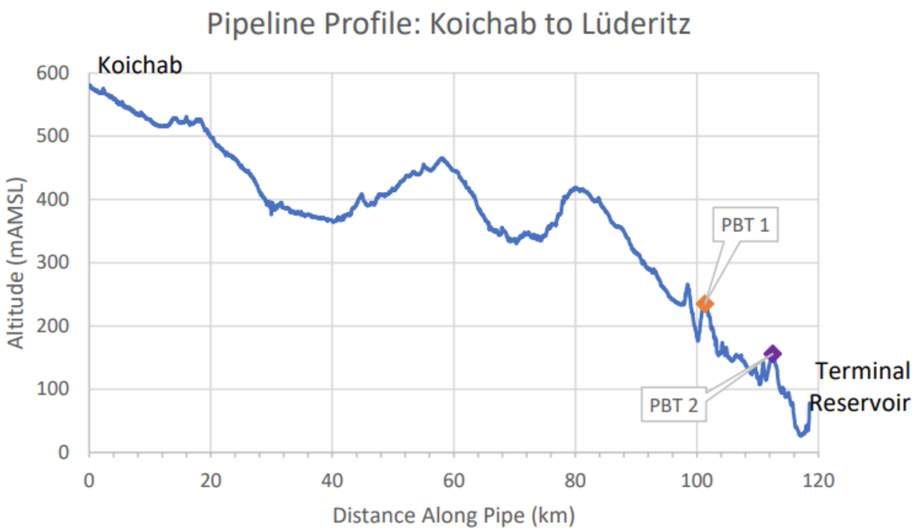


Figure 15.1: Pipeline profile: Koichab to Lüderitz

The sustainable yield of the Koichab Aquifer was estimated at 2m^3 million a year, although hydrologists admit that the aquifer's recharge system is not entirely understood, it is considered that the current abstraction rate is sustainable, but this cannot be guaranteed over the long term. In view of the uncertainty on the sustainable extraction of water from the Koichab Pan, and due to the fact that it is good environmental practice to consider alternative sources of water in a desert environment, alternative solutions will need to be developed over the long term, such as desalination.

In case desalination is an option, additional power needs to be supplied, possibly using a renewable, off-grid technology. Due to the interference of Hyphen Africa, a project that should become the biggest hydrogen plant of the world, the demand for water in Lüderitz would increase significantly. If seawater would be used for the production of hydrogen, chloride ions in seawater would turn into toxic chlorine gas damaging the electrolysers. Hydrogen can only be produced of purified water, so sea water would not be a suitable option unless it is desalinated. To prevent the town from water shortage, the project will also contain a large installation of desalination plants. After conducting numerous interviews with the LTC, they are certain that Lüderitz residents will have access to a plentiful supply of the surplus desalinated water produced by the hydrogen plant, preventing a water scarcity. When developing their processing facility for the production of the biostimulants, Kelp Blue must consider this.

Another factor that should be considered when producing water that is pumped into the water grid, is the quality of water that is supplied. Table 15.1 shows the allowable ranges for the different measuring determinands.

Table 15.1: Water quality parameters

Determinand	Measuring unit	Allowable range
Free chlorine	mg/L	≤ 5
Monochloramine	mg/L	≤ 3
Colour	mg/L Pt-Co	≤ 15
Conductivity	mS/m	≤ 170
Taste and odour	-	Inoffensive
Total dissolved solids	mg/L	≤ 1200
Turbidity	NTU	≤ 1
pH	-	≥ 5 and ≤ 9.7

15.2. Kelp Blue's water demand

The average water usage for Kelp Blue's office is 15 m^3 per month. With Lüderitz's current water infrastructure, this can be simply delivered. In 2022, the price Kelp Blue pays per cubic meter is N$ 37.10. The Namwater water prices can be found in section B.2. If one considers how much water Kelp Blue will use in the future, one comes to the conclusion that the processing facility will be the highest contributor. It is estimated that the water consumption during the processing of giant kelp is 1 to 2 kilograms per kilo giant kelp. The current design of the processing facility can process 500 to 1,000 kg kelp per hour, so a maximum water supply of 2 m^3 per hour is desired. Considering operating hours of 18 hours per day during weekdays, it will have an estimated water demand of 782 m^3 per month. The price corresponding to this amount of water use is N$ 44.19 / m^3 according to section B.2. Luderitz Town Council applies an increase in price per m^3 if consumption goes up.

16

Analysis of energy system

This section follows an analysis of the electricity network in Lüderitz, the types of connection at the various sites and an overview of annual consumption per site.

16.1. Technical specifics

16.1.1. Lüderitz grid

Finding solutions for Kelp Blue requires examining whether Lüderitz's grid is suitable for such connections. In recent years, industry in Lüderitz has declined. Mainly fishing, the city's main industry, is declining. Figure 16.1 obtained from the Lüderitz Town Council shows that the power supplied to the grid has decreased from about 7 MW to about 6.2 MW over the past 10 years. According to the municipality's technical department, the power on the grid used to be towards 9 MW. Furthermore, it was told by this technical department that the grid is able to handle upwards to 15 MW average load. This upgrade has been part of the Structure Plan to accommodate the town with the potential to grow.

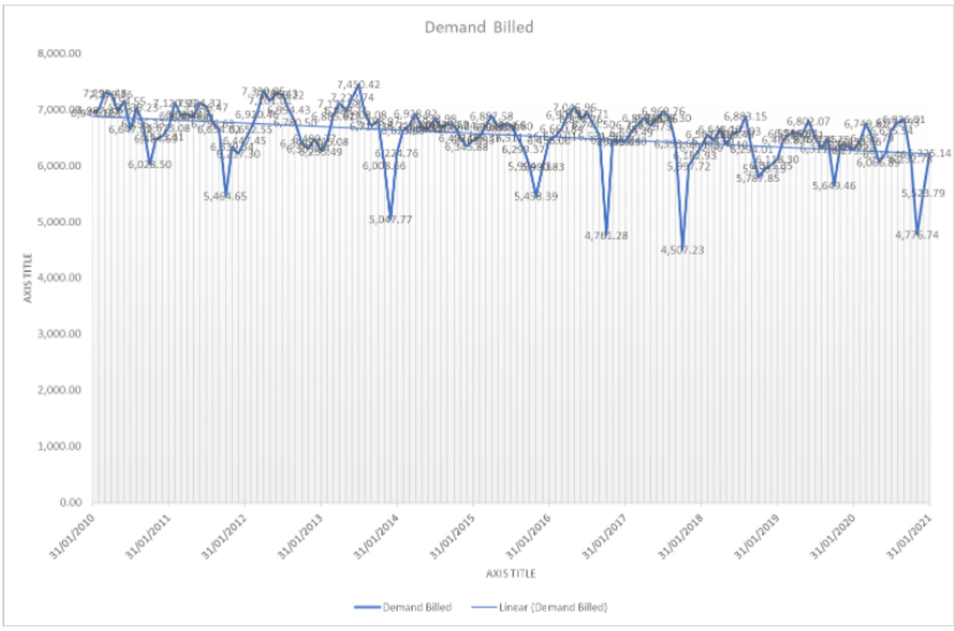


Figure 16.1: Power supplied to grid of Lüderitz

Figure 16.2a shows Lüderitz's network, the red lines represent the 11 kV cables and the yellow lines the branches to mains. In Figure 16.2b another representation of the Lüderitz' grid is shown with its intensity in the branches.

(a) (b)

Figure 16.2: Lüderitz's electricity network

Lüderitz's network is stable. There are minimal power outages, and these are often resolved in a short time. This prevents loss of power from your renewable energy installation. In the recent past, there have been problems with thieves stealing the copper from the wires, but the municipality says this problem has largely been remedied.

It can therefore be concluded that Lüderitz's grid is suitable for the order size of capacity that Kelp Blue and a renewable energy installation entail.

16.1.2. Energy price

The electricity price is set by the ECB. In recent years, this price has increased due to increased demand in Namibia. Last year, the energy price rose by an average of 7.3%.

The energy price to be paid is made up of four components visible in the table below, it also shows the balancing tariff.

Table 16.1: Energy tariffs for 3 phases and more than 25 amps

Energy tariffs	Costs
Energy charge	1.7000 N$/kWh
Capacity charge	25.90 N$/A/month
ECB levy	0.0212 N$/kWh
NEF levy	0.0160 N$/kWh
Feed-in tariff	0.99 N$/kWh

16.1.3. Investments

To power the city in the future as envisioned by the city council, investments will have to be made in the grid. This provides scope for Kelp Blue to be exempted from certain laws when contributing to them. Half of the capital budget portfolio is reserved for non-discretionary tasks, this concerns the baseline guarantee. This includes new urban connections, service provisioning and social obligation projects. The remaining 50% of the budget is reserved for discretionary projects, but includes the following categories: backbone security upgrades ensure a sound platform for future service delivery. Electrification to also connect areas outside built-up areas. Also 15% is reserved for making the current grid operator more efficient in management and operation and finally 5% is invested in support.

For the short term, the budget is said to be N$20M, this will be enough to cover key tasks but will not be enough to fully upgrade the grid to the desired standards. This leaves investment opportunities for private initiatives.

16.2. Kelp Blue energy consumption

To scale the solution correctly, it is important to correctly map energy consumption. That will be done here successively for the Lüderitz office, the pilot processing site and the scaled-up processing site.

16.2.1. Office

At Kelp Blue's office, operations in Namibia are organised. A detailed description of this office can be seen in Figure 13.17a. Operations can be divided into several work streams, these include:

- Environmental monitoring: at this stage of operations, the EM team conducts a baseline survey on the characterisation of the water where the farm is going to be located, nutrients, biodiversity, etc. When the commercial farms are set up, the team will focus on doing the same measurements to see the exact effect of large-scale giant kelp farming.
- Biosystems: develops the kelp from cells to full-fledged kelp for planting in the water, while biosystems also monitors the growth and quality of the kelp when it is in the water.
- Engineering: designs the farm, array structure and engineers various solutions to the practical problems that arise when one wants to farm on water.
- Processing: responsible for harvesting the kelp and successive processing into the various possible end products
- Operational: several employees are involved in operational activities. These include divers, welders, mechanics, etc.

When calculating consumption, the number of people using computers was estimated as this is an important factor of consumption. It was estimated after interviews that this is currently 10 people, growing to 25 in five years.

It is difficult to obtain data on energy consumption in Lüderitz. Pre-paid installations are partly used, and there is also a lot of confusion at Luderitz Town Council about the various connections around the site. As such, it was decided to reject the data and estimate consumption in the office. Office consumption is split between the office itself and all its supplies: lights, computers, refrigerator, etc. And the laboratory, where the kelp is grown. Also taking into account the growth of the business, the overview shows that an estimate is made of the current situation, and the situation in five years' time. The table below shows the consumption of the office without the laboratory.

Table 16.2: Office energy consumption without laboratory

Situation	Peak power [kW]	Energy consumption [MWh/year]
Current	9.4	10.9
Future (five years)	12.2	17.3

The comprehensive overview of office consumption can be seen in Table B.2. The laboratory is a high consumer of power. This is because it needs to be constantly 10 Celsius for the kelp to survive. Currently, a refrigerated container is being used, but soon we will move to a laboratory in the building to create more space.

$$I_{total} = I_{phase}\sqrt{n_{phases}} \tag{16.1}$$

This container operates with three phases; several measurements show that these phases have consecutive currents of 7.0, 7.2 and 7.1 Ampere. According to the Equation 18.1 above, this yields a total current of 12.3 A. Multiplying by the measured voltage of 382 V gives a total power of about 4.7 kW. When finally multiplying this by the total running hours, in this case all hours of the year, we obtain an energy consumption of 41 MWh. To create more space for the expansion of the lab, a new lab is being set up. It consists mainly of air conditioning units, a compressor and industrial blowers. The total current here is 20.5 A at a voltage of 220 V, when multiplied as just done, this amounts to a power of 4.5 kW and an annual energy consumption of 40 MWh, fairly similar to the current lab.

16.2.2. Processing site

To process the kelp into products such as biostimulants, a processing site is used. At this stage of the company's growth, a pilot processing site will be opened first. When the kelp farms are scaled up over time, the processing site will expand to full size.

First, we consider the pilot processing site. The location of this site is described in subsection 13.7.2. This plant will be set up to process about 1000 kilogram of giant kelp per hour. Processing this kelp consumes a lot of energy, the processing diagram showing the consumption of different devices is visible in Figure B.3.

A summary of the various processes is as follows: washing integrated with the conveyor belts, mincing, mechanical extraction, solid/liquid separation, liquid filtration and optionally an RO system in place.

It is assumed the processing sites will run 260 days a year, on weekends the site will not operate. The days when the site is running, it will be in operation 24 hours a day. 18 hours a day will be biostimulant, 4 hours will be cleaning and 2 hours will be maintenance. The different energy consumptions for these processes are 100%, 20% and 0% respectively.

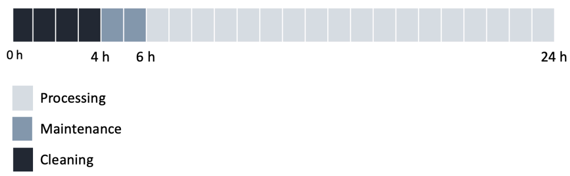


Figure 16.3: Different stages of operation

Of the other consumers, it is assumed that the cold storage does run all the time and that lights and computers are only used during working hours.

Table 16.3: Processing site energy consumption

Situation	Peak power [kW]	Energy consumption [GWh/year]
Pilot site	100	0.49
Full scale	1800	8.8

17 Analysis of carbon emissions

In this section the carbon emissions of Kelp Blue's operations will be discussed. First the point of view of Kelp Blue regarding carbon emissions will be stated. Second, the operations of Kelp Blue and their energy infrastructure is explained. This is followed by the emissions and reductions of Kelp Blue's operations. Afterwards the reduction possibilities of Kelp Blue will be discussed.

17.1. Carbon emissions Kelp Blue

The mission statement of Kelp Blue is to plant kelp to boost the health of the oceans and lock away CO_2 forever. This indicates the importance of Kelp Blue to reduce as much carbon out of the atmosphere as possible. To achieve this goal it is of importance to sequester as much carbon as possible out of the atmosphere, but also to emit a minimum amount of carbon.

The operations of Kelp Blue can be divided into two sections: the Forestry & Harvesting section and the Processing & Sales section. The core objectives for Forestry & Harvesting are as follows Kelp Blue:

- Draw down globally significant masses of CO_2
- Boost biodiversity and ecosystem stability
- Provide large-scale consistent supply of low-cost kelp

And for Processing & Sales:

- Efficiently process wet kelp into high value products
- Replace negative impact products in the global supply chain
- Continually research new and innovative applications of kelp

The core objectives reflect the climate-positive impact the company wants to make. For the Harvesting & Forestry the first objective presents the climate-positive vision, which seems straight forward. For the Processing & Sales section the core objectives that have influence on the climate are:

1. Efficiently process wet kelp into high value products
2. Replace negative impact products in the global supply chain.

To prevent the use of carbon emitting materials, Kelp Blue uses an internal carbon price of 250 USD per tonne CO_2eq in the internal decision making process.

17.2. Kelp Blue's operations and energy infrastructure

To understand the emissions of Kelp Blue it is important to know all the different activities that lead to GHG emissions. Figure 17.1 shows the biostimulant production flow diagram, showing the different processes that cause emissions.

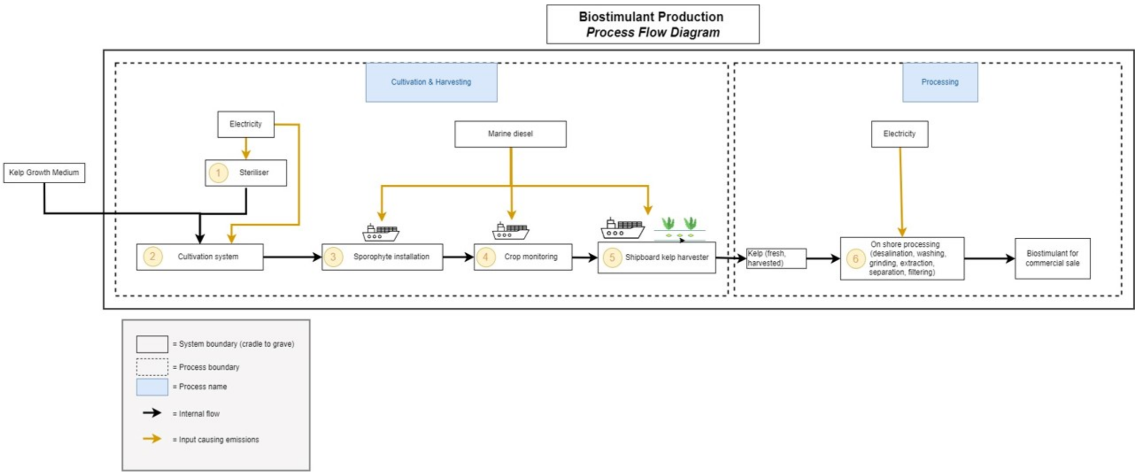


Figure 17.1: Process Flow Diagram of biostimulant production

The activities that lead to the emissions of GHGs are shown by the yellow lines. It is clear that every stage of the procedure produces emissions, ranging from the usage of power to marine diesel. Besides this process there are GHGs emitted during the installation process and everyday business operations. The operations of Kelp Blue can therefore be divided into three sections: Installation, Harvesting & Processing and usual Business Operations as can be seen in Figure 17.2.

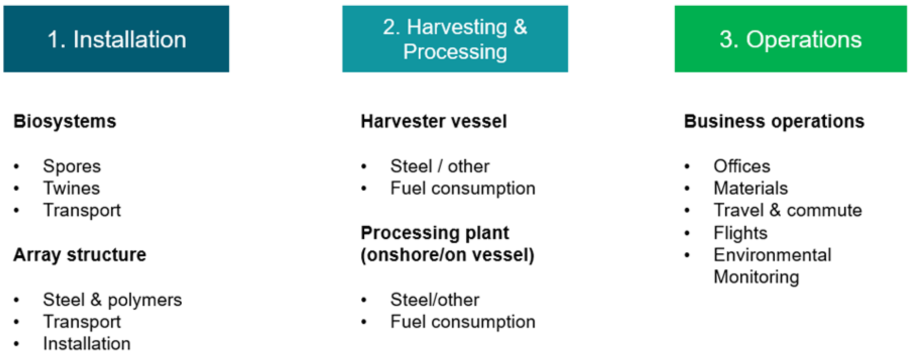


Figure 17.2: The different sections of operations and their emitting factors

17.3. Carbon reductions and emissions of Kelp Blue

17.3.1. Reduction

To draw down globally significant masses of CO_2 Kelp Blue makes use of the carbon reducing properties of giant kelp. The photosynthetic capability of the giant kelp is responsible for it. The estimated carbon sequestration pathways of the kelp forests can be seen in Figure 17.3.

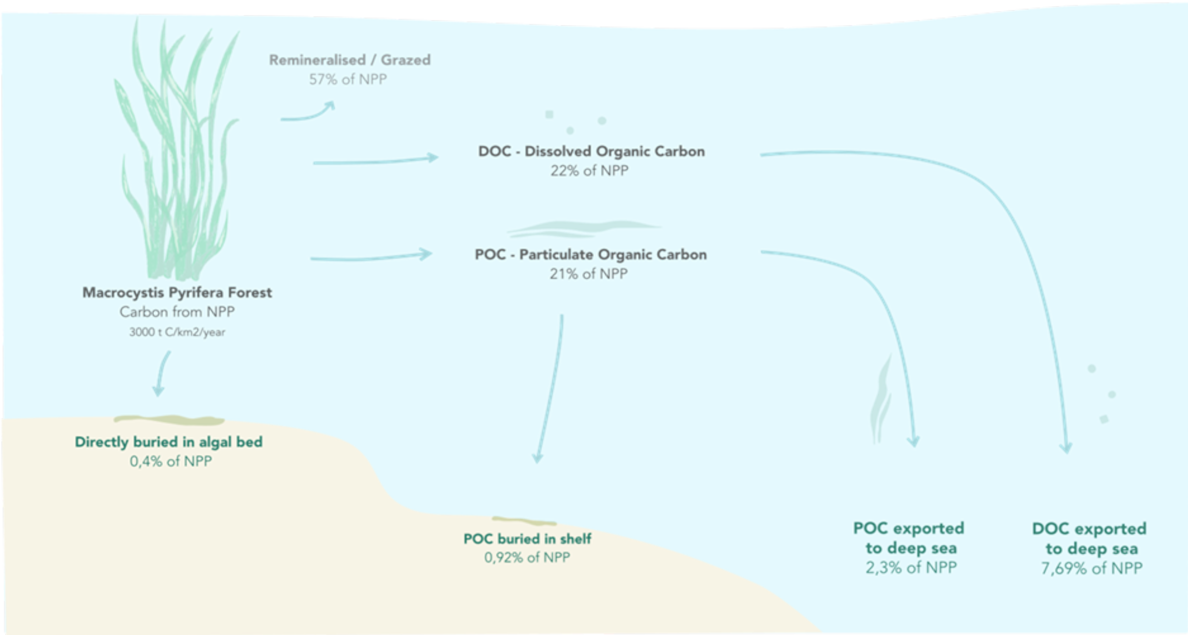


Figure 17.3

It can be seen that an estimation of 10% of the total mass of the forest will eventually be exported to deep sea and therefore be permanently sequestered. This implies a carbon sequestration of 300 t C/km2/year.

17.3.2. Emissions

The emissions are split up in three different areas, such as the operations:

1. Installation
2. Harvesting & Processing
3. Operations

Installation

The installation area consists of the hatchery system and the array structure of the kelp farms. The hatchery system is a significant electricity user when compared to other energy-consuming operations. This is a result of the environment that kelp needs to grow. For the kelp to thrive and flourish, the temperature must be maintained at or around 10 degrees Celsius. The biosystems division currently uses a cooling container in the hatchery to maintain a steady temperature. Every second of the year, this cooling container needs a power source of 4.7 kW. This results in a 41 MWh/year power consumption estimate.

If a coal-fired plant were to supply all of this energy, it would emit close to 33.6 tons of CO_2eq annually (?, ?). Therefore, a remedy should be developed to reduce the volume of GHGs released.

The materials needed to construct the kelp farms, such as the 4.5 t steel spreader bars and the connections utilized in the array construction, result in emissions of 18.5 CO_2eq/ha due to the steel from which they are formed. Other parts of the structures are buoys, moorings, and netting. Plastics are included in these materials, resulting in emissions of 10.5 t CO_2eq/ha of installed array structure. This results in a total CO_2eq/ha of 28.9 t per array structure. Ten years is the intended lifespan of these constructions (Xu Ben Zhang, 2022). In the installation area, consideration is given to the structure's transit and installation in addition to the materials utilized, to complete the emissions causes of this specific area of operations.

Harvesting & Processing

For the Harvesting & Processing area the emissions of the harvester vessel and the processing plant are taken into account. This area is accountable for the most carbon emissions of Kelp Blue in Namibia. The largest source of pollution is marine diesel use. Sadly, there is no environmentally friendly substitute for marine diesel in the marine industry. Marine diesel oil is a major cause of climate change with estimated emissions of 3.206 grams of CO_2 per gram marine diesel used (Herdzik, 2021). The processing facility that will be constructed is another significant energy-intensive process. It is by far the biggest electricity consumer of Kelp Blue's operations, with an estimated demand close to 500 MWh annually. If the energy is generated by a coal power station, a total of 410 tons of CO_2 would be produced annually. Other than these procedures, the office and the nearby facilities consume very little energy, hence they were excluded from the study's focus.

Business operations

The emissions of the everyday business operations consists of energy usage in the office, materials used, travel emissions such as flights and use of 4x4 vehicles and the environmental monitoring workstream operations. The standard fuel for the 4x4 vehicles is diesel, because it generates more torque than benzine, which is favourable for offroad vehicles.

The total yearly emissions of Kelp Blue are estimated to be 5,453 tonnes of CO_2eq (Xu Ben Zhang, 2022). Figure 17.4 shows the distribution of the carbon emissions per area of operations.

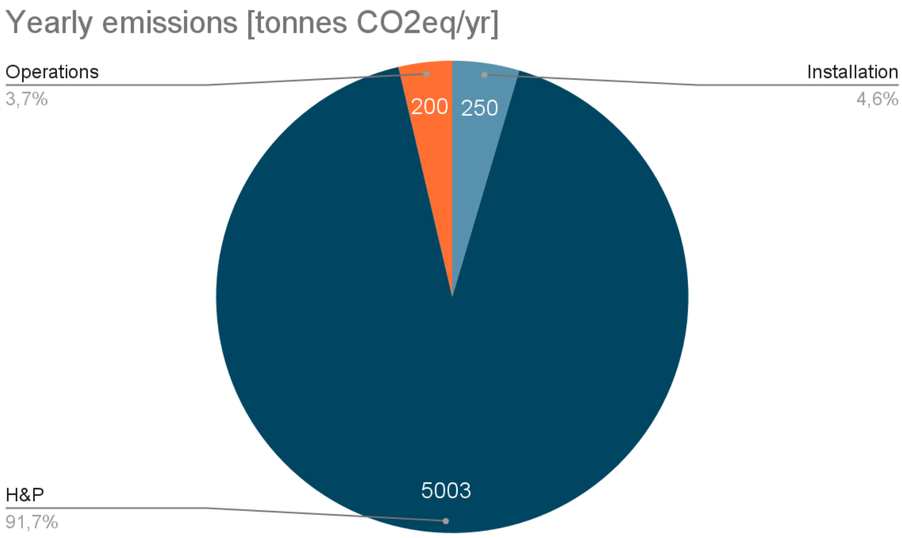


Figure 17.4: Yearly emissions of Kelp Blue's operations

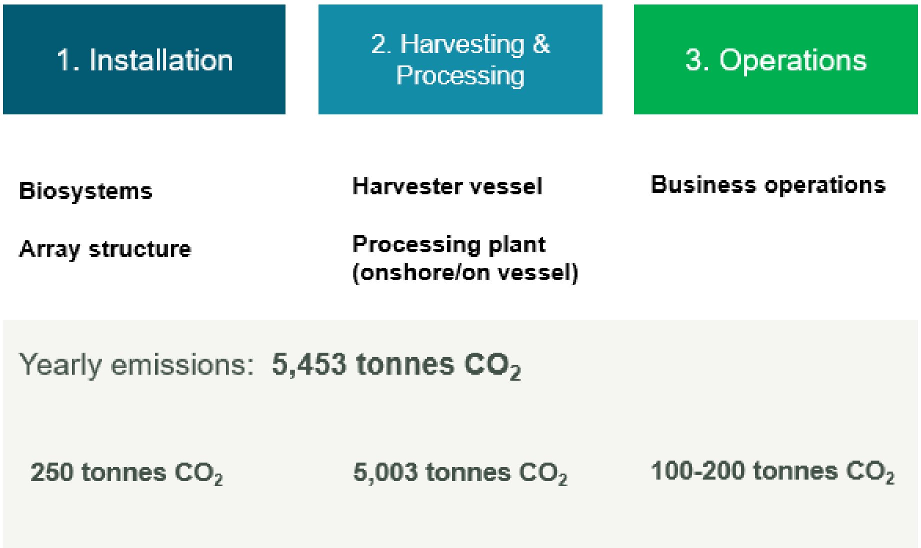


Figure 17.5: Yearly emissions divided by section

It can be concluded that the Harvesting & Processing is the most polluting area with an estimated carbon emissions of 5,003 tonnes CO_2eq per year. This is mainly due to the use of marine diesel, which will cause 4,593 tonnes of CO_2eq annually. Next to that the carbon emissions of the processing of the kelp will cause 410 tonnes CO_2eq, which add up to 5,003 tonnes. Although 410 tonnes of CO_2eq is only 7.5% of the total emissions of 5,453 tonnes, this is currently the most suitable area to reduce the CO_2 emissions of the operations of Kelp Blue.

17.4. Carbon reduction opportunities

In this section the carbon reduction opportunities of Kelp Blue's operations are elaborated. As stated in subsection 17.3.2, the carbon emissions of Kelp Blue are significant and have the perspective to be decreased with the use of techniques such as renewable energies instead of use of fossil fuels. The largest emission contributing processes that can make use of renewable energy sources are the processing centre and the hatchery. If fossil fuels are excluded and replaced with renewable energy, it can prevent the emission of 443t of CO_2 every year. This can be done by solar or wind energy. Therefore a system has to be designed that meets the energy consumption load of the processing facility. The technological advancement of alternative fuels for 4x4 cars and marine boats is presently not at a point where Kelp Blue can make significant progress. Since there is no viable, financially feasible alternative, Kelp Blue is currently unable to reduce its carbon emissions by replacing their dirty engines. The marine industry's technological advancement now limits the development of alternate options. As a result, it was agreed that this study would not concentrate on marine diesel's alternatives, but rather on a procedure that could stand to benefit much from improvement.

18

Exploring solutions

18.1. Desalination plant

Desalination is one of the long-term solutions for water independence that could be established due to the uncertainty surrounding the sustainable extraction of water from the Koichab Pan, according to section 15.1. The fact that desalination is good environmental practice to seek other sources of water in a desert climate next to the sea, it could be a solution to become independent of the water sources of Namwater. This could benefit the company if the Levelized Costs of Water (LCoW) is lower with a desalination plant, than the water price of Namwater of N$ 53.18 / m^3 for large energy consumers, see section B.2.

There are several desalination techniques, with thermal and membrane techniques being distinguished. Multistage flash and multi-effect distillation are now the most used thermal methods. These systems use fossil fuels as their major energy source, but they also consume a sizable amount of electricity to circulate the water (?, ?). Reverse osmosis (RO) systems are now the most widely utilized membrane technology. RO is distinct from thermal technologies since it uses electrical energy. The technique is employed in the majority of desalination plants nowadays because it has the best thermodynamic efficiency. The high specific energy consumption of RO systems, however, may result in expensive electricity costs and a less than ideal solution. It is a procedure that uses a lot of energy, using 3.6 kWh/m^3 (?, ?). If the energy needed for the operations would be extracted from the grid, it would cause a footprint of around 3.6 kg CO_2 per m^3 fresh water. This can be prevented by the use of renewable energy sources for the operations of this plant.

18.1.1. Reverse osmosis

Membranes are used in this method, where the water has to travel a long distance to reach the permeate side. The membrane rejects even the tiniest pollutants when the salty water passes across it. The majority of the time, the membranes are used in crossflow arrangement, where the membrane sheets are positioned within the tubes to collect the permeate. High pressure saltwater enters the system after being pressurized. The membrane is rolled up inside the RO system, and water passes through it. The membrane traps the particles that need to be filtered while allowing water to pass through.

Brine is the term for the pollutants that are gathered outside of the RO system. The highly salty solution needs to be preserved since it may have an adverse effect on the environment. Many people discard the stored brine back into the water since it is a waste product. This ought to be avoided since it could harm marine habitats. According to a study, brine can be utilized to increase the effectiveness of the desalination process. In order to pre-treat saltwater entering the desalination plant, sodium hydroxide (NaOH) or hydrochloric acid (HCl) can be created with the help of the brine. In order to stop the membranes from becoming fouled, this affects how acidic the water is. This is a significant factor in RO system disruptions and failures (Greenlee, Lawler, Freeman, Marrot, & Moulin, 2009).

Figure 18.1 shows a setup of a seawater reverse osmosis system, close to the shore.

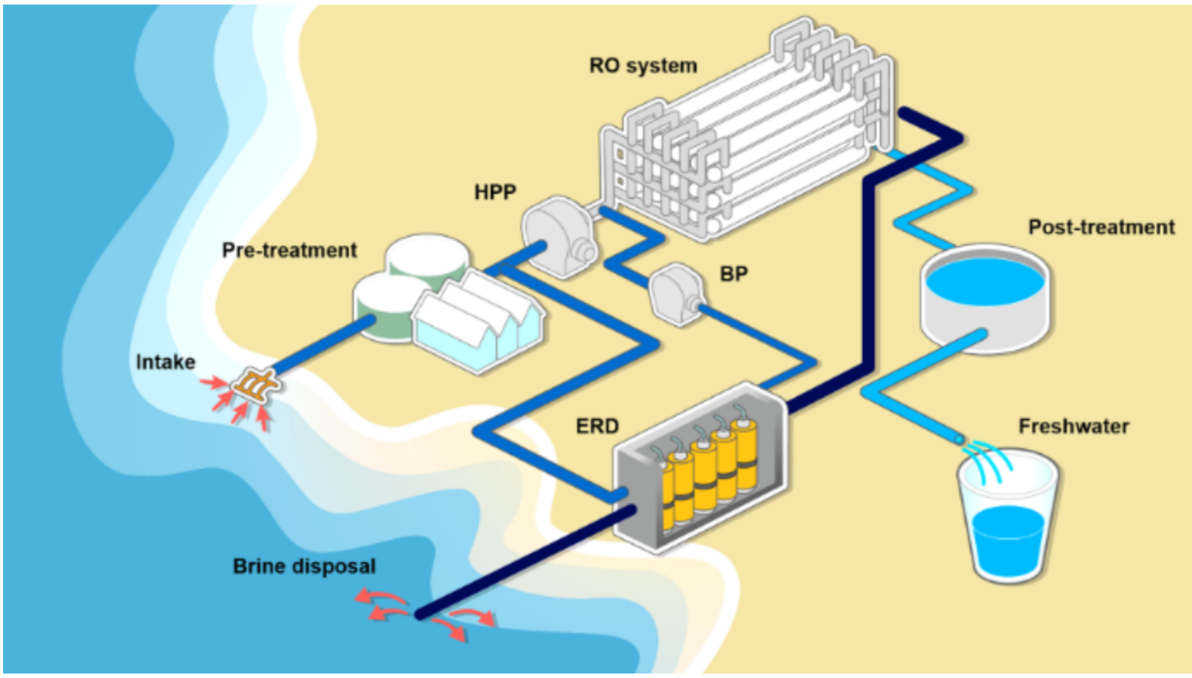


Figure 18.1: Typical SWRO desalination process flow diagram

HPP and BP pressurize the pre-treated feed before it is sent to the RO system, while ERD recovers the hydraulic pressure from the concentrate. Reverse osmosis, or RO. High-pressure pump, or HPP. Pump booster, or BP. Energy recovery device, or ERD.

18.1.2. Configuration possibilities

There are several configurations of a sustainable desalination plant, where wind or solar are the energy generating factors. One can think of a system where RO and the electricity generating systems are working independently, such as a wind turbine or photovoltaic system that produces electricity and provides electricity to the RO system.

Integrated wind desalination plant

Another configuration is one where a wind turbine and RO are integrated, such as the system of Dutch Offshore Turbines (DOT), as can be seen in Figure 18.2 (DOT, 2022).

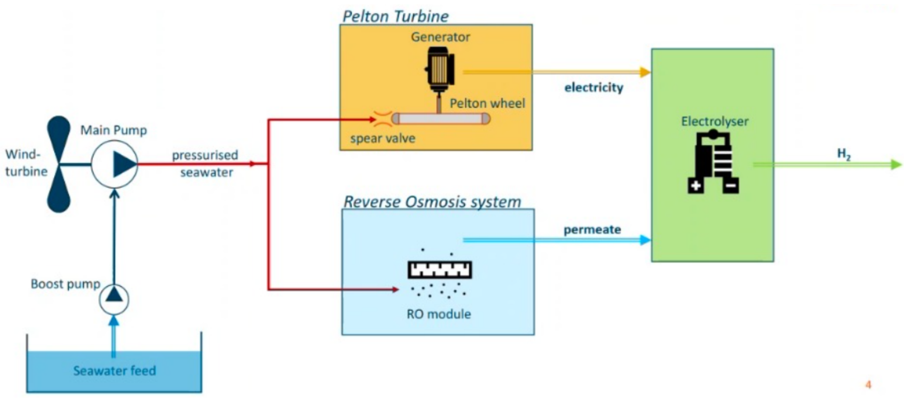


Figure 18.2: Process Flow Diagram - DOT

The nacelle of the wind turbine being utilized here is converted into a hydraulic pump, and the pump is driven by the spinning of the blades. To raise the saltwater being fed into the pump to the level of the nacelle of the turbine, another pump must be used. The water is pressurized and boosted as it travels from the pump in the nacelle to a pelton turbine and the reverse osmosis system. When pressurized water strikes a pelton turbine, it produces electricity that can power a RO system and extra energy that may be utilized to power an electrolyser or other energy-intensive operations. Although this is a highly intriguing concept, it has not been tested in actual application. Figure 18.3 shows the specifications and dimensions of the installation.

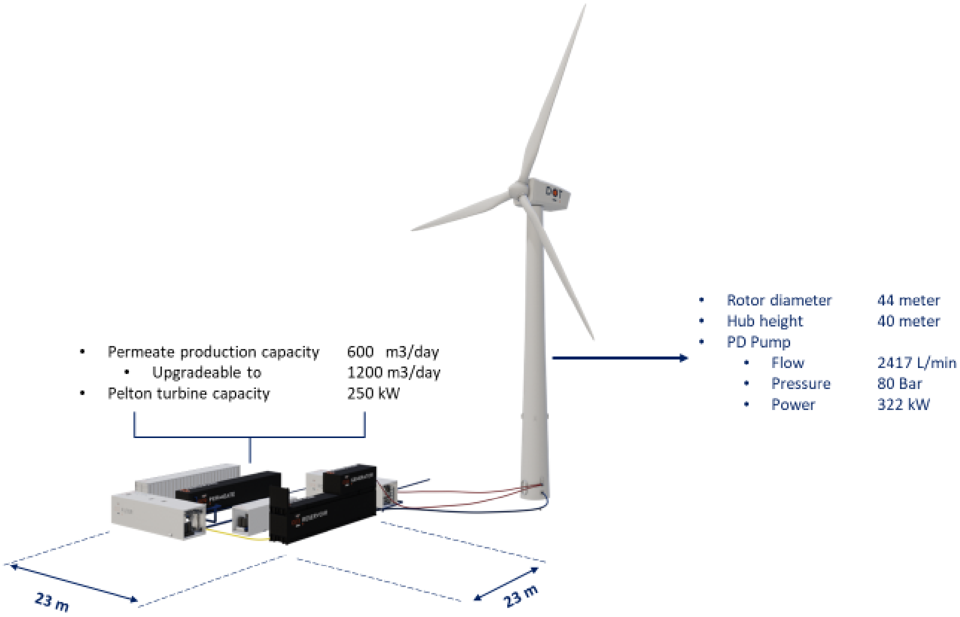


Figure 18.3: DOT installation (DOT, 2022)

The maximum energy yield that is produced by the pelton turbine is 250 kW and the permeate production capacity is up to 600 m^3 per day. The output of this system is significantly higher than the energy and water demand of Kelp Blue. Next to that, the costs of the installation are estimated by DOT to be €1 million to install it in Lüderitz. This is out of budget for Kelp Blue. To make this project interesting it could be established together with the Luderitz Town Council and other large water consumers in Lüderitz. Another factor that makes this solution less attractive is the restriction of the location of the wind turbine by Namibia Nature Foundation due to migration paths of threatened bird species.

Regarding wind turbine projects near the coast in Lüderitz region, the present understanding of the flyways of sea and shorebirds points to the minimum distance from the coast that could be safe should be between 2 and 3 km (depending on the shape and orientation of the coast).

Presently, Lüderitz is home to three wind turbines, each of which is located 2.6, 2.2, and 2.0 kilometers from the shore. As they were judged to be too near to the shoreline, four further sites on Nautilus Hill that were offered for this development—at a distance of 0.6 km and 1.4 and 1.5 km, respectively—were rejected. This implies that it will be impossible to erect a wind turbine close to the coast. The water now needs to be pushed 2 kilometers into the land in order to reach the nacelle. Due to the undulations in the potential location of the wind turbine, it is likely that water will need to be pushed to a higher level. To pump the water to the required location, a solar-powered water pipe might be built. With the help of the Lüderitz Town Council, a suitable place for this installation should be identified.

RO system with seperate renewable energy system

A RO system can also be installed in conjunction with a renewable energy facility, such a solar or wind farm, to generate power. As a result, the appropriate RO system size should be determined, and an estimation of the system's energy consumption should be made. The water consumption of the processing site is estimated to be 36 m^3 per day when having a harvesting yield of 1000 kg of wet giant kelp per hour. This desires an energy load of 34 MWh annually. With a specific photovoltaic output of 2021.4 kWh/kWp per year, the installation size should in theory be at least around 17 kWp for solar to meet the energy demand of the desalination plant. For the wind turbine it would demand an extra installation capacity of 10 kW, with a capacity factor of 0.4.

18.2. Photovoltaic energy system

This section will elaborate on the theoretical knowledge of a photovoltaic system.The system's site circumstances will then be reviewed, and afterwards the system's layout. System sizing will be decided along with the annual consumption load, and it will be followed by the Balance of the System, the elements that complete the photovoltaic system.

18.2.1. Theoretical background

Position of the sun

As a result of solar radiation reaching the Earth, the Sun serves as the energy source for the photovoltaic system. The Sun's position in relation to the Earth will always change because the Earth revolves around it. This indicates that the amount of light that strikes a solar cell will change constantly and the amount of energy depends on the location one is. The Sun's position in relation to the photovoltaic module's placement has a significant impact on the amount of energy produced. Two angles can be used to parameterize the Sun's position. The Sun's angular elevation with regard to the observer's horizon, measured in terms of height a, has a range of [-90°, 90°]. A positive degree indicates that the Sun is above the horizon, making it visible to the observer. The Azimuth A is the second angle in relation to the Sun's location. This angle represents the relationship between the direction of travel and the line of sight projected on the horizontal plane. There are other ways to set up the azimuth, but in this case it is counted eastward, so A is, respectively, 0°, 90°, 180°, and 270° for North, East, South, and West. The visualisation of both angles is shown in Figure 18.4.

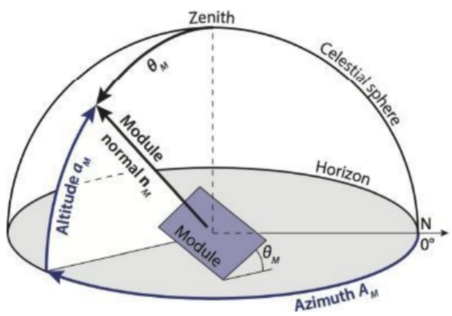


Figure 18.4: Angles to determine the location of the Sun with respect to an object

Components of irradiance

The Sun's position is always shifting, therefore a photovoltaic module's irradiance will also change. Direct, indirect irradiance together with albedo are the three components that make up the irradiance. Gmdir displays the direct irradiance, where the angle of irradiance plays a major role.The scattered light that partially reaches the Earth's surface makes up the diffuse component. Diffuse irradiance is another name for indirect irradiance.The albedo is determined by the surroundings of the panel and is the irradiance that reaches the solar cell after being reflected by surrounding devices. The albedo factor for the processing site was chosen to be 0.30, which is corresponding to a sandy, coastal region.

The different components are determined by the following equations:

$$G_{mtot} = G_{mdir} + G_{mdif} + G_{mground} \tag{18.1}$$

$$G_{mdir} = I_{edir} cos(\gamma) \tag{18.2}$$

Where G_{mdir} reflects the total direct irradiance on the module, G_{mdif} reflects the diffusion component and $G_{mground}$ the albedo component. And where I_{edir} is the direct normal irradiance (DNI); γ is the angle between the surface normal and the incident direction of the sunlight.

Site conditions
On a roof near the Atlantic Ocean is where the photovoltaic system will ideally be installed. Therefore, it's critical that the module can withstand the impacts of high salt concentration. This is to prevent the system from corrosion and steel galvanization. The international standard for such conditions is IEC61701:2020, which describes test sequences useful to determine the resistance of different PV modules to corrosion from salt mist containing Cl (NaCl, MgCl2, etc.) (Iec, 2020).

The roof area and building construction are factors that could limit the system design. The processing facility's roofs are inclined by 25 degrees, which causes a noticeable difference in irradiation on both surfaces. To maximize efficiency, it is crucial to design a system with the highest surface energy yield. The roof's ability to withstand all of the forces that the solar system applies to the roof, in addition to its dimensions and orientation, is of utmost importance. It is difficult to say if the roof is sufficient for the load that will be imposed because there are currently no plans. When designing, we presume that the roofs can support the load of the system.

Another factor that could limit the system design is the renewable energy regulation of the Electricity Control Board, which says that one can't produce more than 30% of its own energy consumption when your renewable energy system size exceeds the limit of 500kW. If this occurs, one should get a licence for an Independent Power Producer and that would have a huge effect on the carbon emissions of the processing site.

18.2.2. Module orientation

Tilt and azimuth
The system's tilt and azimuth are crucial factors in designing a system with a greater solar energy conversion efficiency. There are several mounting system configurations where the mounting is mechanical and the module moves in accordance with the course of the Sun to produce the most energy. Due to the constrained space, this is not a typical installation method for roofs, and the modules will unnecessarily cast shadows as a result. As a result, we will solely concentrate on non-mechanical mounting in which the modules' tilt and azimuth are fixed. It was chosen to install the modules on the roof without any additional tilt in order to avoid the system of shadowing by other modules, in addition to the initial tilt and azimuth of the roofs. Row shadowing is reduced as a result, cutting down on efficiency losses. The average solar irradiation on a module at a specific tilt and azimuth angle can be seen in Figure 18.5.

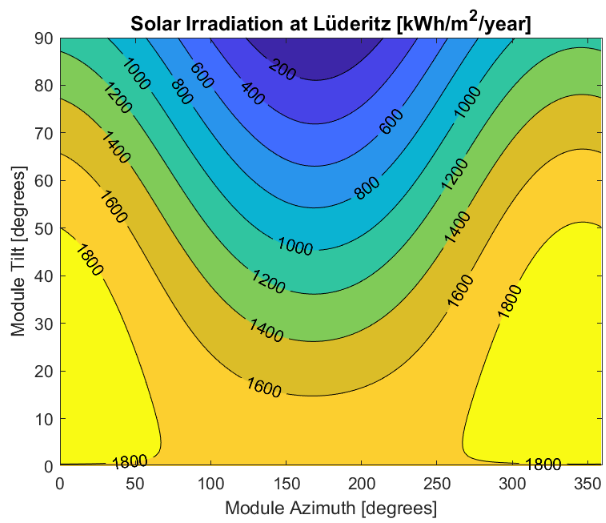


Figure 18.5: Solar irradiation dependent on orientation of module

The ideal azimuth angle, as shown in the picture, is northward, which makes sense for a system located below the equator. The Global Solar Atlas data was used to calculate the best tilt angle for the module, which is 26° for azimuths between 85° and 275°, or the roof of the processing facility. The roof has a 25° slope, thus the initial tilt was already quite near to the optimal angle. Therefore, the module will be mounted without any further inclination directly to the roof. The average annual solar radiation that strikes the roofs is 2126.6 kWh/m2 and 2181.3 kWh/m2 for an Azimuth of 85° and 265°, respectively. A north-facing roof would have an annual irradiation of 2477.8 kWh/m2.

18.2.3. Influence of temperature on PV module performance

The efficiency of a solar module strongly depends on the module's surface temperature. To compare different modules' behaviour on the influence of temperature the operational outcomes of the module at STC-conditions is always included in the data sheet of the module. Standard Test Conditions are characterised by 1000 Wm-2 irradiance, an AM1.5 spectrum and a temperature of 25 °C. All across the world, both industry and (test) laboratories use STC and the AM1.5 spectrum. The module's generation capacity is expressed in Wattpeak (Wp), which corresponds to the power produced by a PV module at STC.

When the conditions are not ideal, which is in reality always the case, the PV modules show different behaviour. There are different thermal models to determine the temperature of a PV array at different weather conditions. The Duffie-Beckman model is the only model that takes the wind speeds into account. Considering Lüderitz as a very windy place, it was decided that this model is used for the determination of the temperature of the model for which the formula is shown in Equation 18.3.

$$T_M = T_a + \frac{T_{NOCT} - 20}{800} G_M (\frac{9.5}{5.7 + 3.8w})(1 - \frac{\eta_{cell}}{T\alpha}) \tag{18.3}$$

Where Ta is ambient temperature, Tnoct can be found on data sheet, Gm is total irradiance, w is wind speed, ncell is efficiency of the cell, T is transmittance of front layer of module, alpha is absorptivity of the module and Talpha is assumed to be 0.9. Figure 18.6 shows the temperature of the module's surface calculated using the Duffie-Beckman model

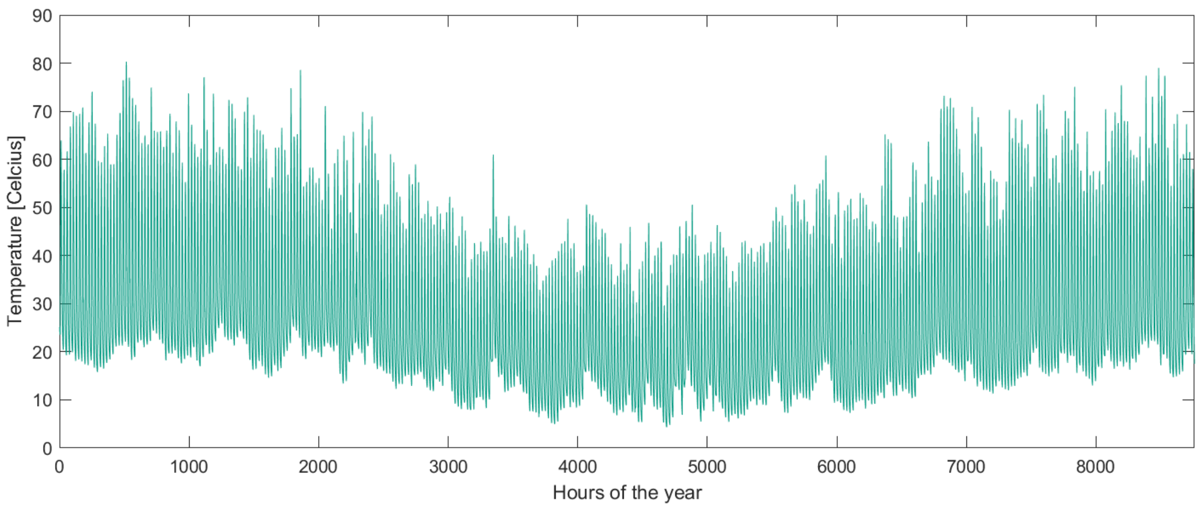


Figure 18.6: Modelled module temperature in Lüderitz, using Duffie-Beckman model

As can be seen from Figure 18.6, the temperature of the panels vary significantly. It is desired for a solar panel to absorb as much sunlight as possible, but that also leads to higher temperatures of the surface. The maximum temperature is 80.3 °C obtained during summer and the minimum temperature is 4.3 °C during winter. The mean operating temperature of the panels is 36.9 °C.

18.2.4. Energy storage

A PV system to cover the total consumption load is designed to be a grid-tied system. A grid-tied system has interaction with the grid, so if the system produces a surplus of energy it can be fed into the grid and for a shortage energy can be supplied by the town's electricity grid. This can be seen as storage of the electricity in the grid where you can extract the electricity back into the processing facility when the solar system can not consume enough to feed energy demand of the process.

Due to the fact that the operations are occurring for at least 18 hours a day with an average consumption of 100 kW per hour, would be hard to realise due to the needed storage capacity during winter months using batteries. Next to that, most batteries contain heavy metals that can harm the environment, it is desirable to avoid utilizing an additional battery system. Additionally, the cost of a solar energy system will significantly rise using batteries, especially when considering the internally used carbon price of $250 per ton carbon emitted of any material used in the operations of Kelp Blue. 150 to 200 kilos of CO_2 would be created for every kWh of batteries produced according to the Swedish Environmental Research Agency (*What is the environmental impact of a battery?*, 2021). The absence of the real time hourly consumption rate of electricity is another factor in the decision to use a grid-tied system, because it is hard to estimate the system sizing of batteries without any hourly data and multiple assumptions of the process.

18.2.5. PV panel choice

As stated in subsubsection 18.2.1.3, the PV module needs to be IEC61701 approved in order to survive potential corrosion from salt mist in coastal areas. The PV panels should also be accessible locally in Namibia. Unfortunately, Namibia's resources are not as well established as they should be to make it simple to discover what kinds of PV modules are accessible. Therefore, we made the decision to get in touch with several contractors to find out which panels they recommend using for the project.

18.2.6. Balancing of system

All the other components of the PV system next to the solar panels are called the balance of system (BOS). These elements affect the system's overall effectiveness, hence they are crucial throughout the design stage. In this grid-tied system, the mounting framework, inverters, and wires make up the BOS. To ensure a stable mounting of the system, the mounting structure must be able to fit on the corrugated cement fibre roof. Such mounting structures are produced by numerous manufacturers, therefore they are widely accessible. The estimation of the costs are €35 per panel.

Inverters

In the PV system, there are two different kinds of inverters employed. The fluctuating voltage produced by the PV panels must first be converted to a constant value using a DC/DC converter. Another crucial component is a DC/AC converter. Since most devices operate on alternating current and the grid also provides AC, the direct current output of the PV panels must be converted into alternating current. It is possible that both inverters are part of the same device. Additionally, an inverter's Maximum Power Point Tracking (MPPT) feature ensures that the voltage is changed to achieve the maximum power point. When choosing the best inverter, the amount of MPPT and the method are crucial considerations. It is crucial that not every panel is linked to the same MPPT in order to achieve higher efficiency because doing so could result in losses. For example, if one of the panels is shaded, the power output of the entire system will be drastically reduced. As a result, multiple inverters are needed for the system's various irradiation surfacesIt was determined to employ one inverter for this system for each azimuth and tilt combination of a particular roof. The irradiance on a certain surface will typically be consistent because there aren't many clouds in the sky in Lüderitz. Besides transforming the DC into AC and MPPT, another important factor of the inverter is the prevention of islanding. Blackouts of the electricity grid often occur in Lüderitz. Therefore it is important to prevent the system of islanding. On a sunny day, the PV system will generate electricity and send it, unprotected, to the grid. The electrical worker who is attempting to fix the grid might then be in danger. Therefore, the inverter needs to be able to recognize when the power grid is turned off. If so, the inverter needs to stop supplying power to the grid. Due to the high load that is obtained during maximum irradiation, it was chosen to use a three-phase inverter.

An inverter has to meet the following requirements:

1. There is a maximum input voltage for each inverter. Ns must be at a minimum value for MPPT to function because of the input voltage window
2. It is necessary to choose the inverter so that its maximum Power is greater than the maximum PV output
3. Additionally, the inverter's nominal DC power should roughly match the PV power at STC. The

nominal DC power of the inverter is typically chosen to be a little lower than the PV power at STC

4. Additionally, single-phase inverters are employed for PDC0 <5 kWp whereas three-phase inverters are suggested for PDC 0 > 5

18.2.7. System sizing

The system is designed to meet the energy demand of the processing site where 1,000 kg of giant kelp is being processed per hour. The system is designed following the energy balance paradigm. This means that the system size is designed such that the annual production of the energy system matches the annual consumption load. Because the processing facility is not operational yet, the annual consumption load has to be estimated. Therefore the total load of the installed devices is calculated. As discussed in Table 16.3, the energy demand is 490 MWh per year for the pilot scale.

It was necessary to identify the systems' locations before estimating the system's size. This affects solar irradiation, which in turn affects energy production per square meter. According to section X, there were five places available for the processing facility's photovoltaic system. The roofs that produce the most energy per square meter are roofs 3 and 4, which face north. These roofs must be utilized in order to develop a system with the highest energy production.

The system will be placed on rooftops, so the space available for installation is limited. This must be taken into account while designing the system. In addition, it is important that voltages and currents remain within limits to ensure safety. The module configuration is of great importance here. Here one can choose between series and parallel circuits. When one connects multiple modules in series, the voltage of a module will multiply by the number of modules connected in series. In addition, a higher current causes greater losses in the cables, so it is desirable to keep the current low.

Another factor that should be taken into account is continuous power production of the system. It is unfavourable to have a generation peak in the early morning and produce significantly less in the afternoon due to the orientation of the modules. Therefore a system should be equally distributed over the path of the Sun to prevent this occurrence.

18.3. Wind energy

This section highlights how wind energy can be used as a solution for Kelp Blue. And what the order size of wind turbines is for the system.

18.3.1. Components

A wind turbine makes energy from the power of the wind. The wind makes the rotor blades rotate because they are shaped in a certain way to capture the maximum amount of wind (Zaaijer & Vire, 2021). The nacelle then contains a generator and often a gearbox to increase efficiency. The generator converts the kinetic energy into electrical energy and a transformer and converter convert the electricity into the correct format.

Rotor blades are the long, curved blades that are mounted on a wind turbine. These blades are designed to capture the wind and convert its kinetic energy into rotational energy, which is then used to generate electricity. The length and shape of the rotor blades is carefully optimized to maximize their efficiency at capturing wind energy. The blades are typically made of strong and lightweight materials such as fiberglass or carbon fiber, and they are attached to a rotor hub, which is connected to the wind turbine's generator. As the wind blows, it causes the rotor blades to spin, generating electricity.

The wind turbine generator is the component of a wind turbine that is responsible for converting the kinetic energy of the wind into electrical energy. The generator consists of a rotor, which is connected to the turbine's rotor blades, and a stator, which is a stationary part of the generator that contains electromagnetic coils. As the rotor blades spin in the wind, they cause the rotor to rotate, generating a magnetic field. This magnetic field interacts with the electromagnetic coils in the stator, inducing an electric current. The electric current is then sent through a transformer, which increases the voltage and allows it to be sent to the grid.

The gearbox is a component that is used to increase the rotational speed of the turbine's rotor, which is necessary for generating electricity. The gearbox consists of a series of gears that are arranged to increase the rotational speed of the rotor. As the rotor blades spin in the wind, they cause the rotor to rotate at a relatively low speed. The gearbox increases this rotational speed, allowing the generator to produce more electricity. The gearbox is a critical component of a wind turbine, as it allows the turbine to efficiently convert the wind's energy into electricity.

The tower is the tall, vertical structure that supports the turbine's rotor blades and nacelle. The tower is made of strong and durable materials such as steel or concrete, and it is typically constructed on-site using cranes and other heavy machinery. The height of the tower is an important factor in a wind turbine's performance, as taller towers allow the turbine to capture more wind energy. The tower is also designed to support the weight of the rotor blades and nacelle, as well as withstand the forces of the wind and other environmental factors. The tower is an essential part of a wind turbine, as it provides the support and stability necessary for the turbine to function effectively.

Thereafter, a transformer is needed in a wind turbine to increase the voltage of the electricity generated by the turbine. The generator in a wind turbine produces electricity at a relatively low voltage, which is not high enough to be sent directly to the grid or used by most electrical devices. The transformer increases the voltage of the electricity, allowing it to be transmitted over longer distances and used more efficiently. Without a transformer, the electricity generated by a wind turbine would be largely unusable. The transformer is an important component of a wind turbine, as it allows the turbine to generate electricity that can be easily used and distributed.

18.3.2. Energy production

A wind turbine generates energy following the power curve (Zaaijer & Vire, 2021), this curve illustrates what the power output is for the given wind speed. The wind turbine will start rotating at the cut-in wind speed, usually between 2 and 3 m/s. Then the power output will increase by the third power of the wind speed, up to the rated power speed, this is usually between 10 and 15 m/s. This power will remain constant until the cut-out wind speed, when the wind is too strong, this usually occurs after 25 m/s.

Another important factor to the generated power is the size of the wind turbine, this being the hub height and rotor diameter. Equation 18.4 is used to estimate the power output of the wind turbine.

$$P = \frac{1}{2}\eta\rho c_p U^3 \pi R^2 \tag{18.4}$$

This shows that the power scales with the diameter squared. It can also be seen that the wind speed U is of great influence. The rest of the factors concern efficiency, air density and the power coefficient. Also, hub height is important. First, because the blades of the turbine should not touch the ground. But also, as described earlier in subsection 13.4.1, because the wind blows harder the higher you get in the boundary layer of the atmosphere (Zaaijer & Vire, 2021). On the other hand, a trade-off has to be made in this, because the higher you get in the atmospheric boundary layer, the less improvement there is in wind speed, and a higher hub does get more and more expensive.

As stated, the wind turbines use the wind to generate electricity, and their wake causes the wind to blow more slowly downstream. The wake spreads as the flow moves downstream, and it then recovers toward free-stream conditions. The cumulative impact of the wind farm's turbines on one another has an impact on the energy output of the wind farm, which is known as the wake effect. Wake impacts from nearby wind farms and potential affects of newly constructed wind farms should both be taken into account. The scenarios of this report assume a single wind turbine, so for this reason wake effects will be ignored.

18.3.3. System sizing

To make an initial estimate of the order of magnitude of the wind turbine for the different sites, the capacity factor is used. This factor is a measure of the productivity of an energy-producing plant and indicates the ratio of actual energy production to actual energy output. According to literature (Nampower, 2018), this is between 0.35 and 0.50 in Lüderitz, 0.40 is used for this study.

When net-metering is used, and so the aim is to have self-generated all the energy used by the processing facility but does not have to run simultaneously, this gives the results as visible in the table below obtained from previous sections in this report.

Table 18.1: Scaling of the wind turbine using the energy consumption data for the processing site

Facility	Max power used	Total energy used	Scaling turbine
Pilot processing	100 kW	500 MWh/year	150 kW
Full scale processing	1800 kW	9 GWh/year	2.5 MW

But this is still incorrect given the restrictions imposed in this particular situation. To comply with local legislation, it is stipulated that wind turbines must be placed at least 2 km from the coast, this is because the Lüderitz coastal area is an environment with many (protected) animals, which are at risk from the blades of the turbines. So electricity will still have to be transported over 2 km, with losses occurring.

When a wind turbine is installed in Lüderitz, a choice can be made to connect it directly to the processing site, requiring cabling and a transformer to convert the wind turbine's 690 volts to 220 volts, the voltage at which the processing site's equipment is located, or converting it to 11 kV and connecting it to the existing grid in Lüderitz. Although the latter will entail more permitting procedures, it is worth it given the losses that may occur over a length of 2 km. To calculate these losses, the following equations are used:

$$R = \rho \frac{l}{A} \tag{18.5}$$

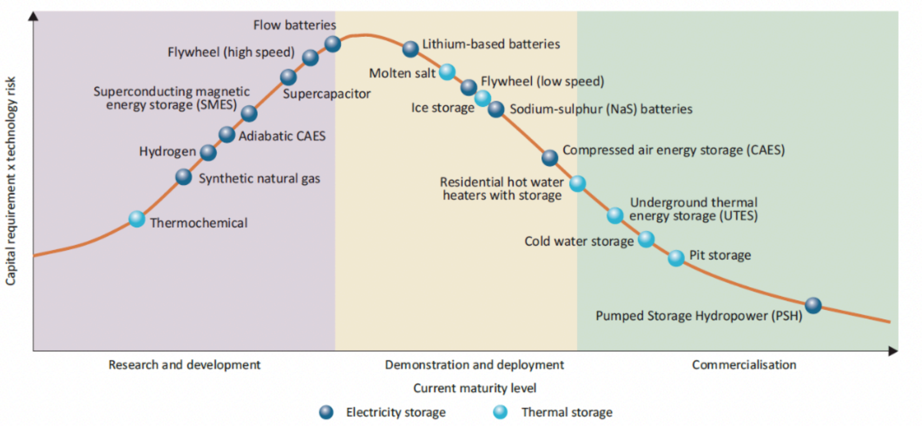
$$P_{loss} = I^2 R \tag{18.6}$$

It is shown in these formulas that the losses scale with the current strength squared. This means that when the voltage is higher, and the power is the same, the current will be lower. The cable losses depend on the capacity required, but they amount to 98% when using Power and Cables's cables for the following sizes.

Using this method does mean that a transformer will have to be purchased. A transformer consists of two coils, a primary and a secondary coil. The primary coil is connected to a voltage source, current passes through the primary coil, creating an electromagnetic field. This creates an induction voltage, i.e. voltage created by the coil being in an electromagnetic field, in the secondary coil. The voltage in the secondary coil does not have to be equal to the voltage in the primary coil. The voltage in the secondary coil is determined by the ratio of the number of windings between the primary and secondary coils. The efficiency of transformers is estimated at 97 to 99%, so 98% is assumed here.

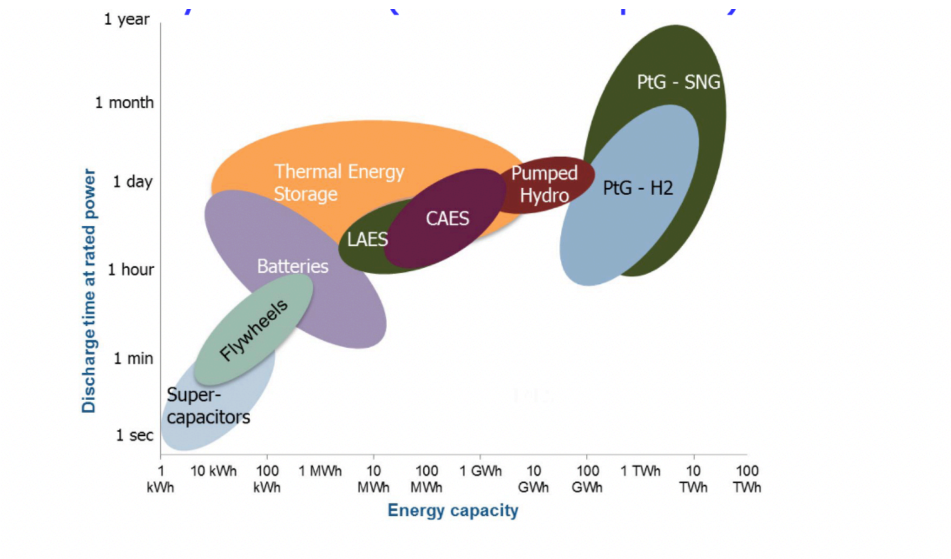
18.4. Energy storage

To advise on the use of energy storage, several technologies are first reviewed. Based on the illustration in Figure 18.7, combined with those in Figure 18.8, we chose to deal with thermal energy storage, pumped hydro storage and battery storage. This is in combination with on-site conditions and financial possibilities.



Source: Decourt, B. and R. Debarre (2013), "Electricity storage", *Factbook*, Schlumberger Business Consulting Energy Institute, Paris, France and Paksoy, H. (2013), "Thermal Energy Storage Today" presented at the IEA Energy Storage Technology Roadmap Stakeholder Engagement Workshop, Paris, France, 14 February.

Figure 18.7: Technology readiness of different storage technologies



Source: PwC (2015) following Sterner et al. (2014)
CAES: Compressed Air, LAES: Liquid Air, PtG: Power to Gas.

Figure 18.8: Discharge time versus energy capacity for several storage technologies

18.4.1. Pumped hydro storage

In a pumped hydro storage (PHS) plant, energy is extracted or stored by means of height difference between two water basins (Rehman, Al-Hadhrami, & Alam, 2015). With surplus energy, water can be pumped from the lower reservoir to the upper reservoir. When energy is demanded, water is released from the upper reservoir, which sets a turbine in motion which generates electricity. A pumped storage plant is a highly efficient and economical form of energy storage with a long lifetime and low wear and tear; the PSH's round-trip energy efficiency ranges from 70% to 80%, with some sources stating it can reach even greater levels. PSH's primary drawback is the specialised nature of the location needed, which requires both geographic height and water accessibility. PSH is vulnerable to social and ecological problems since suitable locations are so likely to be in hilly or mountainous areas, and maybe in areas of natural beauty. In recent developments old mines have been used for PHS, which could be of interest for Namibia.

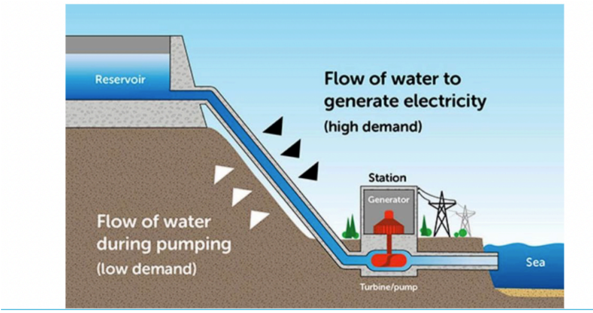


Figure 18.9: Pumped hydro storage installation

18.4.2. Thermal energy storage

Thermal energy is stored by heating water in an insulated storage tank (Sarbu & Sebarchievici, 2018). Hot water storage, for example, is suitable for reducing peak thermal energy demand, both everyday and seasonally. In France, peak thermal energy demand has been reduced by 5% by implementing domestic hot water storage, shifting heat production to off-peak times. Hot water storage is a simple, inexpensive and mature technology that is very reliable. Another method is Underground Thermal Storage (UTS), in which heated water is pumped underground where it is stored in porous rock or in an aquifer. Similar to hot water storage, underground thermal storage can be used to regulate heat on a daily or seasonal basis and can make use of waste heat. Underground storage is a very reliable, simple, mature technology and requires less infrastructure and direct surface utilisation than hot water storage. Nevertheless, it can be considerably more expensive and depends on the right geological conditions.

Large amounts of thermal energy can be stored during a phase change (e.g. the change from water to ice). The thermal energy required for phase change is called latent heat. It is suitable for thermal regulation (both per day and seasonally), capturing demand fluctuations and peak reduction, and utilising thermal waste streams. Latent heat storage has a much higher energy density than other forms of thermal storage. These systems are still under development, making them more expensive than alternative forms of thermal storage.

Thermal energy flows can be effectively stored in molten salts. Compared to other storage materials, molten salts are very stable at high temperatures and under pressure, non-flammable and non-toxic. For example, thermal energy from a solar power plant is usually stored by heating molten salts to produce energy 24 hours a day. This is feasible due to the high heat capacity of molten salts, which allows one to produce energy during the night as well. Using molten salts is a relatively new technology, so it is costly and there is little knowledge about reliability and lifetime.

18.4.3. Batteries

Batteries are a form of electrochemical energy storage, in this case looking at rechargeable batteries or reversible electrochemical reactions. Reversible means that the chemical processes are reversible, by applying an electrical voltage one can force an electron flow in the opposite direction and the chemical reactions will then reverse: energy is thus stored.

Battery technology has come a long way over the years, with different types of batteries now available on the market. The four most common types are lead acid, nickel cadmium, nickel metal hydride and lithium. Each type of battery has its own advantages and disadvantages, so it is important to choose the right one for your needs (Zhang, Wei, Cao, & Lin, 2018).

- Lead-acid batteries are still used in many applications today. They are relatively cheap and durable, but have a low energy density and are therefore not very efficient.
- Nickel-cadmium batteries were once the most popular type of rechargeable battery, but have largely been replaced by nickel-metal hydride batteries. Nickel-cadmium batteries have a high energy density and are very efficient, but they can be expensive and can suffer from a memory effect.

- Nickel-metal hydride batteries are becoming increasingly popular because of their high energy density and low cost. The main disadvantage of nickel-metal hydride batteries is that they are relatively expensive and not as durable as other rechargeable batteries. Another disadvantage of NiMH is that they do not have a high energy density, so the battery does not charge as well over time.
- Lithium batteries are mainly intended for advanced devices and applications where more and longer power is desired. In the past, lithium batteries were used in consumer electronics such as mobile phones, laptops and digital cameras. More recently, however, they have been used in industrial applications where their greater energy density and higher power capacity are ideal.

Using batteries in solar and wind power systems has several advantages. It allows for the smooth integration of renewable energy into the grid, and can help reduce the need for fossil fuels. It also allows for energy to be stored and used when it is most needed, improving the overall efficiency of the system.

However, there are also some challenges to using batteries in solar and wind power systems. Batteries can be expensive, and their performance can degrade over time, which can reduce their effectiveness. Additionally, the disposal of batteries can be difficult and can have environmental impacts.

Overall, the use of batteries in solar and wind power systems can help to improve the reliability and efficiency of the grid, and can help to reduce our reliance on fossil fuels. However, it is important to carefully consider the costs and potential drawbacks of using this technology.

19 Energy Solutions

After analysing the situation, considering geography, climate and different sites, we looked at what possible solutions exist for Kelp Blue's demand. Kelp Blue's goal is to reduce emissions, which is why an analysis of emissions from the company's various branches has been made in section 17.1. This chapter has concluded that the focus is on improving the processing site, with when possible the connection of the office site to this system or alternatively another system for office consumption.

19.1. Desalination plant

Before proceeding to the design of the various energy system solutions, a decision must be made whether to build a desalination plant. This affects the size of the renewable energy system. For this, the Levelized Cost of Water (LCoW) is analysed.

A water supply of at least 36 m3/day is required to meet the processing site's water demand with a processing yield of 1,000 kg per hour. Consequently, a desalination plant may be utilised. A reverse osmosis system is the most suitable choice for desalinating seawater. As the research progressed, it became increasingly clear that there are numerous unknowns to be resolved before a system can be appropriately sized. The system sizing is currently hard to predict due to the following uncertainties:

1. There are now no operations ongoing, and there are still a lot of unknowns regarding the process's output of the final product. Because there is now no accurate data on the growth rate of kelp, the uncertainties begin with the yield of the kelp farms.
2. In addition to the kelp farms' production, it is currently anticipated that 2 litres of water are required for every kilogram of kelp that is processed into biostimulants. This ratio is also uncertain and can be adjusted to the needs of the process.
3. The processing site's operational hours will also affect how big the desalination plant has to be designed. According to Figure 16.3, an operation time of 18 hours per day was considered for this analysis.

An hourly processing capacity of 1,000 kg of wet kelp with an average water consumption of 2 liters per kelp was considered to provide an estimate of system sizing. The processing portion will consume one liter, and the cleaning portion will utilize the other litre each day. This results in a daily water use of 36 m3. If that should be produced only by renewable energy, this amount should be produced between 7 AM and 7 PM. This gives a flow rate of 3 m3 per hour. Assuming an energy demand of 3.6 kWh per m3, leading to an energy demand of 10.8 kWh to power this process. The total energy demand per year is 51 MWh to desalinate all the water that is needed for the processing of biostimulants.

When determining the system's size, multiple system components should be taken into consideration. Of course, the system must have a reverse osmosis system to begin with. A system size that can produce the required amount of water for the process should be designed in order to generate enough water for processing. The desalination plant shouldn't be connected to the grid, and all necessary energy should be generated by renewable energy sources if one wants to ensure that all the water produced is produced without the usage of fossil fuels.

In addition to a reverse osmosis system, a water storage is required to keep the produced water until it is needed. The water tank should be able to supply 18 m3 of water at least throughout the night for cleaning and still be able to supply water during the day because the majority of the water will be utilized for cleaning during the night. In order to reliably be able to supply the facility with high-quality desalinated water, a specified safety factor in the storage capacity should be taken into account. The storage capacity is at least 100 m3 to make sure that the tanks can provide enough water for at least 2 days of operations. This will result in an estimated price of €10,000 for the water tank.

A high pressure pump with an estimated cost of €500 and a flow rate of 3 m3/hour might be used to pump all the water from the desalination plant to the water storage. Multiple pipes must be installed in order to connect all of the system's various parts. Unfortunately, there was no baseline collected for these expenses, thus a €4000 estimate was made. Therefore, it is estimated that the desalination system will cost €74,250 in total and have a 15-year lifespan.

The operations of such a system are quite easy to maintain. Besides the change of filters every 6 months, very little maintenance is needed. Chemicals are needed to pre and post-treat the water for the quality of the water and to get rid of all contaminants.

All desalination project-related costs were entered into Excel and with that the LCoW was calculated. The CapEx was divided by the expected economic lifetime. This was used to calculate the depreciation of the system. The calculations can be found in the Excel sheet Renewable Energy System analysis - Kelp Blue under the tab Desalination dashboard.

19.2. Financials

A LCoW of NAD 13.06/m3 is achieved in the first year of operations, when the energy is generated by solar energy. If it would operate on the electricity provided by the grid, the LCoW would be NAD 17.94 per m3. These prices are 24.5% and 33.7% of the water price which has to be paid to Lüderitz Town Council (NAD 53.18 per m3) respectively. If one compares the costs of the water produced by the desalination plant, the LCoW of the desalination plant is lower compared to the prices of LTC. This makes building a desalination plant a financially attractive option. However, other technical issues also need to be considered.

Figure 19.1 shows the net cash flow overview, where the LCoW of the desalination plant is plotted versus LCoW of the LTC. The net savings from using a desalination plant were set against the difference in water price between LTC and desalination plant, leading to this figure. It can be seen that the payback period is after 5 years of operations. The IRR on own equity over 15 years is 46.6%, assuming no debt capital to install the installation. If the management team of Kelp Blue decides to find investors for this project, the IRR on equity will increase.

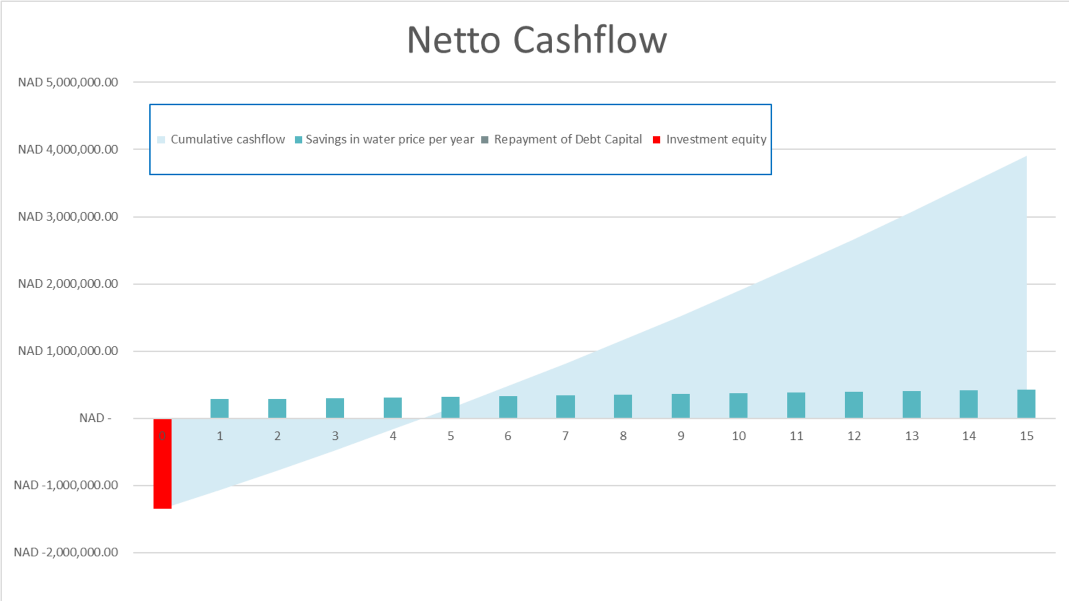


Figure 19.1: Netto cash flow prognosis desalination plant

The initial investment (CAPEX) of the desalination plant comes to NAD 1,262,250. This is equivalent to €74,250 (November 28, 2022). Kelp Blue's management team must decide whether, by the time this project comes to fruition, they want to budget this investment or choose to invest their money elsewhere. The operation expenses consist of filters, post-treatment, operation & maintenance costs, personnel and unforeseen costs, which are estimated to be close to 10% of the CaPex. Table 19.1 shows the breakdown of the costs.

Table 19.1: Cost breakdown of desalination plant

Capex		
Procurement RO system[3 m3/hour]	€ 60,000.00	NAD 1,020,000.00
Watertank [100000 liters]	€ 10,000.00	NAD 170,000.00
High pressure pomp	€ 250.00	NAD 4,250.00
Instal pipes	€ 4,000.00	NAD 68,000.00
Total	**€ 74,250.00**	**NAD 1,262,250.00**
Turnkey investment	**€ 74,250.00**	NAD 1,262,250.00
VAT turnkey investment	**€ -**	NAD -
Opex		
Filters	€ 2,000.00	NAD 34,000.00
Hadex 10 liter (post-treatment)	€ 2,421.51	NAD 41,165.74
O&M per year	€ 1,000.00	NAD 17,000.00
Personel	€ 1,000.00	NAD 17,000.00
Unforseen costs	€ 642.15	NAD 10,916.57
Total O&M en AM [/year]	**€ 7,063.67**	NAD 120,082.32
Cost of Electricity		
Electricity[€/kWh]	€ 0.11	NAD 2.00
Annual energy consumption [kWh]	33789	
Total per year	€ 3,796.47	**NAD 64,539.97**

The scalability of this specific desalination plant is another factor that could make MT decide to not invest. This design is specifically designed to process 1,000 kg giant kelp per hour and if the facility wants to grow in increments, the desalination plant cannot grow with increments. To accommodate the growth of the facility, it may be chosen to install an additional desalination plant.

Another factor that may ensure that the desalination plant will not be built is political interference with the LTC. It may cause tensions to arise between the two parties that will not benefit the relationship. This consideration must be done carefully to ensure that the investment is approved by the local government.

19.3. Energy solution

19.3.1. Multiple criteria analysis

Several systems can be envisioned to improve the sustainability of processing the giant kelp. For this purpose, we looked at whether or not to use a desalination plant and install a wind turbine or a photovoltaic system. In order to make a good consideration, the options were put side by side in a decision matrix to make the right choice. The options are divided into different sections: Financial, Technical, Environmental & Independence. These options were then all divided into topics, as shown in Table 19.2.

19.3.2. MCA evaluation

Table 19.2: Decision matrix for energy solution, 5 = most important, 1 = least important

Financing		Technical		Environmental		Independence	
CAPEX	3	Efficiency system	5	EIA	1	Maintenance	2
LCoE	5	Scalability	4	Carbon reduction	5	Energy storage	4
Payback time	5	Lifetime	4			Political difficulties	4
		Location	1				

All the topics were given a number between 1 and 5 to indicate the importance of the topic, where 5 is the most important and 1 the least important. The topics were scored by the Chief Executive Officer Daniel Hooft. During this research 5 different systems were analysed using the decision matrix. Where 2 solar possibilities and 3 wind possibilities were evaluated. The outcomes of the decision matrix can be found in Table 19.3.

Table 19.3: Multi-criteria analysis

	Score (1-5) 1 = worst / 5 = best		Solar				Wind					
	Variable	**Score (1-5)**	**Invest**		**Rent**		**DOT**		**Invest**		**Rent**	
	CAPEX	3	2	**6**	5	**15**	1	**3**	4	**12**	5	**15**
Financial	LCoE	5	5	**25**	3	**15**	2	**10**	4	**20**	2	**10**
	Payback time	5	5	**25**	N/A	**N/A**	2	**10**	2	**10**	N/A	**N/A**
	Efficiency system	5	3	**15**	3	**15**	5	**25**	4	**20**	4	**20**
Technical	Scalability	4	4	**16**	3	**12**	3	**12**	1	**4**	1	**4**
	Lifetime	4	5	**20**	5	**20**	3	**12**	3	**12**	3	**12**
	Location	1	5	**5**	5	**5**	1	**1**	2	**2**	2	**2**
Environment	EIA	1	5	**5**	5	**5**	1	**1**	2	**2**	2	**2**
	Carbon reduction	5	4	**20**	4	**20**	5	**25**	5	**25**	5	**25**
	Maintenance	2	4	**8**	5	**10**	2	**4**	3	**6**	4	**8**
Independence	Energy storage	4	1	**4**	1	**4**	3	**12**	1	**4**	1	**4**
	Political difficulties	4	3	**12**	3	**12**	1	**4**	2	**8**	2	**8**
		Average		**13.4**		**11.1**		**9.9**		**10.4**		**10.0**

To make a decision based on the different scores the average of the scores is calculated. The situation with the highest score is the investment in a solar system, with an average score 13.4. However, the possibility of building a wind turbine could also be beneficial and therefore is analysed further in section 19.5.

19.4. Photovoltaic solution

19.4.1. Method

In this section the methods used to design the solar system are described. To have a reference point for the system size, the photovoltaic potential for the specified locations was used. Together with the annual energy consumption and the photovoltaic potential, a lower bound for the system size was calculated. After this an approximation was first performed to establish the system sizing for the photovoltaic system, using the software SolarEdge Designer. The software was used in conjunction with Google Maps to configure a 3D model to determine the building's roofs' capacity. Normally, building drawings would be used for this, but since none were available, this was a workable substitute. The azimuths of the buildings were determined using Google Maps. After the capacity was determined, the technical aspect was designed using the modelling software System Advisor Model.

19.4.2. System sizing

To make sure that the system generates enough electricity to power the processing facility's biostimulant production, it has to generate 490 MWh per annum + 51 MWh for the desalination plant. For an initial estimation of the system size the 541 MWh is divided by the photovoltaic output of 2021.4 kWh/kWp per year, leading to a first approximation of 267 kWp. Due to system losses, the sizing will be higher. This will be further discussed in subsubsection 19.4.4.4.

19.4.3. System orientation/location

The roof with the greatest potential for energy is indicated by the yellow roofs to the right of Figure X. This is caused by the azimuth of the roofs on the north face. 96% of the solar radiation that is emitted in Lüderitz during the day is captured by these roofs. The roof of the processing center is visible in Figure 19.2 on the building to the left. These roofs have azimuths of 85 degrees and 265 degrees and are facing east and west, respectively. The roofs absorb 85% of the solar energy as a result of their orientation. As stated in section 13.7, all the roofs have a tilt of 25 degrees. In Table 19.4, the maximum amount of panels per roof section are presented.

Table 19.4: Distribution of the modules over different roof sections

	Azimuth	Tilt angle	Amount of panels
Roof 1	5	25	116
Roof 2	5	25	116
Roof 3	85	25	132
Roof 4	265	25	132
Total	/	/	**496**

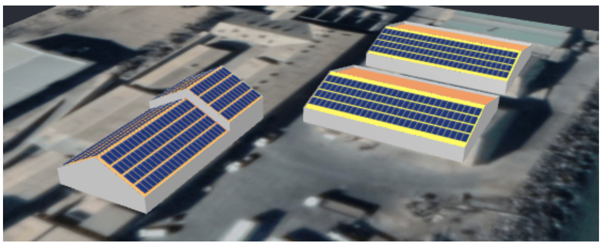


Figure 19.2: Design of photovoltaic installation

It was chosen to put the solar panels directly on the roof, without an additional tilt, to prevent row shadowing. Next to that, the optimal tilt angle for the solar installation for both roofs was 26 degrees, so the modules are already close to optimal tilt when they are placed parallel to the roof.

The designing phase could begin once the system sizes for each roof were approached. To simulate the system's performance in this case, we used the System Advisor Model. Clear understanding of the system's correct technical specs is required for this. The selection of module type, module configuration, and inverters are the technical requirements that are crucial for system design.

19.4.4. Technical

Module

It was decided to use the panel that one of the contractors had proposed for the module. The CS7L-600MS-R mono-C-Si module from Canadian Solar Inc. The details are attached in section B.4. Unfortunately, no additional invoices were received, making it difficult to estimate the variety of module types that could be used for this project in Lüderitz. As a result, it was decided to implement the concept using this particular module. This system can, however, be created using different modules. The module configuration of the system may differ from what is shown here because each module has its own sizes.

Module configuration

The configuration of the module on the roofs is of great importance to the efficiency of the system. To ensure that all roof surfaces are separately monitored by the maximum power point trackers, they must be connected to separate MPP trackers. The modules must be divided into several subarrays, which in turn are divided into several strings. Each string contains 16 modules and there are 8 strings in parallel per subarray. The number of modules per string is series-connected and so the voltage per module is multiplied by the number of modules per string. This gives the electrical composition, which can be found in Table 19.5.

Table 19.5: Electrical configuration

	Subarray 1	Subarray 2	Subarray 3	Subarray 4
Module per string	16	16	16	16
Strings in parallel	8	8	8	8
Number of modules	128	128	128	128
String Voc	660.8	660.8	660.8	660.8
String Vmp	558.4	558.4	558.4	558.4

It is also important that currents and voltages are not too high. To ensure enough safety, the voltage should not become too high. In addition, too high a current creates losses, so that should not get too high either. The current configuration ensures that both aspects are respected. The open circuit voltage of these panels is 41.3 V. This gives a voltage of 660.8 V per string. The short circuit current of the module is 18.47 A. When the string operates at its maximum power point, a power is generated of 9.6 kW. Thus, a total power of 307 kW DC is generated.

Inverter

Every roof surface needs its own configuration with at least one inverter, to generate high energy yields. If different oriented systems would be connected to the same inverter, high losses would occur due to difference in irradiation per surface. Because the module with the lowest irradiation determines the voltage that flows through the subarray, there should be a clear distinction between the different roof surfaces. Therefore, all of the inverters are designated to a subarray. The inverter that was chosen is the CSI Solar Co Ltd: CSI-75K-T480GL02-U [480V]. The maximum power of these inverters is 75 kW, which is high enough to fit all the four subarrays of the system on. This gives a DC to AC ratio of 1.02. This gives an overall AC power of 300 kW. To determine the real outcome of the system the losses have to be taken into account.

System losses & efficiency

The system is not entirely efficient due to a number of factors. The soil that settles on the panels is one occurrence that has a significant impact on the system's effectiveness. The effect is predicted to be 10% for coastal areas. Shading is a different occurrence that can have a significant impact on the system's performance. There won't be a row shadowing because a system is chosen here to be installed parallel to the roof. Next to row shadowing, the environment can create shade, which lowers performance. This effect is only barely taken into consideration with an efficiency loss of 2% because both roofs are in open spaces without any significant objects to cast shadows. The system's performance is also significantly influenced by temperature. STC conditions, or the standard temperature at which a module is tested, are 25 degrees Celsius. SAM estimates a loss of 4.8% since the average operating temperature is

11.9 degrees Celsius higher than that. Another effect that causes losses is clipping. Clipping results from the inverter's undersizing. When a system produces more energy than the inverter can manage, maximum power is produced as a result. Another 4% is lost as a result. Cabling losses are the last type of loss. Friction in the cables results in energy loss. SAM's standard value of 2.5% for DC power loss and an extra 2% for AC wiring were adopted.

This gives a total performance ratio of 0.71. This is mainly due to the soil that lands on the modules. This can be partly solved by maintenance schedules where the soil is removed from the modules. Other losses are unavoidable and common in solar systems and should therefore be considered during design. This gives an annual AC energy output of 549 MWh. This is the size of the system that is desired to power the processing facility and the desalination plant. Therefore the system is sized well.

Next to the overall performance of the panels, the efficiency drops every year. It was assumed that in the first year, the panel's efficiency dropped 2% and the years after with 0.55%.

Carbon reduction

As is well known, solar energy is a renewable energy source that does not emit CO_2 during its operations. In contrast, the materials used to build the system are not entirely sustainable. Therefore, an average CO_2eq emission per kWh can still be calculated. For photovoltaic systems, this is estimated to be 0.041 kg CO_2eq/kWh (*Carbon Dioxide Emissions From Electricity - World Nuclear Association*, 2022). This is a 95.0% improvement over grey electricity generated by coal. So it can be concluded that this is a sustainable alternative. The system that is described in this section emits 22.9 tonnes CO_2eq annually, due to the materials that are used in installation. To produce energy with the installation, no greenhouse gasses are emitted.

EIA

For the environmental impact assessment, there will have to be a study of the environmental impact of installing the plant. How will the installation affect the environment? For example, it must be considered that birds do not regard the panels as water at night due to the reflections from the modules. In addition, the installation should not be placed where many birds go through the breeding season and normally build their nests there. This survey can be done by the contractor or can be done yourself with the help of an expert. This should not cause too many problems according to the Namibia Nature Foundation.

Maintenance

Using a monitor on the wall, you can see what the energy yields are. If the numbers do not match what was predicted in terms of yield beforehand, it may be useful to perform maintenance. Maintenance consists of checking the wiring, making sure the installation is still properly mounted after a heavy storm and periodically cleaning the modules. This can be done by the mechanics of Kelp Blue or done by a third party.

Energy storage

For energy storage, the choice was made to exchange electricity with the grid. What is overproduced during peak days will be supplied to the grid. If too little energy is produced, electricity can be withdrawn from the grid. Thus, all net energy is provided by renewable energy. This is a financially attractive option since a feed-in tariff is paid on the energy you put back into the grid. If batteries were used, the costs would skyrocket. An initial indication from a contractor indicated that it would be at least 15 million NAD. That would mean the cost of energy storage would take up around two-thirds of the entire system. Therefore, this idea was dropped. The LCoE, would raise above the current electricity price and therefore isn't favourable.

Availability

Lüderitz is a remote place and it may take some time for certain products to be delivered. Therefore, it is important to get a better understanding of the materials available in Lüderitz but also in Namibia as a whole. To get better impressions, several contractors were approached to provide information about the products they use for their projects. Unfortunately, only one contractor responded and therefore the materials provided were used. It is certain that materials from several photovoltaic technology manufacturers are available, however, they were not obtained during the study. Many companies focus mainly on very large installations. This makes it more difficult to focus on a relatively small installation. However, with good contacts, this should be possible.

Financials

To arrive at a clear cost picture, it is important to consider the portion that is generated by the system and actually used for operation and the portion that is the surplus and thus fed back to the grid. This is also known as the simultaneous rate, which is assumed to be 55%. For the power that is returned to the grid, a feed-in fee of 0.99 NAD per kWh is generated . To then take that power back from the grid, the LTC price must be paid for it, which consists of an energy tariff and two taxes. That works out to NAD 2.09 / kWh in 2023.

To calculate the LCoE for the solar system, investment costs and maintenance costs must be calculated. To properly estimate the investment cost, a Watt peak price is used. This includes the cost associated with installing the power of 1 Watt peak. These are estimated at NAD 17 per Wp (€0.90 / Wp). This estimate is based on current Watt peak prices in the Netherlands, obtained through an independent solar panel installation consulting firm in the Netherlands. The estimate is €0.15 / Wp higher than the current Watt peak prices in the Netherlands to create a buffer.

The maintenance costs are estimated at NAD 170 per kWp per year and insurance of the installation at 2% of investment costs divided by the depreciation period. This gives an annual insurance premium of NAD 6958.67 per year. Finally, grid management and metering costs are taken into account, set at NAD 600 per year. All these costs give a total LCoE NAD 0.67 per kWh.

The current LCoE is the electricity price from the grid. It amounts to an average of NAD 2.31 / kWh over the next 15 years, assuming indexation costs of 1.50% annually. When this is compared with the new LCoE, NAD 0.67 / kWh, it quickly becomes clear that installing solar panels is an attractive choice financially. Because there are still uncertainties about the processing center and the yield of the kelp forests, a dashboard has been made to make changes to the system size and the electricity prices, to see the financial benefits of this installation compared to the current situation. The dashboard can be found in a separate file. With the assumptions written in this section, the model was run. Figure 19.3, shows the results of the model.

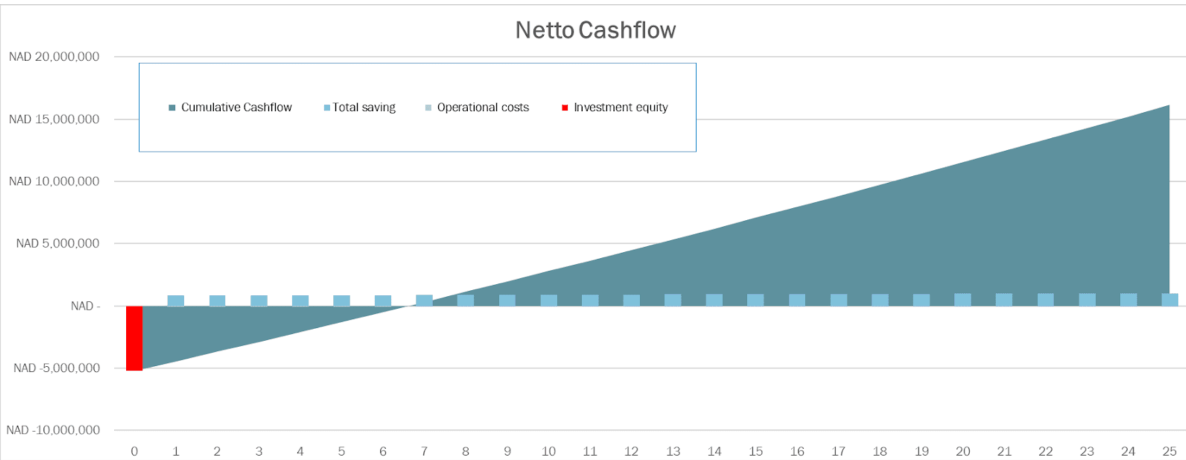


Figure 19.3: Netto cashflow photovoltaic system vs. grid electricity

This gives the cash flow overview of the solar installation compared to the current situation. The investment costs for the installation of 307 kWp, with a Watt peak price of NAD 17, gives in initial investment of NAD 5,219,000 (€287,000). The savings in the first 7 years will be high enough to earn the investment back. With a lifetime of 25 years, this will lead to total savings of NAD 16,165,000. The internal rate of return (IRR) over 15 years is 4.8% and over 25 years 13.4% which make this investment a financially attractive option.

If Kelp Blue is not able to fund this project, there is a possibility that they have to raise funding. This would increase the LCoE because interest has to be paid back to the funding party. If that is not desired there are also other options to consider to fund the project and install the system. One of these possibilities is that Kelp Blue doesn't become the owner of the installation, but the contractor does. This would take all responsibilities of the system away from Kelp Blue, because the maintenance is not its problem. After 20 years, Kelp Blue becomes the owner of the system and can decide what to do with the installation.

Kelp Blue has to pay the contractor a price per kWh to get energy from the contractor's power plant. The price that Kelp Blue has to pay is 1.80 NAD per kWh, which is based on the proposal that was received from SolarSaver, a Namibian solar contractor. This is still less than the price of LTC and you use sustainable energy instead of grey energy. However, the prices that Kelp Blue has to pay per kWh compared to the prices it could pay when investing in their own plant are significant (0.67 NAD vs. 1.80 NAD), where the LCoE of the Kelp Blue owned plot are almost three times lower. A trade-off has to be made by the management team to decide which of the options is favourable.

The internal carbon price used by Kelp Blue is $250 per ton of CO_2eq. 0.82 kg CO_2eq are released for every kWh of grey electricity (*Carbon Dioxide Emissions From Electricity - World Nuclear Association*, 2022). Then, NAD 3.49 per kWh would be the additional cost that would need to be taken into account for grey power. It comes out to NAD 0.17 per kWh when combined with solar power. The price for grey power is then NAD 5.58 per kWh, while the price for solar power is NAD 0.84 per kWh. This demonstrates once more that there is a strong incentive to invest in renewable energy.

Political difficulties

It remains to be seen whether LTC & ECB will agree to allow the system to be built. For that, Kelp Blue must first get its license from the ECB. In that process, there is also the chance that an IPP license will be required, although not necessary under current laws and regulations since the system is under 500 kW. An IPP license is required as soon as your system size exceeds 500 kW. Below 500 kW, you are allowed to produce 100% of your own consumption. If your system is larger than 500 kW, you are only allowed to generate 30% of your energy consumption from your own system. In addition, the 30% would also be increased to 50% in the coming years. To ensure that your installation can be fully utilized, a license must first be issued.

19.4.5. Conclusion

It is recommended to invest in a solar energy system. Putting solar panels into service provides a 95.0% reduction in CO_2 emissions. Not only because it is a sustainable alternative to the current energy supply, but also because it is much cheaper energy. It is an investment that is well worth the money and the cost of which will quickly pay for itself. It is advised against using batteries to store energy and using the grid to store electricity since batteries contain many materials that are harmful to the environment and are also very expensive, therefore making it an undesired solution. To ensure that the plant is allowed to be built and used to its full potential, it must first be licensed by the ECB, have an EIA done and have an engineering firm calculate the roofs. If those procedures are approved, there are no more hurdles in the way. However, more research is expected to be done on different contractors and their abilities. That is something that was not successful during this study. If the situation changes the assumptions that have been made can be changed by using the Excel File: Solar Dashboard - Kelp Blue.

19.5. Wind energy solution

19.5.1. Method

This section explains the method used to explain the most fitting type of wind turbine for this situation.

The following method was used: using the SAM software, several wind turbines were tested using the online data sheets obtained from the website: wind-turbine-models.com, the most suitable wind turbine was modeled iteratively. In this software, one is first asked for the wind profile in the form of a Weibull curve, this is entered from the data that came from the analysis in section 13.4.1. By iterating several times with the different sizes and parts, a suitable wind turbine will eventually be shown.

19.5.2. System sizing

For the initial sizing, use has been made of the method described in section 18.3, this amounts to the use of a capacity factor of 0.429. Now, using the energy consumption data, it is found that the installation would need to generate 490 MWh per year for the processing facility and 51 MWh for the additional desalination plant, totalling an amount of 541 MWh. Using the capacity factor as a reference, will this amount to an installation size of 148.3 kW. This gives a moderate idea of the size of the wind turbine. Now, one will be using the SAM software, where data as shown in Figure 19.4 is filled in, obtained from previous sections covering the wind turbine installations.

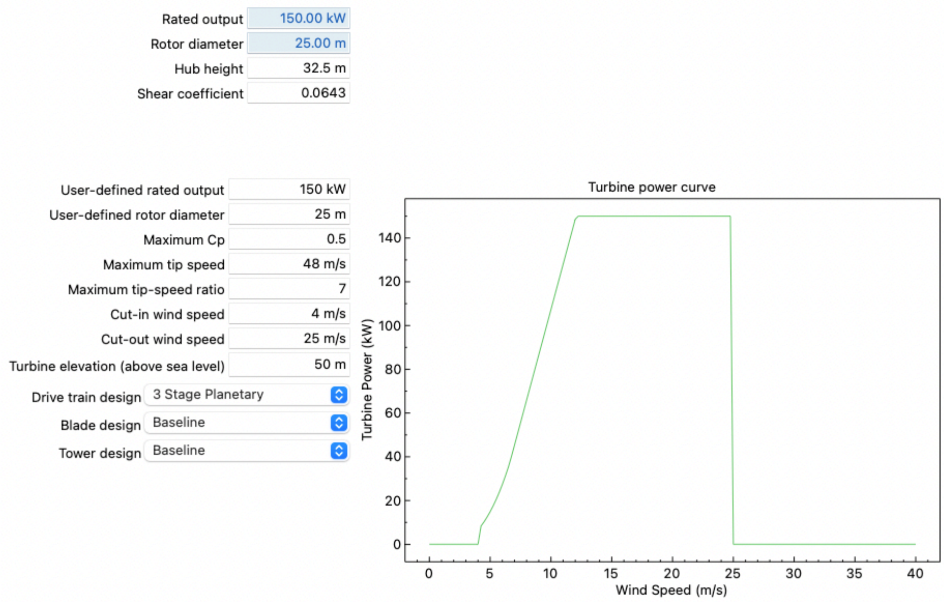


Figure 19.4: System sizing parameters of wind turbine

Since a single wind turbine is used, there is no need to consider placement to minimize wake losses. Finally, the efficiencies are filled in as explained in the previous sections.

The turbine that will be used is Vestas V23/150, a picture of this turbine is shown below in Figure 19.5. The SAM simulate software yields a specific capacity factor of 0.429 in this case, a very high and thus adequate factor. To further develop the model, an Excel has been made in which the losses and costs are entered and the project specifics are shown, this dashboard has been sent to Kelp Blue, and can be made available per request by the authors of this report, or a picture in the Appendix.

Figure 19.5: The Vestas V23/150 turbine

19.5.3. System orientation & location

As described earlier, the construction of the wind turbine near the processing facility is prevented by local regulation. As a result, the turbine will be located about 2 kilometers from the coast, as close as possible to an electricity grid or the processing facility itself. Care must be taken when placing the turbine, for ground profile and possible forms of wake's from other large objects, such as other wind turbines. This will not be a problem with space in Luderitz, and arrangements will be made with the city council for the exact location. As wind turbines can pivot, the compass direction does not bother too much, however it should be noted that as the wind will originate primarily from the south, it should be taken into account if possible.

19.5.4. Technical

Wind turbine

The choses windturbine is the Vestas V23/150, this was a wind turbine produced by Vestas, a Danish company that is one of the leading manufacturers of wind turbines in the world. The V23/150 has a rated power output of 150 kilowatts and is designed for use in small and medium-sized wind power plants. It has a two-bladed horizontal-axis rotor and a tower-mounted nacelle, which contained the turbine's generator, gearbox, and other mechanical and electrical components. The V23/150 is known for its high efficiency and low operating costs, and it is widely used in a variety of locations around the world. Due to these capacities it is considered financially and technically attractive to invest in this second hand.

19.5.5. MCA evaluation

System losses & efficiency

The system losses have previously been described in section 18.3.

Carbon reduction

Wind turbines do not emit carbon dioxide or other greenhouse gasses directly, as they do not burn fossil fuels to generate electricity. However, the process of manufacturing, transporting, and constructing wind turbines does require energy and materials, and this can result in indirect emissions of CO_2 and other greenhouse gasses. These indirect emissions are typically much lower than those associated with the generation of electricity from fossil fuels, and over the lifetime of a wind turbine, the electricity it generates will result in significant net reductions in greenhouse gas emissions compared to fossil fuel-based electricity. A harmonization assessment by Dolan and Heath analyzed 240 LCAs and calculated an average of 11 g CO_2-eq/kWh. When using this wind turbine, some 6.1 tonnes CO_2/year will be emitted annually, compared to the scenario where gray power is consumed, that is a reduction of 98.7%.

EIA

As stated, an environmental impact assessment (EIA) is a process that evaluates the potential effects of a proposed project on the environment. In the case of a wind turbine in Namibia, an EIA would assess the potential impacts of the turbine on air and water quality, wildlife and habitat, and the local community. The assessment would also identify potential mitigation measures to minimize any negative impacts. The following shall generally be done for such an assessment.

The environmental impact analysis for wind turbines typically involves several steps, including:

- Identifying the potential environmental impacts of the proposed wind turbine project, such as noise, visual disturbance, and effects on wildlife.
- Collecting data on the local environment, such as wind patterns, soil conditions, and the presence of sensitive species.
- Developing models to predict the potential environmental impacts of the wind turbine project.
- Evaluating the potential environmental impacts and developing mitigation measures to reduce or eliminate any negative effects.
- Preparing a report summarizing the findings of the environmental impact analysis and presenting it to the relevant government agencies.

The environmental impact analysis for wind turbines is an important step in ensuring that wind energy projects are developed in a responsible and sustainable manner.

The EIA for this project specifically might be a challenge, as according to the Namibia Nature Foundation, a bird migration route is very near to potential building sites. This could cause serious harm to the project, however, three other wind turbines have also been placed near these potential building sites, meaning there is a precedent to building here.

Maintenance

Wind turbines require regular maintenance to ensure that they are operating safely and efficiently. Some of the tasks that may be performed during maintenance include:

- Lubrication: The gearbox and other mechanical components of a wind turbine require regular lubrication to reduce wear and tear.
- Inspection: Wind turbines are inspected on a regular basis to identify any potential problems or damage.
- Cleaning: The blades and other external parts of a wind turbine may need to be cleaned to remove dirt, debris, or ice.
- Repair and replacement: If a problem is identified during an inspection, the necessary repairs or replacements may be made during maintenance.
- Monitoring and data analysis: Maintenance technicians may also perform monitoring and data analysis to identify trends or patterns that could indicate potential issues.

It is important to properly maintain wind turbines to ensure that they are operating at their optimal performance and to extend their lifespan. Maintenance schedules for wind turbines may vary depending on the specific model and the operating environment.

It is our estimate that wind turbines are the less desired option compared to PV systems in terms of maintenance, due to the more difficult tasks of maintaining.

Energy storage

Energy storage is possible in two forms, using a physical storage device, such as batteries, or using a theoretical storage device; net metering. Research has been done on the financial possibility of using a form of storage as previously discussed in this report. However, first indications from contractors stated that the costs of this project would increase by at least 200%, which is beyond the financial possibilities of this research.

Therefore, net metering will be used. Net metering is a policy that allows individuals or businesses with renewable energy systems, such as solar panels or wind turbines, to sell excess electricity back to the grid. When a renewable energy system generates more electricity than the user consumes, the excess is fed back into the grid, and the user's meter runs in reverse, effectively storing the excess energy in the grid. The user is then credited for the excess electricity, which can be used to offset their future energy costs. An important note is that the local regulations are currently not suited for this specific project, but it is believed that Kelp Blue's local influence will be able to persuade the local government into a partnership to make this possible.

Availability

The availability of wind turbines in Namibia is difficult so far, even though the natural resources are great, the industry is just ramping up. Getting a wind turbine or its particles from Europe, the US or China will be a long and expensive journey. South Africa might be a better option but that's also not that easy, distances are long and roads are all right but not great. Unfortunately we didn't get a lot of responses from contractors, but the ones that did respond said these size installations were not attractive enough for them to further look into as of yet.

Finance

To get an overview of the financial feasibility of this project, a financial model was created in Excel to compare the PV and Wind solution with each other. In the financial analysis for the PV solution, a more detailed dashboard was shown that was created after it was decided that a PV solution was more suitable than wind for Kelp Blue's requirements. In this section, the more high-over dashboard will be used to assess the financial feasibility.

The wind turbine specific inputs are the system losses, as previously described, the metrics of the used installation which yield a capacity factor and the lifetime of this wind turbine which equals 20 years. Project specific, a discount rate of 3% is used, which is normal for this kind of project and a simultaneity coefficient that has been estimated at 80% following the typical usage graphs of energy production and consumption. Thereafter, the estimated costs for the wind turbines procurement, shipping, installation, maintenance and decommissioning was used. This was rather difficult to obtain due to almost no responses from Namibian contractors in the period of this project. Therefore, some rough estimates have been used which can be seen in the Excel dashboard.

These inputs are used together to obtain some metrics which are used to compare the wind turbine solution with the PV. The most important one being the Levelized Cost of Electricity (LCoE), where the costs per kWh are shown. The dashboard accounts for the discounted price one gets for using net metering, and uses this to calculate an average total price based on CAPEX and OPEX and keeps in mind degradation of the years to get an average LCoE of €0.053 per kWh. This makes it a bit higher than the solar PV option.

It shall once again be stressed that too many unknowns can have too big of an influence on the financial feasibility of the project, and therefore the dashboard can be used to reassess the situation whenever more information is acquired. The full dashboard can be accessed via the authors.

For financing, the same goes for PV financing. One could take out a loan, or rent the system from a specialized company against a certain fee per kWh. This would also make it easier to maintain as this specialized company will take care of that.

Political difficulties

Building a wind turbine in a small town like Luderitz will have a big impact. Besides the same problems encountered as described in the political difficulties of PV installations, namely the licensing of the energy system, also the environmental impact will play a bigger part. The wind turbine will have to be built a shear 2 km away from the factory near a bird migration zone, this will mean that it will probably be more difficult to get permission to use and build this wind turbine.

19.5.6. Conclusion

It is not recommended to invest in a wind turbine compared to a solar PV system. This is mainly due to its financial advantage, and ease of implementation and scaling. However, it is also recommended to keep in mind the wind solution option as this provides certain other advantages, such as similarity coefficient, efficiency, and the option of integrating a desalination unit with the Delftse Offshore Turbine technology.

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Recommendations

20.1. Solar installation

Since there were still many uncertainties at the time of research, many assumptions were made as a result. Of course, the situation that has been pre-sketched may not correspond to reality. It is therefore important to properly analyze the new situation and compare it with the current analysis.

For example, the roofs that are currently used for the design of the photovoltaic system should be looked at carefully. The roofs must be calculated to see if they can support the forces. An outside engineering firm should be called in to do this.

If it appears that the roofs cannot handle the forces, it is advised to look out for a land that can be used for a land arrangement. For the efficiency of that system, it is recommended to use bifacial modules. These modules also capture light at the bottom of their module and can thus absorb the reflected light rays from the ground and convert them into energy.

In addition, close attention should be paid to the design of the system to avoid as much row shadowing as possible. This is now the case with Pescanova's installation, making the system much less efficient.

20.2. Energy availability

Another component of great importance is the scaling up of the system in the future. Energy water supply must be carefully considered if Kelp Blue is going to scale up. The advice given in this report is based on processing 1,000 kg of giant kelp per hour. In the future, it looks like Kelp Blue wants to scale up their production to eventually 800 ha of harvests per month. That will ensure that giant kelp will be processed in gigantic quantities. This is accompanied by large increases in energy and water supply. To meet the energy demand, it is important to find sustainable solutions. One such solution can be found in purchasing renewable energy from larger solar or wind installations for an agreed upon fee.

20.3. Water availability

According to the LTC, water will still be available in sufficient quantities to meet Luderitz's demand in the coming years. If Kelp Blue starts to scale up from 20 ha to eventually 800 ha, there will be an excessive increase in water demand. This would mean that in theory 31,285 m3 per month will be used by Kelp Blue. Since the sustainable capacity of the Koichab Pan is estimated at 5,500 m3 per day, Kelp Blue will have a significant demand of water of 18.7% of the available water. Therefore Kelp Blue should look into alternative sources for water.

The solution can be found in two different options: Produce its own water or increase the supply of water. The first option is possible by installing a desalination plant with a capacity that meets the demand of the process. Increasing the supply of water could be done by diverting excessive water from the Hyphen project to Lüderitz. This is more difficult to regulate and, as a result, Kelp Blue's operations are likely to become dependent on this project. To stay in control, Kelp Blue would do well to build its own water supply infrastructure by the time it is needed.

20.4. Marine fuel

A very large share of carbon emissions is caused by the use of diesel for the boats. For this reason, it is important to briefly highlight the different technologies of this, and explain why they are or are not suitable for use by Kelp Blue. There are several renewable fuels that can be used to power boats, including biofuels, hydrogen, and electricity. Biofuels are fuels that are derived from biological sources, such as plant oils or animal fats. These fuels can be used in boats that are equipped with engines that are designed to run on biofuels. Hydrogen is another renewable fuel that can be used to power boats. Hydrogen fuel cells generate electricity through a chemical reaction between hydrogen and oxygen, producing only water as a byproduct. Electric boats are also becoming increasingly popular, as they use batteries or fuel cells to power an electric motor. These boats produce no emissions and are quiet, making them a good choice for use in sensitive environments. The technology for using biofuels in boats is well-established and widely used. Biofuels, such as biodiesel and ethanol, can be used in many types of boat engines, including internal combustion engines and diesel engines. These fuels are typically made from plant oils or animal fats, and they can be used as a direct replacement for fossil fuels such as gasoline or diesel. Many boat engines are designed to be flexible and can run on a mixture of biofuels and fossil fuels. Biofuels have several advantages for use in boats, including reduced emissions and the availability of renewable sources of fuel. The use of biofuels in boats is thought to be a mature technology that is prepared for mass use. The technology for using biofuels in industrial boats, such as cargo ships and oil tankers, is still being developed and is not yet widely used. While biofuels can be used in many types of smaller boats, the large engines used in industrial boats require specialized fuel formulations and can be more challenging to adapt for use with biofuels. Additionally, the availability of biofuels in the quantities and locations needed to fuel industrial boats can be a challenge. There is ongoing research and development in this area, and some industrial boat operators are starting to test the use of biofuels, but the technology is not yet considered to be mature or ready for widespread use in this application. The technology for using hydrogen as a fuel in boats is still in the early stages of development and is not yet widely used. While hydrogen fuel cells have been successfully used to power cars and other vehicles, the unique operating conditions of boats, such as the need for fuel that is stable at high temperatures and pressures, have presented challenges for the use of hydrogen as a marine fuel. There is ongoing research and development in this area, and some boat manufacturers and operators are starting to test the use of hydrogen fuel cells, however, the technology is not yet seen as being developed enough or prepared for general usage in boats. The technology for electric industrial boats, such as cargo ships and oil tankers, is still in the early stages of development and is not yet widely used. While electric boats have been successfully used in many smaller applications, the large size and power requirements of industrial boats present significant challenges for the use of electric propulsion. There is ongoing research and development in this area, and some boat manufacturers and operators are starting to test the use of electric propulsion for industrial boats, but the technology is not yet considered to be mature or ready for widespread use in this application. It is our advice to keep monitoring the advancements within this field, as both the finances of Kelp Blue and the technology readiness are not sufficient to be involved in these endeavors as of now, but will surely make a great impact in the future.

Part III

Synthesis

21 Overall conclusion

At the beginning of this project, the research question was asked how Kelp Blue could sustainably scale up their operations in Lüderitz, Namibia. To fully answer this, it was decided to divide this research question into two parts. The first part focused on the sustainable scaling of the actual operations, and the second part focused more on the energy consumption during these operations.
When looking into the actual sustainable up scaling of the operations, it was analyzed that the current installation method was not scalable for Kelp Blue's ambitions. The main reasons for this are use of bulky heavy gravity anchors and spreader bars that are difficult to transport and place, and that connections have to be fastened by hand underwater. These make operations not fast enough and laborious, the error margin high, and thus impossible to scale up sustainably.

This report has proposed a new design for both the installation and the installation method. In order to achieve this point, the following 3 points were considered; ”How to descend the array structure down to the desired depth of 15 [m] from the water surface, without the use of divers or work class ROVs”; ”How to lock the system in place at the desired position, without the use of divers or work class ROVs”, and; ”How can the operations team continue the installation, after they have been absent from the installation site for an indefinite period”.

To get an installation at the desired depth of 15 m, ropes must be used that are cleverly guided through certain points and attached to the corners of a net module. Then by pulling on the ends, the corners will all reach a point where they cannot go any further. This relatively simple option turned out to be the best of all options, which was determined by means of an MCA. Actual testing of the design could not take place due to time and resource constraints.

To secure the nets at the desired point without the use of divers or ROVs, self-fastening mechanisms will have to be used. A number of designs have been made for this, which have been weighed up against each other. Due to time and resource scarcity, it was decided to make a prototype of the latch lock system, which was also tested on a real scale.

Finally, the analysis also revealed that Kelp Blue will need to use additional equipment to install their modules without the help of divers or ROVs. A relatively simple solution has been found for this, which also makes it easy to resume the operation at a later time. By using double ropes and temporary buoys, Kelp Blue can not only stop their operation at any time to continue at a later time, but also recover all unnecessary installation material so that nothing is left behind.

The redesign of the module also came with a redesign of the installation method. All the aforementioned points have been included in a detailed step-by-step manual written for the operations team of Kelp Blue. This will also have to be tested to find out how much time the new design saves compared to the old one.

As part of the research, the carbon emissions of Kelp Blue were analyzed too. The findings revealed that marine fuel was the primary contributor to the company's carbon emissions. This is likely due to the fact that Kelp Blue operates in the marine industry, which is heavily reliant on fossil fuel-powered ships and machinery.

However, the research also found that due to current technological limitations, there is limited potential for significant improvement in this area in the short-term. Despite significant recent advancements in renewable marine fuel technologies such as biofuels, hydrogen, and ammonia, these options are still not widely available and face significant economic and operational challenges. Switching to these alternative energy sources would require significant capital investment and operational changes, and might not yet be technically or economically viable.

While the reliance on marine fuel remains a significant source of emissions, the research suggests that Kelp Blue should consider other opportunities to reduce their carbon footprint. Options to consider include energy-efficient process and equipment design, investments in renewable energy to power processing facilities.

The research has found that Kelp Blue can sustainably scale up their operations in Lüderitz, Namibia by implementing renewable energy sources. The research found that solar energy was the most viable option for powering the processing facility in Lüderitz. The location of the facility in a region with abundant sunlight, as well as the high cost and limited feasibility of building a wind turbine, made solar energy the clear choice. The installation of solar panels and the necessary infrastructure would allow Kelp Blue to significantly reduce their dependence on fossil fuels and lower their carbon footprint.

Additionally, the research found that building a sea water reverse osmosis desalination plant would be a cost-effective solution for obtaining the water necessary for the processing facility. The cost of water obtained through the desalination plant was found to be lower than the cost of water obtained through the Lüderitz water grid, making it a more financially viable option. The desalination plant would also help the facility to not rely on the limited water resources of the region.

Overall, the research suggests that Kelp Blue can effectively scale up their operations in Lüderitz while also ensuring environmental sustainability. The redesigned installation and installation method shown in the first part of the report fulfil the research question. However, it is advised that Kelp Blue takes the necessary steps and actually tests all designs in their Shearwater Bay site before scaling up. The implementation of renewable energy sources, specifically solar energy, and the construction of a desalination plant, will help Kelp Blue to lower their dependence on fossil fuels and to obtain necessary resources in an environmentally sustainable manner. These recommendations, if implemented, will help Kelp Blue to scale up their operations in Lüderitz while also ensuring environmental sustainability.

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Afterword

For 10 weeks we stayed in Lüderitz, Namibia. Very early in the project we found out that this small port town with about 15.000 inhabitants, had more to offer than we thought beforehand. The economy of the old German colonial town was quite prosperous, due to the fishing and diamond mining industry. A large part of town had paved roads and almost all products that we are used to in the Netherlands, could be bought in town. Since we know a lot of Africa by pictures and movies, this was not what we expected at all. We were invited to work in Lüderitz by Kelp Blue, a start-up that is trying to build a company in the seaweed farming industry. Although the company is only situated in town for just over two years, everybody knows it and its activities. Kelp Blue is a company that is actively investing in the community, and this is paying off. The office is situated 200 meters from the sea. At this spot, the jetty they use is located as well, so if any problems occur with one of the kelp farms, they could be dealt with as soon as possible. The team of Kelp Blue, Luderitz, consists of a group of people with different backgrounds. The founder of the company and some engineers from The Netherlands, some interns that study at Universities in Windhoek and Capetown and local employees from Lüderitz itself. Despite the differences in culture, everyone at the office is friendly and gets along. There are regular team building events which make them much closer, although it is partly to learn how to work for a Dutch company with its norms and values. Working in such an environment made the project much more fun.

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A

Appendix farm

A.1. Boundary conditions and assumptions

Boundary conditions

It is required that…

General

- When installed, there are no physical elements between the netting (15m below the surface) and the surface other than kelp, buoys and temporary working lines.

Structural

- A connection is used that allows it to lock itself into place without divers or work class ROVs.
- The design allows a netting module to be extended in two directions.
- The required tension is generated through buoys and helical anchors.
- The required buoyancy is generated through buoys and kelp.
- The final design with commercial dimensions can be downscaled and tested with smaller dimensions at the Shearwater bay site.
- The final design uses at least 60% standardised marine hardware.

Installation

- A single module can be installed with the use of one larger vessel and two smaller ones.
- The netting modules can be installed without the use of divers or work class ROVs.
- The operations team is able to continue the installation of the netting array after they have been absent from the installation site for an indefinite amount of time.

Sustainability

- The material usage for the array structure is minimised.
- The amount of excess material required for installation is minimised.
- Excess material used for installation can be retrieved.
- Retrieved material used for installation can be reused.

Assumptions

It can be assumed that…

General

- There are no budget limitations in terms of material and machinery for the proposed future design.
- Risks of harming personnel during installation of the Macrocystis farms should be minimised by eliminating the use of divers.
- There is always a person present guarding the safety of the people during installation.

Structural

- Kelp Blue will make use of helical anchors as anchoring technique for the array structure.
- All the lines are made of polysteel in varying diameters.

Installation

- Kelp Blue will obtain a large installation vessel that can withstand bad weather situations.
- The helical anchors can be placed at the required location.
- The helical anchors can be installed with the mooring lines already attached.
- The helical anchors can be installed with the mooring lines already attached.
- The self-locking subsurface connections are checked through Micro or Mini observation ROVs.

Sustainability

- No consideration should be given to future maintenance.
- Negative effects on the marine environment should be minimised during installation and operation of the macrocystis farms.

A.2. Backup plan

Elements the project depends on:

1. Latch Lock system
2. Screw anchors
3. Buoys

Usages for these products:

1. Bringing modules to depth and connecting extra modules.
2. Anchoring a module.
3. Connecting screw anchors with mooring lines to a floating buoy which in itself is accessible from the water surface. Therefore, the male part of a netting module can be connected to one of the two female parts inside the buoy.

What to do when an insufficient amount of core elements is delivered?

The situation that could occur is an insufficient amount of products that can be delivered on time. For instance, what to do when only one latch lock system is delivered before the deadline? This problem accounts for all of the core elements. An example solution is given below:
For the second situation, some concepts in our design can still be tested. Bringing down and connecting a netting module, for instance, can still be tested if a buoy is installed by divers at depth. A working line will be pulled through the female part inside the buoy connected with a temporary buoy at the water surface. In addition, the locking mechanism of the design can be tested.

It must be clear that when an insufficient amount of a core element is delivered, the functionality of a single element can still be tested. Therefore this pathway is a simplification of the testing phase. Due to limitations in production processes and in time, this pathway could become one that can be chosen.

What to do if one of these products can't get delivered on time?

Latch lock system

<u>Problem:</u> If the latch lock system is not ready on time or not in a usable state, we encounter major problems, as this latch lock system is one of the key parts of our design. We cannot test the system itself anymore, and it is not possible anymore to submerge a module without any divers or ROVs.

<u>Temporary solution:</u>

- The best temporary solution would be to build a look-a-like with clutches just to get a proof of concept.
- Another solution might be to use a pulley with the exact shape of the latch lock system, to check how smooth the netting goes down. Which might include the help of divers.
- Lock the two corners in place under the surface with the help of divers and keep the last two corners and practice the process of bringing the last two corners down.

Screw Anchors

<u>Problem:</u> Without the screw anchors tests cannot be performed on the mechanism of the concept design. And the screw anchors themselves cannot be tested.
A second problem that could occur is an insufficient amount of anchors that are delivered.

<u>Temporary solution:</u> Find replacement anchors so the module can still be brought to depth. The surface

buoys will float in the water and we can continue testing our system of bringing a module to depth. We can at least test the concept design mechanism or the strength of a single anchor.

What do we need?:

- Replacement anchors. Preferably existing anchors because of time schedule. For example smaller gravity anchors or different kinds of anchors.
- Several lines connecting to the buoys.

Buoys

Problem: Without the buoys the first and an extra netting module can't be brought to depth without the use of divers. Therefore, the core of our project is at risk.

Temporary solution: Find existing buoys that we can use in its original state, or modify to our design, so we can still test our system of bringing a netting module to depth without the use of divers. If we use the existing buoys without modify them, because of time constraints, we have two options:

1. Redesign the male female part so that the female part can be connected to an existing buoy and our subsurface connecting system can still be tested.
2. Use divers to replace the latch lock system and fasten the netting module to the buoys after the required depth is reached. Therefore, we still test the bringing down part of our system by pulling two buoys to each other.

What do we need?:

- Replacement buoys. Preferably existing so time consuming procedures can be avoided.
- A redesign of the latch lock system might be necessary if existing buoys aren't modified.

Subsequent actions

Latch lock system

- Design a new concept with clutches or clamps and build it ourselves mostly to save time.
- Design the system where a pulley is attached to the existing BTP module at depth, so the bringing part of our system can be tested and specific complications can be discovered.

Screw Anchors

- Find replacement anchors which have the same strength as the helical screw anchors. Therefore, the mechanism of bringing down the module without the use of divers can still be tested by connecting the anchors with buoys.

Buoys

- Find replacement buoys in case the design can't be made. The buoys should have the same buoyancy as the concept buoys.
- Redesign of the latch lock system so that the female part can be connected to the outside of a buoy.

A.3. Prototype development

In this part of the appendix, a detailed explanation of the development of the latch lock system is given per different phase. The setup of these different phases was shown in chapter 5.1.

Making technical drawings to hand out to different potential contractors.

A 3D model of the first design made in Solidworks is shown in figure A.1. With this 3D modelling software, technical drawings can be made as well. The first series of technical drawings that were made and given to contractors can be seen in figure A.15-A.19 in Appendix A.5. One element that is missing in this design but was told to the contractors is the spring between the latch and the outer ring that locks the latch in the notch of the male part. The contractors from Lüderitz this design was given to were:

- Kraatz engineering Lüderitz
- Wesco engineering services Lüderitz
- M.M.H. Building Renovations Lüderitz

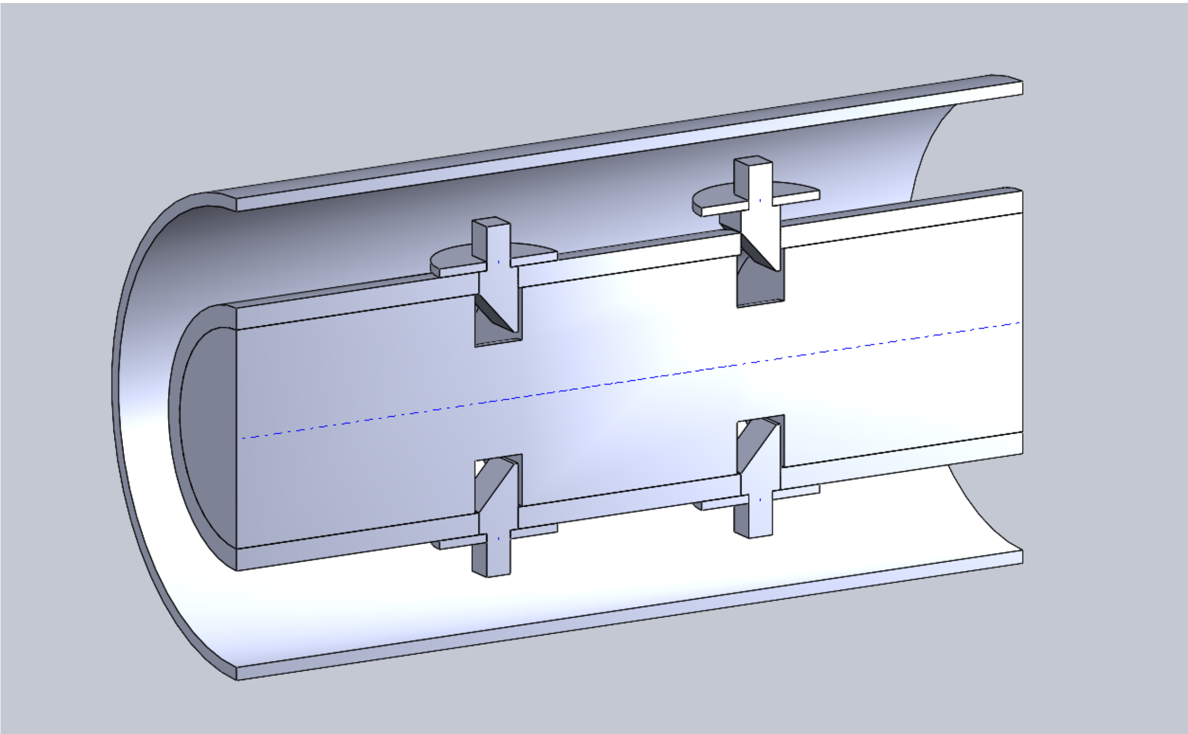


Figure A.1: First design of the latch lock system

Choosing a contractor based on costs, experience and earlier collaborations with the company.

All three contractors were visited when handing out the technical drawings. It was important that a good insight was obtained into the working conditions at the companies.
M.M.H. Building Renovations was based in a scrapyard. Although our contact person seemed to be experienced and the costs for building the prototype were low, the working conditions did not seem to be suitable for making such a prototype.
Wesco Engineering services did seem like a company that could provide the prototype. The company has sufficient equipment available to manufacture steel in a precise manner. However, they were expensive, and this is not something Kelp Blue was willing to invest in at this stage of the design process.

Kraatz engineering was the last option. This company has a fine workshop, and the costs for manufacturing the prototype were also reasonable. For these reasons, this company was chosen to produce the prototype.

Let the contractor start with building the first prototype, getting familiar with the design, and finding its flaws. Keep in close contact with the contractor to think about the adjustments that the design needs.

In consultation with Kraatz, the company started building the first prototype. They said they could deliver the product in two weeks, but this did not seem feasible after a week. The contractor took way longer than promised, and in the process, some flaws in the designs and process were found:

- The springs connecting the latches to the outer ring of the female part should be fitted precisely inside a cylinder. That is because the springs obstruct the movement of the latches if they can move horizontally. The change in design is shown in figure A.2.
- The equipment of Kraatz Engineering is not precise enough. Therefore they had to try to construct the different parts multiple times.
- The male part should not be a solid bar with notches but a hollow bar that fits through the latches with cones welded onto it.

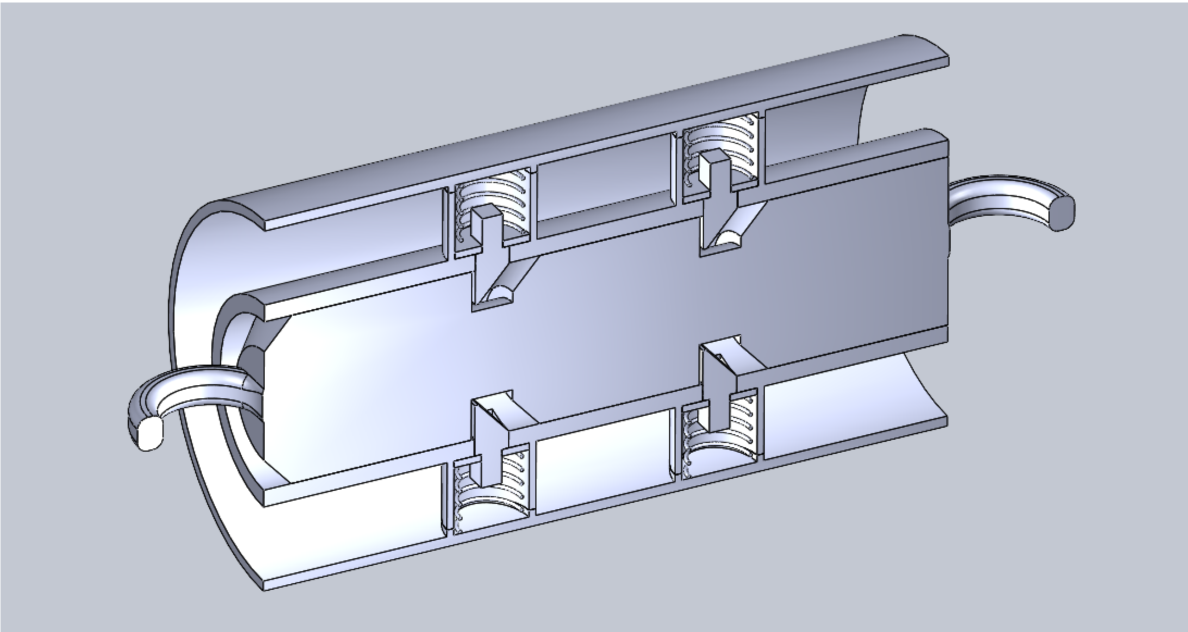


Figure A.2: Final design of the Latch Lock system

Finalise a design and a prototype.

After four weeks, finally, the prototype was delivered. The final design can be seen in figure A.3 - A.4. Some pre-assembled door latches were bought and implemented in the prototype. The male part, indeed a hollow bar with cones welded onto it, passes smoothly along the latches until it locks inside the female part. A plate is welded on the male part's backside to ensure that the male part does not slide through the female part too far. When the two cones have passed the latches, the plate blocks movement in one direction and the latches in the opposite direction. The last one is the direction where eventually, much force needs to be taken up.

(a) Male part

(b) Female part

Figure A.3: The manufactured latch lock system

Figure A.4: The inside of the female part where the latches can be seen

;
Test the prototype

Unfortunately the latch lock system is not tested while installed in a netting module. The latch lock system is individually tested off shore in the water. A sketch of the setup of the test is shown in figures A.5 - A.7 below. The functionality can be tested with this experiment.

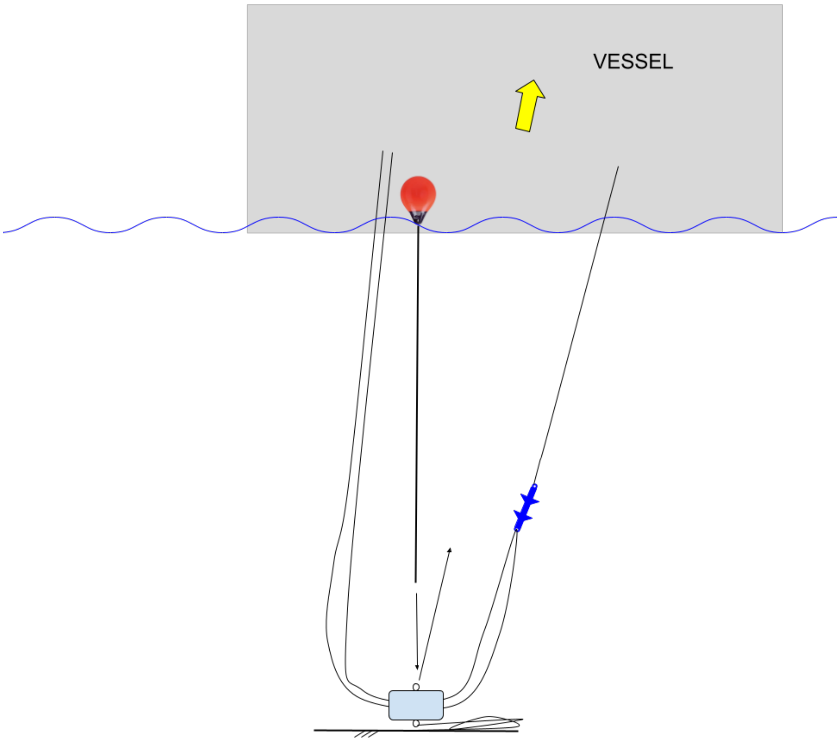


Figure A.5: Phase 1 of the latch lock offshore test

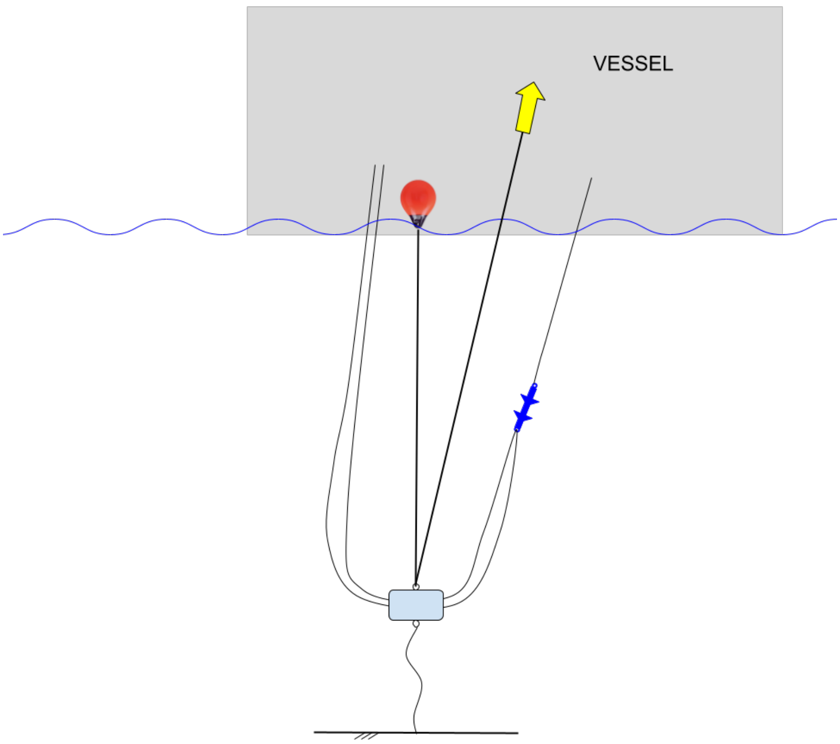


Figure A.6: Phase 2 of the latch lock offshore test

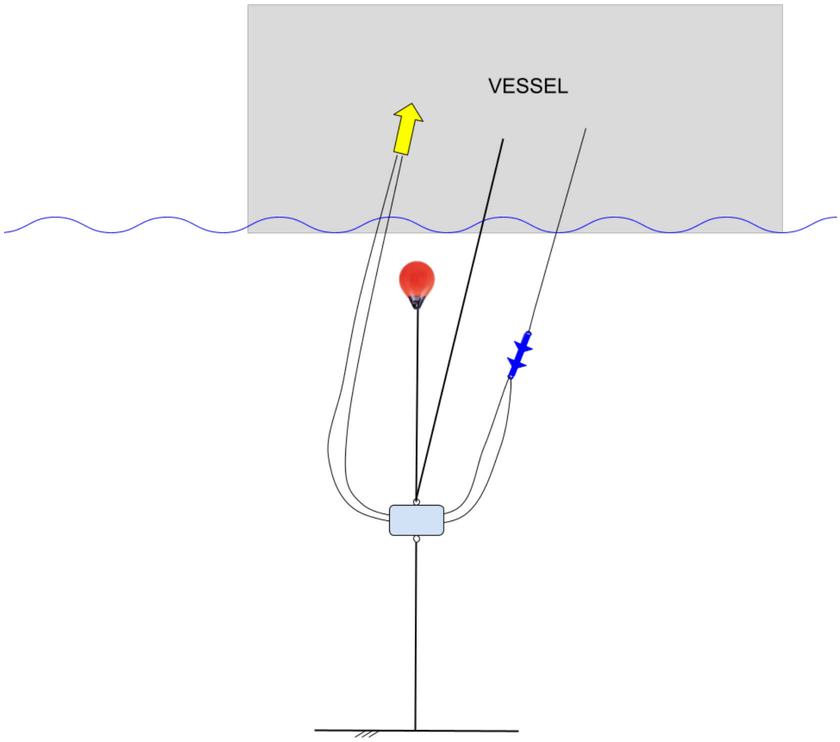


Figure A.7: Phase 3 of the latch lock offshore test

Results

The test of the latch lock system went perfectly. Despite the fact that the helical anchor could not be installed, a temporary weight was used as a downward force. The male and female part locked in perfectly at the desired depth.

A.4. Installation Manual - netting module Shearwater Bay

Phasing of operations

1. Onshore preparations
2. Anchoring
3. Water surface installation
4. Bringing the netting module to required depth
5. Bringing the netting module to required depth
6. Connecting additional module

Before Phases

Assuming the following products are ready for use:

- 6 Subsurface buoys. These are steel drums used in the oil industry.
- 10 Mooring lines (d=18 mm, L = 14.25 m)
- 6 Helical screw anchors
- 6 temporary anchors with 6 temporary buoys connected by 6 working lines of 10 meters long.
- 7 working lines of temporary anchors (d=12 mm, L = 16 m)
- 2 Temporary retrieval surface buoys
- Working lines of netting module(d= 12 mm) (L = 30 m)
- Marine hardware: Shackles, swivels, rings and thimbles
- 6 Poel pulleys
- 2 catenary chains with 4 shackles, the chains are X meters long.
- Netting module
- Marine vessels: Windvogel, Whale Rider, RIB, Dinghy

A.4.1. Phase 1 - Onshore preparations

On shore all the connections will be made so that the whole operations team knows what the module's connections will look like underwater. The module will be laid out once in the courtyard of the office. In figure A.8 a visualization is shown of this lay-out in the courtyard.

Important notes

- A quality check must be done on all the materials to be used
- After attaching lines to buoys make sure the connection is solid

Steps	Activity
Anchoring system	
1	Attach mooring lines (14.25 m) to helical screw anchors with a **thimble connected to a shackle, a swivel, a shackle and then the ring of the screw anchor.** Repeat this step for all **6** screw anchors. sidenote: - **4** of 6 screw anchors need two attachment connections to mooring lines. After disconnecting this from the screw anchor, make sure it is known that this specific combination of connections should be attached to the screw anchors.
2	Attach two mooring lines connected to screw anchors to subsurface buoys with: The mooring lines' **thimbles to shackles to the multi connection rings of the buoys**. Repeat this step for all the subsurface buoys. 10 mooring lines remain with a combination of connections on both anchor and buoy side.
Netting module	
1	The two vertical outer lines (+/- 11 m) of the grid need to be spliced with thimbles on both ends and have **10** knots one metre apart from each other. The two horizontal lines are connected to the end knots of the vertical outer lines of the grid. On both ends of the vertical outer lines of the grid, a pulley is connected as follows; **thimble, shackle, swivel, shackle, pulley** From each multi connection ring, a connection is made to the working line containing the pulley system: **shackle, thimble, workline (other end of the workline through pulley)** This working line will go through the pulley on the netting's corner.

Steps	Activity
Anchoring system	
1	Attach mooring lines (14.25 m) to helical screw anchors with a **thimble connected to a shackle, a swivel, a shackle and then the ring of the screw anchor.** Repeat this step for all **6** screw anchors. sidenote: - **4** of 6 screw anchors need two attachment connections to mooring lines. After disconnecting this from the screw anchor, make sure it is known that this specific combination of connections should be attached to the screw anchors.
2	Attach two mooring lines connected to screw anchors to subsurface buoys with: The mooring lines' **thimbles to shackles to the multi connection rings of the buoys**. Repeat this step for all the subsurface buoys. 10 mooring lines remain with a combination of connections on both anchor and buoy side.
	A mark needs to be placed at 20 metres of the workline that will be pulled on. In that way the operator knows when the winch needs to stop pulling.
2	The netting grid with all its connections is now ready and does NOT need to be disconnected at any points.
Working line of netting module	
1	Mark the working lines (30m) that will pull the netting module down at 10 metres and 20 metres.
Temporary anchor	
1	Preassemble the 6 temporary anchors with working lines of 10,5 metres to temporary buoys.
2	Place the anchors on the ground in the same pattern as in figure A.9 but downscale the dimensions. In between the anchors the working lines of 16 metres should be placed.
Catenary chain system	
1	Attach a shackle to each end of the chain

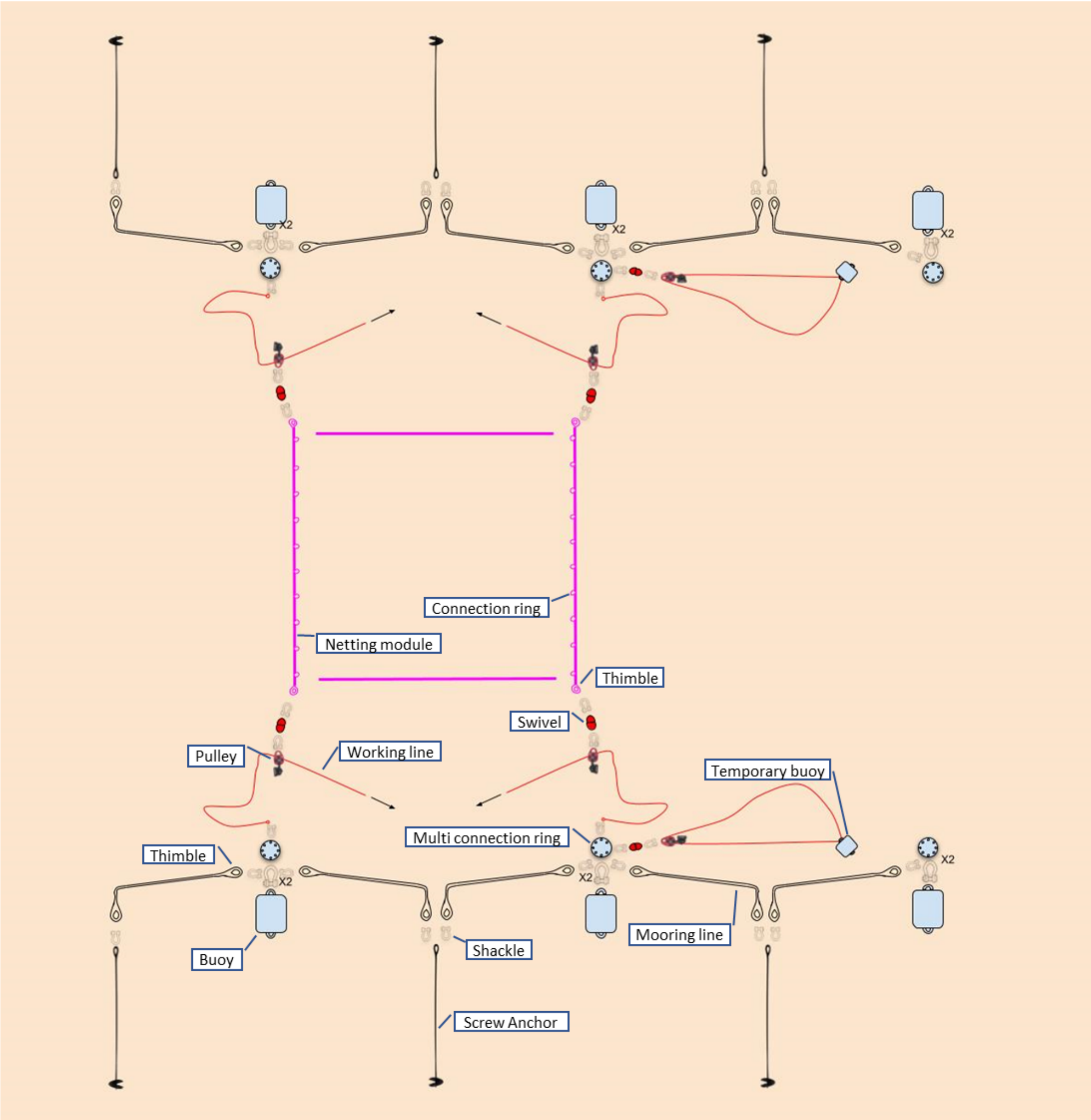


Figure A.8: Onshore preparations

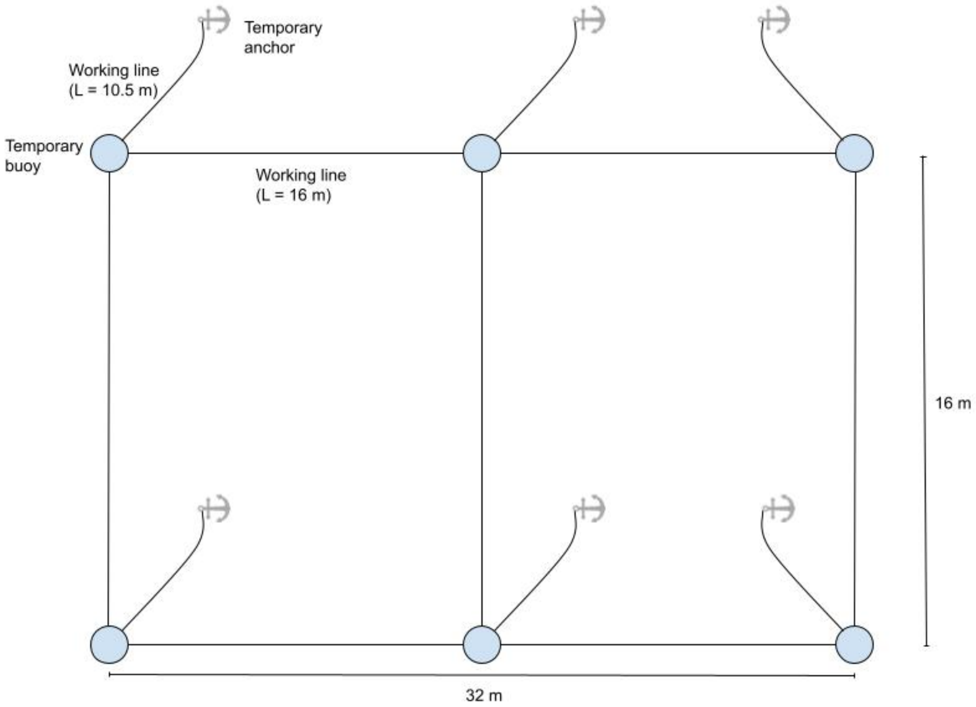


Figure A.9: Temporary anchors, working lines and buoys for the grid of the screw anchor installation

A.4.2. Phase 2 - anchoring

Assuming the following:

- The divers are equipped with the proper diving gear.
- The gear is checked before use and all safety procedures are known.
- The weather is calm and the water is safe to dive in if this is not the case the work should be postponed.
- Enough diving bottles are taken according to the dive time.

Steps	Activity
Placement of temporary anchors for screw anchor installation	
1	Anchor the Whale Rider with a 4 mooring spread, so the vessel lies completely still.
2	Lower down the first temporary anchor attached to a temporary buoy using a workline (10.5 m).
3	With a workline (16 m) sail to a certain direction and lower down the next temporary anchor at the place where the workline is tightly stretched. See figure A.10
4	Repeat this until all 6 temporary anchors are placed as shown in figure A.10
Screw anchor placement	
	At each location of the temporary anchors, a screw anchor will be installed Two divers are needed for the installation of every screw anchor
1	Dive down and screw the anchor in the seafloor. Make sure the anchor is screwed in straight, to the right depth. *Two persons do this by putting a straight bar through the ring on top of the screw anchor. By rotating the straight bar around the anchor is screwed in.*
2	Retrieve the next anchor from the whale rider and dive down again.
3	Repeat step 1 and 2 for each position of the temporary anchors.
Attaching subsurface buoys mooring lines to screw anchors	
1	While divers are installing screw anchors, connect two mooring lines to one subsurface buoy
2	When the divers come back to the water surface, the ends of the mooring lines, which is a swivel, are given to them together with a connecting shackle.
3	They connect the mooring line to the ring of the screw anchor with the shackle
4	Repeat steps 2 and 3 for all the screw anchors.

Figure A.10: Installation of the screw anchors

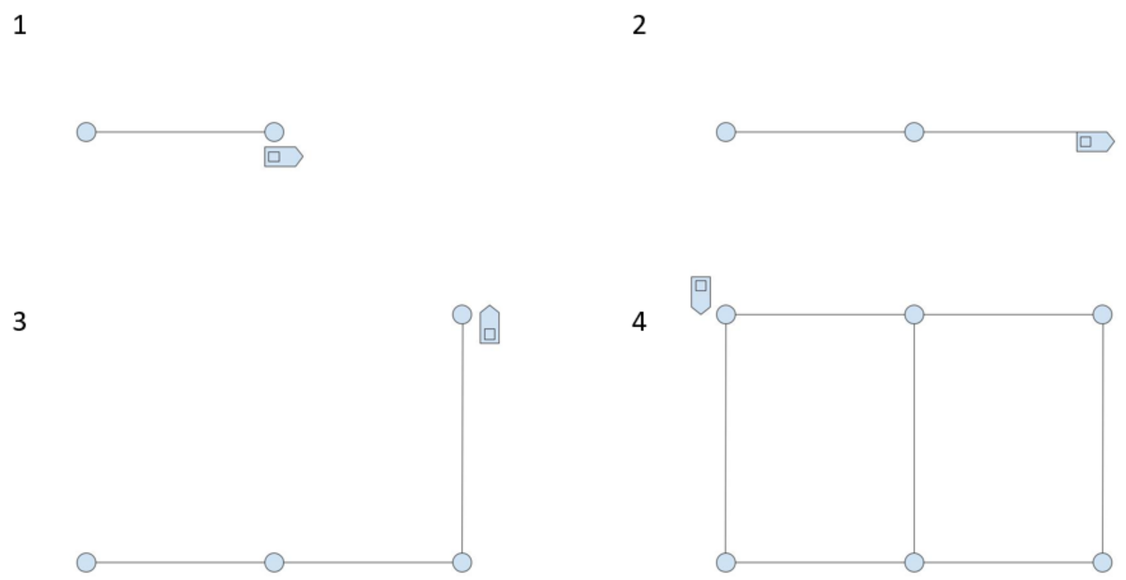


Figure A.11: Installation of the screw anchors

A.4.3. Phase 3 - Water surface installation

Within this phase the following is assumed:

- The ships; the Windvogel, a RIB (rigid inflatable boat) and a dinghy (small boat) are ready for use. The crew is familiar with the skills of a seafarer (rope handling, adaptability etc.)
- The winch on the Windvogel is able to pull the working line at the end of each corner of the netting module.

Steps	Activity
Attaching retrieval/working lines to the buoys	
1	The Windvogel sails to the first two buoys.
3	Two smaller boats (RIB & Dinghy) navigate to the two buoys with working lines (30 m). The working lines at each corner must be collected and pulled through the pulleys in the buoys.
4	Pull the line through the buoy till the mark can be seen. The mark on the rope must just get through the pulley. *This ensures the netting to be placed in the middle of the buoys.*
5	Repeat Step 3 & 4 for the other opposite buoys.
6	The whole netting module is now tied and ready to be brought down to the required depth. The netting lays flat on the water while the buoys are still at the water surface.
Connecting working lines with temporary buoys to subsurface buoy.	
1	The rings at one side of the netting module are connected with two pulleys to temporary buoys as can be seen in figure 1. They are connected through working lines (30 m) with marks at 10 and 20 m. The working line should be pulled through the pulley until one of the marks is reached. (the same as with step 4 in this phase). *This system is later used when the next netting module is installed.*

A.4.4. Phase 4 - Bringing the netting module to depth

The following is assumed in this phase:

- The installation vessel for the BTP area is the Windvogel. The ship consists of a winch that has enough power so it can pull in the working lines OR the ship will pull by sailing in a certain direction.
- The crew handling the winch knows how many meters one wind consists of. Therefore, the crew can calculate how many meters it pulled in by the amount of winds they made.

Steps	Activity
Pulling the netting module so it moves downwards	
1	One by one the dinghy/rib brings a workline to the windvogel.
2	The workline (30m) is winched in until the subsurface buoys meet the corners of the netting.
3	Repeat steps 1 and 2 for all the corners of the netting module
Connecting catenary chain	
1	Our plan is to connect the ring of the buoy to the ring of the netting module's corner, to get the pulley out of the system. A diver needs to connect shackles on both rings and a catenary chain in between. After he pulls the pin from the shackle to release tension on the rope. The tension is transferred to the catenary chain. Could this action be done in a safe manner? Please discuss with us, we might have an idea. FIXED: For now it is possible. On a larger scale it is not.

A.4.5. Phase 5 - Connecting additional module BTP

The following is assumed:

- The first netting module is installed and the two subsurface and the two temporary buoys are floating at the water surface. They are connected with working/retrieval lines.
- The installation vessels needed in this phase are the Windvogel and the two smaller boats (RIB and Dinghy)
- The installation procedures of the previous four phases should be known by the crew.
- The same equipment is needed as in the previous phases, according to the amount of netting modules needed to be installed in a single day.
- On the water surface there are four buoys floating. Two of these are temporary buoys with pulleys, attached to working lines and the subsurface netting system. The other two buoys are bigger surface boys connected to the helical screw anchors with a mooring line.

Important note!
This phase is not run by the makers of the design anymore, but it is a manual for the company to follow when installing the second R&D module

Steps	Activity
Attaching an extra netting module to the pulleys connected to the temporary buoys.	
1	The Windvogel and the smaller boats(Dinghy & RIB) navigate to the temporary buoys floating on the water surface
2	After reaching the buoys, two corners of the netting module need to be given to the crew on the smaller boats.
3	The crew on the two smaller boats sail to the temporary buoys and connect the new netting module to the working lines that are connected to these buoys. This new netting module has two preinstalled temporary buoys on the opposite end, which in a normal situation will be connected to permanent buoys. Figure FIXME
4	The Windvogel navigates away so that the whole netting module can be placed in the water. *The netting now floats flat on the water surface*
5	The crew on the smaller vessel disconnects the temporary buoys. *The retrieval system can now be used by winching the working line.*
6	The crew on the Windvogel attaches the end of the working line on the winch.
7	The working line should be pulled in until the mark. *This ensures the new netting module to be at the exact position at depth.*
8	At the end of this phase one netting module should be installed at the required depth, while the other netting module should be connected on one end. The other end is floating at the surface due to small buoys.

A.4.6. Phase 6 - Connecting additional module

Adding a second module is something that was not done while doing this research. Still a manual was written for this, so that Kelp Blue can continue with the research themselves.

The following is assumed:

- The first netting module is installed and the two subsurface and the two temporary buoys are floating at the water surface. They are connected with working/retrieval lines.
- The installation procedures of the previous four phases should be known by the crew.
- The same equipment is needed as in the previous phases, according to the amount of netting modules needed to be installed in a single day.
- On the water surface there are four buoys floating. Two of these are temporary buoys with a male part of the latch lock system attached to working lines and the subsurface netting system. The other two buoys are bigger subsurface boys connected to the helical screw anchors with a mooring line.

Steps	Activity
Adding extra screw anchors	
1	According to the amount of netting modules, an X amount of screw anchors must be placed as an extension of the installed netting module.
2	Follow step 2-5 from Phase 3: *Screw anchor placement*
Attaching subsurface buoys mooring lines to screw anchors	
1	The only difference with Phase 3 is the fact that there are already 2 subsurface buoys floating at the water surface. Divers need to connect these subsurface buoys to the corresponding screw anchor, the closest one, with a mooring line.
2	The same steps as in Phase 3 have to be followed
3	At the end of these steps all the subsurface buoys are positioned in a parallel line on the water. Within these lines the Windvogel will manoeuvre and the netting modules will be installed.
Attaching retrieval/working lines	
1	The Windvogel navigates to the floating temporary buoys.
2	The crew on the Windvogel gives the two corners of the netting module to be installed to the crew on the RIB and the Dinghy.
3	The crew on the two smaller boats navigate to the subsurface buoys and disconnect the temporary buoy from the working lines. At the same time the crew connects the detached shackles from the male part of the lock system to the rings of the corners of the netting.
4	The windvogel navigates to the next buoys and hands over the

Some connections used in the netting module

Knotted netting outer line

The outer lines of the module are laid out in the onshore preparation phase in the courtyard. The lines are 16 m long and have 15 knots in between the ends of the lines, all 1 m apart. Eventually the inner grid, polysteel ropes with seeded twines, will be installed in between these knots.

Bow shackles

A bow shackle is a connection tool that is used a lot in the maritime industry. They consist of a bow and a pin that can be put through the bow to connect certain components. Bow shackles are manufactured in several different sizes. A picture of a bow shackle is shown in figure A.12.

Figure A.12: A bowshackle

Galvanised Swivel

A galvanised swivel is a connection tool, which allows both components it's connected to, to rotate. This could be desirable in a system where elements can only take up force in one direction plane. A picture of a swivel is shown in figure A.13.

Figure A.13: A swivle

Thimble

A thimble is a connection tool, which can be attached to the end of a rope. With the attachment of a thimble, a piece of rope can be easily connected to shackles. A picture of a bow shackle is shown in figure A.14.

Figure A.14: A thimble

A.5. Technical drawings

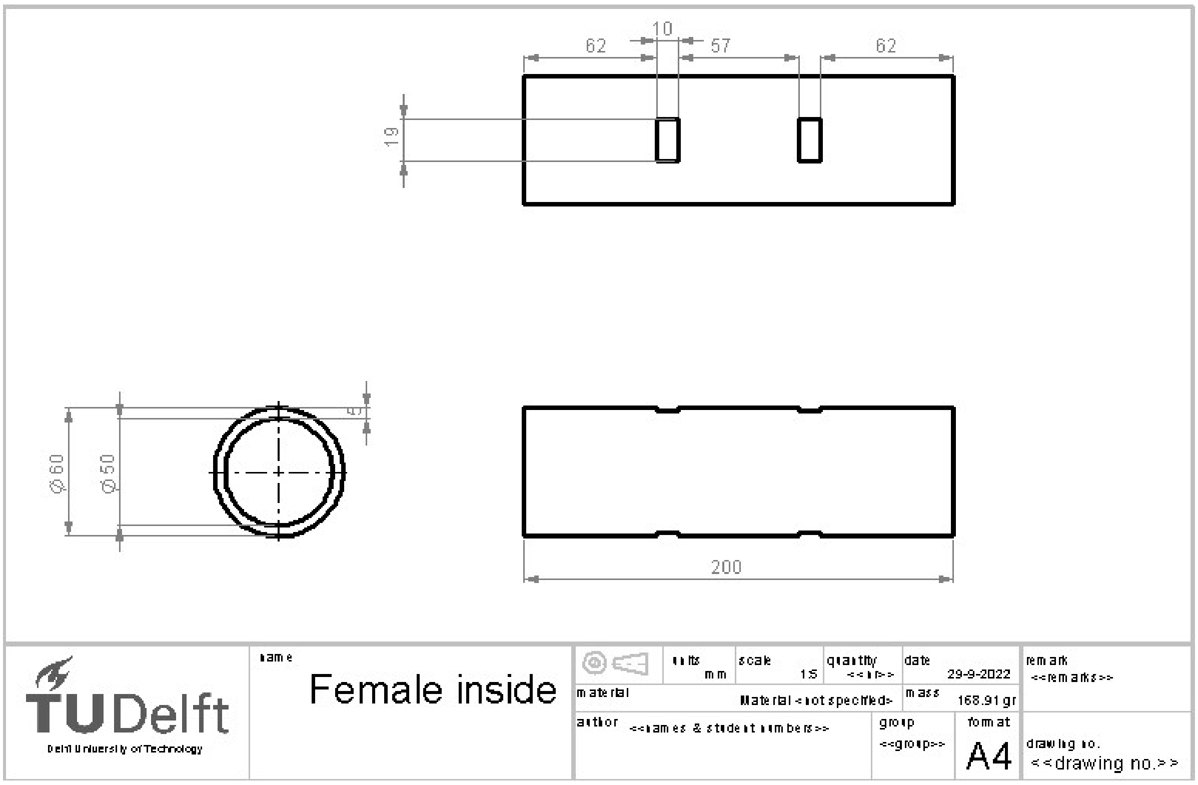


Figure A.15: Latch lock system: Female part inner ring

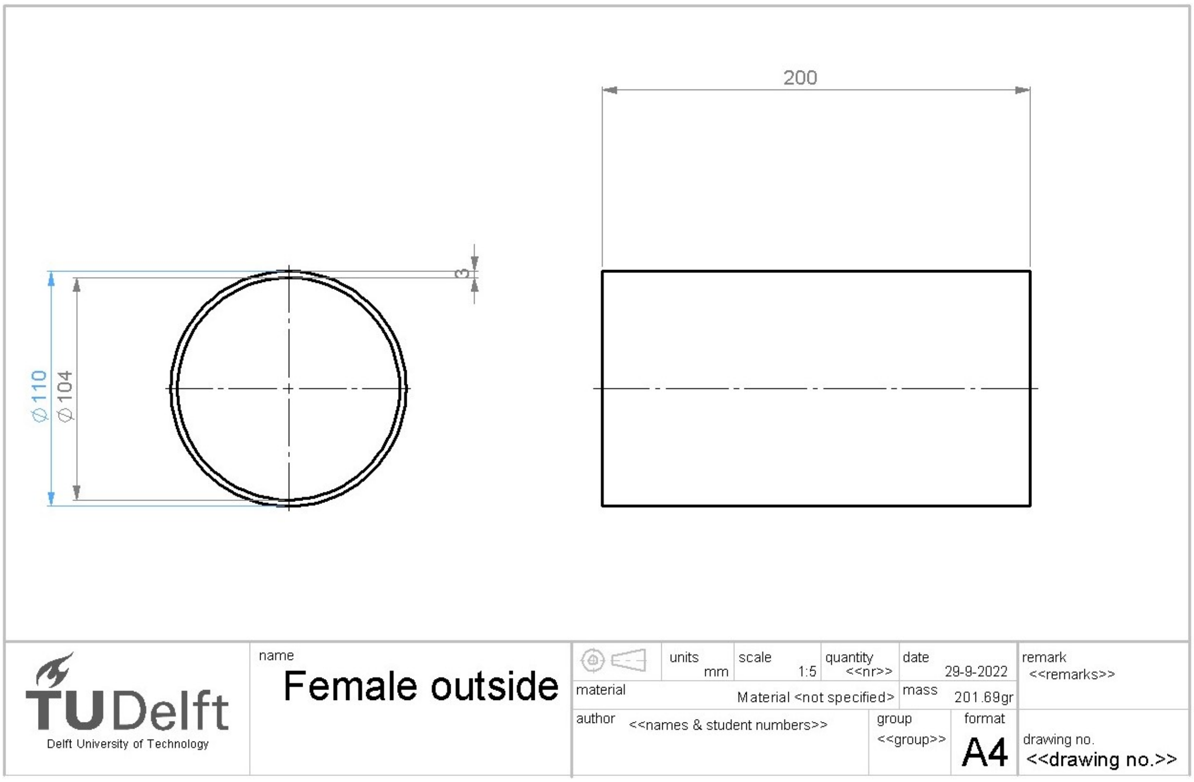


Figure A.16: Latch lock system: female part outer ring

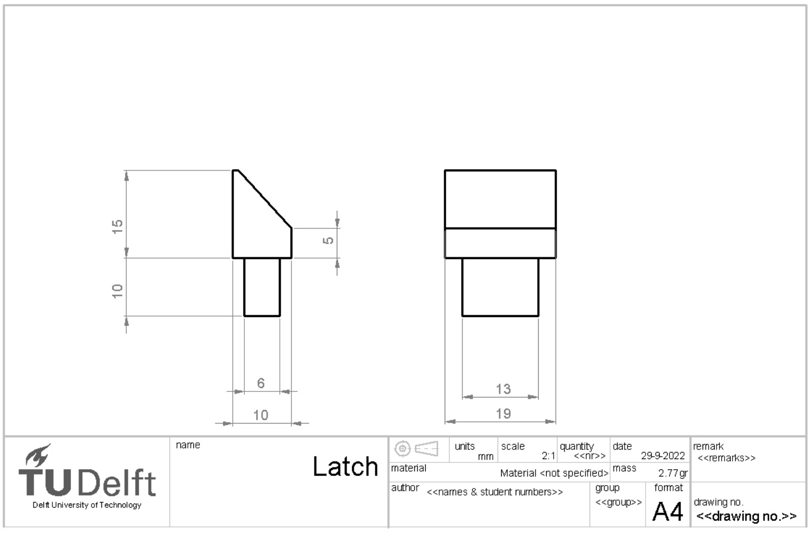


Figure A.17: Latch lock system: Latch

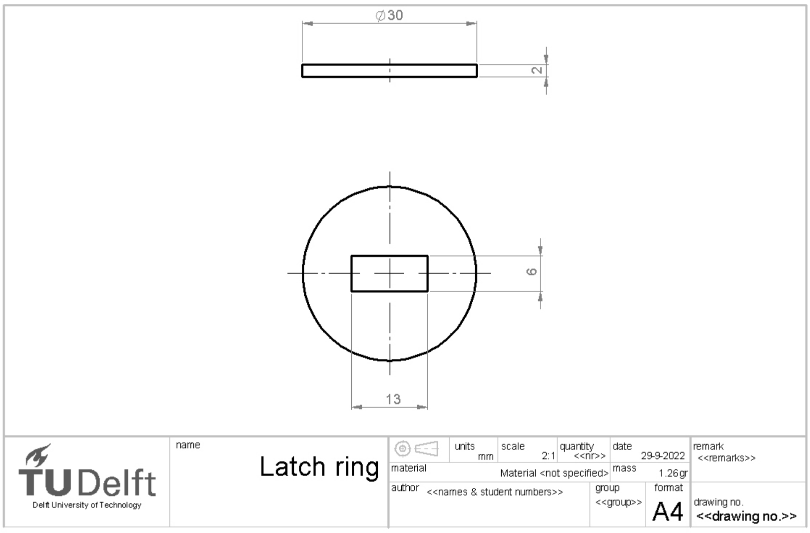


Figure A.18: Latch lock system: Latch ring

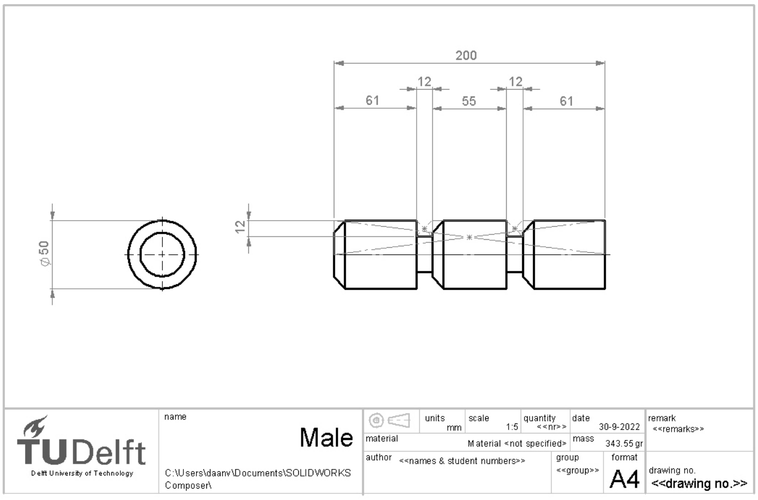


Figure A.19: Latch lock system: Male part

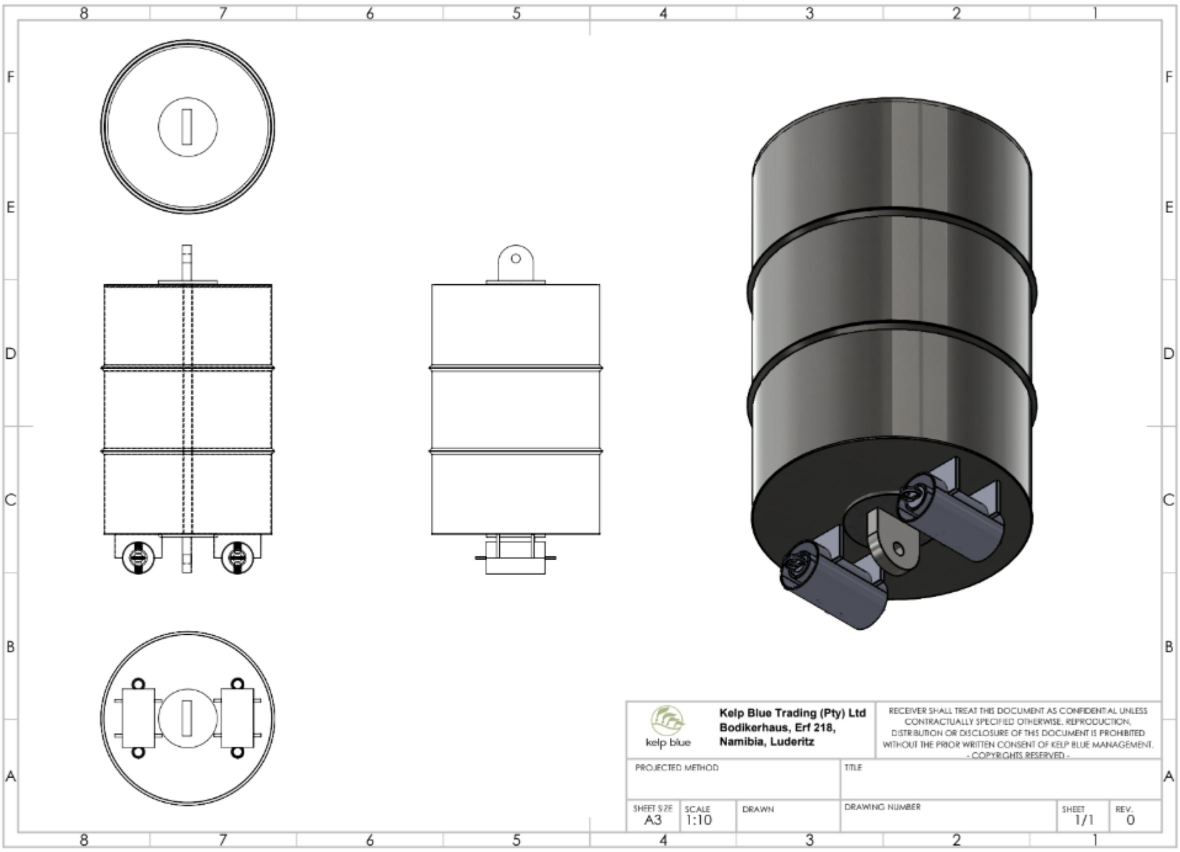


Figure A.20: Design of the buoy with an integrated locking system

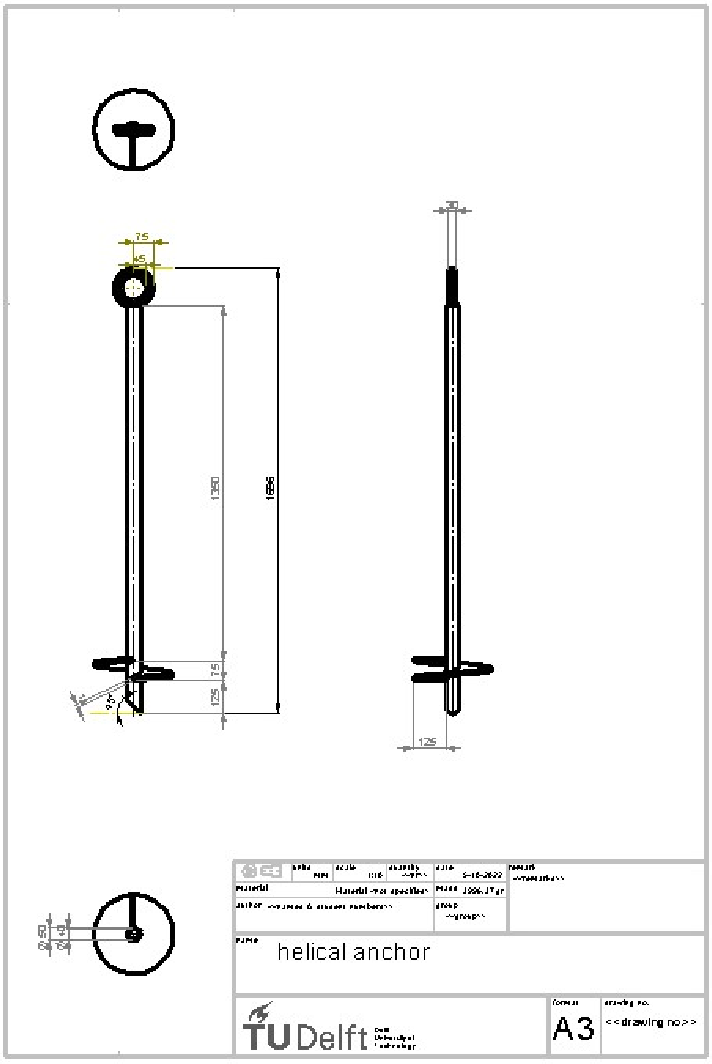


Figure A.21: Technical drawing of the design of the helical screw anchors

The total height of the screw anchor is 1846 mm, where the bar is 1575 mm and the ring 150 mm (outer diameter of 75 mm).

B
Appendix energy

B.1. Energy consumption data

This section shows the energy consumption of the different parts of the energy system at Kelp Blue. The calculation could not fit properly in this format, so a summarized version will be shown here. The full calculation can be found in the Renewable energy analysis - Kelp Blue - dashboard.

B.1.1. Processing site

Table B.1: Energy consumption data from the 20 ha/month processing site

Utility	Power [kW]	Electricity [kWh/year]	Electricity [MWh/year]
Mincer	7.5	28080	28.08
Pump	1.5	5616	5.616
Flow meter incl solenoid valve	0.1	374.4	0.3744
Cutter	11	41184	41.184
Pump	3	11232	11.232
High shear	37	138528	138.528
Pump	1.5	5616	5.616
Flow meter	0.1	374.4	0.3744
Decanter	25.1	93974.4	93.9744
Pump	1.5	5616	5.616
MF	7	26208	26.208
NF	7	26208	26.208
Mixing/dosing tank	0.4	1497.6	1.4976
Boiler	4.5	16848	16.848
Waterpump	5	18720	18.72
Compressor incl dryer	3.1	11606.4	11.6064
SS mixing and heating tank	4	14976	14.976
Total operation	**119.3**	**446659.2**	**446.6592**
Extra			
Office	1	2080	2.08
Lab	1	2080	2.08
Cooling	3	18720	18.72
Total extra	**5**	**22880**	**22.88**
Total processing site	**124.3**	**469539.2**	**469.5392**

B.1.2. Office

Table B.2: Energy consumption data from the office

Utility	Power [W]	Electricity [kWh/year]	Electricity [MWh/year]
Office general			
Lamps 1F	10	332.8	0.3328
Lamps GF	10	166.4	0.1664
Lamps GF2	10	83.2	0.0832
TV board room	100	156	0.156
Meeting thing	20	31.2	0.0312
Fridge	30	252.72	0.25272
Microwave	800	104	0.104
Grill	1500	97.5	0.0975
Coffee maker	800	104	0.104
Toaster	800	52	0.052
Total general	**4080**	**1379.82**	**1.37982**
Office OPS			
Power tools	500	65	0.065
Freezer	300	5256	5.256
Lights	10	124.8	0.1248
Total OPS	**810**	**5445.8**	**5.4458**
Desks			
Laptop	100	208	0.208
Monitor	60	124.8	0.1248
Other	30	62.4	0.0624
Total 1 desk	**190**	**395.2**	**0.3952**
Total all desks	**3800**	**7904**	**7.904**
Total office	**8690**	**14729.62**	**14.72962**

B.1.3. Laboratory

Table B.3: Energy consumption laboratory

Utility	Power [W]	Electricity [kWh/year]	Electricity [MWh/year]
Laboratory	4500	39420	39.42
Total lab	**4500**	**39420**	**39.42**

B.1.4. Desalination plant

Table B.4: Energy consumption for desalination plant

Consumption [kWh/m3]	Water consumption [m3/day]	Electricity [kWh/year]	Electricity [MWh/year]
3.6	36	33696	33.696

B.2. Water Pricing

Building Clause	0.022	0.022	0%
GOVERNMENT 80% of APPROVED VALUE			
Land	0.2	0.2	0%
Improvement	0.2	0.2	0%
AGRICULTURE 25% of approved value			
Land	0.041	0.041	0%
Improvements	0.027	0.027	0%
Undeveloped ervens for more than 2 years on assesment rates	Improvements = 3 x land value		

BY ORDER OF COUNCIL

J. JANSER
CHAIRPERSON OF THE COUNCIL

LÜDERITZ TOWN COUNCIL

No. 415 2022

TARIFFS 2022/2023

The Lüderitz Town Council has under section 30(1) of the Local Authorities Act, 1992 (Act No. 23 of 1992) as amended, amends the charges, fees, rates and other moneys payable in respect of services rendered by the council as set out in the schedule, with effect from 1 July 2022.

SCHEDULE

Tariff Description	**2020/2021 Existing Tariff N$**	**2021/2022 NEW Tariff N$**	**2022/2023 NEW Tariff N$**	**Proposed Increase %**
WATER:				
Residential Consumption				
Conventional meters				
0-8m³ per month	21.78	22.43	22.43	-
9 - 30m³ per month	29.78	30.67	30.67	-
30 - 60m³ per month	41.21	42.45	42.45	-
60m³ > per month	62.82	64.70	64.70	-
Non - Residential Consumption				
0 - 100m³ per month	36.02	37.10	37.10	-
101 - 500m³ per month	37.73	38.86	38.86	-
501 - 1000m³ per month	42.90	44.19	44.19	-
1001 - 1200m³ > per month	47.31	48.73	48.73	-
1201m³ > per month	51.63	53.18	53.18	-
Departmental				
Basic Charges - Domestic				
15mm	51.39	52.93	52.93	-
20mm	117.34	120.86	120.86	-

25mm	170.76	175.88	175.88	-
40mm	477.10	491.41	491.41	-
50mm	667.90	687.94	687.94	-
80mm	954.18	982.81	982.81	-
110mm	1,241.22	1,278.46	1,278.46	-
Basic Charges - Business				
15mm	56.53	58.23	58.23	-
20mm	129.07	132.94	132.94	-
25mm	187.84	193.48	193.48	-
40mm	524.81	540.55	540.55	-
50mm	734.69	756.73	756.73	-
80mm	1,049.60	1,081.09	1,081.09	-
110mm	1,365.00	1,405.95	1,405.95	-
Empty serviced erf/plots Empty serviced erf where water supplies is available but not used.	56.53	56.53	56.53	-
Pensioners	50% of basic charge			
Pre-paid Users				
Domestic				
0-8m³ per month		27.11	27.76	new
9 - 30m³ per month		35.11	36.00	new
30 - 60m³ per month		46.54	47.78	new
60m³ > per month		68.15	70.03	new
Business				
0 - 100m³ per month		43.05	43.05	new
101 - 500m³ per month		44.81	44.81	new
501 - 1000m³ per month		50.14	50.14	new
1001 - 1200m³ > per month		54.68	54.68	new
1201m³ > per month		59.13	59.13	new
Informal areas - per m³	37.43	40.05	40.05	-
per 25 lt		1.00	1.00	-
Replacement Tag/Token				
New Connections				
Reconnection due to account in arrears	527.70	527.70	527.70	-
Pensioners				
Disconnection/Reconnections on consumers request	225.30	225.30	225.30	-
Security Deposits - Refundable				
Residential, Pensioners & Old age homes	740.88	740.88	740.88	-
GRN institutions and NGO’s	1,155.00	1,155.00	1,155.00	-
Businesses	2,100.00	2,100.00	2,100.00	-
Alteration/Relocation/Repair or substitution of water meter on consumer request				
Illegal tampering				
First offence	2,000.00	2,000.00	2,000.00	

B.3. Blue prints - Biostimulants production warehouse

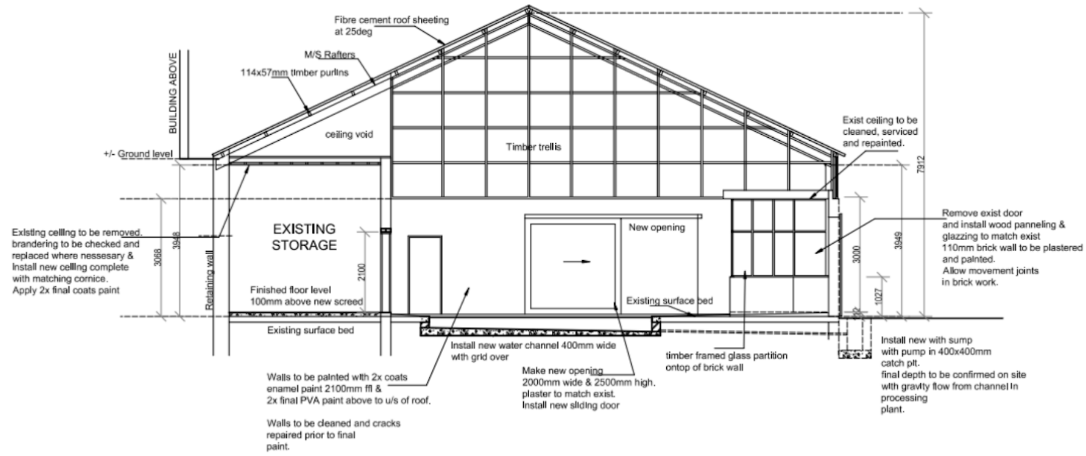


Figure B.1: Side view of the Lalandii workshop

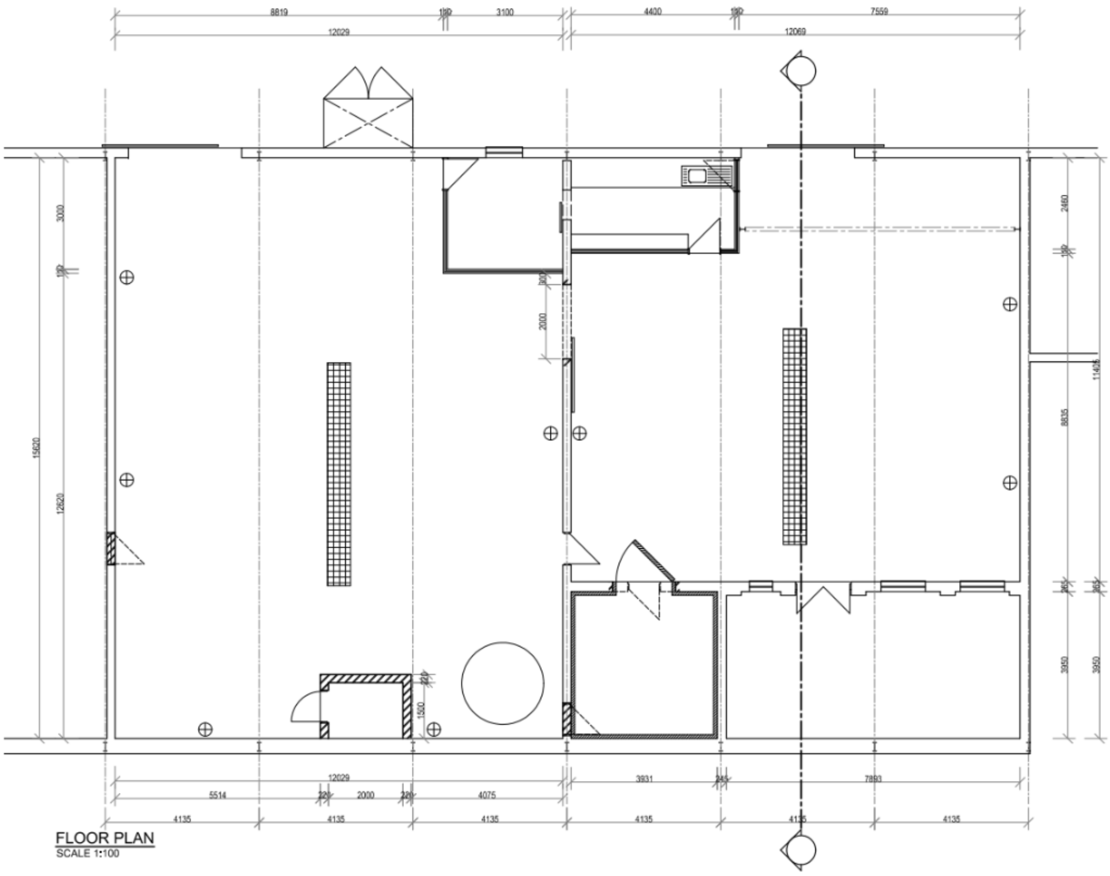


Figure B.2: Floor plan of the Lalandii workshop

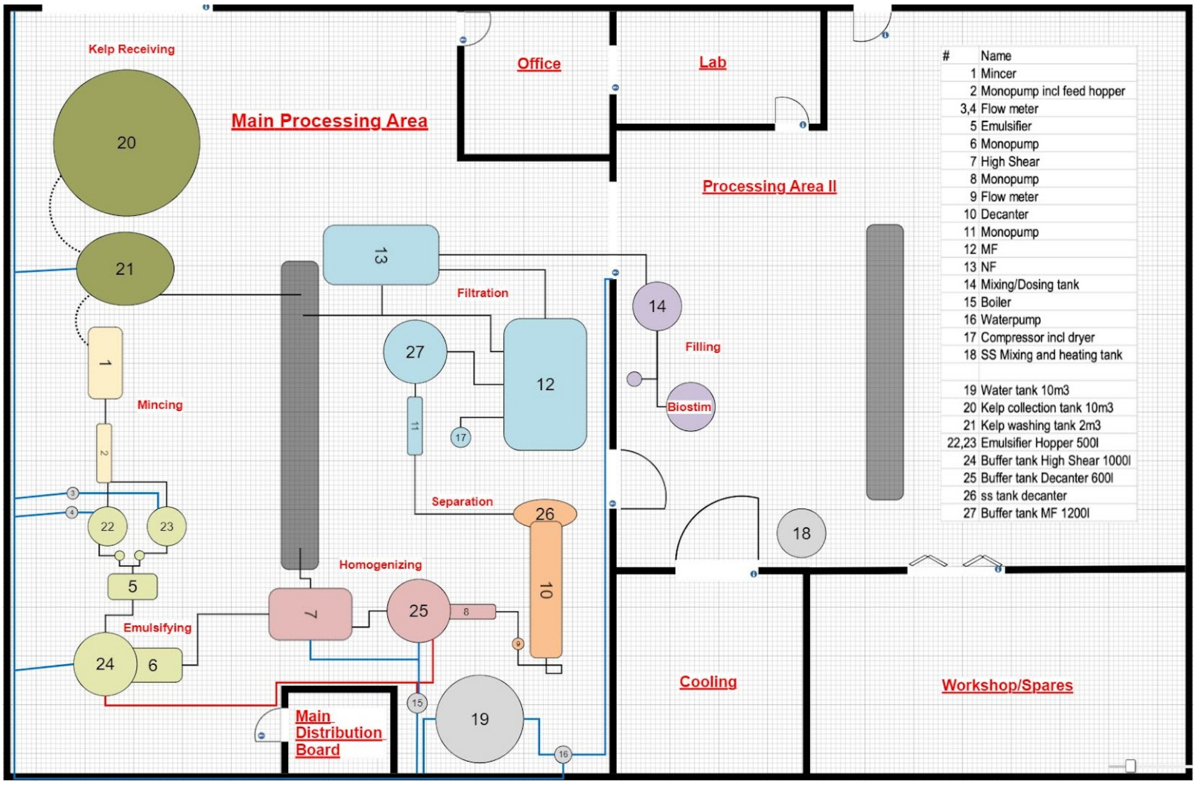


Figure B.3: Processing plan of biostimulants production

B.4. Photovoltaic module data sheet

NEW

CanadianSolar

HiKu7 Mono PERC

575 W ~ 605 W

CS7L-575|580|585|590|595|600|605MS (IEC1000 V)
CS7L-575|580|585|590|595|600|605MS (IEC1500 V)

MORE POWER

605 W — Module power up to 605 W
Module efficiency up to 21.4 %

Up to 3.5 % lower LCOE
Up to 5.7 % lower system cost

Comprehensive LID / LeTID mitigation technology, up to 50% lower degradation

Compatible with mainstream trackers, cost effective product for utility power plant

Better shading tolerance

MORE RELIABLE

40 °C lower hot spot temperature, greatly reduce module failure rate

Minimizes micro-crack impacts

Heavy snow load up to 5400 Pa, wind load up to 2400 Pa*

* For detailed information, please refer to the Installation Manual.

25 Years **Linear Power Performance Warranty***

12 Years Enhanced Product Warranty on Materials and Workmanship*

1st year power degradation no more than 2%
Subsequent annual power degradation no more than 0.55%

*According to the applicable Canadian Solar Limited Warranty Statement.

MANAGEMENT SYSTEM CERTIFICATES*

ISO 9001:2015 / Quality management system
ISO 14001:2015 / Standards for environmental management system
ISO 45001: 2018 / International standards for occupational health & safety

PRODUCT CERTIFICATES*

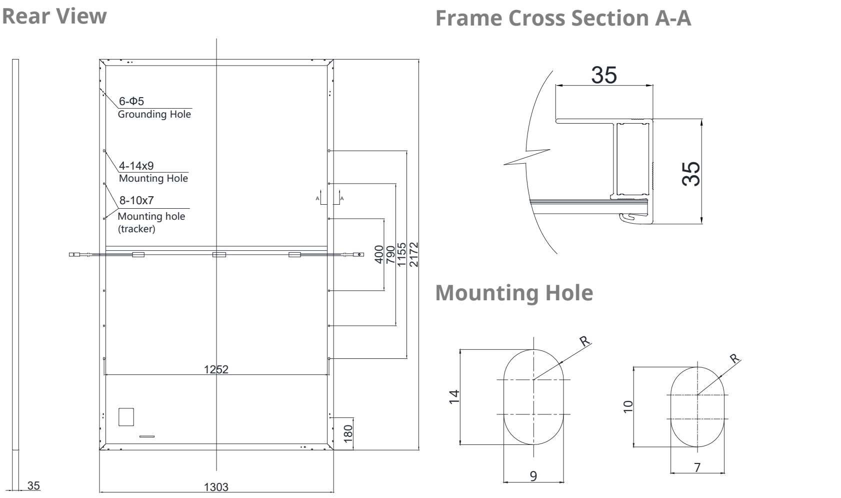
IEC 61215 / IEC 61730 / INMETRO
UL 61730 / IEC 61701 / IEC 62716
Take-e-way
Canadian Solar recycles panels at the end of life cycle

* The specific certificates applicable to different module types and markets will vary, and therefore not all of the certifications listed herein will simultaneously apply to the products you order or use. Please contact your local Canadian Solar sales representative to confirm the specific certificates available for your Product and applicable in the regions in which the products will be used.

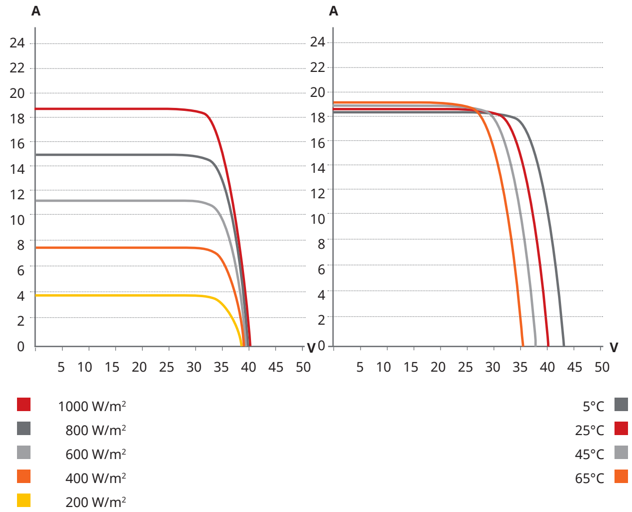
CSI Solar Co., Ltd. is committed to providing high quality solar products, solar system solutions and services to customers around the world. Canadian Solar was recognized as the No. 1 module supplier for quality and performance/price ratio in the IHS Module Customer Insight Survey, and is a leading PV project developer and manufacturer of solar modules, with over 52 GW deployed around the world since 2001.

Canadian Solar MSS (Australia) Pty Ltd.
44 Stephenson St, Cremorne VIC 3121, Australia, sales.au@csisolar.com, www.csisolar.com/au

ENGINEERING DRAWING (mm)



CS7L-590MS / I-V CURVES



ELECTRICAL DATA | STC*

CS7L	575MS	580MS	585MS	590MS	595MS	600MS	605MS
Nominal Max. Power (Pmax)	575 W	580 W	585 W	590 W	595 W	600 W	605 W
Opt. Operating Voltage (Vmp)	33.9 V	34.1 V	34.3 V	34.5 V	34.7 V	34.9 V	35.1 V
Opt. Operating Current (Imp)	16.97 A	17.02 A	17.06 A	17.11 A	17.15 A	17.20 A	17.25 A
Open Circuit Voltage (Voc)	40.3 V	40.5 V	40.7 V	40.9 V	41.1 V	41.3 V	41.5 V
Short Circuit Current (Isc)	18.22 A	18.27 A	18.32 A	18.37 A	18.42 A	18.47 A	18.52 A
Module Efficiency	20.3%	20.5%	20.7%	20.8%	21.0%	21.2%	21.4%
Operating Temperature	-40°C ~ +85°C						
Max. System Voltage	1500V (IEC) or 1000V (IEC)						
Module Fire Performance	CLASS C (IEC 61730)						
Max. Series Fuse Rating	30 A						
Application Classification	Class A						
Power Tolerance	0 ~ + 5 W						

* Under Standard Test Conditions (STC) of irradiance of 1000 W/m², spectrum AM 1.5 and cell temperature of 25°C. Measurement uncertainty: ±3 % (Pmax).

ELECTRICAL DATA | NMOT*

CS7L	575MS	580MS	585MS	590MS	595MS	600MS	605MS
Nominal Max. Power (Pmax)	431 W	435 W	439 W	442 W	446 W	450 W	454 W
Opt. Operating Voltage (Vmp)	31.8 V	32.0 V	32.2 V	32.3 V	32.5 V	32.7 V	32.9 V
Opt. Operating Current (Imp)	13.56 A	13.60 A	13.64 A	13.70 A	13.73 A	13.77 A	13.80 A
Open Circuit Voltage (Voc)	38.1 V	38.3 V	38.5 V	38.7 V	38.8 V	39.0 V	39.2 V
Short Circuit Current (Isc)	14.68 A	14.73 A	14.77 A	14.80 A	14.85 A	14.88 A	14.93 A

* Under Nominal Module Operating Temperature (NMOT), irradiance of 800 W/m², spectrum AM 1.5, ambient temperature 20°C, wind speed 1 m/s.

MECHANICAL DATA

Specification	Data
Cell Type	Mono-crystalline
Cell Arrangement	120 [2 x (10 x 6)]
Dimensions	2172 × 1303 × 35 mm (85.5 × 51.3 × 1.38 in)
Weight	31.4 kg (69.2 lbs)
Front Cover	3.2 mm tempered glass
Frame	Anodized aluminium alloy, crossbar enhanced
J-Box	IP68, 3 bypass diodes
Cable	4 mm² (IEC)
Cable Length (Including Connector)	460 mm (18.1 in) (+) / 340 mm (13.4 in) (-) or customized length*
Connector	PV-KST4/xy-UR, PV-KBT4/xy-UR (IEC 1000 V) or T4-PC-1 (IEC 1500 V) or PV-KST4-EVO2/XY, PV-KBT4-EVO2/XY (IEC 1500 V) or UTXCFA4AM, UTXCMA4AM (IEC 1500 V)
Per Pallet	31 pieces
Per Container (40' HQ)	527 pieces

* For detailed information, please contact your local Canadian Solar sales and technical representatives.

TEMPERATURE CHARACTERISTICS

Specification	Data
Temperature Coefficient (Pmax)	-0.34 % / °C
Temperature Coefficient (Voc)	-0.26 % / °C
Temperature Coefficient (Isc)	0.05 % / °C
Nominal Module Operating Temperature	41 ± 3°C

PARTNER SECTION

* The specifications and key features contained in this datasheet may deviate slightly from our actual products due to the on-going innovation and product enhancement. CSI Solar Co., Ltd. reserves the right to make necessary adjustment to the information described herein at any time without further notice.
Please be kindly advised that PV modules should be handled and installed by qualified people who have professional skills and please carefully read the safety and installation instructions before using our PV modules.

Canadian Solar MSS (Australia) Pty Ltd.
44 Stephenson St, Cremorne VIC 3121, Australia, sales.au@csisolar.com, www.csisolar.com/au

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* Manufactured and assembled in China, Thailand and Vietnam.