ROTEC

FEASIBILITY STUDY
ON DEEP SEAWATER SOLUTIONS
FOR MANADO

“Manado, an ocean of opportunities”

~Team ROTEC~

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ABSTRACT

Due to climate change and growing cities, water scarcity is becoming one of the futures biggest problems. On top of that, the population and prosperity of cities around the equator are growing fast. Meaning that the need for electricity, cooling and drinking water will grow fast in the following decades. ROTEC's vision is that these growing problems require a sustainable approach for the future.

A solution to these challenges can be found in the oceans temperature difference. The top layer of the ocean is heated by the sun, while the deeper layer remains cold. This causes around the equator a temperature difference of more than 20 degrees over the ocean's depth. This temperature difference offers a lot of opportunities. It can be used as a vast source for electricity production (OTEC), large scale drinking water production (ROTEC) and for cooling of buildings (SWAC). Indonesia is one of the best locations worldwide, due to the easy access of cold deep sea water and the abundant presence of hot surface water. North-Sulawesi has a unique access to these sources. Due to the steep slope of the seabed the cold deep seawater can easily be reached. Team ROTEC conducted a research in Manado the past two months and came up with several solutions that can contribute to a more sustainable and beneficial future of North Sulawesi. There was mainly focussed on performing a need assessment for the capital Manado and the touristic Bunaken Island. This pointed out that Manado can reduce their electricity usage during peak loads by implementing a new way of cooling of malls and hotels along the boulevard. Bunaken needs electricity and drinking water in a way that is more easy to maintain and operate. Data analysis and measurements showed that both Bunaken and Manado have a high theoretical potential, since cold deep seawater is close to shore and found at relative shallow depths.

For Manado a new seawater district cooling system is proposed. This system uses cold deep seawater to cool the hotels and malls along the boulevard, instead of conventional chiller-cooling-tower units. The solution reduces their electricity usage for cooling by 96% and more electricity is left for the grid of Manado. The yearly costs for the operation of the cooling is 92% cheaper and the investment for the installation is earned back within 6 years after construction. Peak loads in the grid, emissions equivalent to 19,000 tons CO_2 per year.

For Bunaken an integrated drinking water and electricity solution is found. By just using the temperature difference in the ocean, clean and constant electricity and drinking water from seawater can be produced. The proposed installation can produce the base load (80kW) for Bunaken for the same price as the solar PV and the diesel generators together. Clean drinking water for the villagers is 12 times cheaper than Aqua Danone and 1.4 times cheaper than the not drinkable water from fresh water wells on the island. Such a kind of installation can produce 24/7, is stable and that without the need of fuels.

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PROJECT SCOPE

The research is performed by five Msc. students from Delft University of Technology and focusses on the use of cold deep seawater for sustainable energy production, drinking water production and cooling. The geographical focus is on Manado city and Bunaken island, both located in North Sulawesi, Indonesia and are indicated in Figure 1. After 6 months of preparations, it is carried out in a time span of 2 months, started in September 2017 and finished at 28 October 2017. The project is supported and supervised by Sam Ratulangi Univerisity in Manado and Delft University of Technology.

During the study, an analysis on the energy industry, drinking water industry and cooling industry is performed. Next to that relative air humidity, seawater temperature, density and salinity are measured. After analysing these results a masterplan for Bunaken island and Manado is carried out and presented in this report. On top of that, all findings are shared with local companies, governmental organizations, professors and students. The report is an advisory report and can be used as a starting point for further research on the use of cold deep sea water in this region, for this reason the report has open access.

For project team ROTEC, the success of the project is related to the type and number of people that can be reached with this research. At the moment the use of cold deep seawater is an unknown technology compared to solar PV. Especially in Indonesia few people know what the opportunities of cold deep seawater are. The task of project team ROTEC is to show and share to policy makers, professors and students (the future policy makers) how cold deep seawater can help in the sustainable future of Manado and Bunaken island.

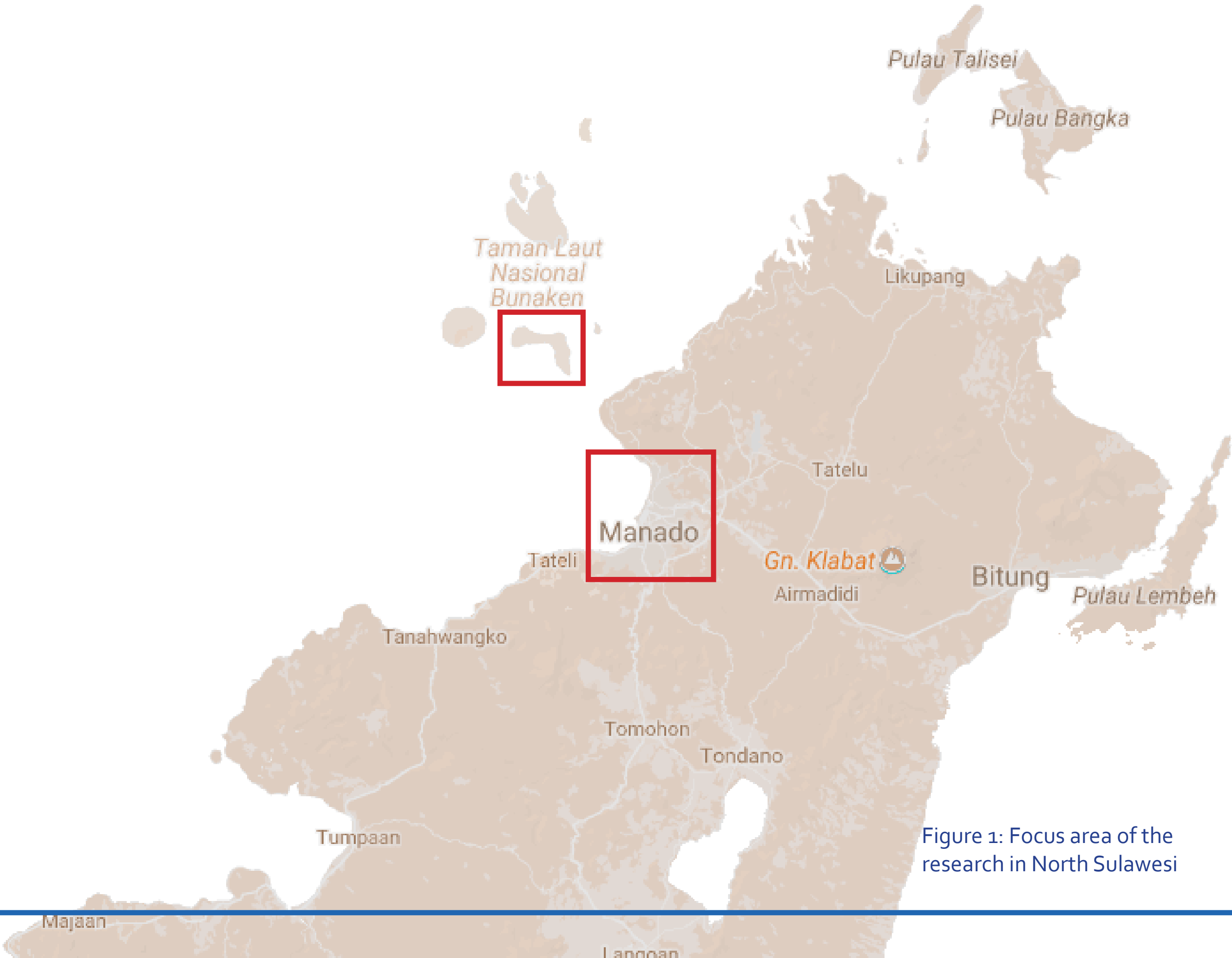

Figure 1: Focus area of the research in North Sulawesi

ACKNOWLEDGEMENTS

It has been a year where we learned a lot and developed ourselves on a lot of different fields. This list, just like this report, would be too long if every single person that had a contribution to this successful project is mentioned. So let us start off by telling that we want to thank everyone who contributed and supported us.

First of all, we would like to thank Berend-Jan Kleute, who gave us the opportunity to partner up with Bluerise and has been thinking along with us from the start, providing us with a lot of useful input with plenty of enthusiasm. The same goes for Joost Kirkenier, who mostly helped us with the preparations of the measurement equipment. Esther Blom, for involving us in the CleanTech Challenge, where we learned a lot of skills about entrepreneurship that came in handy during our project. The same can be said for Leon Pulles, who has also invited us to be guest speakers at the biggest energy conference in Europe, the Power Gen 2017. TU Delft Green office for giving us the chance to go to the Green Challenge in Copenhagen where we represented our University. Due to all of the above we learned that, even as students, it is important to think about the implementation and business side of sustainable projects, rather than just the sustainable technology.

Our supervisors in Delft for their flexible supervision. Bas Heijman for your input on the drinking water part and helping us with all the administrative requirements ar the University. Rusnandi Garsadi for your efforts to help us find contacts in a for us unexplored area, Indonesia. And Antonio for teaching us about sustainable technology. It was your course 'Renewable Energy Technologies' that sparked us to do something with this topic.

Our supervisors in Indonesia. We could not have wished for a warmer welcome than you gave us in Manado. Professor Markus Lasut, for sending us an invitation and offering us one of the best places to work at UNSRAT. Besides the room, which was already way better than we hoped for, you have helped us to get started in a for us unknown environment. Which brings us to Dr. Lusia Manu, Dr. Joice Rimper and Dr. Pheibe Warouw. Thank you for all your help. It was due to you that we had a head start and could do so much in the short time that we were in Manado. Also thanks to Joice, Lusia and Kanto for making our measurement campaign a lot of fun. Furthermore, we would like to thank the students from Pascasarjana, especially Tabita for your Bahasa Indonesia lessons and Ronald for helping with the weights and the rest of the students that were there at our goodbye party. To all the above: Terima kasih banyak dan torang samua basudara.

Harrie de Jong for welcoming us at our base camp on Bunaken island. We enjoyed our time and you made us feel at home and together with Ferdinand taught us a lot about the island and the beautiful marine environment surrounding it. Steffen del Popolo for your inspiring training about implementation, which gave us good insights. Reigan Tan and Reginald Rangingisan for showing us around in Manado and teaching us a lot about the Minahasa culture.

All of the stakeholders that contributed (can be found in the Appendix). You have all been very helpful in our quest to gain insights and obtain important information. Thank you for your cooperation and we hope we can reward you back with a future outcome of this research.

All our sponsors (on the cover of the report), that helped to contribute to a sustainable future. Your support has given us the chance to put a lot of extra effort in this research that would not have been possible without it.

And maybe most importantly team ROTEC itself. Besides being a great team we also became close friends during this adventure. It was the positive working spirit and the individual talents that kept on sparking and motivating each other when the spirit was down, which gave us the strength to keep on going forward for over a year. We hope everyone will enjoy reading this report as much as we did writing and creating it.

READERS' GUIDE

Firstly, it is important to note that this report is the main report where all the findings are summarized. In all appendices, more elaborate background information and motivation can be found for each subject treated in the main report.

In the first chapter, cold deep seawater and the possibilities are introduced after which the important aspects of the status of Indonesia and Manado are introduced for this research. In the second chapter the environmental conditions (e.g. seawater temperature and bathymetry) of the area are discussed. Which results in some important boundary conditions that must be considered in the rest of the research. Chapter 3, 4 and 5 discuss the current and future status of energy, drinking water and cooling respectively. This is done for both Bunaken-island and Manado to identify the need and important stakeholders. This need, in combination with the boundary conditions found in chapter 2 are used to choose promising concepts for the use of cold deep seawater in chapter 6. The two most promising concepts for Manado and Bunaken are discussed in chapter 7 and 8 respectively, where a design is presented and the technical, financial and environmental feasibility are taken into consideration. Chapter 9 discusses the important steps to be taken to implement the concept. In chapter 10, 11 and 12 the results are discussed and a conclusion is drawn that leads to recommendations.

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1. INTRODUCTION

In this chapter, firstly the potential for the use of cold deep seawater is introduced. After this, the cooling, drinking water and energy situation in Indonesia is introduced. After this, Manado, the city of interest is introduced. For more detailed information on these matters, see Appendix D.

1.1 COLD DEEP SEAWATER

The principle to use cold deep seawater for energy production (Ocean Thermal Energy Conversion, or OTEC) has been around since 1881. Due to World War II and the crisis in the 30's, the interest in OTEC decreased. During the oil crisis of 1973 the interest in OTEC increased again but when the oil price decreased so did the interest in OTEC. Now that the offshore industry has developed and the cost have decreased, in combination with increasing interest in renewable energy sources, the interest in OTEC grew again. But next to energy production, there are more things possible with deep seawater.

Let's start off by explaining where deep seawater at the equator originates from and what the possibilities are. Figure 2 shows a cross section of the earth with the South Pole on the left side and the North Pole on the right side. In the middle, at the equator, the sun heats up the ocean's surface. Most part of the heat produced by the sun is stored in the ocean's surface layer. This makes the ocean the biggest solar collector on earth. At the poles, the water is cooled down. As cold water is denser than warm water, the cold water sinks underneath the warm water and travels slowly to the equator. This means that at the equator, there is cold water of roughly 4°C available. Solely the cold water could be used for example to cool buildings and industry or to dehumidify air to produce drinking water. This water can in return be used for food production purposes, for example irrigation. Additionally, the cold deep seawater could also be used in combination with the warmer surface water to constantly, 24/7 produce a base load of power.

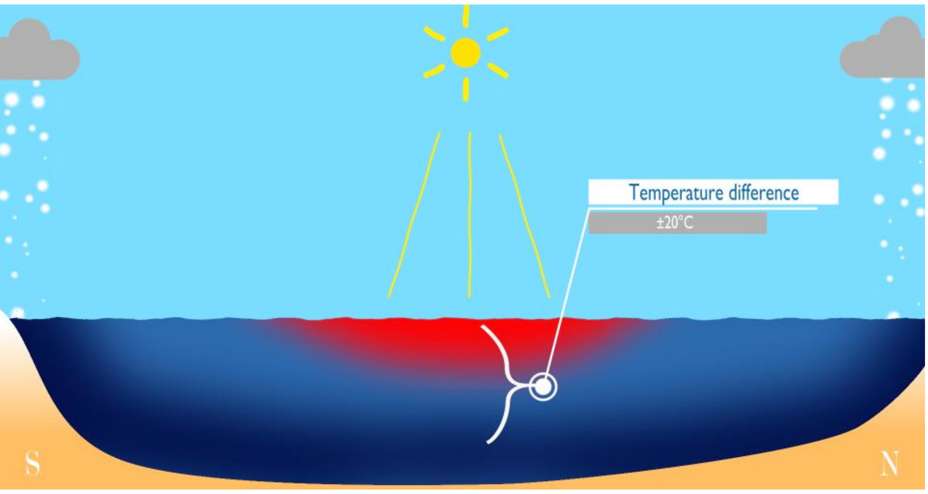


Figure 2: Cross section of the ocean

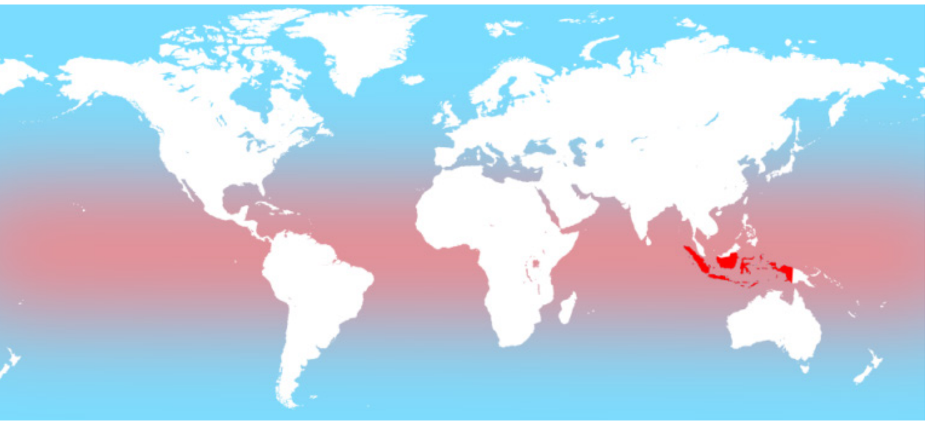


Figure 3: Worldwide ocean potential

Sustainable developments will be of major importance according to the Paris Agreement. With increasing freshwater, energy, food and cooling demand it is a logical step to make use of the ocean's temperature difference in order to tackle multiple problems at the same time. Besides the direct product of the technology, there are more indirect benefits. For example, if drinking water is produced, health care cost can be lowered. Economic growth is stimulated if more people have access to drinking water and exhaustion of onshore water sources can be prevented. Also, it can reduce conflicts between countries because countries can become more self-sustaining. As deep seawater technology is highly sustainable, it reduced the CO_2 emissions and reduced the risk of climate change.

The worldwide energy potential is 10TW which equals twice the world energy demand. As Indonesia is located around the equator and has deep seas and thus deep seawater relatively close to coast, it is potentially one of the best locations worldwide (Appendix A) to apply deep seawater technology. This report results in an advice for the best usage of cold deep seawater for Manado, Indonesia.

1.2 INDONESIA

Indonesia is the 4th most populated country in the world with 264 million inhabitants in 2017 (World population review, 2017). It is the 7th largest country including the national waters and consists of 17.508 islands. The population grew with 1.07 percent in 2017 and it is expected to do so for the coming years. The Indonesian economy is five-folded in the last 30 years, has the largest economy in Southeast Asia and has the 16th economy in the world (UNDP, 2017). The economy has grown from 2000 to 2017 with an annual average of 5.29 % and it is expected that it will do so for the coming years (ADB, 2016).

Indonesia is a stable democracy with Joko Widodo as their chosen president. The country did a great job in accomplishing the targets set by the Millennium Development Goals. At the moment they incorporated the Sustainable Development Goals in their political agenda (UNDP, 2017).

1.2.1. ENERGY

Indonesia is facing a huge challenge. The energy consumption per capita and the electrification ratio (Appendix B) have increased rapidly due to economic and population growth, but the infrastructure is insufficient to meet the demand (PricewaterhouseCoopers, 2017). In 2014, the government launched a plan to implement 35GW by 2019. This plan is already expected to be delayed.

Renewable energy is getting more cost-effective. Furthermore, off-grid solutions are becoming more viable due to up scaling, adding more incentive for renewable solutions. The government and industry are aware of the "Energy Trilemma": a trade-off between security, affordability and sustainability of the power supply. Currently, security and affordability are most important to Indonesia as it is still industrializing. However, it is expected that in 10 years' time, sustainability will have more priority. In "Rencana Usaha Penyediaan Tenaga Listrik 2016-2025" (RUPTL), Pt. PLN Jakarta has increased its target to 19% renewables by 2025. This is however lower than the National Energy Policy target of 23%. To meet this, subsidies are required. But in 2016 the House of Representatives (DPR) declined the subsidies for Pt. PLN. Figure 4 shows the planned installed power vs. the actual installed power.

A concern to implement the 35GW target is the lack of skilled engineers. The local content and manufacturing requirements of Indonesia are high which means that the requirements for local engineers can become a problem to meet the target.

When looking at the "trilemma" for energy policy, security should, in theory, not be a problem as Indonesia has a lot of potential for both conventional and renewable energy sources. In 2016, Indonesia had 28.5 billion tons of coal, 144 trillion standard cubic feet of gas, and 7.3 billion barrels of oil. These resources are depleted quickly and taking into account the problems with the infrastructure and the cost of exploration of these resources, security could become a problem in the near future. Indonesia is a net oil importer and it is expected that in a few years, the gas production cannot meet the demand. Therefore there is need for more sustainable solutions. The potential for renewable energy is shown in Figure 5.

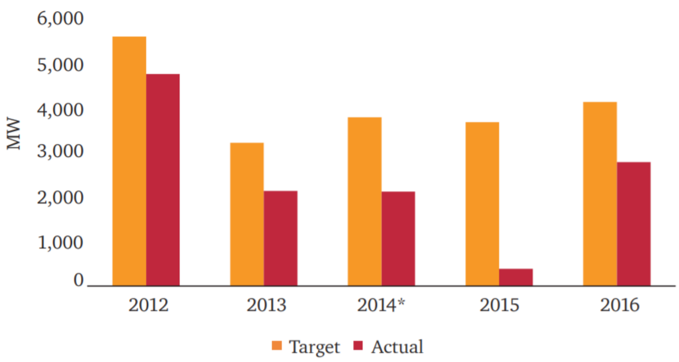


Figure 4: Actual vs. target capacity installation for 2012-2016 (PricewaterhouseCoopers, 2017)

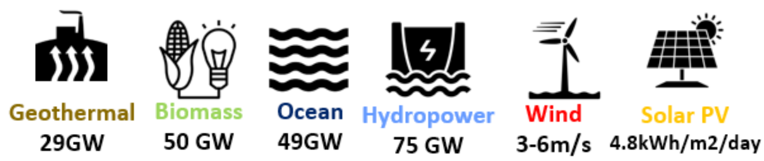


Figure 5: Indonesia renewable energy potential

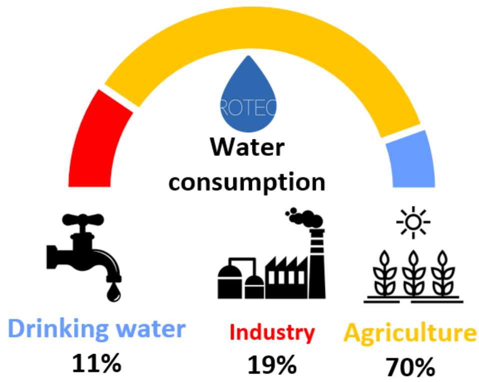


Figure 6: Freshwater distribution Indonesia

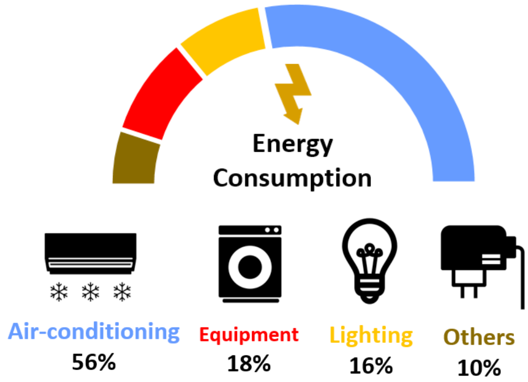


Figure 7: Typical building energy consumption in tropical countries

Indonesia also has a lot of remote islands that are not connected to a grid. Most of these islands still see primary resources such as electricity and water as major obstacle for growth (MONGABAY INDONESIA, 2016). Therefore at the end of 2016, the Government launched the MoEMR Regulation No. 38/2016 on Electrification for Remote Areas. This regulation permits mini-grids with up to 50MW generation capacity to supply remote villages and small islands.

Taking into account the huge ocean energy potential in Indonesia, and the fact that there are many islands with deep seawater nearby, OTEC could be the solution for remote areas. At the moment, OTEC tackles two out of the three from the "trilemma", namely sustainability and security. With a 24/7 base load that comes from renewable energy, OTEC could be the solution for many islands in Indonesia.

1.2.2. DRINKING WATER

Indonesia possesses 21% of the total fresh water available in the Asia-Pacific region and subtracts 113 km3 freshwater every year. The distribution of the water use can be found in Figure 6. In 2015 approximately 68% of the population is connected to an improved water resource. The 32% with no access to an improved water resource mostly lives in remote areas or on small islands. (Adyasar, 2016)

The target of the government is to provide 60% of the population with clean (consumable) tap water. With only 29% access so far, this goal is still far from accomplished (Jakarta Post, 2016). Indonesia is working hard to improve the drinking water accessibility and improved it a lot over the last years, they reached al their MDGs with respect to water supply. Still improvements in preservation of the current resources and water supply in remote areas and small islands is necessary.

1.2.3. COOLING

The current demand for cooling is increasing. According to the Netherlands Environmental Assessment Agency, the energy demand for cooling will overtake the energy demand for heating in 2060 (The Guardian, 2015). Cooling of buildings is one of the largest energy consumers in tropical regions. Figure 7 shows the energy consumption distribution in a typical tropical building. In these buildings approximately 50% of the energy is used for cooling.

Economic growth might be related to the increase for demand of comfort. Which in tropical regions can be related to the demand of cooling (Adrian R KATILI, 2015). As stated before, the economy in Indonesia is continuously growing. In combination with the increasing population might lead to the increase of the cooling demand and thus the energy consumption of Indonesia. It can be said that a big part of Indonesia's energy challenge is a challenge to reduce the cooling load. Manado is the capital of Sulawesi Utara with over 700,000 inhabitants. The city is located at the coast in a bay.

1.3 MANADO

Manado is divided in 11 districts and governed by a local government. This government is controlled by the governor of Sulawesi and indirectly the national government. The past decades, the city has been expanding near the coast. At these locations, huge malls and hotels were built. The mayor of Manado, Vicky Lumentut, emphasized at "Manado Fiesta 2017" to make Manado a better city in the future, especially for tourism (ANTARASULUT, 2017).

With the beautiful surroundings including mangroves, coral reefs and jungle, this city has a big potential for economic growth due to tourism. It is expected that tourism will grow the coming years. The city is preparing for this by planning more land reclamations near the city center.

Although a big part of the city is prosperous relatively to the rest of Indonesia, the city is still coping with a lot of problems. This can be seen by the controversy between the malls and the poorer people that live across the malls. A lot of people do not have a job which leaves the unemployment rate at 14% (Manado Post, 2017).

Manado is a growing city with several problems that have to be tackled for Manado to become more sustainable and prosperous. Luckily Manado is sitting on one of the biggest potential locations for the usage of deep seawater. This report will elaborate on the best usage of cold deep seawater for Manado and surroundings.

Figure 8: Manado Bay

2. ENVIRONMENTAL CONDITIONS

Before designing a system for a certain area, it is important to map the important environmental conditions that should be taken into account when designing a certain plan. In this chapter an overview will be given for both Bunaken island and Manado and their environmental conditions. The wind and wave data were also obtained and can be found in Appendix M5. Due to their mild conditions, they will not be considered in this chapter.

2.1 CLIMATE

According to the Koppen Climate Classification, Manado has a rainforest climate. This means that there is no real dry season. There is not a month with less than 100 mm precipitation.

Due to the climate of Manado, it experiences a humid environment. The humidity is quite constant over the year with an average humidity of 80% (worldweatheronline.com, 2017).

There is a weather station located in Manado, where this data is obtained. However, there is no weather station located at Bunaken. This means that there is no yearly humidity data available for the Bunaken. Measurements (Appendix M2) showed that the relative humidity on Bunaken island does not get below 95%.

2.2 TEMPERATURE & SALINITY

The surface temperature of the ocean in Manado is 30°C . Figure 9 shows the monthly mean temperature of the ocean's surface water. It can be seen that this is almost constant over the year around Manado.

The potential deep sea temperature and salinity are measured for Manado bay and Bunaken. The measuring campaign can be found in Appendix M1. The results are presented in this paragraph and the most important observations are described.

2.2.1. MANADO

In the profile over the vertical several thermoclines can be observed. The most present is at 50 meter depth, where the temperature decreases suddenly from 29 to 21 degrees Celsius. At 170 meters depth, the temperature makes a rapid decrease again from 16 to 11°C. Temperatures of 10°C, 7°C and 5°C are reached at a depth of respectively 310, 550 and 850 meters.

When comparing the temperature measurements at different distances from shore, it can be seen that the water closer to shore is slight-

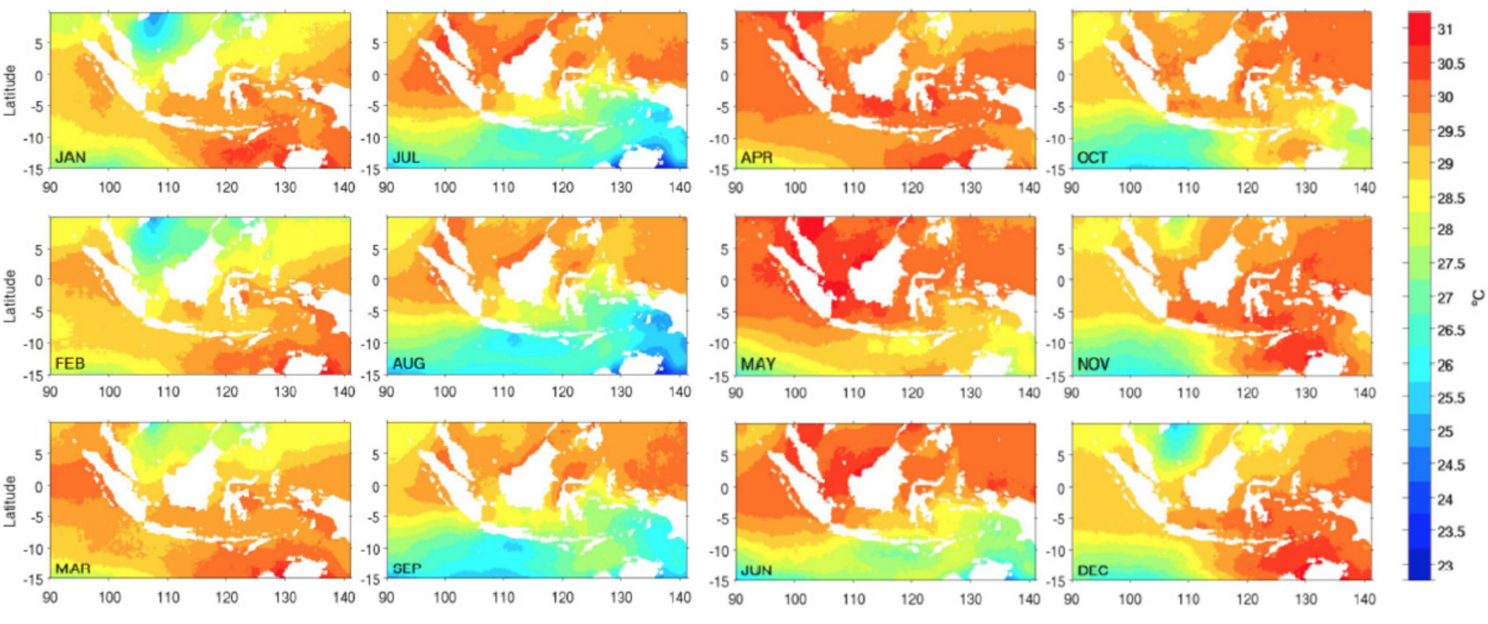


Figure 9: Monthly Mean Surface Temperature of Indonesia of 1998-2003 (Koto & Negara, 2016)

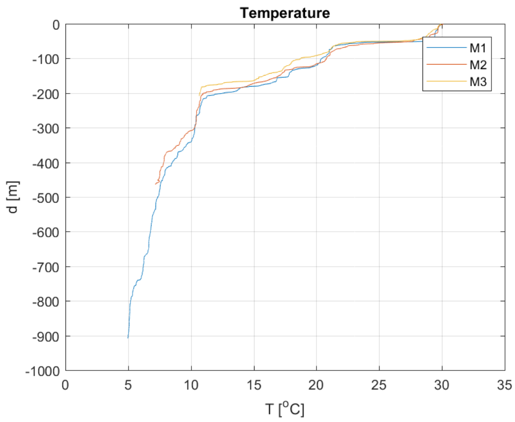


Figure 10: Temperature profile Manado Bay

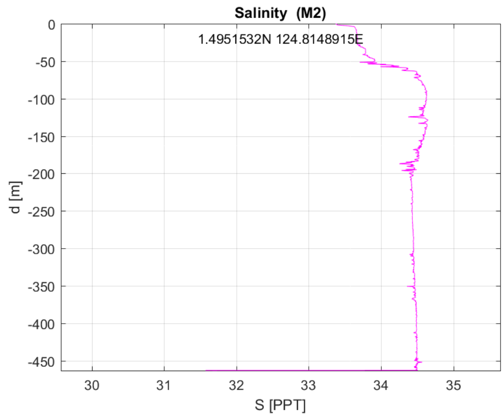


Figure 11: Salinity profile Manado Bay.

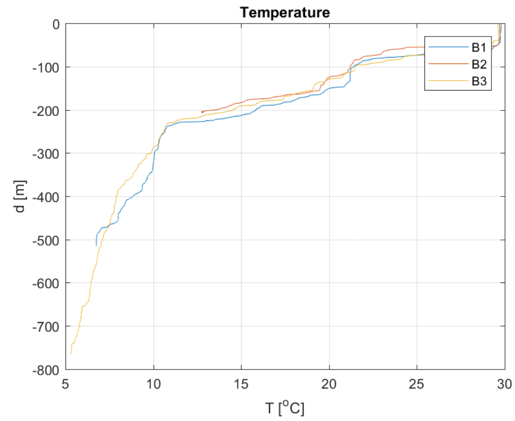


Figure 12: Temperature profile Bunaken island

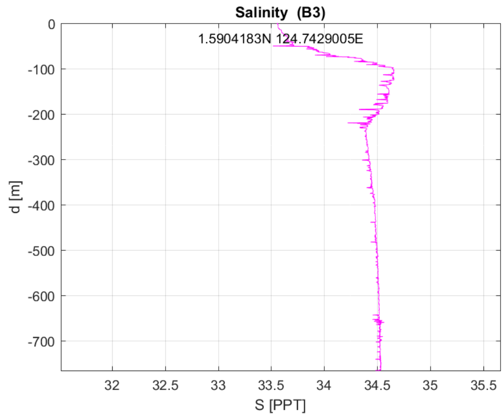


Figure 13: Salinity profile Bunaken island

ly colder after a depth of 100 meter. This could indicate coastal upwelling in Manado bay. By combining the results of the measurements, an approximation of the temperature in the bay is made. See Figure 10.

The salinity, calculated from temperature and conductivity, shows a lower salinity (33PPT) close to the surface of the sea as shown inFigure 11. This is due to the impact of rainfall, river outflow from Manado and the sinking of saltier (denser) water. The salinity increases slowly over depth until the halocline at 50-60 meters depth is reached. The salinity makes a jump from 33.7ppt to 34.6ppt and varies a lot till a depth of 200 meters. Deeper, it stays nearly constant around 34.4ppt.

2.2.2. BUNAKEN

In Figure 12 it can be observed that a thermocline can be found from a depth of 50 meters, the water temperature drops from 29°C to 22°C. Between 150-220 meters the temperature decreases rapidly from 19°C to 11°C. The further from shore the thermoclines are less noticeable. Deeper than 220 meters the temperature slowly decreases towards 5°C. In this case, it can also be said that the upper colder water layers are less deep closer to shore. (B2 closest to shore). This indicates upwelling of the deeper layers.

A temperature difference of 20°C compared to the surface temperature can be found at a depth of 350 meters. Temperatures of 10°C, 7°C and 5°C can be found at respectively 300, 500 and 800 meters depth.

At the surface the salinity at Bunaken is 33.5 ppt. The halocline can be observed at a depth of approximately 60-70 meter, with an increase from 33.7 ppt to 34.6 ppt. Until a depth of 250 meters it decreases to 34.4 ppt and stays more or less constant when going deeper. See Figure 13.

2.3 ECOSYSTEM

The region of North-Sulawesi is known for its diverse coral reefs. However, this is not the only ecosystem that is present. The region holds forest of mangroves. Which, just like the coral reefs, benefit the region.

2.3.1. CORAL REEF

Coral reefs serve, beside a beautiful dive spot, also other purposes. They protect the coasts against waves, and provide the fish with nutrients. Manado Bay is not a marine protected area, thus there is no coral reef present. Bunaken however has a long coral reef. The map with the reefs around Bunaken is shown in Figure 14.

2.3.2. MANGROVES

Mangrove forests serve many purposes. According to USVI, the mangroves protect the beaches from waves. It also protects the coral reefs and seagrass from sedimentation and events made by humans. Next to that, it provides a habitat for a lot of different species and act as nursery ground. Manado bay has no Mangrove forests. Bunaken island has many mangrove forests around the Island. Figure 14 shows where the mangrove is located at the Bunaken. It is good to notice that Mangrove forests are not completely dense forests, which has paths where could be built through.

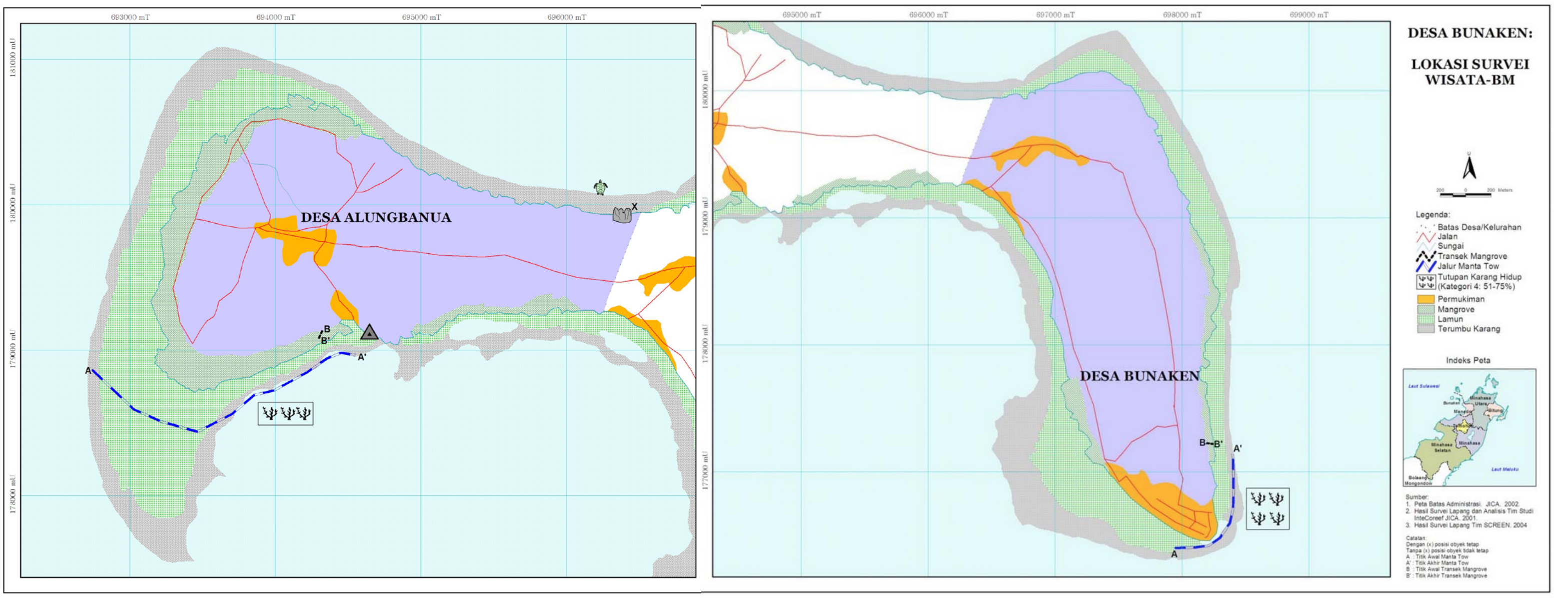


Figure 14: Ecosystems of Bunaken island (Joshian, 2009)

2.4 CURRENT AND TIDES

The tides in Manado occur in counter clockwise direction through the bay. The largest difference between high tide and low tide is 2.4 meters (Noorden & al., 2013). Next to the tidal current, there are other currents available. Figure 16. demonstrates the present currents in Manado Bay and their associated directions. The current in the corresponding area has a counterclockwise direction in the period of January until June. While, in the period of July until December it switches to a clockwise direction (Schaduw, 2017) . Thus, this leads to the fact that in this period there is more transport of garbage to the Bunaken.

Bunaken experiences strong currents around the island. The present currents are illustrated in Figure 15. The velocity of the current differs during the day. When it is high tide, the velocity is 0,85 m/s and during low tide this is 1.46 m/s ((Manongko, 2016). In the Bay of Bunaken the current is the smallest.

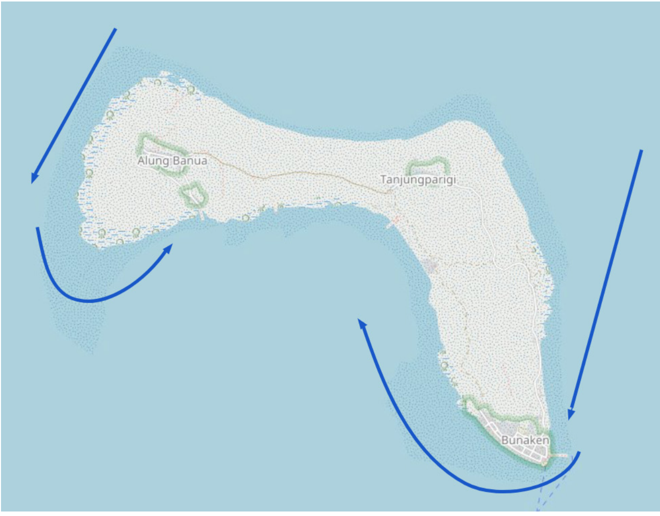


Figure 15: Direction of Currents around Bunaken island

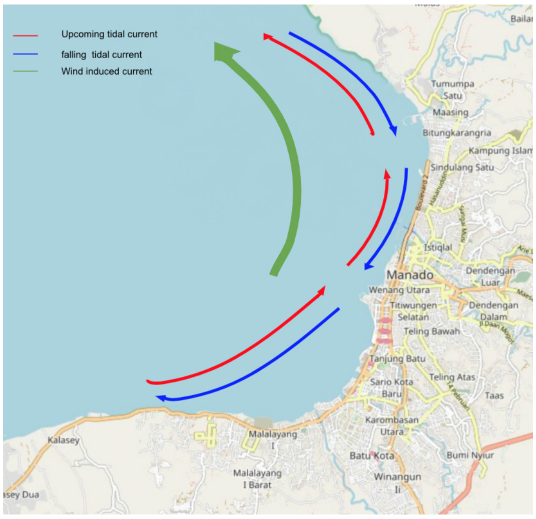


Figure 16: Currents Manado Bay (Noorden & al., 2013)

2.5 BATHYMETRY

There are six maps available which display the bathymetry of the coast of Manado. In accordance with the executed measurements, it was concluded that the map of Hidro Oseanografi TNI-AL has relatively the highest accuracy. The map can be found in Appendix M4. For both the Bunaken and Manado, the continental shelf ends rapidly.

The slope in Manado bay is quite gentle, however there are sections where the slope is steep, with a maximum slope of 65%.

Measurement showed that in the bay of Bunaken there is a vertical wall (Figure 17) present after approximately 180 meters with a slope of 45 degrees. Beside this vertical wall there is a steep slope with a gradient of 78%. Additionally, there is a small lagoon with a depth of 12 meters.

Combining the measurement results with the depth profile, the parameters are presented in Table 1 and Table 2.

Depth (m)	Temperature	Salinity [ppt]	Distance to shore [m]
0	29.5	33.4	0
340	10	34.5	1200
550	7	34.5	2200
850	5	34.5	3600

Table 1: Manado bay temperature and salinity

Depth [m]	Temperature	Salinity [ppt]	Distance to shore [m]
0	29.6	33.6	0
300	10	34.4	750
500	7	34.5	1750
800	5	34.6	3400

Table 2: Bunaken island temperature and salinity

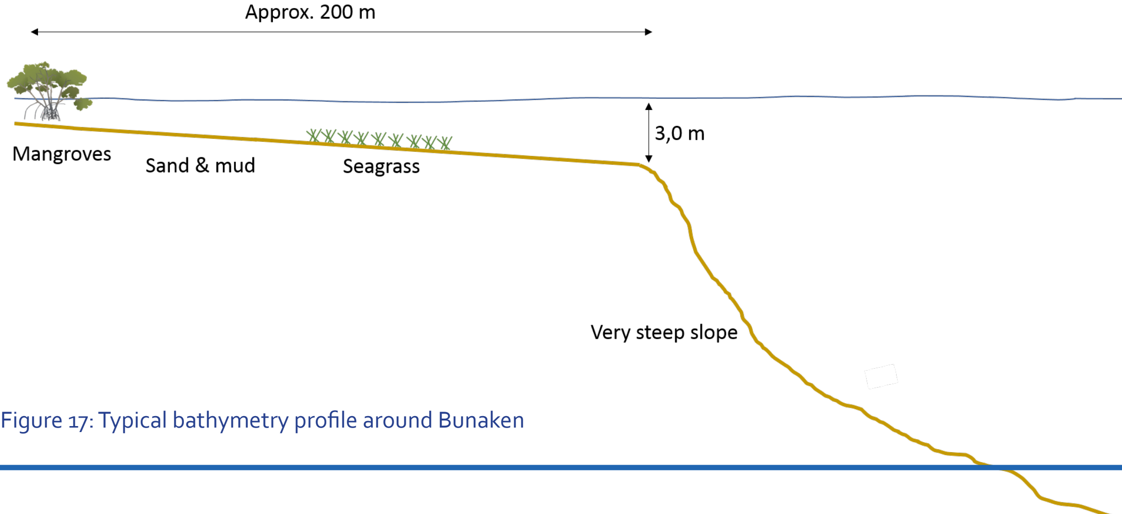


Figure 17: Typical bathymetry profile around Bunaken

3. ENERGY ANALYSIS

This chapter elaborates on the energy supply and demand of North Sulawesi. Firstly, the deep seawater technology for energy production (OTEC) is discussed. After this, an analysis on the focus area of this research is performed. Firstly, an analysis on Manado which includes the grid, the current situation and the future energy projection. Secondly, an analysis on Bunaken island, which deals with the same problems as many small islands in Indonesia. Next to that the energy price and stakeholders are analysed.

3.1 TECHNOLOGY

The temperature difference in the Ocean Thermal Energy Conversion process is relatively low, which leads to a low thermal efficiency. Regardless of this low efficiency, OTEC has a lot of potential and the energy is clean and renewable. In this section the process to produce energy is shortly described. Details about the components of the process can be found in Appendix C1.

There are different types of OTEC whereas closed cycle seems most promising. Closed cycle is relatively compact and Bluerise B.V. already deployed a pilot plant in Delft University of Technology which uses a closed cycle OTEC which seems economically most feasible. As an introduction to the process, a simplified visual of closed cycle OTEC is shown in Figure 18.

Part of the energy that is produced is used to pump up the cold and the warm water from the ocean. This makes the system self-sustaining.

3.1.1. REFERENCE PROJECTS

The Ocean Thermal Energy Conversion (OTEC) industry is still in a pre-commercialized state. Several experimental plants have proven that the technology is sufficient and works, but the sector lacks records and proof of an up-scaled OTEC plant. However, the number of proposed and planned large scale OTEC plants is increasing. A list of existing and planned OTEC plants is given in Appendix C1.8.

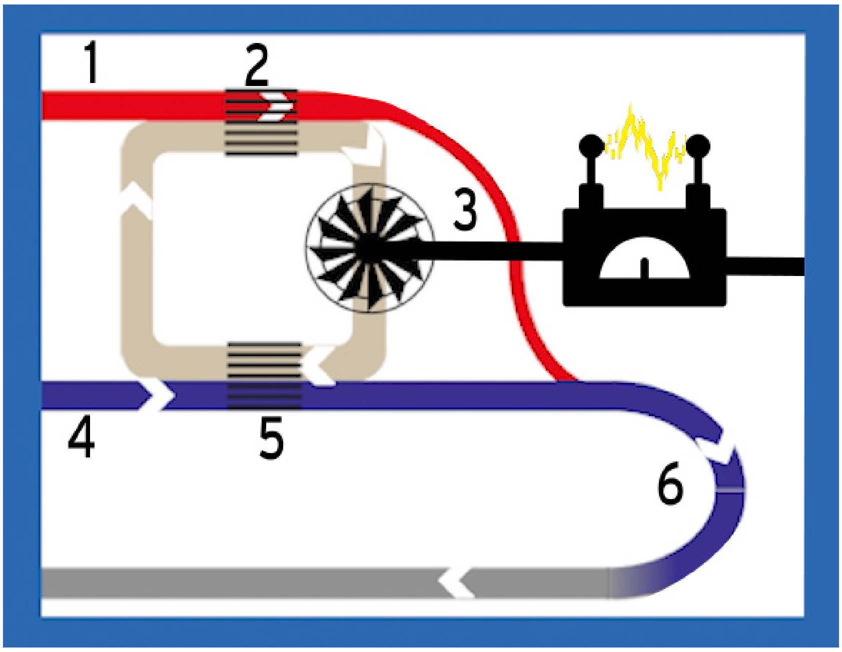


Figure 18: Basic principle of OTEC

1. Warm surface water from the ocean of roughly 28.5°C is pumped into the system.
2. Through heat exchangers/evaporators, energy is transferred from the warm water to the working fluid. In this way it is possible to evaporate the working fluid into a gas.
3. This gas is led through a turbine to produce energy.
4. Cold deep seawater of roughly 8.5°C is pumped into the system in order to obtain a 20°C temperature difference
5. By using heat exchangers/condensers, the cold deep seawater is used to make the working fluid condensate into a liquid again to close the cycle.
6. The cold water can be used for by products or can be disposed back into the ocean.

3.2 MANADO

In this section the current situation in North Sulawesi and the future projections for the energy usage are discussed. The same is done for Bunaken island in section 3.3.

3.2.1. GRID

North Sulawesi, Gorontola and Central Sulawesi are connected with one isolated grid called the SULUTTENGO grid. The grid is shown in Figure 19. The grid is governed by PLN. In Figure 19, the dashed red lines indicate the proposed grid expansion. In North Sulawesi (Sulawesi Utara) 83.5 percent of the households is connected to the grid (Provinsi Sulawesi Selatan, 2015).

There are plans to connect the Bunaken to the grid. This would cost 65 billion Rupiah which equals roughly 5 million USD (Meeting PLN SULUTTENGO, 2017, see Appendix O13).

Figure 19: SULUTTENGO grid (PLN, 2017)

3.2.2. CURRENT ENERGY SITUATION

Power demand

In 2016 the Jakarta Post stated that people in Manado continue to live in the grip of a serious energy crisis (Jakarta Post, 2016). Both the growing population and the economic growth lead to an increase of the energy demand over the last years. Therefore two years ago PLN increased the power production. Nevertheless the power supply remains unstable every now and then. So far, in North Sulawesi the peak demand reached up to 345 MW.

Power supply

Currently, around 400MW is installed in North Sulawesi, see Figure 20. Most power comes from conventional power resources. To solve the power blackouts, the Indonesian government contracted an offshore vessel that produces power through a steam engine (PGTU). This vessel "MVPP Zeynep Sultan" is deployed near Amurang, North-Sulawesi supplying 120 MW to this region. The government pays 0.056 euros per kWh (Sutianto, 2015). This is seen as a temporary solution since the vessel will supply energy for 5 years for North Sulawesi. According to PT PLN Manado, the lifetime of this project will be extended (Meeting PLN Manado, 2017, Appendix O4). After this implementation, there is a 65MW surplus according to PLN.

Besides conventional power plants, PT PLN is also focusing on renewable energy. They are currently exploiting 80MW of the geothermal potential of North Sulawesi (Figure 20). The total geothermal potential is approximately 345 MW (Panas Bumi, 2016). Besides geothermal energy, a large part of the sustainable energy comes from hydropower.

As mentioned in the introduction, Indonesia has a target to get 23% of its power from renewable energy resources. North Sulawesi is one of the country's leading regions with approximately 40% renewable energy.

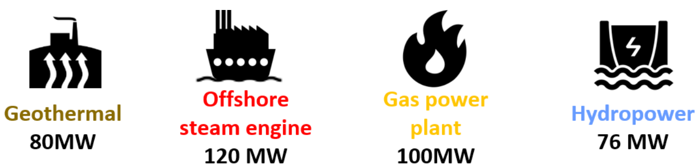


Figure 20: Energy distribution Central and North Sulawesi region

3.2.3. FUTURE ENERGY PROJECTION

Demand

With an increasing population and an economic growing area, the energy demand grows along with it. This means that the energy demand and peak demand will also increase the coming years. The peak demand projection until 2020 is shown in Figure 21.

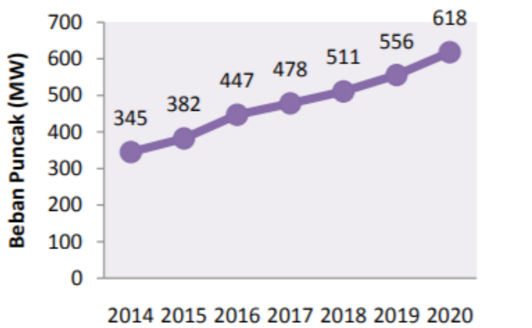


Figure 21: The projected peak load on SULUTENGO grid (RUPTL, 2015)

Supply

The current power capacity is not enough to meet the future demand. As stated before, the 120MW power supply vessel in Amurang is a temporary solution. PT PLN is working on the increase of the power supply and has planned several power exploitations of both renewable and conventional resources for the coming years. The infographic below (Figure 22) summarizes the future power supply (until 2024) for the SULUTTENGO grid, all information is obtained from RUPTL, 2015.

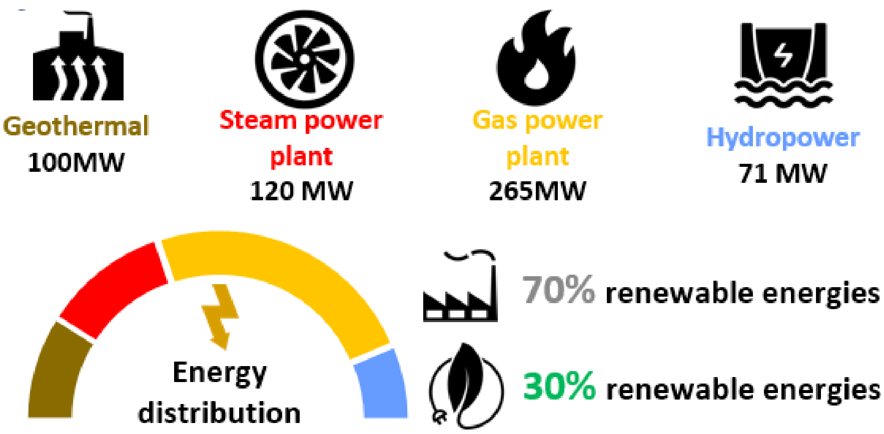


Figure 22: Future plan summary until 2024

According to the plans, the peak load of 2024 could be met by PT PLN. However, it is still unpredictable which part of the capacity can actually produce during peak demand. Of the energy distribution, the hydropower is the least predictable energy sources due to the fluctuating water level of Tondano Lake. As the plans of PT PLN change every year, it is difficult to predict whether the demand would be met by the supply.

3.3 BUNAKEN

Indonesia consists of more than 17.000 islands. The large islands are known to have a well organised energy supply system with relatively high rate of connected households. The smaller and remote islands have problems with their energy supply. Some islands lack power supply others have limited power supply. Mostly the energy is supplied by diesel generators. The fossil fuels are imported from the mainland and this results in relatively high energy prices (Smart Villages, 2015). Additionally the energy generator and resource transportation results in high pollution. PT PLN noticed these problems and initiated in 2010 a plan to help more than thousand islands. The concept is to stimulate the use of photovoltaic power stations in combination with diesel power generators called hybrid PV power plants (VIVA, 2010). PLN chose 7 islands to serve as a pilot. One of these islands is Bunaken island.

3.3.1. GRID

The Bunaken grid (Figure 23) is an isolated grid which connects the three largest villages on the island to the power supply plant. The power supply plant is operated by PT PLN Bunaken.

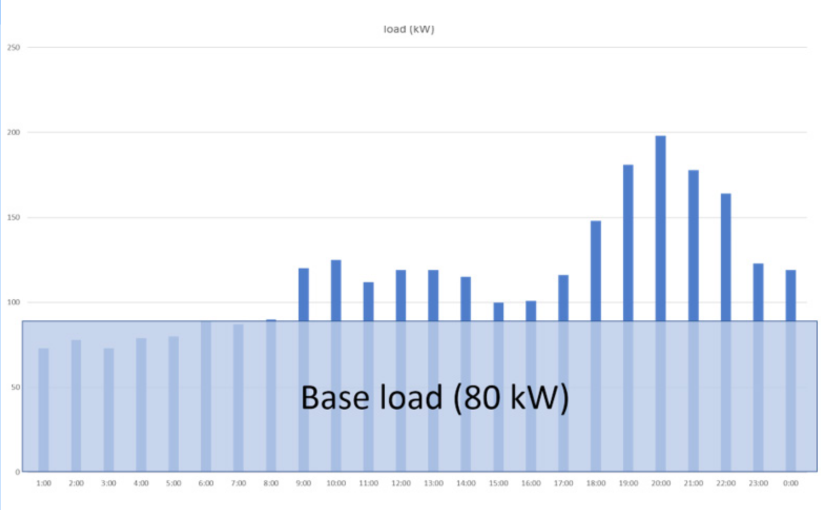
3.3.2. CURRENT SITUATION

Demand

In 2013 an analysis on the electricity demand on the Bunaken is made. A typical load curve Bunaken island can be found in Figure 24. The peak load presented in Figure 24 equals 200 which corresponds to an analysis made in 2013. It is important that the peak load in 2017 could reach up

Figure 23: Rough indication of the grid on Bunaken Island (Frets Pieters, 2017, Appendix O12)

Figure 24: Load curve Bunaken Island in 2013 from PT. PLN Bunaken



to 249 kW, this is stated by an operator of the power plant on Bunaken during a visit.

Supply
The energy is supplied by a solar park in combination with a diesel generator. The park consists of 1444 solar panels with a capacity of 335 kW. Hours without sunlight are covered by batteries and diesel generators. The production costs of the power plant is approximately 0.22 $/kWh (Asikin, 2015), (Meeting PT PLN Manado, 2017, Appendix O4), where the citizens only pay 0.11 $/kWh. The system currently only supplies 18 hours of electricity to their customers. This is mainly due to the lack of organisation and expertise at the island. If the power plant functions it could supply 24 hours of energy to the complete island.

3.3.3. ENERGY PROJECTION BUNAKEN

Demand
Little is known about the future of Bunaken island and its energy demand. It is known that in the last 4 years the peak power demand grew with 5.7% per year, this followed form the peak loads given by PT PLN Bunaken. Whether this trend will go on is very uncertain therefore a more detailed analysis has to be performed.

Supply
PT PLN Manado is planning on connecting Bunaken to the SULUTENGO grid via a 20 kV submerged power cable. The project is initiated this year(2017) and it will take one year before the PT PLN Jakarta will react on the proposal (Meeting PT PLN Manado, 2017, Appendix O4),. It is expected that the execution of this project will take a long time, since many important variables are still unknown, like the bed topography. Which is very rough with large height difference over a short lateral distance(Frets Pieters, 2017, Appendix O12).

According to PT PLN Bunaken, improvements of the current energy supply system are planned. With the replacement of the old batteries it is expected that the plant will be able to supply 24 hours of energy. How long it will take is before the replacements are there and installed is still unknown.

3.4 PRICE

The energy in Indonesia is heavily subsidised by the Ministry of Finance. Part of this subsidy is to encourage the usage of renewable energy. PLN produces and sells energy, but also buys energy from independent power producers (IPPs). The citizens and industry pay a fixed price according to a category that they belong to. Most citizens and malls in Manado fall into the classes presented in Table 3.

These subsidised prices indicated in Table 3 show PLN's favourable price to pay for a certain energy source (Smart Villages, 2015). However research shows that PLN is willing to pay a higher price, if it can stimulate the economic growth of a certain region, like remote areas/islands.

Class	IDR/kWh	$/kWh
1	1.352,00	0,10
2	1.467,28	0,11

Table 3: Energy price in North Sulawesi (PLN Manado, 2017)

3.5 STAKEHOLDERS

The electricity supply in Manado is managed by the local PT PLN which is a governmental company. This is the only electricity company, whereas they take care of the generation, transmission and distribution of the electricity. This makes PLN the most important stakeholder. Figure 25 shows how the energy is distributed including important stakeholders (Patel, 2013).

A stakeholder map is shown in the Figure 26. A general description of the stakeholders can be found in Appendix N and Appendix D1.4 contains more information about the location of important stakeholders. In Section 9 the important stakeholders for implementation are elaborated.

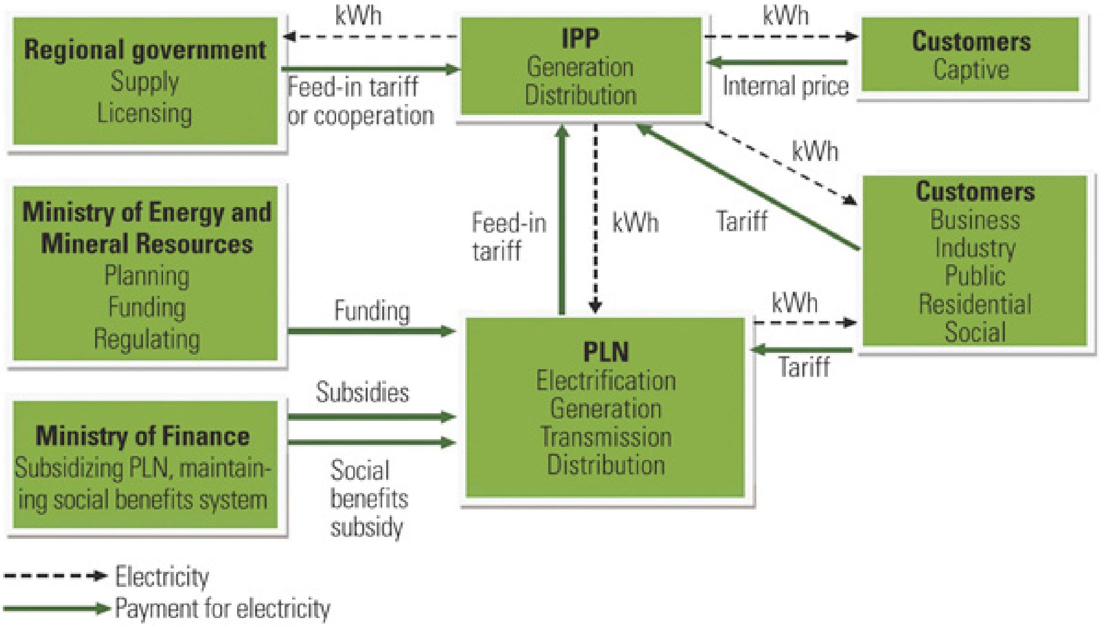


Figure 25: Energy distribution system in Indonesia (Patel, 2013)

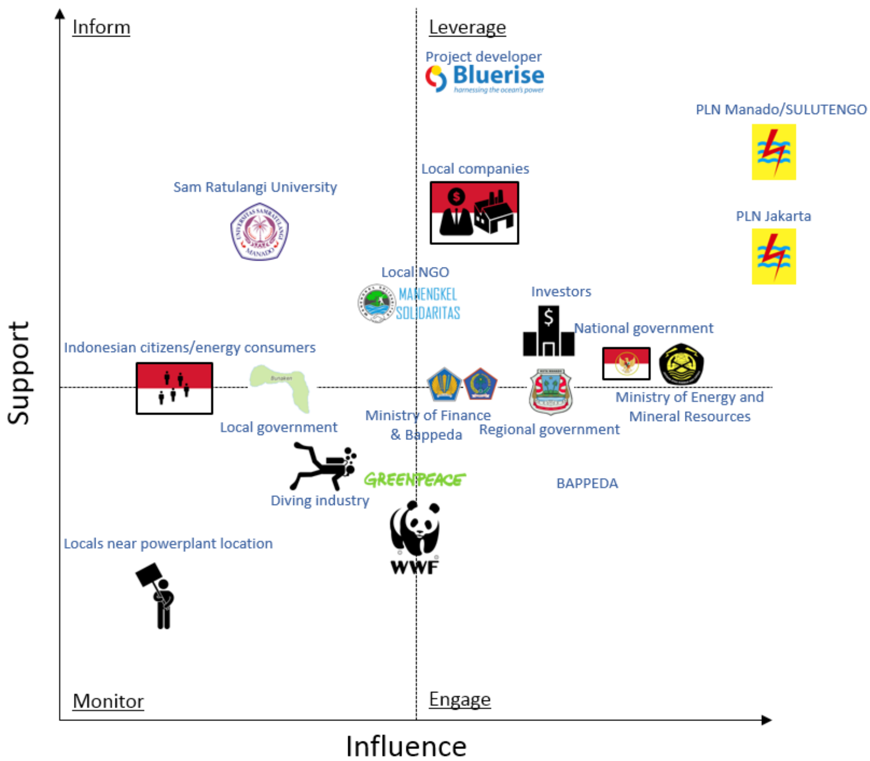


Figure 26: Stakeholder map energy

4. WATER ANALYSIS

In this chapter a summary will be given of different types of drinking water production technologies that use cold deep seawater. Then, the need of drinking water will be displayed for the area of interest which includes Manado city and Bunaken island.

4.1 TECHNOLOGY

Cold deep seawater can be used to produce drinking water. One method to do this is powering Reverse Osmosis (Appendix C2) by the energy stored in the ocean (ROTEC). The second technology uses the cold deep seawater to cool down air such that the air condensates in too a liquid. A technical overview of both technologies is given below.

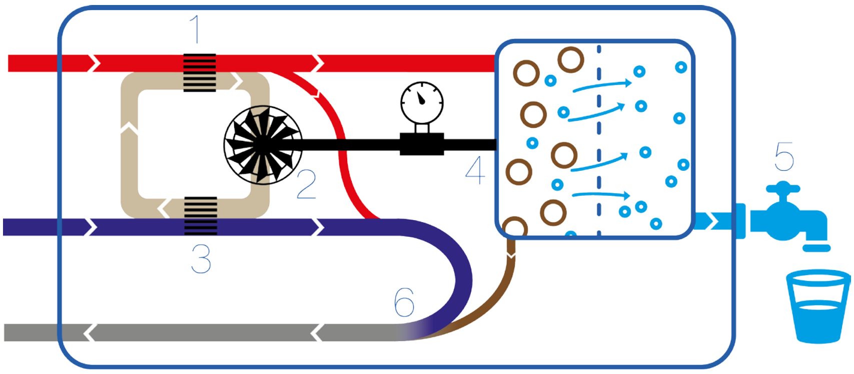


Figure 27: Overview of ROTEC's technology

4.1.1 ROTEC

An overview of the technology is given in Figure 27. A more detailed explanation can be found in Appendix C3.

1. Hot surface water (red) makes a working fluid (beige) evaporate via a heat exchanger.
2. The gas goes through a turbine to power a pressure pump.
3. The gas is cooled with deep sea water (dark blue) via a heat exchanger, to reuse it in a closed cycle.
4. A pump presses a part of the hot surface water through a semi-permeable membrane
5. Fresh water (light blue) passes the membrane and can be treated further.
6. The salty waste (brown) is mixed with the deep seawater and the rest of the hot water and the mixture (grey) is safely discharged.

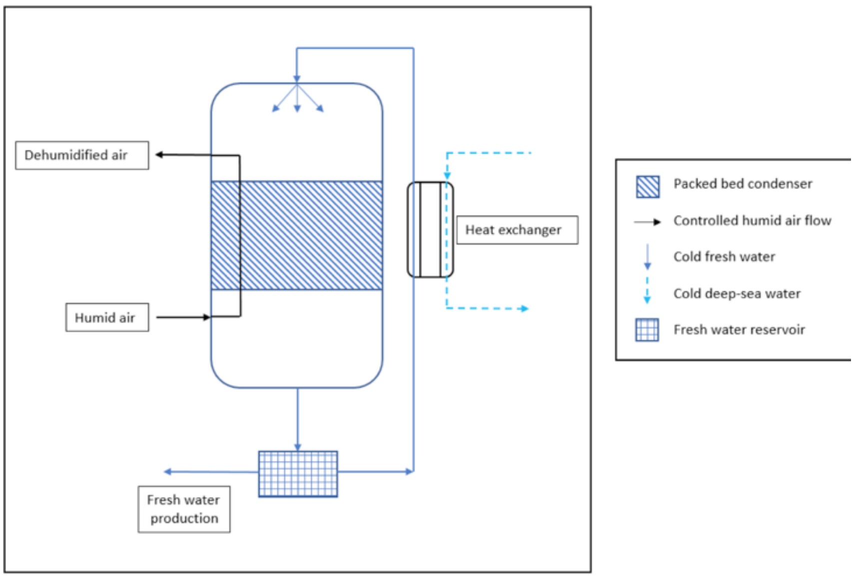


Figure 28: Overview of direct contact dehumidifier (van der Drift,2014)

4.1.2 DEHUMIDIFICATION

Cold deep seawater cools fresh water through a heat exchanger, see the right side of Figure 28. This cold water is sprayed at the top of the packed bed tower where the heat transfer takes place. In this way, a liquid layer is formed. Humid air enters the tower at the bottom, and is then cooled when it gets in contact with the water layer on the bed. The humid air will be cooled to below the dew point, so that the water vapor from the air condenses, leaving liquid water. This condensed water is then added to the fresh water loop (van der Drift, 2014). A more detailed explanation can be found in Appendix C4.

4.2 MANADO

During the research project the current status of drinking water supply in Manado and Bunaken was analyzed. A detailed description of this status is given in Appendix D2.

At the moment, there is no fresh water shortage in Manado City (Appendix D2.1). But the tap water that is available is not drinkable (Veenendaal, 2017, Appendix O6). The water is contaminated and most of the people rely on bottled water when it comes to drinking water. It can be concluded that there is a need to have clean drinking water from the tap. However, the poor water quality of the tap water is mostly caused by the bad piping network. This problem must be tackled before clean drinking water can be delivered to the tap of the households that are connected. Beside this, there is a high need for expansion of the currently available pipe network of PT AIR Manado. During a socio-economic survey, 88% of the respondents who do not have a connection to the tap water, is interested in a connection (Akhir, 2010). PT AIR Manado has currently the plan to expand this network and improve the water quality. A part of this plan is to build an entirely new treatment plant (Jan Wawo, 2017, Appendix O3).

To conclude, currently, there is no need to produce drinking water from ROTEC or dehumidification. However, in the future the demand might grow since the population is growing and deep wells at the coast that extract the groundwater can cause salt intrusion.

4.3 BUNAKEN

unaken already past their limits of available ground water a long time ago. Wells are brackish due to salt intrusion and during dry season wells dry out (Kanto, 2017, Appendix O8). Therefore the national government invested in desalination installations (Reverse Osmosis) for the island and improve access to their first human need. Nevertheless, all desalination (four in total, see Figure 23) failed and as the date of today the islanders remain without drinkable water. The drinking water is imported from Manado city for high prices. The scarcity of water threatens the growth of their tourist industry and the prosperity of the island. It can be concluded that the need for a sustainable and low maintenance desalination plant is very high. This in terms of freshwater need and cost effectiveness. A more detailed explanation of the current status on Bunaken island can be found in Appendix D2.2.

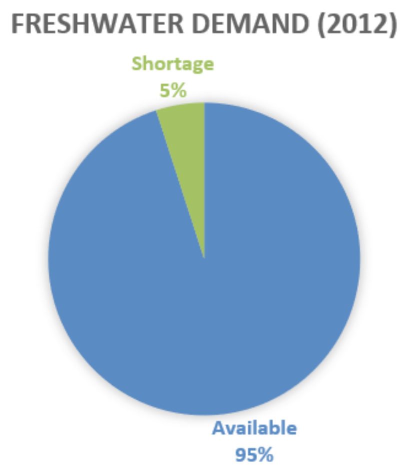
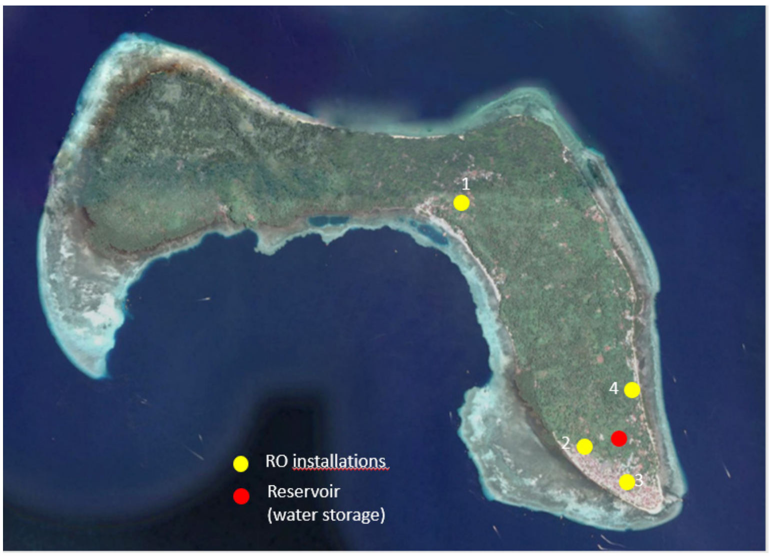


Figure 29: Ground water availability Bunaken (Towoliu, 2012)

Figure 29: Overview of desalination plants



Water type	Price $/m³
Tapwater Bunaken (Sea Garden Resort)	+/- 10.4
Bottled water Bunaken	87.7
Tapwater Manado	0.35
Bottled water Manado	56.1

Table 4: Water prices

4.4 PRICE

In Table 4 an overview of the current water prices are given. A distinction is made between drinking water and tap water. Bunaken has no tap water system. The price given in Table 4 is the price that some inhabitants pay that lack a fresh water well. They pay for a connection to a fresh water well of someone else. The prices of the bottled water are based on the price of a gallon (19L) in the supermarkets.

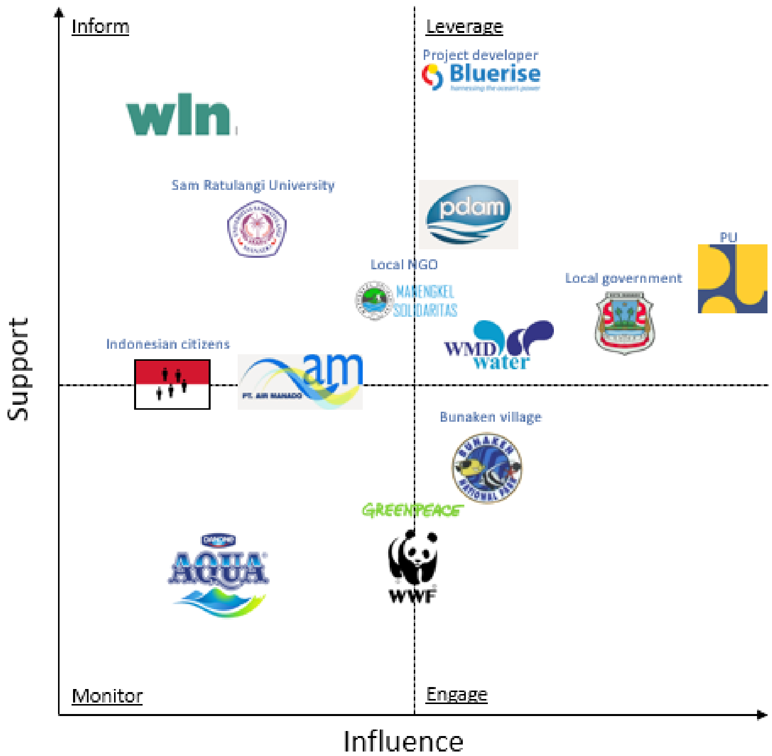


Figure 30: Stakeholder map water

4.5 STAKEHOLDERS

It follows from the current status that there are many different stakeholders of influence on fresh water production. Some stakeholders and their perspectives are shortly described in Appendix D2.4.

The tap water supply in Manado is operated by PT. Air Manado, which is partially owned by Watermaatschappij Drenthe and the local PDAM. New treatment plants are proposed and funded by PU. The same goes PU for Bunaken, but there is currently no party responsible for the operation and maintenance of treatment plants on the island.

5. COOLING ANALYSIS

In this chapter an analysis is made on cooling with a new way of cooling for Manado. First the technology is briefly explained. Secondly the need for cooling in Manado is projected. Bunaken is left out of this part, since the houses on Bunaken are not cooled. A detailed decryption of the current status of cooling in Manado is given in Appendix D3.

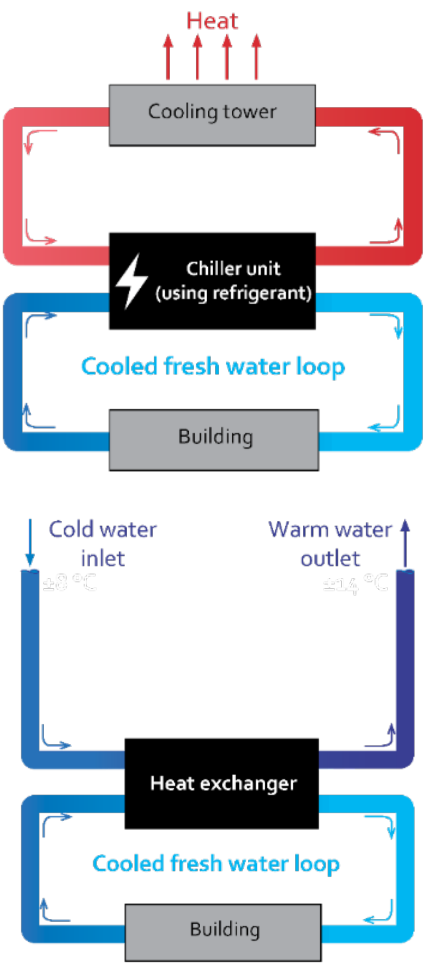


Figure 31: Schematization of conventional cooling with a chiller (upper) and SWAC (lower).

5.1 TECHNOLOGY

5.1.1. SEAWATER AIR CONDITIONING

The conventional way of central cooling for large buildings makes use of a chiller, that transfers heat from the building to the outside using a refrigerant. However, this process requires a lot of energy, because compression of the refrigerant is very energy consuming. On top of that, refrigerants are ozone-depleting materials and they often leak. Therefore, a plan is made to replace the system in Manado with a concept that does not use refrigerants, but replaces it for cold deep seawater. This is called 'Seawater Air Conditioning', or SWAC. In a SWAC-system, the heat is transferred from the building to the cold deep seawater. An overview of both systems is given in Figure 31.

5.1.2. DISTRICT COOLING

Another beneficial way of cooling is called District Cooling (DC). In this technique several buildings are connected to the same cooling system via a distribution network of cold water pipes. From a production facility cold water is pumped around to fulfil the cooling needs. The water can be cooled by several sources. Via heat exchangers buildings can cool down their own fresh water loop as indicated in Figure 31. A schematization of District Cooling is given in Figure 32.

5.1.3. SEAWATER DISTRICT COOLING

Seawater District Cooling (SDC) is a combination of SWAC and DC, where the production facility cools the distributed fresh water with seawater. The technologies are explained in Appendix C5 and reference projects of SWAC, DC and SDC are presented in Appendix C5.2.

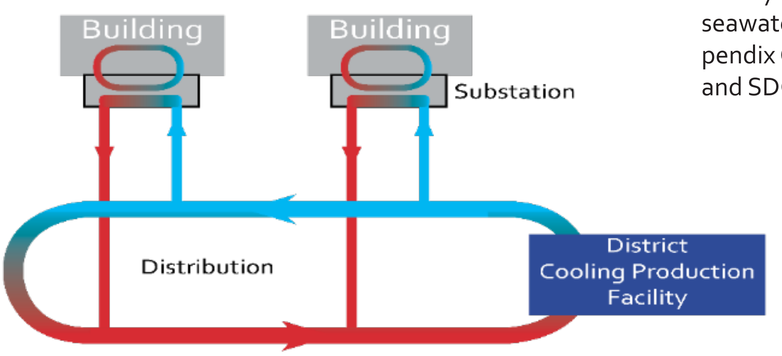


Figure 32: Schematization of District Cooling and its fresh water loops

5.2 MANADO

Air conditioning of dwellings in developing countries is currently rather rare, but increasing personal income (in developing countries) is expected to change that. On top of that, the cooling demand in developing countries are greater than the heating demand, since most of these countries have warm to hot climates.

Next to the demand, the potential of the location is of great importance. The city of Manado is built along the coast of Manado Bay, closed in by volcanoes on the other side. Since the city and economy of Manado keeps on growing, the city becomes more and more crowded. Therefore, the last century, the city has expanded into the ocean by building several land reclamations along almost the entire coastline. The largest area of these reclamations is covered by large shopping malls, hotels and shops. Especially the malls and hotels are cooled.

Next to the location, the cooling load must be high enough. The total cooling need for hotels and malls built on these land reclamations is determined. Some of the values have been confirmed by lead engineers. Some are determined based on the size of the building, the amount of visitors or the amount of hotel rooms. The total peak cooling load of the large hotels and malls on and close to the new land reclamations is at the moment around 10.000 refrigerating tons (1 refrigerating ton is the heat that would be enough to melt 1 metric ton of ice in 24 hours). Taking growth of existing malls and hotels and newly planned real estate projects into account, the peak load can become 18.000 tons. See Figure 33for the location overview of large buildings that are included in the total estimated cooling load.

In Manado there is a large cooling request throughout the whole year and as can be seen there are a lot of buildings with a high cooling load. These large buildings require central cooling and are next to the sea. Since the cooling load of some buildings is above 1000 tons it is attractive to cool them with SWAC (Makai Ocean Engineering, 2017). The fact that the buildings are close to each other and the cooling load density is high, District Cooling is an attractive option as well. Only the low electricity prices make a new solution less attractive.

It can be said that there is a need for cooling, but this is already fulfilled by conventional systems. But, with these characteristics it can be stated that there is a need for an alternative way of cooling in terms of cost effectiveness and sustainability. A total overview of the need on cooling can be found in Appendix D3.1.

Figure 33: Overview of the locations of the land reclamations and large buildings.

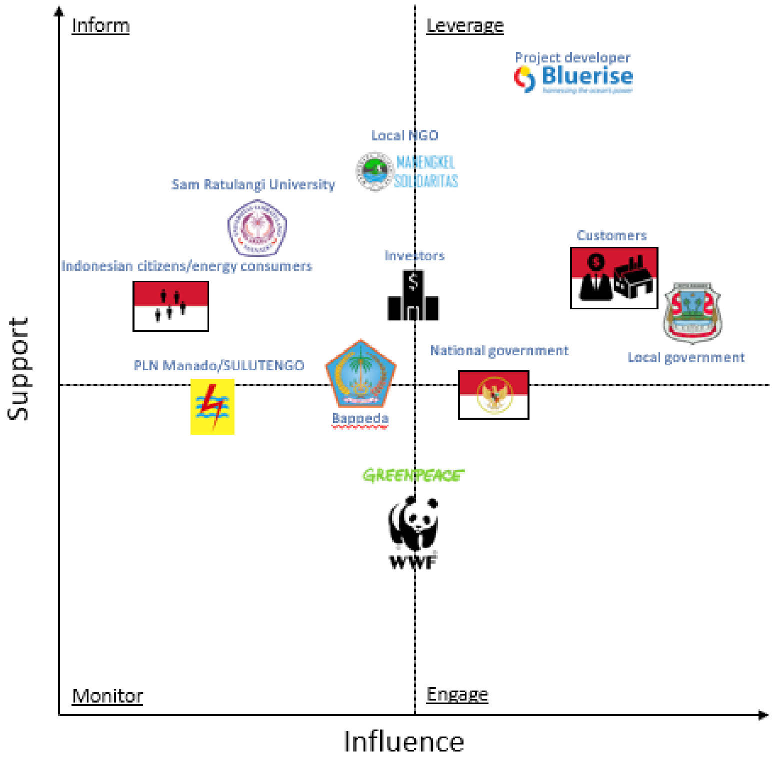


Figure 34: Stakeholder map cooling

5.3 STAKEHOLDERS

At the moment stakeholders are not aware of the benefits of a new cooling system. Fact is that when a good proposal is made for the future, which is financially attractive, stakeholders would become more supportive (see Figure 34). Customers are of great importance, since they should be willing to get a new cooling system. The government needs to be supportive to provide all the permits or make regulations for it. Next to that, the business case must be attractive enough to attract investors.

Some stakeholders and their perspectives are shortly described in Appendix D3.2. The different possible customers in Manado are described in Appendix N.

6. MULTI CRITERIA ANALYSIS

For Manado and surroundings, several solutions for deep water usage can be identified. These can be divided in two major groups: Manado and Bunaken. For both Manado and Bunaken, a Multi Criteria Analysis (MCA) will be done based on three subcategories: water, electricity and cooling. The criteria on which a subcategory is rated, including the choices, will be explained in more detail below. For each criterion, a weighing of 1 (low), 2(medium) or 3(high) can be given. The total scores show whether the solution might be of importance or not. The higher the score, the more important the solution. The total overview can be found in Table 5.

6.1. NEED

The first criterion is need, which is the highest rated criterion, since without a need a product is useless. For Manado, the need for water and electricity are low. Mostly because the current resources are able to cover the demand and an increase in demand is possible. For cooling, the need is quite high since all big malls and hotels need to be cooled, which is very energy consuming. However, since cooling is currently provided, it is rated as 2.

For Bunaken, both water and electricity are needed. Currently, drinking water mostly comes from the mainland (Manado) and is shipped in bottles, which is very expensive and harmful for the environment. On top of that, their (small) RO installations are all broken or out of service. Electricity is only partially available during the day. Increasing the availability would help improve prosperity. The cooling demand is low, no large resorts or hotels are located on Bunaken.

6.2. FUTURE NEED

The current water sources for Manado are able to cover increase in usage for the near future, but especially in the dry season, lakes and wells would not be able to provide the city for its needs when the city keeps on growing like it does now. Besides that, Manado does not want to rely on the power supply vessel that is currently used to produce electricity and therefore sustainable electricity sources are welcome. For cooling, the future need would be moderate. Land reclamations are planned, giving possibilities for new malls and hotels to be built.

For Bunaken, the future need is comparable to their current need. Since the tourism industry is expected to grow, the need for water and electricity will keep on growing. On Bunaken there are no large scale hotels proposed and central cooling will not be a future need.

6.3. DEEP SEA WATER (DSW)

DSW accessibility is the distance offshore till the wanted deep seawater temperature. For Manado, water and electricity score low because very cold water is needed, which can only be find further offshore (5 km). For cooling however, warmer water can be used (say 8-9 degrees), meaning the pipe only has to go to 1700 meters.

At Bunaken, the colder water can be found closer to shore, meaning the ratings are higher.

6.4. TECHNICAL FEASIBILITY

For technical feasibility, things like ease of installation and implementation are considered. For Manado, the seabed is less steep than near Bunaken, where you have a vertical wall (Figure 17). This means installing would be easier near Manado. Besides that, for cooling you only need a pipe and a heat exchanger, whereas for water and electricity production more complex components are necessary. This makes it technically more complex leading to lower gradings.

6.5. ENVIRONMENTAL IMPACT

Near the coast of Manado, coral reefs are destroyed during the installation of the land reclamations. Laying a pipeline there does not have a large impact on the environment anymore. For Bunaken however, the pipeline most probably has to go (partly) through a coral reef, meaning the environmental impact might be very high. Therefore, the rating for Bunaken is lower.

6.6. POLITICAL INCENTIVE

The Indonesian government wants to improve the provision of electricity and water for small islands (VIVA, 2010). The Bunaken would be a great opportunity from which the government can benefit. For Manado, this incentive is smaller. However, for the local politicians it is still beneficial to provide the city with better, sustainable and future proof solutions.

6.7. SOCIAL/ BUSINESS INCENTIVE

For Manado, getting water or electricity from deep seawater technologies are not beneficial, since their current solutions are sufficient or there are cheaper alternatives. However, using deep seawater for cooling could lower the costs of large buildings a lot, which is beneficial.
For Bunaken, this is somehow the other way around. There, cooling is not something that is needed. Water and electricity however are things that Bunaken needs, and would benefit the inhabitants and businesses on the island.

6.8. CONCLUSION

It follows from the Multi Criteria Analysis in Table 5 that designing a new cooling system would be most optimal for the city of Manado. For Bunaken a new water and electricity plant is the most favorable. These options are therefore worked out in the following chapters. First a design for a new cooling system is elaborated upon in chapter 7. Secondly a new plan for water and electricity provision is presented in chapter 8.

		Manado			Bunaken		
	Weighting	Water	Electricity	Cooling	Water	Electricity	Cooling
Need	5	1	1	2	3	3	1
Future need	3	2	3	2	3	3	1
DSW	3	1	1	2	2	2	3
Technical feasibility	4	2	2	3	1	1	2
Environment	3	2	2	2	1	1	1
Political incentive	2	2	2	1	3	3	1
Social incentive	3	1	1	3	2	2	1
Total score		35	38	51	49	49	33

Table 5: Rating of solutions

7. MANADO DESIGN

"In order for a district cooling project to be competitive, a number of factors have to be checked and confirmed before it starts. Normally this is done by an external consultant in the form of a feasibility study." (Swedblom, 2014). These can mostly be divided into technical and economic criteria. Critical criteria that must be thought of are the source of cooling, future storage, the electricity and fresh water supply, the area size, the cooling load distribution and what the future demand looks like. These criteria are described in Appendix E1.

7.1 BASIS OF DESIGN

7.1.1. OFFSHORE INFRASTRUCTURE

The offshore infrastructure consists of the offshore supply and discharge pipelines.

Technical
The level of complexity of installing the offshore pipelines depends on several aspects. The steepness of the seabed is the most important one. Having a slope that is very steep means deep (cold) water is reached faster. However, this also increases complexity of both installation and maintaining position of the pipeline. For SDC for Manado, a cold water temperature of 7 degrees Celsius is needed, which is reached following a slope of approximately 7 degrees at a depth of 550 meters.

Economic
For the offshore pipelines, an attractive and durable material would be HDPE. This materials lifetime is expected to be 50 years (Patterson, 2002), and is economically more attractive than using metals. Since the offshore equipment is one of the most important economic aspects of SDC, it is important to optimize construction and find the most attractive solution.

7.1.2. ONSHORE INFRASTRUCTURE

Production
The production installation is where the cooling process takes place. It houses the heat exchangers that transfers cold from the seawater to the fresh water distribution loop. It needs to be built on land close to the pipe shore landing location.

Distribution
A distribution network will be necessary to provide customers with cold fresh water for their cooling systems. This network will consist of (large diameter) pipelines, running through the city.

To have the best customer service, a good connection is demanded. On top of that, the total district cooling trajectory should be as short as possible, to avoid a large increase of the water temperature.

For customer connection, multiple methods can be used. The most logical solution to connect all the customers to the system is by laying one large closed district cooling loop (Figure 35).

However, it is economically more attractive (in terms of pipe diameter size) to make multiple smaller loops, and connect several buildings to each loop (Figure 36). This could also increase redundancy.

Substations
The users will be connected to the distribution network via substations. These substation will house heat exchangers and will cool the distribution network to in order to cool the already existing in-house fresh water loop of the central cooling system in the buildings. This substation can be either located next to or on top of a building, depending on the location of the central cooling system.

More information can be found in Appendix E2: Technical & Economic Feasibility.

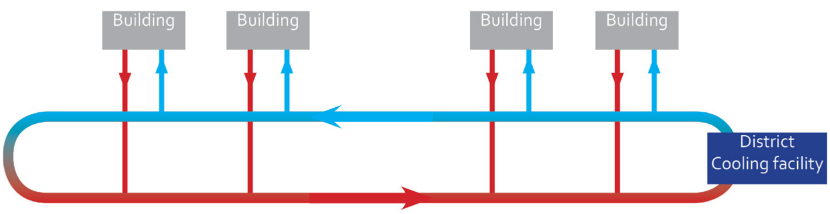


Figure 35: Single loop district cooling

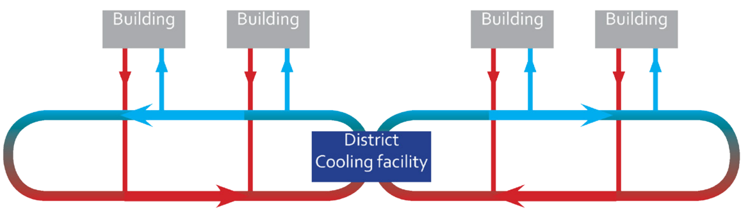


Figure 36: Duo loop district cooling

7.2 MULTI CRITERIA ANALYSIS

To find the best solution for the final concept, three pipelines trajectories are shown, from locations that are still available to build a production facility. The trajectories are chosen, such that the pipeline will lay mostly perpendicular to the bathymetry lines. In this case, it is prevented that the pipe is able to roll down the slope and best stability is increased. The best option follows from a Multi Criteria Analysis, based on the conditions explained in section 7.1, see Table 6 and Figure 37.

facility number	Cooling Density	Distribution diameter	Offsh. pipe length	building space	Operation (pumps)	bathymetry	
weight	1	3	3	1	1	1	
A (yellow)	1	1	3	1	2	3	19
B (pink)	2	2	2	2	3	2	21
C (blue)	3	3	1	2	1	1	19

Table 6: Multi Criteria Analysis for location production facility.

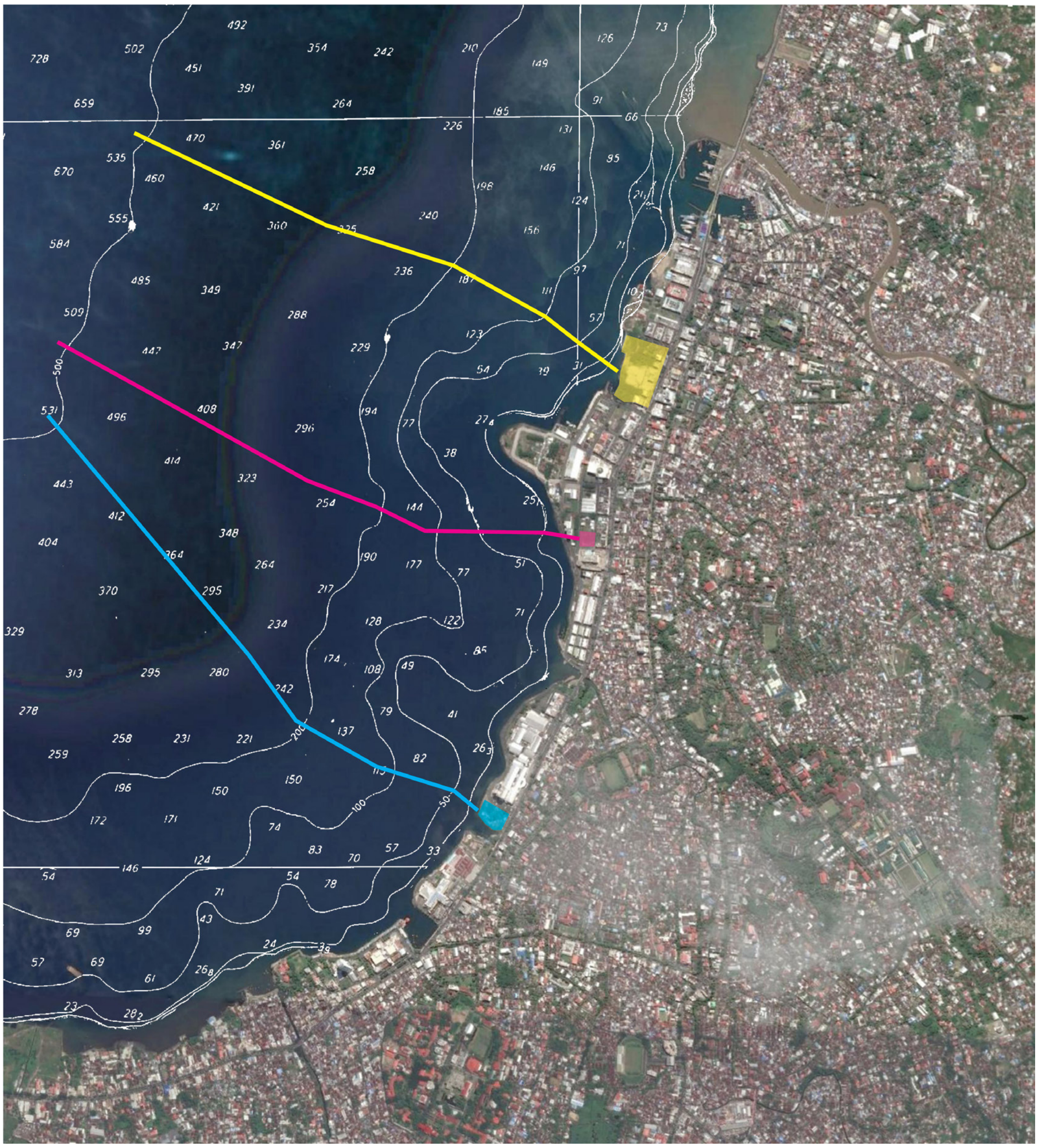


Figure 37: Possible production facility locations

7.3 FINAL DESIGN

There is a need for cooling in Manado, and more specific; in the coastal area of Manado, where land reclamations are full of large shopping malls and hotels. Section 7.1 showed several ways aspects of a good design. It is discussed which infrastructure and equipment is needed. Secondly a financial estimation is done and the economics for investors are discussed. Third, the benefits for the environment, the customers and society are shown.

7.3.1. BOUNDARY CONDITIONS

Section 7.1 already discussed some boundary conditions. On top of that the customers need an internal fresh water loop of at least 10°C (Figure 46 in E2). This would mean that a schematization of the heat exchangers at the production facility would look like Figure 38. To provide additional cooling and foresee thermal losses the cold water is distributed at 8°C.

Location B (pink in Figure 37) showed to be the most appropriate location to build the production facility, mostly because the offshore distance and the fact of using two fresh water loops (North and South). Summarizing all, this results in the boundary conditions, shown in Table 7.

7.3.2. DESIGN CRITERIUM

The peak load determines the size of the SDC installation that needs to be constructed. In Table 5 in Appendix D3 an overview is given of the cooling load distribution in Manado. To make a good design it is chosen to include the future cooling load of existing buildings only. This brings the total peak cooling load to 13500 tons. Dividing this into two loops, results in: 4600 tons for the Northern loop and 8900 tons for the Southern loop. An overview of the buildings connected can be found in Table 8.

7.3.3. EQUIPMENT AND INFRASTRUCTURE

For the proposed Seawater District Cooling (SDC) system, three major parts can be distinguished; the offshore pipeline, onshore cooling facilities, district cooling network and the customer connection. Each of them will be discussed in further detail. The entire overview of the onshore and offshore equipment and locations is given below, see Figure 42.

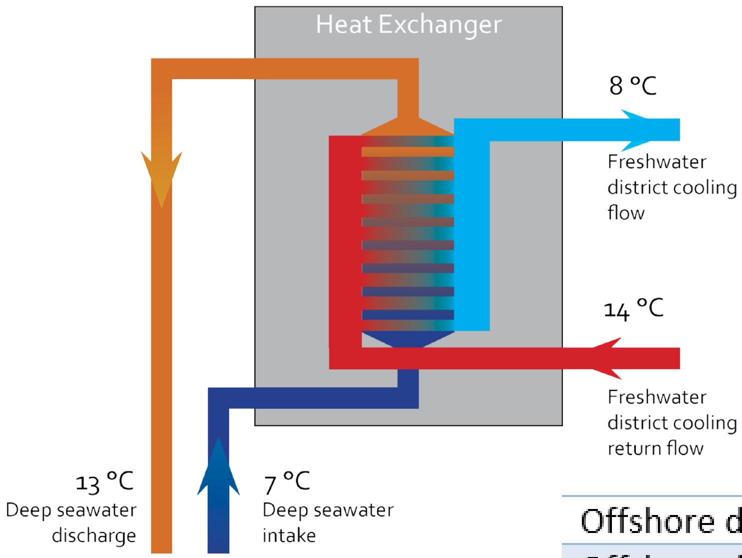


Figure 38: Water flows in production facility

Table 7: Boundary conditions

Offshore distance cold water intake	2200	m
Offshore distance warm water outlet	500	m
Depth cold water intake	550	m
Depth warm water outlet	180	m
Cold seawater - intake temperature	7	°C
Cold seawater - outlet temperature	13	°C
Fresh water - inlet temperature	8	°C
Fresh water - outlet temperature	14	°C
Northern loop distance	900	m
Southern loop distance	2600	m

Figure 39: Location of the production facility

A The intake pipe trajectory shows that the total length of the pipe to reach 7°C (at 2200m from shore) is 2800m (Table 7 in F1.2) and the length of the discharge pipe becomes 531m. The pipes will have a diameter of 1.25m (Appendix L), which falls in the range of manufacturing (ISCO, 2017).

B The production facility will harbor the pumps with a capacity of 0.15MW to pump up the deep sea water (F1.2), heat exchangers with a volume of 26m3 (F1.3) to transfer the heat of the water for a peak cooling load of 13500 tons. Also diesel generators and chiller units will be included in the production facility as a backup in case of power black outs and downtime of the SWAC system. It will be situated next to the sea on an unbuild piece of land, see Figure 39.

C The distribution network, will connect 16 customers in total with two separate loops, buried underground. Every loop consists of cold water supply pipe and a warm water return pipe. The northern loop will have a total pipe length of 1800 meters and a maximum diameter of 0.74m. The southern loop will be 5200 meters with 1.03m. The thermal losses during distribution are bound to 0.1°C (Table 9 in F1.3) and a total pump capacity for both loops to overcome pressure losses is 0.19MW (Table 8 in F1.3).

D Every building will have a heat exchanger in proportion with its peak cooling load to be able to cool its internal freshwater loop to 10°C with the distributed cold water, see Figure 40 and Figure 41.

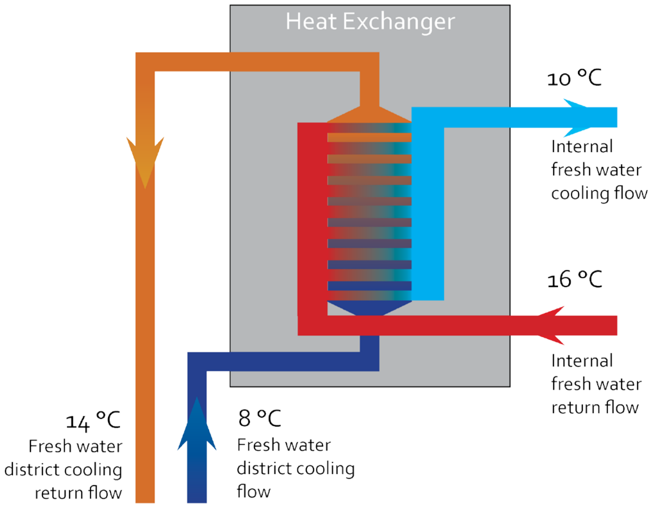


Figure 40: Heat exchanger in substation

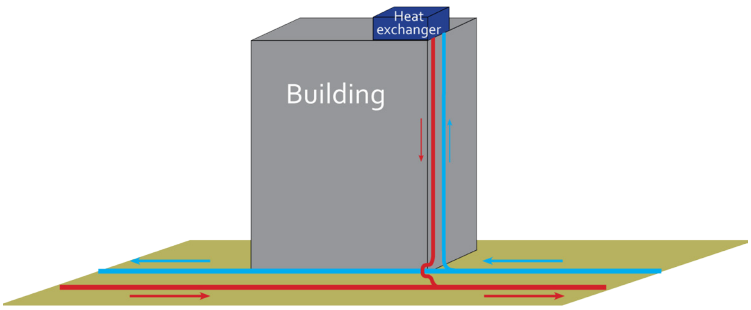


Figure 41: Location of substation, example.

Table 8: Future cooling peak loads in refrigerating tons

Malls	Future peak cooling load [ton]
1 IT Center	*1200*
2 Megamall	1800
3 Mega Trade Center	1200
4 Mantos 1	1200
5 Mantos 2	800
6 Mantos 3	1800
7 Star Square Mall	*2500*
Hotels	
8 Aryaduta Hotel	*400*
9 Ibis	*600*
10 Four Points Hotel	600
11 Lion Hotel	*600*
12 Manado Quality	*300*
Other	
13 Convention Center	*500*
Total	*13500*

Figure 42: Overview of project lay-out

7.4 FINANCIALS AND BENEFITS

For the economics, a comparison between current cooling costs and future seawater district cooling costs will be made. For this economics, confidential indicative prices are provided by Bluerise. The cost buildup of the Capital (CAPEX) and Operational Expenditure Costs (OPEX) can be found in Appendix F2. The total CAPEX and OPEX are respectively $25.93million and $450 thousand.

7.4.1. FINANCIAL FEASIBILITY

The economic feasibility can be divided into two options. The first option is the case where the customer is the investor, based on the economic benefit of SDC compared to conventional cooling. In this way it can be seen for malls, hotels and other buildings how much they can spare, when investing in SDC. The second option focuses on a case for external investors. Since the investment costs are rather high, it is more likely for an investor to build a SDC system, when the IRR and return period are attractive. The customer then pays a capacity and connection fee to the investor. The investor cases look promising for customer and investor and are worked out in Appendix F3.

Conventional air conditioning systems in buildings are evaluated to have approximately a demand of 0.7kW per cooling ton (taking into account a heat over work relation of 5 (coefficient of performance) (Bluerise, 2017). Combining this with the local electricity price, the yearly costs for conventional air conditioning can be determined. The savings of using SDC instead of conventional air conditioning can be displayed as a cash flow. In this case the investment for conventional cooling is not taken into account, since the intended buildings already have those systems. Figure 43 is shows the cash flow that follows from the assumptions in Table 9.

The cumulative cash flow (Figure 44) shows that building such a system is attractive, even with the non-excessive electricity rates in Manado. The payback time after starting the project is 9 years, which is 6 years after the completion of the construction. The IRR is 19% and a net present value of $ 35.4 million. A short overview of the total cost reduction can be found in Figure 45.

Average cooling load	65%
Interest rate	7%
Electricity price	110$/MWh
Lifetime	30 years

Table 9: Economic assumptions, based on available data and track record SDC

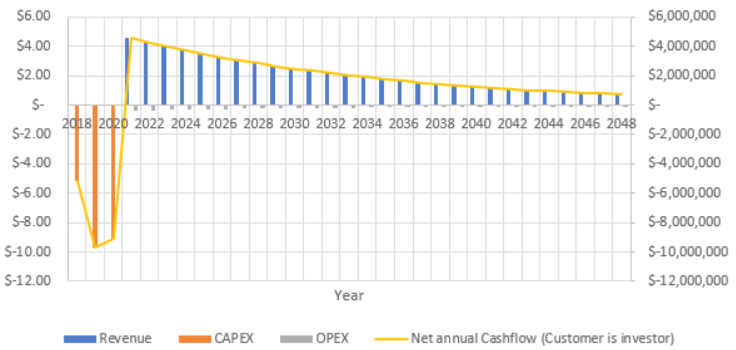


Figure 43: Discount Cashflow SDC

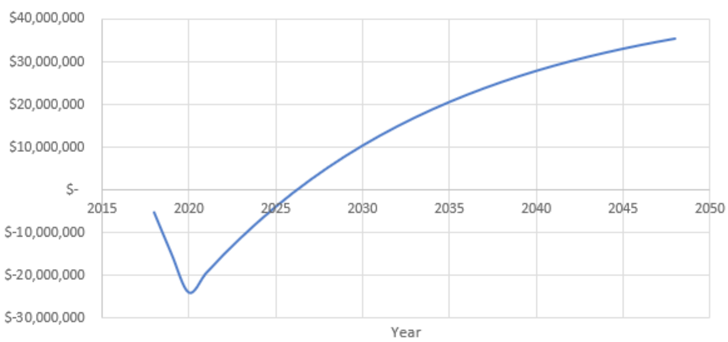


Figure 44: Cumulative cashflow SDC, customer as investor

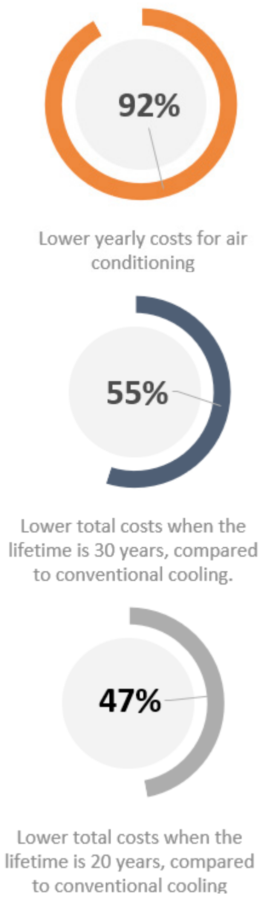


Figure 45: Cost reduction compared to keep using a conventional cooling system.

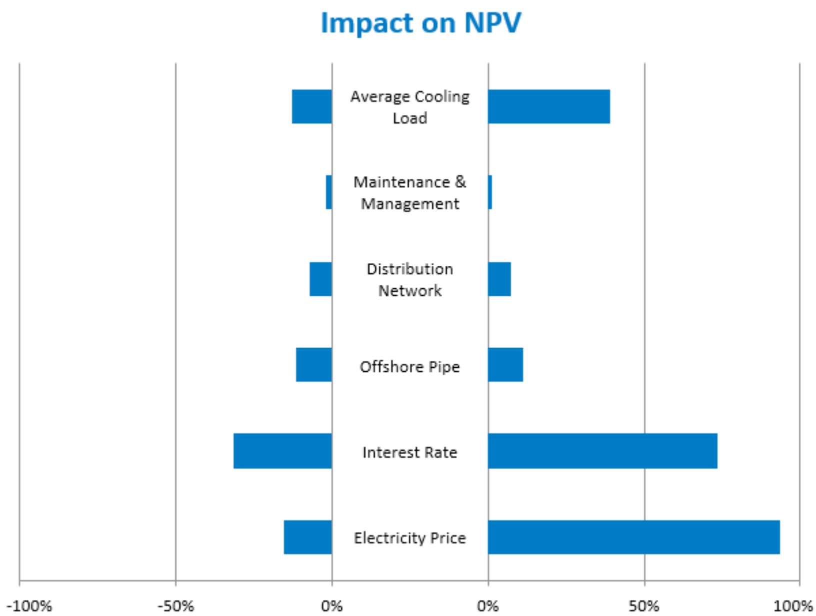


Figure 46: Tornado chart, showing the sensitivity of several aspects of the SDC system.

7.4.2. SENSITIVITY

By varying several financial aspects within their uncertainty boundaries, the impact on the NPV can be shown, see Figure 46. The electricity price in Manado is of great influence, but is expected to become higher in the coming years (subsidies will go down (Christensen, 2016)). Changes in the electricity price can already double the NPV. For a more detailed sensitivity analysis, see Appendix F4.

7.4.3. BENEFITS

The benefits can be summarized as energy related, environmental benefits and secondary benefits (Appendix F5). By using less energy (96%) for SDC it can be concluded that also the emissions will go down for cooling, expressed in CO_2 equivalent. This will be a reduction 501,000 ton over the entire lifetime (Table 15 in F5). This meets with the promises of the Indonesian government at the Paris Agreement to reduce their CO_2 emissions (IPS, 2015). By using less energy the infrastructure improves and less power black outs are caused by high peak loads.

For customers there is next to financial benefits, also a higher security of cooling (less maintenance and centralized production with better equipment) and an increased building value (improved esthetical value of the building, reduced noise and no usage of refrigerants).

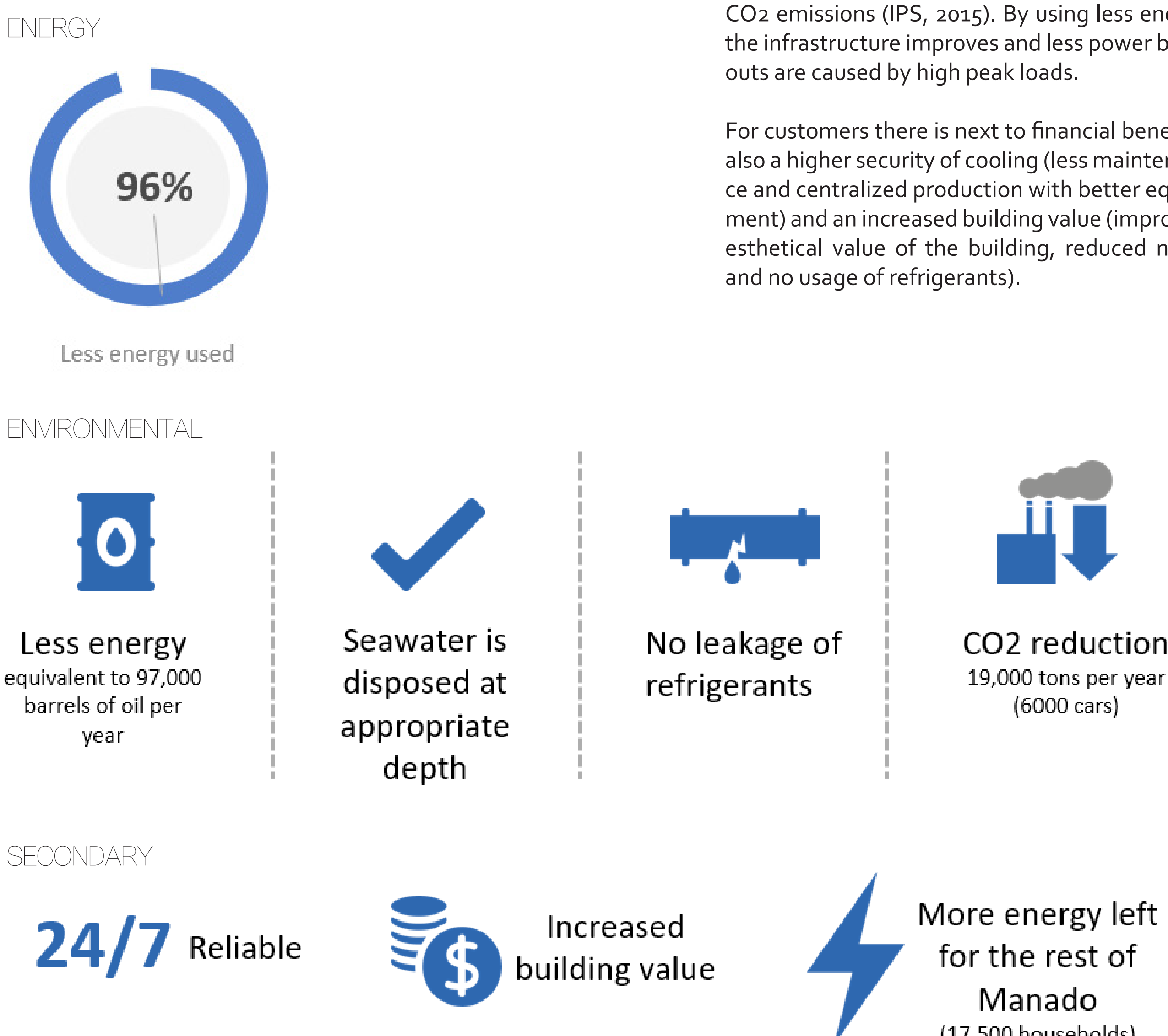


Figure 47: Overview of benefits of the proposed SDC design

8. BUNAKEN DESIGN

From the need assessment (Section 3 and 4) it is evident that there is a need for drinking water and electricity on the Bunaken. The basis of design is presented in section 8.1 and more information can be found in Appendix G. Appendix I in combination with Appendix J also justify the choice for drinking water and energy production and the chosen scale for both. Section 8.2 presents the concept in more detail.

8.1 BASIS OF DESIGN

The potential location for the energy and drinking water plant has to meet five important requirements;

1) Accessibility of cold deep sea water
2) Minimal harm to the environment
3) Close to the grid
4) Close to the drinking water distribution network
5) Need for drinking water and energy

The plant location is shown in Figure 48. The lateral distance to deep seawater is minimized (Appendix M4 & G) and the environmental impact is minimized in this marine sensitive area. As can be seen in Figure 23, the plant location is close to the electrical grid. A drinking water distribution network at this location, is lacking. However, this is not a limiting factor for the choice of the plant location as long as it is close to populated areas (three villages), which are spread over the island. The plant location in Figure 48 has opportunities for construction of the an additional reservoir on a relatively high geographical point. In this way it is possible to distribute the water to all three villages.

Figure 17 shows the typical bathymetry profile around Bunaken. This is an important factor for the pipe design that will be discussed in the next section. The chosen location has a relatively gradual slope compared to the other locations around the island (Frets Pieters, 2017, Appendix O12).

The need followed from Section 3 and 4 is translated in the design criteria. The boundary conditions that are taken into account in the final design are given in Table 10. The drinking water will be provided by an RO plant that is powered by OTEC. The choice for this concept is justified in Appendix I.

Drinking water production	350	m^3/day
Required energy for RO	45	kW
Electricity production	80	kW
Surface temperature	28.5	°C
Deep Sea water temperature	8.5	°C
Depth to reach cold seawater	365	m
Distance from shore	1005	m
Salinity surface water	33.50	ppm

Table 10: Boundary conditions Bunaken

8.2 FINAL DESIGN

Section 8.1 presented the basis of design for a drinking water and energy production plant for Bunaken. This section presents the concept in more detail. More information and numbers can be found in Appendix H.

Figure 48 gives an overview of the final concept. The proposed RO and OTEC plant could provide Bunaken with 350m³/day and a baseload of 80 kW. This is distributed with a drinking water distribution network and the plant is connected to the energy grid.

8.2.1. ONSHORE EQUIPMENT

A schematic representation of the processes in the onshore drinking water and energy production plant are shown in Figure 49. Appendix H1 elaborates more upon the different components which are divided in offshore and onshore equipment.

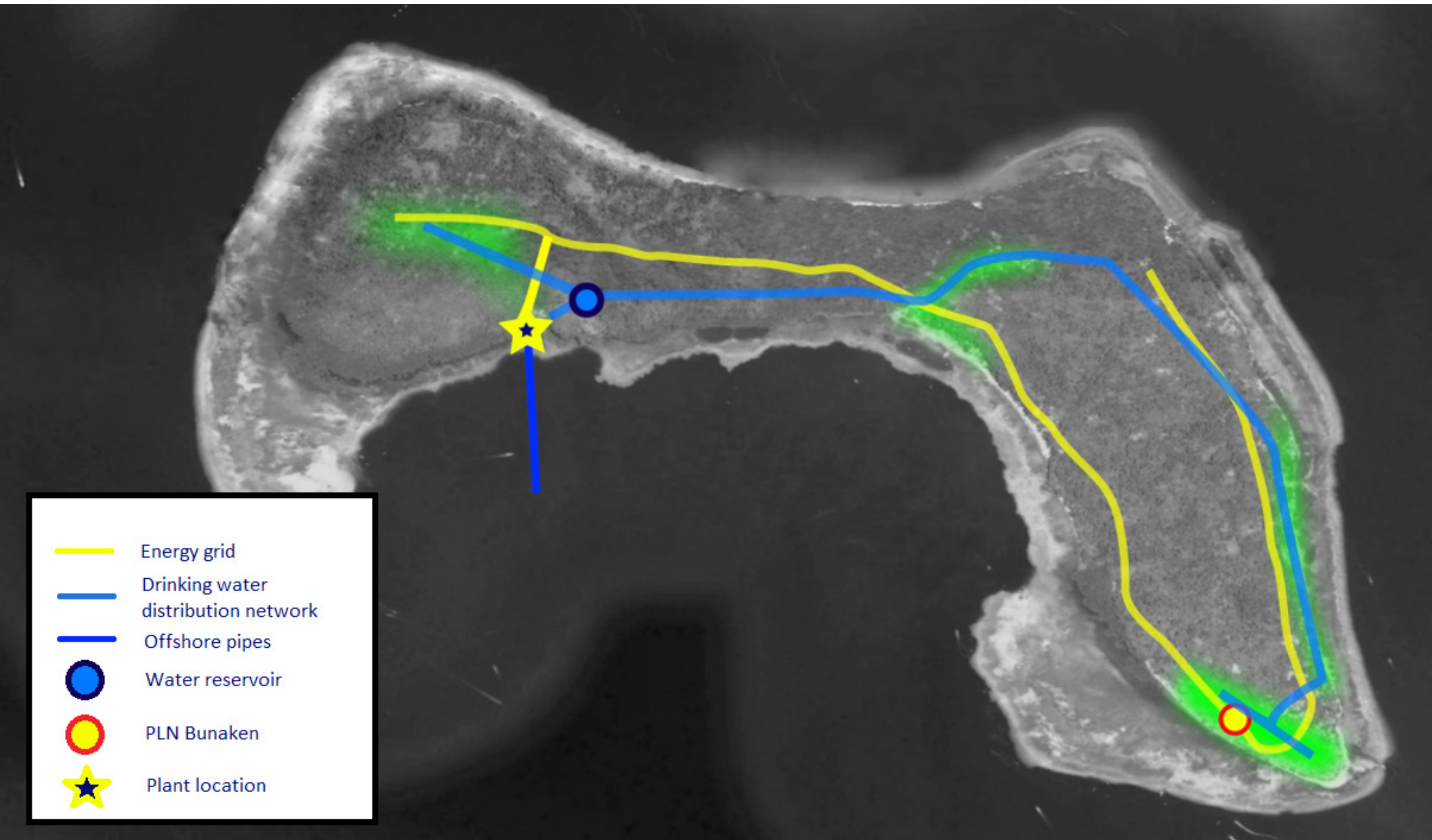
OTEC

In the design a closed cycle OTEC installation is proposed, which is the most convenient type of cycle according to Bluerise B.V. All characteristics can be found in Table 2. The net capacity of the OTEC plant is 125 kW. The total capacity equals 190 kW, including the pumping power. The heat exchangers are made of titanium which minimizes the biofouling in the heat exchangers and thus ensures low maintenance of the system. Little is known about the characteristics of the grid, therefore the connection has to be analysed further in the subsequent stage of the project.

Net OTEC power	125 kW
Total OTEC power	190 kW
Pump capacity	62 kW
Material heat exchanger	Titanium
Surface area evaporator	1040 m²
Surface area condenser	720 m²
Working fluid	Ammonia

Table 11: OTEC power plant characteristics

Figure 48: Final concept Bunaken



Reverse Osmosis
The water production will become executed by a seawater RO (SWRO), with feed water salinity of 33500 PPM. The use of a brackish groundwater well is investigated. Due to the chance of interference with local wells, it is deemed too risky to design for a brackish groundwater source. The option can be investigated further in collaboration with local inhabitants, but this has to be done in a later stage of the project. The water has to be pre-treated in order minimalze the biological growth and increase the lifetime of membranes. Downstream of the membranes the water is post treated which includes re-hardening, PH adjustment, CO_2 content adjustment and disinfection.

The water has to be distributed to the customers. Rough estimates of a distribution network and construction of a reservoir are included in the financial analysis (Appendix I3). It might be possible to reuse parts of the newest RO plant in order to reduce the costs. From the sensitivity analysis in section 8.3.2, it follows that the financial impact of the reverse osmosis plant and water distribution network is minimal, so uncertainties in these components are negligible.

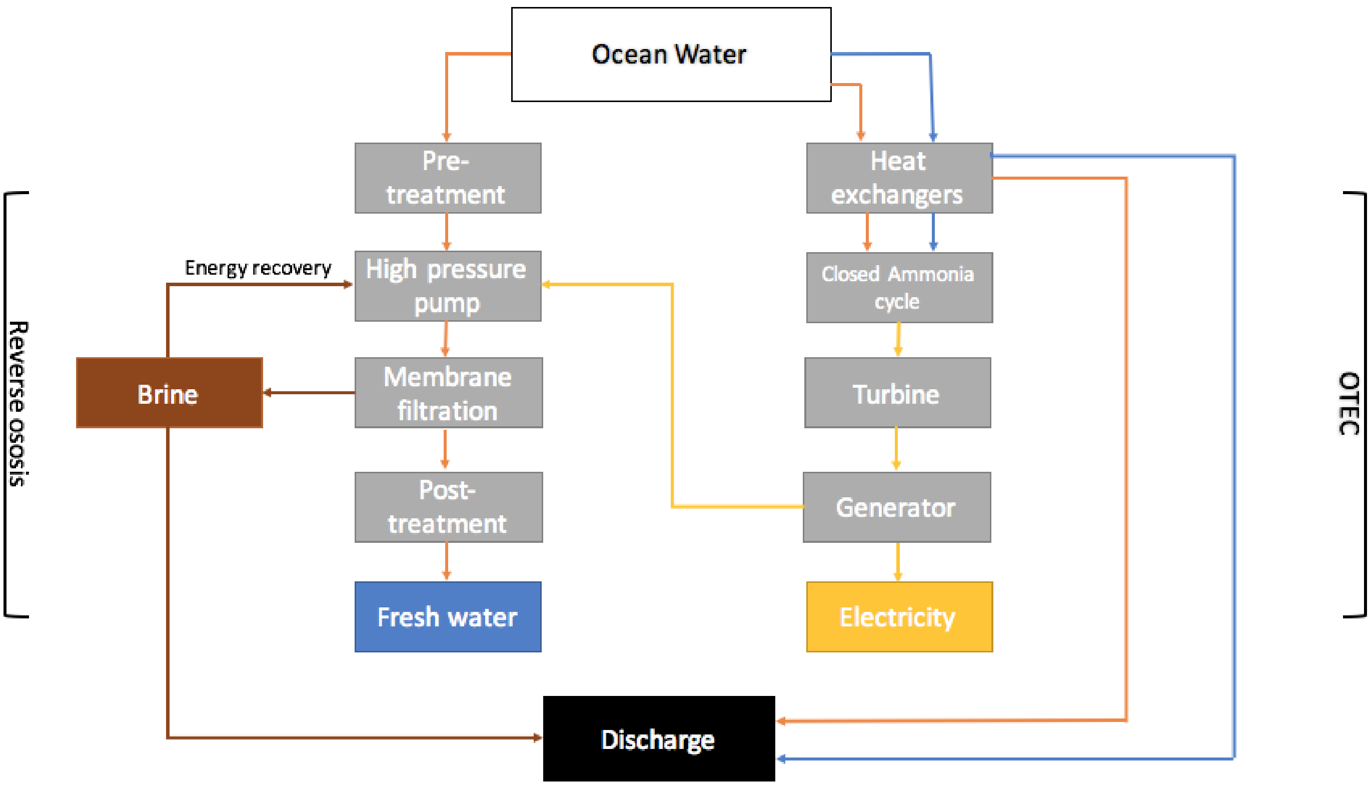


Figure 49: Schematic overview of the processes in final concept Bunaken

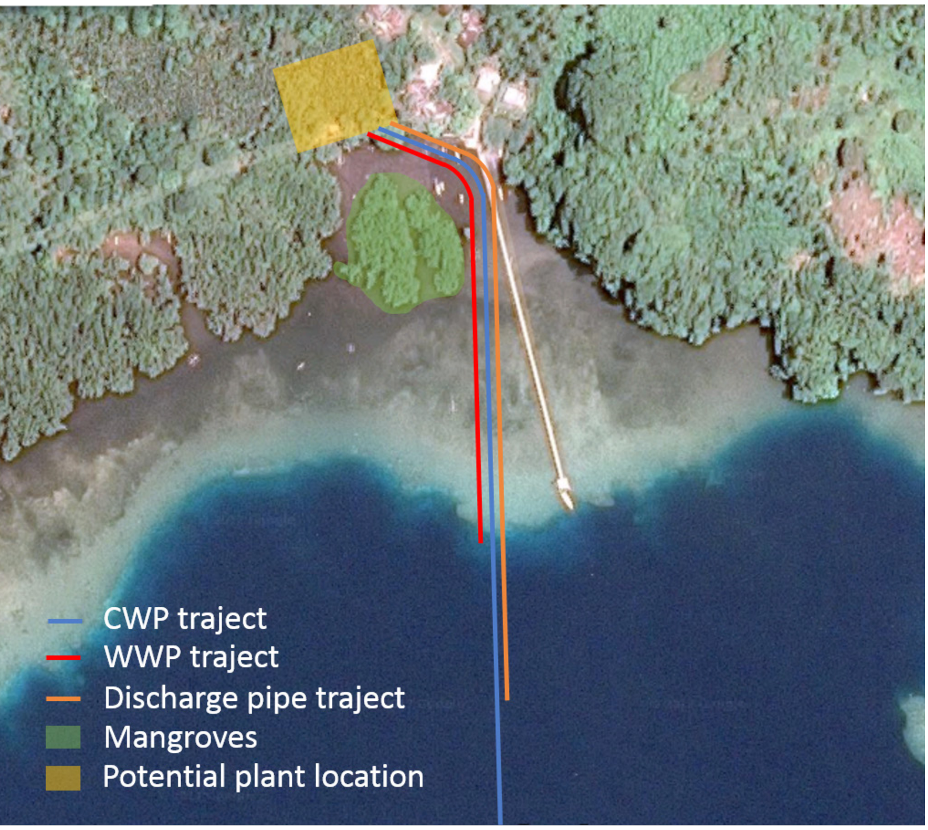


Figure 50: Close-up of the project location and the proposed pipe trajectories

8.2.2. OFFSHORE EQUIPMENT

The pipe route is shown in Figure 50. The pipe is a critical factor in the design, due to the technical challenges, the high financial impact and the unique working environment. To obtain a good overview of the proposed pipe route the project site is visited (see Appendix I1).

The properties of the offshore pipes are summarized in Table 12. These properties were calculated similarly to the method described in Appendix L.

The site where this pipes would be installed was visited and pictures can be found in Appendix I1. The location consisted of a steep seabed with bleached corals. The biggest challenge is the cold water pipe and to overcome the steep slope at the project location. An inversed catenary is proposed which is shown in Figure 51. This type of installation is already performed in by Makai in Hawaii and a design can be found in (Lewis, Ryzin, & Vega, 1988).

	Diameter[m]	Wall thickness[mm]	Intake depth[m]	Length[m]	Material	Flow rate [m3/s]
CWP	0.60	28	365	1070	HDPE	0.4
WWP	0.72	34	20-30	220	HDPE	0.6
MDP	0.93	44	150	335	HDPE	1.0

Table 12: Pipe characteristics Bunaken

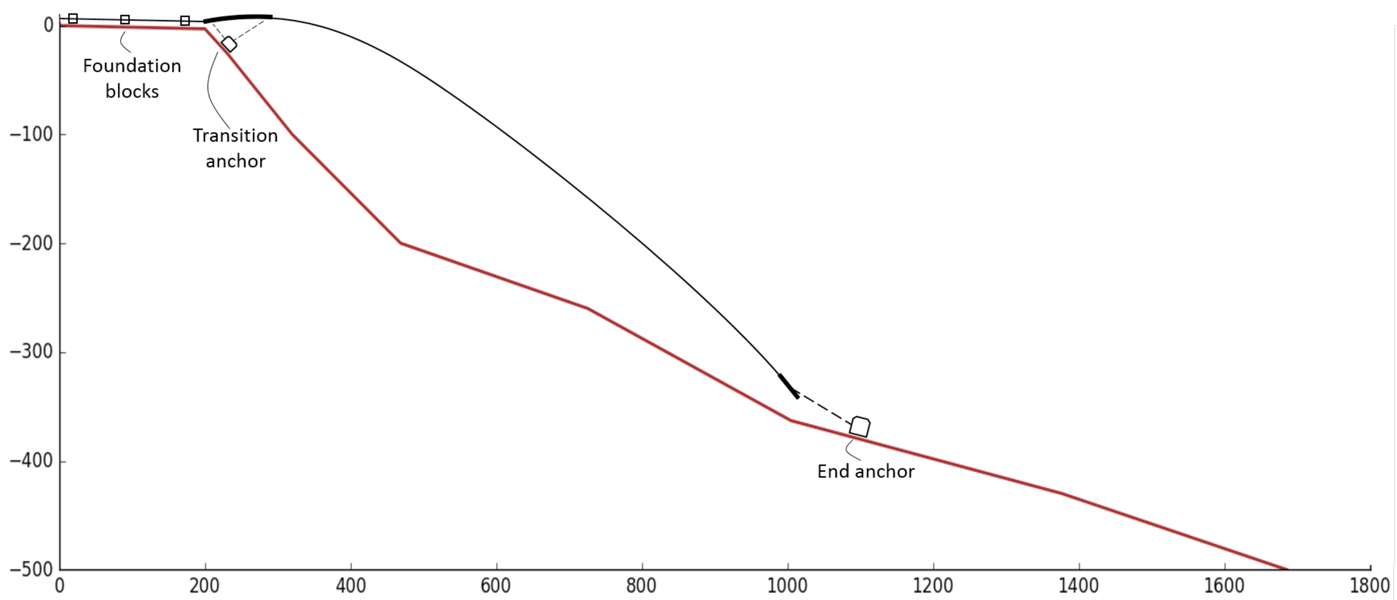


Figure 51: Inverse catenary pipeline

8.3 FINANCIALS AND BENEFITS

8.3.1. FINANCIAL FEASIBILITY

For the financial analysis of this concept, there are several assumptions made. First of all, the CAPEX, OPEX, decommissioning, downtime, insurance and selling prices are estimated based on research, meetings and industry. These assumptions are summarized in table 17 in Appendix H3. The planning before operation is shown in Figure 52. All assumptions result in the cashflow shown in Figure 53. The most important results are presented in Table 13.

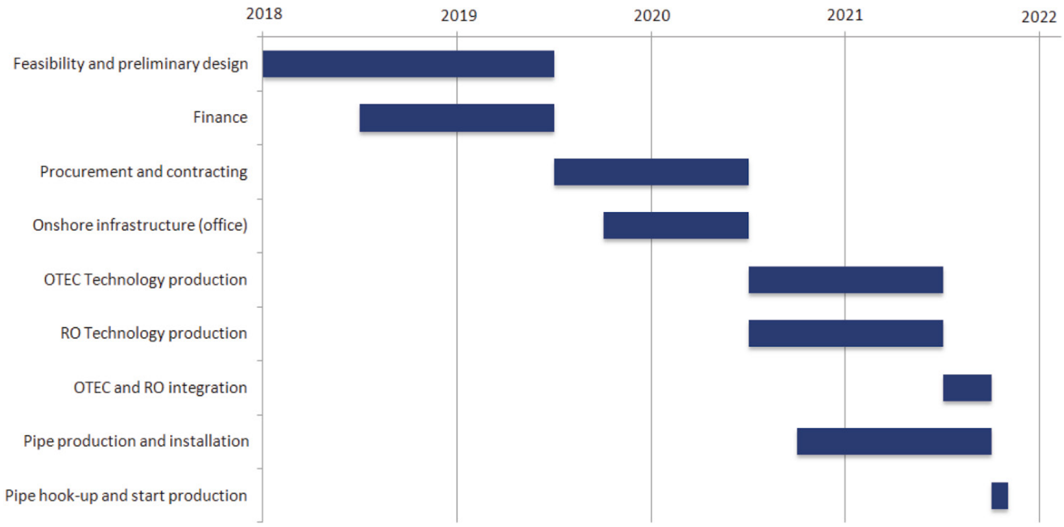


Figure 52: Initial project planning Bunaken

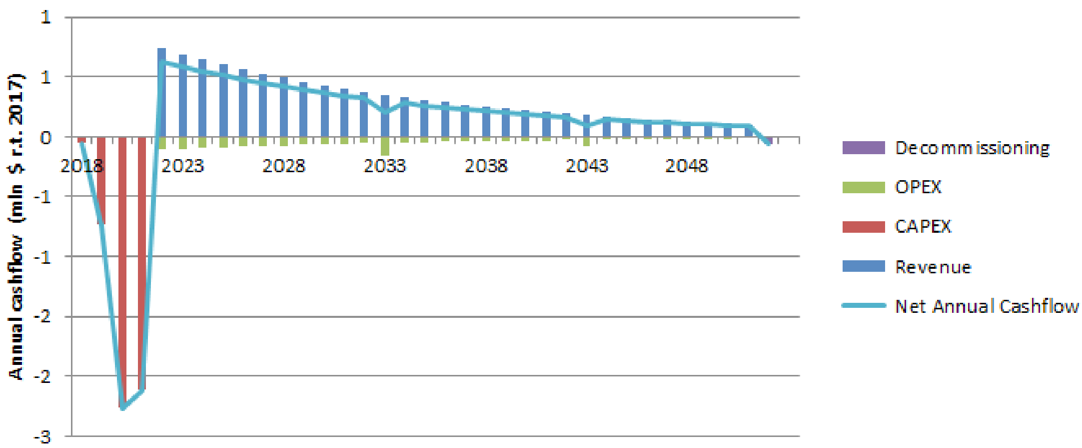


Figure 53: Cash flow Bunaken

Plant lifetime	30 years
Total initial investment	6 million $
Energy price	0.22 $/kWh
Water production price	7.5 $/m3
NPV	$2.970.000
IRR	12%
Payback time	15 years
Production price energy	0.18$/kWh
Production price drinking water	1.23$/m3

Table 13: Financial outcomes Bunaken

8.3.2. SENSITIVITY

From Figure 54 the parameters with the highest impact on the NPV can be obtained:

- Interest rate
- Water selling price
- Energy subsidy

A 7% interest rate is a conservative value when accessing the recent trends of interest rate development for Indonesia. Therefore, the chance of lower interest rate is higher, which has a positive effect on the NPV, this can also be identified in Figure 54. The water selling price has a large influence in on the NPV, this is mainly due to the large uncertainty about the selling price. At the moment is expected that 7.5 $/m3 is a relatively high drinking water price. However, calculations show that (see Appendix K):

- Currently inhabitants pay $0.22 for Danone drinking water daily
- If the inhabitants increase their expenditure by a factor 2.6 than they will receive 30 times more water and can provide them with 75 litre of drinking water from this plant
- Resorts pay 10,4 $/m3 for a connection to a fresh water well, where the water is not consumable.

So in short, the inhabitants have to be willing to increase their daily expenditure on drinking water and this plant will provide them with 75 litre of drinking water on a daily basis. Focus group on Bunaken island should give more insight on this topic.

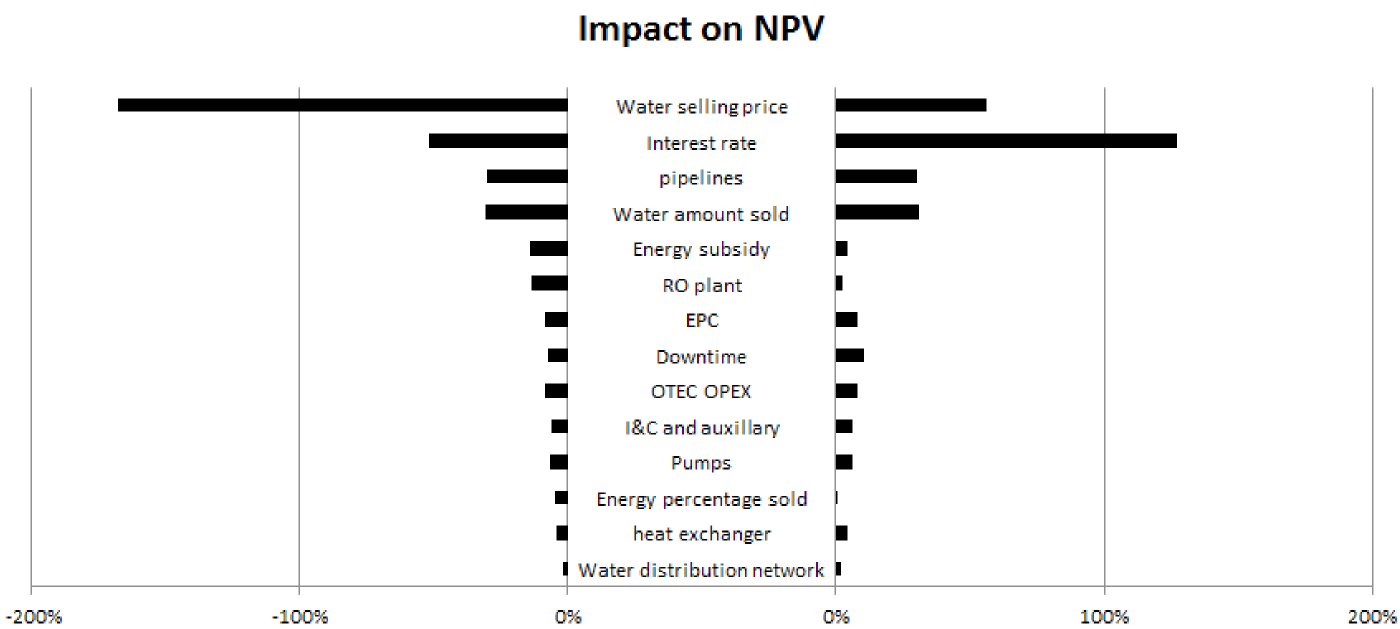


Figure 54: Tornado chart Bunaken

8.3.3. BENEFITS

In this chapter, the environmental impact is shortly described, the benefits which comes with realization of a certain plant, and how this plant can be implemented successfully.

Environmental

Since Bunaken island is a marine protected area, it is important to consider the possible environmental impact caused by this plant. According to research, the impact on the environment will be minimal or even beneficial compared to the current situation.

By implementing this solution, there is a reduction in greenhouse emissions. This reduction is 854 ton Co2 each year. Besides this it has another big advantage. In other RO system the salty waste flow (brine) can have a salt concentration of 70% higher than the salt concentration of the seawater. By mixing this waste flow together with the water used for the power generation, this concentration is only 0.5% higher than the concentration of the discharge flow. This is mainly important for the marine life and ecosystem that is present, so they will not be harmed.

The environmental impact is also limited by pointing out a location with no mangrove forests and coral reefs nearby, to install the plant and pipes. Additionally, to make sure that no fish are sucked up, a small velocity of max 1,5 m/s will be used and the pipes will be equipped with a filter in front of the inlet of the pipe. A more extensive description of the environmental impact is given in Appendix H4.

Others

The realization of the plant of Bunaken has different benefits. The most important benefits are the ones that meet the need of the inhabitants of the island. Which are a constant power and drinking water supply (Figure 55). By using this plant there is a 24 hours' electricity supply and drinking water supply. This can lead to other benefits like the improvement of sanitation, more jobs and less environmental impact like mentioned in the previous paragraph. This will eventually lead to a more self-sustaining island. Additionally, the island becomes more self-sustaining which means it is less dependent on expensive supply from Manado.

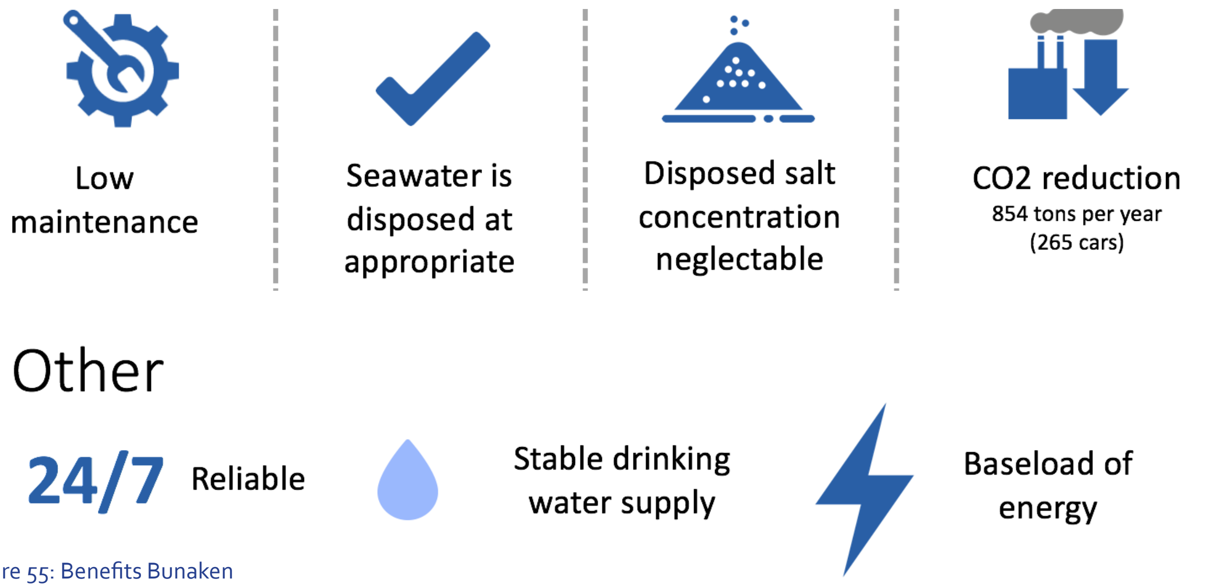


Figure 55: Benefits Bunaken

9. IMPLEMENTATION

Implementing new technologies is a challenging process. Especially when looking at the technologies of the design for Manado and Bunaken island. The challenging aspect of the implementation are the different stakeholders that are involved. For Bunaken, this is because the solution for this island tackles both drinking water and electricity. However, the parties who are responsible are both owned by the government but hardly interact with each other. For Manado, besides the government also the customers have an important role in the implementation.

So, to implement a plan, the local government is the key organization to do this. Financially speaking, the government in Jakarta decides how much money each local government gets for the plans of the following year. This is based on the budget that each local government submits. The local government, mainly the mayor, is the one making all the decisions regarding their corresponded area. If the mayor will approve a certain plan, it is most likely that the plan will be realized. Even if a private investor wants to invest, it must first be approved by the mayor. So, the first step of implementation will be getting the approval of the mayor of Manado. The next step is to make sure that this new system is implemented successfully. According to Prosci- ADKAR method one must take five steps to realize this. From the research project, it can be stated that different government parties are at the point to start the step of knowledge. Meaning there is awareness and desire.

Awareness
The first step is creating awareness. The government must be aware of the problems and that change is required. They must be aware that the inhabitants of Bunaken island are not happy with the current situation. They lack drinking water and a 24-hour electricity supply. For the plan of Manado, the government must be aware that air-conditioning is very big part of the electricity consumption. Using SDC can stabilize the electricity grid. Eliminating this factor means more electricity is available for the rest of the city. On top of that, using a sustainable source to cool buildings contributes to the sustainability goals of the Indonesian government.

The customers are not aware of the impact of using a SDC-system. Since at the moment the customers make use of their own central cooling systems, and it is likely that they do not know better than that. So, for the implementation of this technique, creating awareness about the benefits should be a step to make the customers interested. In this way they will be aware that there is better solution than the conventional air-conditioning system.

Desire
The second step is, creating desire. There must be factors that motivate the different parties in this change. So, what is in it for the local government? When looking at the mayor, one of his goals is to be re-elected. A way of realizing this, is by satisfying the local people, the users of the

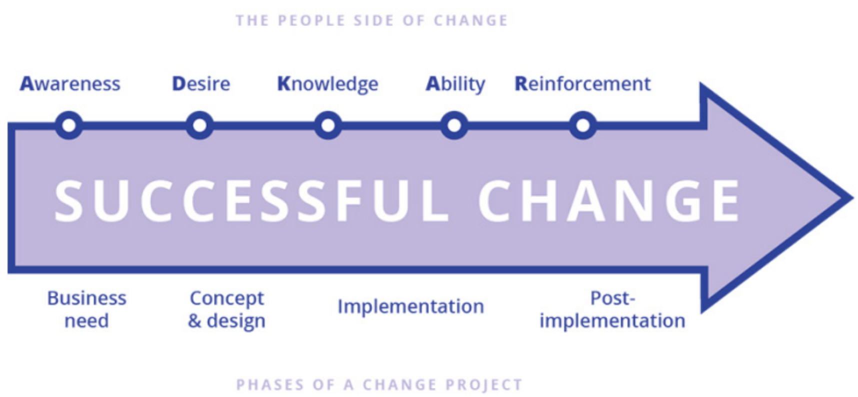


Figure 56: Prosci - ADKAR method overview

facilities. So, there is something in it for the local government. In this way desire can be created. On top of that, using a new technology and building a new system creates jobs and money. Local content can be used, and locals can help building and operating the system. In fact, the Indonesian governments requires companies in the energy sector to make use of at least 35% local content (Going Local: Understanding Indonesia's Local Content Requirements, 2014) to support the growth of the domestic manufacturing industry. To motivate the users of SDC, the benefits should be shown. These are mainly financial benefits. One of the main benefits is that their cooling costs will decline a lot when using SDC (up to 70%).

Knowledge

The next step is knowledge, Engineering companies will come together with local companies to transfer knowledge, planning tasks and determine responsibilities. By training and coaching of the local parties they will gain the knowledge on how to build, manage and maintain the certain plant. Currently, the water supply and electricity supply in Manado is managed by two different governmental organizations. Namely, PT. AIR Manado and PT. PLN Manado. Both organizations must be educated by trainings to understand the plant and how it must be managed. Both parties must know their responsibilities. A select group of both organizations must be chosen who will be responsible for the management of the plant at Bunaken.

Currently, each customer (hotel/mall) has their own engineering team. For the SDC-system, it is important to train these people, since in the buildings, some things will change. On top of that, new people should be trained, who will eventually be responsible for the production and distribution facilities.

Ability

The fourth step is ability, the goal of this step is that the gained knowledge will become abilities. PU (public works) is the governmental organization that builds the plans approved by the local government. It is most likely that after the local government agrees that the plants will be built, PU will partly finance this plant or it will be financed by a private investor. A company like Bluerise could work together with a local contractor to build the plants together and fit the local content requirements. By realizing a project, it will become an ability.

Reinforcement

The final step, is making sure that the change stays. This is called reinforcement. This can be done in the form of maintenance. The realization of the plant is one side of the implementation. Keeping the plant running is the other challenge. As mentioned in D.2.2, part of the cause of many defects of different systems, is the lack of maintenance. During the implementation, there must be parties assigned the responsibility to maintain the plant and its quality. This can be done by training of a local person by the contractor. There are programs available (e.g. YEP) that are suited for these types of projects.

A different way of reinforcement is learning from earlier mistakes to improve the process. These plants will be a learning curve for all parties that are involved, since it is a new technology. Indonesia has many islands that experience the same problems as Bunaken island. So, if this plant will be a success there will be a chance that other islands will desire a comparable solution. The same accounts for an SDC system, there are many places in Indonesia and even in the tropics that could require a certain system. By improving the plant and the process, the realization of more plants could be possible. And the change will stick in the system at another level, which is higher than the local level.

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10. CONCLUSION

POTENTIAL

From the bathymetry data in combination with lead line measurements (Appendix M4) can be concluded that the map supplied by the local Marine authority (Hidro Oseanografi) is the most accurate bathymetry map. In the case of Bunaken depth of 800 meter is reached at a lateral distance of 3400 meter, while a depth of 500 meter is reached at a lateral distance of 1750 meter. For Manado a depth of 850 and 550 meter is reached at a lateral distance of 3600 and 2200 respectively (Appendix M1). From these results can be concluded that large depths are reached at relatively short lateral distance from the coast. Next to that, the results of the seawater temperature measurement campaign (Appendix M1) show that low temperatures can be found in shallower depths than expected. Both make this a theoretical hotspot for application of technologies using cold deep seawater, furthermore during this research similar or better theoretical potential is not found in the existing literature. Of course, a theoretical potential is worthless without the presence of a need.

NEED ASSESSMENT

The need assessment (Section 3.2, 4.2 & 5.2) shows that in the case of Manado; there is a need for drinking water and cooling. However, drinking water produced by a technology that uses cold deep seawater as energy source is an expensive solution when comparing it to treatment of fresh ground or surface water. Additionally, the quality of the water distribution network is one of the main problems in the current tap water supply. Along the boulevard (Jalan Piere Tendean) many potential buildings for Seawater District Cooling are identified. Furthermore these buildings are located within 3.5 km from each other. Comparing this to existing district cooling loops in literature makes it a relatively short cooling loop with a high cooling load density (Section 5.2). So a location with a high potential.

From Section 3.3, 4.3 can be concluded that Bunaken has a need for fresh water and energy. (Note: there is a difference between a need for fresh water and a need for drinking water. A need for fresh water makes it possible to implement desalination technologies, where a need

Figure 57: Artist impression of Manado bay (Note: in reality the onshore pipes are buried and the sizes are disproportional for visual representation)

for drinking water does not necessarily mean desalination is required when other sources are available). Furthermore, it can be concluded that the island has organizational problems with setting-up and maintaining a drinking water supply network. The organization PT PLN Bunaken responsible for maintaining the solar PV power plant has difficulties in planning in advance. The lack of planning causes at the moment down time of the energy supply system. The way of implementation of new solutions is a key factor in success for this kind of projects.

MANADO

For Manado, a concept is proposed that uses Seawater District Cooling for the malls, hotels and big buildings that use an internal freshwater loop for cooling. This can greatly reduce the energy usage of these buildings and reduces the cooling costs of the buildings along Manado Boulevard. This can in return reduce the peak load on the SULUTTENGO grid, which stabilizes the grid and reduces the amount of fossil fuels used. The cooling need density, the environmental conditions and the required cooling temperature make the Manado cooling case very favourable.

Technical feasibility

It is chosen to connect 16 customers to a new Seawater District Cooling Network, with a future peak load of 13,500 refrigerating ton and an average cooling load of 65%, based on sold average cooling from literature. District cooling with a free cooling source is already a proven technology in big cities throughout Europe. In the design for Manado a fresh water loop of minimal 10°C (which is high) (Appendix E2) is used for the central cooling of large buildings, so seawater of 7°C is already sufficient to deliver the right temperature to the customers, taking into account thermal losses (Appendix F1.3).

For the installation, a deep seawater pipe, return pipe, production facility with heat exchangers, distribution network and substations (with heat exchangers) at the customers are needed. An overview of this is given in chapter 7.3. The offshore deep sea water pipe is seen as the largest technical challenge; an HDPE pipe with a diameter of 1.25 meters. Currently larger HDPE pipes can be produced and have been installed (Appendix F1.4). The installation should therefor be a doable challenge, since the slope of the seabed is mostly gradual. The costs could vary significantly seen the uncertainty of the seabed yet.

Financial Feasibility

The deep seawater pipe and the distribution network have the highest investment costs. It is in terms of efficiency (pump power vs. material costs) most favourable to have a distribution network of two separate loops. The costs of the deep seawater pipe, has a high impact on the NPV.

In the current situation the SDC system would have an IRR of 19%, which is an interesting case for investors, since it is a proven technology. Nevertheless, in Indonesia it is still an undiscovered field. Since the income is compared to cooling costs nowadays, the income strongly depends on the electricity price (Appendix F4), at the moment this is rather low in Manado. It is expected that the electricity price will increase in the near future, which will positively affect the business case.

BUNAKEN

A solution is proposed that combines Ocean Thermal Energy Conversion and Reverse Osmosis to produce 350m3/day of drinking water and 80kW for electricity. The drinking water is distributed with a water distribution network and the energy is connected to the isolated Bunaken energy grid. This contributes to the goal of the Indonesian government to make small islands more self-sustaining.

Technical feasibility

For Bunaken an analysis of different desalination technologies and fresh water resources is made (Appendix I1). From the analysis can be concluded that supplying fresh water by using Reverse osmosis is the most promising technology. Next to that can be concluded that the combination of RO with OTEC is expensive, but has many advantages like; the reliability and low maintenance of the system (Appendix I3). RO is deemed a proven concept. Therefore the technical challenges corresponding to this technology are little and not a limiting factor in this concept.

OTEC can be seen as an unproven technology, however in section 3.1 is already explained where the reference projects are located. All current functioning OTEC plants are small scale and this plant is in the same order of magnitude, which gives an indication of the technical feasibility. Additionally, Delft University of Technology in collaboration with Bluerise B.V. owns a small scale prototype OTEC plant. A large technical challenge is the installation and integrity of the cold water pipe. This pipe is one of the most expensive components. Reducing costs for installation and material will increase the financial feasibility of the plant. However reducing costs might have a negative effect on the number and difficulty of the technical challenges. Next to that, the slope at the project location is very steep, therefore an inverse catenary is suggested. This type of installation is already used by Makai to install a cold water pipe (Section 8.2). However, this way of installation is not elaborately studied and thus uncertainties remain. To conclude, few technical challenges are expected for the onshore components. Most technical challenges are related to the cold water pipe where more detailed engineering is necessary.

Financial Feasibility
The financial feasibility is presented in Section 8.3. From this analysis two things can be concluded; 1) it is a risky investment due to the relatively low IRR of 12% and 2) to obtain this business case a relatively high drinking water selling price is needed. Furthermore the sensitivity analysis indicated a high impact of the selling price on the NPV (Section 8.3.2). Although a negative business case was obtained, the reaction from governmental organizations like PT PLN SULUTENGO and the Cities government were positive. For this reason it could be concluded that the business case does not have to be perfect when it solves two unsolved problems.

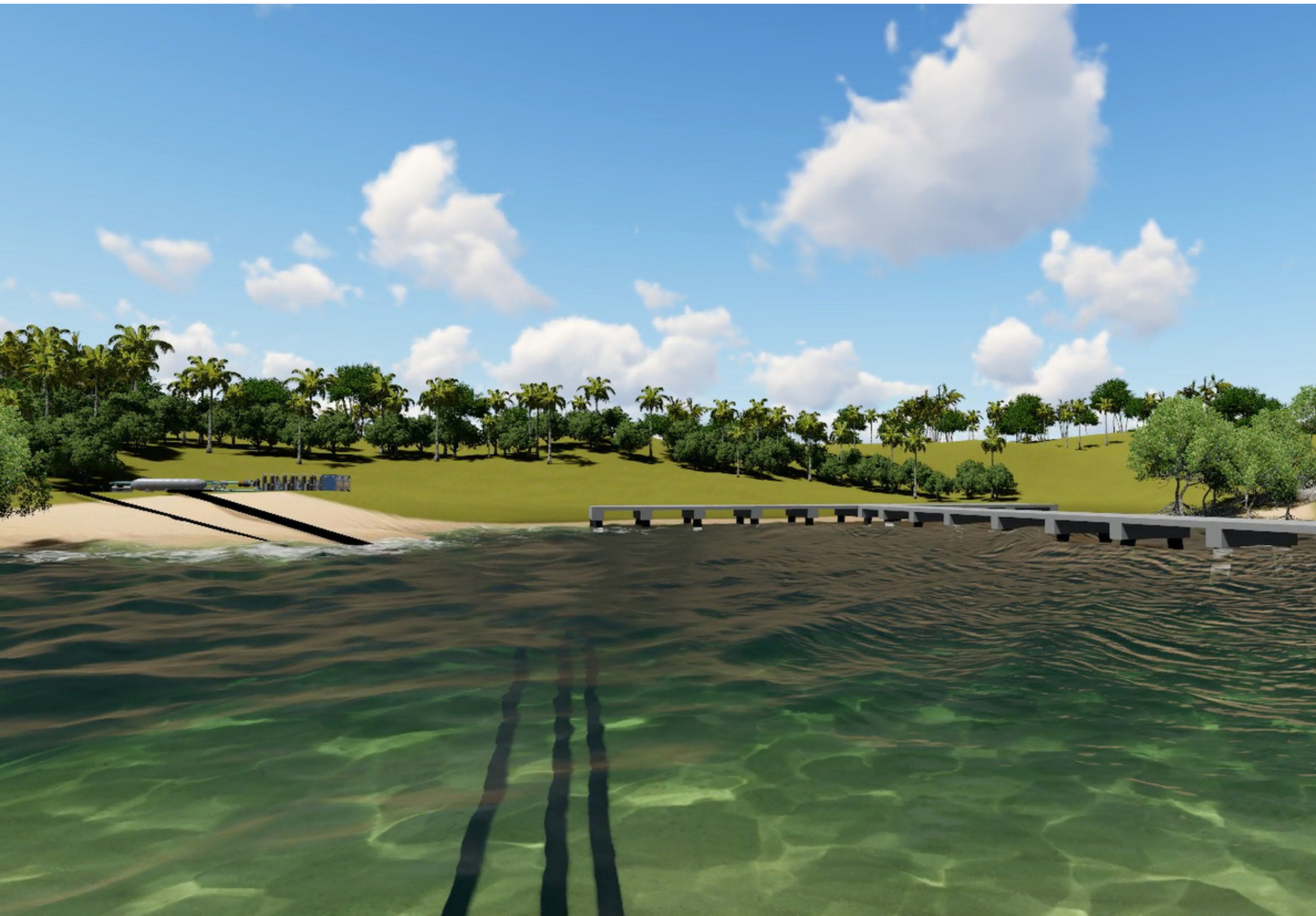

Figure 58: Artist impression of Bunaken facility (Note: sizes are disproportional for visual representation)

11. DISCUSSION & RECOMMENDATIONS

During this research, there are several uncertainties that mostly resulted from assumptions and lack of data. The most important discussion points are summarized below:

Both the energy data about North Sulawesi and Bunaken that was openly available was not always complete. No detailed information about the grid was available. It was not always clear what the exact demand and supply is and whether it is as the reports on the internet say. Further meetings with PLN should point this out.

There were many bathymetry maps and the correct map was chosen according to our measurements. However, there have been several land reclamations and especially around Manado it is not certain what these land reclamations have done with the bathymetry. Thus, only at the measurement location points we are certain that the depth is (mostly) at least the depth we measured. During some measurements the bottom was reached and this can be found in appendix M. A more detailed bathymetry survey is needed as the pipe is an important part of the installation.

The temperature maps are made up by extrapolating the measurements that were done at certain points. This means that local effects like small currents and eddies are not considered. Before a plant is built it is advised to measure at the exact location where the pipe is to be implemented. However, no great temperature deviations are expected.

For the location that is chosen for the cooling case, it is uncertain whether the chosen location is available. It is unbuild at the moment and a meeting with the government could lead to recommendations with respect to a location and what is possible.

The assumed drinking water price for the Bunaken concept is still uncertain. Additionally, there is a certain amount of water expected to be sold. As the whole business case relies on the drinking water price and the amount that is produced and sold, it should be sorted out with both the local citizens and the government before anything is built.

The assumptions that are used for the concepts are often based on rules of thumb. For example, the maintenance costs. Based on the sensitivity analysis of the business case (tornado charts) these costs must be sorted out more accurately to mitigate financial risks and unexpected costs.

The baseload in the Bunaken and the amount of drinking water is estimated based on expected growth. However, the scale of the plant could still be optimized if PLN Bunaken would provide more detailed data about the energy usage of the island.

Import tax of e.g. RO are not taken into account. This must be sorted out to avoid unexpected costs. Additionally, it is advised to meet with PU to discuss the possibilities with the RO installation that is already present on Bunaken island. Whether this can be relocated and used.

A more detailed cost estimation of the drinking water distribution network is recommended. This means that a thorough assessment of the need for tap water connections on Bunaken is done to point out the best route. This can be done together with the drinking water price assessment.

Dehumidification could be a complementary way to use the cold water after OTEC in the Bunaken concept. It could be assessed what the involvement of the dehumidifier in the concept would do to the financial feasibility of the concept.

Even though Solar PV failed due to lack of maintenance, it is still possible that the same problem will happen when implementing OTEC, even though the maintenance is less. This means that there must be a solid plan to make sure there will be proper maintenance. This means proper training and somehow creating a sense of responsibility and incentive to keep the plant running.

The exact sea bottom at the Bunaken is not known. There could be unexpected coral deeper in the sea and a bottom survey must point out the exact bathymetry.

The environmental impact of an OTEC plant on the Bunaken needs further attention. It is important to assess the impact of the discharge flow to the marine environment. Even though no impact is expected.

The pipe installation itself could still be a technical challenge with these steep slopes. An inversed catenary is proposed, but the dynamical behavior should give more insight in the feasibility with respect to fatigue and maximum allowable stress in the pipe.

Although there is an estimation of the current directions, there is no exact data available for the current profile in Manado Bay. These currents could lead to unforeseen problems with the pipe installation and the intake and discharge. This must therefore be assessed before installation.

There is still better insight necessary in the permits that are required to build something. Although it is expected that these are handled by the government after they are convinced, it is still recommended to look into the legislative side of such projects.

For the Manado case, sometimes cooling loads had to be estimated. This means that it is still advisable to look at the minimum viable cooling case for which it would still be worth it to build a seawater district cooling facility. Initial planning on a smaller scale could get the project started in an earlier phase, with the possibility to expand if there are more parties on board.

Unfortunately, it was not possible to talk to all stakeholders. This means that the locations of the stakeholders in the stakeholder maps might not be accurate.

It is advised to make a risk analysis on the concepts with the TECOP analysis. This could point out which aspects of the concepts need most attention before spoiling time on too small details.

The electricity prices in Manado are rather low at the moment, it is therefor very interesting to keep an eye on the change in the prices. The Manado concept is becoming much more profitable for a small increase of the electricity price.

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13. Appendices

Inhoud

Appendix A: Cold deep seawater Potential

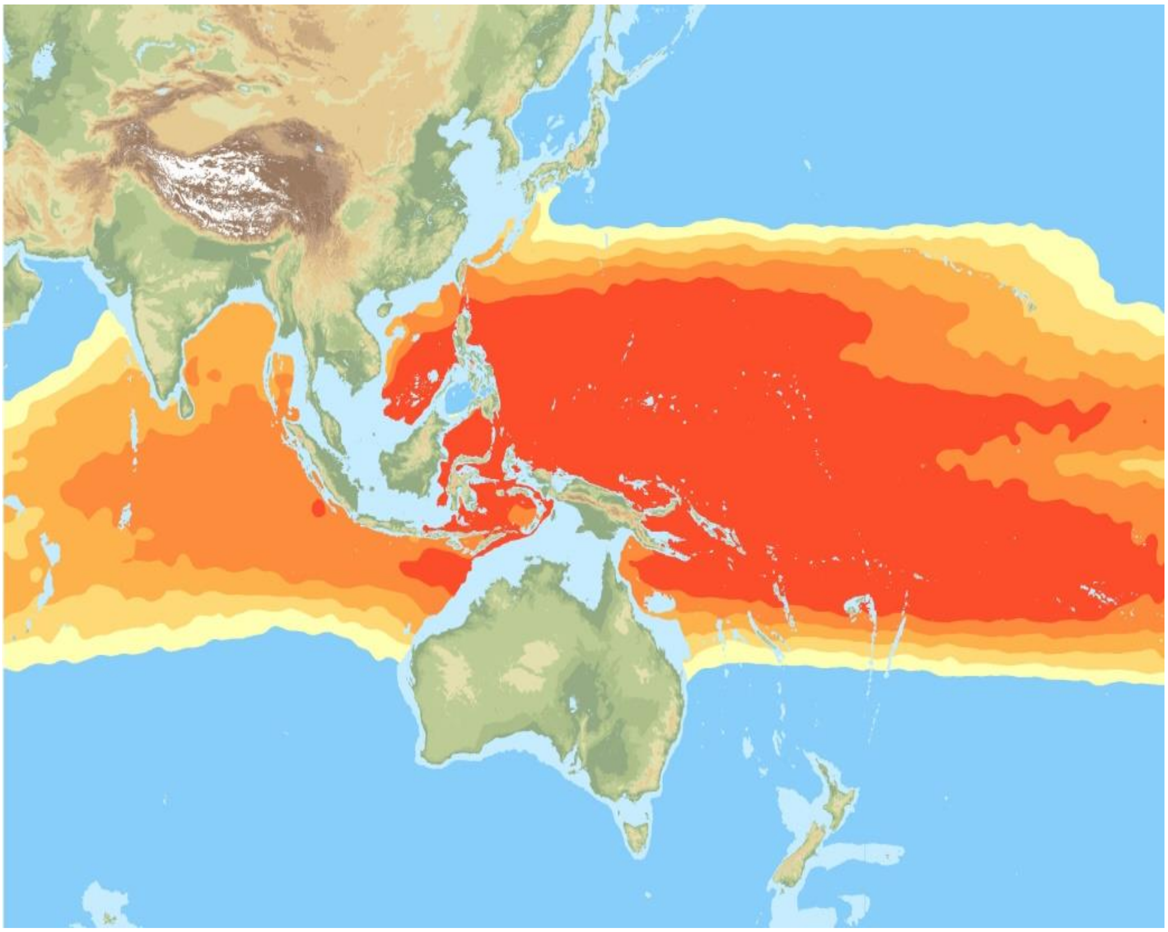


Figure 1: Temperature difference in the ocean over depth. 20 degrees and higher

Appendix B: Energy in Indonesia

At the moment, access to electricity and electricity consumption vary across the Indonesian archipelago. In 2014, the average energy consumption was 0.81 MWh per capita. Figure 2 shows the percentage of access to the grid for each province in 2016.

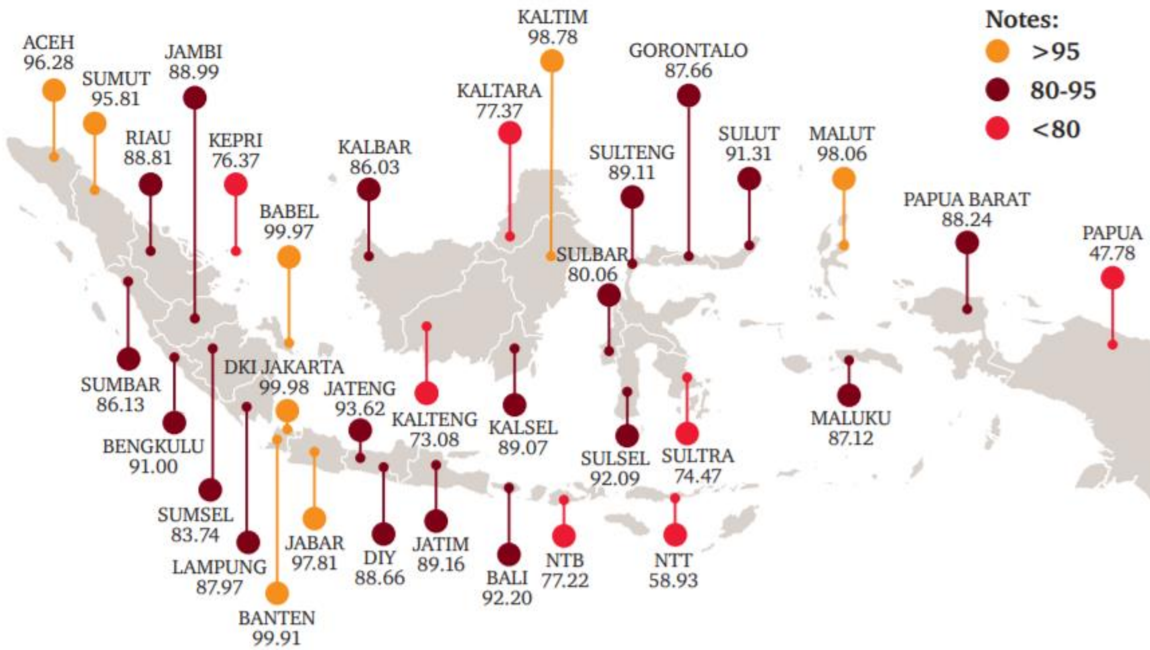


Figure 2: Access to grid (PricewaterhouseCoopers, 2017)

Appendix C: Technology

Appendix C1 - Energy: Ocean Thermal Energy (OTEC)

The temperature difference in the Ocean Thermal Energy Conversion process is relatively low, which leads to a low thermal efficiency. Regardless of this low efficiency, OTEC has a lot of potential and the energy is clean and renewable. In this section the main process equipment needed for the OTEC plant are considered. Firstly the general process is explained. After this, each component of an OTEC plant is highlighted.

C.1.1 OTEC Type

There are different types of OTEC: closed cycle, open cycle and hybrid. The closed cycle uses a working fluid like ammonia. The open cycle uses the water itself as working fluid. The open cycle requires a very large turbine to be viable (Briang Williams, 2017). The hybrid cycle can additionally produce fresh water as a by-product. The hybrid cycle is more complex and the chosen location is considered to be too far for this to be economically feasible. Closed cycle is relatively compact and Bluerise B.V. already has a pilot plant in TU Delft with closed cycle OTEC which seems economically most feasible.

As an introduction to the process, a simplified visual of closed cycle OTEC is shown in Figure 3.

1. Warm surface water from the ocean of roughly 28°C is pumped into the system.
2. Through heat exchangers/evaporators, energy is extracted from the warm water to make a working fluid with a low boiling point evaporate into a gas.
3. This gas is led through a turbine to produce energy.
4. Cold deep seawater of roughly 5°C is pumped into the system.
5. By using heat exchangers/condensers, the cold deep seawater is used to make the working fluid condensate into a liquid again to close the cycle.
6. The cold water can be used for by products or can be disposed back into the ocean.

Part of the energy that is produced is used to pump up the cold and the warm water from the ocean. This makes the system self-sustaining.

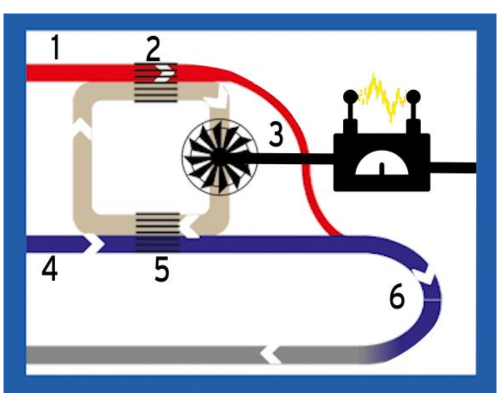


Figure 3: Basic principle of OTEC

C.1.2 Working fluid

Ammonia has a good heat capacity and thermal conductivity. Additionally, it is relatively cheap and has a good track record. Therefore, ammonia is chosen as the working fluid. The water concentration in the working fluid can be adjusted to optimize the process. For example, the best concentration could be chosen such that the energy production is maximal with respect to the seasonal change in the seawater temperature.

C.1.3 Heat exchangers

The limited temperature difference limits the design flexibility for the heat exchangers. There are several aspects that are important when choosing a proper heat exchanger. The maximum heat transfer should be realized (i.e. minimum losses) while keeping the cost, weight and size to a minimum. The cost of the heat exchangers has a significant impact on the CAPEX. Typical materials for heat exchangers are steel, titanium and aluminium.

Furthermore, corrosion and biofouling are important to take into account in a coastal environment. A choice could be made to design new heat exchangers or use existing ones that have a track record. A few existing heat exchangers are listed below:

- Shell-and-tube; expensive and require significant space (Panchal, 2016)
- Aluminium plate-fin heat exchanger
- Stainless steel plate heat exchanger with semi-welded plates
- Alfa-Laval plate heat exchanger
- Titanium plate heat exchanger
- Composite heat exchangers

For seawater applications, titanium plate heat exchangers are highly suitable and show best practice in combination with saline water. They consist of thin plates that form spaces between the plates that are either filled with the seawater or the working fluid. The advantage is that the plates are not smooth which enhances the performance.

For different, less expensive materials the conductivity is lower however this requires around twice the area for the same heat transfer. Also, the pressures will increase when using a different cheaper material for the heat exchangers.

C.1.4 Turbine

The turbine is important for the process as it generates the electricity. An efficient turbine thus has a direct influence on the economic feasibility of the project. There are radial and axial steam turbines on the market. The majority of high power turbines are axial flow turbines. The steam flows in the direction of the axis of the turbine. Several cylinders can be coupled in order to achieve greater energy output. For 10MW or larger turbines, the operating conditions are more favourable for axial turbines (Dankerlui, 2016). Detailed engineering and design is required to optimize the turbine in this application. However, the use of a turbine driven by a vaporized fluid is a proven concept.

C.1.5 Pipes

In total, three pipes are required for an onshore OTEC plant: The warm water intake pipe (WWP), the cold water intake pipe (CWP) and the discharge pipe.

To provide the power plant with sufficient cold and hot water, pipes to a certain depth are preferable. The diameter could become in the order of 3-4 meters and the length can reach to 10km meter, depending on the location. Since steel is a too heavy solution, other materials are investigated, for instance High-density Polyethylene (HDPE). The continuously improving knowledge about plastics has a positive effect on reducing the cost and expanding the OTEC technology. In 2001 a 1.4 meter in diameter pipe is deployed in Hawaii, reaching 900 meters deep. The use of plastics in combination with fibres is also a possibility for pipes exceeding a diameter of 3 meter (Millera, Rosario, & Ascari, 2016).

C.1.6 Pumps

Pumps are needed to pump up the cold and warm water through the intake pipe. These pumps are powered by the OTEC plant itself. Additionally, pumps are used in the closed ammonia cycle. Pumps are a proven concept and can be optimized in the detailed design stage accordingly.

C.1.7 Optimization

Additionally to the process described in Figure 3, extra units can be added to optimize the working fluid cycle. For example, equipment that make the vapor more pure before entering the turbine and equipment to make the separated fluid bypass the turbine. Also, waste heat can be used to improve the process.

The addition of nanofluids to the working fluid could improve the heat transfer. The problem with this is that the pressure drop increases significantly. This pressure drop increases the energy consumption and therefore is not necessarily a good solution.

The type of heat exchanger is a trade-off between the space used, the amount of energy required for the extra heat transfer and the cost. As the market is moving towards more sustainable materials for heat exchangers, it is highly recommended to take the full lifecycle of different types of heat exchangers into consideration in the design process.

Optimization of the process is required in the detailed design stage of an OTEC project.

C.1.8 Reference projects

The Ocean Thermal Energy Conversion (OTEC) industry is still in a pre-commercialized state. Several experimental plants have proven that the technology is sufficient and works, but the sector lacks records and proof of an up-scaled OTEC plant. However, the number of proposed and planned large scale OTEC plants is increasing. One of the characteristics of an OTEC plant is that large quantities of cold and warm water are needed. Scale up companies still see the installation and use of the required large pipe diameters as one of the most challenging aspects. For example the largest offshore pipe installation vessel, the Pioneering Spirit, can lay pipes with a maximum diameter of 1.73m.

Below a list of the current operational OTEC plants (Tidal Energy Today, 2017):

- La Reunion, France 15 kW
- Gosung, South Korea, 20 kW
- Saga, Japan, 50 kW
- Kumejima Island Okinawa, Japan, 100 kW
- Hawaii, 105 kW

The OTEC plants under construction are:

- La Martinique, France 10 MW
- Tarawa Island, Kiribati, 1 MW
- Qingdao, China, 20 MW

The Planned OTEC plants are:

- International Airport, Curacao, 500 kW
- Cabangan, Philippines, 10 MW
- Kumejima Island Okinawa, Japan 1 MW

Numerous proposed plants can be found, but due to the uncertainty of the state of the plans are these not included.

Appendix C2: Reverse Osmosis

In this appendix is explained how desalination with Reverse Osmosis works.

C.2.1 Process

To be able to understand the technology of ROTEC (see Appendix C3), it is important to understand reverse osmosis. Reverse osmosis (RO) is proven to be the most reliable, cost effective and energy efficient in producing fresh water compared to other desalination technologies. Osmosis is the process where a weaker saline solution will tend to migrate to a strong saline solution. A salt water stream and a fresh water stream are separated by a semi-permeable membrane. This membrane allows some atoms or molecules to pass through, but not others.

RO is this exact process, but in reverse, as can be seen in Figure 4. Whereas osmosis occurs naturally without the energy required, you need to apply energy to the system to let it occur. The semi-permeable membrane used for reverse osmosis allows water to flow through, but not the dissolved salt, organics, bacteria and pyrogens. To do so, the salt water needs to be 'pushed' though the membrane by applying a (large) pressure greater than the naturally occurring osmotic pressure to desalinate the water.

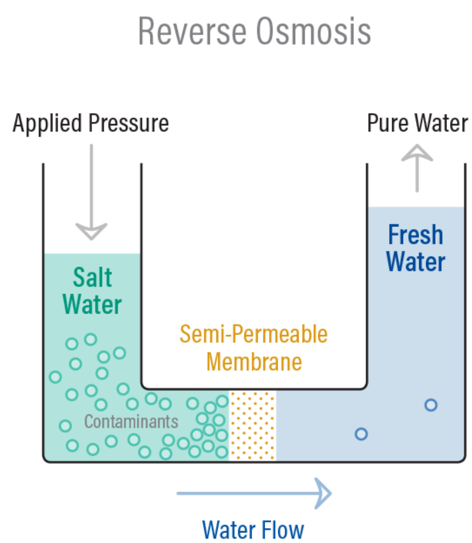


Figure 4: Reverse Osmosis Principle

The required pressure depends on the salt concentration of the feed water. The higher the concentration, the higher the pressure needs to be. Assuming seawater is used, pressures as high as 70 to 80 bars are necessary. Having forced the saline water through the membrane, two outlet streams are created. One so called permeate (or product), which is the water stream that is desalinated and stream called the reject (or concentrate), which contains the concentrated contaminants that did not pass through the RO membrane. Typically, the recovery ratios of sea water RO plants are 30% to 50%, meaning that from the feed water stream, a maximum of 50% permeate water can be obtained.

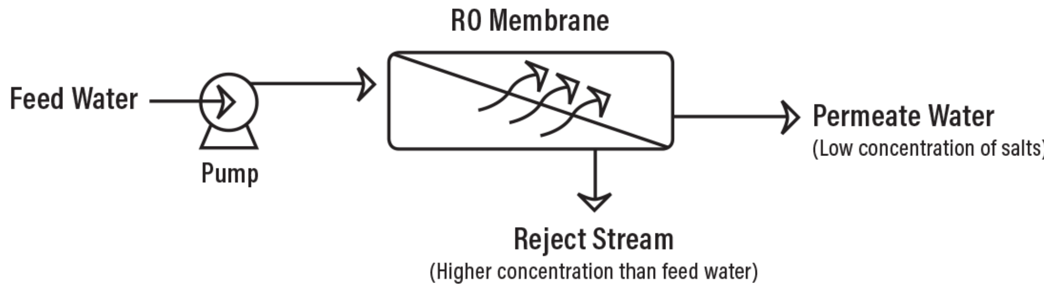


Figure 5: Reverse Osmosis overview

The permeate, or product, usually has around 95% to 99% of the dissolved salt removed from it. To avoid build-up of contaminants, cross flow filtration allows water to sweep away contaminant build up and also allow enough turbulence to keep the membrane surface clean.

C.2.2 Removed particles

A RO systems is capable of remove up to 99%+ of the dissolved salt particles and other contaminations. An RO systems should not be relied upon to remove 100%, since a membrane is only able to reject contaminants based on their size and charge. The smaller the membrane structure, the smaller particles can be removed.

Typically, an RO membrane can reject particles with a molecular weight greater than 200. Water has a molecular weight of 18 and is therefore able to pass. On top of that, the greater the ionic charge of the particle, the more likely it will be that it is unable to pass through. A RO systems in not able to remove gasses from the water, meaning gasses like CO_2 will remain in the water. Depending on the level of CO_2, the PH level can be slightly lower than normal.

C.2.3 Performance and design calculations

The performance of the RO systems depends on several parameters. It is important to know the salt rejection percentage of the RO. You want the product water to have a salt percentage as low as possible. Having a low rejection means the water becomes to saline and something might be wrong with the membrane. The flux determines how many water passes through each square meter of each RO membrane per time unit (for instance per day). This value can be largely different per type of membrane and it is therefore important to choose the right type of membrane (based on water parameters, production rate, etc.).

C.2.4 Energy consumption and energy recovery

Typical electricity consumption of an RO plant, and specifically a sea water reverse osmosis plant (SWRO), is determined to be in the range of 4 to 7 kWh/m (although smaller plants with 3 kWh/m3 have been built) , depending on seawater salinity, recovery ratio, required permeate, plant configuration and energy recovery.

Making use of energy recovery from the concentrate flow, it is possible to reduce the energy consumption of the RO system by 50% or even more. One way of doing this is by implementing a Pelton turbine in the concentrate flow. The pressure of the concentrate flow is slightly lower that then of the feed stream.

Including some pressure losses in the membrane, still a large amount of energy can be recovered from the waste stream. The flow makes the Pelton turbine rotate, and this rotation can create power using a generator.

Another way of recovering energy from the concentrate flow is by using the pressure of this flow and loop it back into the system, as can be seen in Figure 6: Reverse Osmosis overview with recoveryFigure 6. The pressure is slightly lower than of the feed (inlet) stream, so when the concentrate flow is looped back, and added to the feed water stream near the pump, the pump must add a smaller relative pressure to the stream.

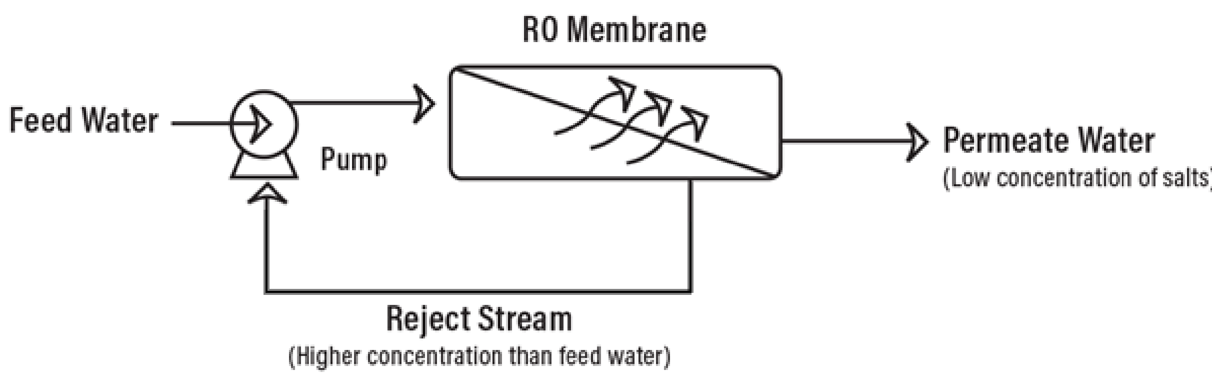


Figure 6: Reverse Osmosis overview with recovery

C.2.5 Materials used in sea water RO systems

The choice for suitable membrane materials is particularly influenced by its resistance to free chlorine, free oxygen, water temperature, bacteria levels in the water and the PH index of the saline solution. To overcome these problems, cellulose acetate membranes have been playing an important part in the seawater desalination. Advantages are low material costs and chlorine resistance. However, these membranes have a relatively short operating life (Al-Karaghouli & Kazmerski, 2010) and suffer pressure compaction. In the last years, the membrane performance of these RO modules is increased dramatically.

Appendix C3 – ROTEC

In this chapter desalination with the method called ROTEC is explained. This method is Desalination of seawater with reverse osmosis which is powered by OTEC (ROTEC).

The reverse osmosis process is, like discussed in Appendix C2, a very energy consuming technology. This can be delivered by several sources like wind, solar or diesel. It also can be powered by OTEC (Ocean Thermal Energy Conversion). This is an interesting combination since it comes with many synergies like constant power input, sustainable energy use so reduction of CO_2 emissions, constant water supply and the elimination of the brine flow.

ROTEC's system consists of mainly two parts. The Reverse Osmosis and the OTEC part. An overview of the technology is given in Figure 7.

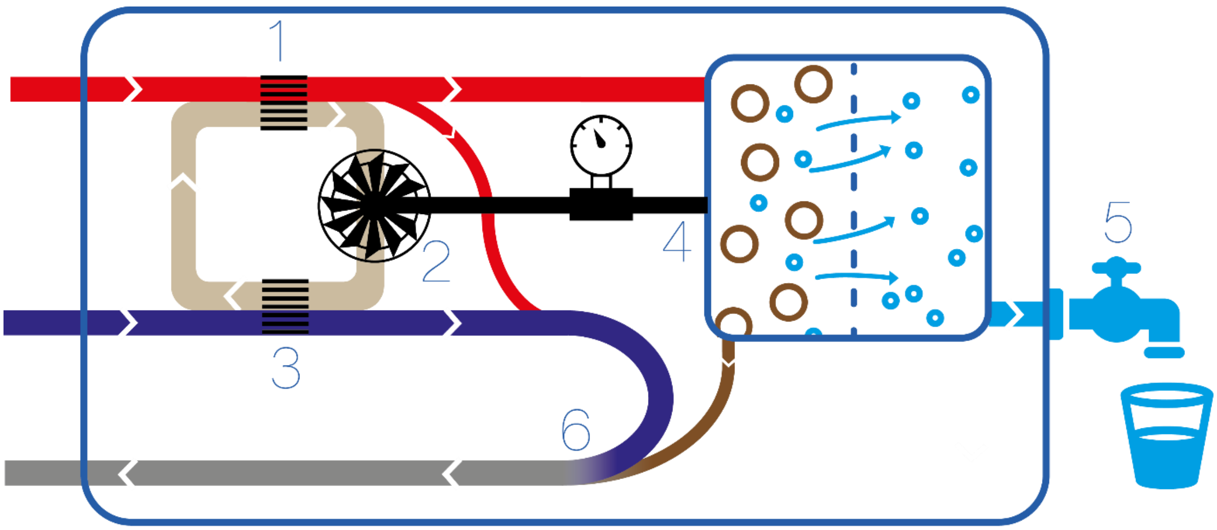


Figure 7: *Overview of ROTEC's technology*

1. Hot surface water (red) makes a working fluid (beige) evaporate via a heat exchanger
2. The gas goes through a turbine to power a pressure pump
3. The gas is cooled with deep sea water (dark blue) via a heat exchanger, to reuse it in a closed cycle
4. A pump presses a part of the hot surface water through a semi-permeable membrane
5. Fresh water (light blue) passes the membrane and can be treated further
6. The salty waste (brown) is mixed with the deep seawater and the rest of the hot water and the mixture (grey) is safely discharged

For more information about individual parts of RO and OTEC see Appendix C1 and C2.

Appendix C4 – Dehumidification

In this appendix, drinking water production by dehumidification is explained.

Besides producing water from obvious water sources, air is a rich source for fresh water as well. The atmosphere contains roughly 12,900km^3 at any point in time. If all the water in the atmosphere rained down, this would cause a layer of water of approximately 2.5cm across the globe (Gleick, 1996). Figure 8 shows relative humidity across the globe. From this figure, it can be seen that there is a big potential in Indonesia for the use of condensation technologies to produce fresh water. The condensation process is also much more efficient with a large temperature difference between the cold deep-sea water and the humid air. A map of the air temperature is shown in Figure 9, where it can be seen that the air temperature is high around the equator.

Before 1980 there has been research on Ocean Thermal Energy Conversion (OTEC) which can be combined with condensation techniques. When the fossil fuel price dropped, the interest in these techniques was lost. With the increasing demand for sustainable development, the interest in OTEC related techniques is being picked up again.

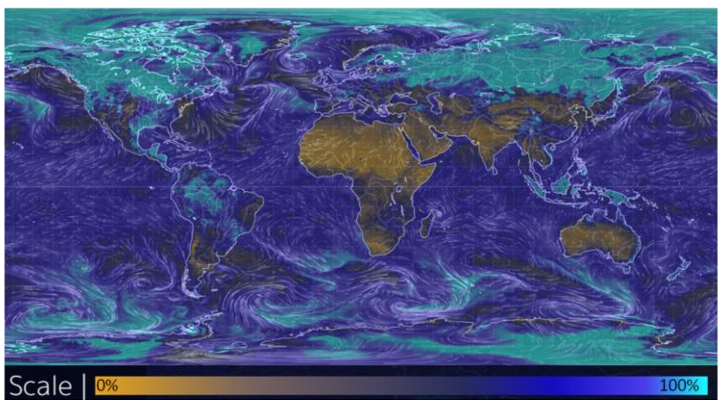


Figure 8: Relative Humidity map (Earth Nullschool, 2017)

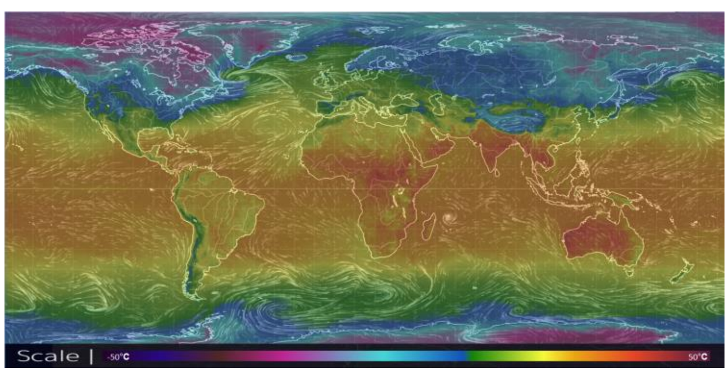


Figure 9: Air temperature map (Earth Nullschool, 2017)

There are many condensation techniques on the market. However, there is still research on the combination of cold deep-sea water and dehumidifier techniques. The most promising technique for this combination seems to be the direct contact humidifier. There is less maintenance required with this technique than with the tube condenser, because there is only seawater present in the heat exchanger. The price per cubic meter (considering the onshore process) is potentially cheaper than desalination techniques since less energy has to be added to the system. Also, there is no brine production as a by-product. (van der Drift, 2014)

Direct Contact Dehumidifier (DCD)

Cold deep-sea water cools fresh water through a heat exchanger, see the right side of Figure 10. This cold water is sprayed at the top of the packed bed tower where the heat transfer takes place. In this way, a liquid layer is formed. Humid air enters the tower at the bottom, and is then cooled when it gets in contact with the water layer on the bed. The humid air will be cooled to below the dew point, so that the water vapour from the air condenses, leaving liquid water. This condensed water is then added to the fresh water loop (van der Drift, 2014).

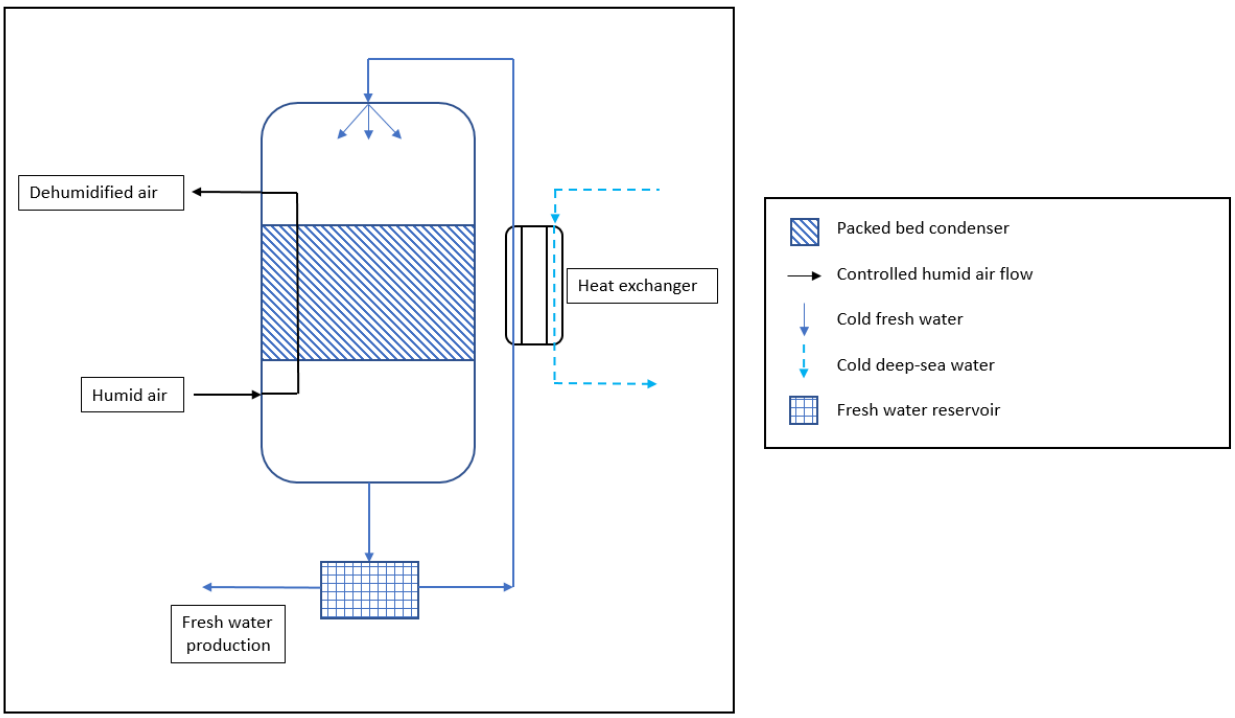


Figure 10: Direct Contact Humidifier

Appendix C5 – Cooling: SWAC & SDC

In this appendix, cooling technology is explained. The technology – state of the art is explained; what is the conventional way of cooling, and what do seawater air conditioning (SWAC) and Seawater District Cooling (SDC) look like (including some reference projects).

C.5.1 Technology – State of the art

Chiller cooling

The conventional way of central cooling for large buildings makes use of a chiller, that transfers heat from the building to the outside. The central cooling installation is mostly built on top or next to a building. A refrigerant is used to cool a closed fresh water loop. The water will become a certain temperature, and with this water, the air for cooling the building is cooled. The water will absorb heat from the air, so it will flow passed the refrigerant again to be cooled, and the cycle begins again. An AC powered compressor compresses the refrigerant gas, resulting into heat. The gas runs through a set of coils, loses heat and condenses into a liquid. The liquid passes an expansion valve and evaporates into cold (low-pressure) gas. The gas then runs through another set of coils, where heat from the fresh water loop can be absorbed.

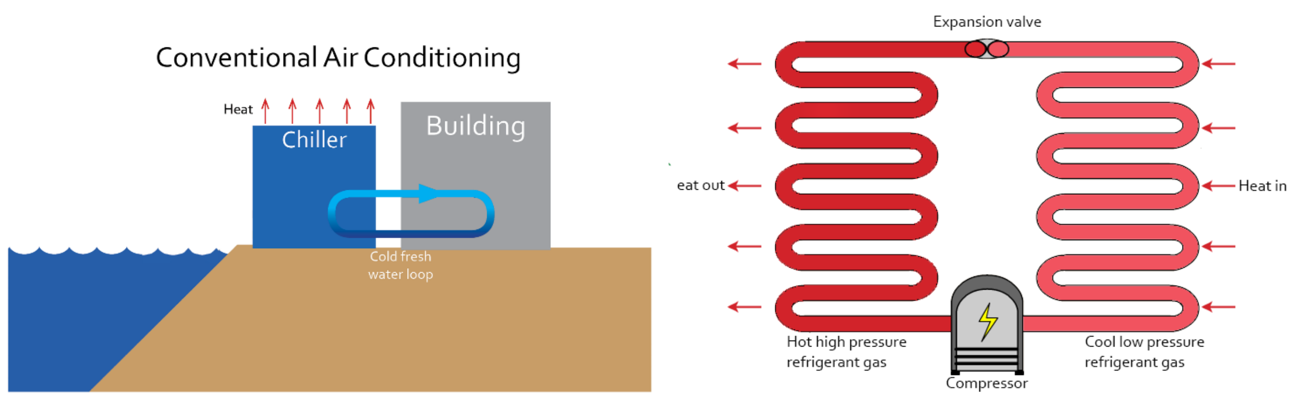


Figure 11: Conventional air conditioning with a chiller (left) and schematization of its refrigerant loop (right).

Seawater Air Conditioning

However, the process mentioned above requires a lot of energy, because the compression of the refrigerant is energy consuming. On top of that, refrigerants are materials that are harmful for the ozone layer (ozone-depleting materials), and often leak. Therefore, a plan is made to come up with a concept that does not use this harmful refrigerants, but replaces it for cold deep seawater. This is called 'Seawater Air Conditioning', or SWAC. In a SWAC-system, the heat is transferred from the building to the cold deep seawater that is being pumped up from a certain depth. The cold deep seawater replaces the refrigerant and cools a closed fresh water loop. This then cools the air, as with the conventional method. The cold deep seawater however will be pumped back into the sea, at an appropriate depth with the same seawater temperature as the outlet flow. As it does not need to be compressed, it saves up a lot of energy and money.

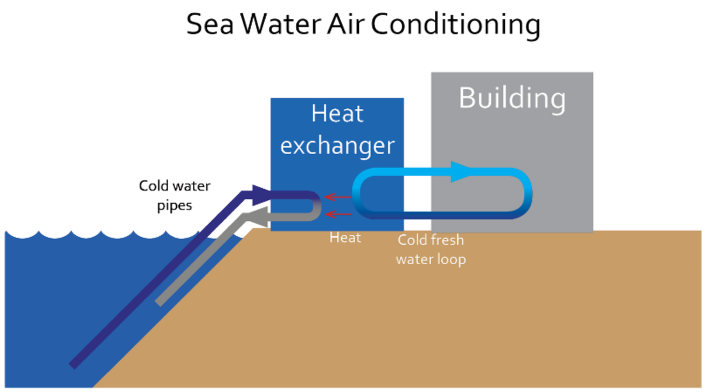


Figure 12: A SWAC-system

The most imported components required for a SWAC installation are the deep sea water pipe, a pump that pumps up the water and heat exchangers to transfer the heat from the air inside the building to the cold deep seawater. The exact temperature difference needed is dependent on the size of the building to be cooled, the materials the building is made of and the number of people inside the building.

SWAC can be applied to already existing buildings, as long as a central air conditioning installation, using a fresh water loop, is already in place. Since a fresh water loop is used, the heat between the freshwater and deep seawater is transferred via heat exchangers. No salty ocean water will enter the building and corrosion is prevented.

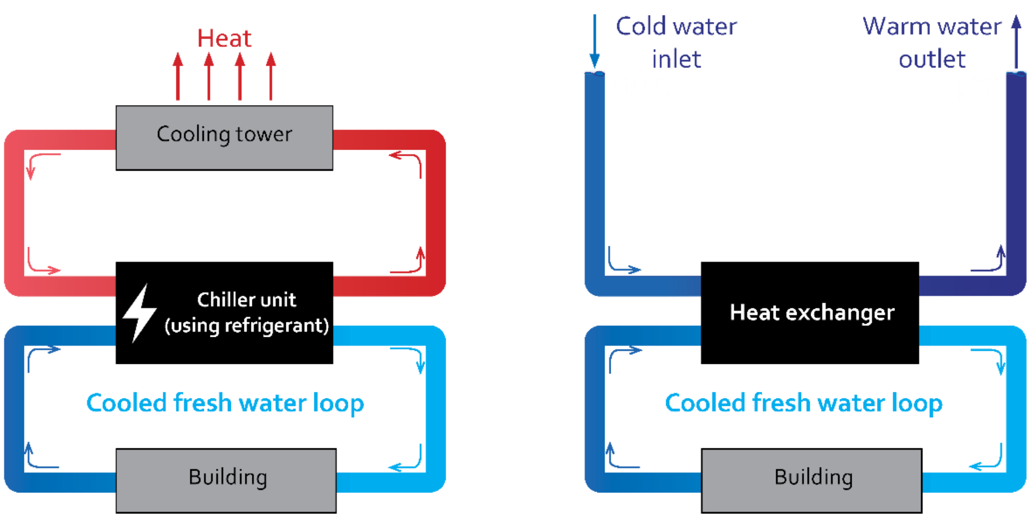


Figure 13: Schematization of conventional cooling with a chiller (left) and SWAC (right). (Makai Ocean Engineering, 2017)

According to several feasibility studies, using SWAC for cooling can reduce electrical consumption by 80 to 90 percent. For an average installation, the payback time can be between three to seven years, depending on the temperature of the used cold water.

District Cooling

District Cooling (DC) is a way of cooling where several buildings are connected to one central cooling facility. This cooling facility cools down fresh water that is transported via pipelines to the customer's buildings. The production facility can use different ways of cooling. For example by using chiller units or free cooling by a river, lake or with seawater. When large amounts of cooling is required in a small area, district cooling is always more beneficial than conventional cooling and is therefore also implemented in some large cities. It turns out to be a reliable, efficient in terms of water and electricity usage, sustainable and cost-effective solution.

District cooling consists mainly of three parts: The production facility, the distribution network and substations. In the production facility, fresh water is cooled down, by either conventional chiller units and refrigerants, or by free cooling via heat exchangers. The fresh water is pumped to the customers via a distribution network of pipes. Every building consists of a substation where the fresh water from the production facility cools down the building's own internal fresh water loop via a heat exchanger. The distributed fresh water returns to the production facility to be cooled again.

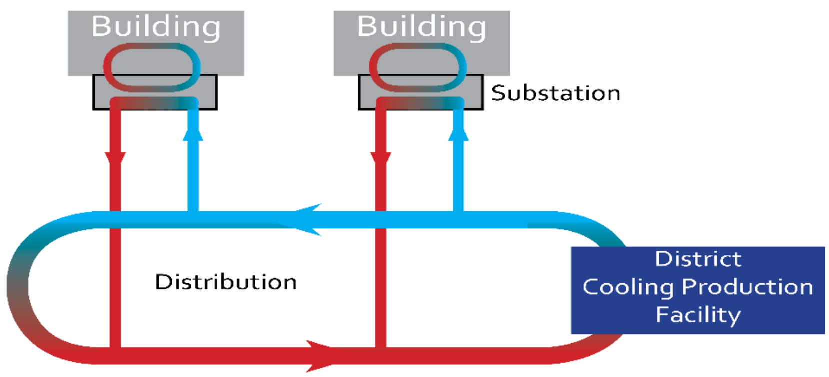


Figure 14: Schematization of District Cooling and its fresh water loops

Seawater District Cooling

Seawater District Cooling (SDC) is a combination of SWAC and DC. A centralized production facility cools a fresh water loop with seawater by using heat exchangers. This means that the production facility is preferably constructed near shore and cold seawater is pumped to the production facility. The seawater is immediately discharged back into sea after cooling the fresh water distributing loop.

C.5.2 Reference Projects

To be able to verify whether SWAC or cooling by using cold sea or river water is feasible, some reference project are given below. They have shown good results and can be used as a reference.

Table 1: Reference Projects Cooling with Seawater

Project	Type	Cooling load (tons)	Year of construction	Source
Paris, France	DC	80,000	1978	River
Kona, Hawaii	SWAC	30-50	1986	Sea
Stockholm, Sweden	SDC	80,000	1995	Sea
Helsinki, Finland	SDC	25,000	1998	Sea
Cornell University, New York	DC	14,500	1999	Lake
Toronto, Canada	DC	58,000	2001	Lake
Bora Bora, French Polynesia	SWAC	450	2006	Sea
Amsterdam, The Netherlands	DC	17,000	2006	Lake
Honolulu, Hawaii	SDC	25,000	planned	Sea
Curacao, Caribbean	SWAC	3000	Planned	Sea

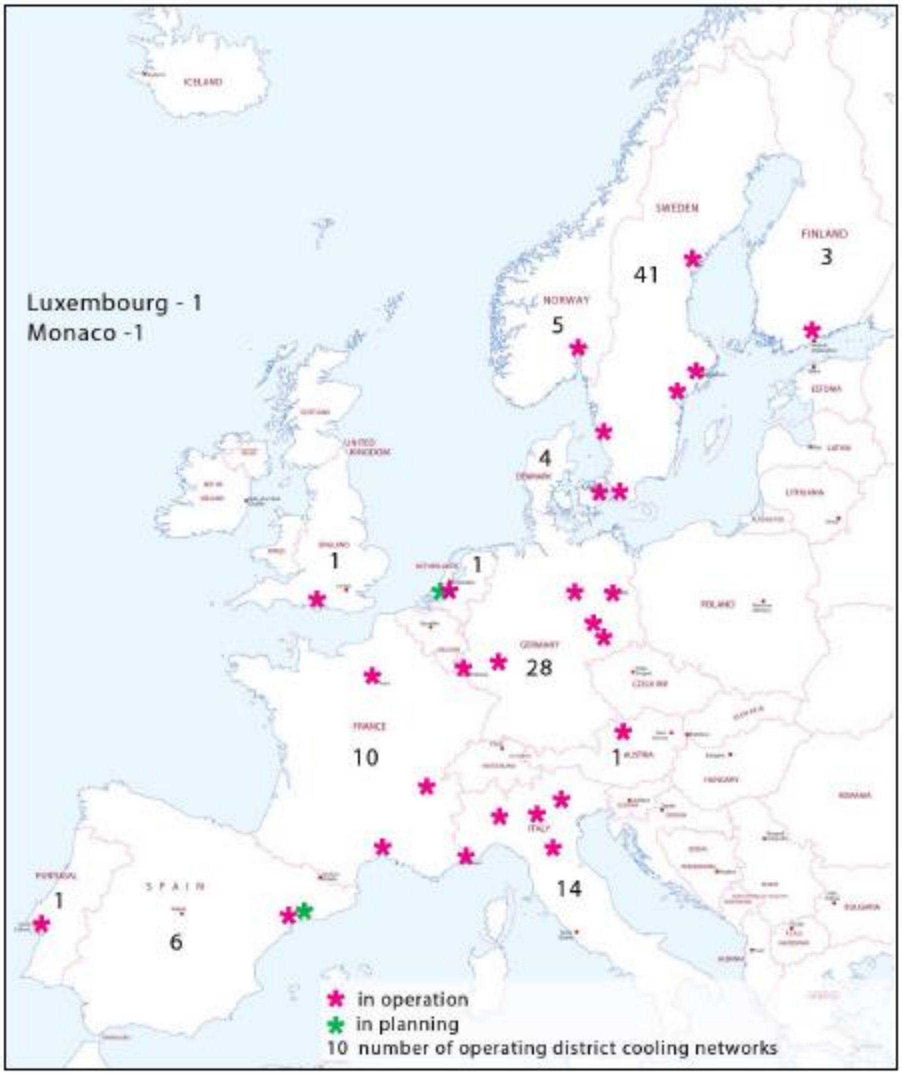


Figure 15: District Cooling in Europe in 2006 (Swedblom, 2014)

The projects show that District Cooling and SWAC are already applied several times in different sizes. The project in Canada was the first District Cooling project to use a deep water source for their cooling. Most District Cooling projects use chiller units as an additional source of cooling. In Europe a lot of projects still grow throughout the years. For example in Helsinki every year the cooling distribution network is expanded.

Appendix D: Analysis

Appendix D1: Analysis of current and future status of energy

D.1.1 Manado

In this section the an analysis on Manado is performed. First the gird is treated, next the current demand and supply of energy. At last is elaborated on the future of the energy demand and supply.

D.1.1.1 Grid

North Sulawesi, Gorontola and Central Sulawesi are connected by one isolated grid called the SULUTTENGO grid. The grid is shown in Figure 16. The grid is governed by PLN. There are plans to connect the grid to the South Sulawesi grid. In Figure 16, the dashed red lines show the plans for the new grid. In North Sulawesi (Sulawesi Utara) 83.5 percent of the households is connected to the grid (Provinsi Sulawesi Selatan, 2015).

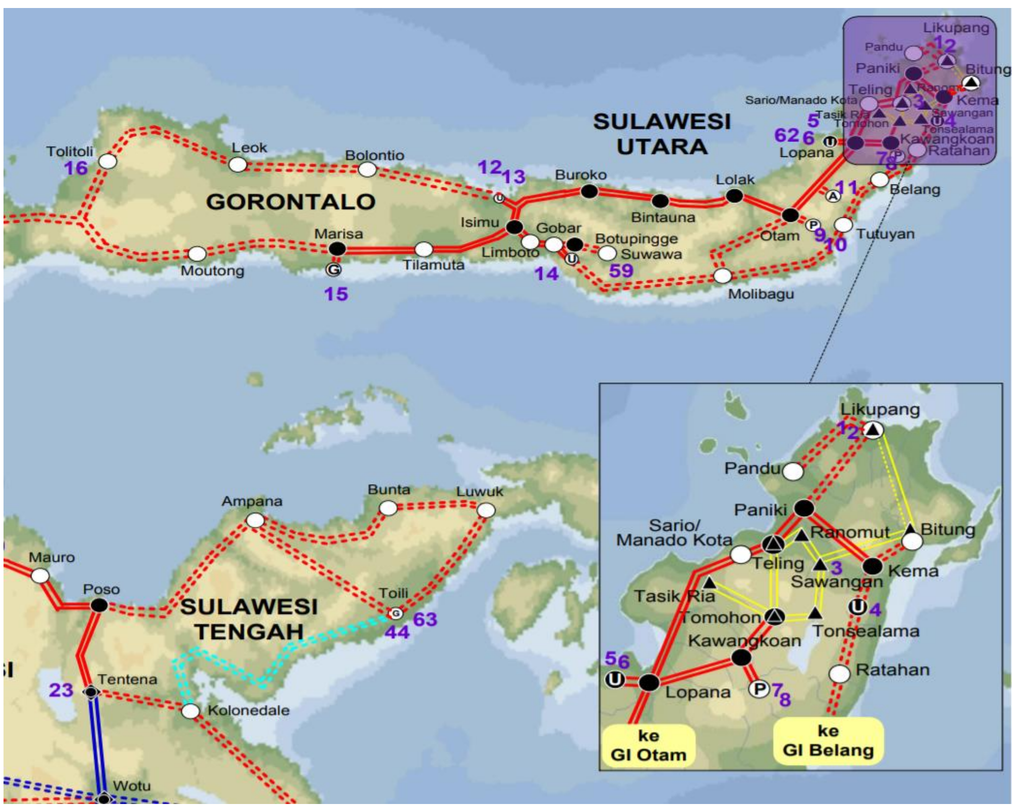


Figure 16: SULUTTENGO grid (red lines near Sulawesi UTARA) (PLN, 2017)

There are plans to connect the Bunaken to the grid. This would cost 65 billion Rupiah which equals roughly 5 million USD (Meeting PLN SULUTTENGO, 2017). PLN Manado sent these plans to PLN Jakarta and the government. They are expecting a decision in 2018 (PLN Manado, 2017). North Sulawesi has several districts with respect to energy supply. These 11 regions include: Manado North, Manado South, Bitung, Tomohon, Tondano, Kawangkoan, Ratahan, Amurang, Motoling, Pineleng, Airmadidi. The Bunaken belongs to Manado South. These districts are almost 100% connected to the grid at the moment (PLN Manado, 2017).

D.1.1.2 Current situation

Power demand

In 2016 the Jakarta Post stated that people in Manado continue to live in the grip of a serious energy crisis (Jakarta Post, 2016). The region has a growing population of 1.3% annually and an economic growth of roughly 6% a year (Energy demand Sulawesi 2020). Since the population of Manado is growing, also the energy demand grows. Therefore two years ago PLN increased the power production. Nevertheless the power supply remains unstable every now and then. Especially when new houses or public buildings are built. In Manado the property sector consumes most of the electricity, since there are almost no factories situated in the city. In Bitung, in the Northeast of North Sulawesi, there is a lot of industrial activity. This means that the demand of a single facility is higher. So far, in North Sulawesi the peak load reached up to 345 MW. These peak loads lead to regular blackouts. Detailed numbers of individual consumers are lacking.

Power supply

Conventional

Currently, around 400MW is installed in North Sulawesi. Most power comes from conventional power resources. There is a 80MW surplus according to PLN. In Manado, 40% of the power comes from diesel (PLN Manado, 2017). However, they are working on decreasing the PLTD to 0%.

Since March 2016 “PLTG Gorontalo” has been producing power for both the Gorontalo province and North Sulawesi. This gas power plant has a capacity of 100MW and is one of the biggest power suppliers of the region. This power plant consists of 4 turbines that produce 25MW each (Rista Rama Dhany, 2015).

Another source is an offshore vessel that produces power through a steam engine (PGTU). In December 2015 the Indonesian government signed a contract with Karpowership, a company from Turkey, to supply an additional 520 MW to Indonesia. The first vessel “MVPP Zeynep Sultan” is deployed near Amurang, North-Sulawesi, supplying 120 MW to this region. The government pays IDR. 870 per kWh. This equals roughly 0.056 euros per kWh (Sutianto, 2015). This is seen as a temporary solution since the vessel will supply energy for 5 years for North Sulawesi. According to PLN, the lifetime of this project will be extended (PLN Manado, 2017). A lot of people in Manado have backup diesel power generators for the power blackouts.

Renewable

Besides conventional power plants, PT PLN is also focusing on renewable energy. They are exploiting the geothermal potential of North Sulawesi. In Tomohon, currently 80 MW of geothermal energy is installed, where the maximum estimated potential of the site is estimated on 220 MW (TEMPO, 2009), (ThinkGeoEnergy, 2012). Another geothermal location is the Kotamobagu field which has an estimated potential of 100 MW and the Airmadidi field has an estimated potential of 25 MW. At both fields additional research is executed and no installations are built yet. That sets the total geothermal potential to 345 MW (Panas Bumi, 2016).

All geothermal installations are built by PT Pertamina, an Indonesian company that focuses on oil, gas and geothermal energy production. As a result, the cost of Lahendong IV totalled US$61.18 million compared to Lahendong II at US$31.89 million. The average cost per megawatt of energy produced was US$1.59 million for Lahendong II and US$3.06 million for Lahendong IV (Bagus Mudiantoro, 2015).

Besides geothermal energy, a significant share of the energy comes from hydropower. A small part of the energy in Manado comes from the Tanggari Hydro Power Plant II. A new project for hydropower "Kuwil Kawangkoan Dam project" is expected to be completed in 2019. This project is for both energy production (1.2MW capacity) and flood reduction due to heavy rainfall. The dam also provides raw water for Manado, Bitung and North Minahasa. The cost to complete the project is approximated to be US$109 million. Together, Tanggari I and Tanggari II have a capacity of 36MW.

The Tonsealama hydropower plant is the oldest hydro power plant in Indonesia and constructed by the Dutch. The capacity of the plant is 40 MW and is located near Tondano (Sulawesi Bisnis, 2016).

The region is also focussing on solar PV. Near Gorontola, a 2 MW solar power plant is built, again connected to the SULUTTENGO Grid system. At islands and small villages along the coast, solar panels are also used for power supply (M.Suhari, 2016).

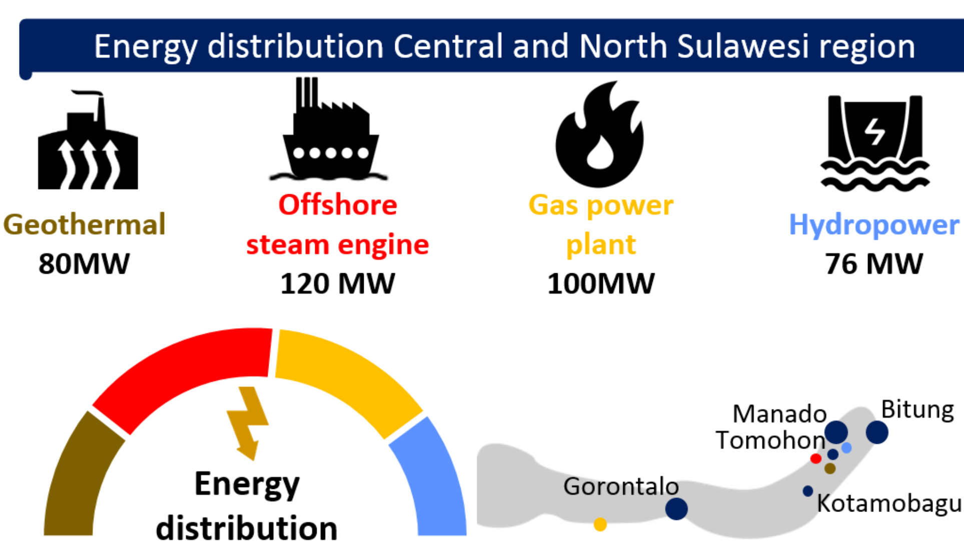


Figure 17: Energy distribution Central and North Sulawesi region

Indonesia has a target to get 23% of its power from renewable energy. North Sulawesi is one of the country's leading regions with approximately 40% renewable energy.

D.1.1.3 Energy projection North Sulawesi

Demand

With an increasing population and an economic growing area, the energy demand grows along with it. This means that the energy demand and peak demand will also increase the coming years. The peak demand projection until 2020 is shown in Figure 18. The next subsection explains what will be done to meet the future energy demand projections.

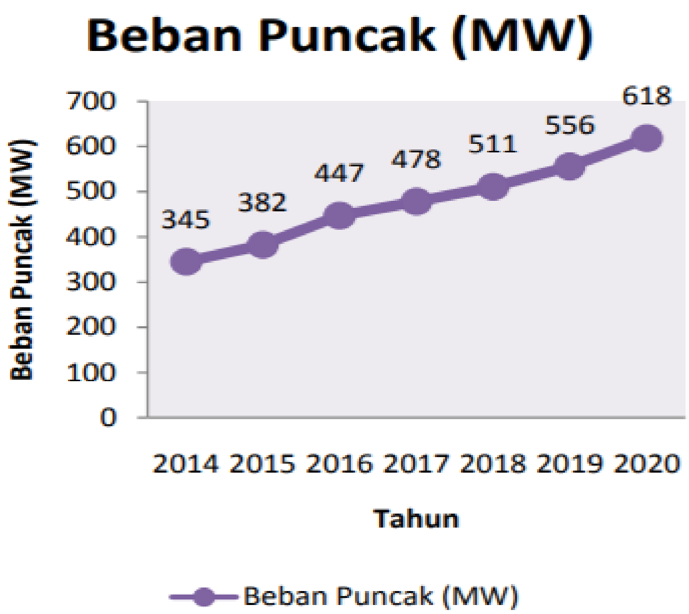


Figure 18: The projected peak load on SULUTENGO grid

Furthermore, Bitung is a harbour city in North Manado that is expected to grow and thus the energy demand will also grow. The city is also connected to the SULUTENGO grid. Bitung is expected to have a power demand of 300MW.

Supply

The current power capacity is not enough to meet the future demand. As stated before, the 120MW power supply vessel in Amurang is a temporary solution. Pt. PLN is working on the increase of the power supply and has planned several power exploitations of both renewable and conventional resources for the coming years. A summary of the planned projects is given in Figure 19.

No	Project	Type		Developers (Assumed)	Capacity (MW)	COD
1	Mobile PP North Sulawesi (Amurang)	PLTG/MG	Gas/Gas Engine	PLN	100.0	2016
2	Minahasa Peaker	PLTG/MG/GU	Gas/Gas Engine/Steam Gas	PLN	150.0	2017
3	Talaud	PLTU	Steam	PLN	2x3	2017
4	Tahuna	PLTMG	Gas Engine	PLN	10.0	2018
5	North Sulawesi 1	PLTU	Steam	PLN	2x25	2018
6	Scattered PLTM North Sulawesi	PLTM	Mini Hydro	PLN	0.5	2018
7	Sawangan	PLTA	Hydro	PLN	2x6	2020
8	Kotamobagu (FTP 2)	PLTP	Geothermal	PLN	80.0	2024
9	Amurang	PLTU	Steam	LEASED	2x25	2017
10	Scattered PLTM North Sulawesi	PLTM	Mini Hydro	IPP	3.5	2017
11	Lahendong V (FTP 2)	PLTP	Geothermal	IPP	20.0	2017
12	Scattered PLTM North Sulawesi	PLTM	Mini Hydro	IPP	0.5	2018
13	Lahendong VI (FTP 2)	PLTA	Hydro	IPP	20.0	2018
14	Scattered PLTM North Sulawesi	PLTM	Mini Hydro	IPP	4.2	2019
15	Poigar 2	PLTA	Hydro	IPP	30.0	2021
16	North Sulawesi 3	PLTU	Steam	IPP	2x50	2019/20
17	Tahuna	PLTMG	Gas Engine	Unallocated	5.0	2021
18	Sulbagut 2	PLTU	Steam	Unallocated	2x100	2022/23
19	Sulbagut Peaker	PLTG/MG/GU	Gas/Gas Engine/Steam Gas	Unallocated	100.0	2024
	Total North Sulawesi				942.0	

Figure 19: Future plans North Sulawesi

The infographic below summarizes the future plans.

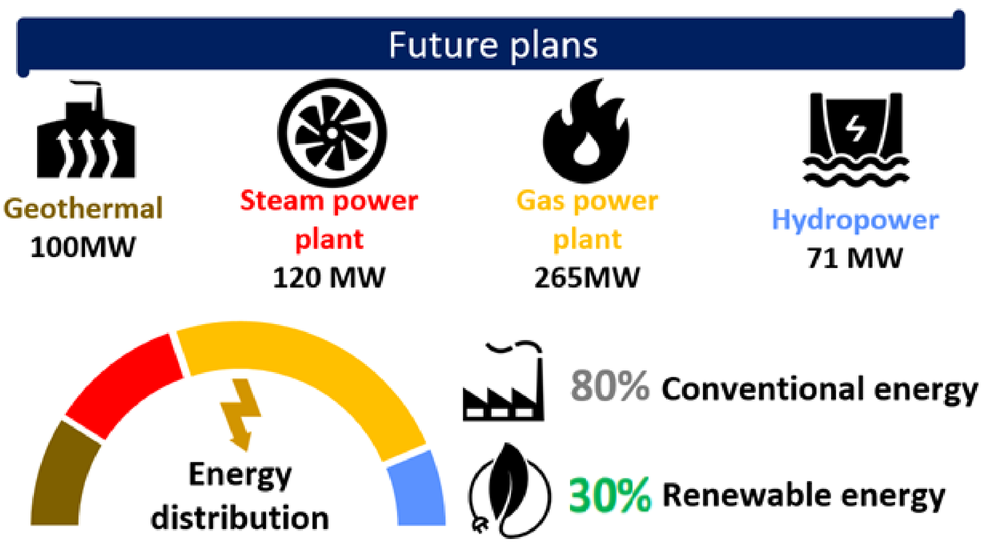


Figure 20: Future plan summary

The expected power production and sales are plotted in Figure 21. In 2020, there is a relatively big increase in the production due to the North Sulawesi 3 PLTU (100MW).

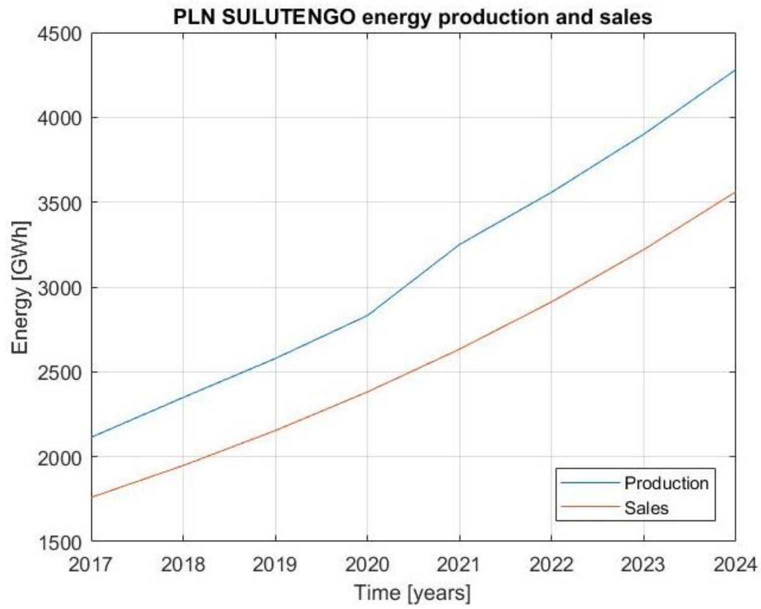


Figure 21: Expected PLN SULUTTENGO energy production and sales (RUPTL, 2015)

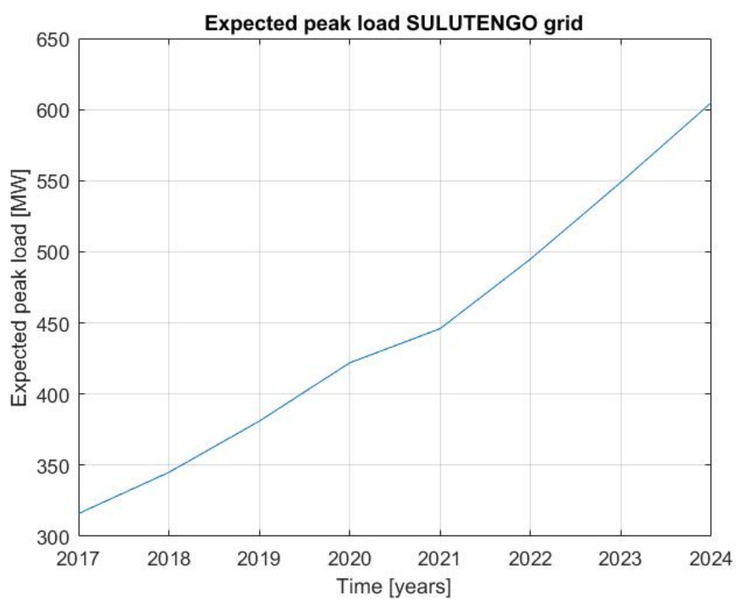


Figure 22: Expected peak load SULUTTENGO grid (RUPTL, 2015)

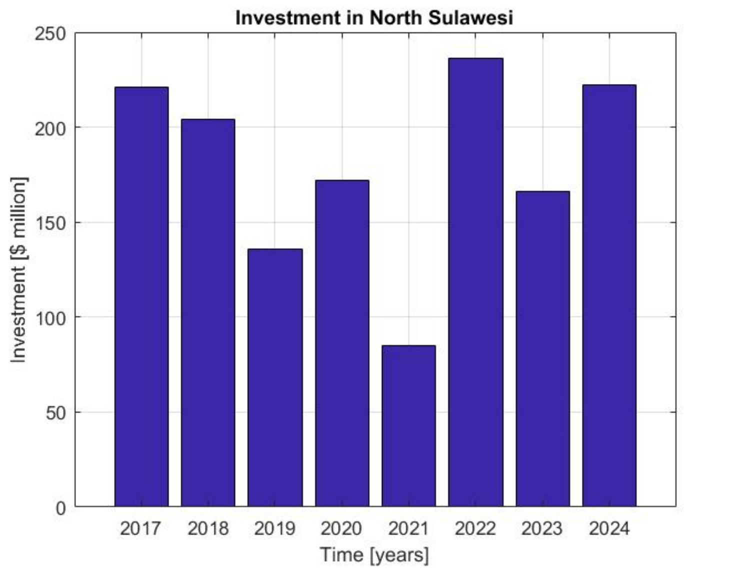


Figure 23: Investment in energy facilities in North Sulawesi (RUPTL, 2015)

According to the plans, the peak load of 2024 could be met by PLN. However, it is still uncertain how much of the capacity can actually produce when it is needed. Of the energy distribution, the hydropower is the least predictable. The water level of the Tondano is currently difficult to manage due to the heavy rain and droughts. As the plans of PLN change every year, it is difficult to predict whether the demand would be met by the supply.

D.1.2 Bunaken

In this section, the an analysis on Bunaken is performed. First the gird is treated, next the current demand and supply of energy. At last is elaborated on the future of the energy demand and supply.

Indonesia consists of more than 17.000 islands. The large islands are known to have a well organised energy supply system with relatively high rate of connected households. The smaller and remote islands have problems with their energy supply. Some islands lack power supply, others have limited power supply. Mostly the energy is supplied by diesel generators. The fossil fuels are imported from the mainland and this results in relatively high energy prices (Smart Villages, 2015). Additionally, the energy generator and resource transportation results in high pollution. PT PLN noticed these problems and initiated a plan in 2010 to help more than thousand islands. The concept is to stimulate the use of photovoltaic power stations in combination with diesel power generators called hybrid PV power plants (VIVA, 2010). PLN chose 7 islands to serve as a pilot. One of these islands is Bunaken island, it is a small island located North-West of Manado.

D.1.2.1 Grid

The Bunaken grid is an isolated grid which connects the three largest villages on the island to the power supply plant. The power supply plant is operated by PT. PLN Bunaken, which is under supervision of PT. PLN Manado.

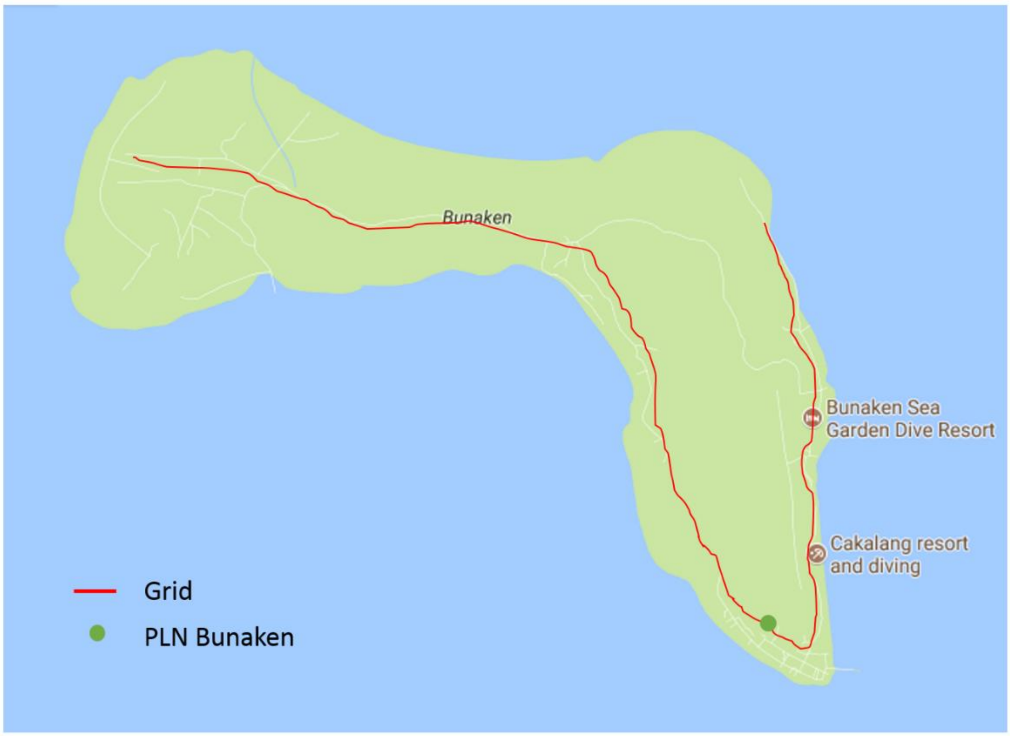


Figure 24: Rough indication of the electrical grid on Bunaken island

D.1.2.2 Current situation

Demand

In 2013 an analysis on the electricity demand on the Bunaken is made. A typical load curve of Bunaken island can be found in Figure 25. Important is that the peak load in 2017 could reach up to 249 kW (Meeting PT. PLN Bunaken)

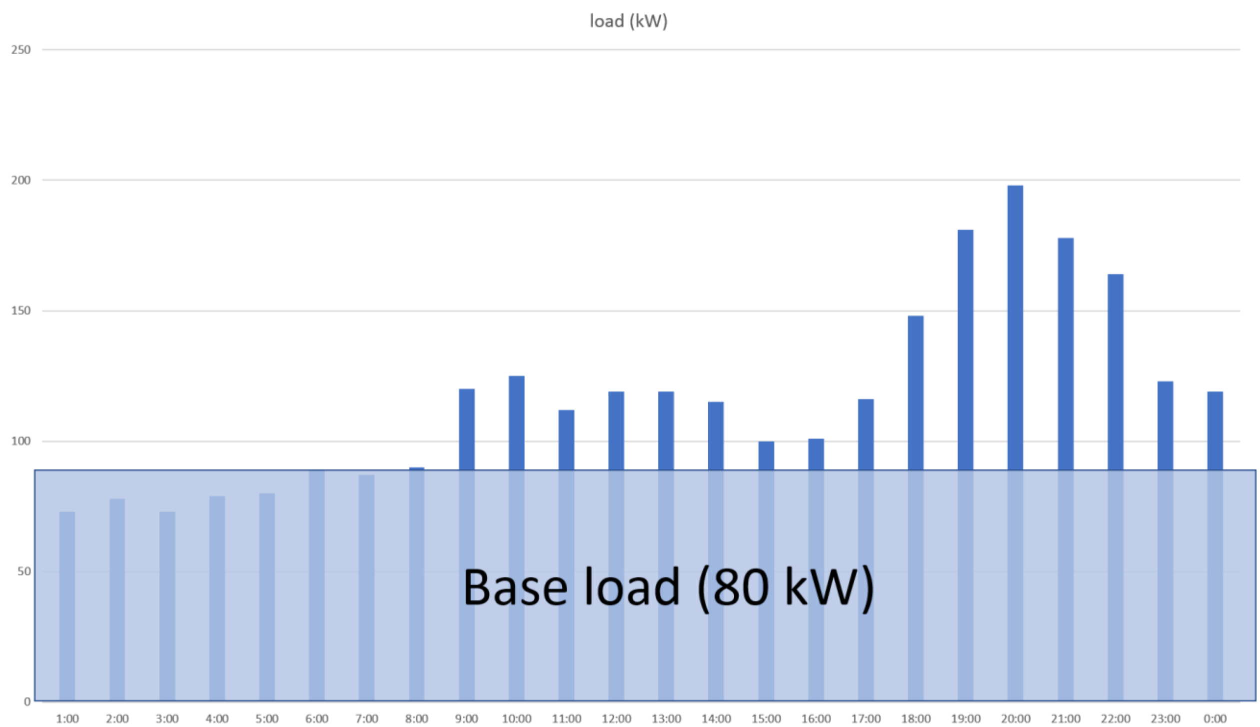


Figure 25: Load curve Bunaken Island in 2013

Supply

At the moment the energy at the island is supplied by a Solar park in combination with a diesel generator. The peak capacity of the park is 335 kW and supplies energy to all the inhabitants of the island. The park consist of 1444 solar panels and energy can be stored in a battery pack. The power plant is now partly out of operation, due to lack of maintenance and new components (Smart Villages, 2015)(Meeting Pt. PLN Bunaken). The power plant can only supply 18 hours of electricity to their customers, because the battery pack needs to be replaced. New batteries are ordered, but it will still take a lot of time before they will be delivered.

The current prices for a PLTS (Hybrid solar power plant) are 2600-2900 IDR/kWh or 0.20-0.22 $/kWh (Asikin, 2015). PT. PLN Manado states that in the case of Bunaken the Hybrid Power system produces energy for 0.22 $/kWh (Meeting PT. PLN Manado).

The downside of the current system is the limited supply and the continuous maintenance to the systems, which led to limited operation of the power plant located on the Bunaken. High energy production prices and the lack of a suitable and reliable solution for this problem gives an opportunity for the implementation of OTEC.

D.1.2.3 Energy projection Bunaken

Demand

Little is known about the future of Bunaken island and its energy demand. However it is known that from 2013 to 2017 the peak demand increased from 200 kW to approximately 250 kW. This is an increase of 25% in 4 years. With the increased focus on tourism this trend could go on for more years, which will ensure a significant increase in energy usage on the island. Whether this will happen is very uncertain and therefore a more detailed analysis on the energy consumption has to be performed.

Supply

As stated before, in May 2017 PLN announced new plans to connect Bunaken to the SULUTENGO grid. They will be connected through a 20 kV submerged power cable. At the moment, the project is proposed to PT. PLN Jakarta. According to PT.PLN Manado it will take approximately 1 year before next steps will be taken. Besides this is the plan still in an early phase, according to a local coastal engineer and locals from Bunaken is the bed topography very rough with large height differences over a short lateral distance. Next to that is no bathymetry measurement performed. All together makes it an ambitious plan with many obstacles ahead which will cost a lot of extra time, so no implementation in a short notice is expected.

D.1.3 Energy price

The energy in Indonesia is heavily subsidised by the Ministry of Finance. Part of this subsidy is to encourage the usage of renewable energy. PLN produces and sells energy, but also buys energy from independent power producers (IPPs). The citizens and industry pay a fixed price according to a category that they belong to. Most citizens and malls in Manado fall into the following classes:

Class	IDR/kWh	$/kWh
1	1.352,00	0,10
2	1.467,28	0,11

Table 2: Energy price in North Sulawesi (PLN Manado, 2017)

These subsidised prices indicated in Table 2 show PLN's favourable price to pay for a certain energy source (Smart Villages, 2015). However, research shows that PLN is willing to pay a higher price, if it can stimulate the economic growth of a certain region, like remote areas/islands.

D.1.4 Stakeholders

The electricity supply in Manado is managed by the local PLN which is a governmental company. This is the only electricity company, whereas they take care of the generation, transmission and distribution of the electricity. This makes PLN the most important stakeholder. In 2009, a law was implemented that allows independent power producers (IPPS) to generate and sell electricity. PLN remains heavily subsidized. Figure 26 shows how the energy is distributed including important stakeholders (Patel, 2013).

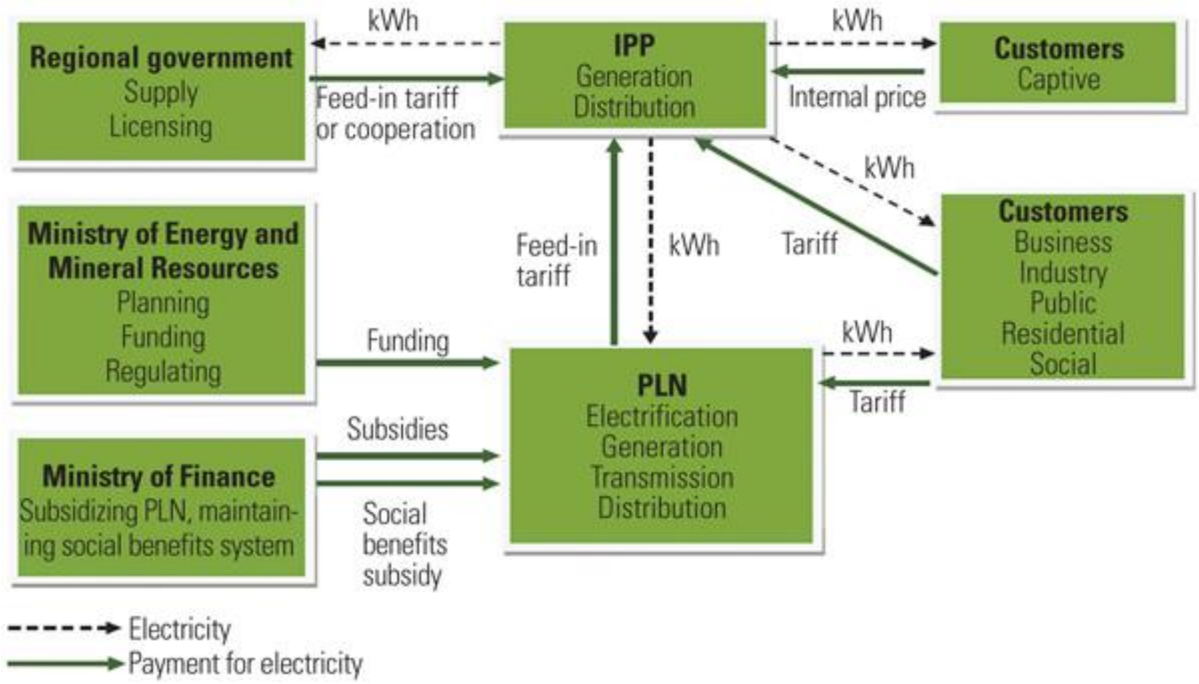


Figure 26: Energy distribution system in Indonesia (Patel, 2013)

When building an OTEC plant, the plant owner could be an IPP or work together with PLN to realize such a project. In any case, the regional government and PLN are most important when it comes to the energy production part. A stakeholder map is shown in the Figure 27.

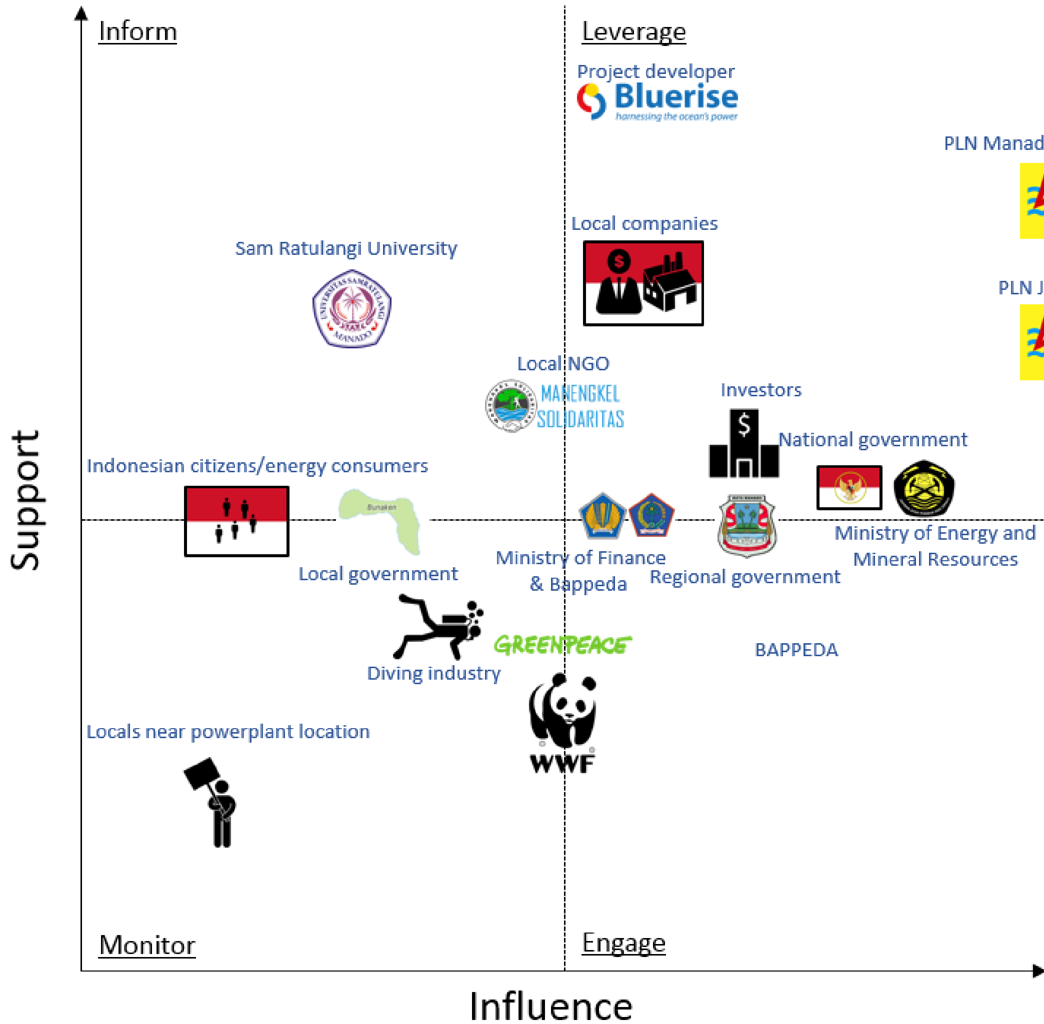


Figure 27: Stakeholder map

PLN

As stated before, PLN is one of the most important stakeholders. Both the local PLN and PLN Jakarta have to be convinced before a project is realized. Both PLN Jakarta and PLN Manado are interested in renewable energy and it is expected that with a good plan including favourable financial benefits, they are supportive. Firstly, a plan would be filed from the local PLN to PLN Jakarta which has to either accept or decline the request.

National government

The national government supports the implementation of renewable energy. However, as there are many forms of renewable energy, financially attractive forms of energy are most important. If, however, the energy can solve multiple problems at the same time, it could be that the government is more supportive. The position of the national government in this graph is therefore a little bit conservative when it comes to support.

Regional government

The regional government will supply licensing of a power plant. They eventually facilitate the legislative part of a project and have some influence. However, this influence is relatively small as PLN makes the decisions about project proposals. Note: the governor of North Sulawesi has a lot of influence. It is important to convince the governor and gain his support.

Local government

The local government of sub district Bunaken island has to support the idea. Their power is limited, but their support is vital in the success of the concept. If they the local government agrees that a concept will improve the quality of life, then they will support it. Certain utilization zones are indicated in the environmental analysis, in these zones activity is allowed but has to be in consultation with the local government. The Lura is the person who can summon the important island people and therefore an important person in this group.

Investors

If PLN supports the project, the investment for PLN's part of the project comes from the Ministry of Energy and Natural Resources and the Ministry of Finance (subsidies). A project planner like Bluerise has to complete their own funding. If the project is financially attractive, this is not expected to be a problem. As investors are looking into sustainable technology, it is expected that investors are on the supportive side and have an above average influence as they bring in part of the money.

Ministry of finance

The ministry of finance makes decisions about the subsidy for renewable energy. As most energy in Indonesia is subsidized, it is expected that the energy from an OTEC plant will also be subsidized. This makes the ministry of finance a stakeholder with above average influence. The support depends on the financial outcome of a project and is thus assumed to be neutral.

Local companies

Indonesia has high local content requirements. This makes local companies important for the implementation of a project. Their influence is relatively neutral. They only have a high influence on the success of a project when it comes to the implementation and maintenance of technology but their influence with respect to decision making is small.

NGO's

The position of a NGO is not straightforward as there are more aspects that play a role. For example, the NGO's are expected to be positive towards using renewable sources of energy to bring down pollution from fossil fuels. This makes them supportive. But as there might be a pipe installation required in the sea, it could be that the NGO's are less supportive. Therefore it is important to work together with the NGO's to mitigate the environmental impact as much as possible.

Manengkel Solidaritas a non-profit group that works in the field for coastal and marine issues. It is the biggest NGO in Manado and surroundings. They protect the environment and are pushing for renewable energy.

Project developer

The project developer is one of the most supportive stakeholders. Bluerise is one of the market leaders in OTEC and has a test installation at the Delft University of Technology. Bluerise would be one of the parties working together with PLN to realise energy production for Manado or Bunaken.

Recreational industry and fishery

Fishing and snorkelling/scuba diving tourism are important sources of income to many inhabitants. An offshore pipe might raise concerns. This means that the support will be low. However, an offshore pipe could also be an interesting spot to dive. For example wreck diving is interesting for divers. The pipe could for instance be engineered such that it could be a nice addition to the environment.

University

As a knowledge institution, the Sam Ratulangi University has a lot of knowledge about Manado and the surroundings. With a lot of different faculties like fisheries and aquatic science, it is important to involve researchers in a project.

Indonesian citizens

The Indonesian citizens are eventually the people that are getting energy from the grid. As most people are not bothered by where the energy comes from, and there is currently a surplus in Manado, they are rather neutral with respect to support. Their influence is relatively low, but if they collide together, their influence could be much higher than their current position in the stakeholder map above.

Locals near power plant location

The location of the power plant should be chosen such that the lowest amount of people are bothered by the project. However, sometimes it is inevitable to satisfy all parties. It could be that there are people that are opposing to a power plant nearby their home. It is important to keep these people informed and involve them in the process such that they can prepare for the new situation.

Appendix D2: Analysis of current and future status of drinking water

In this appendix the current status of water supply in both Manado and Bunaken Island will be analysed. A distinction is be made between tap water and the bottled market. From this the need is assessed and the most important stakeholders are discussed.

D.2.1 Current Status in Manado

Like mentioned in the introduction, Manado is located at the coast. It is given that most coastal areas are experiencing water scarcity. This is because at coastal areas there is only a thin layer of freshwater in the ground. Making groundwater a scare source.

Figure 28: Groundwater Availability Indonesia

Figure 28 shows a map of the availability of groundwater per region in Indonesia. It can clearly be seen that North Sulawesi lays in a ground water scarce area. However, Manado has other freshwater sources that will be mentioned in this paragraph.

Tap Water

The tap water is the responsibility by PT Air Manado which is owned by of the local government and Watermaatschappij Drenthe (WMD). Not everybody is connected to the tap water at the moment. Most of the population has its own well where they extract their demanded water. Also the malls and hotels own mostly their own well since they do not trust the quality of the tap water. Some of these wells reach up to a depth of 125 metres. This can eventually lead to salt intrusion along the coast. Table 3 displays how many inhabitants were connected to the tap water from the period of 2008-2013 (WMD, 2013).

Year	2008	2009	2010	2011	2012	2013
Connected inhabitants (%)	20%	21%	26%	28%	29%	29%

Table 3: Tapwater connections Manado (WMD, 2013)

Since 2013 this percentage has hardly changed. Only 29% of the people is connected. This is 39% of the households (29.000 households) (Jan Wawo, 2017, Appendix O.3).

At the moment, PT Air Manado owns seven installations for the production of water. Each installation provides certain districts, Figure 29 gives an illustration of the treatment plants and the corresponding area.

Figure 29: Water Treatment Plants Manado (PT. Air Manado)

Four of these installations use the water from the Tondano river. The water in the river originates from the Tondano Lake. This lake is located approximately 36 km from the city of Manado and is the largest lake in North Sulawesi with an area of 4.278 ha.

The water in the lake flows into the Tondano river, where the water is treated. When looking at the river water quality in Figure 30: River pollution Indonesia

, it can be stated that the river water in Manado area is polluted.

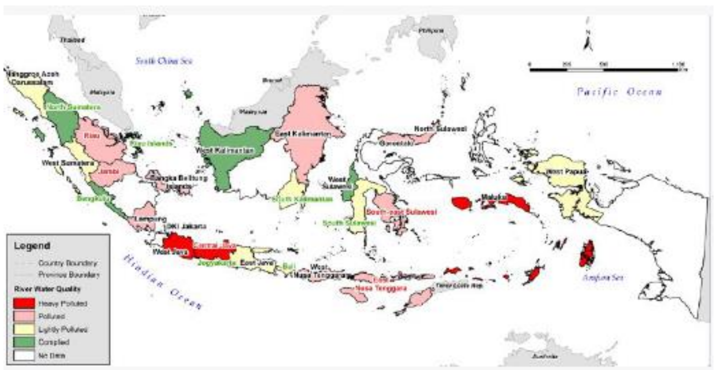


Figure 30: River pollution Indonesia

Figure 31: Part of the treatment plant Paal II

The treatment chain consist of four conventional steps; coagulation, flocculation, sedimentation, filtering, reservoir for distribution (Rakhmadi, 2017, Appendix O4). Figure 31 shows part of the treatment plan of Paal II. The treated water is labelled as ‘clean water’ and not drinking water.

Besides the water of the river, three different springs are used as source for the tap water. This water is only disinfected before distribution. However, this is done by chloride which is safe disinfection chemical up to a certain point, but has its downside. Some of the microorganisms that are present can be resistant to chlorine, which makes the disinfection useless and will have a bad impact on the health of consumers.

The production per installation of august 2017 is given in Table 4. It can be seen that most of the tap water provided by PT. AIR Manado is mostly from the Tondano river. According to PT Air Manado this is a reliable source and is not exhausted. They extract 10% of the rivers discharge and use dams to regulate the water level (Wawo, 2017, Appendix O3). However, reduction of the absorbent area can affect the capacity of this water source. Especially in the future, since the population is growing.

Table 4: Production of tap water per facility (Report of water production august 2017 (PT. AIR Manado)) 1,2, 4 and 5 are rivers. 3, 6 and 7 is ground water

No.	Installation	Production m^3/month
1	Paal II Degremont	440,024
2	Paal II Konvensional	190,238
3	Malalayang	295,246
4	Lotta	402,546
5	Pancuran	90,253
6	Sea	10,888
7	Koka	11,046
	Total production	**1440,221**

Energy usage

The required power for the treatment comes entirely from the grid. For all treatment plants there was a total usage of 6.5 GWh against a total production of 17 million m^3 in 2016. This means that water treatment in Manado costs 0,38 kWh/m^3.

The price for electricity that PT. Air Manado pays is IDR/kWh. The total electricity costs in 2016 was 780 million IDR, so 454,4 IDR/m^3.

Price

Currently there is a fixed price if one uses the service of PT Air Manado. But this price differs when it comes to for example a school, households, hotel and so on. The selling price for households is 4600 IDR/m^3 while the average selling price is slightly higher, namely 5250 IDR/m^3.

Figure 32: Broken water pipe

Connections

The tap water system consists of a pipe network around the city that delivers the water treated from the different plants to the households that are connected. The water that eventually reaches these households is still contaminated and not drinkable. One of the biggest causes is the bad pipe network. Many of the pipes are corroded or even broken, see Figure 32. The broken pipes lead to the fact that the pressure drops in the pipes. Sometimes these pipes intersect with the sewer system. Before improving the treatment at the treatment plants such that the water will be drinkable, the distribution network must be improved (Veenendaal, 2017, Appendix O6). Watermaatschappij Drenthe (WMD), is trying to tackle this problem together with PT.AIR Manado. They have set up a masterplan for the improvement of the bad pipe network and the poor tap water quality. However, the realisation of these plans has not been started yet.

Bottled Water

The bottled water market in Manado is growing, which is the case for all parts of Indonesia. It has been growing since the introduction of bottled market in 1901 and the establishment of Aqua Indonesia in 1973 (Prasetiawan, 2017) . There are studies that show that the choice of drinking bottled water is becoming part of the culture. As an example, one can look at the villages surrounding Manado. They are situated in the mountains and have access to clean drinkable wells, which they use for their tap water. Nevertheless, they stick to bottled water for drinking (Smits, 2017, Appendix O2).

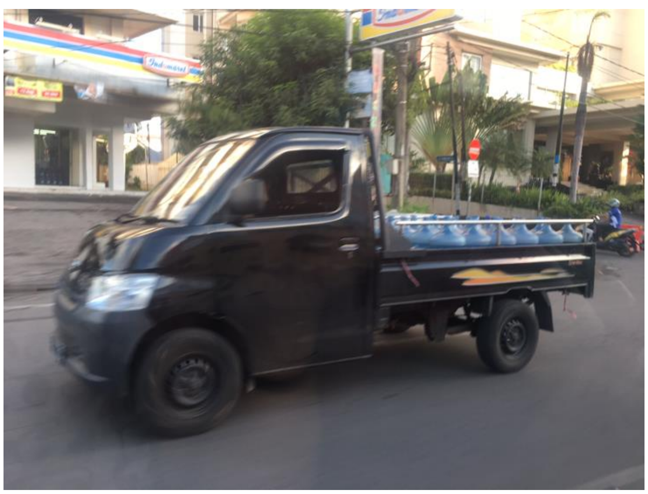


Figure 33: Transportation of Bottled Water

Since the bottled water is the main drinking water source, it is most common to buy bottles of one gallon (19L). These gallons can be bought new or refilled. The average price is 16,000 IDR/gallon, which is equal to 63.3 $\$/m^3$. Figure 33 shows how the gallons of water is transported through the city. A couple of companies provide Manado with bottled water. The biggest one is Aqua, owned by Danone. All bottled water companies have the same source for their water, which is on Kalabat Mountain in the village Airmadidi. Aqua Danone refills the gallons of the inhabitants of this village for free.

D.2.2 Current Status on Bunaken Island

Besides that it is recognised as one of the best dive spots in the world, the Island of Bunaken is struggling with a water scarcity. The sources for fresh water on the island are scarce and is mostly not drinkable. The groundwater is mostly brackish and there are no rivers or lakes. At the current status the inhabitants of Bunaken more or less rely on their own initiatives to provide their water needs.

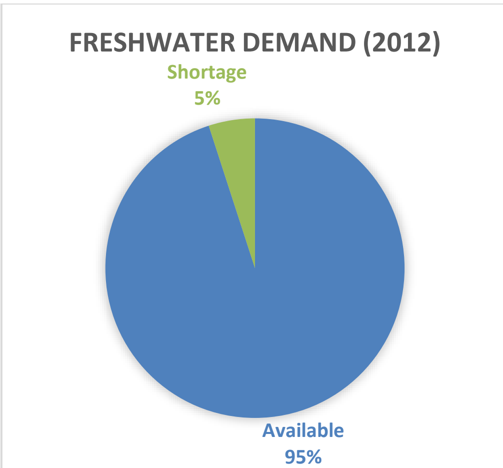


Figure 34: Fresh water availability Bunaken

The tourist industry has been an important factor for Bunaken, with an annual average of 40.000-50.000 visiting tourists (Towoliu, 2012). The development as a tourist attraction started when the National Park was founded. This growth has resulted in a shortage of water on the islands population of 3200 inhabitants, consisting of 937 families. Udayana University researched the Island's water scarcity and showed that the average water consumption is 904.4 liters or 1 m^3/room/day. The residential use rate is 57.4 L/capita/day (Towoliu, 2012).

Tap water

At the moment the people have no access to tap water despite the facilities that are stated below.

Ground water

A lot of people rely on their own water supply and the sustainability of it is threatened. The estimated demand of water in 2012 was 370.5 m^3/day. The available groundwater in Bunaken is only 95% of the demand in 2012 (Towoliu, 2012), see Figure 34. Meaning that there is a shortage in fresh water on the island since a long time. Nevertheless most islanders make use of a well. But most ground water is brackish in dry season and even during wet season only drinkable after boiling. But still this is the only available source for them at the moment. (Kanto, 2017, Appendix O8).

Figure 35: Well on Bunaken island

There are fresh water wells on the island (see Figure 35), but they are scarce, since salt intrusion from the sea during dry season is likely to occur. Villagers can buy water from people who have a fresh water well. This is mostly done by resorts outside of Bunaken village. The resorts (for example Seagarden dive resort) build their own piping network and pay a monthly tariff to the owner of the land where the well is located, depending on the size of their resort (Sea garden with 11 twin rooms pays +- 3 million IDR/month) (De Jonge, 2017, Appendix O7).

Some resorts (for example Cakalang Resort) use brackish ground water, mixed with rainwater, but this is still too salty to drink. There is at least one resort known (Oasis resort) that uses its own RO installation to produce their tap water.

Since there is an absence of catchment zones, like rivers and lakes, wells are likely to dry out. It is expected that the growing population and amounts of resorts will further dry up the available wells. This will affect Bunaken as a tourist destination in the future. The development will not work optimally, since the tourism industry can only grow when the water supply can be sustained. Investors will less likely invest in water scarce areas.

Desalination

Since the ground water is not a good source for fresh water at the island, several initiatives for desalination have been carried out. In total four desalination plants have been built on the island and are operated by the islanders themselves.

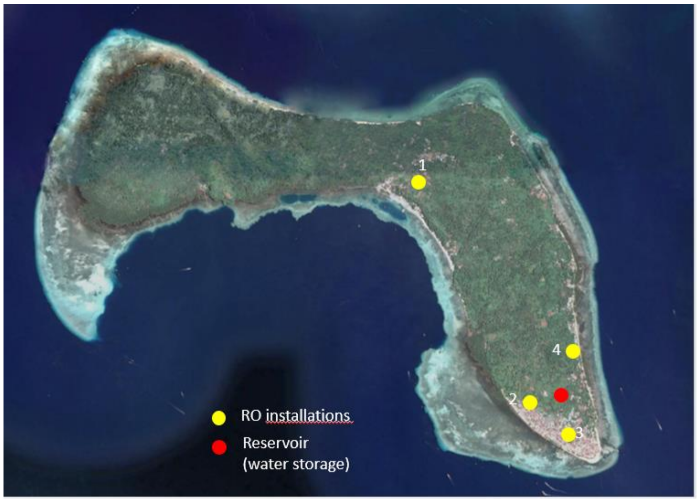


Figure 36: Overview of desalination plants

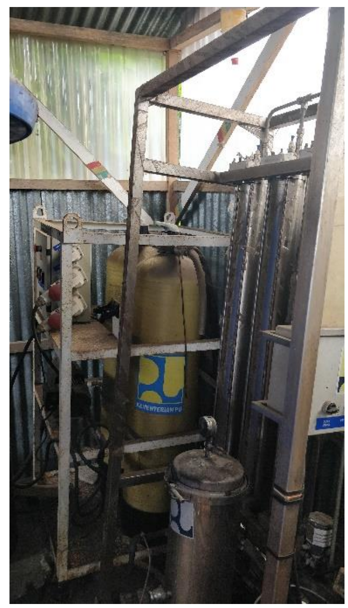


Figure 37: Leftovers of RO installation number 3

In 2007 two smaller desalination plants were running at Bunaken island (indicated with 1 and 2 in Figure 36), they were pumping up brackish ground water. After some planning, there was chosen for a well, due to too much plastic inlet for taking surface water. The small installations are said to produce between 1100 l (Kanto, 2017, Appendix O8) and 25.000 l per day (Musak, 2013) were driven by diesel generators. After some time they lacked maintenance and were considered damaged. There is a high possibility that the membranes were damaged, because they were not kept wet constantly. The installations broke after 2-3 years of service.

A third installation (indicated with 3 in Figure 36) was installed in the year 2010 and could produce 1500l of fresh water per day (Kanto, 2017, Appendix O8). It already stopped working after 6 months. For all these RO-installations it was free for the islanders to pick up water at the production facilities. All above mentioned installations were built by the ministry of Public Works and People's Housing (PU) and the operation and maintenance was caried out by the islanders themselves.

Nevertheless, PU built a new RO installation (indicated with number 4 in Figure 36), a reservoir and a piping network, that was completed in 2014. The RO installation has its own diesel generator to produce water.

The installation is a so-called SWRO (sea water reverse osmosis) plant that provides Bunaken village with clean water. It is supposed that the water can be directly drunk, the former mayor of Manado stated: "The water can be drunk right away. The water is the same as regular mineral water" (Bappeda Manado, 2014). After the installation was built by PU it was handed over to the local government. At that moment it was not quite clear which governmental organization would control the plant (PDAM or something else). At the establishment of the SWRO facility, it was stated that the it could be maintained and utilized properly by the Government and people of Bunaken Island in order to meet their needs of drinking water. The facility is located at the east side of the island, at Pangalisan beach. The capacity of the plant is 2.5l/s and could serve 800 families on the island (Bappeda Manado, 2014).

The plant is only operated on Sundays at the moment and people can pick up water at the production facility. The piping network is not working (Pieters, 2017, Appendix O12), and it is not agreed upon who will pay for the diesel. It is only a matter of time until this installation will fail as well.

Figure 38: RO installation number 4 at Pangalisan beach

Bottled water

Almost all the drinking water is transported by boat from Manado. Several resorts and hotels are doing this by using their own private boat to transport gallons of drinking water. But there also sellers that transport the gallons of drinking water and sell them on the island for a higher price of approximately 25.000 IDR. Usually, this is done every day by taxi boat. This is more expensive than the approximate price of 1000 IDR per gallon for water from a fresh water well or the RO installation on Sundays (Dion DB Putra, 2016).

D.2.3 Need Assessment

This section will summarize whether there is a need for drinking water.

1.3.1 Manado

At the moment, there is no fresh water shortage in Manado City. But the tap water that is available is not drinkable. As mentioned before, this water is contaminated and most of the people rely on bottled water when it comes to drinking water. There is a need to have clean drinking water from the tap. However, the poor water quality of the tap water is mostly caused by the bad piping network. This problem must be tackled before clean drinking water can be delivered to the tap of the households that are connected. Beside this, there is a high need for expansion of the currently available water distribution network of PT AIR Manado. During a socio-economic survey, 88% of the respondents that do not have a connection to the tap water, says to have interest in a connection (Akhir, 2010) PT AIR Manado currently has the plan to expand this network and improve the water quality. A part of this plan is to build an entirely new treatment plant.

So currently, there is no need to produce drinking water from ROTEC or dehumidification. However, this can be a need in the future since the population is growing and deep wells around the coast that extract the groundwater can cause salt intrusion.

1.3.2 Bunaken

The Island of Bunaken is experiencing a fresh water scarcity. The groundwater that is present is characterised as brackish and therefore unsafe for drinking. Beside that the water is brackish the water level drops significantly in the dry season and the salinity increases due to the salt intrusion of the ocean water.

An even bigger problem is the drinking water demand. This demand is extreme since there is no drinking water available on Bunaken. All the demanded drinking water is transported from Manado. There is a high need for affordable fresh water on the island.

There are no catchment zones for rainwater, this causes water to run off into the ocean immediately. Desalination of the salty water is done without success. Due to lack of maintenance and unexperienced operation, already four reverse osmosis plants failed.

In 2017, islanders are still importing drinking water from the mainland or are making use of their own salty wells. It can be concluded that there is an extremely high need for drinking water solutions that can be maintained easily. The need for desalination is growing, since the rainwater catchment will not be sufficient and the ground water is brackish.

D.2.4 Stakeholders

It follows from the current status that there are many different stakeholders of influence on fresh water production. Some stakeholders and their perspectives are shortly described below. For a more specific explanation of the stakeholders, see Appendix N.

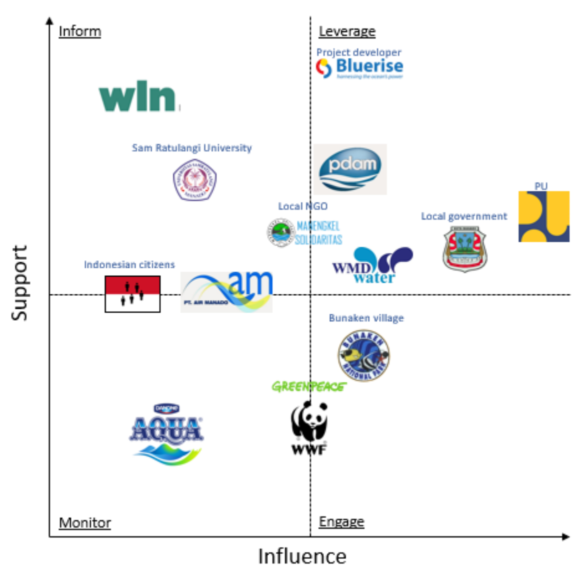


Figure 39: Stakeholder map water

Tap water companies

Tap water companies are mostly there to operate and maintain drinking water plants. Therefore their influence on new built projects is not very high. Nevertheless they can initiate new projects (Rakhmadi, 2017, Appendix O10) and are responsible for the piping network. They are looking for ways to connect more people to tap water and improve the water quality and are therefore, in general supporters. WMD and PDAM own PT Air Manado and are therefore the more influencing parties. WMD has a greater part of the shares and PDAM can be summand by the local government.

Government

The cities government can make the final decisions and has therefore a great influence. They are more supportive than government of Bunaken Village, that are rather careful concerning the coral reef and the past projects that did not work out.

Since the national coordinated PU proposes and budgets water facilities, they are of great influence. Since the government has as one of their main goals to make small islands like Bunaken more connected, and PU has built on the island before, it is likely to say that they also have great support for new initiated projects.

Bottled water companies

Bottled water companies (like Danone) are most likely to see new water production facilities as a threat for their business. They are not likely to invest in a new drinking water facility. Since their business model focusses on the cheapest source, due to the cheap transportation costs.

Appendix D3: Analysis of current and future status of cooling

In this part the cooling demand is explained. The current cooling need for Indonesia, and Manado specific, will be discussed. This assessment looks at the need for cooling in Manado specific but also takes into account the possibility of using SWAC/SDC. Lastly the current stakeholders for cooling in Manado are shown.

D.3.1 Need assessment

Cooling demand

Air conditioning of dwellings in developing countries is currently rather rare but increasing personal income is expected to change that. On top of that, the cooling demands in developing countries are greater than the heating demands, since most of these countries have warm to hot climates. For Manado, the total cooling degree days (CDD) (Investopedia, 2017) can be calculated by using (average) temperatures. This gives approximately 3100 CDD per year, making it a city that can be compared to cities like Jakarta and Ho Chi Min City. 1 CDD means that during the entire year, the air conditioning needed to cool 1°C for 1 day. Meaning that 3100 CDD per year means that you need to cool approximately 8.5°C per day (subtracting 18°C from the average daily temperature, and sum only positives values for a year). (Energy Policy, Elsevier 2008)

Cooling location

The city of Manado is built along the coast of Manado Bay, closed in by volcanoes (both active and passive ones) on the other side. Since the city of Manado keeps on growing, with an estimated average of 1.15% between 2010 and 2015 and 0.95% between 2015 and 2020, the city becomes more and more crowded, and eventually little to no place for buildings and houses will be left. Therefore, the last century, the city has been expanded into the ocean by building several land reclamations along almost the entire coastline. The largest area of these reclamations is covered by large shopping malls, hotels and shops. Especially the malls and hotels are cooled, to make sure customers and guests feel comfortable when shopping or staying overnight. The need for cooling at this location is enormous. The main road of the city: Jalan Piere Tendean (mainly known as the Boulevard), follows the former coastline and connects all the land reclamations. The easy connection and the location close to shore makes it an attractive area for a new, integrated way of cooling. In Figure 40 an overview is given of the location. In green planned projects are shown.

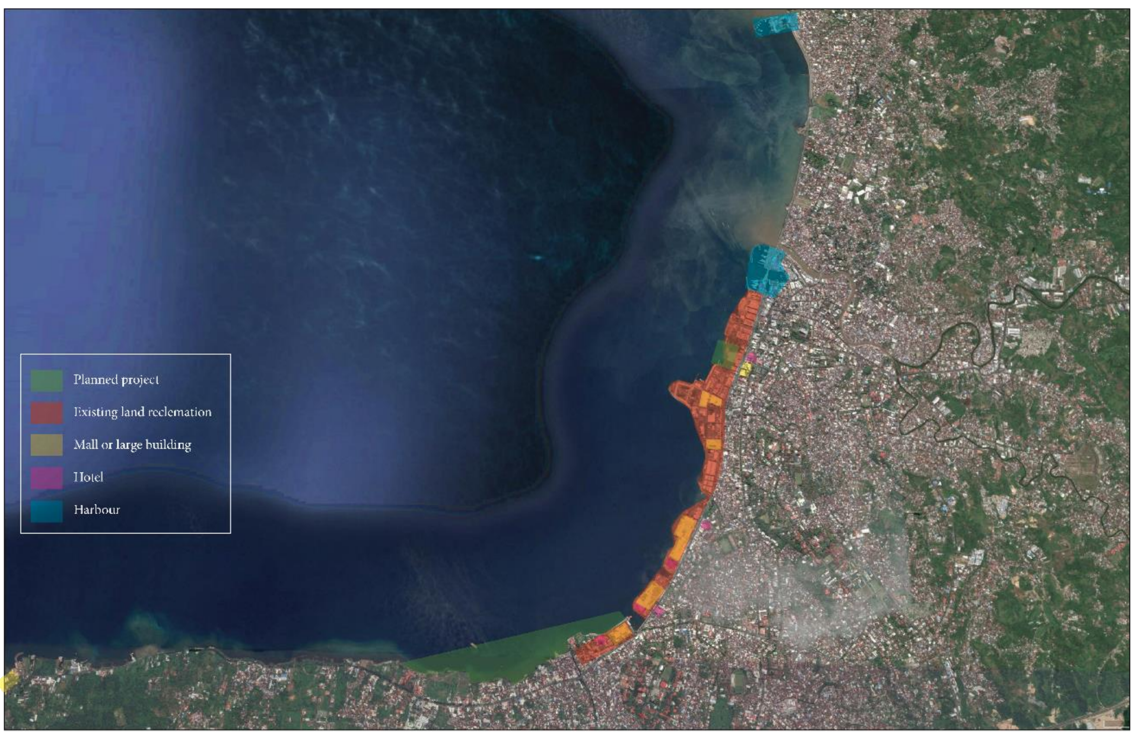


Figure 40: Overview of the locations of the land reclamations and large buildings.

Cooling load

Residential houses in Manado are often of small size and not cooled. Only the larger and more luxurious houses and houses that are rented to foreign visitors have air conditioning. However, these houses are not cooled using central cooling, but make use of separate devices (per room or house), meaning it is impossible to cool them using SWAC. For large buildings instead SWAC/SDC can be very attractive and it is interesting to make an estimation of the cooling load.

The cooling load is a quantity to express the cooling need of a building. This describes the heat that needs to be removed from a space to maintain a qualitatively good temperature and humidity, i.e. thermal comfort and indoor air quality. This cooling load is important for the determination of equipment for Heating, Ventilation and Air Conditioning (HVAC). The calculation of the cooling load depends on many aspects, for example: the number of heat sources in the building, the heat conduction through surfaces, the heat conduction through sunlit surfaces, the heat conduction through windows, heat generated by people, heat gain from lightning and infiltrating airflow. Mostly the cooling load can be expressed in BTU/hr (British Thermal Unit per hour) or RT (Refrigeration Ton). RT is based on the heat removed, that would be enough to melt 1 metric ton of ice in 24 hours. Both can be expressed in the SI unit J/s (Watt).

Since the calculation of the cooling load required for a building depends on a lot of factors, it is hard to make a direct estimate for the cooling load of a building. Nevertheless, there are rules of thumb available from existing HVAC-systems. To make an estimate for Manado's need of cooling. An estimate is made from existing data.

The total cooling need for hotels and malls build on this land reclamations is determined. Some of the values have been confirmed by lead engineers, some are determined based on the size of the building, the number of visitors or the amount of hotel rooms. An overview of the current cooling need is given for the largest hotels and malls along the boulevard of Manado and can be found in Table 5.

Cooling future

Malls and hotels

It is expected that with the growing economy the cooling load of existing malls and hotels will grow slightly. The expectations are based on the fact that the capacity hotels and malls are already designed for this future growth. Unknown buildings are compared with known expectations. The outcome only approximates the future total cooling demand. For individual parties the expectation can differ. The expectations for future peak loads can be found in Table 5.

Food and beverages

Besides the demand for the cooling of buildings, the demand for the cooling of food and beverages is increasing as well. With Indonesia being the second biggest fishing country in the world (after China) according to the Food and Agriculture Organization of the United Nations, storage and cooling facilities become more and more needed. In Manado, local fishers sell their fish on local markets immediately after they are caught. This is done mostly because of the lack of cooled storage room (in both Manado and Bunaken island). Neighbor city Bitung already has a large canning industry for fish and exports across the world. Having proper cooling will help the economic growth of Manado as more fish can be caught, stored, transported and eventually sold. On a nationwide level, most fish products (70 percent by weight) are still consumed fresh, while 30 percent are eaten as preserved or processed products. In general, even frozen fish from Europe and North America are sent to Asia (including Indonesia) for filleting and packaging and are then re-imported (FAO, 2014).

At the moment, this is no existing industry in Manado but has a potential to grow in size and is interesting to keep in mind to implement SWAC solutions in an early stage.

Planned Projects

In the future, new land reclamations are planned for Manado. With former land reclamations it can be seen that they are covered with large buildings with a high cooling demand, directly next to shore. In the south there is a land reclamation planned for the far future (indicated in green in Figure 40). A little more north close to the main harbor a new project called Monaco Bay is planned for the near future. Nine skyscrapers are planned, and a large cooling load is most probable. Estimations have been made for these future cooling needs, see Table 5.

Table 5: Current and future cooling peak loads and installed capacity in refrigerating tons [RT]

Malls	Used	Future	Installed
Mantos 1	1200	1200	-
Mantos 2	700	800	-
Mantos 3	1200	1800	2400
Megamall	1400	1800	1800
Mega Trade Center	800	1200	1800
IT Center	*1000*	*1200*	-
Star Square Mall	*500*	*2500*	-
Hotels			
Four Points Hotel	500	600	750
Lion Hotel	*500*	*600*	-
Best Western	*350*	*400*	*
Ibis	*500*	*600*	-
Aryaduta Hotel	*400*	*400*	
Manado Quality	*300*	*300*	-
Other			
Convention Center	*500*	*500*	-
Siloam Hospital	*500*	*500*	
New land reclamation		*2200*	
Fishing industry		*1500*	**

*uses no central cooling. **requires additional cooling. ⁻unknown.

Electrical prices

The electricity prices are quite low in Manado (see Appendix D), which is not very fortunate for a new, more sustainable cooling system. Since the old systems fully rely on electricity it keeps them attractive.

Conclusion

In Manado there is a large cooling request throughout the whole year and there are a lot of buildings with a high cooling load. These large buildings require central cooling and are next to the sea. Since the cooling load of some buildings is above 1000 tons it is attractive to cool them with SWAC (Makai Ocean Engineering, 2017). The fact that the buildings are close to each other and the cooling load density is high, District Cooling is an attractive option as well. However, the low electricity price is a downside.

It can be said that there is a need for cooling, but this is already fulfilled by conventional systems. But, with these characteristics it can be stated that there is a need for an alternative way of cooling in terms of cost effectiveness and sustainability.

D.3.2 Stakeholders

Different stakeholders are of influence when proposing a new cooling system. Some stakeholders and their perspectives are shortly described below. For a more specific description of the stakeholders, see Appendix N.

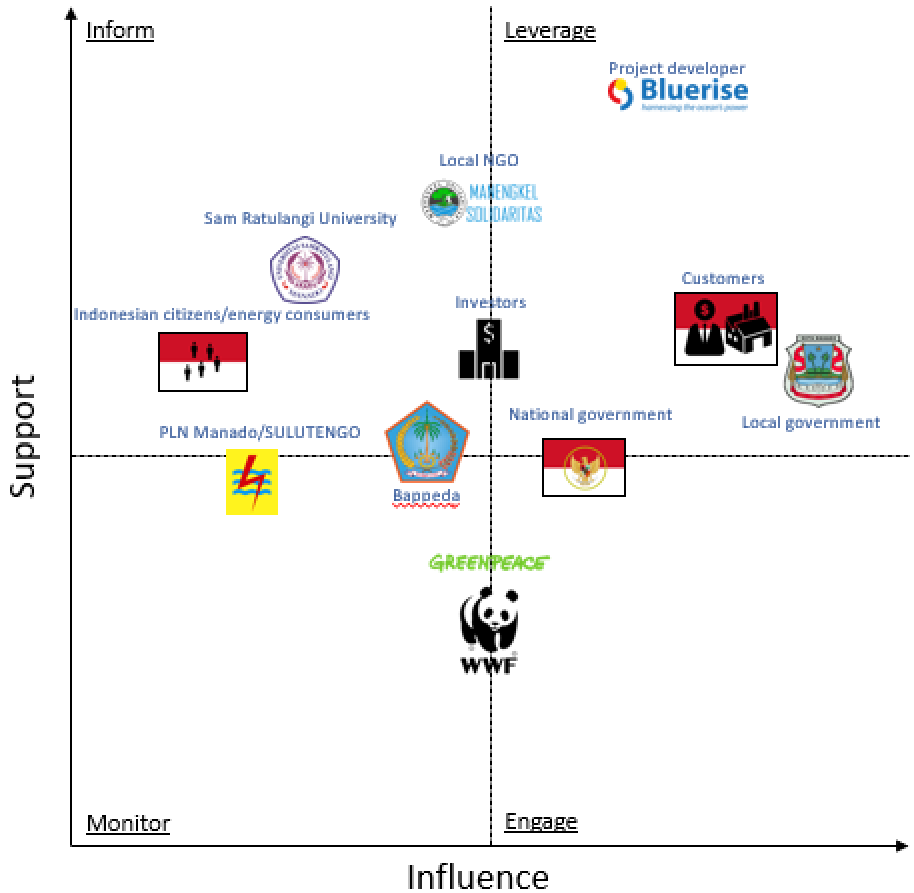


Figure 41: Stakeholder map cooling

Customers

They are one of the most important stakeholders, since they should all agree with a connection to a new cooling system. They are supportive because of the financial benefits for them and also have an influence.

Government

The government consists of different levels. The energy company PLN has not much influence but could be supportive because energy peak loads are reduced. They could also become less supportive, because their largest customers are decreasing in demand. Bappeda, the planning department of the government has less influence, because they do not take the decision. The National government, can make regulations for sustainable cooling and can become of great influence with this. The local government has the most influence and is supportive to make the city more sustainable and reduce the grid load.

Investors

Investors are supportive, since the cooling techniques like DC are well known and a proven concept with good results. Since a high investment is needed, they are also of influence on whether the project will happen.

NGO's

NGO's are most likely to respond positive to using less energy. But are also careful, due to environmental impact. Manado is close to a marine national park, and they could be skeptic about seawater solutions. Therefore their support depends on their perspective.

Appendix E: Manado basis of design

Appendix E1: Critical criteria

Before identifying an optimal design for SDC, critical criteria must be assessed. These can mostly be divided in technical and economic criteria that determine the best solution. Since the feasibility of a SDC-system depends mostly on the capital expenditure it is of great importance to know the most beneficial way of building and which boundary conditions are critical. These criteria determine for a large part the operational costs of a SDC system.

Free cooling

It is known that free cooling (i.e. cooling with a sea or lake as a source) is more beneficial than district cooling with conventional chillers. The bay of Manado has a steep slope and deep seawater of 7°C is accessible 2200 meters from shore at a depth of 550 meters. All this data can be found in Appendix M1

Storage

As most future techniques, one of the most important challenges is storage. To increase efficiency, most district cooling networks build in storage. Seasonal storage for cooling will not be be needed, since the outside temperature in Manado is nearly constant throughout the year. Night-to-day storage can be useful for overcapacity during night (Swedblom, 2014), when most malls are closed. This is not considered in this study, since the deep seawater is readily available and gives a storage of coldness in the deep ocean.

Electricity

At the moment, sufficient electricity is available for the North-Sulawesi grid. Short power blackouts occur weekly. The large cooled buildings are seen as one of the reasons for the power blackouts, and their cooling needs are rather high. The subsidised electricity costs for the malls and hotels falls mostly in class two: 0.11$/kWh, see Appendix D.1.3. The amount of electricity that is needed is determined by the required pumping power. The length, diameter and the velocity in the pipe determine the required pumping power. It can be said that the pumping uses much less energy than conventional ways of cooling. This means that high electricity prices are in favour of SDC. This is a good combination with the fact that the equipment has a longer lifetime than conventional air conditioning systems.

Water

The tap water in Manado delivered by PT. Air Manado is known as clean but is not always safe to drink. Most hotels make use of a deep water well, because they do not want to rely on the local water company. They also use this well for their centrally cooled fresh water loop. In the future the production of the tap water and the number of connections is expected to increase. The river discharges will be sufficient to provide the growth. The average price of tap water in Manado is 0.345$/m^3.

Area

The total area that will be connected to SDC determines the efficiency. In other words, the cooling load per area. The highest density will be the most beneficial in terms of investment in equipment. Nevertheless, the area must be sufficient large to gain large cooling loads. This trade off will determine the optimum district size.

Cooling load

Important is the need for cooling in a certain area. Therefore, a need assessment was performed for buildings along Manado Boulevard and on the new land reclamations (see Figure 42). The total demand for cooling was directly checked with the building's chief engineers or estimated by using the area of malls and number of rooms in hotels. The higher the need for cooling, the more beneficial a SDC system will be. The cooling load looks as follows.

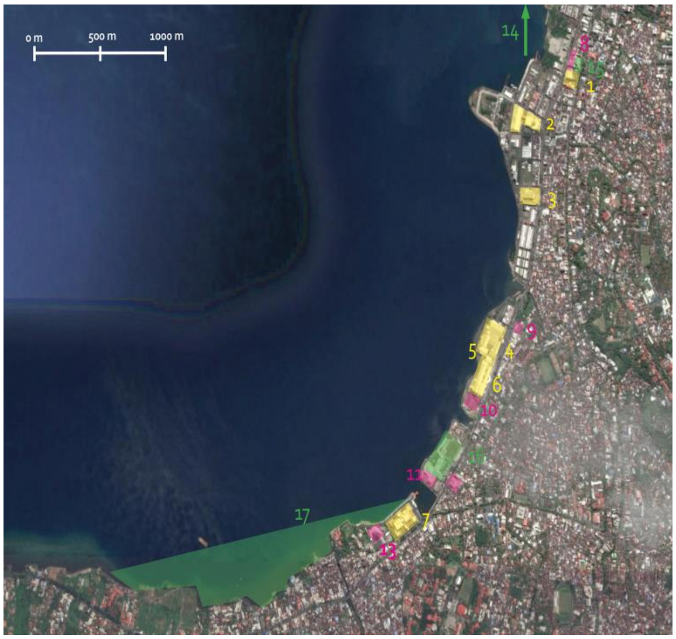


Figure 42 Cooled buildings and future land reclamation (names for the numbers can be found in

Table 6)

Expanding business

Building a future proof system is of great importance for the city of Manado. The city is planning on making more land reclamations along the coast. Most probably, new hotels and malls will be placed on these reclamations, meaning more cooling demand and thus a large future potential for the district cooling system. Therefore it would be best to already take into account future growth of the cooling capacity and district cooling system.

To do this, the SDC system has to be designed as if more cooling tonnages are required. This means the offshore pipelines need to have a larger diameter, the heat exchanger will grow in size and the onshore infrastructure will become bigger. Next to that there always needs to be designed for the peak cooling load, since this requirement should be met.

Appendix E2: Technical & Economic Feasibility

E.2.1 Offshore infrastructure

The bathymetry determines the distance to the appropriate depth to pump up the cold water. The offshore supply and discharge pipe form the offshore equipment.

Technical

The level of complexity of installing the offshore pipelines depends on several aspects. The steepness of the seabed is one of the most important parameter to take into account. Since SDC requires cold water, it is best to find this as close to shore as possible, such that the shortest pipeline possible can be used. The steeper the slope, the faster it becomes deep. However, the steeper the slope also means that installation of the pipe as well as maintaining the pipe in place becomes really challenging. For SDC, it is decided to use water having a temperature of approximately 7°C. As can be seen in Appendix M1, an approximate offshore distance of 2200 meters, meaning a slope of approximately 22 degrees. See Figure 43 for the bathymetry in front of the land reclamations of Manado.

Figure 43: Bathymetry in front of the land reclamations

Economic

Since the offshore equipment is one of the most important economic aspects of SDC, it is important to find the economic most attractive situation. Shorter pipes and smaller diameters induce lower installation costs. To optimize construction, operational and material costs must be minimized.

The length of the pipes is determined by the location of the onshore cooling facility, the distance at which the pipe reaches an appropriate depth, the route planning of the pipe and a possible bury depth of the pipe. In Manado Bay the slope is relatively steep, which is beneficial for the capital expenditure and operational costs (less pumping).

Large diameters are more expensive and are less resistant against buckling. Mostly stiffening is needed of large diameter pipes. In this case minimizing the pipe diameter also gives the pipe stiffness. On the other hand, smaller pipe diameters require relatively higher operational costs (pumping), due to pipe friction and in some cases a larger flow velocity is needed.

An attractive material for the construction of the pipes is HDPE. This material is expected to have a lifetime of 50 years, but it could last even much longer, since it is protected from radiation under the sea surface. This material was used in other deep-sea pipe installations, like Hawaii. The long lifetime beneficial to cover for the large capital expenditure.

E.2.2 Onshore infrastructure

Onshore infrastructure contains mainly of three parts; production, distribution and substations.

E.2.2.1 Production

Technical

The onshore production installation is where the cooling process takes place before the water is distributed towards the buildings via district cooling pipes. The production facility contains the heat exchangers that transfer the cold from the seawater to the fresh water distribution loop. This offers a renewable way of cooling. The pumps are also included to pump around the fresh water for distribution and pump up the deep seawater from Manado bay. It needs to be built on land at a location where the pipe landing is possible (close by) and there is sufficient space to build it. Next to that it must be possible to serve the customers easily with the cold water of the fresh water loop.

Economic

In the map shown below (Figure 44), three locations are marked, that currently have sufficient space to build a production facility. For the final design, a location should be chosen that lies on a good spot for both the offshore-onshore pipe connection and the connection to the district cooling network. Finding the optimal combination will be economically most attractive.

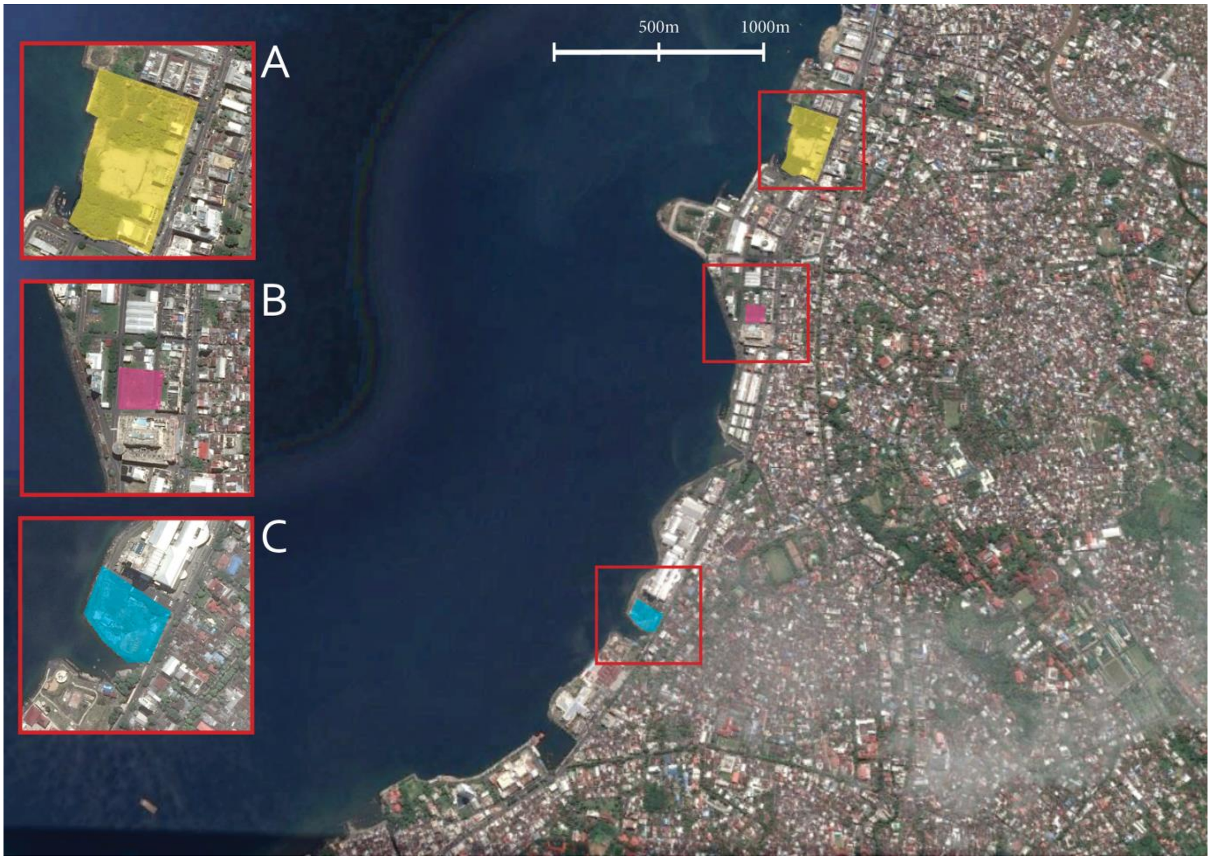


Figure 44 Possible locations for production facility

Storage

It is chosen to not build storage (see Appendix E1: Critical Criteria for more information) next to the production facility. Later on, in the design there will be looked at the total required deep-sea pipe diameter to meet with the peak cooling loads. To be able to extend the network later on, a storage facility can be built to cover higher peak loads by storing cold water during night.

E.2.2.2 Distribution

Technical

A distribution network needs to be built to provide the customers with sufficient cold fresh water from the production facility. This can be done by installing a fresh water loop that runs along the customers. The pipes can be buried as well as constructed in the air. The temperature drop of the cooled fresh water in the loop is negligible. The pipes need to be insulated to minimize thermal losses. Next to that humid air condensates on the colder surface of the pipe. Insulation averts corrosion of the pipe.

Pressure drops can occur in the pipe, but are not seen as challenging, and can easily be avoided by using booster pumps. Standard pipes that are available on the market with a diameter close to the requirements can be used.

Economic

The most expensive in the distribution network is the installation. Significantly more expensive than the material costs. Large pipes are more expensive than small pipes and large water volumes require more pumping power. Therefore it is more beneficial to implement the piping network in two single loops to the customers.

For district cooling, the most optimal situation would be to cool all big malls and hotels along the boulevard. This would mean the district piping system would have a length of approximately 3 kilometre (see map). As can be seen from Figure 45, all buildings lay approximately in one line. The pipeline can be placed along the Jalan Pierre Tendean, the main road of the city. In this way no buildings have to be avoided when placing the pipe.

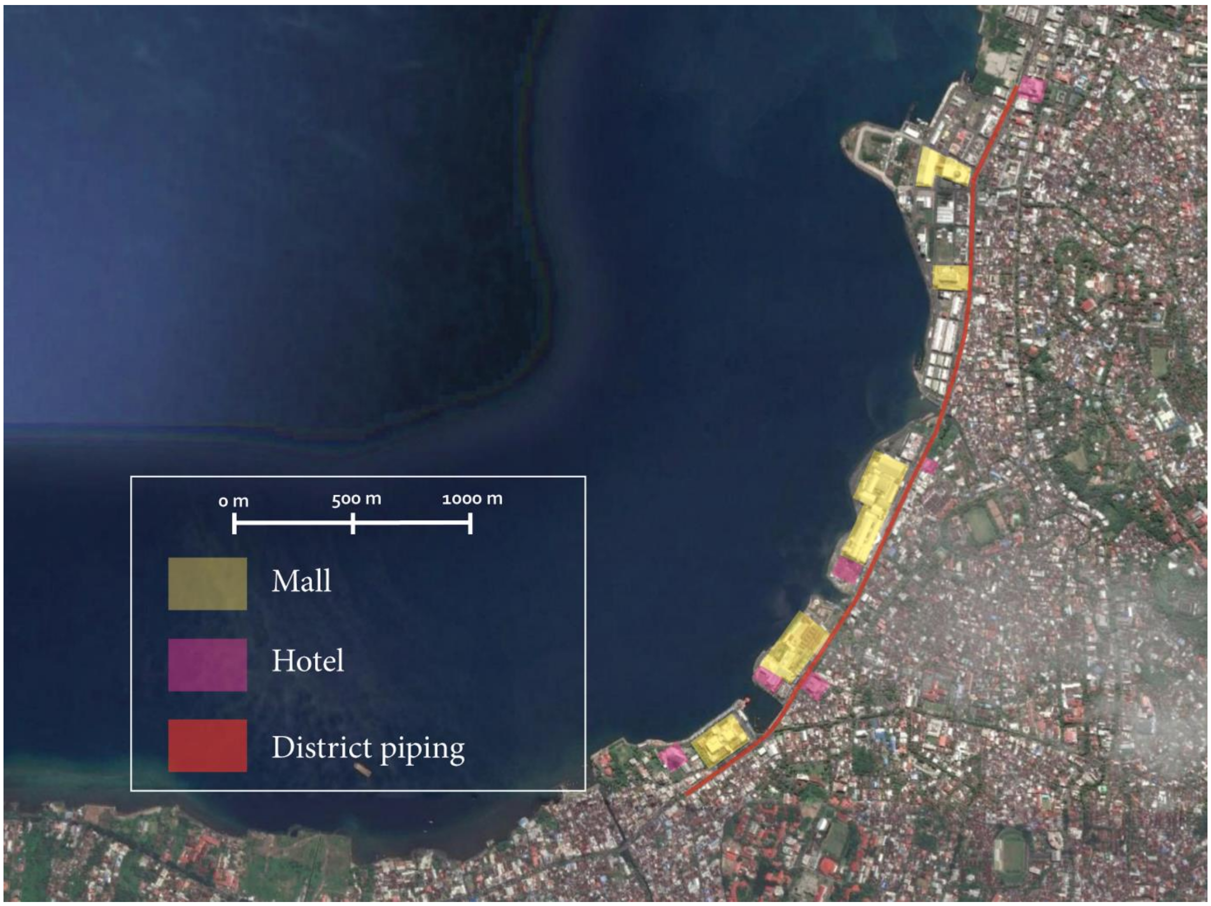


Figure 45: Overview of connecting pipe in district cooling

E.2.2.3 Substation

Technical

The users are connected to the fresh water loop via a substation. The substation consists of a heat exchanger that transfers the cold of the fresh water loop to the buildings own loop of central air conditioning. At this place can also be measured how much cooling the user uses. Most buildings at the Manado boulevard were built recently and make use of central cooling techniques.

The currently installed central cooling systems use an internal cold fresh water loop to cool their buildings. For most buildings, this water has an average temperature between 10°C and 12°C. As can be seen in Figure 46 Cooling water temperature Mega Trade Centre (MTC) below, the internal freshwater cooling loop of Mega Trade Centre should be 10 °C.

For that reason, the water temperature of the district cooling loop should be lower (around 8 °C, so that via heat exchangers the internal fresh water loops can be cooled.

Figure 46 Cooling water temperature Mega Trade Centre (MTC)

Per building, the cooling installation is located on a different place. For some, this means a pipeline should go to the roof, 10 to 15 meters high. Probably the biggest challenge with this would be the installation and location of the pipe. This should be designed in consultation with the building owner/engineer. Since the water that goes up has the same flow rate as the water that goes down, and the heights are similar, no extra pressure is needed to pump the water up to a certain height, see Figure 47.

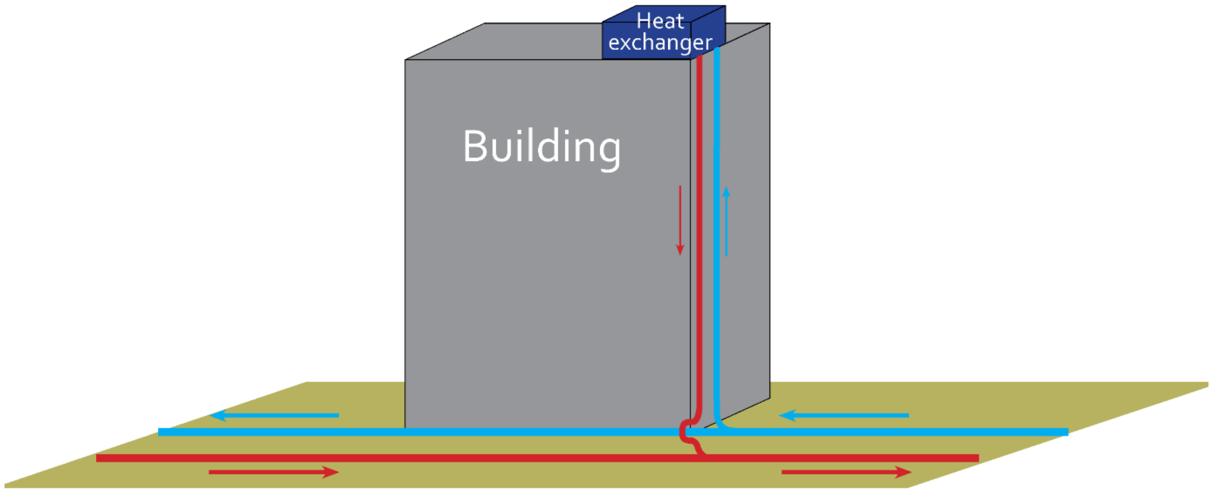


Figure 47: Distribution to certain height

Economic

Most of the intended buildings can be connected with their fresh water loop to a substation. Buildings that can be connected and do not have sufficient cooling at the moment are not really common in Manado. Since most are designed for a larger capacity, this is not seen as a challenge. It is more beneficial to later upgrade the building with larger area heat exchangers than building for a too large overcapacity.

E.2.3 Customer connection

The distribution network (as mentioned earlier) can be designed in several ways. However, it is key to design the district cooling pipeline trajectory to be as short as possible. In this way, large increase of the cooling water temperature and pumping costs are limited.

As can be seen in Figure 45, all large malls and hotels are located near shore, approximately all in one line. The most logical solution to connect all the customers to the system is by laying one large closed district cooling loop (single loop) near the main road and connect each building to this loop using so called 'branch loops'. In this way, one outgoing cooling flow and one return flow is needed. Figure 48 shows such a singe loop.

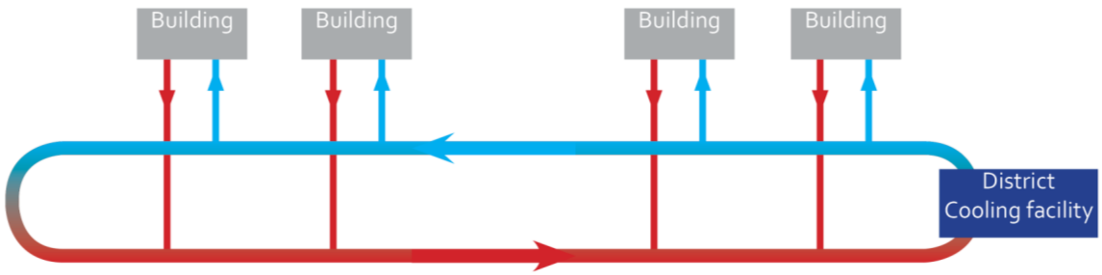


Figure 48 Single loop district cooling

However, it might also be possible to make multiple smaller loops (as shown in Figure 49) and connect several buildings to each loop. In this case, the cold water would have to travel a shorter distance, meaning a smaller temperature increase can be realized. On top of that, such a cooling system means that per loop less cooling water is needed. This makes it possible to use smaller dimension pipelines, making it economically more attractive. For the final concept, it will be determined whether it is cost and energy efficient to use such a system.

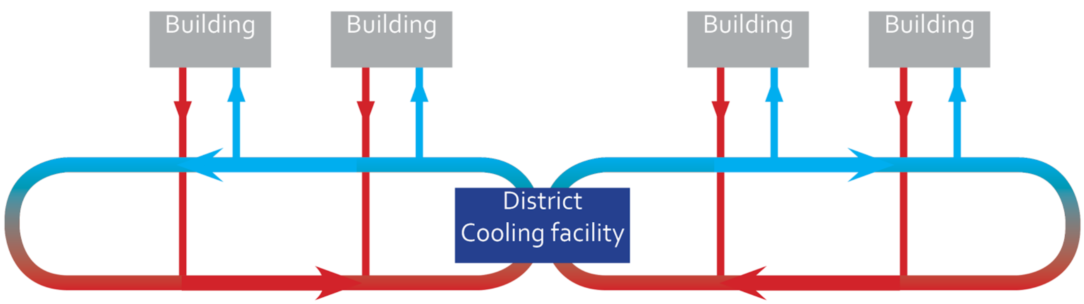


Figure 49 Duo loop district cooling

E.2.4 Conclusion

For both the offshore pipeline, the district pipeline and the connection of the buildings to the cooling system, no major challenges are found. Making a solid design would be enough to overcome these challenges, making district cooling highly feasible, seen from a technical perspective.

The economics of District Seawater Cooling depends mostly on the cooling demand in a certain area that can be connected to district cooling, the electricity- and water price at location. It is also of importance if it is mandatory for users to make a connection with the district cooling network. Otherwise every party needs to be convinced and individual contracts must be set up. Since the hotels and malls interesting for district cooling in Manado are already an established area, it is most common to make individual contracts with the owners.

The time of construction is of great importance on the cash flow and financing of the whole project. The most ideal situation is to have a narrow area with a few customers with high needs. This is the case along the Manado Boulevard, which is characterized for the large amount of hotels and malls, where the outside temperature is above 30°C most time of the year.

The economic feasibility can be made more attractive when taking a look at the synergy with other concepts, like reusing the water, gas or sewage pipelines, electricity- and drinking water production.

Appendix F: Manado masterplan

Appendix F1: Equipment and infrastructure design

F.1.1 Design cooling load

It is chosen to include the future cooling load of existing buildings only, that already use central cooling with a fresh water loop.

The determined location for the production facility in Appendix E.2.2 , indicates a northern and a southern loop. In Figure 50, the buildings for the Northern loop are shown in red and the buildings connected to the southern loop are shown in white.

Table 6 shows the future cooling peak loads per loop of all the connected buildings. The Northern loop will need a cooling load of 4600 ton and the Southern 8900 ton. The total peak load to design for will become 13.500 ton.

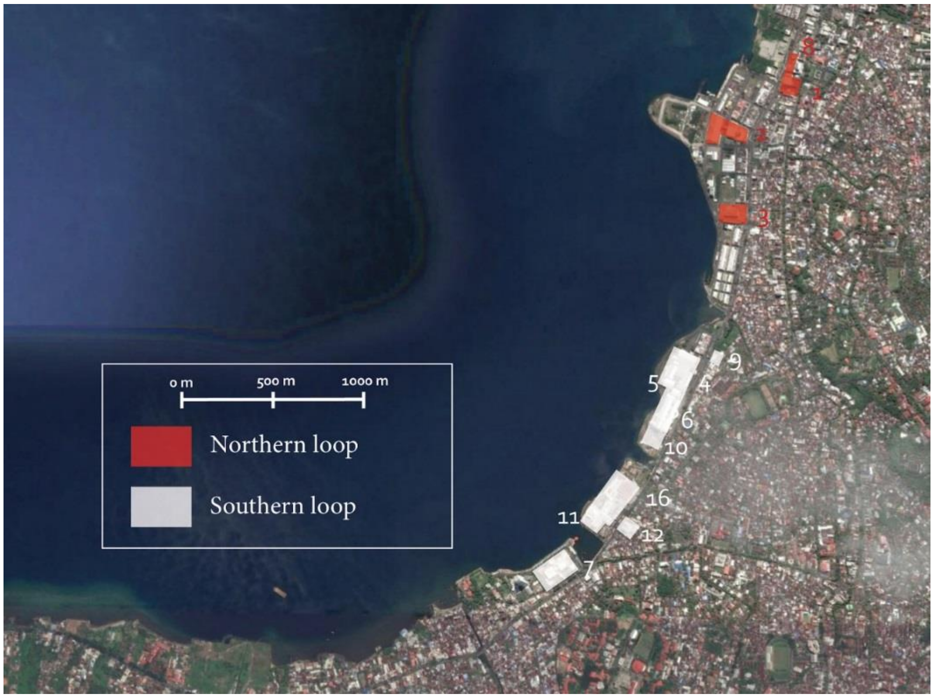


Figure 50: Location of proposed buildings for SDC

Table 6: Overview of proposed buildings for SDC and their future peak cooling load

Northern Loop			Southern Loop		
Number	**Name**	**Future cooling load (ton)**	**Number**	**Name**	**Future cooling load (ton)**
1	IT Center	1200	4	Mantos 1	1200
2	Megamall	1800	5	Mantos 2	800
3	Mega Trade Center	1200	6	Mantos 3	1800
8	Aryaduta Hotel	400	7	Star Square Mall	2500
Total:	**-**	**4600**	9	Ibis	600
			10	Four Points Hotel	600
			11	Lion Hotel	600
			12	Manado Quality Hotel	300
			16	Convention Center	500
			Total:	**-**	**8900**

F.1.2 Offshore equipment

The offshore pipeline will be connected to the onshore production facility. This pipeline will be of HDPE (high-density polyethylene). For existing projects and projects currently being built, this material is proven to be better than steel. HDPE is a lightweight material that is less expensive per meter per diameter than for example steel. On top of that, multiple methods for installing the pipe can be used, making it more attractive for such projects.

To get water with a temperature of 7°C, the pipe needs to reach a depth of 550 meters (See Appendix M1). This depth can be found approximately 2200 meters from shore. As can be seen from Figure 51, the seabed does not have a slope with a constant angle and the bathymetry changes a lot. To prevent the offshore pipeline from rolling down a (steep) slope, the pathway of the pipe is drawn perpendicular to the bathymetry lines. This will make the path towards 550 meters deep water longer instead of going in a straight line, but it decreases the risk of a moving/buckling pipeline. In total, the length of the offshore pipe will be 2800 meters. See Table 7 for the length determination, by following the pipe trajectory and the coordinates with origin at the position of the on shore pipe landing. A side view of the pipeline is given in Figure 51.

Table 7: calculation of pipe length with bathymetry and pipe trajectory

Depth [m]	0	25	50	100	200	300	500	550
x coordinate [m]	0	73	398	604	873	1367	2441	2488
y coordinate [m]	0	13	13	13	126	515	929	953
pipe length to origin [m]		76	402	613	922	1558	2727	2800

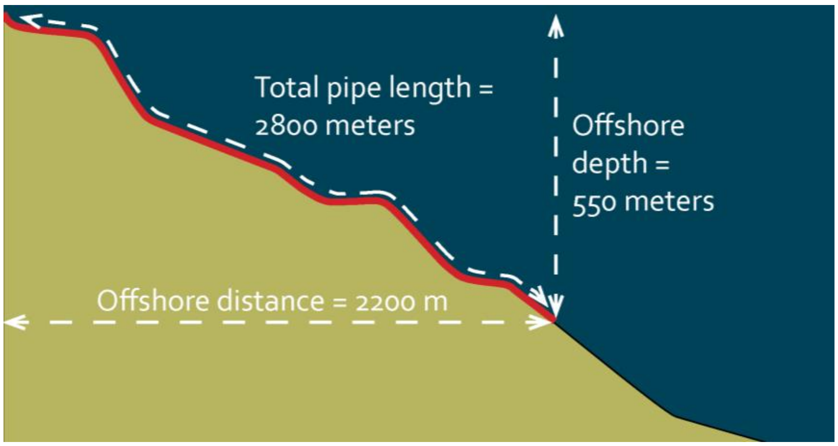


Figure 51: Overview of the pipe length on its trajectory

The warm water will be discharge at a depth at which the seawater has a similar temperature. From measurements, this water can be found at a depth of 180 meter, 500 meters from shore. This means the offshore pipeline will become approximately 530 meters long.

Diameter

For determining the offshore pipe diameters, the water velocity and the water flow rates are needed. To prevent fishes from being sucked into the pipe, a filter is used at the inlet. However, having a large inlet velocity would still mean that sea life cannot swim passed the inlet. Therefore a velocity of 1.5 m/s will be used.

To determine the flow rate for the offshore pipeline, the inlet and discharge temperatures are needed as well as the density, the specific heat capacity and the total cooling load in MWt. These 5 parameters are all known. As mentioned in the previous section, the inlet water temperature is 7°C and the discharge temperature is around 13°C (see Figure 53). The density of the cold seawater is around 1030 kg/m^3, which can be found in Appendix M1. The specific heat capacity of water with these characteristics is approximately 4186 J/(kgK). Lastly, the cooling load was determined to be 13.500 ton. With this, the flow rate for the offshore pipeline becomes approximately 1,84 m^3/s. Now having both velocity and flow rate, the internal diameter can be easily calculated, giving 1.25 meters. The exact calculations can be found in Appendix L: Pipe dimension calculations.

Pump power

Now that all dimensions and characteristics of the pipe are known, the pressure drops and pumping power can be calculated.

Pressure drop due to skin friction can be done with Darcy-Weisbach (The Engineering Toolbox, 2017):

$$\Delta p_{pipe} = f\rho_{seawater}\frac{L}{D}\frac{v^2}{2} \quad [Pa]$$

Where f is the Darcy friction factor that can be found when solving the Colebrook-White equation (Nuclear Power for Everybody, 2017):

$$\frac{1}{\sqrt{f}} = -2\log\left(\frac{\epsilon}{3.72D} + \frac{2.51}{Re\sqrt{f}}\right)$$

With: L=pipe length, D=diameter, v=flow velocity, ρ=density and ϵ=roughness. This brings the total pressure loss of the intake and discharge pipe to $\Delta p_{pipe} = 39.5\ kPa$. The pressure drop over the entrance can be calculated with the K-method (Native Dynamics, 2017):

$$\Delta p_{intake} = K\rho_{seawater}\frac{v^2}{2} \quad [Pa]$$

With K=0.5, this leads to a pressure drop of $\Delta p_{intake} = 0.6\ kPa$. On top of that it is accounted that the pressure drop over the heat exchanger is equal to 3 meters water column. Indicating another pressure rise of $\Delta P_{Heat\ exchanger} = 30kPa$. In total the pressure drop is:

$$\Delta p = \Delta p_{pipe} + \Delta p_{intake} + \Delta p_{Heat\ exchanger} = 70kPa$$

The required power for pumping is defined by:

$$P = \eta_{pump} q \Delta p \quad [W]$$

With q=volumetric flow rate and η=efficiency. This leads to a total required power of 0.15 MW for the offshore pipe.

Future possibility

The pipe diameter of 1.25 meters is exactly the size with which the current cooling demand can be fulfilled. However, to take the future growth and demand of Manado into account, it should be possible to increase the cooling load. To do this, in the future it would be possible to build an (underground) storage facility. In this way, during night cold water can be stored, since the demand for cooling at night is very low. During day, this cold water can be added to the system and thus increasing the cooling load.

Feasibility check

The required dimensions of the cold-water intake pipe are crucial for the technical feasibility. With a bigger pipe, more cold water can be pumped to shore. However, the bigger the pipe, the more challenging it is to install and manufacture. On top of that, the depth and the inclination of the seabed are important for the feasibility. Currently, high-density polyethylene (HDPE) pipes of over 3m diameter can already be manufactured (ISCO, 2017). Pipes made of composite or fiber could also be feasible options. However, the limiting factor is the installation. The biggest HDPE pipe that is currently installed by the offshore industry is in Hawaii, which is 1.4m in diameter (Makai, 2017). The slope in Manado bay is not seen as a big challenge for the installation of the HDPE pipeline, since the slope is mostly gradual. Therefore, the cold-water pipe, including the pumps, can be considered as proven technology since the pipe used for this project has a maximum diameter of 1.25 meters.

F.1.3 Onshore Equipment

For Manado, it is found that the total cooling peak load necessary is 13500 tons, divided into two districts; a northern and a southern district. For the Northern district, a cooling load of 4600 ton is needed and for the Southern district, a cooling load of 8900 ton is needed. With this cooling load, the SDC system is designed to be future proof, such that hotels and malls have the option to grow and increase their cooling load. A list of future cooling loads is provided in Appendix F1.1: Design cooling load.

Production

To begin, the location for the onshore production facility is discussed. This location is the most important one, since both the onshore and offshore piping systems will be connected at that location. A MCA showed location B as the most suitable. This site is located in between all malls and hotels, so that multiple district cooling loops can be used (see Figure 50). On top of that, location B is (together with A) located closest to the 550 meter deep water, such that with this location the offshore pipeline will be the shortest. In Figure 52, the location of the installation area (in green) and its dimensions can be found.

Figure 52: Location of cooling production facility

To achieve the required cooling load, cold sea water of approximately 7°C is pumped up from the sea. The cold seawater enters the heat exchanger. The cold sea water takes heat from a ‘relatively warm’ fresh water return flow, that was used to cool buildings. In that way, the freshwater cools down to approximately 8°C whereas the seawater becomes warmer and reaches a temperature near 13°C. See visualization below.

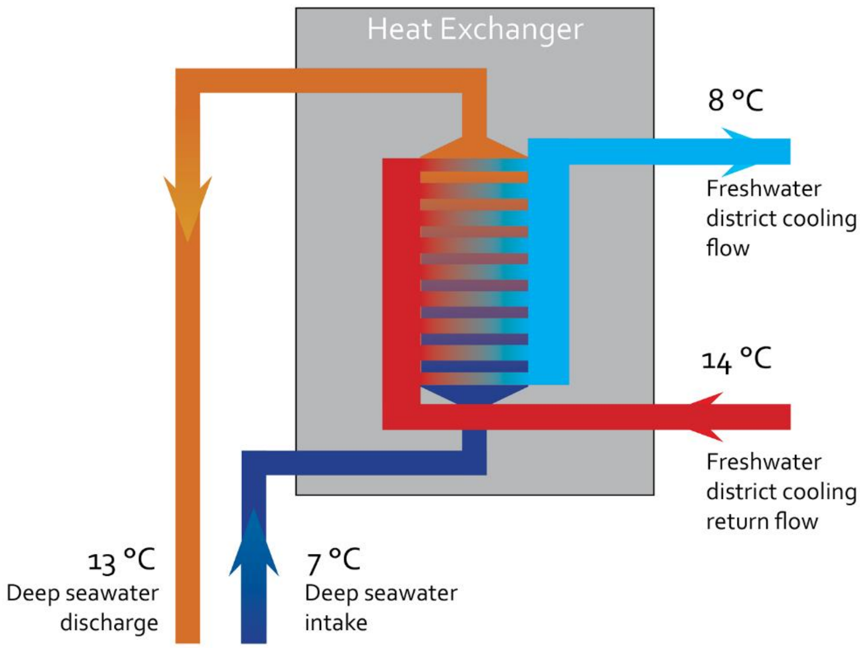


Figure 53:Water flows in production facility

The 'warmer' seawater (indicated in orange) is discharged back into the ocean at a depth at which the sea has the same temperature. However, besides discharging the warmer seawater directly back into the ocean, it can be first used for more multiple other purposes. For instance, the seawater can first be used to cool the ground. In this way, the ground becomes colder and will attract more moisture (air condensates then near ground), making it more fertile. Other purposes might be to use the water for industrial cooling or marine technologies. Using it before discharging will increase the seawaters flow temperature even more, meaning that is can be discharged at an even shallower depth, and shorter discharge pipes are needed. For this final concept, such purposes are not investigated in more detail, but it might be worthwhile further investigating this for implementing it in the future.

Heat exchanger

The peak load 13.500 tons can be transformed to exchanged heat in watt: 1 refrigerating ton = 3.517 kW (The Engineering Toolbox, 2017). This brings the peak exchanged heat to 47.5 MW. This can directly be transferred to the exchange area (Alfa Laval, 2017):

$$A = \frac{Q}{U * LMTD} \quad [m^2]$$

With Q being the exchanged heat in watts, U the transfer coefficient in watt/kelvin/m^2 and LMTD the logarithmic mean temperature difference. This brings the total required heat exchanger area to 6600 m^2.

Since plate heat exchangers can be compacted, the total required volume of heat exchangers for this installation is around 26m^3. However, with this required volume, it can be concluded that the production facility does not need to be of very large size, and just a small part of the location area described above has to be used.

Other equipment

It is known that the total amount of power required for both the onshore and offshore equipment lies around 0.35MW, see Table 8**.** Since Manado's electricity network is not stable, and power blackouts happen at least once a week, back up diesel generators are necessary. Therefore, the production facility will house generators of similar power size.

Next to that it is also wise to include chillers in the building. In case of downtime of the seawater cooling the customer still needs cooling. A chiller system is then necessary as a backup to cool the fresh water loop.

Distribution

The distribution starts at the production facility. Using multiple cooling loops that go to different directions is economically more attractive (see Appendix E.2.3).

The district cooling network will be connected to the onshore production facility, and will provide the buildings with cold fresh water for their central cooling system.

Figure 54:Overview of connection of distribution network to production facility

As can be seen from Figure 54, two separate cooling loops will be used; one going in northern direction and one going south (the dimensions of the pipelines in this picture are out of proportion). The blue line represents the cold water supply pipe, the red line represents the 'warm' water return pipe. In total, the two loops have a length of 7000 meters. For the northern loop, the cooling pipe and return pipe each have a length of 900 meters, so 1800 in total. For the southern loop, both the cooling pipe and the return pipe have a length of 2600 meters, so 5200 meters in total.

From Figure 53, it can be seen that the cold freshwater supply from the production facility has a temperature of 8°C. The return flow has a temperature of 13°C. In Appendix L: Pipeline dimension calculations, the calculations for determining the pipe dimensions for both the Northern and Southern loop can be found. For the Northern loop, the diameter of the district pipeline will be 0.74 meters. For the Southern loop, the diameter will become 1.03m.

Pump power

For determining the pressure drops and pump power, only the pipe and the heat exchangers are take into account. This is calculated in the same way as, presented in F.1.2 Offshore equipment. Most of these losses occur due the length of the pipelines, creating large friction, see Table 8. Knowing this pressure drop, a total pumping power of 0.19 MW is needed for the distribution of the district cooling system.

Table 8: Pressure losses in pipes and required power for pumping

	Length	Diameter	q	Δp_{pipe}	Δp_{inlet}	$\Delta p_{H.e.}$	P
	[m]	[m]	[m^3/s]	[kPa]	[kPa]	[kPa]	[MW]
Offshore (intake & discharge)	3331	1.25	1.84	39.5	0.6	30	0.15
North loop	1800	0.74	0.64	33.8	-	30	0.05
South loop	5200	1.03	1.25	66.3	-	30	0.14

Temperature drop

Since all buildings to be cooled are located near the main road on the boulevard, the pipe will be installed along this road. Since above ground, the impact of the outside temperature is larger on the pipelines, and thicker insulation layers are necessary to prevent the cold water from heating up too much, the district cooling system will be buried underneath the road or sidewalk. In this way, it is also prevented that houses need to be demolished because of the pipeline. Next to that it is of higher aesthetic value when it is beneath the ground. To do a rough check on the thermal losses the temperature drop can be determined.

First the conductive heat loss can be calculated in the following manner (The Engineering Toolbox, 2017):

$$Q_{heat} = \frac{T_{outer} - T_{inner}}{2\pi \mathrm{kL} * \ln\left(\frac{r_{outer}}{r_{inner}}\right)}$$

With Q_{heat}=heat transfer [W], T=temperature [°C], k=thermal conductivity of insulation [W/mK], L= length of pipe [m] and r=radius of insulation [m].

The energy lost in the time that water flows from one end of the pipe to the other is then expressed as:

$$E_{loss} = \frac{Q_{heat} L}{v} \quad [J]$$

The mass of the water in the pipe can be expressed as:

$$m_{in\ pipe} = \frac{L}{v} q \rho_{freshwater} \quad [kg]$$

The energy loss per mass:

$$E_{loss\ per\ kg} = \frac{E_{loss}}{m_{in\ pipe}} \quad [J/kg]$$

The temperature drop in the pipe can then be calculated with the specific heat capacity of water:

$$\Delta T = \frac{E_{los\ per\ kg}}{c} \quad [K\ or\ °C]$$

With c=specific heat capacity of water in J/(kg.K). Implementing these formulas leads for the cold water supply pipes to the results presented in Table 9.

Table 9: heat losses in cold water supply flow.

	length	Q_{heat}	$m_{in\ pipe}$	E_{loss}	$E_{loss\ per\ kg}$	ΔT
	[m]	[kW]	[ton]	[MJ]	[J/kg]	[°C]
North	900	20.6	384	12.4	32.3	0.008
South	2600	80.5	2160	139.4	64.6	0.015

$T_{outer} = 32°C, T_{inner} = 8°C, K = 0.0274\ \mathrm{W/mK}, insulation\ thickness = 7.5cm$

The temperature drop for the cold water supply pipe will be the largest and most critical since the cooling customers need to be served well. Additional thermal losses can happen in joints of the pipe but this is much less in magnitude than the temperature drop presented in Table 9. When the supply and return pipe will be buried together, the outer surface that is in contact with the outside temperature becomes smaller and the temperature drop can be minimized more. It can be concluded that a temperature drop of around 0.01°C is negligible and sufficient cold water can be supplied.

Substation

The cool fresh water flow of 8°C from the production facility (see Figure 55) is used to cool the buildings and enter a building at the substation. Most buildings in Manado currently use an internal fresh water loop that uses water with a temperature of around 10°C. Using even colder water would mean that cooling becomes easier, and less water has to be used to acquire the same inside temperature of the building to be cooled.

Figure 55 below shows the setting of a substation and a heat exchanger with a 10°C internal fresh water temperature. The substation will take in the place of the chiller units and the cooling towers in every building. Via the heat exchanger in the substation there will be some thermal losses, but the building's internal fresh water loop will still be sufficiently cold.

The heat exchangers size will depend on the buildings' cooling demand, but will be relatively small in size compared to the size presented in section F.1.3 and is not seen as a technical challenge.

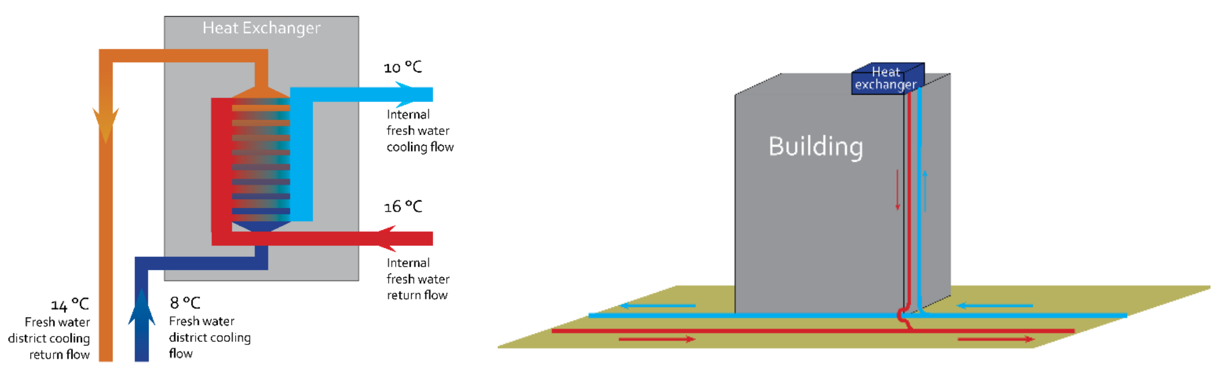


Figure 55: Heat exchanger in substation

Appendix F2: SDC Costs

The economics of District Seawater Cooling depends mostly on the cooling demand in a certain area that can be connected to district cooling and the electricity price at location.

It is also of importance whether it is mandatory for users to make a connection with the district cooling network. Otherwise every party needs to be convinced and individual contracts must be set up. Since the hotels and malls interesting for district cooling in Manado are already an established area, it is most common to make individual contracts with the owners. The time of construction is of great importance on the cash flow and financing of the whole project.

F.2.1 CAPEX

The total investment costs, or Capital Expenditures (CAPEX) for an installation described above can be determined. To do so, the installation will be again divided into three parts: the onshore cooling facility, the offshore pipelines and the onshore district cooling network. See Table 10 for the CAPEX of different parts.

- The onshore facility houses the heat exchangers, pumps for both the offshore and onshore network and monitoring systems.
- For the offshore pipelines (both cold water inlet and warm water discharge pipe), several costs are of importance. To begin, the manufacturing costs of the pipeline itself. Secondly, the installation costs for the offshore pipeline. And thirdly, the costs of offshore surveys that need to be done before installing the pipeline.
- For the district cooling, onshore pipelines, monitoring systems and pumps need to be installed.
- Besides having material, the entire installation has to be designed by engineers and constructed.

Table 10: CAPEX SDC system

	Million US$
Offshore equipment and installation	11.23
Production facility	2.23
Distribution	10.12
Engineering & Procurement	2.36
Total	**25.93**

F.2.2 OPEX

Operation expenditures include project management, yearly maintenance and electricity costs (mostly for the pumps). To be able to overcome the pressure drops a total of 0.35MW power is needed for the peak cooling load (see Table 8). This means that per year, a maximum of approximately 3090 MWh is used. It is assumed that the average cooling load is 65% of the peak cooling load. Using the local electricity price for companies, malls and hotels, which currently lies around 110$/MWh, the total electricity costs can be determined, and will be $0.22 million per year. See Table 11 for the total OPEX.

Table 11: OPEX SDC system

	Thousand US$
Project Management	170
Electricity	220
Maintenance	70
Total	**450**

Appendix F3: Investor financing cases

With this option a fee is asked from the users of the SDC system. The investor builds and operates the plant and gains a monthly income from the customers. Important is that the monthly fee for the customers is cheaper and more interesting than their current conventional way of cooling. As a way of income there can be thought of different ways of charging customers. This can be done in the form of fees based on connection, capacity and supply usage.

Connection and Capacity fee

A connection fee is an initial fee for customers to connect them to the SDC network. This is to finance the substation and installation. In this way they contribute to the initial investment. The capacity fee is based on the cooling load capacity that is installed at the customer. The supply usage or energy fee is based on the actual supply. Energy companies mostly use a combination where the connection fee and capacity fee are high, instead of an energy fee. The same is the case in Indonesia, where mostly the energy price is based on connected capacity. The same concept is applied for district cooling. Therefore only the connection and capacity fee are taken into account.

In Table 12 below different cases are presented. An estimate is made for the connection fee (initial investment) customers pay. This is displayed for 50%, 30% and 0% of the investment. The rest is paid by the investor. It is chosen that the capacity fee is respectively 50%, 60% and 90% of the revenue that one would make compared to the current cooling costs of their air conditioning system. Case 1 shows the previously described case where the customers would pay 100% of the investment.

This indicates that the investor pays (partially or fully) the investment to build the installation and operates it. The customers have cheaper cooling, that is constant, do not have to think of maintenance and are more sustainable. An overview of the possibilities is given in Table 12.

The connection fee is given relative to the initial investment (CAPEX). The capacity fee is given relative to the yearly savings on operational costs (5.6 million $) compared to conventional cooling.

Table 12: Economic results for different financing possibilities. Results for customer (C) and investor (I).

case	Connection fee [%]	Capacity fee [%]	**Payback time [years]**		**IRR [%]**		**NPV [million $]**	
			C	I	C	I	C	I
1	100 (CAPEX)	0	9	-	19	-	35.4	-
2	50	50	9	9	19	19	17.7	17.7
3	30	60	7	10	24	16	16.5	18.8
4	0	90	-	10	-	17	5.9	29.4

For an overview of the cash flows for the different cases, see Figure 56. It can be concluded that it is more beneficial for customers to invest more in the beginning of the project to ensure most gain after the lifetime. Surely when the payback time is relatively short.
For investors it is also the most interesting to invest more in the beginning. It ensures a larger NPV in the end. Nevertheless the risk is higher, since the IRR goes down. Most wisely a decision is made that lies somewhat in-between to share the risk and benefits.

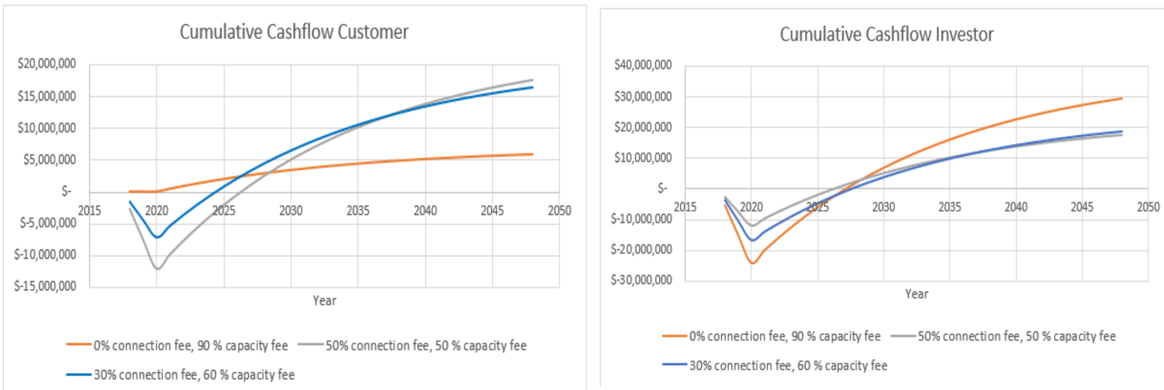


Figure 56: Cashflow for customer and investor for different financing cases

The yearly savings are 5.6 million dollars compared to conventional cooling for all the customers. Meaning that the investor has, for case 2, 3 and 4, a yearly revenue of respectively \$2.8, \$3.4 and \$5.0 million. This indicates an annual capacity fee of 20.700\$, 24,800\$ and 37.200\$ per 100 tons cooling load for the customers. For easy calculations for different customers (malls and hotels) Table 13 can be applied.

Table 13: Lookup table for the connection and capacity fee for customers per case

case	Connection fee [1000$/100 tons]	Capacity fee [1000$/100 tons]
1	192.1 (CAPEX)	3.3 (OPEX)
2	96.0	20.7
3	57.6	24.8
4	0	37.3

Appendix F4: Sensitivity

A sensitivity analysis can point out which parts of the project are most critical. Which parts can induce a critical uncertainty and should be paid extra attention to. It also unveils opportunities of which parts can become more attractive. In Table 14 several financial aspects are varied. The average cooling load can become lower in a worse case but has good potential to grow, when thinking of storage and future projects in Manado. Next to that a lot of the air conditioning is used for a large part during the day, all year around. The electricity prices in Indonesia are most likely to grow (Christensen, 2016). The current production costs of electricity in Manado are 170 $/MWh (Asrofi, 2016), but the subsidized price is 110 $/MWh. The impact of the variation of the financial aspects on the NPV is shown in the Tornado chart in Figure 57.

Table 14: variation in sensitive parts of the project's financial aspects

Average cooling load	60-80%
Maintenance & Management	30% deviation
Distribution network (CAPEX)	25% deviation
Offshore pipe (fabrication and deployment)	30% deviation
Interest rate	4-9%
Electricity price	100-170 $/MWh

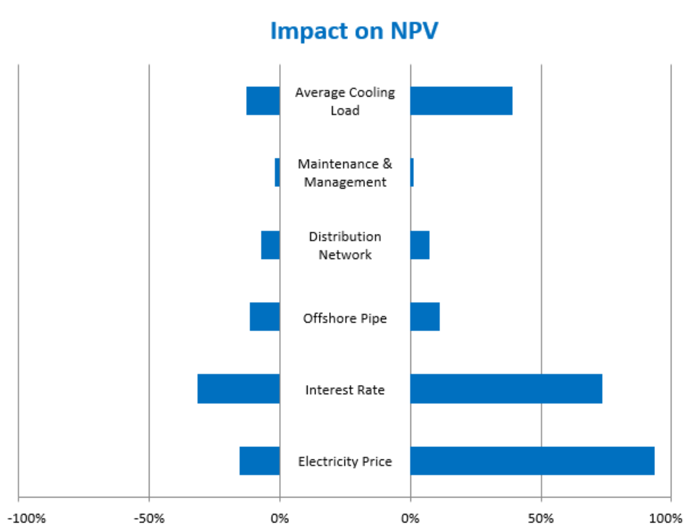


Figure 57: Tornado chart, showing the sensitivity of several aspects of the project.

Levelized costs of expenditure

The levelized costs of expenditure of CCS and SDC can be compared. The total made costs, divided over the lifetime. This is done for varying electricity prices and average sold cooling load, since they have a great influence on the NPV, as seen in Figure 57. The result in Figure 58 shows that the LCOE of SDC is in all cases lower than that of CCS. The LCOE of CCS only includes the operational costs of it, since the installation is already there. The LCOE of CCS consists of the CAPEX and OPEX.

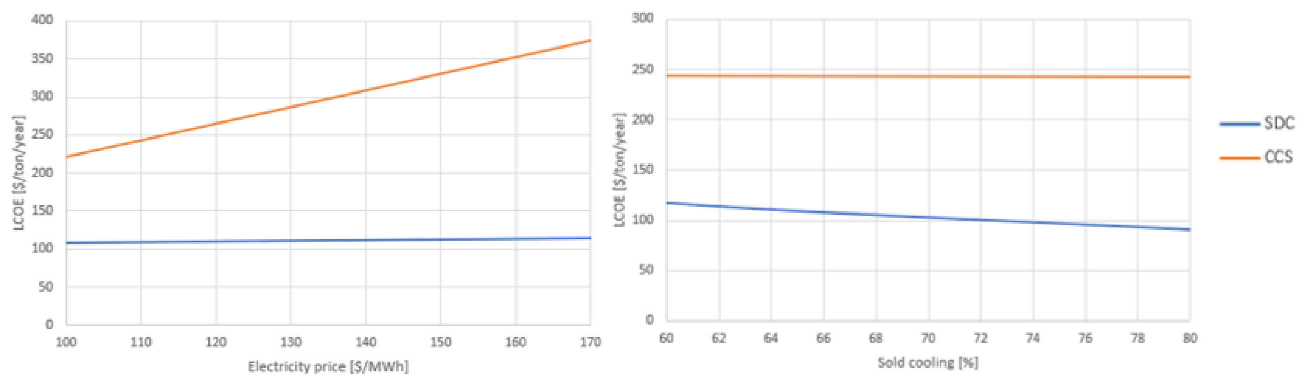


Figure 58: LCOE of CCS vs. SDC with varying electricity price and sold average cooling percentage of installed peak load

Electricity price

The electricity price of large influence on the projects economics. As a comparison the cumulative cash flows are given in Figure 59 for three different possible future electricity prices. It can be seen that it has a great impact on the NPV and payback time.

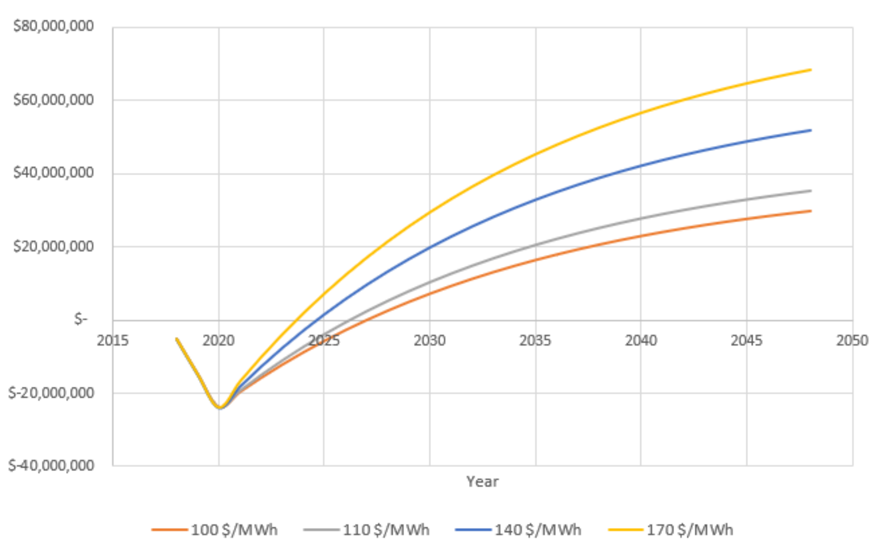


Figure 59: Cumulative cash flow for varying electricity prices

Appendix F5: Benefits

Next to benefits on a financial basis between conventional and district cooling for the boulevard of Manado, there are more benefits of making use of district cooling, these can be divided into the environment, security, economics, infrastructure and building value.

Environment

A huge benefit is reached by using less energy. This is done by energy reduction and less over production. SDC for Manado uses 0.23MW instead of 6.18MW (on average cooling load of 65%) for conventional cooling this indicates a reduction of about 96.3% of electricity consumption can be reached. The savings are displayed in Table 15. As a reference 1 crude barrel of oil, tons CO2 equivalent emissions and the number of cars that produce the same emissions are displayed. The following characteristics are used: 1 bbl = 537kWh (State of Hawaii, 2002), 1bbl = 159 l, 1kWh = 0.36 kg CO2eq and 13.300 car km = 3115 kg CO2eq/year (Milieu Centraal, 2017).

Table 15: savings compared to conventional cooling system

	MWh	bbl of crude oil	Ton CO2 equivalent	Number of cars
Per year	52,000	97,000	19,000	6000
Entire lifetime	1,408,000	2,622,000	501,000	6000
Per 100 R-ton per year	590	1,100	210	68

This is a significant gain looking on environmental aspects. On top of that there are no refrigerants needed for cooling, inducing no leakage of refrigerants which leads to even less emissions. The refrigerants mostly leak at decentralized cooling systems and are harmful for the environment. Centralized cooling gives also the opportunity to invest in more sustainable equipment, instead of that the customers use all their own cooling equipment.

These environmental benefits meet the promised ideas of the Indonesian government at the Paris Agreement to reduce their CO2 emissions with 29% by 2030 (IPS, 2015).

Security

SDC ensures constant cooling with a high reliability. There is less maintenance needed than for conventional cooling systems. The down-time is much lower and is expected to be one day a year in total.

Economics

As shown in Appendix F3: Investor financing cases, SDC has much lower operational costs. Also the risk can be minimized for the customers, by asking a fixed capacity fee from the customer. In this way the customers have a constant price for the total lifetime and can do more easy planning of their future plans. As at most places, in Manado customers do not have a clear idea of how much they spend on cooling. By using SDC they have a clearer overview of their cost expenses.

Infrastructure

As Manado has power black outs every now and then, some say caused by the big power demand of hotels and customers, the electricity grid is overloaded. By using SDC this can be overcome and less electricity is required. When looking at efficiency, SDC will use less energy when there is a peak demand. This means that real peaks in the cities electricity grid can be reduced. The electricity reduction is equal to 17,500 households in Manado (usage of 3000 kWh/household per year in Manado).

Also less water and leakage will occur. This means that the mostly private wells of the customers will deteriorate less fast and seawater intrusion and inclination of the soil can be prevented .

Building value

SDC has influence on the building of a customer. By using a substation instead of a chiller and cooling tower. It not only improves the esthetical value of the building but also reduces the noise and the use of chemicals (refrigerants) close to the building. On top of that it is easy to adjust the cooling load required in the building when expanding. The number/area of heat exchangers can easily be in- or decreased. For conventional cooling, this would mean installing new extra chiller units. Next to the adjustability, a SDC connection saves space in the building. All these factors increase the building value of a building that is connected to SDC.

Appendix G: Bunaken basis of design

From the previous chapters/appendices, it is evident that there is a need for drinking water and electricity on the Bunaken. This appendix summarizes the options and considerations for the final design.

The potential location has to meet five important requirements;

1) Accessibility of cold deep sea water
2) Minimal harm to the environment
3) Close to the grid
4) Close to the drinking water distribution network
5) Need for drinking water and energy

The accessibility of deep sea water is shown in Figure 60. The only potential location to reach deep seawater close to shore is South of the island (the bay). As mentioned in the environmental conditions (sections 2.3 and 2.5), Bunaken is surrounded by a wall, but at certain places the bathymetry is more gradual. A typical configuration of the wall is given in Figure 61. Maps do not clearly indicate this, therefore locals and a researcher in this area were interviewed. They could point out the location with a more gradual slope and little coral. According to Frets Pieters (see appendix O12), the current is weakest in the bay of Bunaken island. It is concluded that the bay of Bunaken island is potentially the best location for implementation.

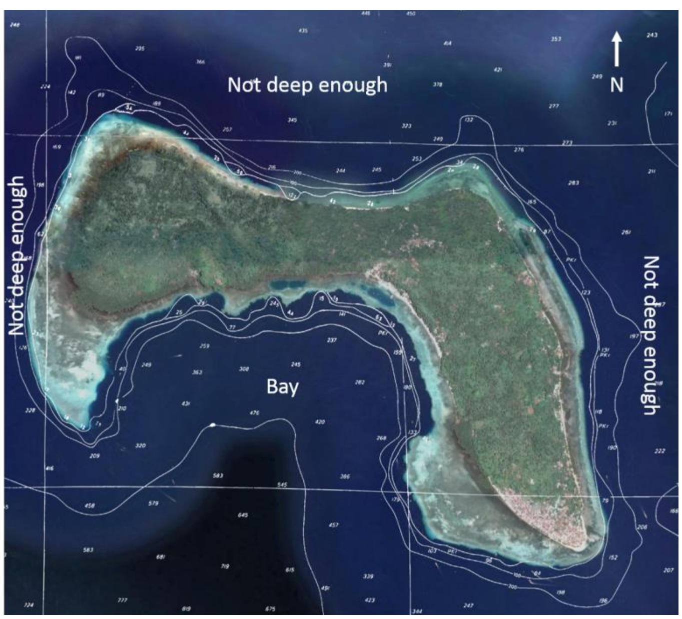


Figure 60: Bathymetry map Bunaken Island (Hidro Oceanografi, see appendix M4)

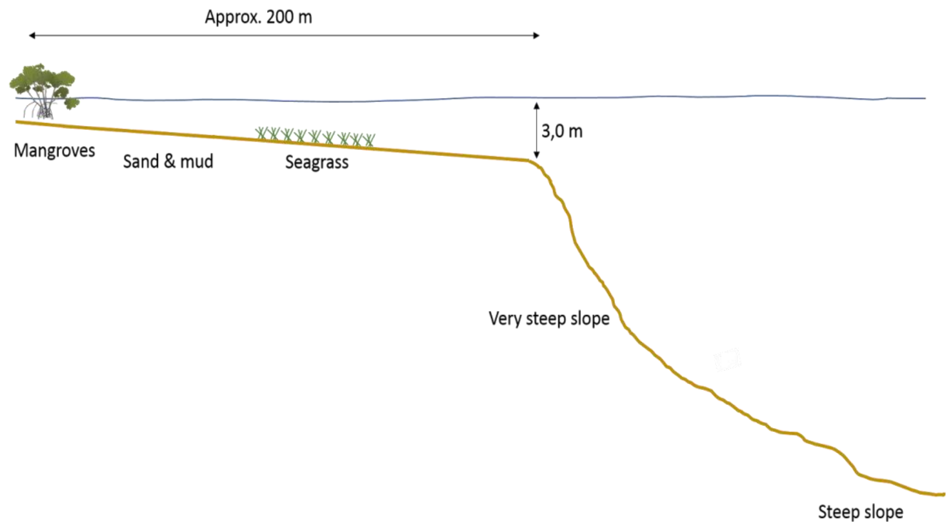


Figure 61: Typical bathymetry profile around Manado

Besides deep water nearby, the temperatures are favourable around the Bunaken. Figure 103 in chapter M.1.3.3 shows the temperature profile south of the island. There is a temperature difference of roughly 20 degrees needed for OTEC. Due to the constant warm surface water is not expected to drop below 28.5 °C throughout the year, the cold deep seawater has to be pumped up at around 8.5°C that can be found at a depth of approximately 365m.

The second requirement limits the location of the plant, inside the bay. A combination of local knowledge and the marine protected area map in section 2.3 (in the main report) point out the best location inside the bay. This location is presented in figure Figure 63. This location also meets the third requirement of a close by grid.

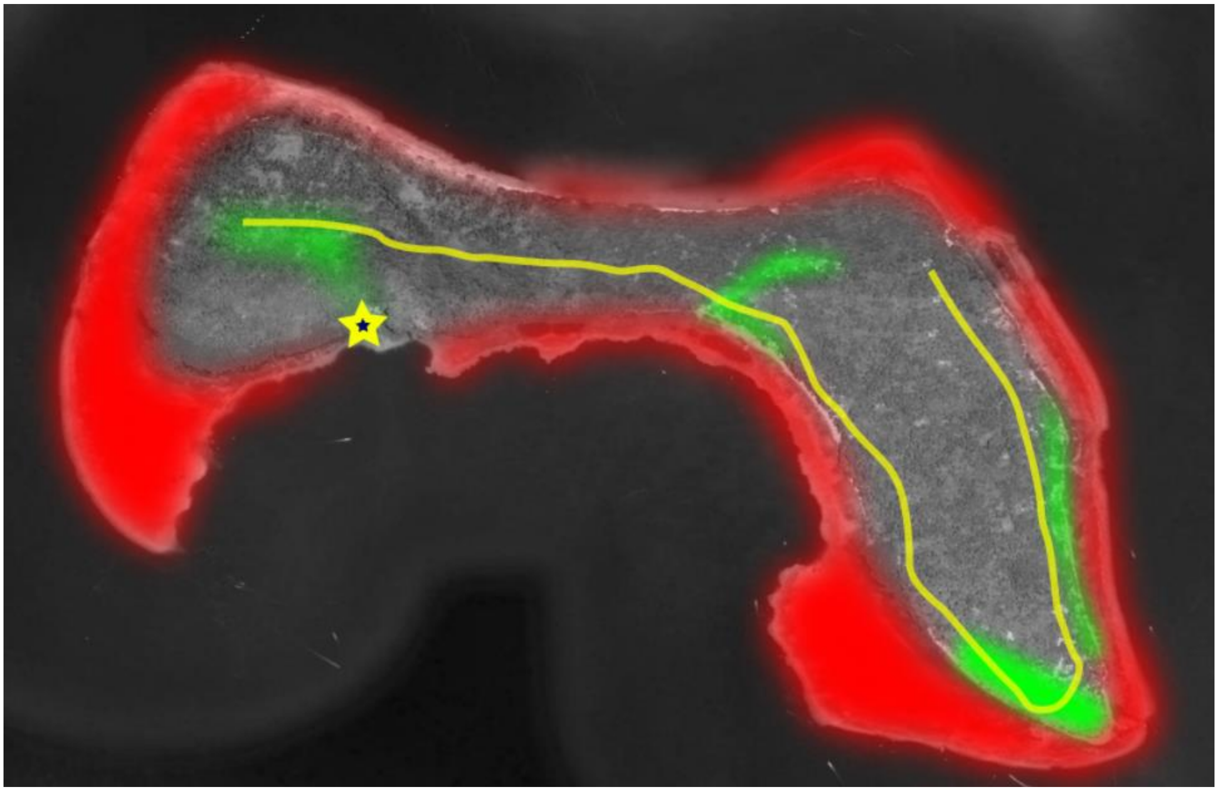


Figure 62: Marine sensitive area (red) and with corresponding optimal location (star)

The fourth requirement cannot be met due to a missing drinking water distribution network. The current RO plants present on Bunaken are shown in Figure 63 including a reservoir. Only one is still functioning 2 hours a week, which is number 4. There is a short distribution network from this RO plants to Bunaken village but this is not working properly. This means that a distribution network would be necessary to prepare Bunaken island for the future. When routing a pipe system, the route should include the 3 villages in Bunaken island and there should be a reservoir present. The plant location in Figure 63 has a potential location nearby at the top of a mountain to ensure water pressure for the distribution network.

The fifth requirement followed from the need assessments in the previous chapters/appendices. The drinking water will be provided by an RO plant that is powered by OTEC. The choice for this concept is justified in appendix I. The plant will be designed to produce 350m^3 drinking water per day. This is 100L/d for 3500 inhabitants of Bunaken island. The drinking water production is requires 45kW of energy. By adding the energy base load of 80 kW as described in appendix D.1.2.2, which will be produced for the grid it adds up to a 125 kW OTEC plant together with a reverse osmosis plant. Although from appendix H6 it is shown that the production price is lower if solely drinking water is produced, the choice is to still produce extra power. Producing energy actually makes the business case less attractive, provided that the drinking water price assumptions are reasonable. This is due to the fact that the drinking water is sold for approximately 5 times more than the production costs. While the energy is sold for 1/5th more than the production costs. Due to this, the scaling of the plant from 45kW to 125kW, adding energy production, the benefits of selling more in quantity in combination with the scaling effect do not weigh up to the extra costs of scaling up. However, as the energy problem in the Bunaken is such a big problem for PLN and the government, it is expected that the government is willing to pay a little bit more to kill two birds with one stone.

Figure 63: Bunaken overview

A summary of the boundary conditions are given in Table 16.

Drinking water production	350	m3/d
Required energy for RO	45	kW
Electricity production	80	kW
Surface temperature	28.5	°C
Deep Sea water temperature	8.5	°C
Max depth	365	m
Distance from shore	1005	m
Salinity surface water	33.500	ppm

Table 16: Boundary conditions Bunaken

Appendix H: Bunaken Masterplan

In this appendix, the final concept is presented. Firstly, the basis of design is described after which the location is chosen. Next, the onshore and offshore equipment is listed in the detailed design and a financial estimation is done, including financial risk. Finally, the environmental impact and the implementation in society, including local content is discussed.

In Table 16, the basis of design was summarized. The OTEC plant is 125kW of which 45kW is used for a RO plant to produce 350m3/day of drinking water. In Figure 63 the potential project location was indicated.

Figure 64 gives an overview of the final design. In the following sections the different aspects of the design are treated.

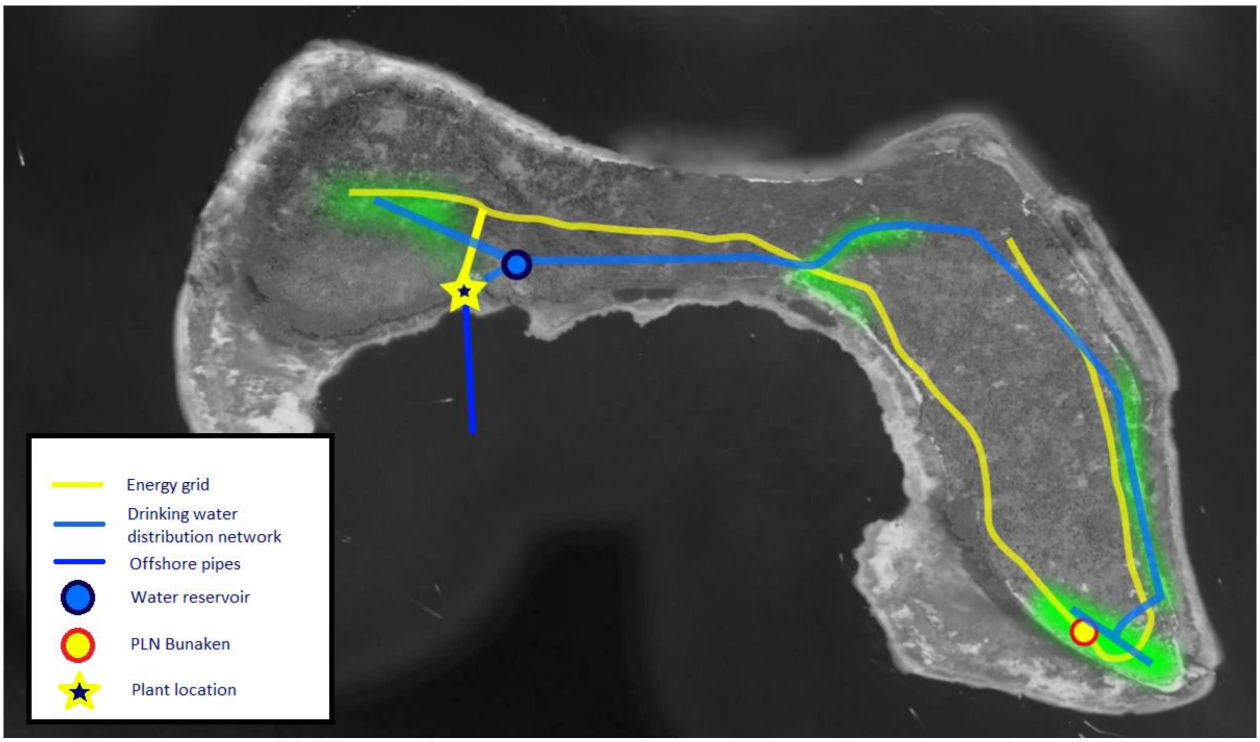


Figure 64: Final design

Appendix H1: Equipment and Infrastructure design

A schematic representation of the processes for the drinking water and energy production are shown in Figure 65. The following subsections elaborate on the different components which are divided in offshore and onshore equipment.

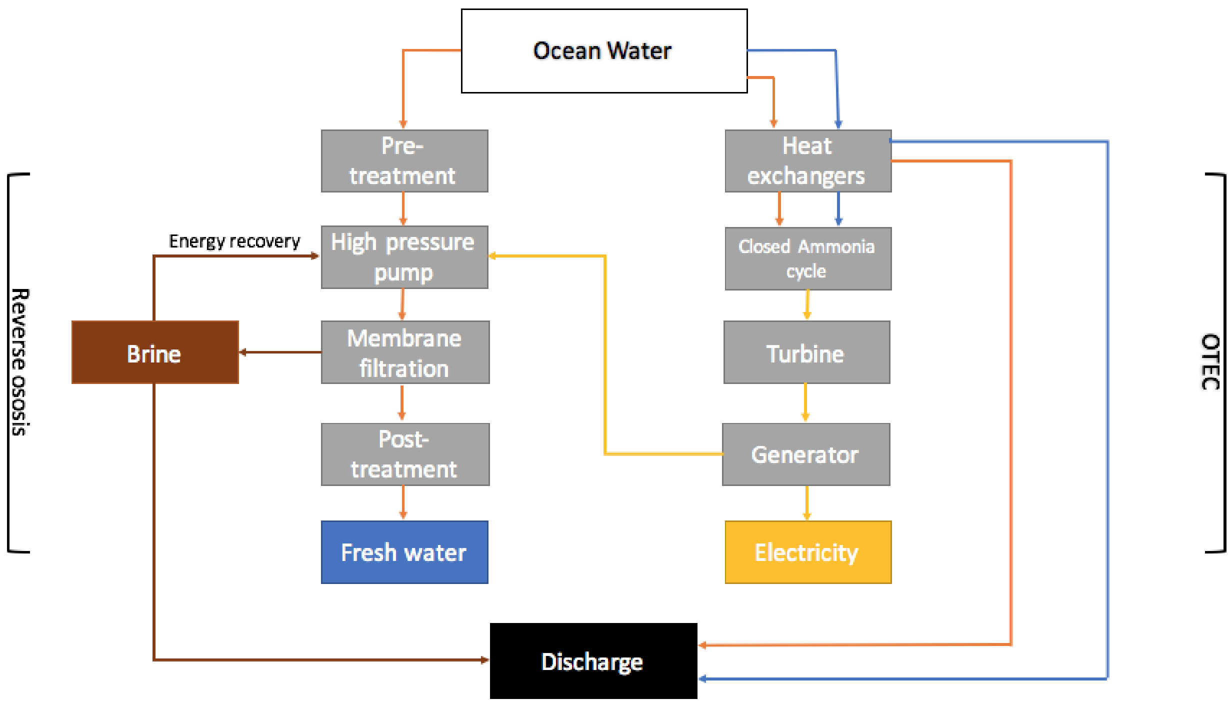


Figure 65: Schematic overview of the processes in the concept plant

H.1.1 Onshore equipment

The technique for both OTEC and RO are described in Appendix C1 and C2. The direct drive system for ROTEC is not taken into account as there is also electricity production involved. Therefore it would be best to first produce electricity and then use part of the electricity to power the RO installation. The most important components to produce the required electricity with OTEC are summarized below.

Heat exchangers

For the heat exchangers, the most suitable solution seems to be titanium plate heat exchangers. These heat exchangers have proven to be suited for saltwater applications and have a high heat transfer coefficient of 2,500 W/m^2K. The rough surface of the plate heat exchanger enhances the performance. A first estimation of the required surface area of the condenser and evaporator are 720m^2 and 1040m^2 respectively. For a more detailed design stage of the project it is advised to optimize the heat exchanger as it has a high impact on the CAPEX. The heat exchangers are a proven concept which means that there are no problems expected in the detailed design, a typical design of the heat exchangers can be found in Figure 66.

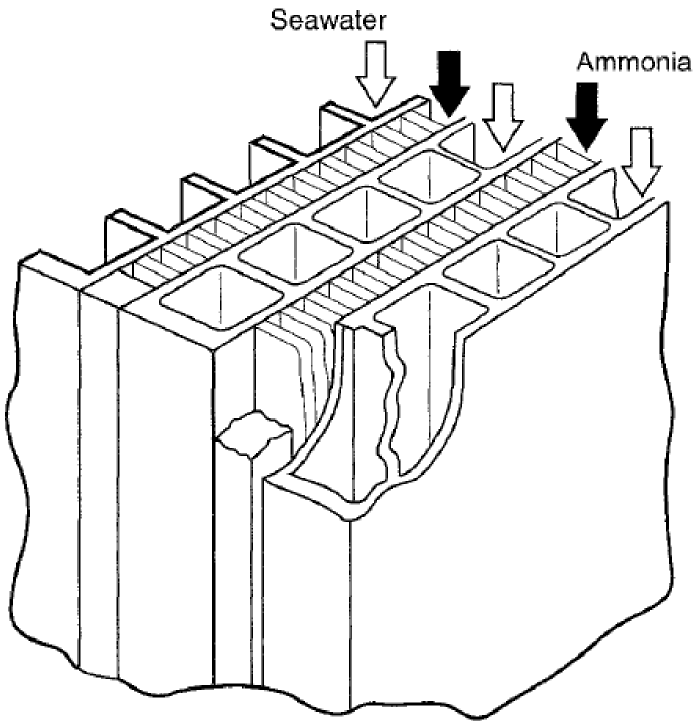


Figure 66: Typical design of a OTEC heat exchanger

Closed loop ammonia cycle

Ammonia is used as working fluid because it has a large track record, it is cheap, and has a low boiling point. It is produced commercially and can be easily liquified, transported and stored by standard methods and equipment (Avery, 1994). This boiling point can be adjusted by adding water to the fluid. After passing the evaporator, the working fluid boils and is at a pressure of roughly 940 kPa (Avery OTEC Bible, 1994). After passing the condenser, the vapor pressure is reduced to 620 kPa. This pressure difference can drive a turbo generator. Ammonia costs less than 5$/kW and makes it economically the most feasible option, as environmental impact is not expected due to the closed cycle.

Turbo Generator

To produce the power, the turbine is directly connected to an electric generator. This so called turbo generator has an efficiency of 80-90%. A turbo generator is a proven concept and is therefore not considered a bottleneck for the project.

Pumps

Part of the energy that is produced by the turbo generator is used to pump up the cold deep seawater and the warm surface water. Due to hydrostatic pressure, the only head loss in the pipes are those due to the friction caused by the flow. There are several pressure drops due to friction and outflow that need to be compensated by pumps. The pressure drops that are taken into account for this preliminary research are:

- Pressure drop over cold water pipe
- Pressure drop over warm water pipe
- Pressure drop over mixed discharge pipe
- Pressure drop over OTEC condenser
- Pressure drop over OTEC evaporator
- Cold seawater flow
- Warm seawater flow
- Discharge flow

The total pump capacity required is 62kW, taking efficiency into account.

Connection to the grid

The energy is distributed over the island via the grid. The grid was already shown in Figure 63 and Figure 64. The distance from the OTEC plant to the closest point of the grid is around 500m. Meetings with Pt. PLN (Bunaken/Manado) should point out which location is best. As a grid connection has been done many times and there are no problems expected here, further details about the grid connection are considered beyond the scope of this report.

Note: Details about the technical performance of the heat exchangers and pumps (e.g. pressure drops, area) were provided by rule of thumb spreadsheets by Bluerise. The corresponding costs were taken into account in the financial analysis and are confidential.

RO installation (state of the art, 2007)

A RO desalination plant is already discussed in appendix C2 and contains the following stages;

- Water abstraction
- Pre-treatment
- Pumping system
- Membrane separation unit
- Energy recovery system
- Post treatment

Water abstraction

The raw water resource influences the efficiency of the desalination process. Two types of raw water input can be used; 1) direct seawater abstraction, 2) brackish groundwater from coastal area. Typical salinity values are respectively 30.000-38.000 ppm and 2.000 - 15.000 ppm. For Bunaken seawater will be used, due to lack of information about the quality and availability of groundwater wells, this has to be further investigated in a more detailed design. Measured salinity at the Bunaken is 33.500 PPM.

Pre-treatment

Pre-treatment is necessary to preserve the membranes and ensure production level. In order to determine the necessary pre-treatment, the raw water characteristics have to be analysed. The fouling potential is often indicated with a SDI value and preferably lower than 3. It is expected that cartridge filtration is needed to roughly filter the raw water source. Additionally, chlorination is necessary to disinfect the raw water and reduce biological growth in the membranes. Before the feed water enters the RO membranes it has to be dechlorinated, because it is harmful for the membranes. Next to that the PH of the raw water is reduced to ensure a longer lifetime of the membranes. A manufacturer of the membranes has more information about the exact composition of the feed water to maintain the membranes.

Pumping system

High pressure pump will provide the pressure in the system. The pressure needed is dependent on the salinity of the feed water. For brackish water 10-15 bar is needed and for seawater 55-65 bar. At the moment is chosen for SWRO so the high pressure pump will provide a pressure between 55-65 bar. The exact pump will be specified by the manufacturer of the membranes.

Membranes

The type of membranes can differ per application. In this case low maintenance membranes are a must, since different projects failed due to the maintenance needed. The manufacturer of RO membranes will provide more insight about this component. The development of membranes is explained in appendix C2**.**

Energy recovery system

This system is explained in appendix C2. It will increase the efficiency of the RO process and will therefore be included in the design of the RO plant.

Post treatment

Downstream of the RO membrane the permeate has to be post treated, since it is not healthy to drink. The following steps are taken in a post treatment process:

- The permeate has to be re-hardened
- PH value has to be increased
- CO_2 content has to be adjusted
- Not all bacteria are removed, so it needs to be further disinfected
- The boron content has to be reduced

The manufacturer of the membranes will have information about the type of post treatment necessary with the current membranes.

Water distribution network

As mentioned in Appendix C, at the moment the drinking water is distributed by a network connected to a current not functioning RO plant. The concept is to connect the old distribution network to the proposed plant, expected is that 10km pipe (main distribution network) and an extra reservoir are necessary. It is beneficial to place the reservoir at an high altitude to secure pressure. Next to that, it is advised that the current RO plant components that are already present on Bunaken will be re-used. In this way the costs can be reduced. A new RO system is however taken into account in the financials due to the uncertainty. Besides cost reduction is it possible to extend and repair the current distribution network and supply the complete island with drinking water. In Figure 64 an overview of the distribution network and an extra reservoir is shown. Note: the proposed route is a starting point for the design and meetings with the government in combination with a more detailed assessment of the facilities on the island should point out what would be the best route of the distribution network.

Opportunity

As mentioned in appendix C4 the dehumidifier can be used for drinking water production next to the OTEC system. A comparison between different drinking water production concepts is made in appendix I. In order to design the dehumidifier, input from Bluerise B.V. is used.

H.1.2 Offshore equipment

In Appendix G the potential location of the project was indicated. At this location several offshore pipes need to be installed in order to obtain the warm surface water and cold water to the plant. In Figure 67 more detailed image of the project location is shown. The location of the plant followed from a site visit. The indicated area seems most promising, however whether it is possible to build on that ground is unknown and has to follow from a workgroup with local inhabitants.

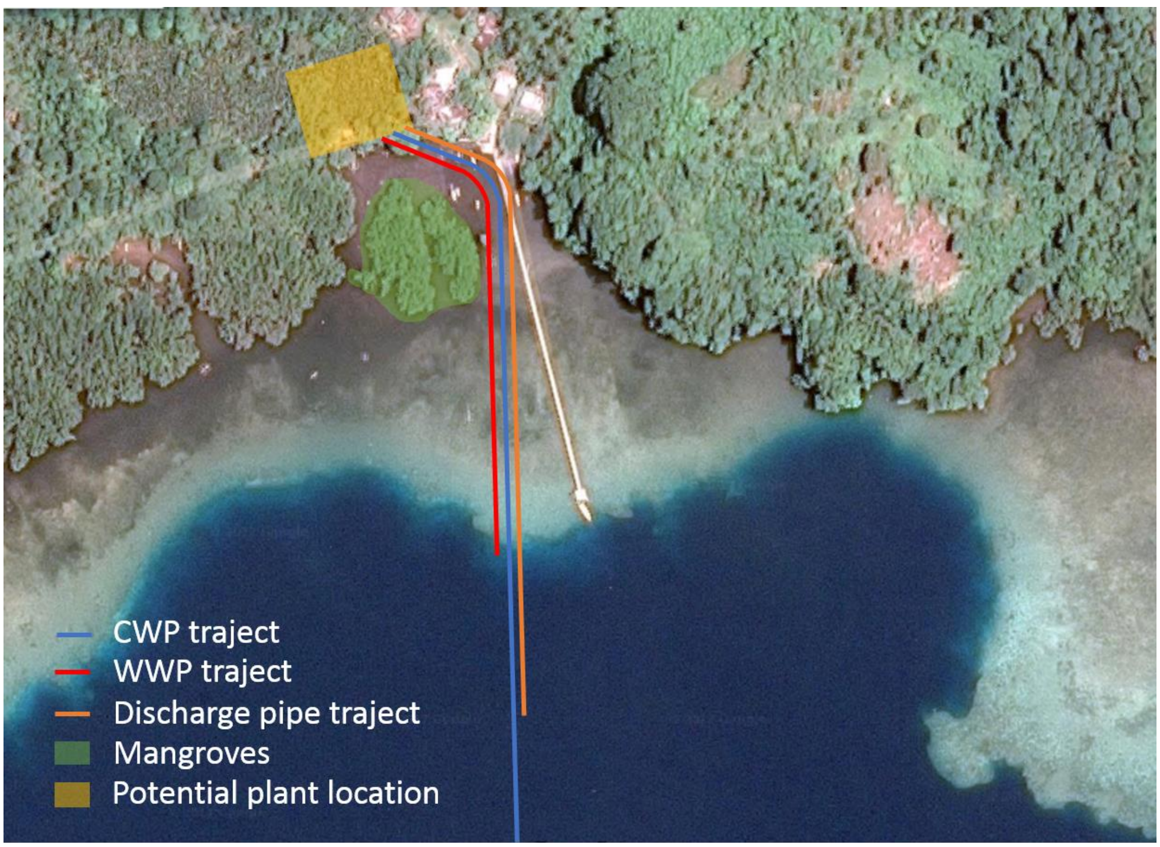


Figure 67: Close-up of the project location and the proposed pipe trajectories

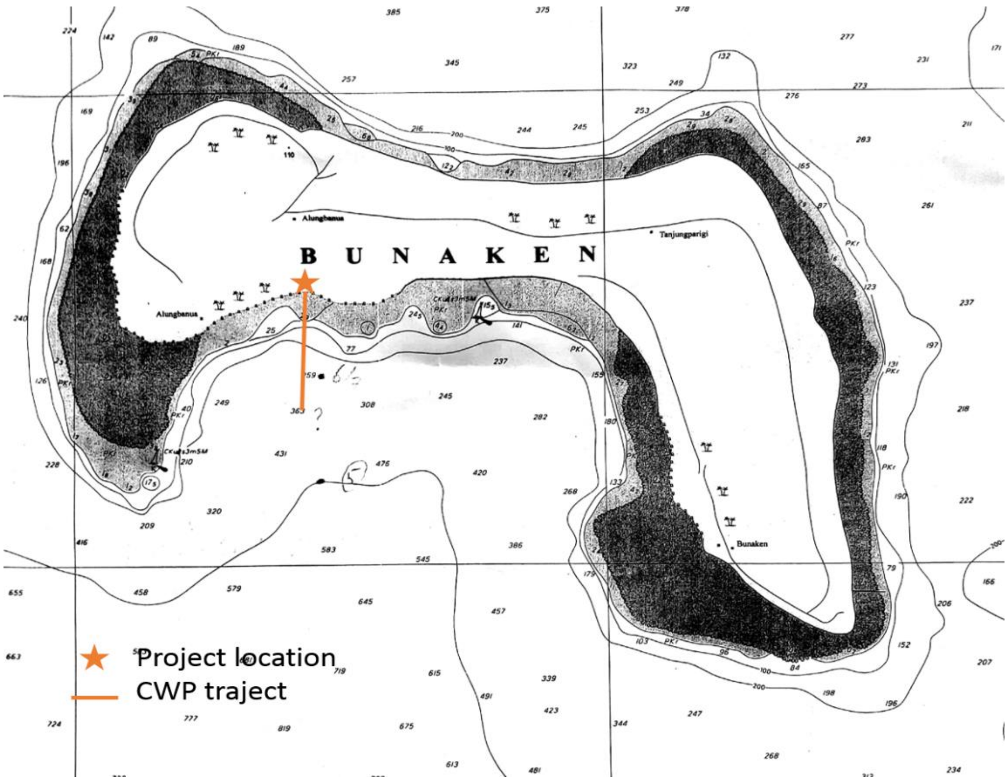


Figure 68: Cold water pipe trajectory and bathymetry

The offshore equipment consists mainly of the water intake pipes, these are indicated in Figure 67 and the cold water pipe in Figure 68. These pipes together take approximately 50% of the CAPEX for their account, but depends strongly on the scale of the plant. In total 3 pipes have to be installed; 1) warm water pipe (WWP) to approximately a depth of 20-30 metre, 2) cold water pipe (CWP) to approximately a depth of 363 metre and 3) discharge pipe to approximately a depth of 150 metre, see Figure 67 for the trajectories.

Warm water pipe

The WWP will provide warm sea water to the system. The measurements show that from the surface until a depth of 50 to 60 metre the seawater temperature is relatively constant, namely 29 ˚C. Taking into account that most debris accumulates close to surface, the WWP will have its intake at 20-30 metre depth. The characteristics of the WWP are summed up below;

- Diameter: 0.72m
- Wall thickness: 34mm
- Intake depth: 20-30m
- Length: 220m
- Material: HDPE
- Flow rate: 0.61m^3/s

Cold water pipe

The CWP will provide water of approximately 8.5 ˚C to the system. From the measurement campaign followed that a temperature of 8.5˚C is found at a depth of 363 metre with a lateral distance of 1005 metres to shore. The characteristics of the pipe are summed up below:

- Diameter: 0.60m
- Wall thickness: 28mm
- Intake depth: 363m
- Length: 1070m
- Material: HDPE
- Flow rate: 0.4m^3/s

Discharge pipe

The discharge pipe contains the cold deep seawater, warm water and brine flow from the RO system. The pipe's outlet will reach to a depth of approximately 150 metre. In this way the discharge flow will have the least effect on marine life and will the possible generation of internal waves be minimized.

- Diameter: 0.93 m
- Wall thickness: 44mm
- Outlet depth: 150m
- Length: 335m
- Material: HDPE
- Flow rate: 1.0m^3/s

Pipe foundation

In the pipe foundation methodology two types of foundation are considered: 1) the pipe can be installed with foundation blocks, which makes the pipe sink. The pipe will follow the bathymetry, which is favourable with sandy gradual slopes. 2) The inverse catenary is a technology in which the buoyancy of the pipe is used. Some additional buoys can be added in order to the create a favourable catenary. A large advantage of this concept is that the pipe will not touch the bottom, this is favourable with steep slopes and rocky bottom. The preliminary pipe installation is shown in Figure 69. In this case is chosen for an inverse catenary, because the slope close to shore is very steep, next to that is found that the bottom mainly rocky, but covert with a thin layer of sand, followed from visiting the construction site. An inverse catenary is common practice in the offshore industry and is already performed by Makai in Hawaii (Lewis, Ryzin, & Vega, 1988).

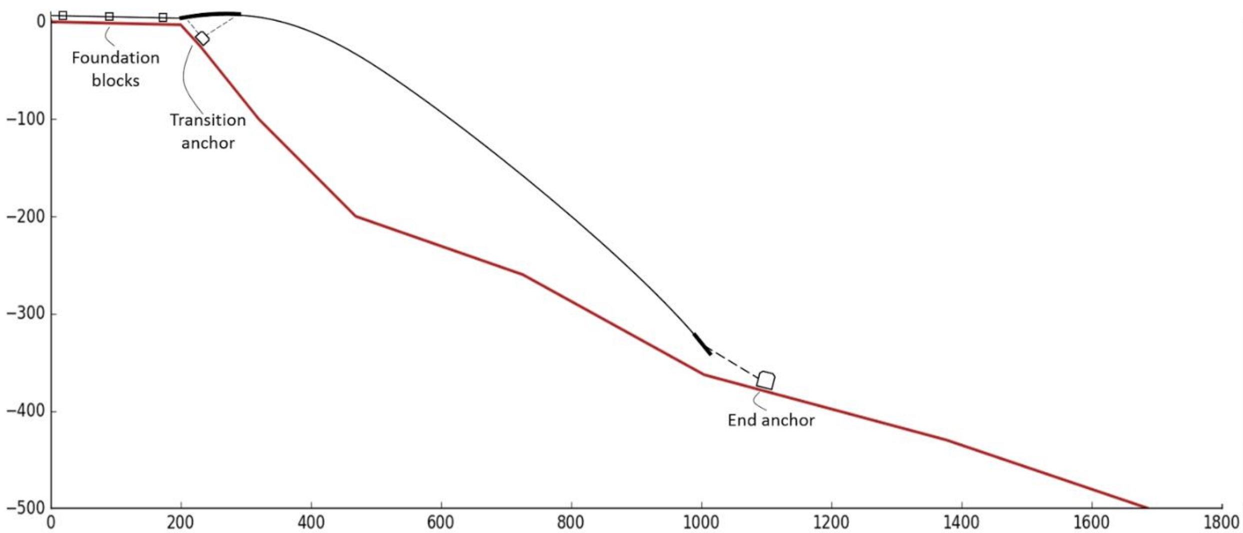


Figure 69: Inverse catenary pipeline

The pipe foundation can be divided into four different sections: (from left to right, Figure 69**)**

- Pipe founded by concrete gravity blocks
- Transition piece, anchored by transition anchor
- Inverse catenary with some additional buoyancy
- End piece with end anchor

Extra care should be taken in designing the transition piece and end piece of the pipe. Large forces are expected at these places, computer models have to give more insight in the exact forces. Expected is that the transition piece needs to be a stronger element of the pipe, detailed engineering will show how the connection from the anchor to the pipe will be made.

H.1.3 Site visit

The site was visited to assess the conditions. Next to the pier, as seen from google earth, there were mangroves present. They are shown in Figure 70.

Figure 70: Site visit pier on the right and mangroves on the left

On the right in this figure, the higher part of the island shown which can be suitable for a reservoir. This is also the reason that the pipe landing should be on the west side of the pier. From the same perspective as Figure 70, the view underwater is shown in Figure 71.

Moving form offshore to shore gives the following perspectives.

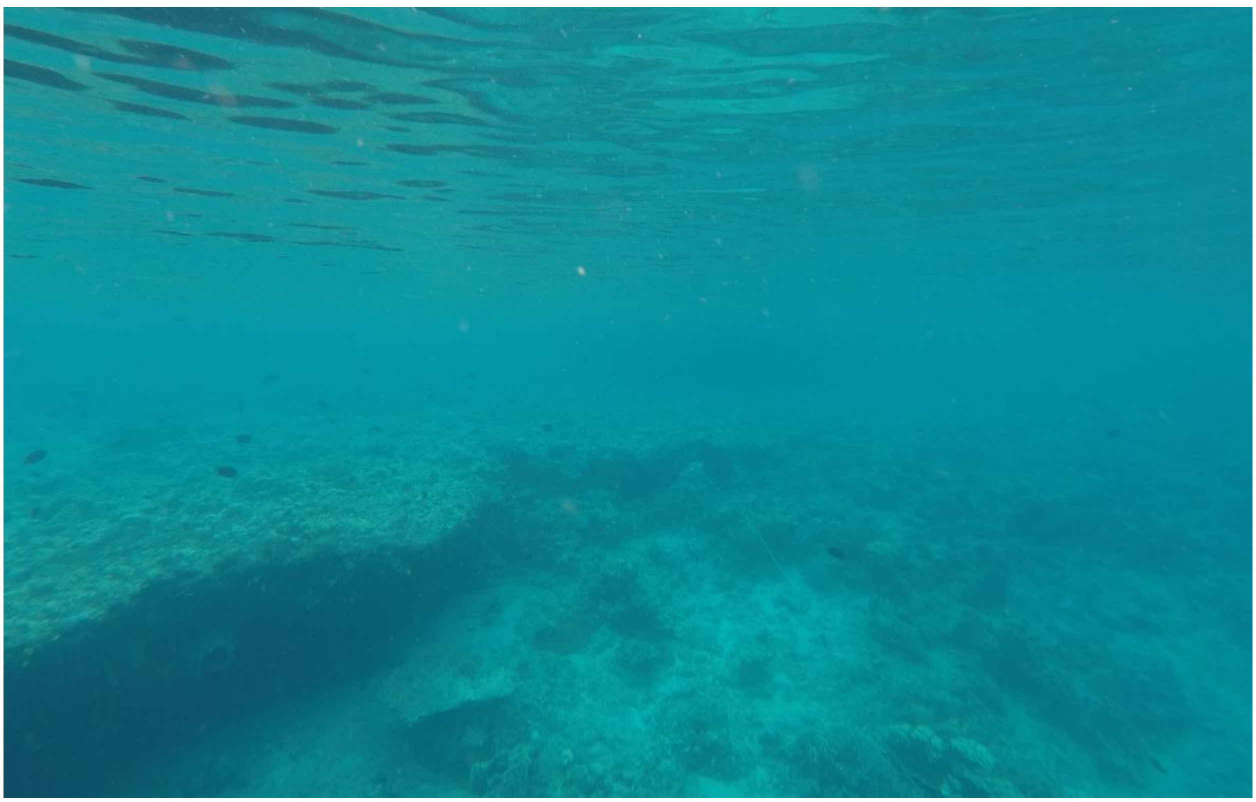


Figure 71: Overview underwater, moving closer to the pier

And even closer to the pier:

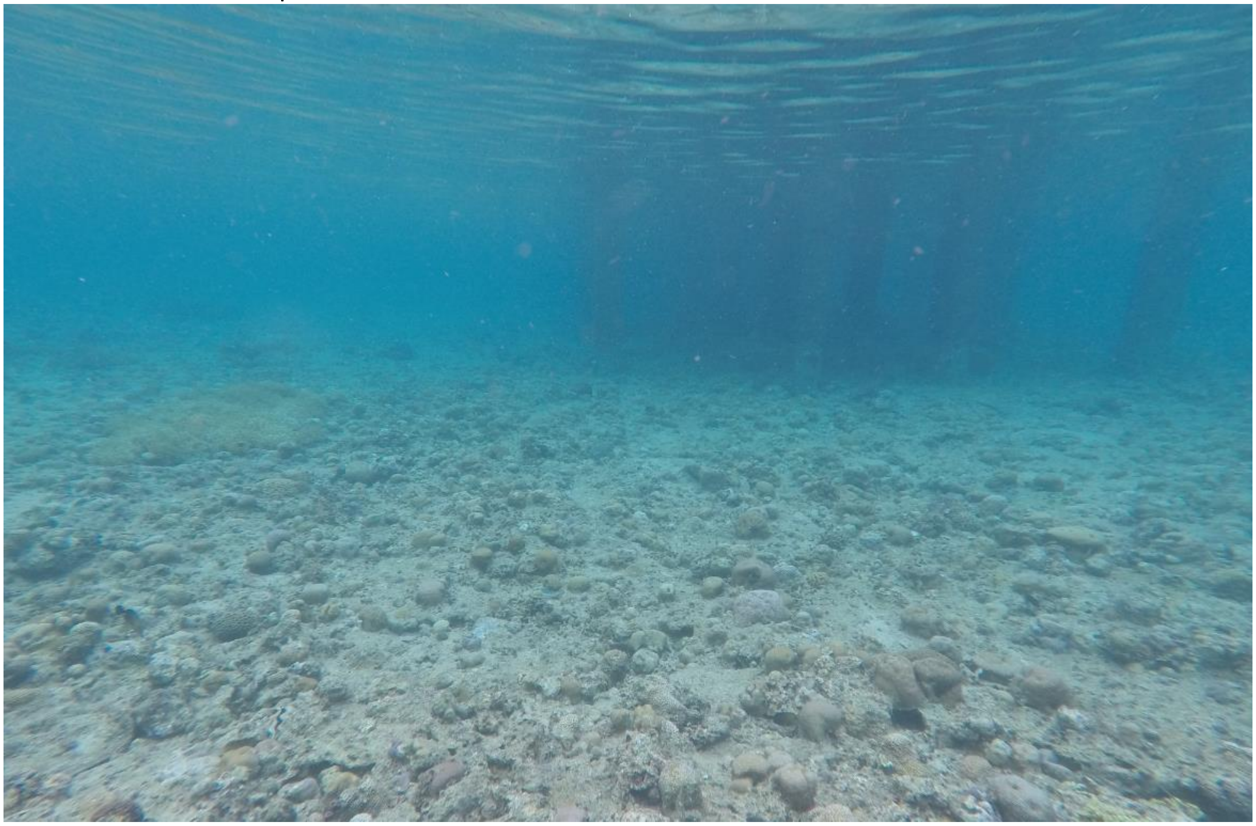


Figure 72: Overview seabed close to the pier

As can be seen in the figure below, the location consists of sand and bleached coral.

Figure 73: Seabed type (Sandy & Bleached coral)


Figure 74: Seabed type (Bleached coral)

Going from the pier further offshore, resulted in a steep seabed slope. Looking straight down (vertically) the following can be seen approximately 15-20m from the pier, see Figure 75. The slope is steep and the water becomes deep quickly. And compared to the surroundings, most of the coral is bleached and the bottom is sandy.

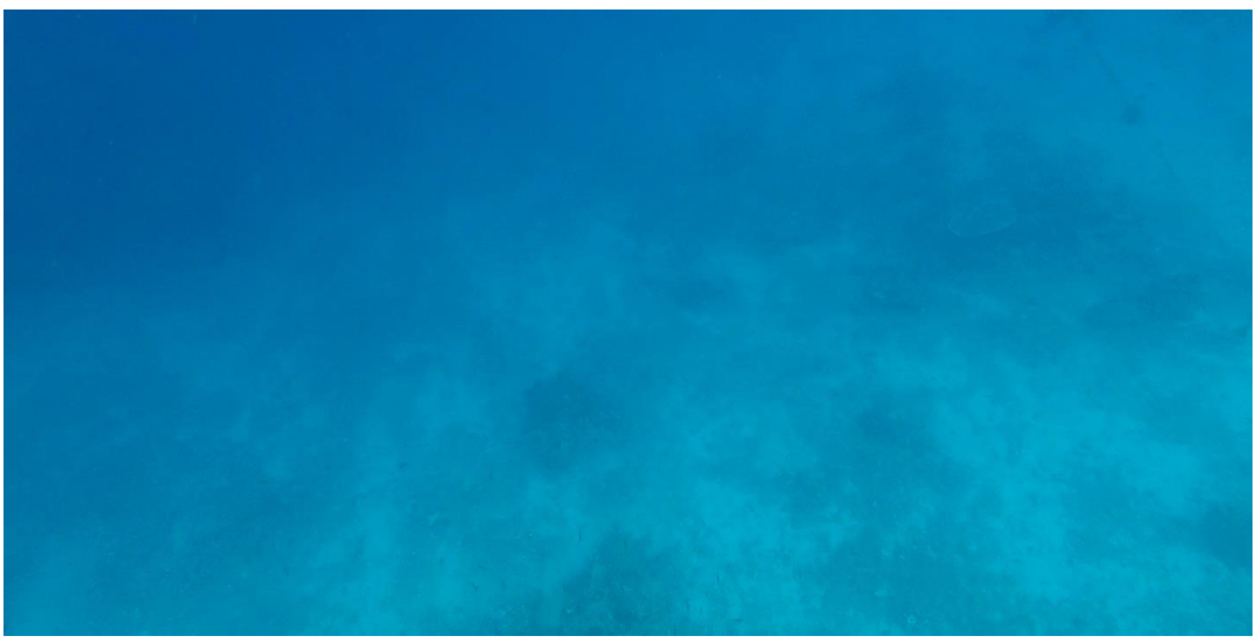


Figure 75: The steep slope at the pipe trajectory

For the pipe landing, the location between the mangroves and the pier is proposed. There is a small village present here for which the impact should be carefully taken into account. For the implementation of a plant, an overview can be found in Figure 76.

Figure 76: Overview of the project area

Appendix H2: Project lifecycle

H.2.1 Planning

The planning of the project lifecycle is important for the project to be successful. An indication of the planning for the first years is given in the Gantt chart in Figure 77. In reality, there is a strong dependence for different stages of the project. This planning is therefore highly simplified to give a proper insight in the planning of the project. Each main phase will consist of smaller phases. For example, the pipe installation consists of a transport phase and an installation phase. The big investments are postponed as long as possible such that the economics are more favorable. It is important that the project contains decision gates to make sure that the right calls are made. An important aspect of the planning is the vessels availability, the type of vessels will follow from the pipe installation methodology.

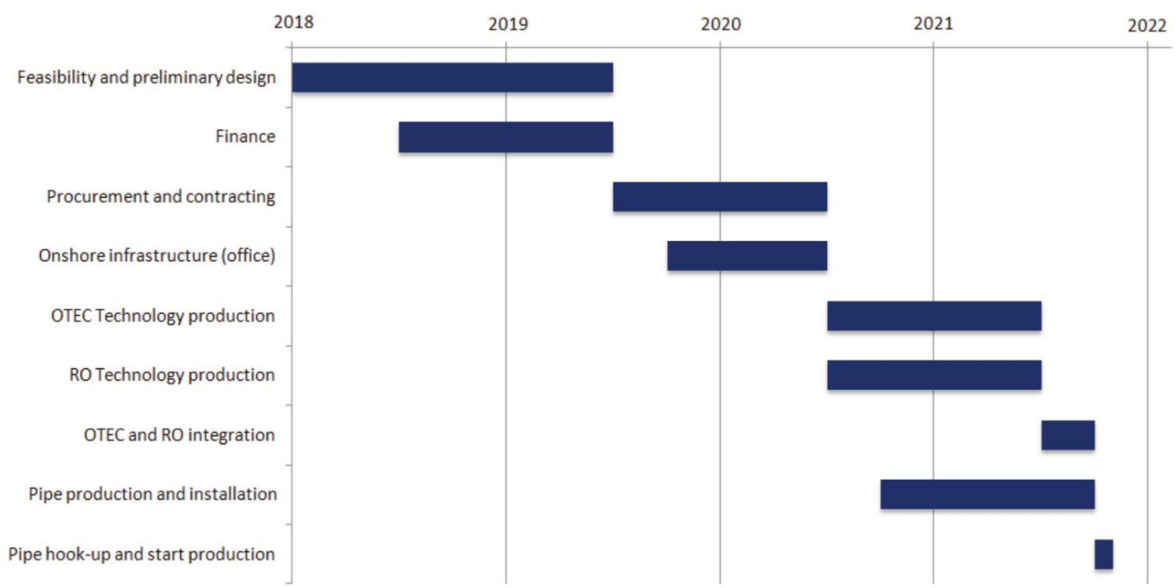


Figure 77: Initial project planning

H.2.2 Contracting

There are many types of contracts. The choice of the contract depends on the type of work and the level of control that the companies involved want to maintain. Closer involvement of the contractor can provide a common incentive that can improve the quality, efficiency and safety of the project, which ROTEC considers to be of utmost importance. The proposed contracts for such a project are depicted in Figure 78. The figure provides an overview of the contracting strategy for the most important stages of the project. The most common types of contracts are (Jahn et al., 2008):

- Lump Sum contract: contractor manages and executes the specified work for a fixed price. Payments can be staged. Favoured if the scope of work can be well defined. A type of Lump sum contract is the EPIC (Engineering, Procurement, Installation and Commissioning) contract;
- Schedule of Rates contract; the labour cost is agreed on a rate basis without specifying the exact hours. The cost of the materials is not specified. This type of contract is often seen within inspection and repair;

• Day rate: For this contract a set price is agreed on a daily basis. So in case of delays the contractor will still earn the same amount of money.

	Design, procure, transport and commission	Inspect/repair	Production	Decommissioning
RO plant	EPIC	Schedule of Rates	Day Rate	Lump Sum
OTEC plant	EPIC	Schedule of Rates	Day Rate	Lump Sum
Intake and discharge pipes	EPIC	Schedule of Rates		Lump Sum

Figure 78: Contracting strategy

H.2.3 Contractors

There are two project developers that have to be involved to produce energy with OTEC and water with RO. This means that there will be two parties that are responsible for the project development and they will individually hire contractors for example for the pipe installation.

Bluerise B.V. is proposed as the developer for the energy part of the installation as it has experience with planning projects involving the use of deep seawater. As the market for OTEC is still relatively small, Bluerise B.V. is one of the market leaders. For the RO part, there are many project developers available. It should be thoroughly investigated which contractor has a good track record with maintenance by locals and working together with local inhabitants. As maintenance is seen as a bottleneck for the Bunaken.

H.2.4 Operation and maintenance

As most equipment is onshore, O&M is relatively easy to perform. The biggest part of the operations and maintenance is required for the moving parts and the filters of the RO. Local workforce should be trained and involved in order to meet the local content requirements. This can for example be done by involving someone from the YEP program. In this way the project developer can train a local to operate and maintain a plant.

A good inspection, maintenance and repair (IMR) policy is necessary, OTEC equipment and RO plant. They are designed to withstand the production lifetime before they need to have major reparations. The frequency of inspection is based on the component type. Advice on the frequency is gained by maintaining a good relationship with the manufacturers of the different components. The calm weather windows are used if the offshore pipes need maintenance.

As most technology is onshore, the maintenance is relatively easy to perform. The heat exchangers are turned off once a year to clean them from the seawater corrosion and debris. Also, the filter at the intake pipeline must be cleaned regularly to make sure the intake losses are low to maintain the efficiency of the pumping system. The downtime is approximated to be max 5%. The operations can be monitored from shore using an onshore office with IT. Local people can be trained which will save costs and improve the local support for this project. The work force must be trained and there must be strict guidelines for the operations that are well known for the personnel. A rough estimate of the maintenance strategy is given in Figure 79.

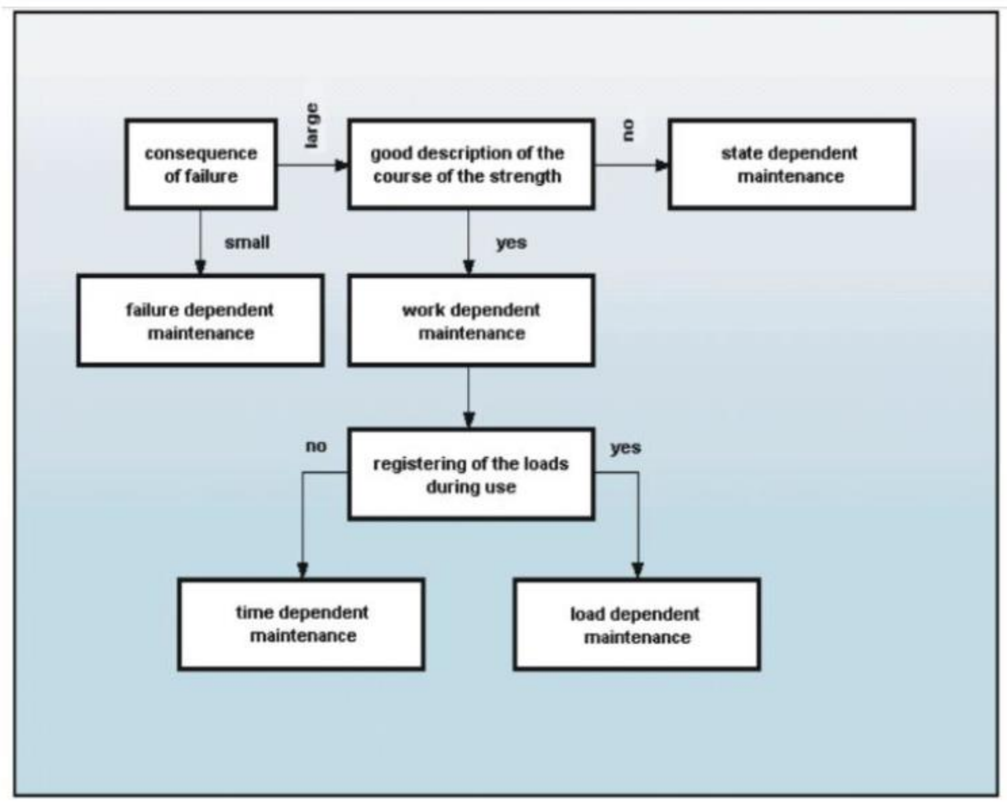


Figure 79: Maintenance strategy (Jonkman et. Al, 2016)

H.2.5 Decomissioning

When the project lifetime is matured, the facilities must be decommissioned. The process consists the following steps that are shown in Figure 80.

Figure 80: Decommissioning strategy

• Permits: Operators must ensure these are in place and contract local consulting firms to ensure all the permits are in order before the decommissioning starts. The firms are ought to work conform the regulatory framework for Indonesia;
• Offshore operations: The intake and discharge pipes are decommissioned and transported to shore. The pipe is cut in pieces and transported on barges or vessels. The pipe materials could be reused for other purposes if possible.
• RO & OTEC facility: The technology is decommissioned and brought back to the manufacturer where it could be refurbished. This will raise salvage revenue. The technology that is not suitable for refurbishing anymore can be scrapped and recycled.
• Site cleanup: After the decommissioning, surveys are performed to map any debris that is left behind in decommissioning phase. Project ROTEC requires 100% cleanup such that the environmental impact is limited.

Appendix H3: Financial analysis

The plant will provide 80 kW of energy and 350 m3/day drinking water. The included components in the CAPEX and OPEX are listed in Table 17. Next to that are other important parameters presented. The corresponding investment costs are deducted from reference projects, papers, companies and presentations from the RO, OTEC and the offshore industry.

CAPEX	OPEX	Other important parameters
Building, office and land	RO OPEX	Discount rate - 7%
Pumps OTEC	OTEC OPEX	Decommissioning - 30% of CAPEX
Turbo generator	Insurance	Salvage - 5% of CAPEX
CWP, WWP and Discharge pipe	OPEX 3 times higher every 10 years	Downtime - 5%
Instrumentation and control OTEC		Energy percentage sold - 100%
Auxiliary components for OTEC		Water percentage sold 90 %
Heat exchangers		Unsubsidized energy price -0.11 $/kWh
Connection to the grid		Current price PLTS system - 0.22 $/kWh
Water storage reservoir		Project duration: 34 years, 4 years of engineering and construction, 30 years of operation
RO Plant (including pre-filtration, pre-treatment, pumps, membranes and post-treatment)		Water selling price 7.5 $/m3
Water reservoir		
Water distribution network (connection to the current system)		
EPC		
Total: $6.000.000	Total: 141.000 $/year	

Table 17: Financial assessment assumptions

From Table 17 it can be seen that an initial investment of 6.0 million is necessary to be able to cover the costs of all capital expenditures. Next to that will the investment be spread over 4 years, see Table 18.

Year 1	Year 2	Year 3	Year 4
$55.000	$787.000	$2.600.000	$2.600.000

Table 18: Investment timeline

After this, the potential feasibility is determined by assessing the cash flow of the project. The cash flow is determined by taking a production time span of 30 years (total project lifetime of 34 years). This lifetime is relatively high but is possible with an adequate maintenance strategy. The drinking water and energy selling price are important to determine the revenues of the plant. The prices are:

- Energy: 0.22 $/kWh (the same selling price set by current PLTS system)
- Drinking water: 7.5 $/m3 (a value set by research, see Appendix K)

It has to be noted that there is still a large uncertainty in the drinking water selling price. This effect will be further investigated in the sensitivity analysis. The energy price is given by Pt. PLN Manado and is deemed as a reliable source.

As can be seen in Figure 81, the project's payback time is approximately **15 years** and the net present value (NPV) equals **$2.97 million** with an internal rate of return (IRR) of **12.0%**.

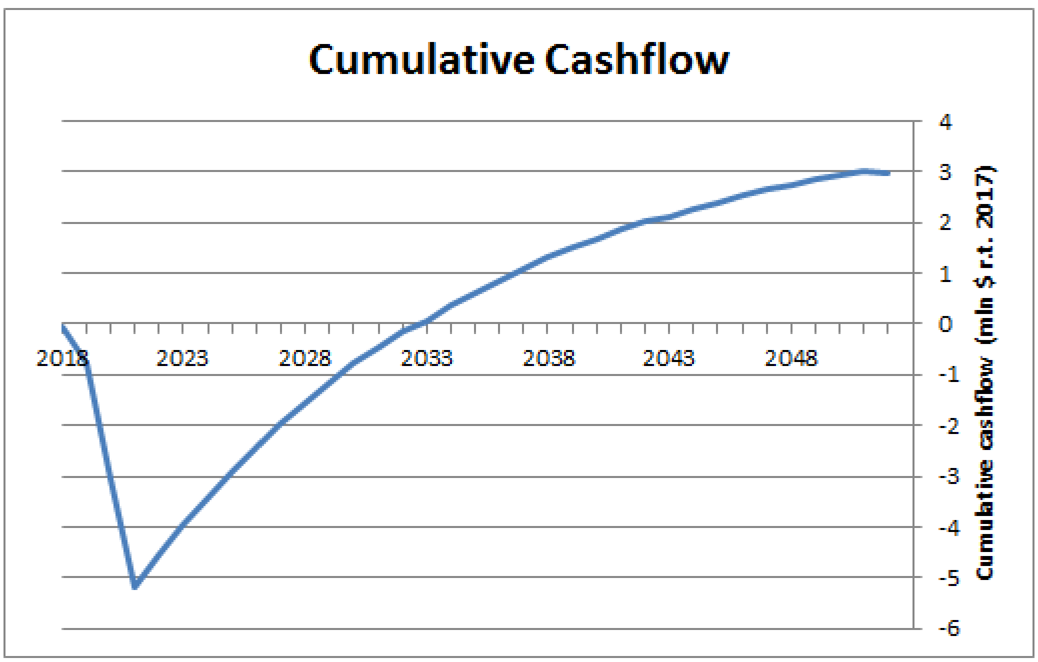


Figure 81: Cumulative cashflow Bunaken

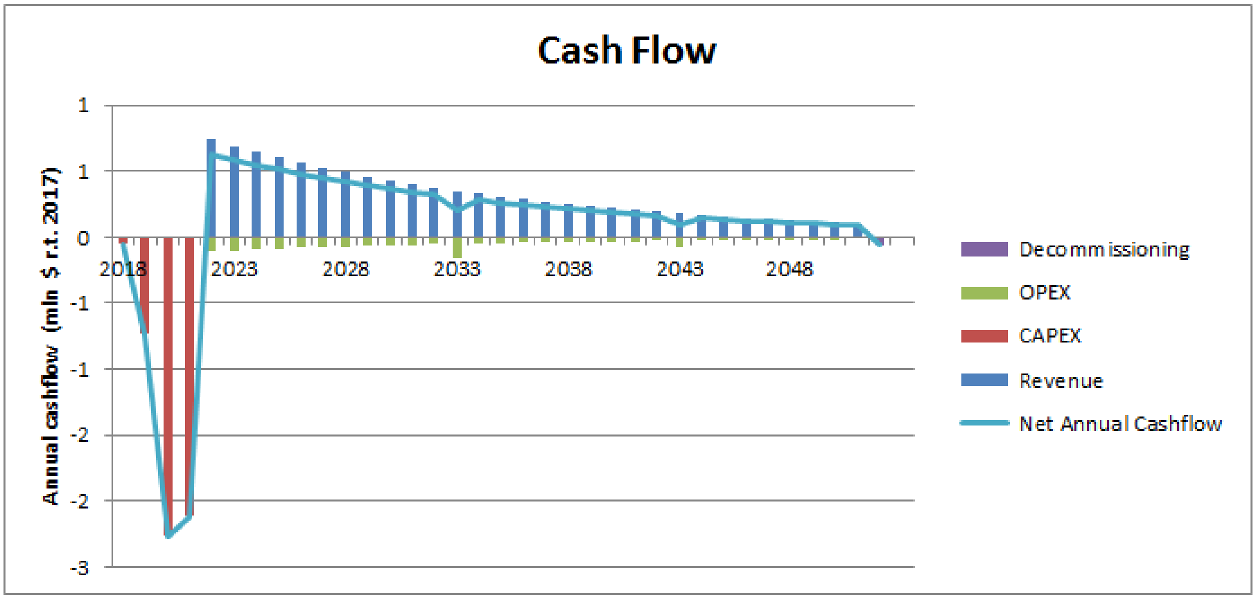


Figure 82: Cash flow Bunaken

The sensitivity and financial risk of the most important parameters is shown in Figure 83. This tornado chart shows the most critical factors and their impact on the NPV. Negative percentages have a negative effect on you NPV and positive percentages a positive effect on you NPV. The ranges of variation of the parameters are estimated based on the uncertainty around the parameter for the preliminary feasibility.

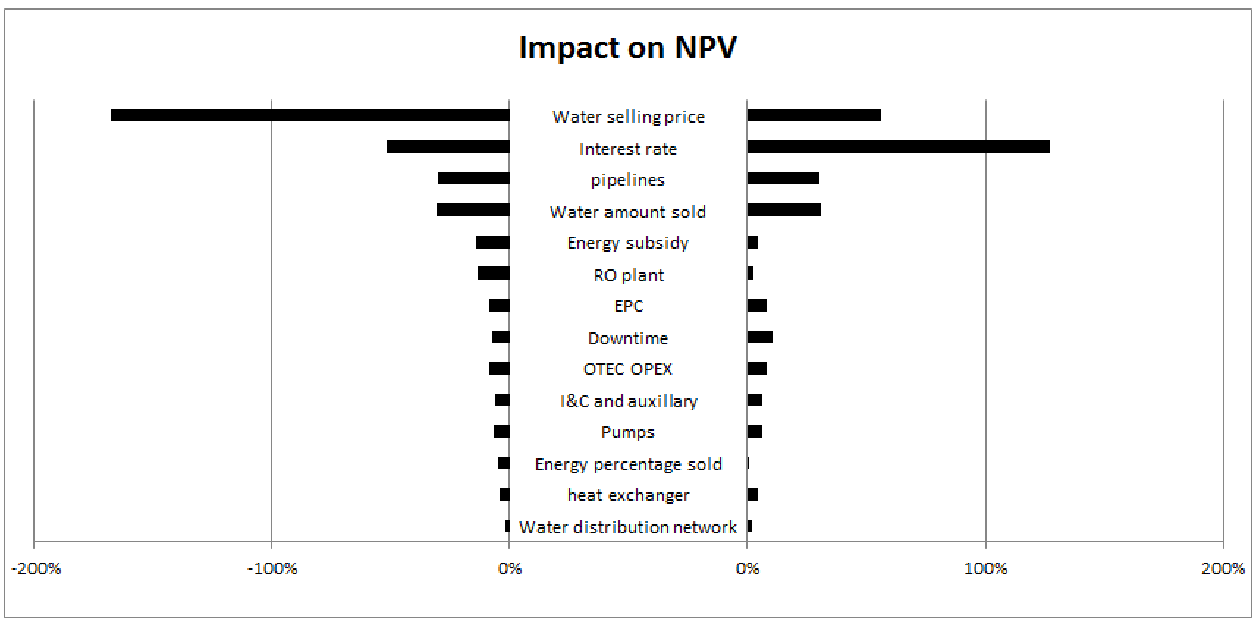


Figure 83: Tornado chart Bunaken

The parameters with the highest impact on the NPV are:

- Interest rate
- Water selling price
- Energy subsidy

A 7% interest rate is a conservative value when accessing the recent trends of interest rate development for Indonesia. Therefore, the chance of lower interest rate is higher than a higher interest rate, this can also be identified in Figure 83. The water selling price has a large influence in on the NPV, this is mainly due to the large uncertainty about the price. At the moment is expected that 7.5 $/m3 is a little bit too high drinking water price, however calculations show that (see appendix):

- Currently inhabitants pay $0.22 for Danone drinking water daily
- If the inhabitants increase their expenditure by 2.6 than they will receive 30 times more water, or will provide them with 75 litre of drinking water from this plant

So in short the inhabitants have to be willing to double their daily expenditure on drinking water and this plant will provide them daily with 75 litre of drinking water. Focus group on Bunaken island will give more insight on this topic.

The production price is calculated separately for both drinking water and energy. In order to do so, the cash flow is scaled based on the amount of energy used for each process. This means that CAPEX, OPEX and decommissioning for OTEC are scaled based on 45kW/125kW for drinking water and 80kW/125kW for energy production. The costs that are solely for drinking water (e.g. RO, water distribution network, reservoir) are only taken into account in the drinking water production price calculation and the energy cost (e.g. electrical infrastructure) for energy. This means that the overlap is basically the OTEC plant and its components for which the costs are shared. All yearly costs are discounted and added up to calculate the price in $/kWh and $/m3. The production price for energy is 0.18$/kW and the production price for water is 1.23$/m3.

Financial conclusion

The most important results are presented in Table 19**.**

Plant lifetime	30 years
Total initial investment	6 million $
Energy price	0.22 $/kWh
Water production price	7.5 $/m3
NPV	$2.970.000
IRR	12%
Payback time	15 years
Production price energy	0.18$/kWh
Production price drinking water	1.23$/m3

Table 19: Financial outcomes Bunaken

The largest financial risks of this concept are:

- Drinking water selling price
- Interest rate

As mentioned before is the drinking water selling price has to be discussed with the inhabitant. This will create more insight in their willingness to increase their daily expenditure on drinking water. First calculations on the current expenditure of the inhabitants is made in appendix K.

To conclude, this specific plant will be a new development in a still relatively unexplored field of work. Therefore for investors it is suggested to have at least an IRR of 35% to cover the risks they are taking (Kirsch, 2013). However this plant will improve the quality of life for the inhabitants of Bunaken Island. So if the government can identify with the purpose of this concept and sees it implemented on more small and remote island they might be willing to take the risk.

Appendix H4: Environmental Impact

Bunaken island is a marine protected area. The environmental impact of a new plant is of big concern for this island. The impact must be limited or eliminated. In this appendix, the possible impact and the corresponding solutions are described.

Salinity

After the feed water is pressed through the membrane, there will be a substance left with a very high salt concentration, called brine. In a conventional RO systems, this concentration can be 70% higher (60.000 ppm) than the salt concentration of seawater. The disposal of this brine flow is one of the main causes of pollution. The brine flow can also have traces of chemicals used for the cleaning of the membranes. Usually the brine flow is directly discharged into the sea and because of the high density the layer will sink to the bottom of the sea. This will affect marine life in deep layers of the sea and around the outflow.

As there is much more water required for the power production with the OTEC system. The cold deep seawater and part of the hot surface water (that is not used for RO) is mixed with the brine flow before the disposal of it. In this way, the salinity of the discharge flow is only 0.5% higher than the seawater salinity. Ocean and tidal currents in the sea will cause further mixing.

Carbon footprint

The carbon dioxide emissions can be categorized in three types. First, there is the emission due to the construction of the plant and the production and transportation of the materials needed to construct this plant. The regulatory framework must be followed to limit this impact.

The second type of emission is the one that occurs during the power generation of the OTEC plant. This type is a short-term release. However, this type of release is inapplicable for a system that uses a closed cycle.

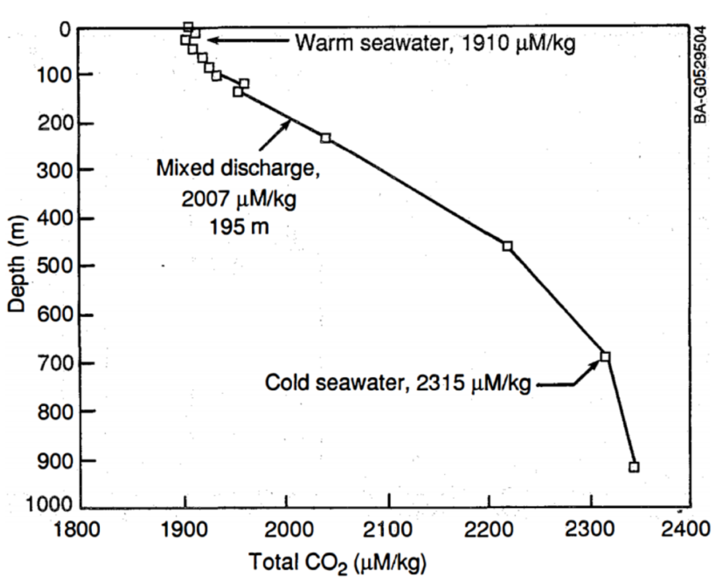


Figure 84: CO2 encaptured in the sea (Green & Guenther, 1990)

Lastly, the cold seawater consists more CO_2 compared to the warm surface seawater. This relation is shown in Figure 84. There is a possibility that the CO_2 of the cold seawater will be released if this water will make contact with the atmosphere which has less CO_2. This can be prevented by ensuring that this water will not come in contact with the atmosphere and is released safely back into the ocean. (Green & Guenther, 1990)

Temperature

Cold deep seawater is being pumped up to the surface. The mixing of the cold water at the surface, after producing power, could influence the surface temperature. The temperature difference between deep sea and discharge is approximately 10°C. If the water is discharged at 100m water depth, the density is slightly higher than the surrounding environment where it will stabilize and dilute in the environment. This is not recognized 1km down the current.

Impact on sea life

Pumping up water can cause fish and sea mammals to be sucked up. To prevent this, it is favorable to use filters or nets at the intake and pump with small velocities, resulting in the requirement of larger diameter pipes. This will be done using a flow velocity of only 1.5 m/s. This is especially necessary for the surface water. Because in the deep oceans there is very low level of marine life, the effects should be negligible for the deep seawater.

Cold deep seawater contains more nutrients than surface water. This means that also the discharge flow of the plant could contain more nutrients. Nutrient rich water can cause a large growth of algae, if there is sufficient sunlight at that depth. The algae could deoxygenate the water and make the life for fish difficult. Another theory is that the nutrients support the growth of fish due to the extra amount of food (Upshaw, 2012).

During installation and operation of the process and offshore equipment, the noise must be limited such that the impact is limited on the marine environment and personnel. During installation, the marine environment is most likely chased away during the most significant environmental impact, due to noise. However, no big noise incidents are expected offshore.

Another environmental impact could originate from the chemicals of the OTEC installation. Chemicals like the working fluid (ammonia) could leak. However, this is only a serious threat to the environment and health if this is leaked at a large rate. Small volume release can on the other hand enhance marine growth since it is a nutrient. Also, metals from corrosion and filter backwashes could have an impact on the environment. Research should point out the magnitude of the environmental impact. Lastly, it has been tested that chlorine can function as a biocide to prevent biofouling of the evaporator surfaces on the seawater side. Research showed that biofouling control of a OTEC plant will have minimal impact on the marine life. (Green & Guenther, 1990)

Constant pressure

A RO membrane uses its maximum efficiency if it is exposed to a constant pressure of the feed water. In the case of ROTEC, this requirement is met because the energy source (the ocean), does not undergo any fluctuations that can affect the pressure applied on the membrane. There is a constant temperature difference and an unlimited seawater source. This constant pressure leads to less maintenance needed, compared to RO's driven by wind turbines or solar panels. This will result in less cleaning with toxic chemicals and replacement of components of the RO. Indirectly this causes less impact on the environment by Reverse Osmosis.

Energy Recovery

The power RO uses, is significant for its sustainability. By using the pressure that is still in the resultant (brine) flow, the total pump power can be lowered. The pressure in the brine flow is just slightly lower than the pressure that is needed in the RO process. With an energy recovery device, a turbine driven by the pressure in the brine flow, the power needed for the RO can be reduced with 80%. In the ROTEC plant this means that a smaller OTEC cycle is needed and which reduces indirect environmental impacts from OTEC.

Coral reef and Mangrove forests

The present coral reefs must be preserved in the best manner. The same applies for the mangrove forests, since they are very important for local ecosystems. The location of the plant was therefore attentively investigated. The chosen location is part of Bunaken Island where there is no coral reef nor a mangrove forests at the site. As shown in appendix H.1.3, the only coral that is present are bleached corals. There is a scaffolding present which indicates the border of the mangrove forest.

Carbon dioxide reduction

Bunaken Island gets its electricity partly from diesel generators. By using diesel as a fuel the following greenhouse gasses are released. see Table 20.

Greenhouse gas	Global warming potential	emission kg/l
Carbon dioxide CO2	1	2.65
Methane CH4	21	$3.6*10^{-4}$
Nitrous Oxide N2O	310	$2.1*10^{-5}$

Table 20: Greenhouse gasses by per liter of diesel emission and their GWP

With the global warming potential of the gases the total emissions can be expressed in tonCO2 equivalents. Knowing that the total generator size that will be 'replaced' is 125 kW for both the electricity production and drinking water production. To keep a certain generator running there is 35 l/h diesel required. The magnitude of emissions of a conventional diesel generators can be estimated. This is in total 817 tonCO2 per year. In this solution, these emissions are eliminated. On top of this, there will be less emissions since there will not be transport of water and diesel needed to the island. This will lead to the fact that even 854 tonCO2 of CO2 emissions are avoided. avoided each year.

Appendix H5: Benefits

Energy

The proposed solution is a risky investment if you purely look at the economics, however besides the importance of money, there are several benefits. The solution provides a sustainable reliable baseload of energy for the island which is still not 24/7 electrified. With growing tourism and population, the energy demand will grow along with it. As the base load is currently partly provided by diesel generators, which can be shut down which reduces CO_2 emissions. In combination with the currently installed solar PV installation this could be a pilot island for the goal of the Indonesian government to make small islands self-sustaining.

Moreover, a reliable source of energy can contribute to economic growth and more tourism. Whether more tourism on Bunaken island is beneficial is worth a debate itself but looking at it from an economic perspective it is.

The current plans for an expensive connection of the Bunaken to the SULUTTENGO grid would not be necessary anymore. This would require a long cable crossing a location where the seabed is irregular and with high currents. This makes the connection more expensive than the ±3.5$ million expected now (PLN SULUTTENGO, 2017, see Appendix O13). Furthermore, this would require the cable to land around the east coast of Bunaken. As described before, the island is surrounded by a wall of coral reefs and this would mean that this cable installation could seriously harm the environment.

Drinking water

By producing drinking water on the island, no more plastic bottles of drinking water have to be imported from Manado. This means less plastic in the sensitive marine environment of Bunaken and cheaper water for the villagers. These improvements of the drinking water facilities could also make room for growth in sanitary facilities. All these benefits have a positive impact on the health of the citizens on the long term. People that are now exploiting their own brackish water wells do not have to cook their water anymore before they drink it as the water is safe to drink from the tap.

The salty waste of the RO installation is added to the discharge flow which means minimal impact for the sensitive marine environment. This is a big benefit compared to the current RO systems on the Bunaken. Combining a constant power input for the RO also reduces the amount of maintenance required. As maintenance is a problem in countries under development, this is beneficial compared to the current RO systems that rely on fluctuating power input.

Community

Additionally, jobs are created. It can be stated that the operation and maintenance of facilities on the island is not ideal. However, by combining a drinking water and energy production plant, there is a bigger risk at stake if these facilities fail. This could mean that there is more incentive to keep the plant running. However, this is still speculation and has to be verified.

By building and maintaining the plant, jobs are created. A plan for local content has to be written and implemented to make sure that besides the facilities itself, the local people have benefits. These benefits can of course contribute to the sense of responsibility for the plant which is stated above.

The resorts on the island have said to be prepared to pay a little bit more for drinking water to make it cheaper for the villagers. In this way, they can do something back for the local community that welcomed them to exploit their surroundings for tourism.

To conclude, the island is made more self-sustaining by improving the drinking water and energy facilities without transporting unsustainable diesel and plastic water gallons/bottles to the island.

Appendix H6: Financial analysis - Bunaken standalone drinking water supply

The plant will provide 350 m^3/day drinking water for Bunaken Island. The included components in the CAPEX and OPEX are listed in Table 21. Next to that are other important parameters presented. The corresponding investment costs are deducted from reference projects, papers, companies and presentations from the RO, OTEC and the offshore industry.

CAPEX	OPEX	Other important parameters
Building, office and land	RO OPEX	Discount rate - 7%
Pumps OTEC	OTEC OPEX	Decommissioning - 30% of CAPEX
Turbo generator	Insurance	Salvage - 5% of CAPEX
CWP, WWP and Discharge pipe		Downtime - 5%
Instrumentation and control OTEC		Water percentage sold - 90 %
Auxiliary components for OTEC		Project duration: 34 years, 4 years of engineering and construction, 30 years of operation
Heat exchangers		Water selling price - 7.5 $/m3
Water storage reservoir		
RO Plant (including pre-filtration, pre-treatment, pumps, membranes and post-treatment)		
Water reservoir		
Water distribution network (connection to the current system)		
EPC		
Total: $3.900.000	**Total: 98.500 $/y**	

Table 21: Important parameters for financial analysis

From Table 21 it can be seen that an initial investment of **$3.9** million is necessary to be able to cover the costs of all capital expenditures. Next to that will the investment be spread over 4 years, see the table below.

Year 1	Year 2	Year 3	Year 4
$36.000	$498.000	$1.685.000	$1.685.000

Table 22: Investment scheme

After this, the potential feasibility is determined by assessing the cash flow of the project. The cash flow is determined by taking a production time span of **30 years** (total project lifetime of **34 years**). The drinking water price is:

- Drinking water price: 7.5 $\$/m^3$ (a value set by research, see appendix M)

It has to be noted that there is still a large uncertainty in the drinking water selling price. This effect will be further investigated in the sensitivity analysis.

As can be seen in Figure 85, the project's payback time is approximately **11 years** and the net present value (NPV) equals **$3.68 million** with an internal rate of return (IRR) of **15.1%**.

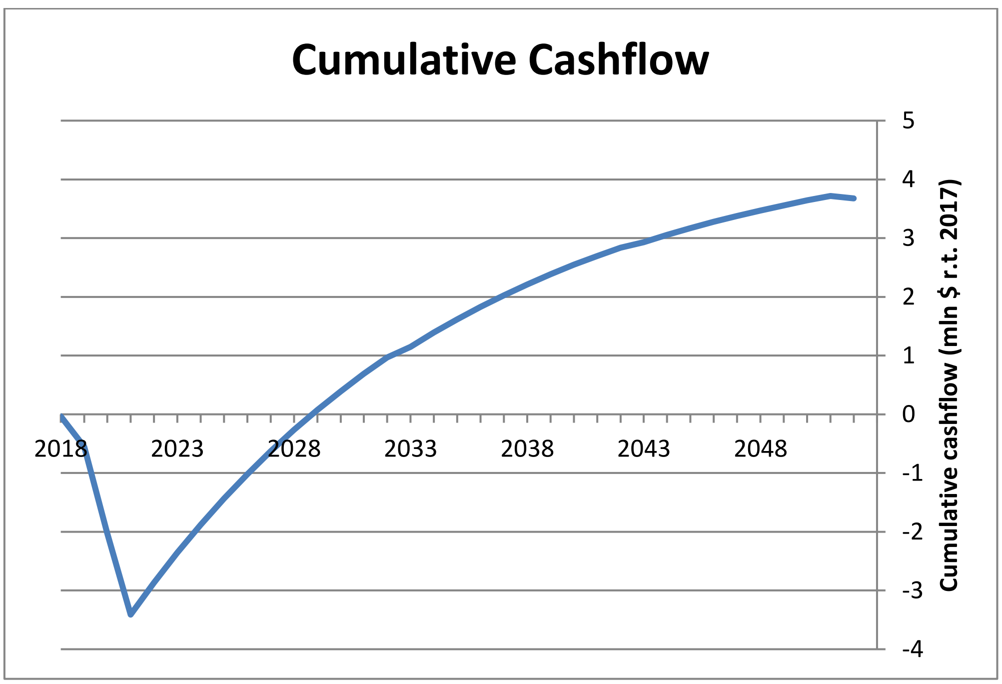


Figure 85: Cumulative Cashflow RO driven by OTEC

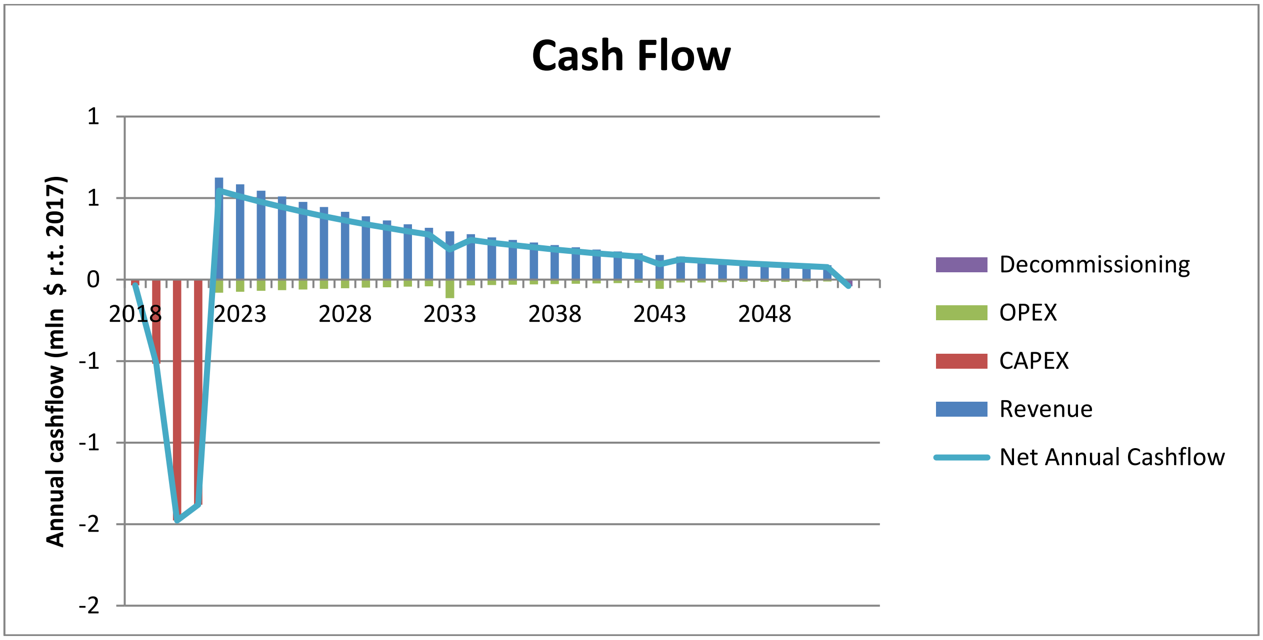


Figure 86: Cashflow RO driven by OTEC

The sensitivity and financial risk of the most important parameters is shown in Figure 87Figure 87. This tornado chart shows the most critical factors and their impact on the NPV. Negative percentages have a negative effect on you NPV and positive percentages a positive effect on you NPV.

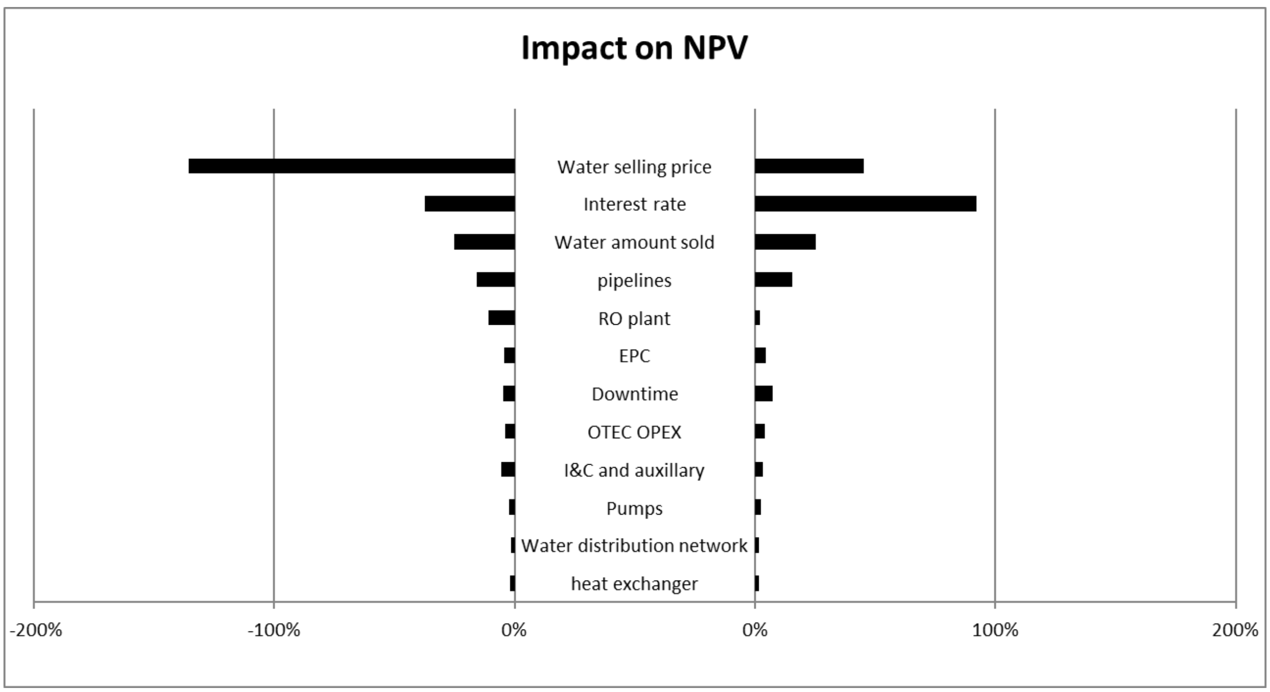


Figure 87: Tornado chart of RO driven by OTEC

The parameters with the highest impact on the NPV are:

- Interest rate
- Water selling price

A 7% interest rate is a conservative value when accessing the recent trends of interest rate development for Indonesia. Therefore, the chance of a lower interest rate is higher than a higher interest rate, this can also be identified in Figure 87**.** The water selling price has a large influence on the NPV, this is mainly due to the large uncertainty about the price. At the moment is expected that 7.5 $/m^3$ is a little bit too high drinking water price, however calculations show that, See also appendix for the complete analysis:

- Currently inhabitants pay \$0.22 for 2.5 litre of Danone drinking water daily.
- By increasing their daily expenditure with 2.6 they will spend \$0.57, this will provide them with 75 litre of drinking water from this plant.

So in short the inhabitants have to be willing to double their daily expenditure on drinking water and this plant will provide them daily with 75 litre of drinking water. Focus group on Bunaken island will give more insight on this topic.

In Table 23 are the results of the financial analysis summarised.

Plant lifetime	30 years
Water production price	7.5 $/m^3$
NPV	\$3.680.000
IRR	15.0%
Payback time	11 years

Table 23: Summary of the financial analysis

The largest financial risks of this concept are:

- Interest rate
- Drinking water selling price

To conclude, the this is deemed a risky investment, since a project like this has a favourable IRR of 35%. Comparing this solution to the solution including the electricity production showed three important things:

1. The impact of the drinking water selling price has less impact on the financial feasibility of the plant when electricity production is included.
2. Including electricity in the concept will probably gain support from the government since they are looking for a solutions dealing with both problems.
3. The business case is more favourable when only drinking water is sold.

So , as mentioned before this drinking waters' selling price is very uncertain and is it more favourable to lower the impact of this parameter. Next to that is support from the regional government important. Therefore the case including 350 m^3/day drinking water production combined with 80kw baseload electricity production is more favourable.

Appendix I: Comparison of drinking water production plants

From the MCA above, it is concluded that the most feasible option is to use cold deep seawater for a small island, the Bunaken. The Bunaken is taken as an example case study, as there are many more remote islands with similar problems in Indonesia. This subsection makes a comparison between different drinking water solutions for small remote islands in Indonesia.

I.1 Bunaken and small islands

For the comparison between different drinking water solutions, several assumptions are used that are summarized from chapter D.2.2:

- 3200 inhabitants at Bunaken
- 25 resorts
- 937 families
- Water demand 450 m^3/day
- Current RO plant 2.5 L/s can serve 800 families, but is at the moment not working.

For small islands the following freshwater resources can be identified. More can be found, but are not considered in this project, because they are just barely proven technologies.

- Freshwater well
- Rainwater catchment
- Dehumidification
- Desalination (groundwater and seawater)

I.1.1 Fresh water well

As mentioned in the need assessment, most of the fresh water wells deal with salt intrusion. These problems intensify during the dry season. A visit to a local village on the Bunaken showed that the well consisted of 440 PPM which is on the border of drinkable water. Next to that the water has to be boiled before consumption. As mentioned in appendix D.2.2 the use of fresh water wells is nowadays the most common source of fresh water on the Bunaken. However, during the dry season, these wells do not produce enough fresh water to supply everyone on the Bunaken. The expected growth of tourism will enlarge the fresh water extraction and will lead to more intrusion. So this so cannot be considered as a sustainable solution.

I.1.2 Rainwater catchment

Rainwater catchment is a common source of fresh water. The roofs of houses on Bunaken are designed to catch the water and direct it to storages tank. The water is not suited for direct consumption, so it has to be treated or boiled. Next to that is the source not reliable due to the presence of a dry and wet season and cannot provide all the current drinking water demand, so at the moment is insufficient and will be in the future.

I.1.3 Dehumidification

Dehumidification is a freshwater production method and the considered technology is explained in Appendix D4. Numerous different technologies can be found, but only this technology will be considered. A dehumidifier condenses air by cooling it down to its dew point. Important is that the air contains a lot of water and has all day long a high relative humidity. The humidity measurements at Bunaken island show. A well-known problem to dehumidification is the amount of water that can be obtained with such a system and the scalability. However, the system can produce all day long water and can be integrated with a OTEC installation. Due to the stable high humidity and temperature all year long can this technique be interesting for small remote islands and will therefore be considered in the next comparison.

I.1.4 Desalination

Desalination is the technique where the salt is removed from the water and fresh water is produced. As raw water source often brackish groundwater or seawater is used. Desalination is often implemented in arid regions, with a high fresh water demand. Next to that is it often implemented in remote areas and small islands which lack access to a freshwater resource.

Water desalination technologies can be divided in two categories; 1) thermal technologies and 2) membrane technologies. In both categories 1 technology is present with a large market share in 1) Multi Stage Flash with 27% and 2) Reverse osmosis with 60%. (IRENA & IEA-ETSAP, 2012)

Thermal technologies

The first method is Multi Stage Flash or MSF. Water is heated until 90-110 degrees Celsius and will flow through different stages with decreasing pressure. Due to the pressure differences water will quickly evaporate, also called flash. The water damp is condensed and collected. Next to that, the already available heat will be used to produce electricity. This method is commonly used in the Middle East, due to the low oil prices in this region, which makes it a financial feasible technology.

The positive and negative aspects of thermal technologies are summed up below (History of Water Filters, 2010):

Positive

- Removes bacteria, viruses and heavy metals
- Useful for heavily contaminated water

Negative

- Does not remove harmful chemicals with a lower boiling point than water like: pesticides, herbicides and chlorine solutions
- Very slow process
- Also removes natural trace elements, which negatively affects the taste and is not consumable.
- Heat sources often comes from fossil fuels
- Only feasible in combination with low oil prices

In the case of Bunaken is the oil price relatively high, because it has to be imported by small boats. Therefore, this type of desalination is not suitable for small islands with high oil prices. Next to that is it a non-sustainable way of drinking water production, since the heat mostly comes from fossil fuels.

Membrane technologies

The second one is Reverse Osmosis (RO), this technology is broadly discussed in Appendix D2. With over 15,000 RO plants worldwide, over 0.6% of the global drinking water comes from desalination with Reverse Osmosis. Almost 1% of the global energy consumption is used for desalination, while in 2012 only 1% of this share of energy comes from renewable resources. The rest comes from fossil fuels and are mostly powered by diesel generators in remote areas.

At the Bunaken already three RO plants are built, but due to lack of maintenance two of them are permanent out of function. On top of that is the third plant out of function at the moment, but local inhabitants think it will be fixed soon.

The positive and negative aspects of RO are summed up below (History of Water Filters, 2010), (Fritzmann, Lowenberg, Wintgens, & Melin, 2007):

Positive

- Removes bacteria and disease-causing pathogens
- Provides mineral free water
- Lower energy consumption than MSF

Negative

- Does not remove pesticides, herbicides and chlorine. Therefore carbon filter is needed.
- Removes healthy minerals, so post-treatment is necessary to add them
- Very slow process
- Large brine waste stream
- Biofouling of the membranes.

As mentioned are most of the current RO systems powered by electricity which mostly comes from fossil fuels. So at the moment the technology is not sustainable, but due to the following facts and developments water supply by using this technology becomes more interesting (IRENA & IEA-ETSAP, 2012):

1. The cost of RO desalination mostly depends on the price of the energy source
2. The increasing research and market for renewable energy
3. Depletion of freshwater resources creates the need for alternative sources

With an increasing market for renewable energy, desalination with renewables is a large market potential. Desalination powered by renewables can enable growth for local communities. The investment could reduce external, social, environmental and operational costs. The use of sustainable RO, or RO driven by sustainable energy will be further elaborated in the following section.

I.2 Comparison of concepts

In this section the most promising technologies from section I.1 are compared. In that section is found that dehumidification and sustainable RO could provide a solution for the current problems on an island and especially in the case in the case Bunaken.

For the technical and cost effectiveness assessment of renewable desalination, a variety of factors must be analyzed. For example the location, quality of the feed-water, available renewable energy source, plant capacity and the availability of grid electricity.

In total, four techniques are compared. For each technique, the pros and cons of the solution are summarized and the cost is estimated. For a fair comparison, it is assumed that the full 450m^3/day is produced by each different technique.

As there is not a lot of wind, wind energy solutions are not taken into account for this comparison. The end of this section concludes with a multi-criteria analysis to point out what solution is most feasible.

Diesel + RO

Pro’s

- Proven technology
- Reliable
- Constant energy input for RO
- Relatively easy to maintain for locals
- Scalability
- Compact
- No exhaustion of raw water sources

Con’s

- High CO2 emissions
- Salty waste
- Not self-sustaining
- Diesel must be shipped from mainland which means indirect environmental impact
- When the diesel generator stops producing power, the RO membranes become dry which is bad for the RO installation
- Noisy and smelly
- High salt concentration waste
- A diesel generator does not have a long lifetime, which causes the RO system to stop operating and will cause water shortages (Setiawan, et al., 2015)

Costs

- $300,000 onshore infrastructure cost
- RO plant
  - CAPEX $1.2 million (ALMAR water solutions, 2016)
  - 3 kWh/m^3 constant production (Al-Karaghouli & Kazmerski, 2010)
  - 0.35 $/m^3 OPEX (ALMAR water solutions, 2016)
- Diesel consumption 100% operational 4.8 gallon/hr (Diesel Service & Supply, sd). 24 hours a day 56 kw gives: $\frac{56}{60} * 4.8 * 24 = 410\ L/day$
  - Diesel price: 0.45 $/litre, every day a boat to the Bunaken is estimated on 37 $/day, including labor.
- Yearly OPEX Diesel generator 3% of CAPEX (Sarjiya, 2015)
- Yearly insurance 1% of CAPEX
- 7% interest rate
- 25 year lifetime (Setiawan, et al., 2015)
- 5% downtime
- Investing in the first 4 years
- Every 5 years OPEX 3 times as big for thorough maintenance
- 5% salvage cost

Solar PV + RO

Pro's

- Sustainable drinking water solution
- Self-sustaining
- Proven technology
- No moving parts in solar PV
- Big market
- No noise (solar PV)
- Applicable everywhere (on the island)
- Scalability
- No exhaustion of raw water sources
- Can be combined with sustainable energy production

Con's

- Battery storage necessary
- Fluctuating power input for RO
- Unpredictable power input for RO
- High maintenance demand
- Fragile/damaged easily
- Solar power requires cooling to maintain efficiency
- Solar PV encountered problems on Bunaken which caused higher cost than planned
- Large area required for solar panels
- High salt concentration waste

The main issue of PV desalination is the (still) high cost of PV cells and batteries for electricity storage. Careful maintenance and operation of battery systems are also necessary.

Costs

Assumptions:

- $300,000 onshore infrastructure cost
- RO plant
  - CAPEX $1.2 million (ALMAR water solutions, 2016)
  - 3 kWh/m^3 constant production (Al-Karaghouli & Kazmerski, 2010)
  - OPEX 0.35 $/$m^3$ (ALMAR water solutions, 2016)
- Installed solar PV capacity 280kW with a 20% capacity factor (IRENA, 2015)
- Solar PV
  - CAPEX Solar PV 4,100 $/kW (Sarjiya, 2015)
  - OPEX 5% of CAPEX yearly (Sarjiya, 2015)
- Yearly insurance 1% of CAPEX
- 7% interest rate
- 25 year lifetime (Setiawan, et al., 2015)
- 5% downtime
- Investing in the first 4 years
- Every 5 years OPEX 3 times as big for thorough maintenance
- 5% salvage cost

RO + OTEC (ROTEC)

Pro's

- High salt concentration waste is eliminated.
- Highly predictable
- Constant power input for RO
- Sustainable drinking water solution
- Self-sustaining
- Relatively low maintenance
- Low downtime
- No exhaustion of raw water sources
- Easy to monitor from a distance
- Almost no seasonal variation
- Can be combined with sustainable energy production/cooling

Con's

- High initial investment
- Not proven on large scale
- Limited locations to implement
- Possible environmental impact due to pipe laying
- Possible technical challenges with pipe installation
- No track record/trained people in less developed countries

- Cold water and warm water need to be discharged at a certain depth

Costs

Assumptions:

- $300,000 onshore infrastructure cost
- RO plant
  - CAPEX $1.2 million (ALMAR water solutions, 2016)
  - 3 kWh/m^3 constant production (Al-Karaghouli & Kazmerski, 2010)
  - 0.35 $/m3 OPEX (ALMAR water solutions, 2016)
- OTEC (OTEC cost data are available under Non-Disclosure Agreement with Bluerise B.V.)
  - Pump costs. (confidential)
  - Heat exchanger cost. (confidential)
  - Turbine cost. (confidential)
  - Pipes 1500 metre, . (confidential)
  - OTEC yearly OPEX. (confidential)
- Yearly insurance 1% of CAPEX
- 7% interest rate
- 30 year lifetime
- 5% downtime
- Investing in the first 4 years
- Every 10 years OPEX 3 times as big for thorough maintenance
- 5% salvage cost
- Offshore pipes decommissioning is 30% of CAPEX for pipes

Dehumidifier

Pro's

- No exhaustion of raw water sources
- Can be combined with sustainable electricity production/cooling
- No salt concentration waste
- Sustainable drinking water solution, when energy for the pumps is supplied by renewable source.
- Robustness

Con's

- Scalability
- High initial investment
- No track record
- Seasonal variation in relative humidity, thus production
- Difficult to predict humidity
- Limited locations to implement
- Cold water needs to be discharged at a certain depth
- Technical challenges in pipe installation
- Environmental impact due to pipe laying

Costs

- Capex (Provided by Bluerise BV.)
    - Cold deep water (CDW) pipe is calculated separately, with same method as RO + OTEC
- O&M 3% of Capex
- Yearly insurance 1% of CAPEX
- 7% interest rate
- 30 year lifetime
- 5% downtime
- Investing in the first 4 years
- Every 10 years OPEX 3 times as big for thorough maintenance
- 5% salvage cost
- Offshore pipes decommissioning is 30% of CAPEX for pipes

I.3 MCA

System	Weight	Diesel+RO	PV+RO	ROTEC	Dehumidifier
Technical feasibility	3	2	2	0	-1
Track record	2	2	1	0	-1
Scalability	2	2	2	1	1
Cost	5	2	1	-1	-2
Maintenance	4	-1	-1	1	1
Sustainability	4	-2	2	2	2
Environmental impact	3	-1	-1	1	1
Resupply rate	3	-2	0	1	2
Location applicability	2	2	1	-1	-1
Possibility to combine with other sustainable technologies	2	-2	1	2	2
Security of drinking water supply	2	2	0	2	2
Initial investment risk	1	2	1	-1	-2
Total		**9**	**23**	**20**	**12**

Cost, sustainability and security

Every sustainable concept positions itself within the Sustainable trilemma; 1) Costs, 2) security and 3) sustainability. A high score on these three aspects gives a technology a high chance of success. This research focusses mainly on the costs and sustainability of a concept and less on the security, since it is seen more as an opportunity than a must. For every concept cashflows are calculated and production prices are obtained, the scores indicate the difference in production prices. Every sustainable technology had the same score on sustainability. Solar PV + RO scored low on the security of the drinking water supply, since it depends on the sun hours per day. A week with few sun hours will automatically lead to lower production rates.

Maintenance

Maintenance is a key factor in the success of a project on the island, this followed from a meeting with PT. PLN Manado and Island inhabitants (Frets Pieters), see Appendix O12.

Technical feasibility

The technical feasibility indicates the number of technical challenges present with every concept. For technologies like solar PV and Diesel generator are these minimal, but for OTEC and dehumidifier are these fairly large.

Track record

A track record shows the status of technology and is important to gain trust from investors.

Scalability

The tourism is the main industry on the island. The focus of Manado is to increase the tourism to the region in this way the demand on the island could increase for the coming years. For this reason it is important that a technology is scalable.

Environmental Impact

For numerous small islands is fishing very important, therefore the environmental impact on marine live should be as low as possible. RO driven by a diesel generator and solar PV discharge locally the high salt concentration waste. This waste can have an impact on the marine live and thus unfavorable.

Resupply rate

Islands depend completely on transport by boat from mainland. First the equipment has to be prepared and sent to an island, which takes time and causes extra down time. For this reason a low resupply rate of the concept is a must.

Location applicability

Large differences can be found in the location applicability, since ROTEC and the dehumidifier require cold deep seawater close to shore.

Possibility to combine it with other sustainable technologies

Nowadays, more and more technologies try to deal with more than one problem, that is why the possibility to combine it with other sustainable technologies is added to the MCA.

Investment risk

At last the initial investment risk is considered. A technology with a high initial investment and low O&M cost is less attractive for investors than an investment with a low investment but high O&M costs, when considering the interest rate.

I.4 Conclusion

From the MCA and the financial analysis it may be concluded that for small scale drinking water production RO in combination with solar PV is the best solution. The reliability of the concepts is not completely favorable, nevertheless it scores high on other aspects such as cost and scalability. ROTEC is seen as a good second option, the solution provides a constant reliable drinking water source. However it lost a lot of points on the costs of the solution due to the high initial investment and the high production cost of the water. The dehumidifier is ranked third. A standalone dehumidifier is an expensive solution with again a high initial investment. The technology scored on many criteria the same as the ROTEC concept, but due to the absence of an existing project it scored less on technical feasibility and track record. The lowest ranked option is the RO driven by a diesel generator. This is mainly due to the high resupply rate of the technology and the fact that it is not sustainable. However, in the case of Bunaken it is the cheapest option. Next to that diesel generators need high maintenance and thus scored lower on this criterium. So in short small scale sustainable drinking water production on the Bunaken can best be done with RO driven by solar PV.

Now the question is which markets are accessible with drinking water production by using cold deep sea water.

As mentioned before ROTEC will become more feasible when the scale of the plant increases. To be precise it depends on the diameter of the pipe, since this component is a large part of the CAPEX. The diameter of the pipe can be increased by increasing the scale of the drinking water production plant, next to that it can be increased by using cold deep seawater for other processes like energy production. So another option is increasing the cold water pipe diameter and use a part of the available cold deep seawater for producing drinking water and a part for production of energy. This could be a very interesting case since numerous remote islands deal with a deficiency in energy and freshwater at the same time. Increasing the pipe diameter and use the cold deep seawater for two processes can lead to a financial feasible drinking water and energy production plant. More detail about the scaling of a ROTEC plant can be found in Appendix J.

Appendix J: ROTEC plant scaling

In this assessment, the cost for different sizes of plants for standalone drinking water with RO and OTEC are compared for both Manado and Bunaken. The site specific conditions for these locations are taken into account as a case study. The cost is estimated by making use of industry expertise and literature.

The assumptions for the financial assessment are similar to those in Appendix H3. However, the CAPEX differs over the assessment as the investment is higher for higher production rates. For Manado, the horizontal distance for the cold water pipe is 1700m, that will reach to a depth of 400m, where the water is 8.5°C. The warm water is pumped up at 28.5°C with a pipe length of 50m and a mixed discharge pipe length of 450m. For Bunaken, 8.5°C is found at a distance of 850m offshore at a depth of 365m. The warm water pipe is 220m and the discharge pipe is assumed to be 335m.

For Manado, the production rate is scaled from 100m3/day up to 5000m3/day. The results are summarized below.

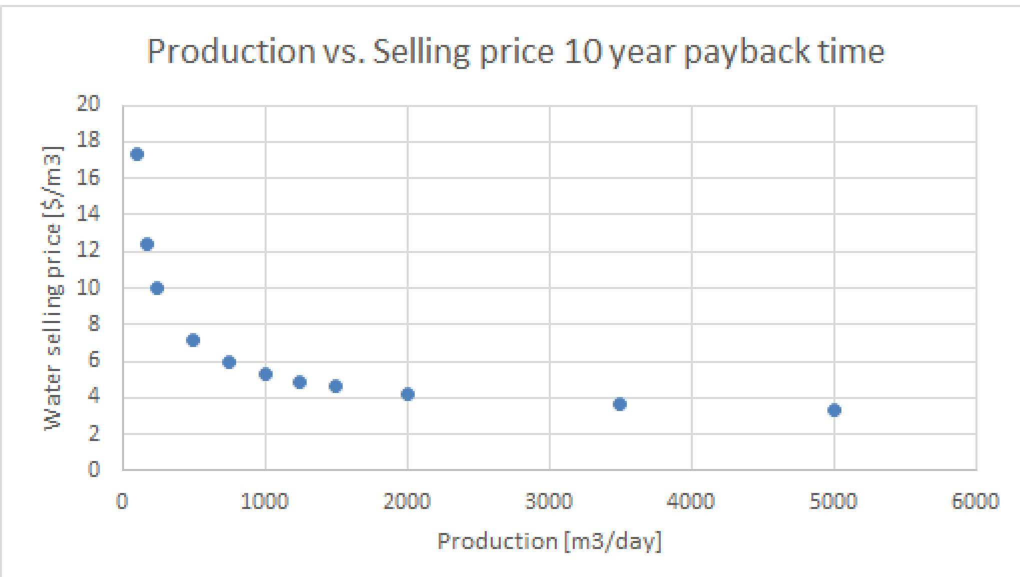


Figure 88: Production vs. Selling price for a 10 year payback time in Manado

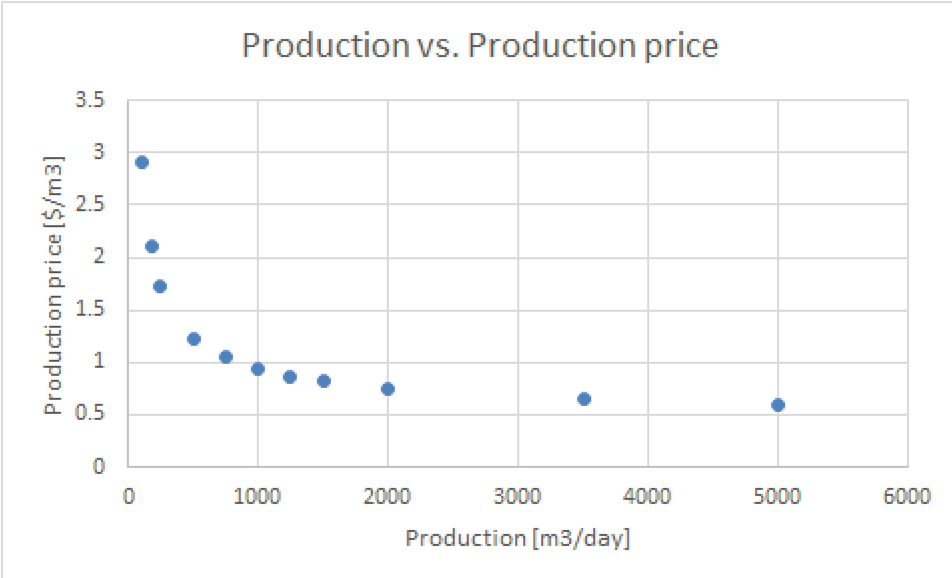


Figure 89: Production vs. Production price for a 10 year payback time in Manado

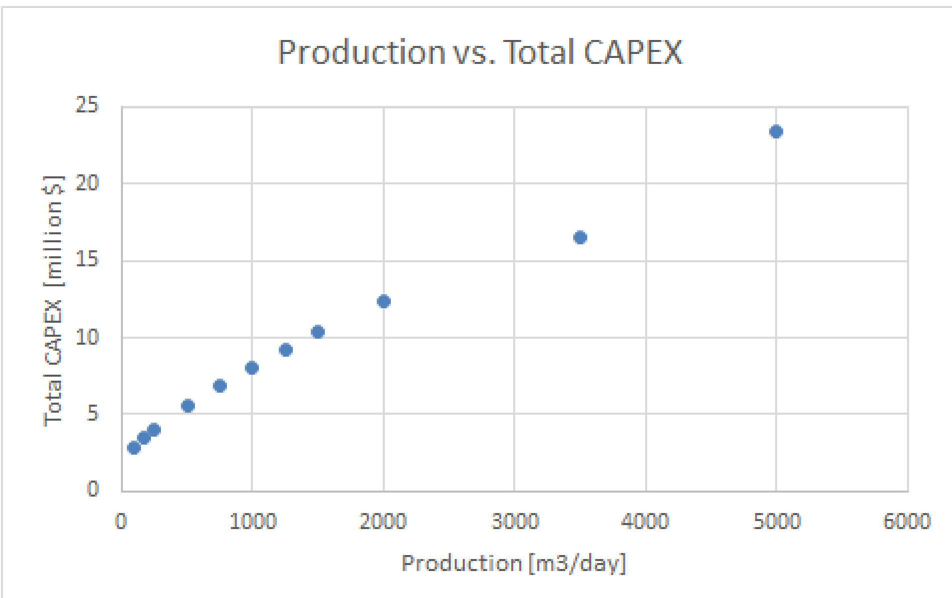


Figure 90: Production vs. total CAPEX for a 10 year payback time in Manado

For Bunaken island, the production rates are varied from 100m3/day to 500m3/day. The higher production rates are way too high for the island's needs but are taken as a reference as there are many similar islands in the world with similar drinking water problems. The results are summarized below.

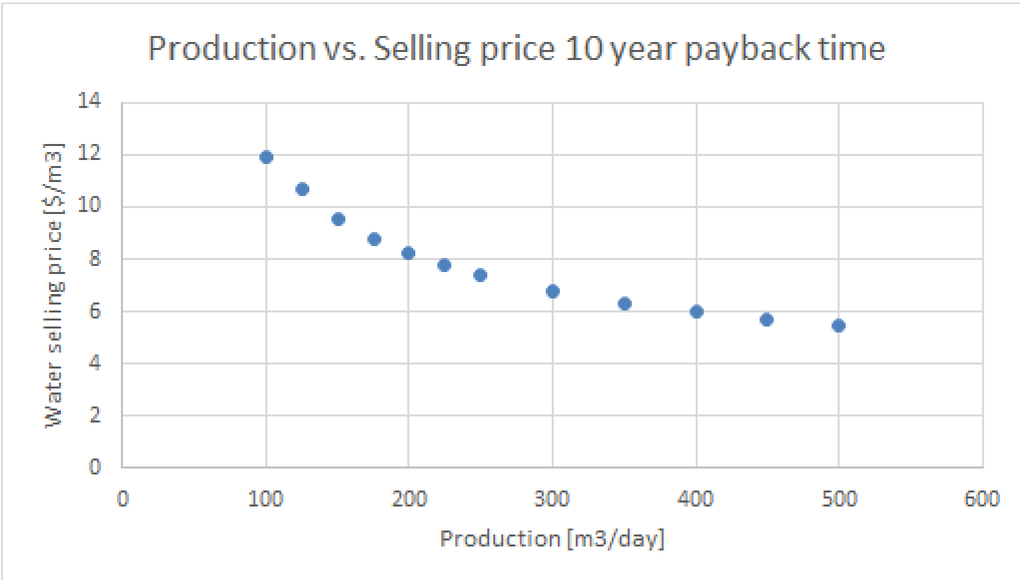


Figure 91: Production vs. Selling price for a 10 year payback time in Bunaken

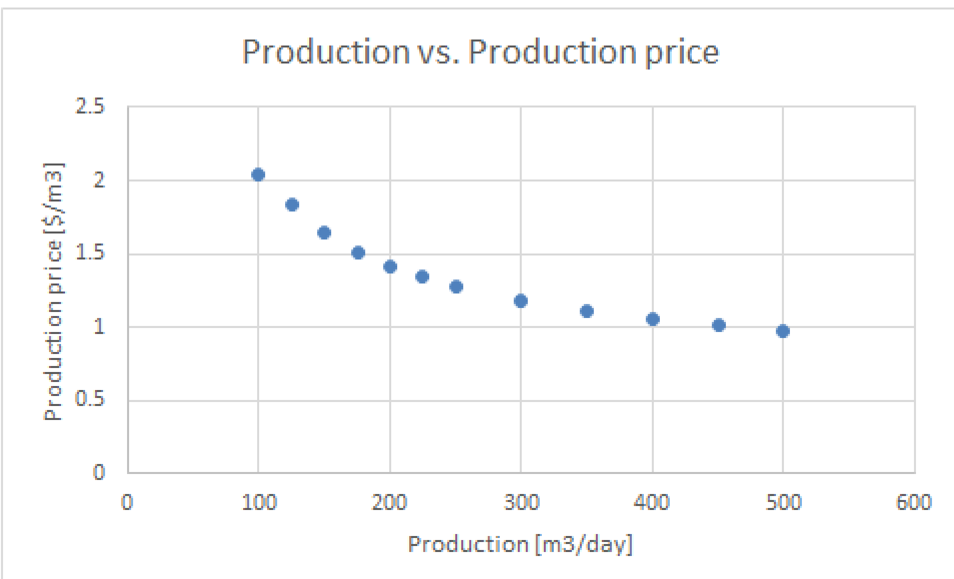


Figure 92: Production vs. Production price for a 10 year payback time in Bunaken

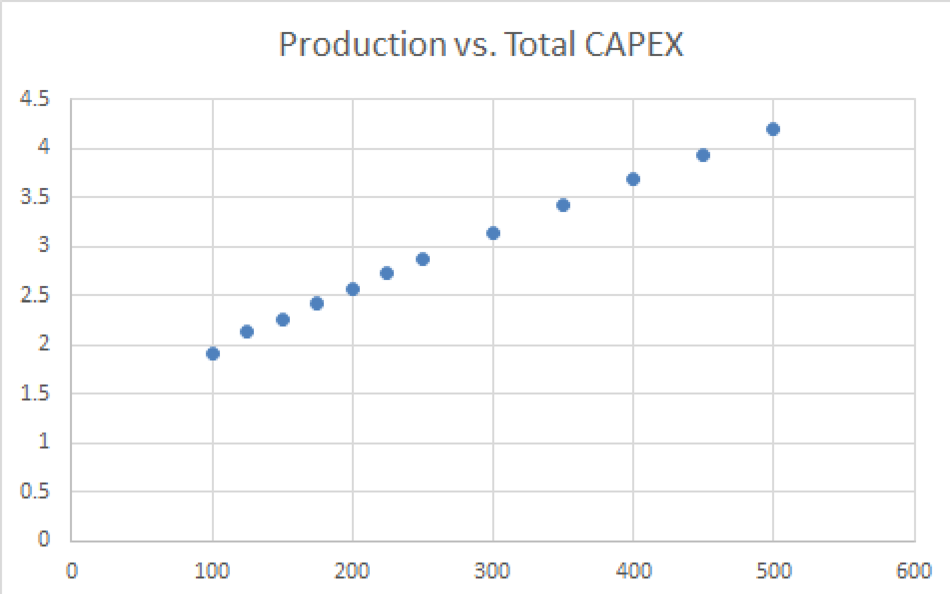


Figure 93: Production vs. total CAPEX for a 10 year payback time in Bunaken

Conclusion

For Manado, from a production of approximately 1000m3/day and higher, the production price decreases relatively linearly. So the biggest scaling effect is partly diminished. For a production lower than 1000m3/day, the price is relatively high and the scaling has a large effect on the financial feasibility. This means that it would be favorable to build a large scale plant of 1000m3/day or higher to be financially most feasible. However, from the need assessment of Manado, it followed that there is not necessarily a lack of drinking water, and the biggest problem is the distribution network. Therefore this solution is not yet feasible for now. If the cost of OTEC and RO decrease in the future and the distribution network would be cleaner and better developed, such that ready to drink water can be supplied at the tap, this would be worth considering.

For Bunaken island, there is a relatively linear decrease of the water production price and water selling price after 300m3/day. The selling price would be below 7$/m3 with a production price lower than 1,20/m3.

Thus, it is more favorable to go for a higher scale but the scale from where the scaling effect is less important, depends on the location. Also, the production has to meet the need. But it can be concluded that small scale production facilities, below approximately 200m3/day that combine RO and OTEC are not financially attractive.

Appendix K: Assessment drinking water selling price for Bunaken Island

In order to verify the assumption of a 7.5 $/m^3$ drinking water price some calculations are made. First the current sources of (drinking) water are summed up:

	Resource	Cost	Quality	Availability
1	Rainwater catchment	Free	Medium - not consumable	Medium
2	Private groundwater well	Not available	Low - cooked before consumption	Medium - salt intrusion in dry season
3	Danone drinking water - Gallon 19L	IDR 20000-25000	High	High
4	Connection to groundwater well	Depends per well Seagarden resort: 3000000 IDR/month	Medium - not always consumable	High

Table 24: Summary all freshwater resources Bunaken island

First identified customers are the villagers of Bunaken village. They mostly use the combination of rainwater catchment or private groundwater well and Danone drinking water Gallons. Since the price of private groundwater wells and rainwater catchment is hard to predict, only the price for Danone drinking water is used.

Assumptions: a person in Indonesia has to drink between 2.1 L - 4.0 L drinking water a day. For now is assumed they will consume 2.5 L of Danone drinking water. Next to that, the aimed consumption of the citizens is 75 L/day in order to realize the business case mentioned in appendix H3.

What	Amount [L]	Cost [IDR]	Cost [$]
Danone gallon	19	22500	1.67
Average daily drinking water consumption Indonesian person - Danone	2.5	2961	0.22
Concept plant Project ROTEC	1000	101250	7.5
Average daily drinking water consumption Indonesian person - concept plant Project ROTEC	2.5	253	0.015
Aimed consumption inhabitants - concept plant Project ROTEC	75	7594	0.56

Table 25: Current expenditure on Danone drinking water

So if the inhabitants increase their expenditure on drinking water by 0.56/0.22 = **2.6** then they will receive 75/2.5 = **30 times** more drinking water. Which can be used for consumption, washing, cooking and showering.

Second the drinking water consumption of resorts is investigated. For this calculation information provided by Bunaken Seagarden resort is used. They pump water from another well owner, they are going to pay 3000000 IDR/month. Important assumptions:

- Average water use customer/tenant: 100 L/day
- Average yearly occupation resort: 7 persons/day

Water consumption resort	Amount [L]	Amount [m^3]	Cost [IDR]	Cost [$]
Daily	700	0.7	98361	7.3
Monthly	21350	21.35	3000000	222
per m^3	1000	1	141515	10.4

Table 26: Current expenditure resorts on freshwater

From Table 26 follows that Bunaken Seagarden resort spends **10.4 $/m^3$** fresh water which cannot be consumed. Next to that they have to install their own pump to distribute the water, which is not taken into account yet. In short 10.4 $/m^3$ is above the Project ROTEC concept plant selling price, therefore it is interesting to connect resorts to the water supply system.

Appendix L: Pipe dimension calculations

L.1 Offshore pipeline

To determine the diameter needed for the offshore pipeline, some basic calculations can be used. The parameters in Table 27 need to be used.

Table 27: Parameters used for offshore pipe diameter calculations

Parameter	Symbol	Value
Offshore pipeline internal Diameter (in m)	$D_{i,off}$	-
Cold seawater flow velocity (in $\mathrm{m}/_\mathrm{s}$)	v_{sw}	1.5
Volume velocity cold seawater (in $\mathrm{m}^3/_\mathrm{s}$)	$\dot{V}_{sw}$	-
Temperature cold water inlet (in °C)	$T_{sw,in}$	7
Temperature cold water outlet (in °C)	$T_{sw,out}$	13
Density of cold seawater (in $\mathrm{kg}/_{\mathrm{m}^3}$)	ρ_{sw}	1030
Specific heat capacity of seawater (in $\mathrm{J}/_{\mathrm{kg}\cdot\mathrm{K}}$)	C_{sw}	4186
Cooling peak load (in ton)	$L_{cool,ton}$	13500
Cooling peak load (in MWt)	$L_{cool,MW}$	-

The internal diameter of the offshore pipeline can be calculated using the following formula.

$$D_{i,off} = \sqrt{\frac{\frac{\dot{V}_{sw}}{v_{sw}}}{\pi}} \cdot 2$$

In here, the flow velocity is a value that needs to be chosen. The volume velocity however should be determined using the following formula:

$$\dot{V}_{sw} = \frac{L_{cool,MW} \cdot 10^6}{(\Delta \mathrm{T} \cdot \rho_{sw} \cdot C_{sw})}$$

Where:

$$\Delta T = (T_{sw,out} - T_{sw,in}) = 6°\mathrm{C} = 6\mathrm{K}$$

And:

$$L_{cool,MW} = \frac{L_{cool,ton} \cdot 3.517}{1000} = 47.48\ MWt$$

Now the volume velocity can be determined:

$$V_{sw} = \frac{47.48 \cdot 10^6}{6 \cdot 1030 \cdot 4186} = 1.84\ {}^{m^3}/_{s}$$

Having all values $\mathrm{D_{i,off}}$ can be found:

$$D_{i,off} = \sqrt{\frac{\frac{1.84}{1.5}}{\pi}} \cdot 2 = 1.25\ m$$

L.2 District cooling pipelines

To determine the diameter needed for the district cooling pipelines, some basic calculations can be used (similar to the calculations for the offshore pipeline). However, since two cooling loops will be needed, the calculations need to be done twice. The loops will be named $\mathrm{Loop_{north}}$ and $\mathrm{Loop_{south}}$. The relevant parameters are displayed in Table 28.

Table 28: Parameters used for offshore pipe diameter calculations

Parameter	Symbol	Value
District pipeline internal Diameter $\mathrm{Loop_{north}}$(in m)	$D_{d,north}$	-
District pipeline internal Diameter $\mathrm{Loop_{south}}$(in m)	$D_{d,south}$	-
District water flow velocity (in ${}^{\mathrm{m}}/_{\mathrm{s}}$)	v_{dis}	1.5
Volume velocity district water $\mathrm{Loop_{north}}$ (in ${}^{\mathrm{m}^3}/_{\mathrm{s}}$)	$\dot{V}_{d,north}$	-
Volume velocity district water $\mathrm{Loop_{south}}$ (in ${}^{\mathrm{m}^3}/_{\mathrm{s}}$)	$\dot{V}_{d,south}$	-
Temperature district cooling water inlet flow (in °C)	$T_{d,in}$	8
Temperature district cooling water return flow (in °C)	$T_{d,return}$	14
Density of fresh district cooling water (in ${}^{\mathrm{kg}}/_{\mathrm{m}^3}$)	ρ_{dw}	1000
Specific heat capacity of district cooling water (in ${}^{\mathrm{J}}/_{\mathrm{kg} \cdot \mathrm{K}}$)	C_{dw}	4186
Cooling peak load $\mathrm{Loop_{north}}$ (in ton)	$L_{north,ton}$	4600
Cooling peak load $\mathrm{Loop_{south}}$ (in ton)	$L_{south,ton}$	8900

Cooling peak load $\mathrm{Loop_{north}}$ (in MWt)	$L_{north,MW}$	-
Cooling peak load $\mathrm{Loop_{south}}$ (in MWt)	$L_{south,MW}$	-

The internal diameters for the two district cooling loops can be defined as follows:

$$D_{north} = \sqrt{\frac{\frac{\dot{V}_{d,north}}{v_{dis}}}{\pi}} \cdot 2$$

$$D_{south} = \sqrt{\frac{\frac{\dot{V}_{d,south}}{v_{dis}}}{\pi}} \cdot 2$$

In here, the flow velocity is a value that is chosen according to several assumptions. The two volume velocities are determined using the following formula:

$$\dot{V}_{d,north} = \frac{L_{north,MW} \cdot 10^6}{(\Delta \mathrm{T}_d \cdot \rho_{dw} \cdot C_{dw})}$$

$$\dot{V}_{d,south} = \frac{L_{south,MW} \cdot 10^6}{(\Delta \mathrm{T}_d \cdot \rho_{dw} \cdot C_{dw})}$$

Where:

$$\Delta T_d = (T_{d,return} - T_{d,in}) = 6°\mathrm{C} = 6\mathrm{K}$$

And:

$$L_{north,MW} = \frac{L_{north,ton} \cdot 3.517}{1000} = 16.18\ MWt$$

$$L_{south,MW} = \frac{L_{south,ton} \cdot 3.517}{1000} = 31.30\ MWt$$

Now the two volume velocities can be determined:

$$\dot{V}_{d,north} = \frac{16.18 \cdot 10^6}{6 \cdot 1000 \cdot 4186} = 0.64\ {m^3}/{s}$$

$$\dot{V}_{d,north} = \frac{31.30 \cdot 10^6}{6 \cdot 1000 \cdot 4186} = 1.25\ {m^3}/{s}$$

Having all values $D_{d,north}$ and $D_{d,south}$ can be found:

$$D_{d,north} = \sqrt{\frac{\frac{0.64}{1.5}}{\pi}} \cdot 2 = 0.74\ m$$

$$D_{d,south} = \sqrt{\frac{\frac{1.25}{1.5}}{\pi}} \cdot 2 = 1.03\ m$$

Appendix M: Data

Appendix M1: Conductivity, Temperature & Depth Measurements

M.1.1 Equipment

During this research equipment from the Netherlands was brought in order to perform measurements to validate assumptions. First the different components of the equipment are summed up, subsequently the specifications are given, see Table 29.

Table 29: Equipment specifics of equipment supplied by Seabed.

No.	Description	Range	Accuracy
1	AML Oceanographic Minos X CTD unit	Up to 6000 m	
2	Temperature sensor	-2°C - 32°C	+/- 0.005°C
3	Pressure sensor	0 – 1000 dbar	+/- 0.50 dbar
4	Conductivity sensor	Up to 70 mS/cm	+/- 0.01 mS/cm

The Minos X (see Figure 94) can be used in extreme environments as shown in Table 29. It contains hardware which stores the data during the measurements and can easily be withdrawn after measurements by using SeaCast software. This software can also be used to change the Minos X settings. The sampling frequency can be changed up to 25 Hz or to 0.01 dbar and greater. In total three sensors can be installed on the Minos X. In this survey only the above mentioned sensors are used, however the conductivity sensor is exchangeable with a sound velocity sensor.

Figure 94: Minos X CTD unit with three sensors

Table 30: Equipment supplied by Bluerise and others. (Stress Free Marine, 2017)

No.	Description	Load
5	Stress Free Marine Deep sea fishing rod	max. 36 kg
6	Stress Free Marine electric fishing winch (retrieval rate: 45 – 60 m/min)	max. 150 kg
7	1600 m Dyneema wire	max. 90 kg
8	Though Book laptop	
9	Battery, 45 Ah	

To lower the Minos X to the required depth, deep sea fishing equipment will be used. The equipment is supplied by Bluerise B.V. and manufactured/distributed from Stress Free Marine, see Table 30. To haul in the line an electric winch can be used which is powered by 12 V batteries. Total weight attached to the deep sea fishing equipment is approximately 5 kg.

M.1.2 Measurement specifications

To optimize and investigate the feasibility of a cold deep water pipe, data about the ocean's temperature, salinity and density is needed. It is expected that the favourable temperature of 4 ∘C can be found around a depth of 800 m. However, data from Fugro N.V. shows that it might be possible to find the cold water less deep. Therefore Msc. student project ROTEC will perform measurements until a depth of approximately 1000 m.

M.1.2.1 Vessel

To execute the measurements a vessel to transport divers will be used, this vessel gives us sufficient workspace and protection against sun and rain. A mount for the equipment is constructed by the captain in cooperation with team ROTEC, see Figure 95. During the measurements one captain will come along and will try to keep the vessel in position during the measurements.

Figure 95: Mount for the equipment

M.1.2.2 Sampling frequency

The lowering velocity of the Minos X CTD unit is hard to control, therefore the sample frequency will be set on 0.3 dbar. This means that approximately every 0.3 m a data point is created. It is important to not exceed the maximum sample frequency of 25Hz, so do not lower the Minos X CTD unit faster than 12.5 m/s. Experience shows that it is not the case. With 0.3 m as sample frequency some information is lost close to the surface where the conditions change rapidly.

M.1.2.3 Location

The potential locations follow from the need assessment. Subsequently, the least lateral distance to deep water (according to Hidro Oseanografi TNI-AL) is used and this distance will be divided in measurements at three different depths (approx. 1000m, 500m, 250m). This will determine the survey locations. During the measurement it is important to keep the vessel as close as possible to the specified coordinate. Some drift of 100 meter is allowed. The location of the vessel will be controlled and tracked by the GPS on at least two cell phones. The two GPS outputs will be compared.

M.1.2.4 Output

As stated before SeaCast software will be used to configure prior to the measurements and data withdrawal after a measurements from the Minos x CTD. The output is;

- Conductivity (mS/cm)
- Temperature (°C)
- Pressure/depth (m) (1 dBar = 1.01974m)
- Voltage of battery (V)

All values can directly be converted by the CTD head to:

- Salinity (ppt/psu)
- Density (kg/m^3)
- Sound velocity (m/s)

Before every measurement the CTD-head's calculation channels must be turned on, in order to unlock the calculation. Salinity is calculated from temperature, depth and conductivity, density from temperature and salinity, and sound velocity from temperature, salinity and depth.

Table 31: Range and error of calculated parameters

No.	Description	Equation	Range	Accuracy
1	Salinity	EOS80	0 to 42 ppt	+/- 0.025 ppt
2	Density	EOS80	990 to 1230 kg/m^3	+/- 0.027 kg/m^3
3	Sound velocity	NRLII	1375 to 1650 m/s	+/- 1 m/s

This indicates that the calculation of sound velocity is a combination of measurement errors and calculation errors, since two empirical equations are used for the calculation of sound velocity (one to calculate salinity). Next to that, each of the sensors has a different response time that can add up to the error, see Table 31. Still, it can be stated that the sound velocity calculated from CTD gives similar values, but with a margin and peaks are mostly flattened out.

Response time

The sensors know a different response time, see Table 32.

Table 32: Response time of the different sensors.

Sensor	Response time [ms]
Conductivity	25
Temperature	100
Depth	10

This miss-match in response time can result in spikes in the calculated parameters. This can be observed at the graphed pycnoclines and haloclines. It takes a little longer for the conductivity sensor to adjust to the correct sensor value in a new water layer than the temperature sensor. The magnitude of these spikes depends on the response time miss-match.

Down- and upcasting

Down casting and upcasting may give different results during measuring. This can be assigned to the response time of the sensors and causes mainly different results between down casting and upcasting at haloclines and pycnoclines. This indicates that a difference in depth of a thermocline is caused by the time response of the temperature sensor.

M.1.3 Results

The goal of the measurements is to verify different environmental conditions close to Manado and Bunaken Island, to assess the accessibility of water suitable for drinking water, cooling and electricity production. This is done by verifying the depth (pressure), measuring the conductivity and temperature. These results are used to determine the salinity, density and sound velocity of the water layers. Especially the temperature and salinity are discussed in this section, in order to assess later the different production methods. The measurements were performed around the transition period from dry to wet season (September).

M.1.3.1 Measurement locations

Since Bunaken and Manado are the main areas of interest in this research, several measurement points are determined beforehand. This resulted in the measurement locations, presented in Figure 96, Figure 97 and Table 33.

Figure 96: overview of the measurement locations

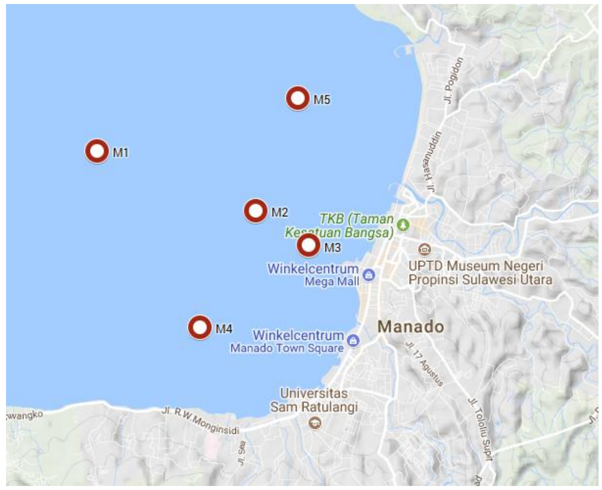


Figure 97: Measurement locations around Bunaken and Manado bay

Table 33: Initial specifics of measurement points

Measurement point	Coordinate [decimal]	Estimated depth [m]
M1	1.5056N; 124.7869E	1000
M2	1.4952N; 124.8149E	500
M3	1.4891N; 124.8241E	200
M4	1.4747N; 124.8050E	330
M5	1.5148N; 124.8222E	250
B1	1.6050N; 124.7481E	500
B2	1.6125N; 124.7483E	200
B3	1.5904N; 124.7429E	700

The south part of Bunaken, has the easiest accessibility of deep sea water according to maps. It has the lowest current and has at some location a more gradual slope then at other parts of the island. It was decided to conduct three measurements here at different distances from shore with different depths. Manado Bay has, compared with Bunaken at all locations a gradual slope and has along the coastline a lot of facilities. For that reason it is chosen to verify several locations along the coast and some at a certain distance.

M.1.3.2 Manado Bay

The measurements for Manado show similar results and the most important observations are described as follows.

Temperature

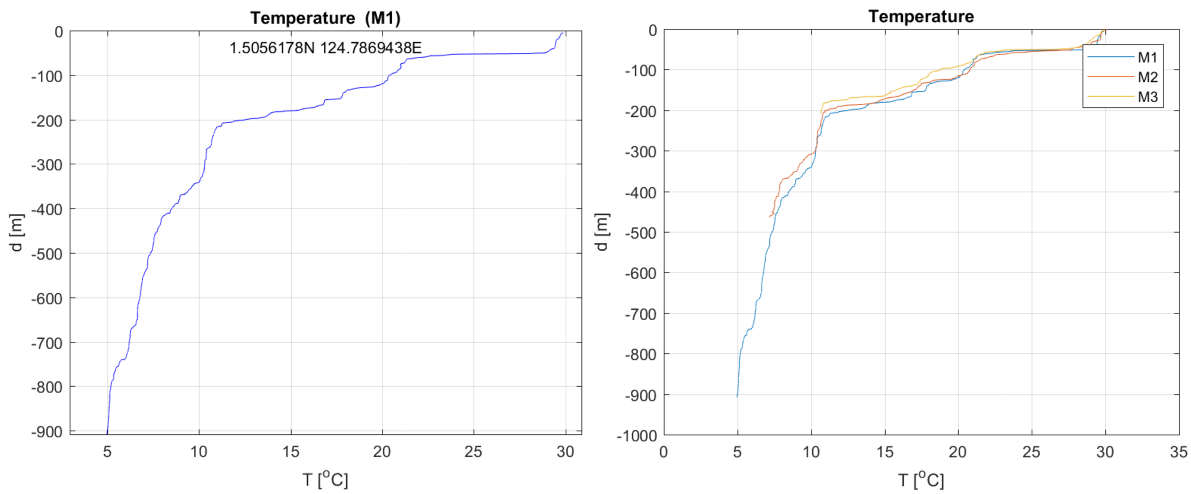


Figure 98: Temperature profile in Manado Bay

In the profile over the vertical several thermoclines can be observed, see Figure 98. The most present is at 50 meter depth, where the temperature decreases suddenly from 29 to 21 degrees Celsius. At 170 meters depth the temperature makes a rapid decrease again from 16 to 11 degrees Celsius. 10°C, 7°C and 5°C are reached at a depth of respectively 310, 550 and 850 meters.

When comparing the temperature measurements at different distances from shore, it can be seen that the water closer to shore is slightly colder after a depth of 100 meter. This could indicate coastal upwelling in Manado bay. By combining the results of the measurements, an approximation of the temperature in the bay is made. See Figure 99.

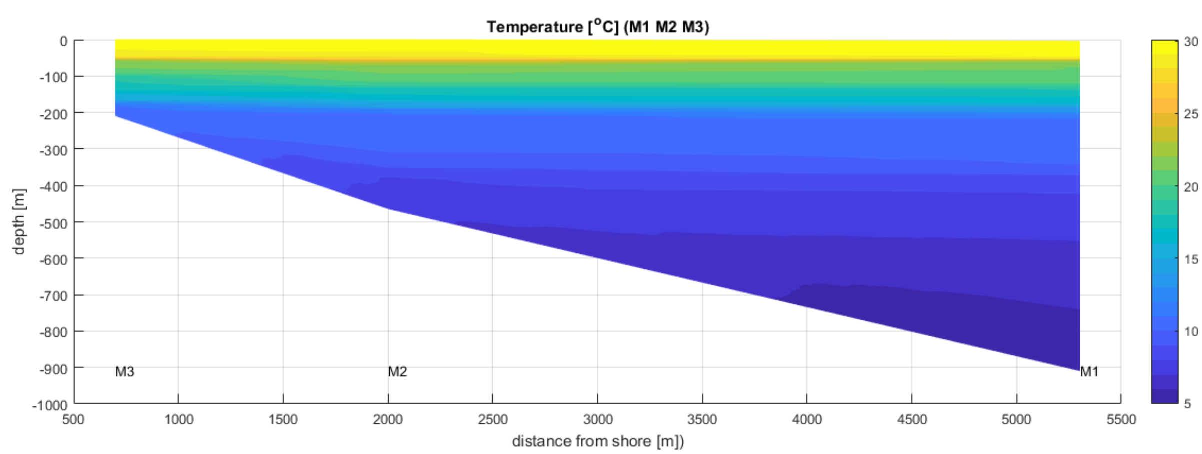


Figure 99: Interpolation of measured temperature profile results of M1, M2 and M3.

Salinity

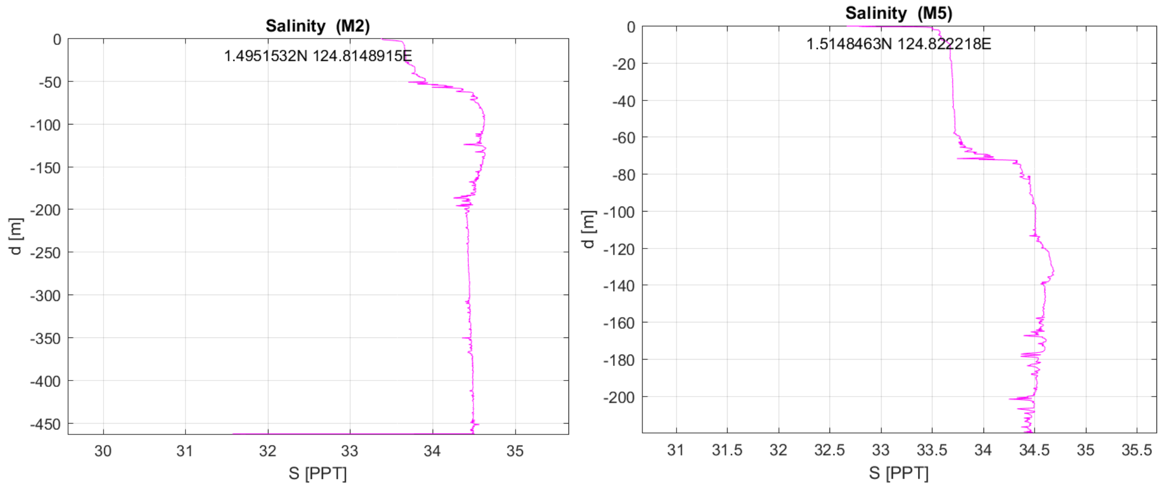


Figure 100: Salinity profile in Manado Bay

The salinity, see Figure 100, calculated from temperature and conductivity, shows a lower salinity (33PPT) close to the surface of the sea. This is due to the impact of rainfall, river outflow from Manado and the sinking of saltier (denser) water. The salinity increases slowly over depth until the halocline at 50-60 meters depth is reached. The salinity makes a jump from 33.7ppt to 34.6ppt and varies a lot till a depth of 200 meters. Where after it stays nearly constant 34.4ppt. At measurement point M5 the halocline is observed deeper (at 75 meters) than at the other locations. An explanation is that the point is close to the river mouth of Tondano river and currents moving in the direction of M5.

Also for the salinity a cross section of the bay can be drawn, see Figure 101.

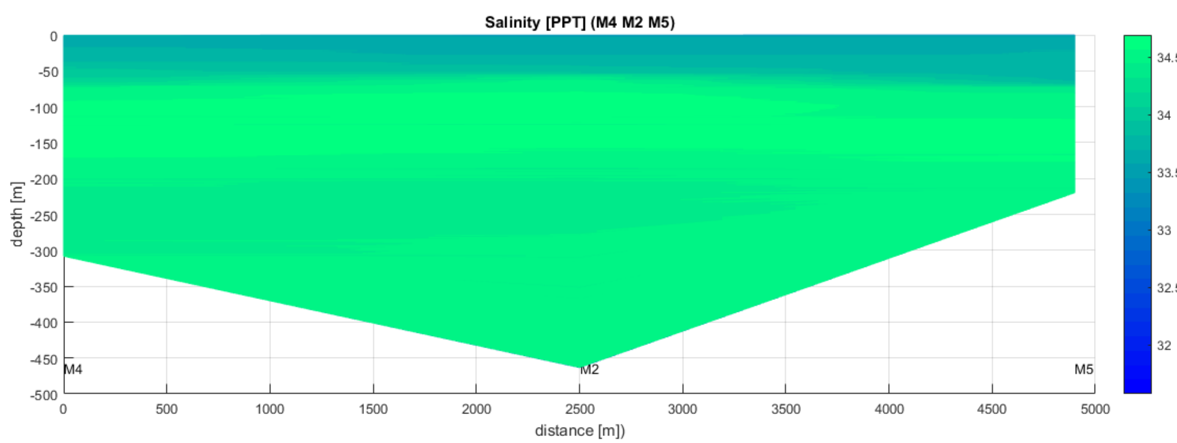


Figure 101: Interpolation of measured salinity profile results of M4, M2 and M5.

Density

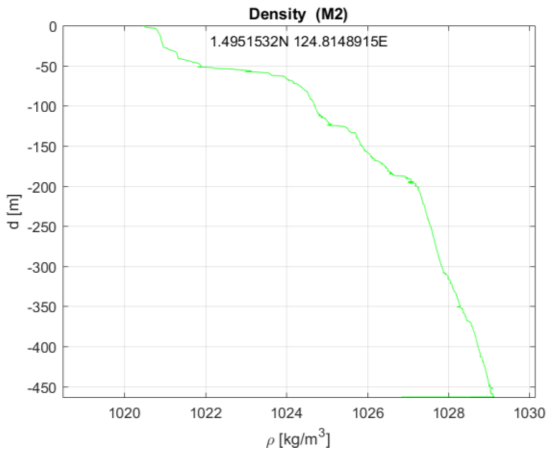


Figure 102: Density profile in Manado Bay

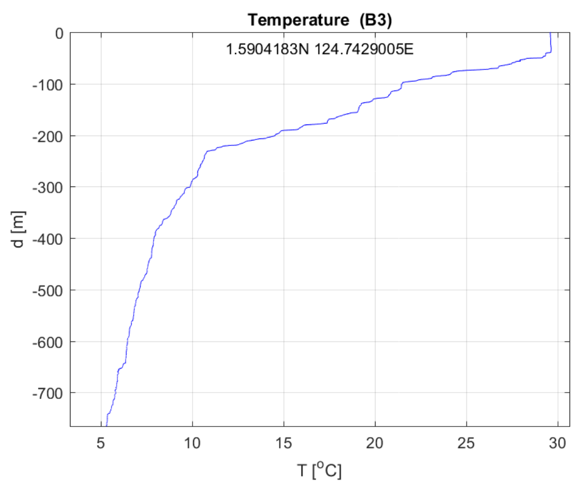
The density at the surface in Manado bay is approximately 1020 kg/m^3 and increases slowly until its pycnocline at 50-60 meters (at point M5 at 75 meters) of depth where density increases from 1021 to 1024 kg/m^3, see Figure 102.

Other less significant pycnoclines can be observed at 130 and 180 meters depth with a rise of 0.5 kg/m^3. After that a linear increase of density can be observed, until temperature and salinity have reached a constant value.

M.1.3.3 Bunaken

The measurements for Bunaken are described in this part.

Temperature



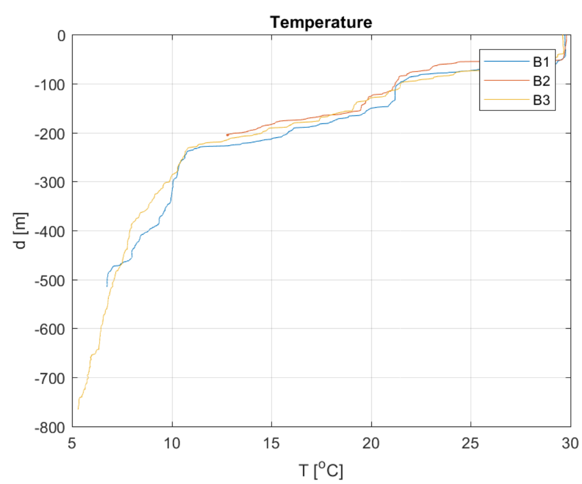


Figure 103: Temperature profile at Bunaken

In Figure 103, South of Bunaken it can be observed that a thermocline can be found from a depth of 50 meters, the water temperature drops from 29°C to 22°C. Between 150-220 meters the temperature decreases rapidly from 19°C to 11°C. The further from shore the thermoclines are less noticeable. Deeper than 220 meters the temperature slowly decreases towards 5°C. In this case it can also be said that the upper colder water layers are less deep closer to shore. (B2 closest to shore). This indicates upwelling of the deeper layers, see Figure 104.

A temperature difference of 20°C compared to the surface temperature can be found at a depth of 350 meters. Temperatures of 10°C, 7°C and 5°C can be found at respectively 300, 500 and 800 meters depth.

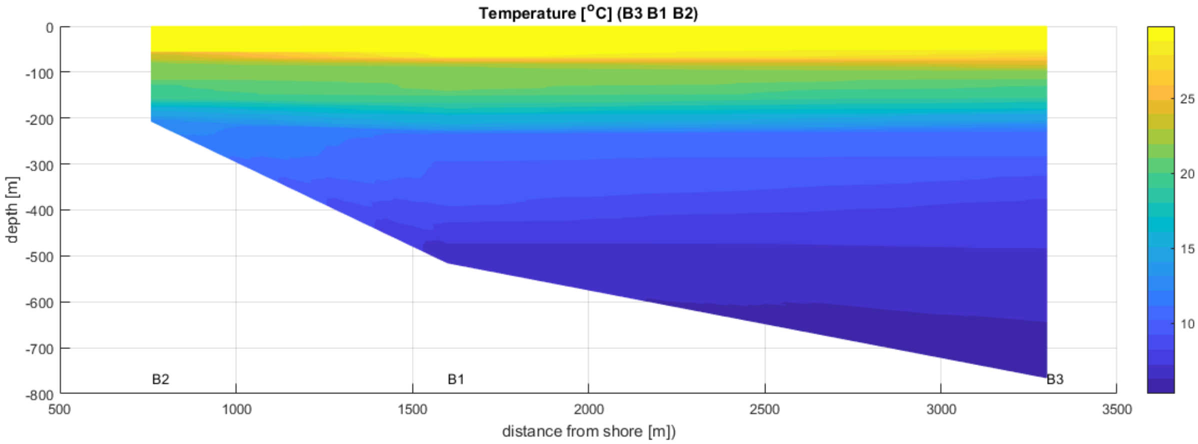


Figure 104: Interpolation of measured temperature profile results of B3, B1 and B2.

Salinity

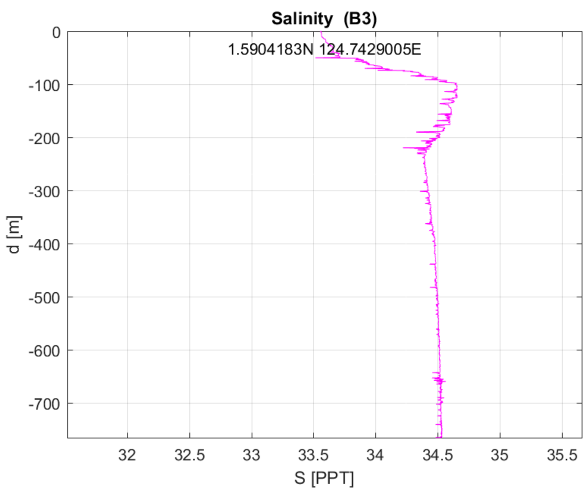


Figure 105: Salinity profile at Bunaken

In Figure 105, at the surface the salinity at Bunaken is 33.5 ppt. The halocline can be observed at a depth of approximately 60-70 meter, with an increase from 33.7 ppt to 34.6 ppt. Until a depth of 250 meters it decreases to 34.4 ppt and stays more or less constant when going deeper.

Density

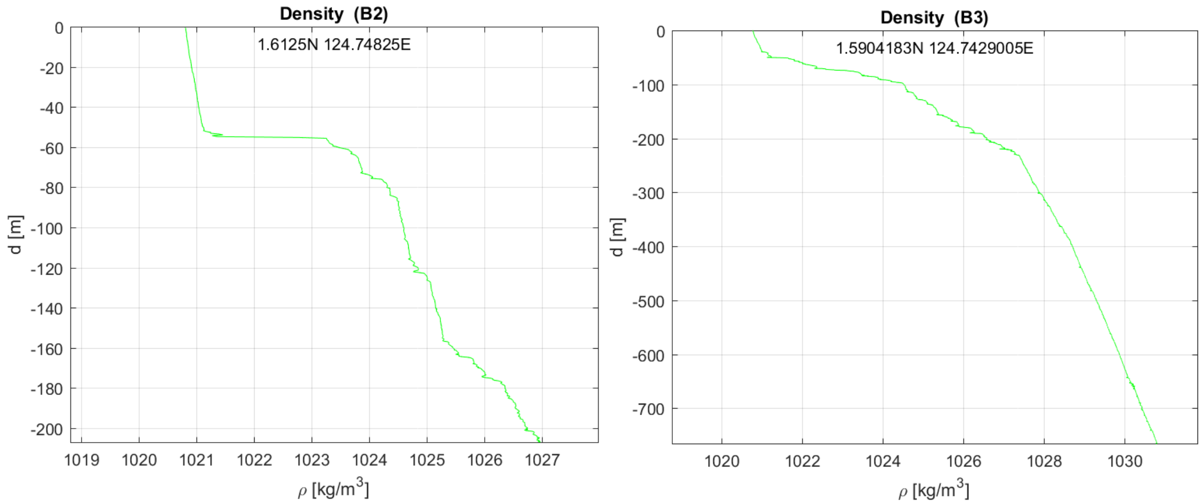


Figure 106: Density profile at Bunaken

In Figure 106, the density at the surface is 2021 kg/m^3. At 70-80 meters depth a pycnocline can be observed where the density increases from 1021 kg/m^3 to 1024.5 kg/m^3. Closer to shore a really steep pycnocline at 55meters is found. Less deep than more offshore, indicating the upwelling at Bunaken. Going deeper, the density increases linearly with a jump of 1 kg/m^3 at 230 meters depth.

M.1.4 Comparison

There are small differences between Manado Bay and Bunaken. First of all the bathymetry in Manado Bay is characterized by its gradually declining slope, whereas Bunaken has a steep sloping part. Next to that, a comparison with other water masses in the world can be made by looking at the TS-diagrams and analyze the water masses, see Figure 107. The water TS-diagram of Manado and Bunaken look similar, which is expected, due to small distance between both locations and the current directions.

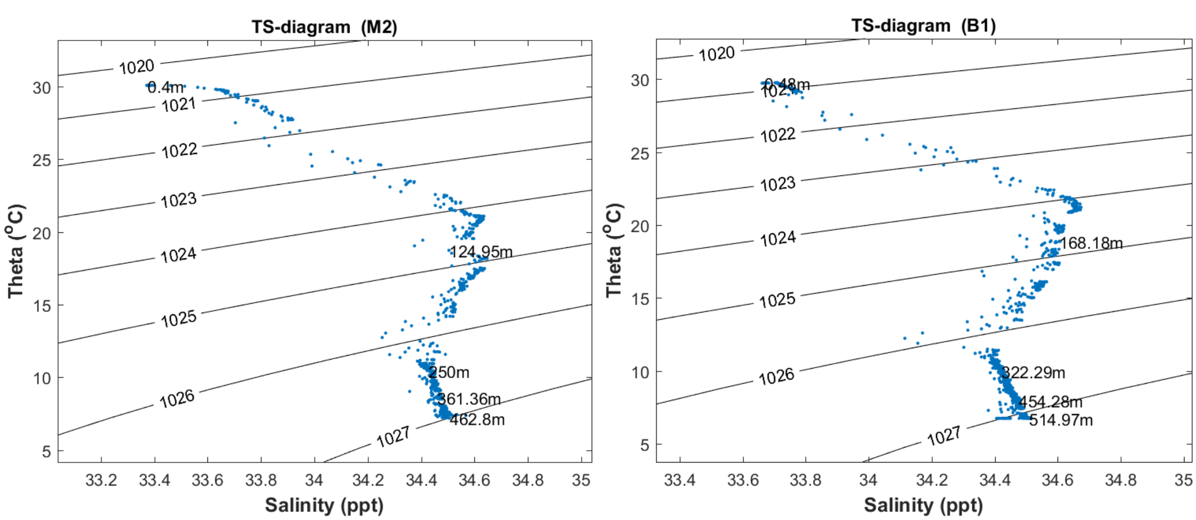


Figure 107: TS-diagram for Manado (left) and Bunaken (right)

M.1.4.1Depth

When lowering the CTD head, it was avoided that the rope would not roll off more than the estimated depth, to prevent hitting and getting stuck to the seafloor of the sensors. The exact depth of the CTD head was measured by the instrument itself. After this procedure it can be concluded that the map of the Local Marine Authority and of Quod Fish are the most accurate. They can be found in Appendix M4: Bathymetry. These nautical maps nevertheless are quite old, are probably obtained by conventional lead line and could give only a rough idea. But, when looking at the results they are still applicable.

The large difference between the bathymetry maps of Fugro and Google can be explained by the fact that these make use of gravity measurements and not direct sounding. This leads to less accurate results in near shore areas.

M.1.5 Conclusion

Combining the measurement results with the depth profile, results in the following conlcusions.

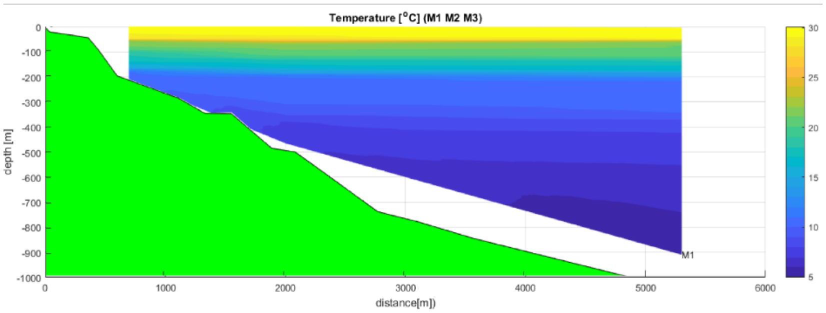


Figure 108: Depth and temperature profile Manado bay, in line with M3, M2 and M1.

Table 34: Manado bay

Depth (m)	Temperature	Salinity [ppt]	Distance to shore [m]
0	29.5	33.4	0
340	10	34.5	1200
550	7	34.5	2200
850	5	34.5	3600

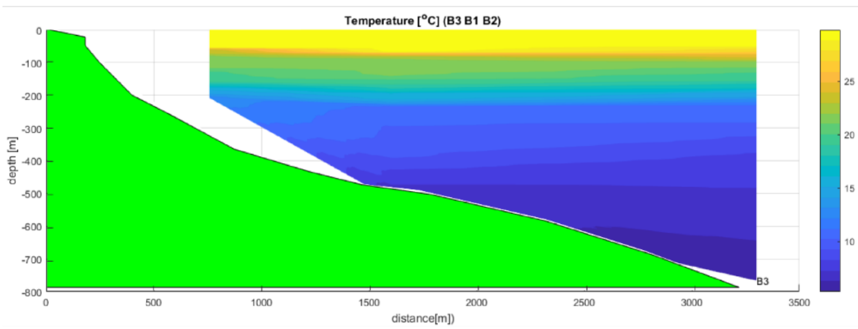


Figure 109: Depth and temperature at Bunaken, in line with B2, B1 and B3.

Table 35: Bunaken

Depth [m]	Temperature	Salinity [ppt]	Distance to shore [m]
0	29.6	33.6	0
300	10	34.4	750
500	7	34.5	1750
800	5	34.6	3400

Appendix M2: Air humidity and temperature measurements

M.2.1 Equipment

Relative air humidity and temperature can be measured with a probe, the equipment is manufactured by Hygrosens. It can be connected to a computer/laptop and will measure using a Python script. The technical data of the humidity and temperature measurements is summed up in Table 36. All equipment is supplied by Bluerise BV.

	Humidity measurements	***Temperature measurements***
Measuring range	0 - 100 % RH	-40 - 80 ˚C
Resolution	0.01%	0.01 ˚C
Accuracy	± 2% (at 23 ˚C)	± 0.3 K (between 0 – 40 ˚C)

Table 36: Technical data air temperature and humidity measurements

M.2.2 Methodology

The feasibility of the dehumidifier is highly dependent on the relative humidity. It will measured using the Hygrosens. The measurement setup can be found in figure. It is important that the sensor is in contact with continuously free flowing air.

M.2.2.1 Location

These different timeslots will be measured on these different locations:

- Close to the sea, morning, evening
- Inland, whole day measurement.
- Bunaken Island, morning, evening.

It would be favorable to measure these locations more often. In practice this is not possible. It is important to incorporate a shot of the weather forecast in the results, in this way comparisons can be made. Due to difficulties with the equipment, only the measurements close to the ocean (during evening) and the measurements on Bunaken are good measurements.

M.2.2.2 output

The data is obtained by using Python 2.0. By running the script every two seconds the data is stored in a CSV file. It was not possible to change the sample frequency. In Table 36 the accuracy of the output is shown.

M.2.3 Results

In this section the results of the measurements are presented. First an evening measurement at the sea is discussed next the measurements at Bunaken island are discussed.

M.2.3.1 Manado – evening close to the ocean

This measurement is executed at Wisata Bahari a restaurant at the boulevard of Manado. The measurement is conducted at 20-09-2017 and commenced at 17:57 and ended at 20:10 local time, so measuring time is approximately 2 hours. The weather forecast is not included since it is difficult to obtain the weather back in time.

Average temperature: 25.9˚C

Average relative humidity: 88.1%

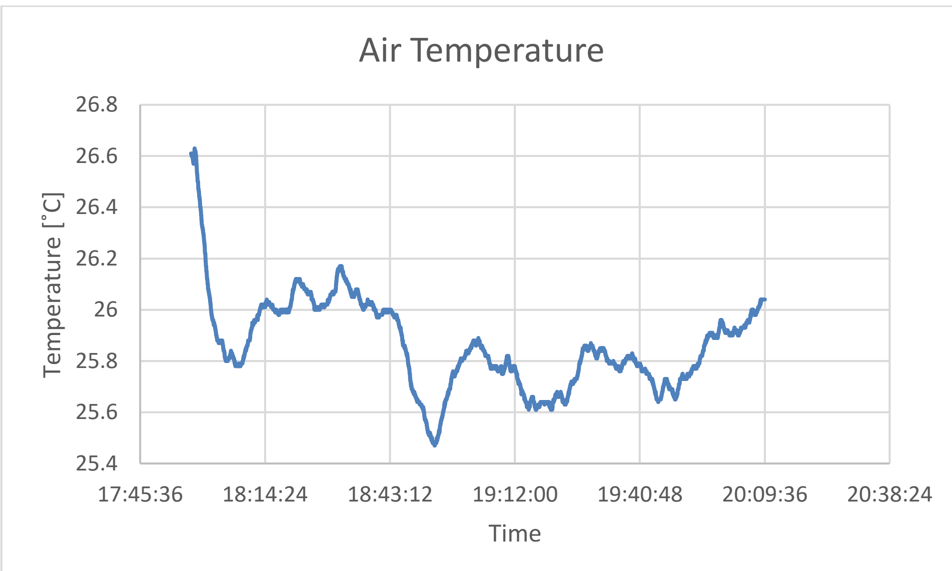


Figure 110: Air temperature at restaurant Wisata Bahari Manado

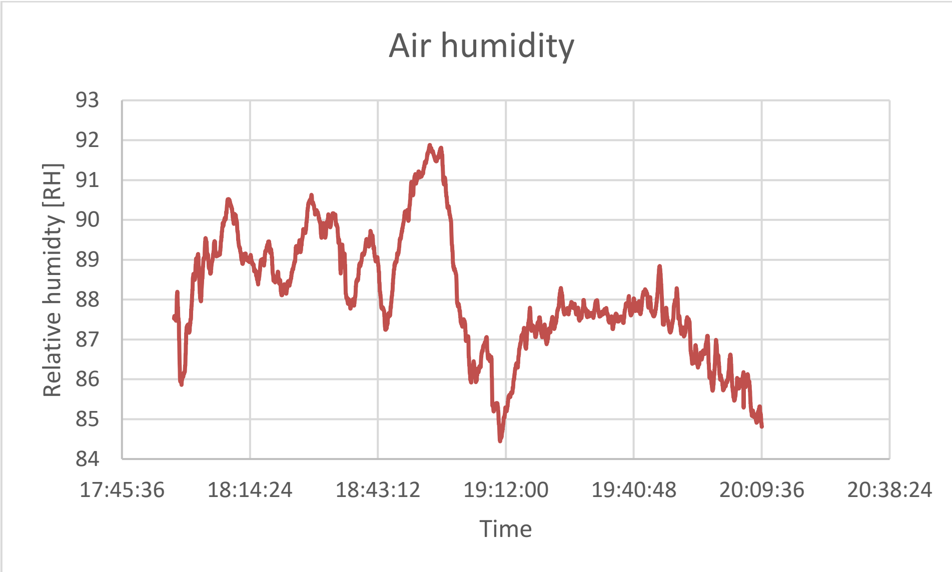


Figure 111: Air relative humidity at restaurant Wisata Bahari Manado

From Figure 110 and Figure 111 and the results it can be concluded that in the evening the average humidity lies below 90%. It is expected that during the night this value will reach above 90% and will decrease during the morning. Some short Afternoon experiments show that during the day the Relative humidity can reach 70%.

M.2.3.2 Bunaken – morning and evening measurements

This measurement is executed at Bunaken Seagarden resort and is located at the coastline of Bunaken island. The measurement commenced at 14-10-2017 at 17:20 and ended at 15-10-2017 at 12:14 local time, so measuring time is approximately 17 hours. The weather forecast is not included since it is difficult to obtain the weather back in time. An important side note is that from 12:00 until 17:00 not measurements are conducted, due to a technical problem. In the graph the measurements of 15-10-2017 are plotted left and the measurements of 14-10-2017 are plotted right.

The average evening temperature (17:20 until 00:00): 26.8˚C

The average evening relative humidity (17:20 until 00:00): 95.5 %

The average temperature at night (00:00 until 05:30): 24.9˚C

The average temperature at night (00:00 until 05:30): 99.8%

The average morning temperature (05:30 until 12:00): 27.1˚C

The average morning relative humidity (05:30 until 12:00): 95.4%

From Figure 112 and Figure 113 and the results indicated above can be concluded that for 17 hours long the relative humidity does not go below 95%. Next to that, the air temperature only fluctuates a little over time. The high relative humidity makes this location suitable for implementation of a dehumidification system and can be further investigated in another research.

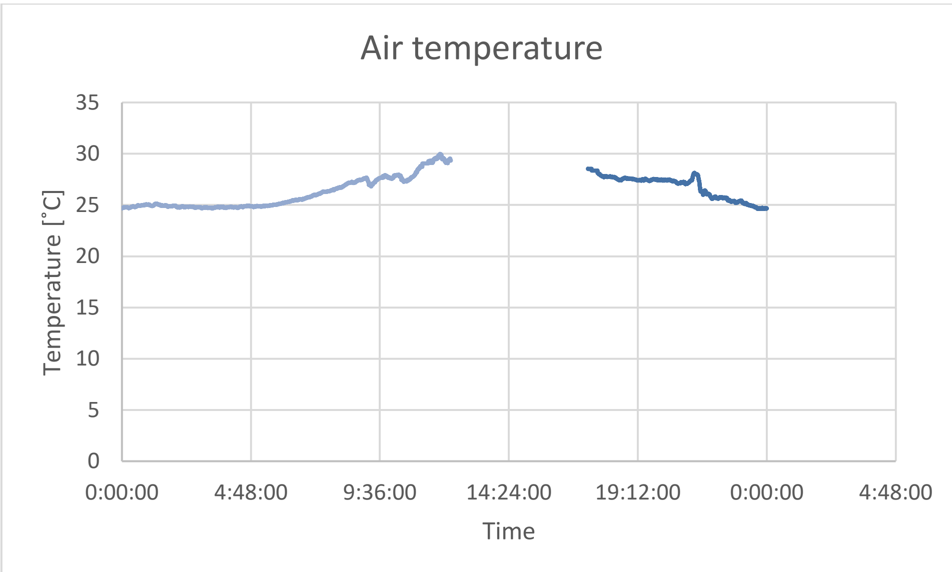


Figure 112: Air temperature at Bunaken Seagarden resort

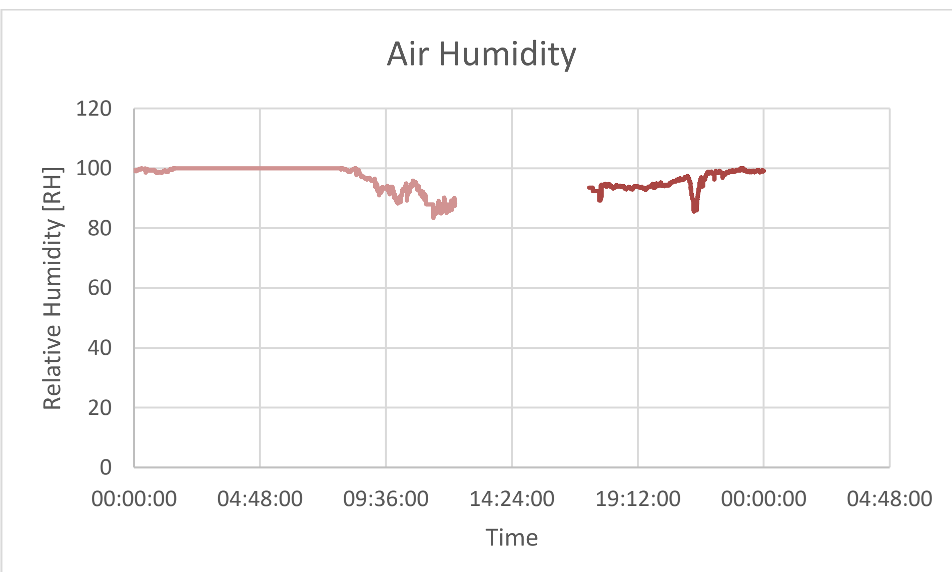


Figure 113: Relative air humidity at Bunaken Seagarden resort

Appendix M3: Parts per million (PPM) in air & drinking water measurements

M.3.1 Equipment

For these measurements a probe with a conductivity sensor is used. The probe automatically displays the PPM value of a fluid. The equipment is very useful for fluids with a PPM lower than 999. For higher values of PPM (like seawater) the Minos X CTD unit is used. More information about this equipment can be found in Appendix M.1.1

M.3.2 Methodology

The idea of these measurements is to get a feeling for the dissolved particles in a fluid (water) and especially of condensed air. For this reason water from all kind sources will be tested with the probe or with the Minos X CTD.

M.3.2.1 Collecting condensate

For the condensation of air a convenient technique is used. An old and plastic bottle is filled with ice and put outside. The air condenses due to the direct contact of the cold plastic surface with the air. After some time water droplets are formed at the side of the bottle and will roll down when the surface stress becomes less than the gravity. The water is collected by putting a bowl or a plate underneath the bottle.

The downside of this technique is that external particles can settle in the condensate which influences the PPM of the condensate. Furthermore any particle/organism attached to the surface of the bottle can end up in the condensate. These aspects will not be a problem since the purpose of these measurements is orienting.

M.3.2.2 Output

The accuracy of the probe is unknown. However, this is not very important since these measurements are used for orientation and not for actual calculations. For more accurate details about the condensate it has to be collected and analysed in the lab.

M.3.3 Results

In this section the results of the measurements are presented. In Table 37 the result are displayed. It is important to not that indication of drinkable water lies around 500 PPM. Of course are any bacteria not measured with these devices. An important conclusion is that at Bunaken island the condensate has a 3 times higher PPM compared to the condensate collected in Manado. This could be due to the salt content present in the air, since the tests at Bunaken island are executed next to the sea and in Manado 1 kilometer inland.

Date	Where	what	Source	PPM
22-9-2017	Bunaken - Seagarden	Tap water	Groundwater	294
22-9-2017	Bunaken - Seagarden	Bottled water	Aqua Danone	78
22-9-2017	Bunaken	Seawater	-	32500
24-9-2017	Bunaken - Cakalang	Tap water	Rain water + groundwater	3410
25-09-2017	Manado - apartment	Tap water	Groundwater Well	220
26-09-2017	Manado - apartment	Condensate	-	17
29-09-2017	Bunaken - Village	Tap water	Groundwater Well	440
14-10-2017	Bunaken - Seagarden	Condensate	-	57
16-10-2017 / 19-10-2017	Manado - Apartment	Condensate (3-4 day average)	-	19

Table 37: Results of the PPM measurements

Appendix M4: Bathymetry

M.4.1 Methodology

To obtain Bathymetry data, different sources are consulted:

- Google Earth, Fugro (gravity measurements)
- Local marine Authority (Hidro Oseanografi TNI-AL)
- Navionics
- Van Oord (offshore contractor)
- Admiralty Chart 2638
- Quod fish (TU Delft licence)

The maps show great differences in terms of water depth in Manado Bay and close to Bunaken Island. Large contrast is found when comparing the data close to the coasts, this difference can reach up to 800m. Take for instance coordinate 1°30'21"N, 124°47'28"E Fugro and Google earth show depths of 30 m to 100 m, whereas all other maps indicate depths reaching 900 m to 1100 m.

So Local Marine Authority, Navionics, Van Oord (Admiralty Chart 2638) and Quod Fish (TU Delft license) show similarities, but are not exact the same.

Google earth and Fugro (gravity measurements) show great similarities. Fugro stated that gravity measurements are accurate in deep waters, but will lose accuracy in shallow water and close to the coast.

M.4.1.1 Validation

Due to the great contrast between the different sources, own measurements will be carried out. These are simple lead line experiments with fishing line counters and a check with the CTD unit. In the followed procedure is a weight of 1.5 kg lowered to the seabed and the length of the line measured with a line counter. This gave a rough indication of the depth, in order to verify this the Minos X CTD unit is lowered to the same depth.

M.4.2 Conclusion

The measurements show that the maps from the Local Marine Authority (Hidro Oseanografi) are most accurate**.** For results of the measurements is referred to Appendix M.1.3.

M.4.3 Bathymetry data

Copies of 5 maps are included at the very end of this report. Navionics is not included since it can be found online and contained less data than the later:

1) Admiralty Chart 2638 (Van Oord)
2) Local marine Authority (Hidro Oseanografi TNI-AL)
3) Fugro (Gravity Measurements)
4) Google Earth (Gravity Measurements)
5) Quod Fish (license TU Delft)

Appendix M5: Wind and Wave Conditions

M.5.1 Wind

In Figure 114 it is displayed that the wind, of a certain offshore point in Manado bay originates from different directions during a year. However, the wind speed does not exceed 7.5 m/s.

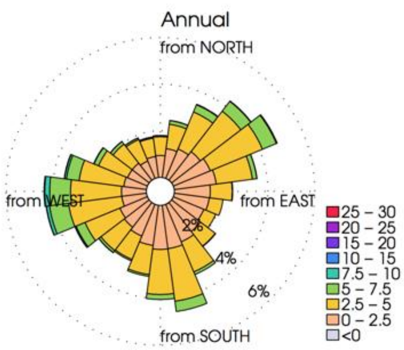


Figure 114: Wind Rose (van Oord, 2017)

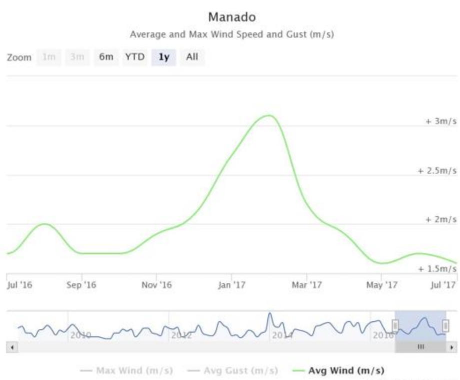


Figure 115: Annual wind speeds (m/s) Manado (worldweatheronline.com, 2017)

The wind speeds in Manado are illustrated in the graph of Figure 115. One can see that the wind speed is mild and is fluctuating during a year with a maximum of 3.1 m/s in February. This wind speeds are not seen as a big challenge for this project and will not be considered for this phase of the design.

M.5.2 Wave

The data for the offshore wave conditions were obtained. These conditions are shown in the wave rose, seeFigure 116. The waves are originating mostly from one direction, which is the Northeast.

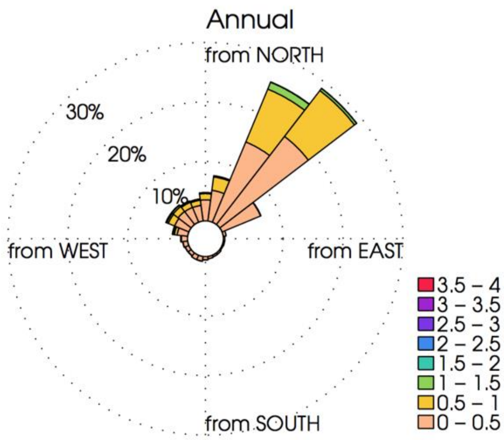


Figure 116: Wave Rose (Van Oord, 2017)

The figure shows that the maximum wave heights are 1.0- 1.5 meters. This is not different for the waves in the bay of Manado. The waves are not high, due to the very deep bay of Manado and the sheltered location. The most common wave direction is of coast. But the waves entering the bay are significantly from North-West (Christiaan Tenthof van Noorden, 2013).

Appendix N: Stakeholder description

The main important stakeholders in Manado are described in this part. To start with governmental organizations that are of importance in Manado. Secondly other authorities involved are described. At last the malls and hotels that are of interest for district cooling are shown.

Governmental organizations

Bappeda

Badan Perencanaan Pembangunan Daerah (Bappeda) (Development Planning Agency at Sub-National Level) is the governmental organization that does the planning of big projects in North Sulawesi. Works closely together with the provincial government. Its task is to do research and regional development planning and assist the governor in doing more integrated planning, with an eye on sustainability, balance and development in the region. It is said that they bring the right parties for a project together. They are interested in deep seawater solutions but suggest to lobby for regulations in Jakarta.

BMKG

Badan Meteorologi, Klimatologi, dan Geofisika is the governmental institution that carries out all programmes needed concerning meteorology, climatology, air and water quality. They advise the government for future plans and have a lot of data available.

Kota Manado

This is the cities government. Every decision needs to be agreed with the mayor of the city. They are interested in making Manado more sustainable, by getting rid of plastic and using more sustainable energy. They can play an important role in this. Nevertheless, it is known that Indonesia leaves a lot to the society/market. A need/wish of the people/industry must be there. The city also has its own R&D department, that is interested in bringing new techniques to Manado. For this region, Kota Manado is the decision maker and there is not so much influence from Jakarta. Although they need to follow regulations. Bunaken island is also under control of Kota Manado. Kota Manado is very eager to implement sustainable solutions from seawater.

North Sulawesi Provincial Government

The governor is the most important person in North Sulawesi. If you want to get something done, you need the support of the provincial government.

PDAM

The local tap water company. Co-owner of PT. Air Manado (49%) and also has some other small projects on their own. They mainly do the operating of tap water plants and sometimes build small projects themselves. Large projects are initiated by PU. PDAM has no centralized management and are only headed by the local government (mayor/governor).

Ministry of finance

The ministry of finance is responsible for finance and state assets. It assists the president in running the state governance.

PLN Manado/Bunaken

Perusahaan Listrik Negara (PLN) is the governmental electricity company that has a monopoly on distributing electricity. Every region has its own office that controls the cities electricity. They are interested in possibilities with especially OTEC. Manado and Bunaken both have their own office, where they control the local electricity production, distribution and money collection. PLN is local but central managed by a main office in Jakarta.

PLN Sulutengo

Is the department of PLN that controls the grid of Gorontalo and North Sulawesi. They do the overall grid and electricity capacity planning. They think that OTEC can be of great influence on the whole region of North Sulawesi.

PT Air Manado

PT. Air Manado is the local tap water company, which is owned by PDAM and WMD since 10 years. In the following years this joint venture and with that PT. Air Manado will disappear. The operating of the tap water will then be in hands of PDAM again. PT. Air Manado's working field covers almost all the areas of Manado.

Public Works

Kementerian Pekerjaan Umum dan Perumahan Rakyat (PU) (Ministry of Public works and housing) is the governmental organization which proposes and budgets infrastructural projects. For example roads and bridges are often constructed/funded by PU. At Bunaken island they also are responsible for the construction of desalination plants. PU only executes projects in its planning/commissioning phase and is not involved in maintenance. If something is being built by the government, mostly PU is the responsible ministry.

WLN

Water Laboratory Nusantara is a laboratory derived from the Water Laboratory Noord in the Netherlands. It is owned by WMD and has branches in Manado and Makassar as well. WMD needed a laboratory to control/check the water quality in Manado. Now the laboratory is also used for several commercial activities.

WMD

Watermaatschappij Drenthe is the local drinking water company of Drenthe, The Netherlands and they founded together with the local PDAM in 2005 PT. Air Manado. They have 51% the shares in the joint venture but this will be decreased in the following 5 years. They are already involved in drinking water projects in Indonesia since 1997. They did a lot for water quality improvement in Manado, but the joint venture does not seem to function that well.

National government

President Widodo's political agenda focuses on development of the eastern part of Indonesia and pursues position as global maritime axis. This encompasses heavy development of infrastructure: roads, ports and industrial zones.

Other authorities

Aqua Danone

This is the largest bottled drinking water company in North Sulawesi. They get their water from Airmadidi on Klabat Mountain. There they bottle all the water and transport it everywhere by trucks.

Greenpeace

Greenpeace focuses on global environmental issues and climate change. Has big potential of turning public opinion.

Palm oil industry/deforestation is Greenpeace's main subject in Indonesia (PepsiCo, Johnson&Johnson, Unilever, etc.).

ITM

Institut Teknologi Minaesa is a technical institute in Tomohon that teaches in a lot of fields that has a connection with deep sea water solutions. They are very eager to cooperate in the future more with companies and other institutes.

Manengkel Solidaritas

Is a non-profit organization that is active in coastal and marine related issues. Their main focusses are: conservation, ecology surveys, education, development of marine sanctuaries and transplantation of coral and mangroves. They are the only really active NGO in Manado.

WWF

WWF focuses on environmental issues, climate change and particularly wildlife preservation. It has 13 global initiatives; one of them is the Coral Triangle, where Manado is located in.

Masarang

Masarang is an NGO located in Tomohon. They fight for conservation of bio-diversity and rain forests, better possibilities for local citizens and the usage of sustainable farming and production techniques. They keep an eye on ground water levels, local farming, drinking water production and pollution.

Sea Garden Resort

A dive resort on Bunaken owned by a Dutchman. Is connected to a fresh water well and the grid. Nevertheless the water is not drinkable and the power is still partially delivered by private owned diesel generators.

TU Delft

Delft University of Technology is a university in the Netherlands. It is well known for its innovative projects and a lot of students are sent over the world to do their own (research) projects. For example in Indonesia.

UNSRAT

Universitas Sam Ratulangi is the largest university of Manado, and wants to become more international. It has several exchange programs and is attaches a lot of value to a sustainable development of the city of Manado and the future of the natural beauty in the surroundings.

Malls

IT Center Manado

This mall consists of 6 floors and focuses mainly on electrical products. It is located on the boulevard, has a lot of small shops and is mostly busy. The upper floor is occupied by a food court and game facilities. The cooling load of IT Center is estimated to be 1000 tons and in the future a peak load of 1200 tons is expected.

Manado Convention Center

Manado Convention Center is located at the Jalan Pierre Tendean (Boulevard) and can be used for national and international meetings, seminars, training, workshops, boardroom meetings, product launches, exhibitions, gala dinners, fashion shows, award evenings, graduations, wedding receptions and other religious activities. The centre has 12 Meeting Rooms and a Plenary Hall. The first floor has an area of ± 3592m^2 and the second floor an area 1445m^2. It is estimated that the cooling load is 500 tons.

Manado Town Square (Mantos)

Manado Town Square (Mantos) is a mall in Manado. This mall is located in downtown Manado on Jalan Pierre Tendean (known as the Boulevard).

Developer: PT. Gateway of Nusa Perkasa
Owner: Hengky Wijaya

The mall consists of three parts: Manado Town Square 1, 2 and 3. The first two consist of two floors with different shops, department stores, play halls and restaurants. Manado Town Square 3 consists of 4 floors, of which the upper floor accommodates cinemas.

Mantos 1 was the first of the three to be build, completed in June 2006. The others followed in 2011 and 2015. According to some experienced estimates, Mantos 1 does not make use of a chiller unit. This estimate can be confirmed when comparing the temperatures of Mantos 1 with 2 and 3. It is confirmed that Mantos 2 and 3 make use of chillers for their air conditioning.
The chillers of Mantos 3 are situated in the same building as the chillers of Four Points Hotel. They have 4 chillers of 600 tons. At the moment they use on average 1200 tons for cooling and it is estimated that the future peak load of Mantos 1, 2 and 3 will be respectively 1200, 800 and 1800 tons. The water for the central cooling system comes from a deep ground water well.

Megamall (Megamas)

Megamall is the first mall built in Manado and is part of Megamas (together with MTC), completed on January 27, 2004. The mall has an area of about 29.161 m^2 and houses many large stores and is completely cooled using central air conditioning. To do this, the mall has three chillers installed on top of the building. Of these three chillers (Trane), on average two are used to cool the building and one chiller is for backup. The cooling load of these chillers is 600 ton each, having a total installed load of 1800 ton. On average, 1200 ton cooling load is active.

Developer: PT. Megasurya Nusalestari

Mega Trade Centre (MTC ; Megamas)

Mega Trade Centre (MTC) is part of Megamas. MTC houses small local shops and companies. It has 6 floors and a basement. The basements, ground floor and floor 1 and 2 are cooled using central air conditioning. To do this, the building has three chillers (Trane) of which one is always on. A second one is used in December/January when more people visit (due to Christmas). The third one is only as backup. The cooling load of these chillers is also 600 ton each, having a total installed load of 1800 ton. On average 600-800 ton cooling load is active, depending on time of the year and number of visitors.

Monaco Bay

This future project has just started in Manado. It is a project of the real estate development company Lippo Group and will consist of 9 skyscrapers, facilitating luxury suites, a mall, offices, cinema, play zone, a convention center, a chapel, a school, a hospital and a port. The first three skyscrapers will soon be under construction and are expected to be finished in 2019. The cooling load is hard to estimate at the moment, but it will be large.

Star Square Mall (Bahu Mall)

Star Square Mall, also known as Bahu Mall, has to become the largest shopping center in Manado. This mall was established in 2009. The concept of the Mall is to provide all family needs in one place. Star square mall is built next to Bahu mall. The mall consists of seven floors of which 2 floors are occupied by restaurants and stores at the moment. Due to the large amount of other malls and shops, only few people visit this relatively new mall compared to Mantos. However they are still building the mall when this report was published. It is estimated that their current average load is 500 tons and their future peak load could lead up to 2500 ton.

Hotels

Aryaduta Hotel

Aryaduta Manado is a hotel located north on the Manado Boulevard. The hotel has 198 rooms and suites and uses most probably a chiller air conditioning system. The hotel is side to side connected to the Siloam Hospital and owned by the same company. The hotel has an estimated cooling load of 400 tons.

Best Western Lagoon Hotel

Best Western The Lagoon Hotel is located at the Bay of Manado in one of the eye-catching buildings of the city. The hotel has 187 rooms and makes use of conventional air conditioning. Nevertheless, it does not make use of chillers and cooling towers but of mini-split air conditioning units.

Four Points Hotel

Four Points hotel by Sheraton is a high end hotel that is connected to Mantos and is also located on the existing land reclamation. It was opened in march 2017. The hotel has 257 rooms, including 41 luxury suites.

To cool the hotel, a central cooling system is used, consisting of 3 chillers. Each chiller has a cooling load of 250 ton, giving a total load of 750 ton installed. However, mostly one chiller is used. Depending on occupation, a second one is turned on if necessary. They use their own well of 125 meters deep. It is estimated that in the future their peak load can grow to 600 tons.

Ibis Hotel

This hotel has 154 rooms, a restaurant, bar and 3 meeting rooms. They use a central cooling system. The current peak load is estimated to be 500 tons and the future peak load 600 tons.

Lion Hotel

The hotel consists of 170 rooms. It also has 44,450 m^2 of entertainment and shopping space as its website claims, but it seems not to be occupied at the moment. It is estimated that the current cooling load is 500 tons and the future cooling load is 600 tons.

Manado Quality Hotel

This hotel is located along the boulevard, facing the convention center. It offers hotel rooms, convention rooms and has a bar/restaurant. Its cooling load is estimated to be 300 tons. Since the hotel is rather old, it is not expected to grow anymore in the future.

Appendix O: Stakeholder Meetings

O.1 Manengkel Solidaritos (NGO)

Manengkel Solidaritas is a non-profit group that works in the field for coastal and marine issues. Is since three years running and has volunteers from western countries. They give them food and accommodation for free and there are always some volunteers around. Next to that they organize trips and sell food and coffee. They have good contacts in the government and know a lot about the area. It is the biggest NGO in Manado and surroundings. There is also Wildlife conservation society, but they are not that active anymore.

At the moment they have 15 sites in North Sulawesi and on Bangka Island and other islands. Their main activities are:

- Conservation of natural sites
- Ecology surveys
- Socio-economical surveys
- Education of children about how to prevent that the natural sites disappear
- Develop the marine sanctuary
- Transplant coral and mangrove forest

Marine law

Since 2014 the North-Sulawesi government agreed on a new law, concerning marine protected areas. The Fisheries and Marine Agency is responsible for this programme and Manengkel supports the programme of the government. The new law "Managing coastal and small islands", brings the decision taking from region level to province authority. In this way the protecting of the nature got better, since there is one clear line for everyone and less money is spent on bureaucracy. Important person to contact is Ronald Sorongan. He is head of the agency.

Water sector

The tap water in Indonesia comes from the Tondano river that flows into the Sulawesi sea at Manado. This river originates from the higher situated Tondano lake (Taldua) in the mountains. The tap water is extracted from the Tondano river in the middle of the city (Jalan Josudaso 12), where also the office of PDAM (local tap "drinking" water authority) is situated. Some years ago, a Dutch company tried to improve the tap water supply, since then the name PDAM was changed to AM (Air Manado). The improvement of the supply seemed not to work out well. AM is a governmental organization which is part of the local government. The person making decisions over AM would be the mayor only.

The local tap water prices are estimated to be 50.000 rupiahs per household (3 pers.) per month. Manengkel knows that they pay approximately 200.000 for their water at the office.

The bottled water market serves as drinking water supply. Bottles are sold from different brands, whereas "Aqua" of Danone is most common. The water comes from a source (probably a river) at Kalabat mountain, close to Manado. At the same location the different water producers are situated. When asking for "PT.Tirta Investama – Aqua Airmadidi", one can come to this place.

The water bottles can be sold the cheapest for a price of 16.000 rupiahs for 19L.

Electricity

The electricity supply in Manado is managed by the local PLN (governmental company). This is the only electricity company, whereas they take care of the production of the electricity as well as the construction of the grid and other facilities. The office of PLN can be found in Sario in sub district Wenang (in front of the sport area). PLN has also a central office in Jakarta.

Two power plants produce electricity for Manado:

- Hydropower plant in Tangarni
- Vessel with diesel generators in Amarung (South-Minahasa)

There is a third power plant (natural gas) nearby. This one probably produces electricity for Bitung. It can be observed from Mahawu mountain, when facing Tondano.

The electricity price rate depends on the amount of electricity the user uses. When using more electricity, the price per kWh is more expensive. A normal household (3 pers.) is estimated to pay 100.000 rupiahs per month and Manengkel pays 200.000 per 3 days (they use aircon and have several computers).

PLN is looking into renewable energy already. Some years they started a project together with the German agency GIS on solar panels in Bunaken and Nine Islands. This does not seem to work that well. A lot of solar panels do not functionat during day, due to lack of maintenance and proper training. It could be that they are also looking into desalinating water with solar PV. Next to that PLN is looking into possibilities with geothermal around Tomohon. Jaika from Japan was mentioned as another partner for the development of renewable energy.

Since the population of Manado is growing, also the energy demand grows. Therefore two years ago they increased the power production. Nevertheless the power supply remains unstable every now and then. Especially when new houses or public buildings are built, the electricity becomes very unstable. In Manado the property sector consumes most of the electricity, since there are almost no factories situated in the city. Only distributors, that maybe use some power for cooling of their warehouses. Mostly PLN keeps secret the energy usage of single users. Otherwise people would complain when the energy becomes unstable. In Bitung the electricity demand of single facilities is higher, since there is more industry and even a refinery situated.

Cooling

Along the new land reclamation are several malls, that use central cooling for their buildings. They could be connected to a SWAC system to decrease their costs. The main fishing port in Manado (Tumpa port) has no cooling facility. Leading to the fact that the caught fish is directly transported to the local market. A cooling facility would be welcome so that the fish can be treated further and exported. This could mean an economic boost for the sector. Overfishing is not an issue at the moment, and the fishing industry can be expanded. At the moment most fisher boats go to Bitung (even from Maluku), here the fish is treated further and exported to for example Hong Kong and Singapore. An opportunity Manado does not want to miss. For the islands like Bunaken, one of the problems is that all the fish is brought to the mainland and needs to be imported from the mainland again, although it has been caught around their island.

General

- Ministry has a development and research agency that could be interested in our project. As well as research agency Lipi in Jakarta.
- There used to be a gold mining company active in South-East Minahasa, called New Mont. They measured the seawater temperature long ago, and Manengkel remembers that the thermocline was already around 200m
- To have knowledge of the location of the corals around Bunaken island, one should ask local dive centres (they have dived there hundreds of times). Google Earth gives a good estimate of where the coral reefs are, but is not trustworthy enough on where the special coral species grow (even when there is no reef).

O.2 Willie Smits (NGO)

Willie Smits is a trained forester, a microbiologist, conservationist, animal rights activist, wilderness engineer and social entrepreneur. He is founder of Masarang, that was elected to be in the top 5 NGO's worldwide. Masarang also runs an office in Tomohon. At the moment he is director of the University of Tomohon, and advices the third largest political party of Indonesia.

The meeting was also attended by Dr. Tartius Timpal, rector of the Technical University of Tomohon (ITM), (They would be very happy if we give a class at his university) and Richard Siwu, also a rector. He can get us in touch with the mayor/governor. His friend Roy Lengkon (speaks German and English), he is advisor of the mayor of Manado, and can arrange a meeting.

Introduction

Sulawesi is formed by the Australian and Asian tectonic plates pushing against each other. This causes the strange shape of Sulawesi, the geothermal activity and the steep slope at the shore around Manado, since the plates are pushed up against each other.

Lambay street (and another one) creates upwelling of cold water at Manado bay. The fish are pushed in the direction of Bunaken and the other reefs. The cold water provides sufficient nutrients for the fish to live. In the region also lives a special ancient fish species, called: Coelacanth menadoensisis. It is blue and sometimes caught by fishermen. Due to the new land reclamations, more eddies and upwelling occur. This causes the plastic waste not to sink and float to the reefs of Bunaken and endangers the wild life.

Energy

North-Sulawesi has a good opportunity for small Hydropower dams. At the moment around Manado: Tangari 1, 2 and 3. Three hydropower plants of 70 MW max. But it produces mostly below 50 MW. Because of problems with maintenance and the water hyacinth occurring in the Tondano lake.

There has also been a big development in geothermal. At the moment they have 60 MW installed in Tomohon and 120 MW in Tompasso. It is estimated that there is still a 100 MW potential available. Next to the geothermal plant in Tompasso Willie Smits created a sugar factory that uses the rest heat of the plant. This is used to concentrate the sugar. In this way less wood is needed to heat the process. With this concentrate one can yield extra rice and more power is left for the grid. Along the coast small houses use a solar panel for energy. When looking at the future, it can be said that North-Sulawesi has a relatively stable grid, that can be expanded further easily.

It is clear that North-Sulawesi already has a lot of possibilities for renewable energy and good alternatives for OTEC. Nevertheless there are plans to build a new carbon power plant in Maleien.

Water

The water supply differs per city. In Tomohon they use water from wells. This water is used as tap water and is drinkable. In Manado the tap water comes mostly from the highly polluted Tondano river.

In times of draught (sometimes 7 months no rain due to climate change), the ground water level in Tomohon can drop with 15m and they run out of water and import is needed. The solution to this is reforestation. In this way the wells do not fall dry anymore, since trees can hold the water. Special trees are planted with roots that reach to 12 m depth. Examples of those projects are the Masarang spring, that does not fall dry anymore and the Uluna spring, that is refilling now because of the reforestation by Willie Smits and the PDAM of Tomohon. Falling dry of wells, is a huge concern. Only in Java, already 10.000 springs have fallen dry the last years.

Most drinking water problems occur in coastal regions, like Manado. Most coastal cities have polluted rivers and use ground water, but can only use the thin upper layer of fresh water in the ground. Glyphosate is used much for the cleaning of the river water in Manado. Whereas the complete cleaning process of the water is quite conservative (the standard procedure), while the Tondano river has a heavy bacterial load. Next to that the river contains chemicals that originate from the agricultural activities around Tondano lake. There are some houses in Manado that get their drinking water from a well: Warambunang. They have built a little dam there.

In Manado they drink bottled water instead of tap water. Now the culture of drinking bottled water comes from the city to the villages. Although they can drink their tap water, they start to buy bottles.

Data

Some time ago Water Maatschappij Drenthe (WMD) did research in Manado. They worked together with AM and have all the data of Manado available concerning water quality, water usage etc. They even set up a water laboratory in Manado. The former director Karst Hoogsteen was in touch with Willie Smits about this.

WWF did research on the coral reef around Manado. The data can be checked on (Coral) Reef Check, and the Coral triangle Conference. WWF mapped the coral reefs around Manado bay and should have an easy accessible database. In this way one can check the exact location of the reefs. The Coral Triangle Conference was organized by the government and one can find all the detailed information of the participants and conclusions online.

General

- The only way to make a change or to make something happen is to get the governor on board.

- For financial aspects one can contact SME, an infrastructure agency from OJK (Otorita Jasa Knenang). They are ruling the water related issues, considering funding. But when building something, always a private sector investor is needed.
- When building something, lots of permits are needed (f.e. environmental impact assessment must be done, permit to make use of land etc.) This is better to be sorted out by an external party.
- When building, there are no companies in North-Sulawesi that are able to do that. Most come from East Java (Surabaya mostly).
- There is no industry in Manado, except of maybe Bimolie, a coconut oil industry. Next to that the main industry is the agricultural industry and some fishery. In Bitung although there is a big canning industry.
- In Bitung you also connect Dinas Belatuten. They have all the environmental data.
- Another NGO active in the region is WCS (Wildlife Conservation Society).
- PILI NGO has database on the laws concerning the environment. ENVAL is very important.
- The environmental advisor of the governor is John Tasirin, professors at UNSRAT could get us in touch with him.

O.3 Jan Wawo (PT. Air Manado)

He is director of finance and general affairs of PT. Air Manado. This is a joint venture of WMD and the local PDAM. WMD had 51%, but this will be decreased in the following years. They already have the cooperation since 10 years. 3 experts of WMD were doing a lot of measurements. This became rare after 2013.

Now there is a building in construction to even further clean water from a spring, so that the water is safely drinkable. Water from a spring is then transported over distance to this (AM) location. Hopefully next year (2018) they have drinkable water. The river water extraction can also be expanded, since only 10% of the river water is used for water production.

For future provision it is the idea to construct a dam at Kuwil, 20-35km from Manado. This dam can be used as a water reservoir and drink water production.

Not everybody is connected to the water at the moment. Only 29% of the people is connected. This is 39% of the households (29.000 households). The goal is to have 70% of the citizens connected in the future. At the moment some people still pump up water from the ground for their selves and drink it directly. This causes the land to sink at some locations. In the mountains, sometimes there is a pipe connection, but the water cannot be pumped up.

Selling price

4600 IDR/m^3 (this is for households)

5250 IDR/m^3 (this average selling price)

The price is different. For example a school pays a different price then households or hospitals. Most households just pay a monthly tariff for their water (e.g. 100.000 IDR per month).

PDAM has a desalination plant on Bunaken. This plant uses RO and most probably pumps up salty ground water. This place is close to sea, a well (Sumur).

As WMD mentioned, the piping system is also one of the problems. This will be reconstructed part by part. The idea is that AM is waiting for WMD to retreat and start the construction.

Cleaning process:

<u>River water</u>	<u>Spring water</u>
Coagulation	Disinfection (with chloride)
Flocculation	
Sedimentation	
Filtering	
Reservoir for distribution	

Costs

The production costs shared with team ROTEC. Also the different prices, concerning chemicals and electricity are given. The estimated electricity costs of all the treatment plants is +- IDR 500-600 million per month.

O.4 Rakhmat Putra (PLN Manado)

Mr. Putra is planner of PLN Manado. During the meeting we explained our cause in Manado. PLN was interested in OTEC and wants to know more about the potential. The contact person in PLN was not familiar with OTEC and said there was no incentive yet for OTEC. However, PLN Manado is working on decreasing the use of fossil fuels. At the moment, 40% of the power for Manado comes from diesel. They work on decreasing this to 0% by decreasing the PLTD.

At the moment, Manado has a 80MW energy surplus. This is due to the Amurang vessel. The vessel was initially planned to be in North Sulawesi for 5 years but this will be extended.

The contact person at PLN Manado thinks that it would be interesting for us to meet with PLN SULUTENGO because he thinks that this technology has a high potential for the whole regency instead of just Manado and the Bunaken. North Sulawesi has several districts with respect to energy supply. These 11 regions include: Manado South, Manado South, Bitung, Tomohon, Tondano, Kawangkoan, Ratahan, Amurang, Motoling, Pineleng, Airmadidi. The Bunaken belongs to Manado South. These districts are almost 100% connected to the grid at the moment.

In the Bunaken, electricity is produced by a PLTS and a PLTD system. The islands around Manado are mainly powered by PLTD systems. The price including subsidies is 1400 Rp./kWh. However, the price to produce the electricity is 3000Rp The solar PV plan for Bunaken is still ongoing, according to Putra. Next to that, Putra confirmed the planning of a grid connection from Manado city to Bunaken. The plan was proposed by PLN Manado and they hope to get a confirmation from PLN Jakarta and the government in a year.

The production price of the different types of energy was not known to the contact person. Geothermal is for example IPP and this is bought from a company by PLN to distribute the energy. However, we received information about the consumer prices. This can be found in Appendix D.1.3. 60% of the inhabitants fall under class number 1. This is the only class that is subsidized. Malls are mostly in class number 1 and 2. All the prices include the subsidies.

The contact person in PLN Manado is going to help with more detailed grid information. Furthermore he will look at the production prices, the Bunaken grid, peak load grids, produced MW on the grids. We requested a follow up meeting to present our findings and requested a meeting with PLN SULUTENGO.

O.5 Mr. Tardjo, Mr. Indra (Megamas)

Megamall and Mega Trade Center (MTC) are two malls that belong to the same owner. Together they are known as Megamas.

The total area of MTC is 47,000 m^2. Where they cool 4 floors with chillers (basement, ground, first and Second floor. The upper floor is occupied by the management and cooling equipment. Meaning that the chillers are almost on the roof of the building. To cool they use chillers with refrigerants and a cool tower to eventually cool a fresh water loop that runs through the building. Megamall uses the same system (not sure if also on upper floor).

They both have three chillers with a capacity of 1600 BTU/h (=600 ton, not 1600 btu/h after further study). In MTC they mostly use one chiller and two when it is busy (one as back up). At Megamall they mostly use two chillers and one extra when it is very busy. Meaning that Megamall requires more cooling than MTC, although MTC is bigger in size. This is because Megamall is often more crowded than MTC. It can be said that at the moment the cooling capacity is sufficient in both buildings.

The electricity usage of the system at MTC per year is 300.000 kWh. They pay a price of +- 2000 Rph/kWh. But this can vary, depending on the total amount they use. The cooling system requires from time to time maintenance. Mostly they have to clean the pipes of the whole system, due to dirt and silica/lime that remains in the pipes. This is because of the poor water quality in the city. Mostly they do this maintenance once a year.

The desired temperature in the malls is 23-24 degrees Celsius, therefore they cool the fresh water loop to a temperature of 9-10 degrees Celsius.

In between MTC and Megamall, a little closer to shore, there is a small power plant. The house contains 8 diesel generators, producing a capacity of 12 MW. Until last year, it was used to power the surrounding area of Megamas, when a power blackout occurred. This almost occurred 5 days a week, between 6 and 10 pm. Since PLN uses the Turkish power ship in North-Sulawesi, this did not occur as often.

O.6 Gerrit Veenendaal (WMD)

WMD heeft in het verleden onderzoek gedaan naar optimalisatie van het systeem voor de productie en distributie van drinkwater. Daarna zijn beide systemen geoptimaliseerd. Het is echter geen drinkwater, maar “clean-water”. De grootste productieplant is Paal II, waar het water van een vervuilde rivier wordt gezuiverd via coagulatie, sedimentatie en zandfiltratie. Het distributiesysteem is niet hygiënisch betrouwbaar, soms lopen leiding door de rioolkanalen en af en toe valt de druk weg. Er zijn ook enkele grondwater locaties.

In het rapport staat specifiek de beginsituatie in Manado. Er ligt geen embargo op dit rapport, maar het voegt op dit moment, denk ik, weinig toe.

Hij kent het systeem redelijk goed en kom regelmatig in Manado voor de ondersteuning van PT WLN. Als er nog specifieke vragen zijn wil ik die met alle plezier beantwoorden.

Het drinkwater bedrijf PT Air Manado is nu nog 51% eigendom van WMD, maar de aandelen worden binnen enkele weken overgedragen aan het overheidsbedrijf (PDAM).

Voor kwaliteitsgegevens van drinkwater kan het beste PT WLN worden benaderd (Arief). Zoals gezegd is dit clean-water met een, afhankelijk van het seizoen, wisselende samenstelling.

In principe is er voldoende water op het vaste land. Dat ligt anders op de eilanden, zoals Bunaken. Wellicht interessant om deze eilanden in het onderzoek te betrekken.

O.7 Harrie de Jonge (Sea Garden Resort)

Harry has been travelling to Bunaken island for many years and is managing Sea Garden Resort. Due to this he knows the area quite well.

Most people at Bunaken live in the village of Bunaken that can be separated in a Muslim and a catholic part. The rest of the island is mostly occupied by forests and resorts.

Drinking water

Almost all the drinking water on Bunaken comes from Manado. Mostly the resorts import drinking water their selves by boat. Although there is a drinking water seller in the village that imports drinking water, but for a higher price. +-25.000 IDR per 19L.

Although the Island is small, there are freshwater springs that deliver tap water. Everybody has to take care of this himself. At Sea Garden resort they take water from a fresh water source a little higher uphill. Nevertheless the water is not safe to drink. Via pipes the water is pumped up the roof to distribute it in the resort. They pay 1.8 million Rph per month to the private owner of the spring, this will be raised to 3 million IDR soon, because Sea Garden built new facilities. Other places use a mixture of brackish ground water and rain water, like Cakalang. Oasis resort has its own Reverse Osmosis installation.

The government built a Reverse Osmosis installation (probably in combination with its own diesel generator) close to shore to clean brackish ground water. This is distributed in the village only, and should be drinkable. At the moment the installation is shut down, since it is broken. They are still waiting for repair.

There is also a well in the Muslim part of the city, but this is brackish water, causing that a lot of people shower with salt water.

Energy

The island has electricity from its own grid between 5 in the evening till 7 in the morning, and officially everyone is only allowed to use 350W per grid connection. This is set by the government, but mostly the islanders do not adhere to this and more is produced. The electricity on the island comes from a solar panel plant and diesel generators, close to Bunaken village. Most probably batteries are charged during the day. When the solar panel plant was build the electricity prices were raised slightly in the village. This caused unknown adolescents to throw stones on the solar panel, assuming that the solar panels were no good for the future.

Sea Garden resort operates two diesel generators itself, for when there is no electricity anymore (one of 4 kW and one of 15 kW). The 15 kW is especially required for the starting process of the compressor that fills diving cylinders. When the electricity is gone for 10 minutes they switch on the generators for electricity production of the resort. Other resorts use a similar system. The generators are 380V and can produce a 3 phase current of 220V.

Bunaken is expanding, this can easily be seen in the past 6 years. The number of resorts grew from 5 to 25. Back then it used to be a fishermen island, that lived on fish. The subsidies on kerosene were high, so that all the fisherman had vessels that used kerosene (sometimes they started the vessel with diesel and then switched to a kerosene tank). When the subsidies on kerosene stopped, a lot of fishermen switched to the tourist industry.

Environment

Bunaken Island is surrounded by coral reefs and is known for its good diving location. Therefore there must be carefully looked at the possibilities of installing a pipe in this vulnerable environment. The islanders statement is that if it brings a lot of prosperity to the island, it is allowed. Nevertheless, the surrounding coral reef is characterized by its strong currents and steep slope (an underwater wall).

A few things can be said about the possible locations, the lagoon is known for its somewhat more gradual slope and has lower currents. Although the slope is still quite steep. Mostly the places where the vessels of the resorts sail out (everywhere on the island) the coral is less than at other places.

Apparently there are maps available that show the currents surrounding Manado and Bunaken. But they only give a global impression. One of the certainties is that the currents bring the plastic from Manado to Bunaken. Since some time there is a voluntary organization from the resorts at Bunaken that clean the reef little by little. They also have a patrol that checks on divers and snorkelers, since that resorts from Manado bring boats full of Chinese tourists that ruin the coral by standing on it, taking it as souvenir and throwing anchors on it. The resorts on the mainland, also attract dive masters to work for them. Leaving a gap at the environmental conscious resorts on Bunaken.

- Officially every tourist on Bunaken has to pay 150.000 IDR as tourist tax. Resorts stopped asking this tax from their guests, until it is clear that it will be used for coral reef protection. The thought is that it is just used for new police cars in Manado for example.
- At Banka island, a Chinese company started to mine iron, without permission. They bribed the local government and the citizens. For exporting the iron, they build a port on the coral reef. This is why protection is hard, when people can be bribed.
- The soil type of the seabed is mostly soft stone, especially the top layers.

O.8 Kanto (Local Bunaken)

The ship builder Kanto brought us to his village on Bunaken island and showed us the primary facilities. He lives in the Muslim part of Bunaken village.

Drinking water

Most villagers have their own well (put) next to their house where they take their water from. Most wells in the village provide freshwater. After trying the water (440 ppm (all particles)) it can be said that the water is fresh. This was after a rainy day, but during the dry season, when there is no rain for a long time, all wells become salty and it cannot be used as drinking water anymore. Also during the wet season the villagers first cook the water before consuming. During the dry season all water needs to be imported from the mainland.

In order to provide the island with drinking water, some years ago two RO installations were built in the Muslim part of the island. People could come to the installations to pick-up drinking water for their selves. Due to a lack of maintenance and miscommunication with the mainland, both installations failed after some time and got never repaired.

- The first installation was built in 2007, could produce 1100L of fresh water per day, but stopped working after 2-3 years of service
- The second installation was built in 2010, could produce 1500L of fresh water per day and already stopped working after 5-6 months. The installation had a waste of 2-3kg per day. It used about 25L of diesel for its own diesel generator to desalinate the water.

Since the installation are not working since a long time, the islanders started to use the parts of the installations for themselves, for example as material/equipment on ships. With the statement: "We can better make use of it, when nobody uses it". Kanto mentioned that the villagers know who uses which parts and they will all return when somebody wants to repair the installation.

After this a third RO installation was built on the east side of the island in 2014. This installation is much bigger and should provide most of the village. A piping network was installed that runs throughout the whole village with tap connections in every street, with sub-pump stations. Until this moment no water comes out of the taps. Some people say that one could go to the installation to pick up water, but at the moment the installation is broken as well.

All RO's are covered with the logo of PU, The ministry of Public works, they seem to build all these installations, but who has the responsibility for maintenance is not clear.

Energy

The whole island is powered by PLN Bunaken. They have a small plant where they produce energy. This plant consists of a field of solar collectors (apparently the biggest in eastern Indonesia) and a bunch of diesel generators.

The solar panels provide energy during the day, but seemed switched of when we visited the plant. Depending on the amount of sunlight they can electrify the island. Already some of the solar panels and batteries are broken and wait to be replaced by a German company. Apparently this should be enough to electrify 500 households.

At 17 o'clock in the evening they switch on a diesel generator, that operated till 7 o'clock in the morning. The plant consists of 4 diesel generators, 2 old ones are not in use any more and the newest one still waits to start operating. The 4th generator, that is in use, requires approximately 700L of diesel per day.

O.9 Qamarud Zaman (Four Points Hotel)

Mr. Qamarud Zaman is chief engineer at Four Points. The hotel Four Points by Sheraton is a brand new luxe hotel in Manado, opened in March of this year(2017). The hotel is connected to Mantos 3.

It makes use of a central air conditioning with chillers. The fresh water from the fresh water loop is directly pumped from their own well, which goes 125 meters deep into the ground. This water is also used for showering and toilets, for which 120 m3 of water is used per day. The water is treated at 4 Points, since they do not want to be dependent on Pt. Air Manado (in case there is not enough water).

In total, Four Points has 3 chillers units, each with a cooling load of 250 ton. Mostly, just 1 chiller is used, but depending on the occupation of the rooms, a second chiller can be turned on in necessary. The total capacity is 1400 kVA, or 1400*0,8 (Power Factor)= 1120 kW, but monthly on average they have a capacity of 800 kVA, or 640 kW.

The desired temperature in the hotel is 20 degrees Celsius. Therefore, they cool the fresh water loop to a temperature of 10 degrees Celsius.

The cooling system of Mantos 3 is at the same location as the cooling of 4Points, however they use different and bigger chillers. In total, Mantos 3 has 4 chillers of 600 ton each.

In case of black outs, 4 Points and Mantos 1,2 and 3 have 6 backup generators in total, each having a capacity of 1,000 kVA, or 800kW, meaning they have 4.8 MW of backup.

According to Qamarud Zaman, the Best Western hotel also makes use of chillers, although we thought this was not the case. Therefore, it might be interesting to have a look over there as well.

O.10 Arief Rakhmadi (WLN)

At WLN the meeting was with Arief Rahkmadi (CEO), Miranda and Fajar. WLN (Water Laboratory Nusantara) is a laboratory with different facilities in Indonesia. In Manado, Makassar, Sorong and Java for sure.

In 2005/06 WMD started a cooperation with the city of Manado (PDAM) and founded together PT Air Manado (PT AM). This was later then the first joint venture of WMD with Ambon in 1997. The joint venture will be slowly decreased in the following years (+-5 years) and after that PT AM will disappear and everything will be part of PDAM. It can be said that the joint venture PT AM is not a governmental organization.

At the moment, almost all drinking water facilities are managed by this joint venture, although PDAM still controls some small areas itself. Examples of areas covered by PT AM are Paal Dua (river water), Malalayang (river and spring combination) and Rotta (river water). WMD is also the owner of WLN and made the set up equivalent to their WLN (Water Laboratorium Noord) near Groningen. They also have a training program together with WLNoord.

They needed a laboratory for controlling the water quality. Not only as a service for PT AM, but also for commercial activities. Since the government has now obligated to check the discharge of industrial waste water (ISO 17-2005), WLN does environmental monitoring for commercial activities. For example for industry, oil and gas and mining companies in whole Indonesia. They also analyse fish, food and air now. Danone Aqua is also one of their clients.

WLN works together with different Dutch companies in Indonesia (i.e. Witteveen+Bos (Textile waste water), Royal Eijkelkamp, Royal HaskoningDHV (monitored the seawater in West Java)). WLN has a cooperation with KWR and NCIDC.

PU is the department of the government that does the budgeting and project phase of water plants. PDAM sometimes build their selves, but only for small projects.

Water Quality

At the moment the water in Manado cannot be used for drinking and is of bad quality. This due to the fact that the quality of the treatment fluctuates (this is believed by citizens mostly) and there is not always a constant flow through the pipes (low pressure). This causes sediment to settle down. When taking water from the tap and leaving it in a glass overnight it can be observed that particles have sunk. It is advised to drink bottled water only or elsewise boil it before drinking. It is expected that in the following years the water quality will stay the same and there are no direct possibilities to improve it.

For the future there are different aspects that threaten maintaining sufficient clean water.

- Growth of population
- Growth of tap connections
- Growth of wealth
- The weak quality of Tondano River
- Sea water intrusion (Since a lot of people/malls/hotels are pumping up ground water near shore)
- Deforestation (for agriculture or housing) (this can threaten the refilling the wells more uphill)

There is a big chance that desalination will become very important for the water production of Manado in the future. At the moment one of the biggest concerns is that plans for the future of clean water from the government are completely missing. Not really plans for in 5 years or 10 years.

Water treatment

At Paal Dua they use conventional water treatment:

- (Pre-)Sedimentation
- Flocculation (with aluminium)

- Sedimentation
- Filtration
- Pumped to reservoir
- Disinfection (with Poly Aluminium Chloride PAC, more expensive then Alum but better)

For the waste water there is no treatment, this is directly led to the rivers, meaning that all the garbage is also discharged to the river.

O.11 Nicolas Schaduw (UNSRAT)

Gave us data about:

- coral around Bunaken
- Issues in 2002 around Manado, Bitung and Minahasa
- Water quality around North Sulawesi
- Current
- National parks in North Sulawesi
- Transportation routes in North Sulawesi
- Topography Bunaken and Manado Tua

There is a large trench between Bunaken island and Manado Tua, according to Nicolas could this trench is interesting for pipe installation. The depth is approx. 1000 m

Our project deals with 2 problems:

- Ecological → preservation of coral
- social problem → must identify benefits for the local people

A valuable contact at the Bunaken is Frets Pieters. He is a guide in Bunaken. Furthermore he can help to find contact with chief of Bunaken and knows what the people on Bunaken want.

Important to know is that Mangrove is mainly no problem to build a pipe trough. The problem is the coral, however if the project is beneficial for the locals it will be no problem. To know where it potentially can be build we have to talk to Frets Pieters.

About the current, according to Nicolas is the current from January to July towards the bunaken and the other months from Bunaken to manado city. We still have to verify this.

- Frets Pieters knows where the RO plants are located and has more information about them.
- Liang beach there is a Jetty and data about the sediment erosion and deposition is known.
- Maybe use fish finder to find the depth close to shore, by using markers.
- BMKG the weather station, can maybe help with more data about the current and sediment transport.

O.12 Frets Pieters (Local Bunaken)

Due to the lack of information about Bunaken island a meeting is held with a local who lived a large part of his life on the island. He is still active for an initiative called Bunaken care, was active for a NGO concerning the national park Bunaken and is at the moment tour guide. Next to that he is very active in the local community and he knows how the politics work on Bunaken Island. His English is also sufficient.

Energy

Provided by:

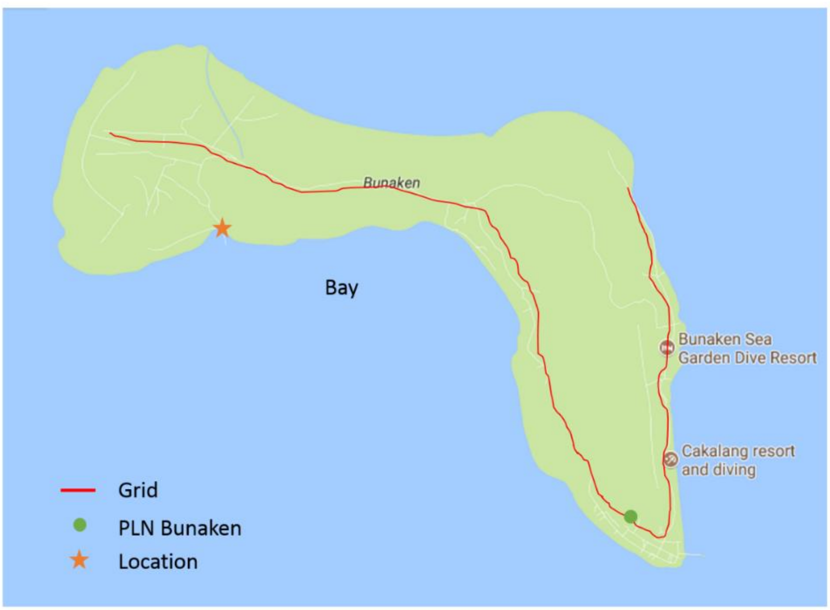
- solar park (338 kW)
- Diesel generators (250 kW and 200 kW)

During the night (12 hours) the Diesel generators produce electricity and during the day the solar panels. The solar panels cannot provide electricity for the whole island so 6 hours gets 1 part of the grid electricity and other 6 hours the other part.

At the moment the battery pack has to be renewed. This has to be done every 4-5 years which is a large investment and has to be ordered from Germany, which takes a long time.

Currently the solar park needs new components, but this takes a very long time. Right personnel takes 3-7 days before they reach the island the same problem is present for the new components. According to Frets is the lack of expertise the biggest problem in the lack of functioning of the plant.

Grid according to Frets:



Fresh water

Fresh water mostly comes from wells, which are mostly brackish in Bunaken village. The other two villages have access to fresh water wells, but still in dry season they even can encounter salt intrusion. The government encountered this problem and therefore PU Jakarta (central government) constructed a desalination plant with a capacity of 2260 liter per day. They included a reservoir and a water distribution system to get the water to the citizens. However this is not working as mentioned in another meeting with Kanto (local boat constructor). According to Frets it is out of function due to the absence of a proper pipe. He states: "the pipe is broken somewhere and has to be fixed", he does not know who is responsible for repairing it. Now people can obtain their drinking water from the desalination plant with jerrycans every Sunday at 1 o'clock in the afternoon.

The reservoir and desalination plant were visited. The distribution system in the village was already visited.

Local content

Frets Pieters states that for a project on Bunaken it is vital to include the locals. According to him are local people willing to help and share their knowledge about the island. Next to that, if the locals and the village head (or Lura) thinks it will help the local people they will allow you to build something in the utilization zones of the National park, which is vital in working in marine protected areas.

Environment

So if the local inhabitants support the idea, it can be built in the utilizations zones of the park. These are also indicated in the environmental analysis. Next to that some locations are discussed with Frets Pieters, he states that the bay would be a good option since the currents are somewhat weaker than average. Additionally he stated that the proposed project location does not have the wall but a more gradual slope and little coral is present.

O.13 Other Meetings

Government Manado

The secretary of the city was met. Third in line after the mayor and the vice-mayor. He was impressed by the financial aspects of Bunaken and the gain you can get with cooling for Manado. He will immediately direct it to the mayor and he will decide. They were also wondering whether we know companies that can build this. The meeting was also attended by the head of the cities R&D department and two deputies of that department.

PLN Sulutengo

The planning manager of PLN Sulutengo was met. There were three juniors present and Lucy (supervisor) too. He was very interested in the Bunaken case. He told us that they are struggling to find a solution for this problem. They though that this really could be interesting and wanted to have the slides of the presentation, so that they could discuss it internally. They were most interested in the Bunaken masterplan.

Bappeda of North Sulawesi

Bappeda is the governmental organization that does the planning of big projects in North Sulawesi and gets the right people together. Works closely together with the governor. They are pretty interested and advise to go to the government in Jakarta to make a regulation to make cities use deep seawater solutions. This is a good solution for Manado and he will show it to the department head of Bappeda and the governor of North Sulawesi. They were on a business trip to Jakarta during the meeting

Royal HaskoningDHV

RHDHV flew to Manado to hear our plans for the future of North Sulawesi. They are very interested to do something with the drinking water part and wanted to invite us to their head office in Jakarta. Unfortunately we could not go, seen the time we had left. They already do some projects in North Sulawesi with sanitation. Including Bitung and Bunaken.

Institut Teknologi Minaesa

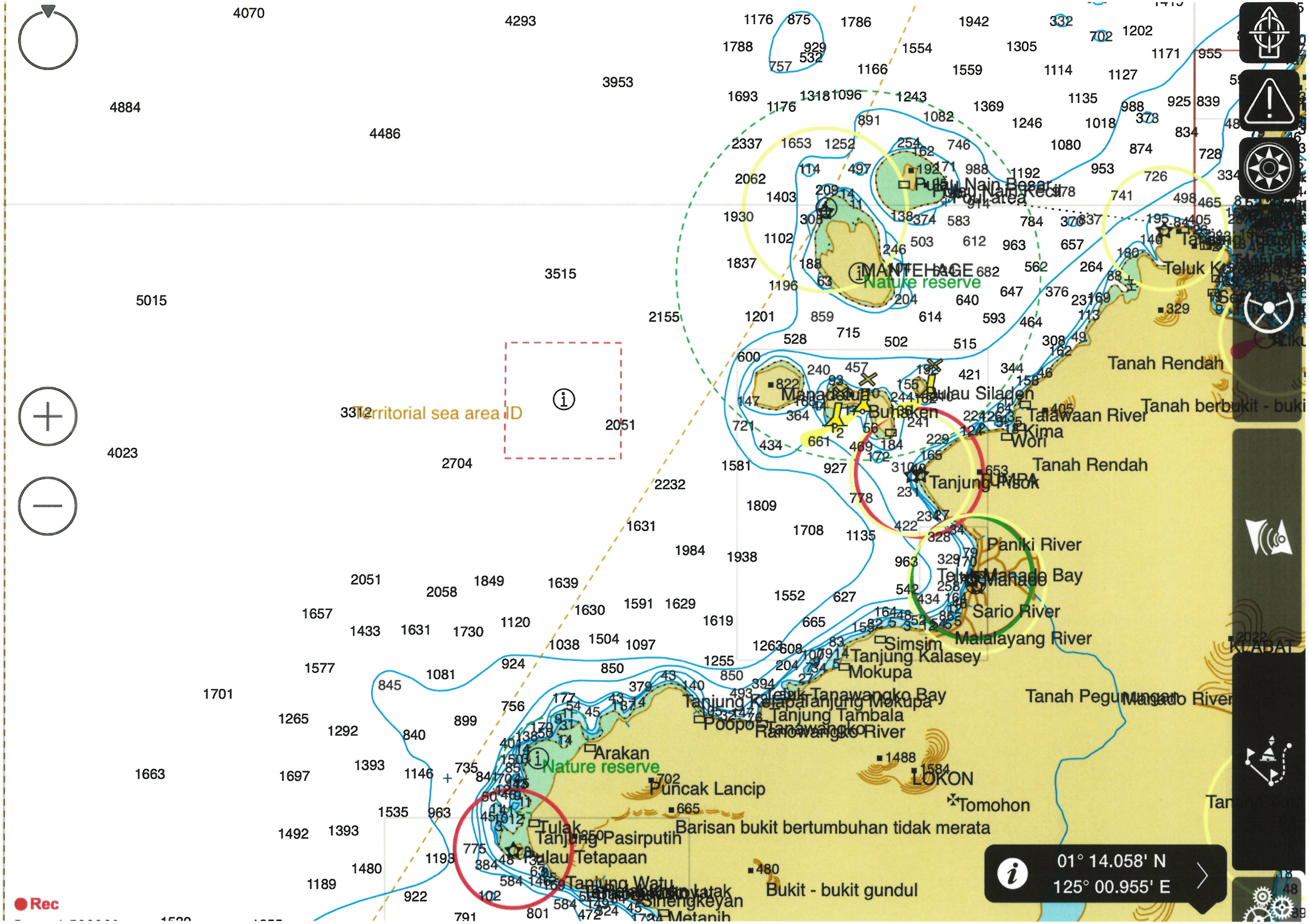
This one hour presentation was visited by +-100 students and lecturers of Industrial Engineering, Architecture, Electrical Engineering, Marine Engineering and Computer Sciences. They had interesting questions and really enjoyed the subject. ITM could be a key partner in further research on this matter in North-Sulawesi.

Universitas Sam Ratulangi

This one hour presentation of us was visited by +- 150 students and lecturers of Marine Sciences. They were very interested and could be of important value in the future for using deep seawater.

Local government Bunaken

This presentation was attended by important people form the island of Bunaken. Frets Pieters initiated the presentation and invited the village head or Lura. Without the presence of the Lura other interested people like the secretary of the sub district Bunaken could not join the presentation. Most of the people could not speak English therefore the whole presentation/discussion was translated by Frets Pieters. Most important outcome these people are enthusiastic but are waiting for the government to take action. We initiated an open letter from the village head towards the government about the future of this concept on Bunaken Island. Whether the local inhabitants will take action is unknown, however the secretary of the sub district Bunaken was enthusiastic about the concept.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MANTEHAGE
Nature reserve
Pulau Nain Besar
Pulau Siladen
Bunaken
Talawaan River
Kima
Wori
Tanah Rendah
Tanah berbukit - bukit
Tanjung Pisok
Paniki River
Manado Bay
Sario River
Malalayang River
Simsim
Tanjung Kalasey
Mokupa
Tanjung Tambala
Tanah Pegunungan
Arakan
Nature reserve
Puncak Lancip
LOKON
Tomohon
Barisan bukit bertumbuhan tidak merata
Tulak
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Pulau Tetapaan
Bukit - bukit gundul
KLABAT
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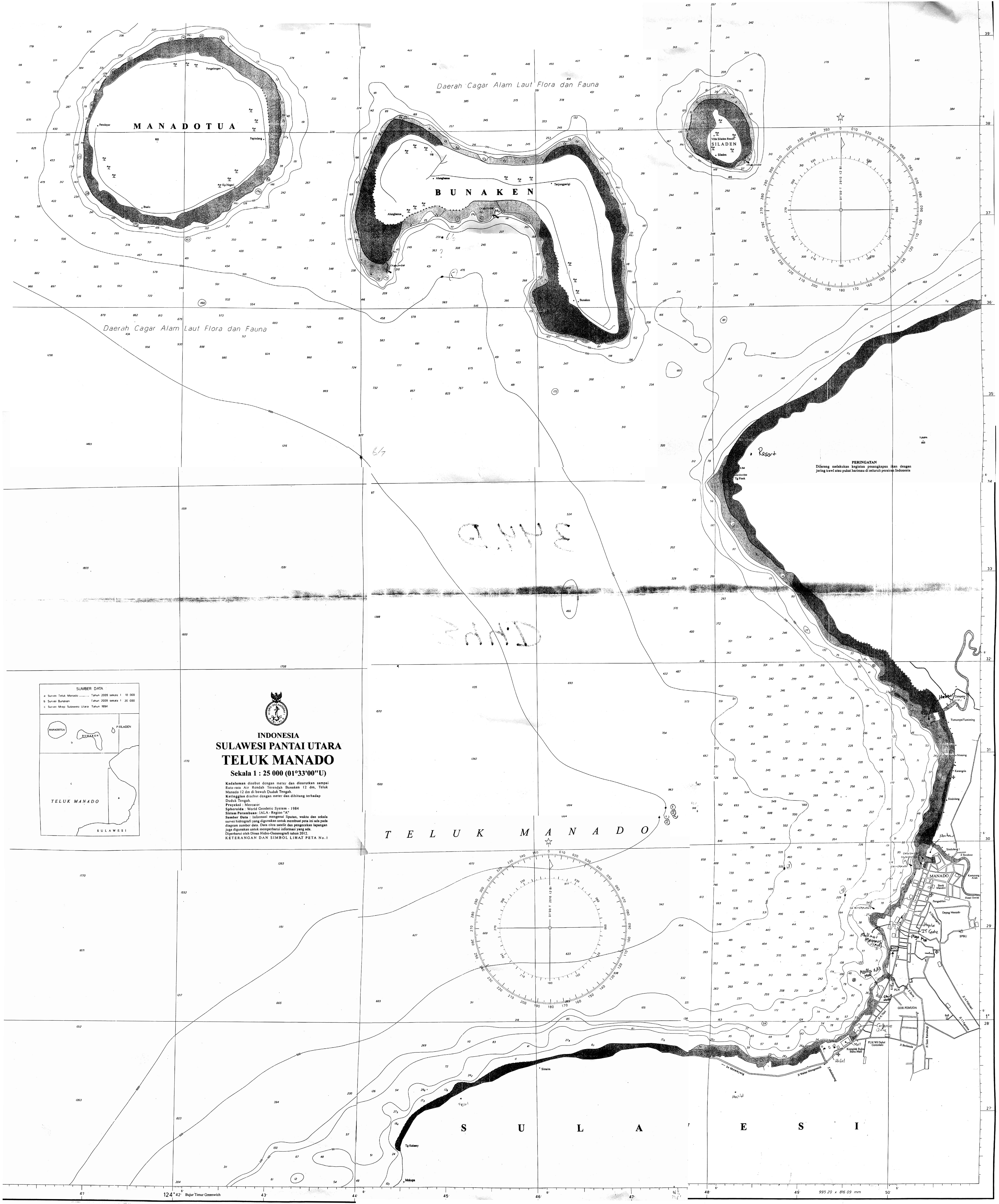
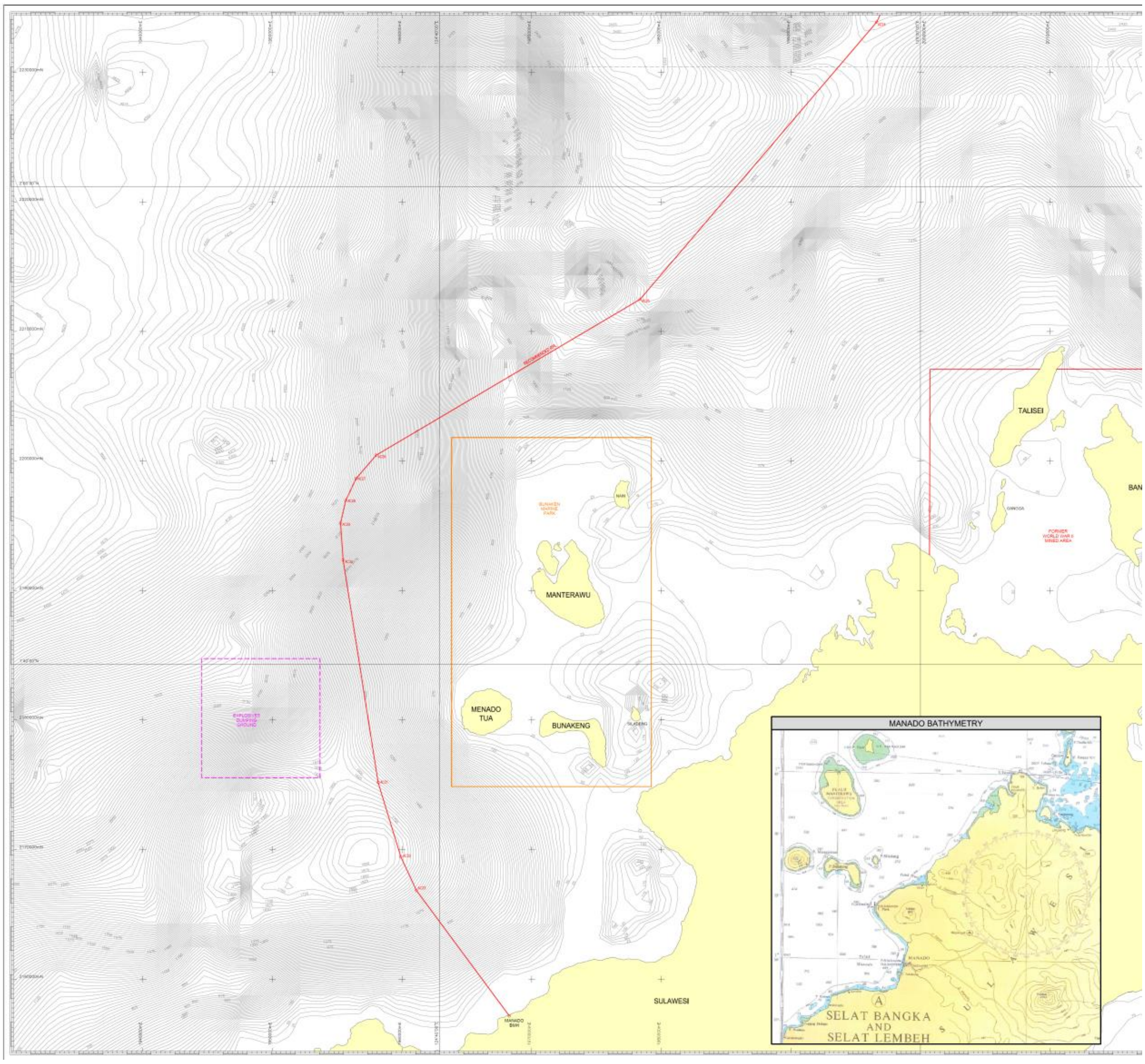
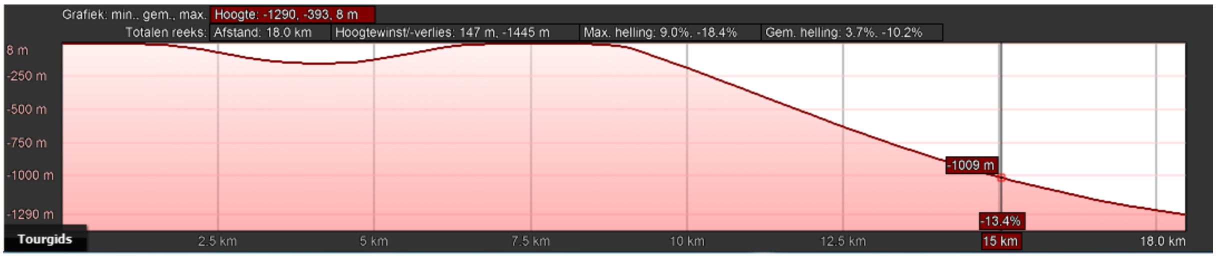
125° 00.955' E
Rec


INDONESIA
SULAWESI PANTAI UTARA
TELUK MANADO
Sekala 1 : 25 000 (01°33'00"U)
Kedalaman disebut dengan meter dan disurutkan sampai Rata-rata Air Rendah Terendah Bunaken 12 dm, Teluk Manado 12 dm di bawah Duduk Tengah.
Ketinggian disebut dengan meter dan dihitung terhadap Duduk Tengah.
Proyeksi : Mercator
Spheroida : World Geodetic System - 1984
Sistem Perambuan : IALA - Region "A"
Sumber Data : Informasi mengenai liputan, waktu dan sekala survei hidrografi yang digunakan untuk membuat peta ini ada pada diagram sumber data. Data citra satelit dan pengecekan lapangan juga digunakan untuk memperbarui informasi yang ada.
Diperbarui oleh Dinas Hidro-Oseanografi tahun 2012.
KETERANGAN DAN SIMBOL LIHAT PETA No.1
SUMBER DATA
a Survei Teluk Manado Tahun 2009 sekala 1 10 000
b Survei Bunaken Tahun 2009 sekala 1 20 000
c Survei Mrep Sulawesi Utara Tahun 1994
MANADOTUA
BUNAKEN
P SILADEN
TELUK MANADO
SULAWESI
PERINGATAN
Dilarang melakukan kegiatan penangkapan ikan dengan jaring trawl atau pukat harimau di seluruh perairan Indonesia
Daerah Cagar Alam Laut Flora dan Fauna
M A N A D O T U A
B U N A K E N
SILADEN
T E L U K M A N A D O
S U L A W E S I
MANADO
Tg Kalasey
TUMPA
124°42' Bujur Timur Greenwich

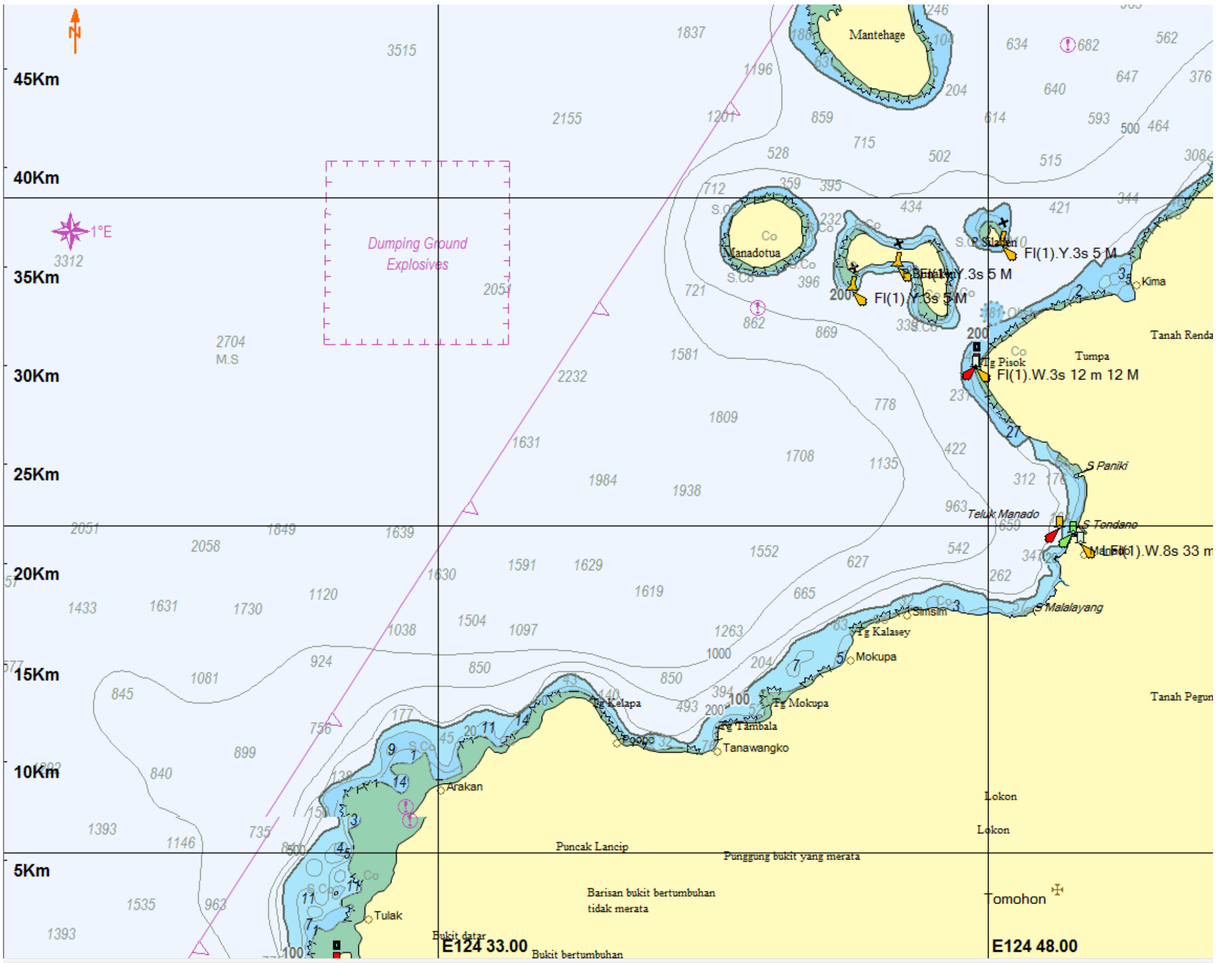
Fugro – Gravity based



Google Earth – Gravity based



Quod Fish – TU Delft license



Koerslijn lengte: **10 min**