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FINAL REPORT

of

OCEAN ENERGY TECHNICAL PRE-FEASIBILITY STUDY

[Country: Nauru]

Implementing Entity:

Overseas Environmental Cooperation Center, Japan (OECC)

Index

Executive Summary

1. Selection of most suitable ocean technology and candidate sites in Nauru

As Nauru is surrounded by the ocean and has abundant ocean energy resources, a wide range of ocean energy technologies can be raised as candidates to be applied.

Among such potential ocean energy technologies, three options have been selected for evaluation according to TOR which states that "scientific data collected through the monitoring equipment will be processed and used to analyze in systemic way, the most suitable sites for the different ocean energies (wave, tidal or thermal) to provide both renewable energy-based electricity and water security to the island".

As explained in the first progress report, given the travel restrictions due to the COVID-19 pandemic, the OECC team requested OTPE (The Department of Ocean Technology, Policy and Environment, The University of Tokyo) to analyze ocean energy data and develop a model as an alternative method to the conduction of direct measurements on site. After conducting analysis of ocean energy data, OPTE found out that OTEC (thermal energy) is likely to be the most suitable ocean technology in relation to other two technologies, and 5 potential sites for the installation of the OTEC plant has been suggested.

In this report, three candidate ocean technologies are compared and analyzed by the technical team under various pre-defined criteria and method including MCDA, and eventually OTEC has been found to be the most suitable ocean energy technology for Nauru.

As for the site, the most suitable location among the 5 options has been suggested, however it is expected that some decision regarding the site may take in the upcoming stakeholder's meeting. Due to its importance, this is a decision that needs to considered by the central government.

2. Design of OTEC Plant

(1) Decision of type of OTEC plant

There are two major types of OTEC systems, namely closed-cycle and open-cycle. Open-cycle OTEC refers to systems that use ocean water as the working fluid, whereas Closed-cycle OTEC refers to a more traditional power generation technique in which low-boiling-point working fluid (Ammonia) is used in a closed system utilizing the so-called Rankine cycle, which is deployed for the OTEC plant developed by TEPCO in 1981 in Nauru.

In this study, the discussion was centered on which is the most favorable technology “single Rankine cycle” or “double Rankine cycle” for Nauru. In conclusion, from a cost perspective, OECC is favoring the Double Rankine Cycle. Double Rankine cycle is advantageous not only from the perspective of cost but also for operational reasons. The two-line system configuration (Double Rankine cycle) has a good advantage since it can be maintained without stopping the entire system even when a problem occurs.

(2) Decision of the output capacity of OTEC

As a result of the discussion with the government of Nauru and the National Utility Corporation (NUC) at the Stakeholder Meeting held on 22nd July 2021, it has been decided that the most appropriate capacity of the OTEC installed plan in Nauru is 1 MW, which is the baseline of the design work conducted by the OECC technical team.

There are no MW-scale OTEC plants in operation so far in the world, yet the technical team has long been engaged in the planning and installation of 1 MW OTEC Plant project in Kumejima (Japan). Accordingly, this experience and efforts made on the design provided a lot of practical information about the 1 MW OTEC plant which now is being applied and considered for the plant for Nauru.

(3) Ocean water intake system

The ocean water intake facility, including intake pipes are a crucial factor towards enabling the installation of the OTEC plant. Due to the longer pipe (1,300m) and depth (700m), DOW (Deep Ocean Water) is the primary area of concern when discussing intake systems for OTEC and DOW use. The OTEC with DOW intake system can contribute to provide a stable electricity source, while at the same time becoming an enabler for the development of economic sectors such as agriculture and food production in the island through the provision of DOW.

In consideration of the potential contribution from new business opportunities and the significant initial investment required for the construction of a new pipeline (about US$27M), it would be realistic, as with other utilities, to expect the possibility of having an initial cost to be covered by grants or subsidies while operation and maintenance costs will be covered by operating income from water sales.

(4) Fresh water production facility

Fresh water production facility is one component of the OTEC plant, which is crucial for countries such as Nauru in which water security is strongly related to issues such as agriculture and food security.

In the case of the water production facility coupled with OTEC, the temperature difference of effluent from OTEC, which is SOW (Surface Ocean Water) and DOW (Deep Ocean Water), is the driving force of desalination. This method is called LTTD (Low Temperature Thermal Desalination) and is less costly and less energy consuming than the existing membrane method using RO (Reverse Osmosis) membrane.

(5) Deep ocean cooling (DOW cooling) is another advantage of the introduction of OTEC technology

DOW Cooling refers to the cooling of buildings through the utilization of the naturally occurring cold DOW resource. Temperature of the effluent of DOW from OTEC is less than 12℃ which can be delivered to hotels, office buildings, schools, etc.

As for the existing cooling facilities, large-scale commercial chillers use energy intensive compressors, fans, and refrigerants to chill fresh water that can then circulate through a building to supply cold to individual spaces. In comparison, significant amount of electricity can be saved since no such electricity consumptions is required.

It is of course necessary to count the initial cost for the installation of water circulation piping network (CAPEX) from the OTEC site to target buildings, however, it is believed that cash flow analysis will show that it would be obviously beneficial.

(6) The feasibility study of 1MW OTEC plant is ongoing in Kumejima, Japan in parallel with this pre-feasibility study for Nauru.

There is plenty of information coming from the study for Kumejima, and the image of the "Kumejima model" is taking shape. During the conduction of the pre-feasibility study for Nauru, it becomes quite effective approach to seek the conformation of the "Nauru model" while tracing the results of the "Kumejima model" by taking into account the different features of Kumejima and Nauru.

Introduction of the Final Report

Currently, the Republic of Nauru lacks technical and financial resources as well as in-country expertise to conduct a pre-feasibility study and assess the potential of OTEC in comparison to other ocean energy possible solutions. Therefore, Nauru has requested technical assistance to the Climate Technology Centre & Network (CTCN) to conduct a technical, socio-economic and financial analysis of an OTEC plant project in comparison to other ocean energy potential solutions.

The CTCN has selected the Overseas Environmental Cooperation Center, Japan (OECC) and its partners, the Institute of Ocean Energy Saga University (IOES), Deloitte Tohmatsu Financial Advisory LLC (DTFA), and R-Quest Corporation, to conduct this pre-feasibility study.

This document constitutes the Second Progress Report of the technical assistant entrusted by the CTCN. It is divided in two main parts (A3.1 and A3.2), following the activities indicated in the Terms of Reference: A3.1 the Technical Pre-Feasibility Study, which summarizes findings of an external study conducted by the Department of Ocean Technology, Policy and Environment, The University of Tokyo (OTPE) in relation to [2] Renewable energy potential for ocean energies for Nauru, and [3-8] the Technical analysis for renewable energy implementation, conducted by IOES and its partner, Xenesys Inc.; and A3.2 the Socio-Economic and financial analysis, composed by a Multi Criteria Decision Analysis (MCDA), used to choose the relevant ocean technology for Nauru, and the corresponding pre-feasibility study which describes the overall approach and methodology used to choose the relevant ocean technology for Nauru, and finally the results of the financial analysis.[1]

As indicated in the Terms of Reference, in addition to the results obtained in the Pre-Feasibility Study, this report also includes information obtained through the Stakeholder's Consultation.

[1] A3.1 and A3.2 refer to the number of activities as designated in the Terms of Reference of the project.

I. Technical Pre-Feasibility Study

1. Introduction and Background

As other small island nations, Nauru is particularly vulnerable to the impacts of climate change, including sea level rise, droughts and the impact that an increase in temperature will have on marine resources and already stressed water and vegetative resources. Nauru has developed a number of development strategies and policy instruments as a response to climate change since 2005. These include the NSDS 2005-2025 (rev 2009); Nauru's Utility Sector-A Strategy for Reform; National Energy Policy Framework; National Energy Roadmap (NERM) 2014-2020; Nauru Utilities Cooperation Act, the Intended Nationally Determined Contribution (NDC), second national communication and RONAdapt, among others.

However, the country still needs to implement most of the actions identified in these documents. With a population of 11,690 inhabitants as of 2020, Nauru has very limited capacity to respond to a global threat of this magnitude. As such, Nauru's response has to be streamlined to sit with its capabilities. The country requires support in financing and technology development and transfer to achieve tangible outcomes.

In Nauru, most sectors are interconnected and interdependent, and adaptation actions have significant mitigation co-benefits. Nauru's energy sector is key to achieving most of Nauru's objectives in terms of adaptation. It is crucial to secure energy security, as Nauru mainly relies almost exclusively on foreign fossil fuel imports, with 99 percent of its needs imported for its electricity and other energy needs. Electricity production is mostly powered by diesel and accounts for 6 to 7 million liter a year. The energy sector represents 13.34 Gt CO_2e (68 percent of total GHG emissions of the country), of which more than half of which is used for electricity generation (36 percent). Transitioning to renewable energy is thus a priority for the country, as shown by Nauru's NDC and NERM. The key mitigation intervention is to replace a substantial part of the existing diesel generation with a large scale grid connected solar photovoltaic (PV) system which would assist in reducing the emissions from fossil fuels.

However, to rely on solar PV generation and other sources of variable renewable energy, such as wind, Nauru will need to invest in technologies that will enable the power grid to supply a base load of energy to end-users, as well as to account for the high night time electrical load on the island. Energy storage systems remain expensive and their lifecycle, including recycling and waste management, may prove challenging for a small country such as Nauru.

The country will thus require to diversify its energy mix by investing in other technologies. This includes ocean energy technologies, such as wave energy, tidal energy and ocean thermal energy conversion energy. Ocean energy is predictable across a longer period of time compared to other renewable energy. This makes it one of the best choices to be coupled with solar PV and wind power generation capacities, to stabilize power output to the grid and limit variability.

In addition to the energy sector, Nauru is also extremely vulnerable in terms of water availability. Nauru lacks significant surface water resources; desalination plants and groundwater are its only potable water sources. Water scarcity is already affecting human health. Climate change and disasters will exacerbate these existing challenges of meeting demand for potable water, posing threats to basic livelihoods and constraining opportunities for economic development. Projections indicate Nauru may receive more rainfall in future, but within shorter periods of intense rain. This could therefore reduce the sustainability of the country’s groundwater resources, the health of its population, and the persistence of a vegetation ecosystem. Enhancing water security is therefore both a key national development priority and also fundamental to reducing vulnerability to climate change and to potential disaster events.

The desalination plants are energy-intensive and high demand for water thus presents additional burden on the government budget. This emphasizes the significant relationship between the energy sector and other sectors in Nauru. In addition to its relationship with water, the energy sector may also be related to the agriculture sector, which requires water, produced by energy. Food insecurity is a major risk for Nauru, given the island’s dependence on imported foods and its geographic isolation. Improving water security specifically for agricultural production is a key need, particularly since previous government initiatives; such as Grow and Green, have stalled because of inadequate water.

Ocean energy can bring key technological and socio-economic benefits, in addition to helping mitigate climate change. Ocean energy can bring co-benefits relevant to these sectors. For example, OTEC produces fresh water either from evaporated warm seawater or through condensation. Ocean energies are thus extremely relevant to Nauru’s challenges.

Furthermore, the enormous potential of ocean energy for Nauru has long been known. As the first pilot plant established by Japan's Tokyo Electric Power Company in 1981, it was the first

OTEC plant to feed power to an operating commercial grid. The Nauru test plant's pipes washed away after tests were completed in heavy weather. Engineering for long-term pipe deployment avoids such risks.

Since the installation of the OTEC pilot plant in 1981, there have been significant improvements in OTEC technology and design, with side benefits such as the production of large amounts of fresh water. With the very rapid drop-off beyond the reef in Nauru, there is an opportunity for OTEC energy development in the country. Experience in long-term deep water intake exists in several locations around the world, with improved techniques ensuring climate resiliency.

2. Renewable Energy Potential for Ocean Energies

2.1 General

The objective of this pre-feasibility study is to seek the most appropriate solution under the recognition that the main contribution of the Republic of Nauru to climate change mitigation is the implementation of its Energy Road Map (NERM) 2014-2020 in order to reduce greenhouse gas emissions and achieve energy security by reducing reliance on imported fuel.

Nauru is surrounded the ocean with abundant ocean energy resources related to a wide range of renewable energy technologies. There could currently be several options available when it comes to ocean energy harnessing, namely technologies using wave energy, ocean tidal energy, and ocean thermal energy, converting them into a useful form, typically electricity.

The main goal of this study is to ensure the provision of electricity and water security for the Republic Nauru through the evaluation of potential technologies through collected scientific oceanographic data and simulation models.

Considering the current technological feasibility and the future energy potential, this report analyzed three ocean energy technologies: tidal, wave, and ocean thermal energy conversion (OTEC). The most widely developed technologies across geographies are tidal and wave energy converters. In terms of energy potential, OTEC is the largest potential source of ocean energy, followed by wave energy. According to the analysis from the International Renewable Energy

Agency (IRENA), the theoretical resource potential of ocean energy is well above the twice the current global demand for electricity, which is between 45,000 terawatt-hours (TWh) and potentially over 130,000TWh of electricity per year. Figure 2.1 below shows the breakdown of major ocean energy resource potential.

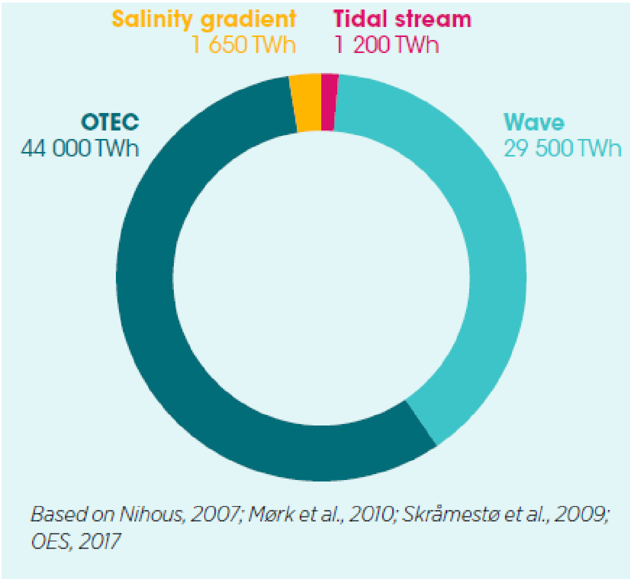


Figure 2.1 Ocean energy resource potential (TWh/year)

2.2 Wave Energy

While the South Pacific has extremely high wave energy potential with locations such as Tubuai in French Polynesia having values over 30kW/m, Nauru, is located in the Central Pacific area, where wave energy potential is much less in comparison. For Nauru, the range of values is only from 7 to 10 kW/m, far below in energy density.

Wave energy potential has been studied before in the context of Pacific Island countries, showing that several promising sites could use wave energy as an alternative source. The latest study by Bosserelle et al. (2015) estimated wave energy flux for 33 islands in the Pacific Ocean (Figure 2.2), as well as annual energy output and energy generation costs.

The results showed that French Polynesia, Tonga, Fiji, Cook Islands, and Niue are strong candidates due to high energy output and low generation costs. When it comes to Nauru, however, its geographical location in the Central Pacific makes it an unsuitable site for wave energy power generation, since there is low wave energy flux in this area (Figure 2.2).

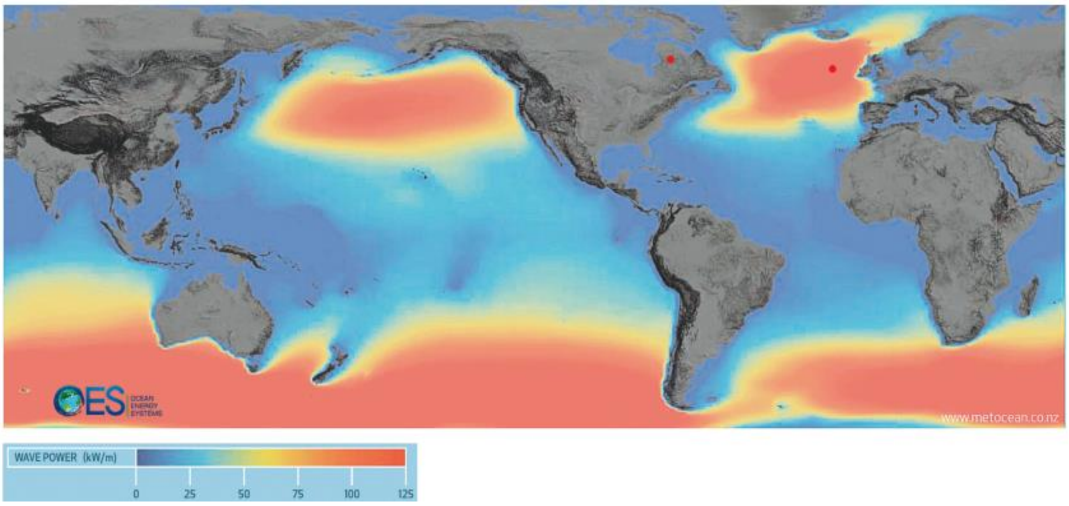


Figure 2.2. Average wave power in the world (kW/m): sourced from "An International Vision for Ocean Energy" (2012, IEA-OES) by NEDO

The Bureau of Meteorology and CSIRO (Commonwealth Scientific and Industrial Research Organization) have developed a hindcast model, known as the CAWCR (Centre for Australian Weather and Climate Research). The CAWCR Wave Hindcast Aggregated Collection is the highest resolution wave product in the Pacific and was used to verify the wave energy potential near Nauru.

A yearly average map using 2020 data was created (Figure 2.3) showing that wave energy flux is between 7.5 and 10.5 kw/m, which are relatively low numbers. Aside from the low wave energy potential, the areas with higher energy flux are very distant from the island, which means that only offshore wave energy converters (WECs) could be considered for energy harnessing, onshore and nearshore WECs are not suitable.

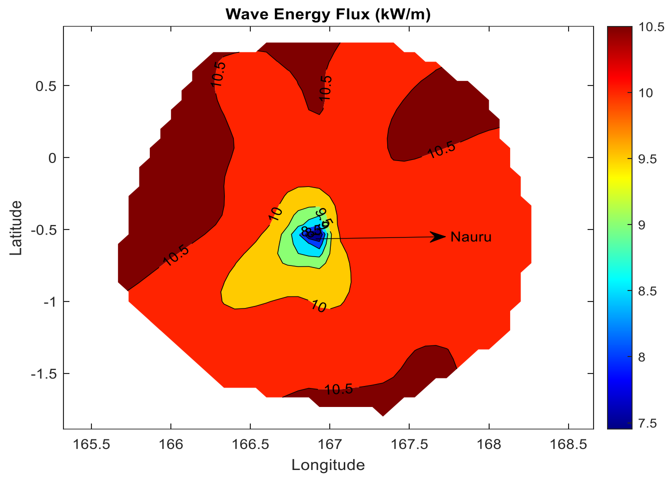


Figure 2.3. Wave energy flux in kW/m for the surroundings of Nauru (data source: CAWCR Wave Hindcast Aggregated Collection).

2.3 Tidal Energy

Tides, or natural rises and falls in ocean water level, can be harnessed to energy generation with two different approaches. The first approach is tidal range. Tidal range technology harvests the potential energy of the difference in water levels, by making use of the actual height difference between high and low tide.

While this technology is relatively more established, its deployment is difficult partly due to the limited availability of sites allowing the technology to be operational and efficient. In most locations, the usual sea-level difference between high and low tide is below one meter, which is not enough to fully leverage tidal energy potential.

Some research suggests that the mean tidal amplitude should exceed 2.5 meters and others declare at least 7 meters is required for commercial applications.

Since the technology requires specific geographic conditions, only a limited number of countries can harness the tidal energy such as France, the UK and the Republic of Korea, but in the sea area around Nauru, potential would not be very limited. (Figure 2.4)

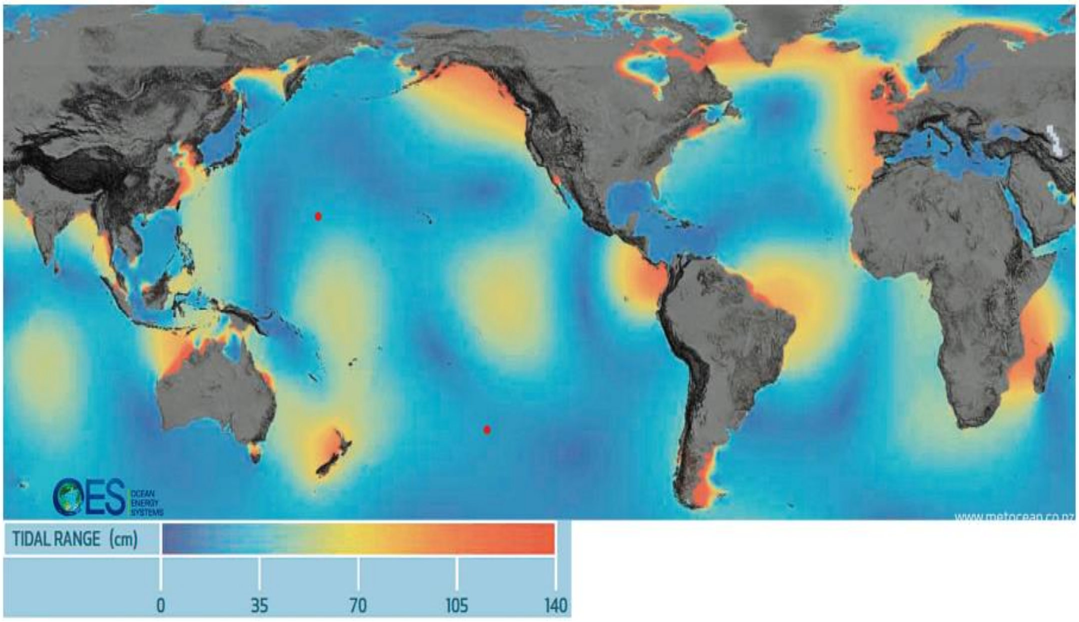


Figure 2.4. Global Tidal range distribution on for Ocean Energy, 2012, (IEA-OES)

Another approach is tidal current, which utilizes the kinetic energy in the flow of the incoming (flow) and outgoing horizontal flow of water in bays, harbors, estuaries, and straits. Marine current power generation is a power generation system that generally uses a water turbine as an energy conversion device and converts the kinetic energy of the sea current into electrical energy via the rotation of a turbine.

The location of strong ocean currents is more than a few kilometers away from the land, and the depth of the water is so deep that it is difficult to install and manage equipment. In addition, the transmission distance is long.

Many issues remain for practical use. It requires the flow's speed to be at least 1.5 to 2 meters per second for energy generation. It is less mature than tidal range (one step behind) but approaching to the same maturity level. Tidal stream will experience less constraints for site selection compared to tidal range technology, and is thus expected to become more prominent in the future.

2.4 Thermal energy

Ocean Thermal Energy Conversion (OTEC) is a power generation technology that utilizes the temperature difference between warm ocean water on the surface (surface water) and cold ocean water in the deep sea (deep water). Part of the solar energy is stored as heat in the ocean water up to about 200 m on the surface of the ocean, and it is maintained at about 26 to 30℃ throughout the year in low latitude regions.

On the other hand, ocean water cooled in the polar regions moves to low latitude regions according to the ocean general circulation. Due to the movement, a temperature difference occurs with the surrounding ocean water. Cold ocean water from the polar regions, which have a relatively high density, sinks into the deep layers.

This surface ocean water (SOW) and deep ocean water (DOW) existing in the deep layer 600 to 1,000 m are taken in, and power is generated by utilizing the temperature difference. (Figure 2.5)

Figure 2.5. Global Temperature Difference distribution, Surface and 1,000 depth

IOES (Institute of Ocean Energy, Saga Univ.) H.P

With current technology, an annual average temperature difference of around 20 degrees Celsius (°C) is necessary for such a conversion cycle to be economical. In our study, the average temperature of DOW at 700m depth in the area surrounding Nauru is displayed in the Figure 2.6 (approximately 6.15°C).

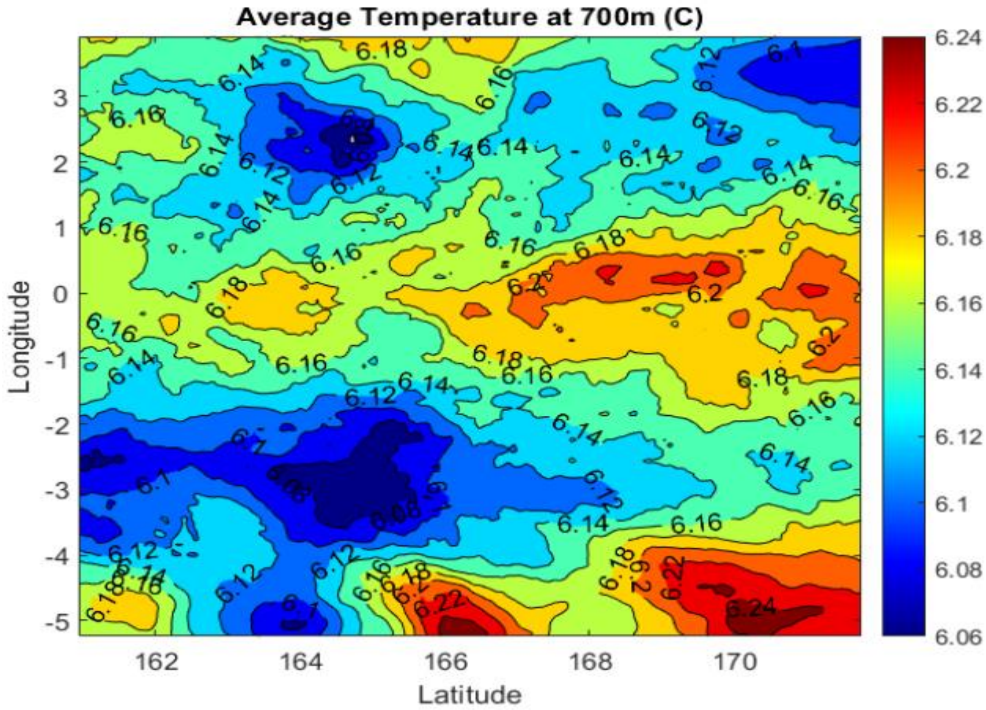


Figure 2.6. Average DOW temperature at 700m depth near Nauru

Since Nauru is located in the western Equatorial region, SOW temperature will be higher when compared to the East, which is an additional benefit for OTEC. The surface temperature range near Nauru is relatively high, which is more than 29°C (Figure 2.7), as a result the average temperature difference of DOW and SOW is in a range of 22 – 23°C, which is more than 20°C.

Ocean thermal energy conversion is a relatively stable energy source that does not fluctuate day and night because the temperature of DOW and SOW are both stable, and since seasonal fluctuations can be predicted, it can be used as a base power source and systematic power generation is possible.

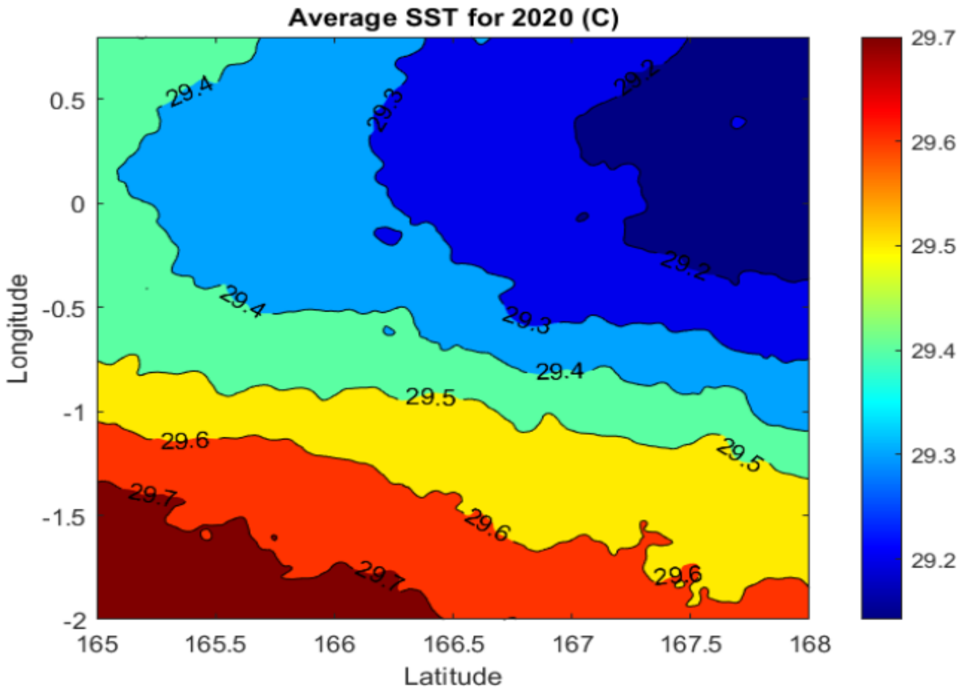


Figure 2.7 The annual average for SOW Temperature near Nauru in degrees Celsius.

2.5 Selection of the Most Suitable Technology

At global scale, ocean energy has significant theoretical resource potential, however, as shown in Table 3, each technology has its own strengths and weaknesses in suitability for Nauru.

Under the criteria defined, evaluation is made respectively for the suitability of each technology in terms of suitability to Nauru.

Table 2.1 Evaluation of Ocean Energy Technology

Criteria	Tidal Energy	Wave Energy	OTEC
Required ocean condition	Flow of water in bays, harbors, estuaries and straits higher speed	Higher Power density is required (30kW/m) Near Nauru is relatively low (7 – 10kW/m)	Temperature difference between deep and surface ocean water of 20°C or more is desired. Near Nauru more than 20°C is possible

Suitable geological location	Suitable geographical location is shown in Figure 2.4, which indicate that Central Pacific is not suitable.	In South Pacific, more power density can be expected Nauru is in Central Pacific.	Tropical regions with latitudes between north and south 30 degrees
Potential site	Suitable site is far from Nauru	Suitable site is far from Nauru	Suitable site can be found close to Nauru
Stability of electricity generation	Since it flows regularly due to the ebb and flow of the tide, it is a predictable and highly reliable energy source.	Prediction is easy but not stable due to change of wind and current	Stable through the year because temperature difference is almost same
Economy in capacity factor(CF) and availability(AR)	CF: 25 – 35% AR: 65 – 95%	CF: 35 – 42% AR: 75 – 98%	CF: 90 – 95% AR: 95 – 99% Thanks to better stability, can be expected to be base load
Industry and Employment Creation, By-product	Power generation only	Power generation or desalination	Industry by utilizing DOW - Desalination, - District cooling, - By-product like Agricultural and aquatic product
Operation record	In Europe, there seems some cases.	In Europe, many devices with long operation history	7 years or more operational record in Kumejima in Okinawa, Hawaii, etc.
Suitability to Nauru	Not suitable	Not suitable	Well suited

2.6 Selection of the Most Suitable Site

OTEC needs high-temperature differences to provide higher energy outputs, however, the depth from which we find DOW can vary according to the local temperature profile. Ideally, we would have DOW available in shallow areas to reduce installation and maintenance costs, but in reality, it can be extracted from 500 to 1000 m depth (Hamedi and Sadeghzadeh, 2017).

For this reason, we have reduced the search for potential sites to areas where we could find depths within the 500m to 1000m range. Distance to the shore is another important variable that will have direct impacts on the overall costs of a project, thus, we have analyzed the distance from potential sites to Nauru shore using the ArcGIS base map for Nauru and the ruler tool to measure distance. The sites that were closest to the shore were therefore further analyzed.

Lastly, the distance to the main districts was considered as a parameter for site selection, since being closer to the populated and economically active areas will add relevance to an OTEC project. The most populated districts of Nauru are Location, Meneng, Aiwo, Boe, and Yaren (Figure 2.8). "The Location" is a housing compound built in the Denigomodu district to house the expatriate, mostly from Tuvalu and Kiribati, who worked for Nauru Phosphate Corporation (United Nations Development Programme, 2020). Thus, Location is also considered as part of Denigomodu.

In this study, we have considered the distance to the districts of Denigomodu, Meneng, and Aiwo as a final parameter.

The five selected sites can be seen in Figure 2.8, while the coordinates for each site are listed in Table 2.2. We expect that the most suitable site selection is to be selected from among the 5 in Table 2.2 after the discussions by relevant stakeholders on various considerations.

In addition, Figure 2.9 compares average temperature profiles in degrees Celsius for each site.

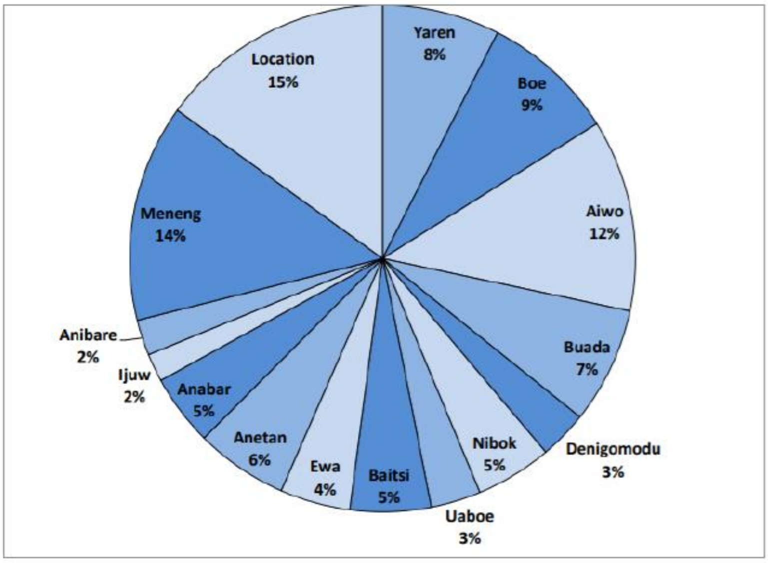


Figure 2.8. Population Distribution by District (%), Nauru: 2011 (Republic of Nauru, 2011).

Figure 2.9. Location of the Five Selected Sites in Nauru Island to harness Ocean Thermal Energy.

Table 2.2 Exact Locations of Five Selected Site Coordinates

Point	Longitude	Latitude	Distance (km)	Depth (m)
1	166.9104104°E	0.5519202°S	0.89	809
2	166.9064007°E	0.5398911°S	0.48	754
3	166.9074354°E	0.5193250°S	0.65	647
4	166.9154549°E	0.5111762°S	0.86	573
5	166.9311058°E	0.4942318°S	1.02	749

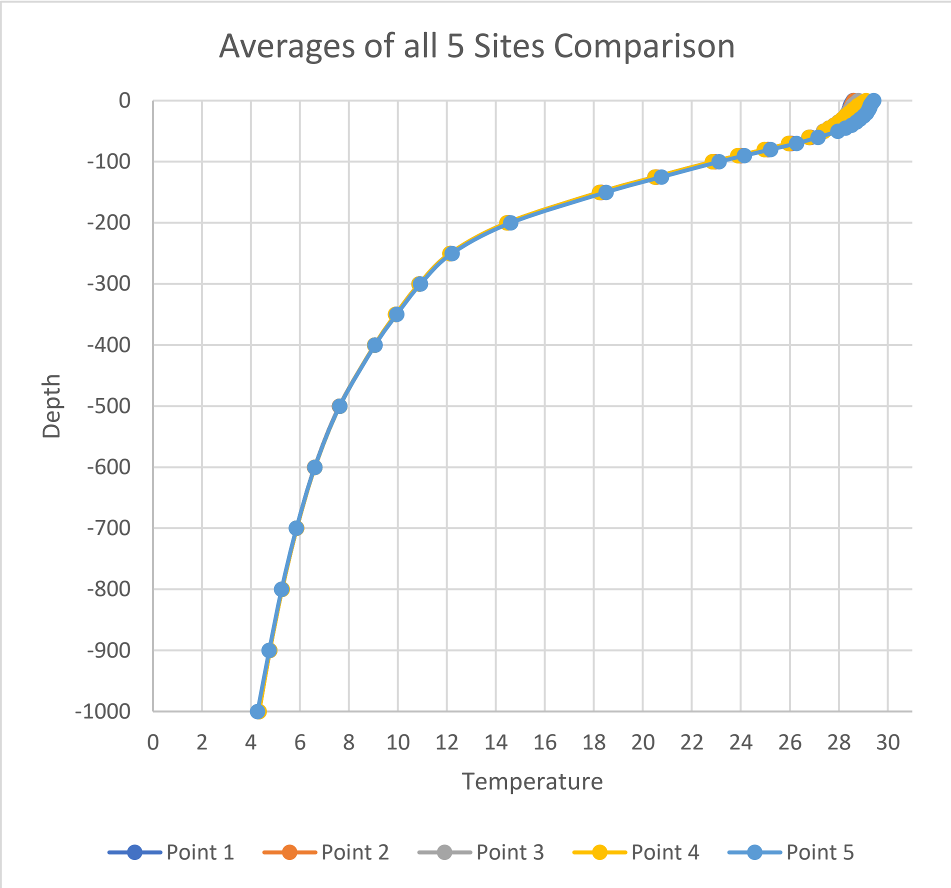


Figure 2.10. Average Temperature Profiles in Degrees Celsius for Each Site

3. Technical Analysis for Renewable Energy Implementation

3.1 Overview of the Selected Technology (OTEC) and State of the Art

OTEC is a technology to generate electricity by utilizing temperature differentials between warm surface ocean water (SOW) and cold deep ocean water (DOW).

The characteristics of OTEC are as follows;

- ✓ The system can generate electricity, utilizing only ocean waters (SOW and DOW) as its energy sources. There is no consumption of fuels such as oil or gas;
- ✓ The energy sources are renewable and abundant in the vicinity of Nauru;
- ✓ As the temperature of the SOW and DOW are very stable throughout the day and the year, the OTEC plant will supply stable base-load electricity to Nauru.
- ✓ The system can reduce or have the effects of reducing the environmental impacts in terms of CO2, SOx, or NOx emissions, which would have been inevitably emitted to the environment when using the conventional diesel power plants.

There are two main OTEC subtypes, open-cycle OTEC and closed-cycle OTEC. Open-cycle OTEC refers to systems that use ocean water as the working fluid, requiring vacuum pumps, large low-pressure turbines, and a pressure vessel. Closed-cycle OTEC refers to more traditional power generation techniques in which low-boiling-point working fluids are used in a closed system utilizing the cycles discussed below, thus OTEC is a subset of binary power generation.

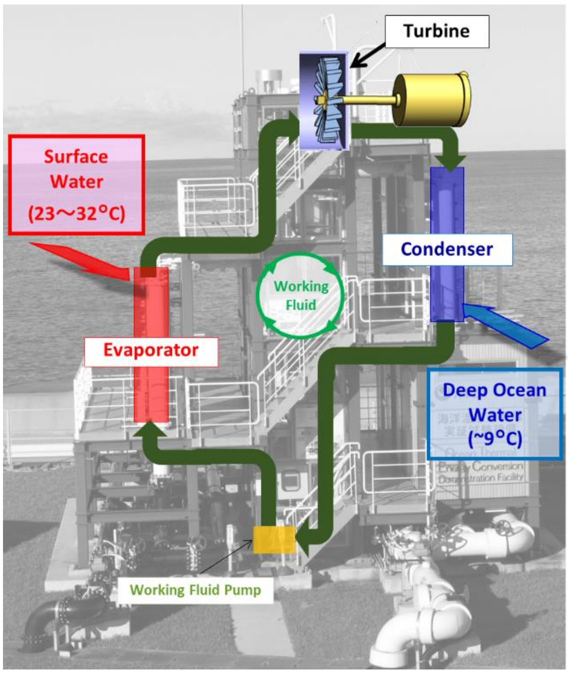


Figure 3.1. Diagram of a Simple Rankine Cycle. Simplified Working Fluid Flow at the Okinawa Prefecture OTEC Demonstration Facility.

OTEC was initially conceptualized in the late 1800s by French Physicist Jacques-Arsène d'Arsonval with initial tests by his student Georges Claude in 1926 [7]. It was not until the oil shock of the 1970's, however, that funding for new energies such as OTEC became available in the United States, Japan, and other locations. This culminated in the "Mini OTEC" ship-based experiments in Hawaii in 1979, the first net power demonstration at sea and in 1981, Tokyo Electric Design Company's (TEPSCO) installation of a short-term OTEC demonstration facility in Nauru to facilitate development of large-scale OTEC deployment. The Nauru facility ran several experiments including a 10-day continuous operation experiment and achieved 120kW output but was not a long-term installation [21]. Based on results, TEPSCO released a study considering 500kW and 5000kW scale OTEC facilities for Nauru.

Initial research proved interesting, yet with the end of the oil crisis, much of the funding for renewable energies stopped as well. Still, development and deployment of deep ocean water industries and intake equipment continued, with deployment of a 13,000m^3/d capacity intake at Kumejima in Okinawa in 2000 and 1.4m intake pipe to 900m meters with capacity of 155,520m^3/d at the Natural Energy Laboratory of Hawaii Authority in 2001[22], expanding existing capacity there.

In addition to DOW intake, between 1994 and 1998 testing of an open-cycle plant took place at NELHA achieving 210kW, and in 2003, Saga University opened the Institute of Ocean Energy with 40kW OTEC experimental equipment.

After the 2008 oil crisis, research in renewable energies increased. When considering patents, a total of sixty-five patent applications for OTEC were submitted among major countries in 2010 compared with only two in 2000 [8]. The same period saw an increase in the number of countries applying for OTEC patents [8]. This highlights the increased potential and interest in ocean thermal energy.

3.1.1 Types of OTEC Cycles

For closed-cycle OTEC there are several options in deploying a working fluid. Working fluid is heated and evaporated by warm heat sources (SOW) in the evaporators. The vaporized working fluid drives the turbine shaft and generates electricity. Then, the working fluid is condensed back to the liquid in the condensers by cooling sources (DOW). The basic Rankine cycle is described in Figure 3.2 below.

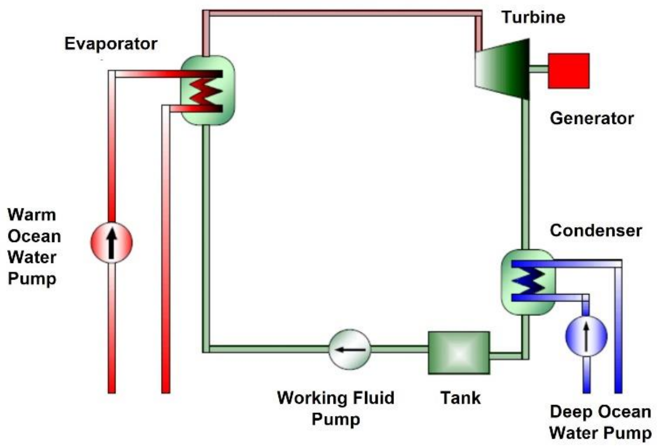


Figure 3.2 Basic Rankine Cycle Concept

As an improved Rankine cycle, Double Rankine Cycle has been developed. Double Rankine Cycle has two Rankine cycles with cascaded ocean water lines. For two Rankine cycles, SOW and DOW flows in sequence as in the following figure. Compared to the original Rankine Cycle, this Double Rankine Cycle generates power more efficiently.

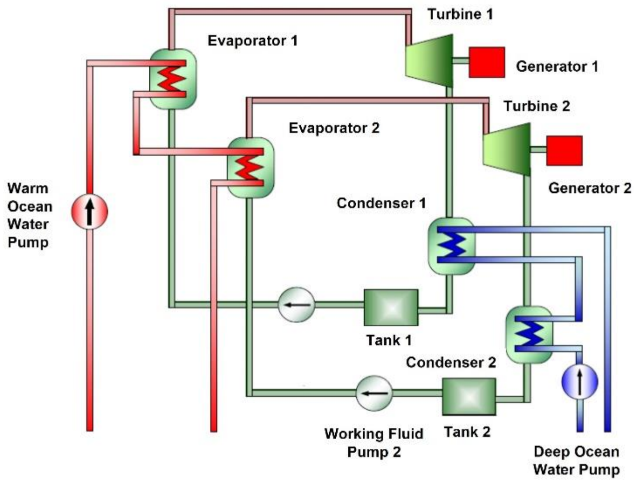


Figure 3.3. Double Rankine Cycle Basic Concept

In advanced OTEC systems such as the Kalina and Uehara Cycles which uses zeotropic refrigerant as working fluid such as the ammonia/water mixture instead of pure ammonia for better efficiency of the system. There are various heat recovery measures integrated in the system with extraction and absorption processes. The conceptual diagram of advanced systems is described in Figure 3.4 below. In this study, determination of cycle will be discussed in section 3.3.1.

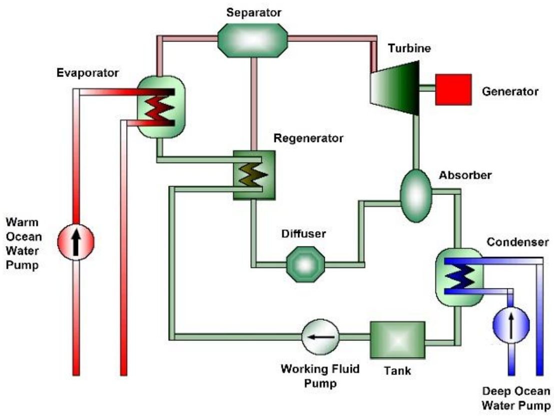


Figure 3.4. Ammonia/Water Mixture Cycle Basic Concept

3.1.2 OTEC Development in Japan

In Japan, the Institute of Ocean Energy, Saga University (IOES) has led OTEC development with research continuing since the 1970s. In particular, research into heat exchangers has led to increases in efficiency, and a decrease in the size of heat exchangers required for OTEC applications. Though lab-scale testing in Rankine, Double Rankine, and Uehara Cycle OTEC has been performed at IOES, the facilities do not have access to DOW resources. In order to test computer models at small scale and demonstrate the viability of researched technology, Okinawa Prefecture in 2013 built the Okinawa OTEC Demonstration Facility to utilize existing water resources at the ODRC for small-scale OTEC demonstration and testing.

Since the OTEC facility has all-welded titanium heat exchangers, water leaving the OTEC facility maintains its high quality while DOW is warmed, and SOW is cooled. The facility operated under an Okinawa Prefecture project through March 2019, and has continued operations under consignment, producing more than 8 years of operational data.

Currently, ocean water at the ODRC is generally used only once, limiting the capacity for power generation and the overall capacity for current and future industries. The OTEC facility only receives surplus water not being used by the ODRC or industry, leading to more DOW access in the winter months, but far less in the summer months. The shared ODRC capacity means that while the OTEC facility is 100kW-class, less power is generated on average. A 1MW-class OTEC facility on Kumejima would require roughly 180,000 tons of DOW per day [6], a figure that matches well with current demand for more water from DOW users on Kumejima, but which is not available with current infrastructure.

The Okinawa OTEC Facility was originally configured with a single turbine unit for power production experiments, accompanied by a second unit for engineering testing and operation. The second unit did not initially have a turbine, however, in 2016, the Okinawa OTEC Facility was retrofitted with a second turbine and equipment to operate with the Double Rankine Cycle under the New Energy and Industrial Technology Development Organization (NEDO) “Ocean Energy Power Generation System Demonstration and Research” Project operated by Japan Marine United and Saga University. This additional equipment allowed the testing of a more advanced cycle and higher power output utilizing the same ocean water resource.

3.1.3 Worldwide OTEC

In addition to the demonstration facility on Kumejima, the Makai Ocean Engineering Heat Exchanger test facility, built in 2011, was retrofitted in 2015 as a 105kW OTEC test platform. Along with the Okinawa facility, these are the only two OTEC facilities with access to SOW and DOW, though other labs and test facilities have been developed around the world including but not limited to Saga University, Japan; CEMIE-Oceano, Mexico; La Reunion University, France; Delft University, The Netherlands; and in China.

In 2019, the Korean OTEC team at the Korea Research Institute of Ships and Ocean Engineering (KRISO) tested their K-OTEC1000 equipment on a barge in Korean waters, producing 328kW in suboptimal test conditions [9]. The equipment is awaiting shipment to South Tarawa, Kiribati for installation as a 1MW-gross onshore facility.

In 2020, the Ocean Thermal Energy Association was established as an international network of academia, government, and industry to further encourage and support the establishment of ocean thermal technologies including OTEC, Sea Water Air Conditioning (SWAC), and DOW industrial use. The organization has members and observers from 43 countries.

3.2 Potential Plant Size

3.2.1 OTEC Potential Near the Selected Site

Given the temperature profiles identified in Figure 2.9 in section 2.4, there is sufficient thermal difference for any scale of OTEC power generation. Generally, four types of OTEC facility deployment can be considered; onshore, nearshore, offshore, and harvesting.

Currently, only onshore OTEC facilities exist. They are easy to maintain and are the most practical solution for research and follow-on deep ocean water industrial use. They also generally require longer intake pipelines to connect to deep ocean resources. Research in Japan considers onshore to be the preferred choice for installations with a capacity up to roughly 5MW, depending on local conditions.

Nearshore deployment is a concept for locations with long continental shelves or existing nearshore installations that may be repurposed. This concept considers reducing the necessary intake pipe distance for a given location, but the use case is limited to specific situations.

Offshore OTEC refers to a moored offshore facility. Electricity is supplied by undersea cable and there is a significant advantage from reduced intake pipe length. The requirements of an offshore facility, while well known, do represent costs that suggest economies of scale be applied. 10MW and larger facilities are expected to be offshore.

Harvesting platforms refers to a concept of installing OTEC equipment on a moving platform such as a converted drill ship. Advantages from mobility may be offset by issues in energy delivery.

In Hawaii, Kumejima, South Korea, Taiwan and other locations around the world with deep ocean pipelines, the deep ocean resource provides opportunities for new industries and product development that make onshore installation attractive for local communities.

3.2.2. Sizing of the OTEC Plant

In terms of deciding the size of an initial OTEC plant for Nauru, the energy situation in Nauru, technology readiness, and economic constraints were considered in consultation with the Nauru Government towards a consensus for realistic and achievable introduction of renewable energy in a timely manner.

The Nauru Utilities Corporation (NUC) has provided background information on the current grid needs and expected future renewable energy installation and demands. The NUC noted it could utilize a baseload OTEC plant on a scale of 3-4MW (Figure 3.5) to meet a current peak demand of 5.7MW. In addition, we note that Nauru has clean energy goals with targets in 2025 and 2030.

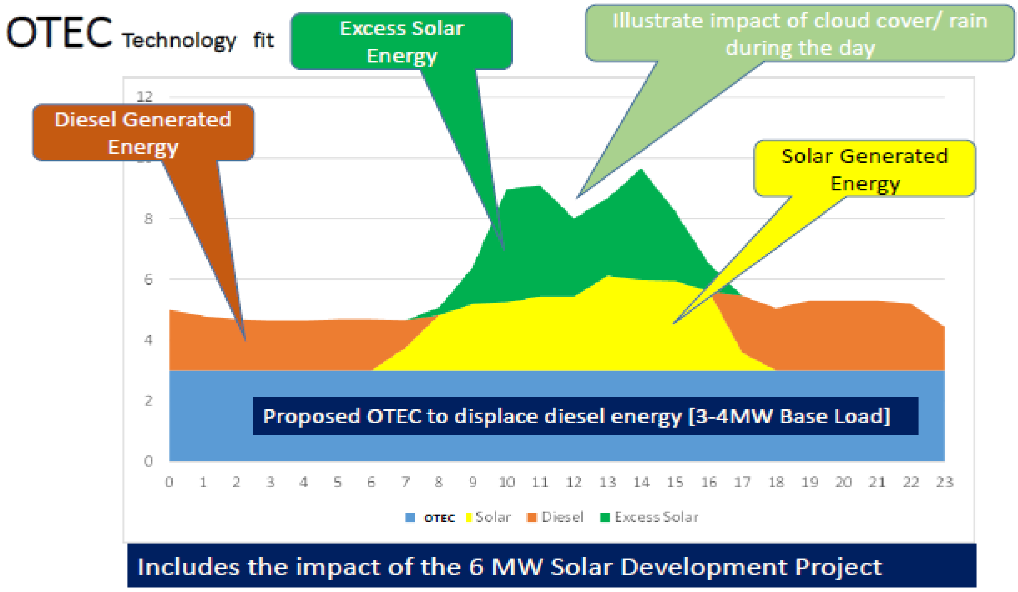


Figure 3.5 NUC's Proposed Future Power Generation Mix with a Baseload OTEC Plant on a Scale of 3-4MW

Based on demand provided by NUC and consideration of existing implementations plans, and in order to achieve competitive OTEC power generation costs (compared with diesel) in Nauru, a minimum scale of 1MW is expected to be required. We summarize the technical readiness of two cases: 1MW and 3-4MW, both onshore and referring to net power output in Table 3.1.

Table 3.1 Considering Technical Readiness for OTEC Implementation Strategies

Plant Size	Intake	Turbine and Pumps	Heat Exchangers
1MW Onshore	• Similar size installed in Hawaii • Installation planned in Kumejima	Commercially available or existing installations	• Installation case in India (in 2000 with Japan) • Installation case in South Korea (test facility)
3-4MW Onshore	Technically feasible but no installation record	Commercially available or existing installations	Technically feasible but no installation record

As noted above, there are no MW-scale OTEC plants in operation, yet Nauru is aiming for early adoption to meet its urgent energy needs. Table 3.2 provides a summary comparative analysis between a 1MW or 3-4MW facility.

Table 3.1. Comparative Analysis on Implementation Strategies

	1MW Facility	3-4 MW Facility	Notes
Meets Nauru's 2025 Goals	○	×	Any project will require some lead time, including a feasibility study and preparatory surveys, etc. Implementation by 2025 cannot be guaranteed, however, a 1MW-scale facility can be implemented more quickly than a larger project.
Meets Nauru's 2030 Goals	○	◎	A 3-4MW facility would meet Nauru's 100% RE goals if implemented, however, a smaller facility can accelerate progress while not missing out on future technology advances.
Time to Implementation	○	×	Lead time to implementation a 1MW facility would be significantly shorter than a larger project. Funding for a large-scale project would also be expected to take longer.
Within Targeted Financing Options	○	×	An initial MW-scale project should be within existing funding mechanisms, depending on implementation location and method. A larger project would likely require alternative funding approaches.
Opportunities for Follow-on Economic Development through DOW Use	◎	△	An onshore OTEC facility can provide DOW resources for industry and economic development, however, for plants larger than 1-2MW, the scale of water resources use would make implementation difficult due to lack of established infrastructure or industry. Offshore plants are expected to produce only power initially.
Implementation Strategy in-place	◎	△	The Kumejima Model provides an existing structure to build from and adapt to Nauru's needs and situation with real-world data and studies already completed or in production. A single larger facility would require study on the best method for implementation.
Overall	◎	△	For the purposes of this pre-FS limiting scope to a 1MW facility is suggested.

Considering the NUC's renewable energy (RE) target in 2025 (50%), a 1MW OTEC facility will complement the upcoming 6MW solar farm and the existing 2.32MW of distributed solar, going afar beyond the 2025 goal, reaching almost 70%. The technical team suggests building on the existing study and planning done for Kumejima to bootstrap development of an installation in Nauru. The technical team proposed focusing on a 1MW net scale towards the earliest possible installation to Stakeholders in Nauru on July 22nd, 2021, and after consultations, it was agreed to focus on this approach.

3.3 Performance and cost

3.3.1. Overall System Design

The proposed overall system design uses renewable ocean water resources in Nauru to secure renewable power and water production, fully utilizing the DOW resource for electricity production (OTEC), water production (desalination), cooling (air conditioning), aquaculture, agriculture, cosmetics, and so on. This multi-use of DOW is shown in Figure 3.6. The temperature difference between SOW and DOW can produce 1 MW electricity through OTEC and 1000 m^3/day of water by desalination. The low temperature thermal desalination (LTTD) will not only produce potable water, but also to reduce power consumption compared with the existing RO process desalination. Air conditioning for buildings can be applied using DOW, which will also reduce power consumption. DOW multi-use can provide resilience for Nauru's infrastructure and economy. In this section, the basic concept and design are provided.

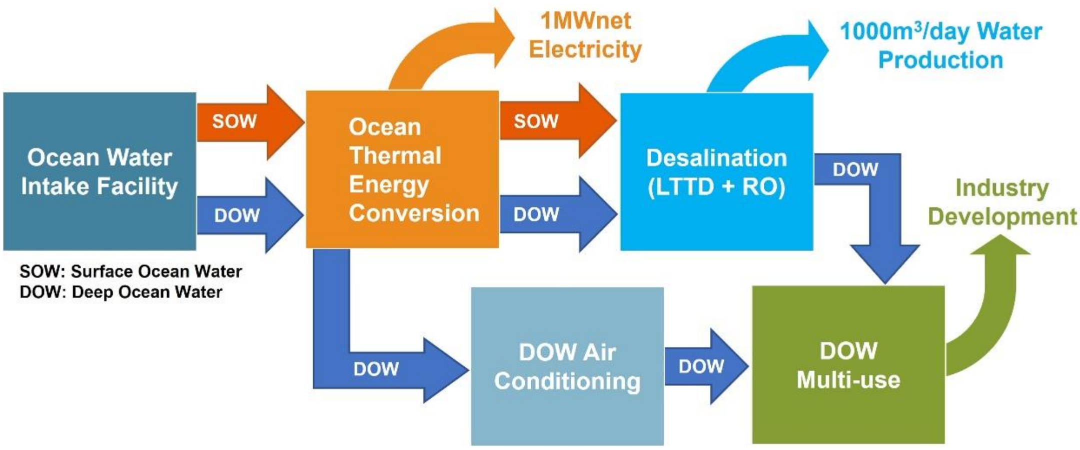


Figure 3.6 Overall System Design for Renewable Ocean Water Resource Utilization.

3.3.2. Design of an OTEC Plant

The overall design of OTEC starts with determining the design heat source temperature and required power plant capacity that is connected to the grid. In an OTEC system, the internal pumping power is not negligible, so we generally use net power of the plant in referencing the normal capacity of the OTEC plant. The generator is larger than the normal capacity to cover internal use.

The available power in the OTEC plant will be the balance of the performance of components, including heat exchangers, turbine/generators, pumps, piping system, and ancillary equipment. Due to the limited available heat source and heat sink temperatures in the ocean, for the optimum design of the OTEC we need to consider two points of optimization. As the first stage of optimization, Figure 7(a) shows the image of the conceptual optimum design point in the constant warm and deep ocean water flow rates to maximize the power output from OTEC heat engines. According to Figure 7(a), the increase in the heat source temperature change, showing the warm heat source temperature decline in the OTEC process, increases the heat transfer rate; however, the thermal efficiency will decrease due to decrease of available temperature in the heat engine.

The resulting power output of the heat engine has the maximum constant heat source flow rates. Figure 7(b) shows the concept of maximum point of the net power in the OTEC system. As the heat source flow rate increases, the power output of the heat engine will increase, in contrast, the heat source pumping power will increase roughly as a cube of the heat flow rate. Then, the net power to be supplied to the grid will maximized at a constant heat source flow rate. Understanding of the optimum conditions is the key to achieving maximum net power an OTEC system, in other words, to minimize the cost of electricity of an OTEC system.

As an OTEC system is a renewable energy and no fuel is required for the operation, the minimum capital expenditure (CAPEX) per the net power generation can be expected. If OTEC systems were widely commercialized around the world, the cost of components would be clearer and it would be easier to minimize the CAPEX. Indeed, although some researchers are working to minimize the CAPEX using expected simplified cost curve of the components to calculate the levelized cost of electricity (LCOE), it would be inaccurate to utilize this method for discussion of a practical project. Therefore, as an initial design method, we apply the minimization of the total heat transfer area of heat exchangers per the net power of the OTEC plant in this study because the heat exchangers are one of the most expensive components in the system and the most dominant parameter for the footprint of the plant. After determination of initial parameters, further optimization will consider intake in section 3.3.4.

The optimum condition depends on the performance of configurations such as cycles shown in Figure 3.2, Figure 3.3 and Figure 3.4, evaporators, condensers, turbine/generators, and pumps. In the next section, we will discuss the concrete basic design of the system configuration of the plant.

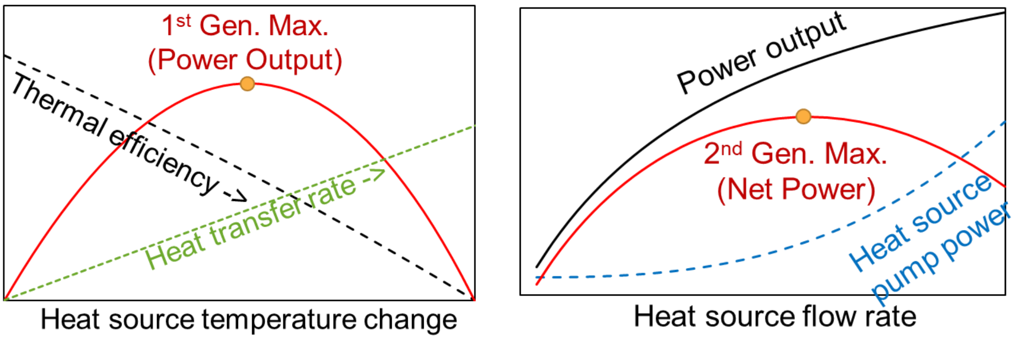


Figure 3.7. The optimization concept of an OTEC system in (a) the maximization of power output in the heat engine with constant ocean water flow rates, and (b) the maximization of power output as a function of ocean water flow rate.

3.3.3. Design of the Plant's System Configuration

The design process starts from design bases including heat source condition, heat engine configuration, and heat balance including the performance of equipment. Referring the temperature profiles of five sites outlined in the first progress report, we selected surface and deep ocean water temperatures of 28.4ºC at 20 m depth and 5.9ºC at 700 m depth as design ocean water temperatures and depths, respectively. We assume 0.5ºC of temperature rise due to heat exchange during conveying the DOW to the on-land OTEC plant site through the deep ocean water intake pipe. This design temperature and condition corresponds to site 2, and we assume that the deep ocean water piping length of 1200 m, and the deep ocean water piping diameter is 1.5 m, which size is planned to be applied to 1MWnet OTEC in Kumejima, Japan.

Table 3.3 Design Ocean Water Temperature and Distance

Site No.	2
SOW design temperature at 20m depth (^oC)	28.4
DOW design temperature at 700m depth (^oC)	5.9
DOW design temperature at the site (^oC)	6.4
Distance between DOW intake point and shoreline (km)	0.48
Depth of the DOW intake point (m)	700

Considering the reference demonstration plants, we apply the Rankine cycle (shown in Figure 3.2) and double-stage Rankine cycle (shown in Figure 3.3) to the heat engine of the OTEC system. And we compare the two cycles by minimization of the total heat exchanger heat transfer area over net power at the 1 MW net power condition. After selected the cycle by this comparison, the final design, which minimize the total capital expenditure, is conducted in section 3.3.4.

The Rankine cycle consists of an evaporator, turbine/generator, condenser, working fluid circulation pump, and piping system (Figure 3.2). The double-stage Rankine cycle consists of two circuits of the Rankine cycle, where the SOW will flow to first-stage Rankine cycle then to second-stage Rankine cycle. The DOW will flow firstly to second-stage and then through the first-stage.

We calculated the heat and mass balance in accordance with the energy conservation law in the system and heat exchangers as the basic design. In the system, we consider the efficiency of turbines, generators, pumps, and motors. In heat exchangers, the heat transfer coefficient of ocean water and working fluid sides, and heat conduction of the plate, are computed by empirical formulas. The heat transfer rates of fluids and plate are balanced. In addition, we designed two cases of the system, one is the Rankine cycle and the other is two-stage Rankine cycle as shown in Figure 3.2 and Figure 3.3, respectively.

The design condition in each system is optimized to minimize the total heat transfer area of heat exchangers over net power output by changing the variables in the constraints of the plate specifications and heat transfer coefficients, by a FORTRAN-based in-house code. We use four variables; mean velocity of evaporators, mean velocity of condensers, evaporation temperatures, and condensation temperatures. The optimum conditions are computed by a non-liner gradient method. The initial conditions of the variables are checked by changing the input variables to find the global optimum condition.

Figure 3.23.7 and Figure 3.33.8 show the heat and mass balance results for the Rankine cycle and the double-stage Rankine cycle. The minimum objective functions at the design conditions in the Rankine cycle and double-stage Rankine cycle are 8.0 m2/kW and 8.6 m2/kW, respectively. The mean velocity of DOW in the intake piping is 2.2 m/s for the Rankine cycle and 1.9 m/s for the double-stage Rankine cycle. Figure 3.43.9 and Figure 3.53.10 shows the electrical power balance in the power plant and exergetic balance in the system. According to Figure 3.43.9, the power consumption of DOW pump in the double-stage Rankine is smaller than that of the Rankine, but SOW pump in the Rankine is smaller than that of the double-stage Rankine. And the exergetic efficiency of the double-stage Rankine of 16% is much higher than that of the Rankine of 11%. Here, the exergy of OTEC $E_{x,OTEC}$ and exergetic efficiency $\eta_{ex,OTEC}$ are defined as follows:

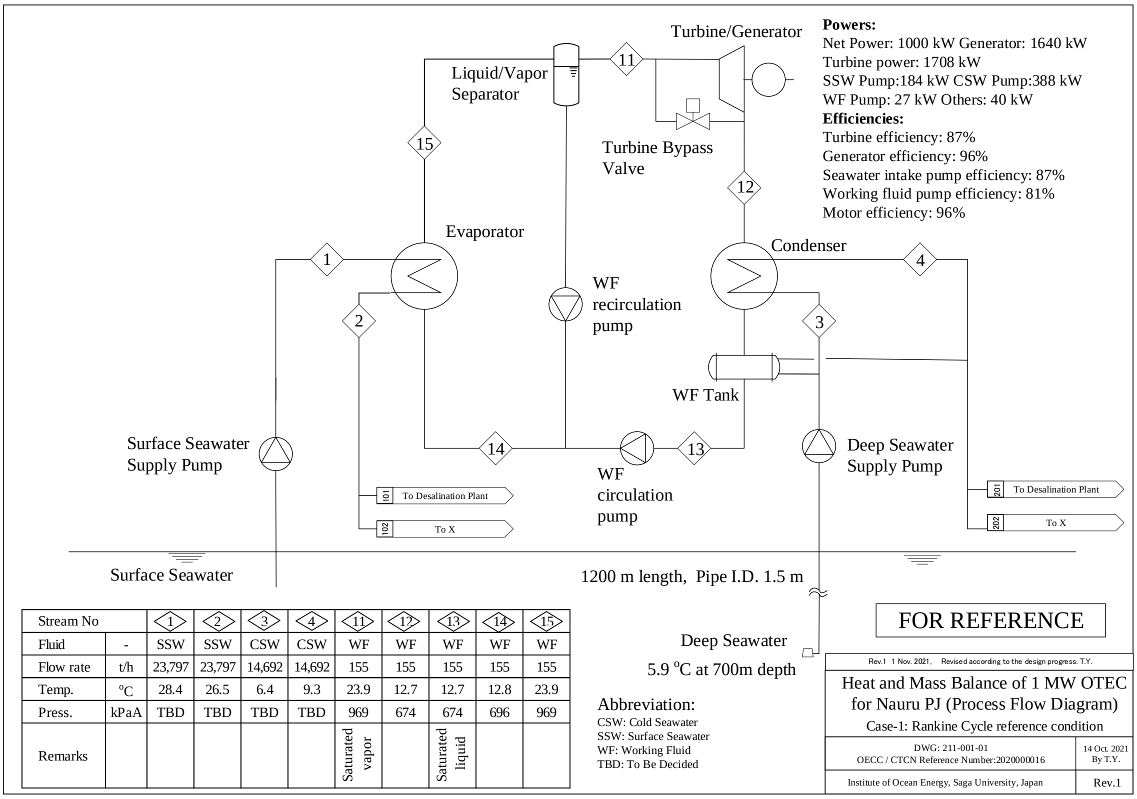
$$E_{x,OTEC} = (mc_p)_W T_{W,in} + (mc_p)_C T_{C,in} - \left[(mc_p)_W + (mc_p)_C\right] T_{W,in}^{\frac{(mc_p)_W}{(mc_p)_W+(mc_p)_C}} T_{C,in}^{\frac{(mc_p)_C}{(mc_p)_W+(mc_p)_C}}$$

$$\eta_{ex,OTEC} = \frac{W_{net}}{E_{x,OTEC}}$$

where $E_{x,OTEC}$ (kW) is the exergy, m (kg/s) is the mass flow rate, c_p (kJ/(kgK)) is the specific heat at constant pressure, T (K) is the temperature of ocean waters, and W_{net} (kW) is the net power. The subscripts of C, in, out, and W are cold deep ocean water, inlet, outlet, and warm surface ocean water, respectively.

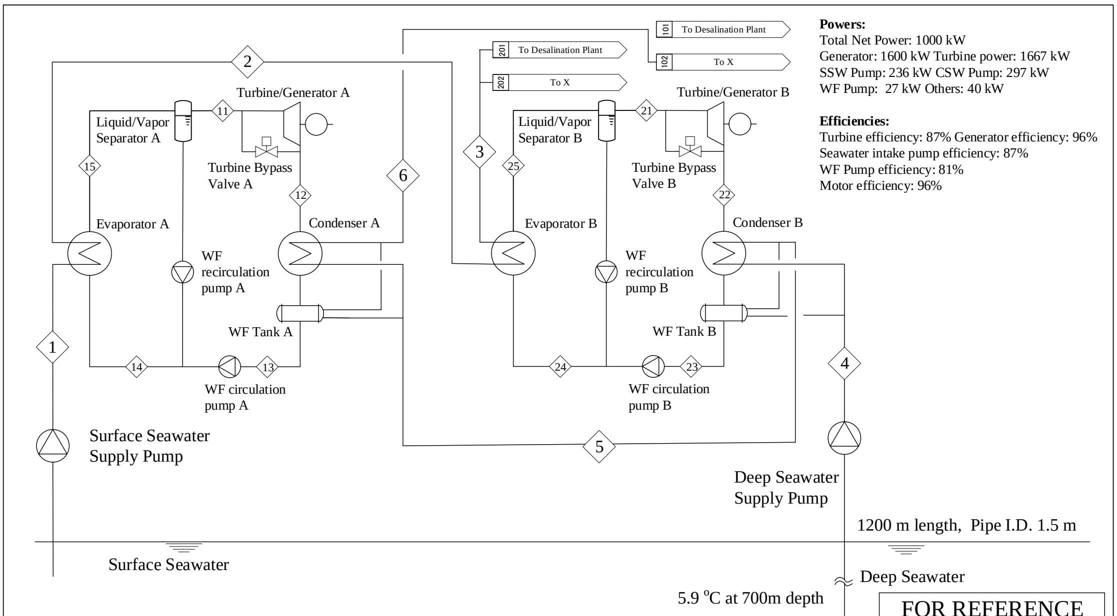
The exergetic efficiency can be more simply considered as the ocean water required to produce rated net power capacity. Specially, the DOW is a base resource to provide temperature difference in the OTEC system. Therefore, the effectiveness of the OTEC power plant will be evaluated by the required DOW over the net power output. Figure 3.6 shows the comparison of required DOW for the net power production between single and double Rankine cycle. According to Figure 3.6, the double-stage Rankine cycle is 2.4 t/kWh smaller than that of the Rankine cycle, which corresponds to approximately 20% reduction in double-stage Rankine cycle DOW requirements. The comparison shows that the double-stage Rankine cycle will reduce DOW flow rate and the piping capital expenditure as well.

In the case of the Rankine cycle, as the required heat exchanger volumes are smaller, the footprint of the plant may be slightly smaller than double-stage Rankine cycle; however, double-stage Rankine cycle requires less total ocean water. According to studies for Kumejima, the cost of an ocean water intake facility will be the dominant factor in the case of a one MW-capacity onshore OTEC installation. Regarding the footprint of the plant, the number of turbines will be doubled in the case of the double-stage Rankine cycle, however, two turbines can have common generator and auxiliary unit and the footprint increase can be minimized. Therefore, overall, we recommend applying double-stage Rankine cycle in terms of cost and performance.



Stream No		1	2	3	4	11	12	13	14	15
Fluid	-	SSW	SSW	CSW	CSW	WF	WF	WF	WF	WF
Flow rate	t/h	23,797	23,797	14,692	14,692	155	155	155	155	155
Temp.	°C	28.4	26.5	6.4	9.3	23.9	12.7	12.7	12.8	23.9
Press.	kPaA	TBD	TBD	TBD	TBD	969	674	674	696	969
Remarks						Saturated vapor		Saturated liquid		

Figure 3.2 The Optimized 1MWnet Rankine Cycle Heat and Mass Balance



Stream No		1	2	3	4	3	6	11	12	13	14	15	21	22	23	24	25
Fluid	-	SSW	SSW	SSW	CSW	CSW	CSW	WF	WF	WF	WF	WF	WF	WF	WF	WF	WF
Flow rate	t/h	13,170	13,170	13,170	12,307	12,307	12,307	83	83	83	83	83	83	83	83	83	83
Temp.	°C	28.4	26.6	24.7	6.4	8.3	10.2	24.1	13.6	13.6	13.7	24.1	22.1	11.9	11.9	12.0	22.1
Press.	kPaA	TBD	TBD	TBD	TBD	TBD	TBD	975	695	695	975	975	917	656	656	917	917
Remarks								Saturated vapor		Saturated liquid			Saturated vapor		Saturated liquid		

Abbreviation:
CSW: Cold Seawater
SSW: Surface Seawater
WF: Working Fluid
TBD: To Be Decided

Rev.1 1 Nov. 2021, Revised according to the design progress. T.Y.

Heat and Mass Balance of 1 MW OTEC for Nauru PJ (Process Flow Diagram)

Case-2: Double-Stage Rankine Cycle reference condition

DWG: 211-001-02
OECC / CTCN Reference Number:2020000016

14 Oct. 2021
By T.Y.

Institute of Ocean Energy, Saga University, Japan

Rev.1

Figure 3.3 The Optimized 1MWnet Double-stage Rankine Cycle Heat and Mass Balance

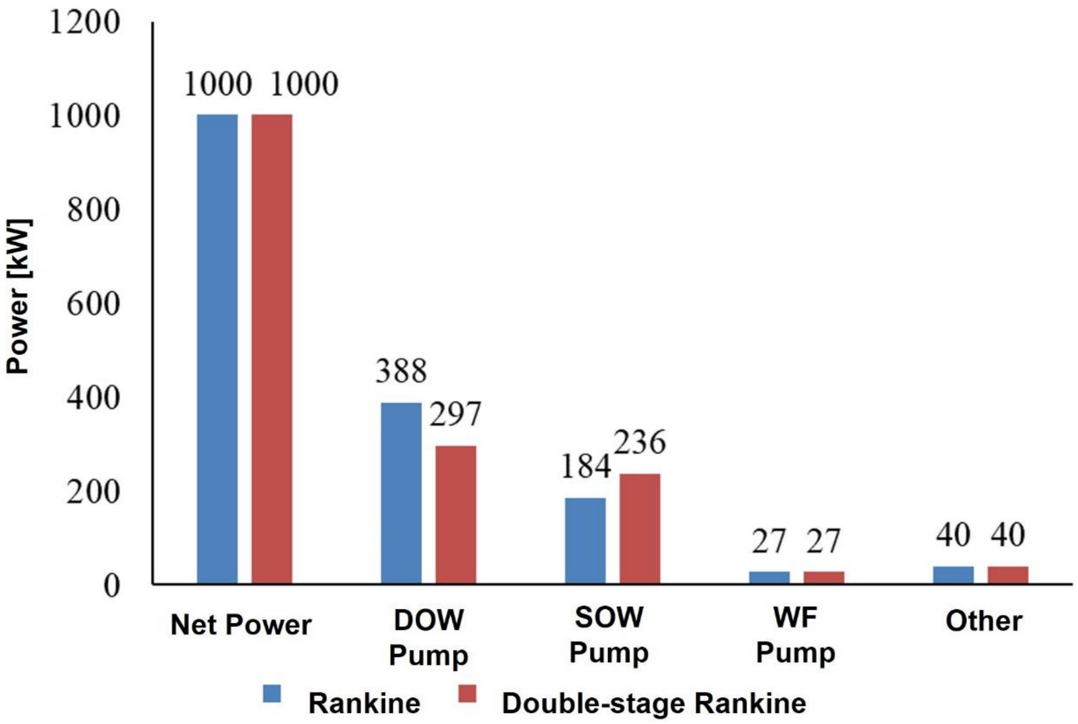


Figure 3.4 Power Output and Consumption in the OTEC Plant

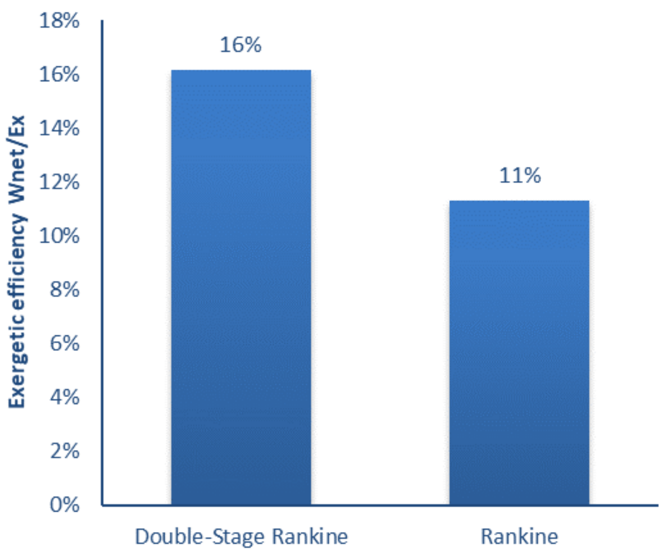


Figure 3.5 Comparison of Exergetic Efficiency

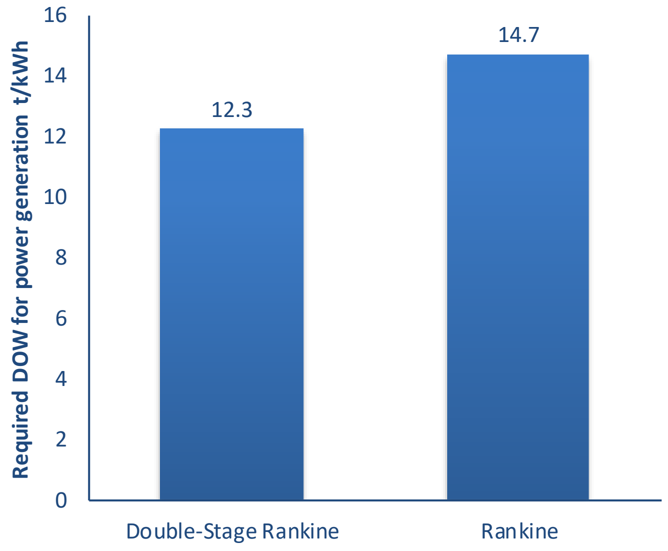


Figure 3.6 Required Deep Ocean Water for Net Power Production

3.3.4. Design of the Ocean Water Intake System

While OTEC design and implementation is a relatively straight forward process, with many similar installations in place utilizing waste heat, geothermal, or other warm sources, the intake facility, including intake pipes are a critical factor towards enabling OTEC implementation. Due to the difficultly in working in a marine environment, the materials and installation method must be considered for each location as bathymetry, climate, and local conditions change at each site. Still, there is a breadth of successful long-term installations and collective knowhow to work from, which will be briefly discussed in section 3.4.

Due to the longer pipe and depth, DOW is the primary area of concern when discussing intake systems for OTEC and DOW use. In Japan, DOW is defined as water below 200-meter depth. This is below the euphotic zone, and thus has properties unique from surface layers due to the significantly different environment. Although there are several useful properties of DOW, the most commonly used attributes are the cleanliness, nutrient richness, and cold aspects.

For the initial 3 years of operation at the Okinawa OTEC Facility, water used through the facility was returned to the ocean offshore and at 25-meter depth. While the water was still viable, there was no infrastructure in place to transport it to other users. In fiscal year 2016, new pipelines connecting post-OTEC DOW to users in the industrial zone next to the ODRC were installed. These pipelines supply post-OTEC DOW and SOW allowing industries to utilize more water than the previously existing supply system. This project has helped to validate the multi-stage ocean water resource use aspect of the "Kumejima Model" while also providing follow-on benefits for local industries.

Further details on combining OTEC with DOW industries will be discussed in sections 4-6. For Nauru we propose a similar installation and operation system to that designed for the Kumejima Model, which is introduced in more detail in section 5.1.1. A concept drawing for cascade ocean water flow is provided in Figure 3.7.

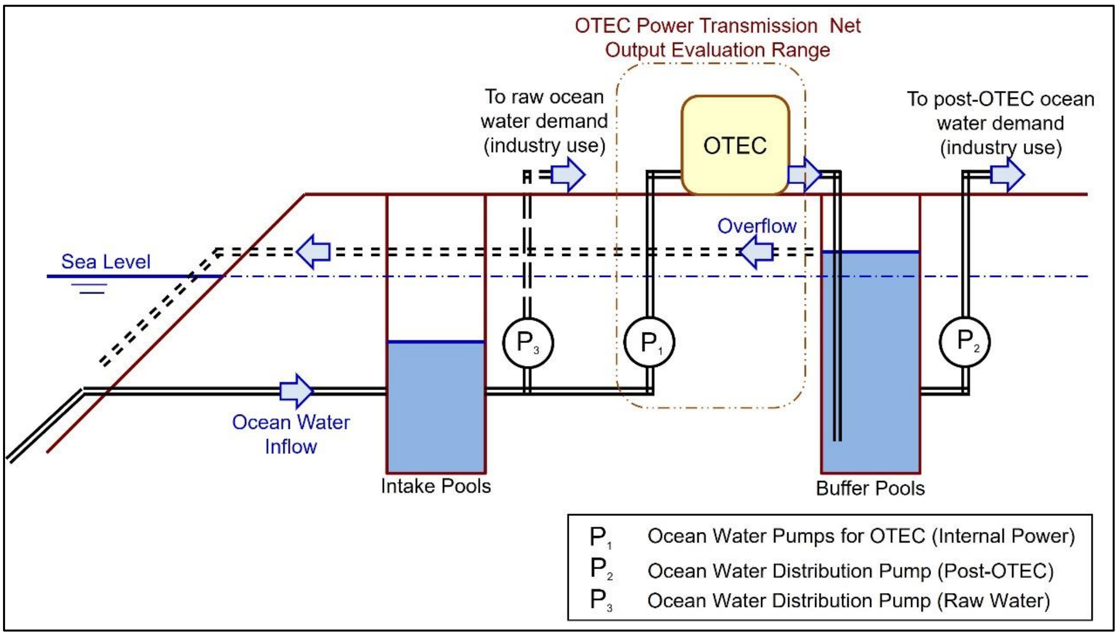


Figure 3.7 Cascade Ocean Water Flow Concept.

In the concept presented, ocean water intake operates as a utility, providing ocean water to industrial uses including OTEC. As the intake piping is connected to intake pools with depth below sea level, ocean water naturally flows into each pool by motive force of surface level difference between sea-level and water surface level in the intake pools. There is one pool for surface and one for deep, which fill to a level below sea level. Pumps will be used to lift the ocean water from each pool to each use area, such as the OTEC facility. Post-OTEC water can also be discharged into a buffer pool for reuse in downstream industries such as desalination, etc. OTEC will provide its own ocean water pumps, powered internally (see section 3.3.4. for more detail). After leaving the OTEC facility, water will be made available to ocean water users.

The proposed project implementation and operation structure is as follows.

1. Construction of Intake Facilities

   As a utility, design and construction of intake facilities will be contracted to a capable and vetted service provider after tender based on the terms of financing available to the project owner. The project owner will own the Intake Facilities and contract with an organization for operation and maintenance.

2. Intake Facilities Operation and Management

   An organization contracted by the project owner will be responsible for water distribution (sales), and maintenance of the intake facilities. Sale prices of ocean water to industries will be set so that pumping power costs, maintenance, and other operational costs including a reserve are recovered. Ocean water sales prices may differ based on scale, intended use, and public need. Responsibility and management will extend to main distribution lines from which ocean water industries will be able to connect and retrieve water.

3. OTEC Facility Operation

   The OTEC Facility can be constructed as part of the overall plan or separately contracted for installation. Although it will be the primary source for most ocean water industry users, in terms of business and operations it can be a separate entity, such as NUC. NUC or another owner can contract to install the facility, then operate to NUC specifications. The facility owner will sell electricity which will supply funds for operation, maintenance, and any fees to the Intake Operation and Management system. There are many options available, however, in terms of reducing energy costs for the people of Nauru, a fixed annual fee for ocean water use is the preferred method. The fixed fee also considers the benefit from reduced pumping costs provided by lifting the water from the intake pit below sea-level to a higher elevation, thus reducing pumping costs to other ocean water users. Other benefits include a stable and long-term revenue stream to the facility operation and management.

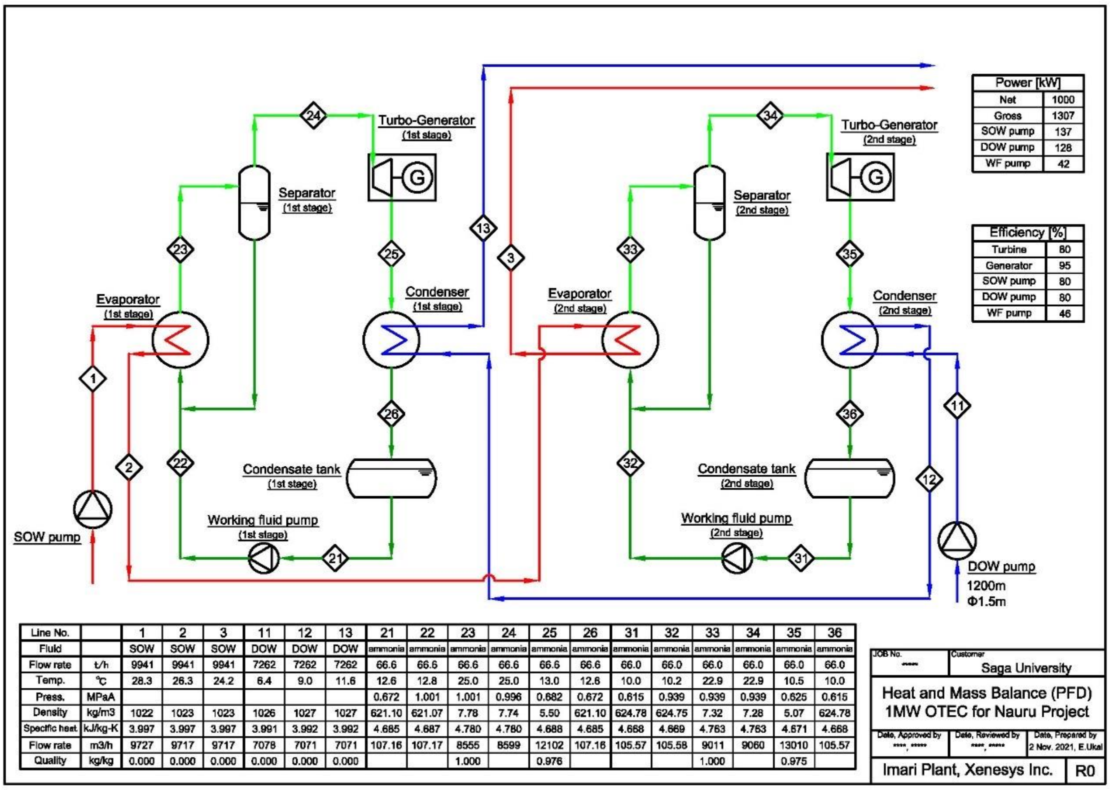
4. Ocean Water Industries

   Individual companies will be responsible for installing piping to connect from the distribution main to their own facilities. Such industries may include desalination, cooling, aquaculture, agriculture, etc. To promote economic development and innovation, some consideration should be made towards facilitating initial startup and connection businesses through loans, credits, or other incubation initiatives. These industries will pay for water use from the Intake operator and create products or services. These industries will require support and time to develop, but can be the key to achieving a sustainable, self-sufficient island society.

3.3.5. Potential Electricity Power Generation of the OTEC Plant

Based on the selected intake system, we can determine the amount of electricity required to operate the facility. As with any modern power plant, some electricity will be necessary for control and operations equipment. In the case of OTEC, a submersible pump is used to move the water to the OTEC facility, generally with enough head to travel to the top of the highest point in the OTEC facility's ducting, which is generally the heat exchanger. A significant design point for OTEC is minimizing the amount of power needed to operate both this deep ocean water pump and the surface ocean water pump.

Based on initial optimizations to determine cycle and sizing, further optimization was carried out by industry specialists, considering overall intake method to balance CAPEX reduction and operating expenses. The fully optimized process flow diagram for this study is included in Figure 3.13.



Line No.		1	2	3	11	12	13	21	22	23	24	25	26	31	32	33	34	35	36
Fluid		SOW	SOW	SOW	DOW	DOW	DOW	ammonia	ammonia	ammonia	ammonia	ammonia	ammonia	ammonia	ammonia	ammonia	ammonia	ammonia	ammonia
Flow rate	t/h	9941	9941	9941	7262	7262	7262	66.6	66.6	66.6	66.6	66.6	66.6	66.0	66.0	66.0	66.0	66.0	66.0
Temp.	℃	28.3	26.3	24.2	6.4	9.0	11.6	12.6	12.8	25.0	25.0	13.0	12.6	10.0	10.2	22.9	22.9	10.5	10.0
Press.	MPaA							0.672	1.001	1.001	0.996	0.682	0.672	0.615	0.939	0.939	0.939	0.625	0.615
Density	kg/m3	1022	1023	1023	1026	1027	1027	621.10	621.07	7.78	7.74	5.50	621.10	624.78	624.75	7.32	7.28	5.07	624.78
Specific heat	kJ/kg-K	3.997	3.997	3.997	3.991	3.992	3.992	4.685	4.687	4.780	4.780	4.688	4.685	4.668	4.669	4.763	4.763	4.671	4.668
Flow rate	m3/h	9727	9717	9717	7078	7071	7071	107.16	107.17	8555	8599	12102	107.16	105.57	105.58	9011	9060	13010	105.57
Quality	kg/kg	0.000	0.000	0.000	0.000	0.000	0.000			1.000		0.976				1.000		0.975	

Figure 3.13 Fully Optimized 1MWnet Double-stage Rankine Cycle Process Flow Diagram

Based on overall optimization, a plot plan has been developed that provides the general layout of the OTEC facility provided in Figure 3.14 and Figure 3.15 below.

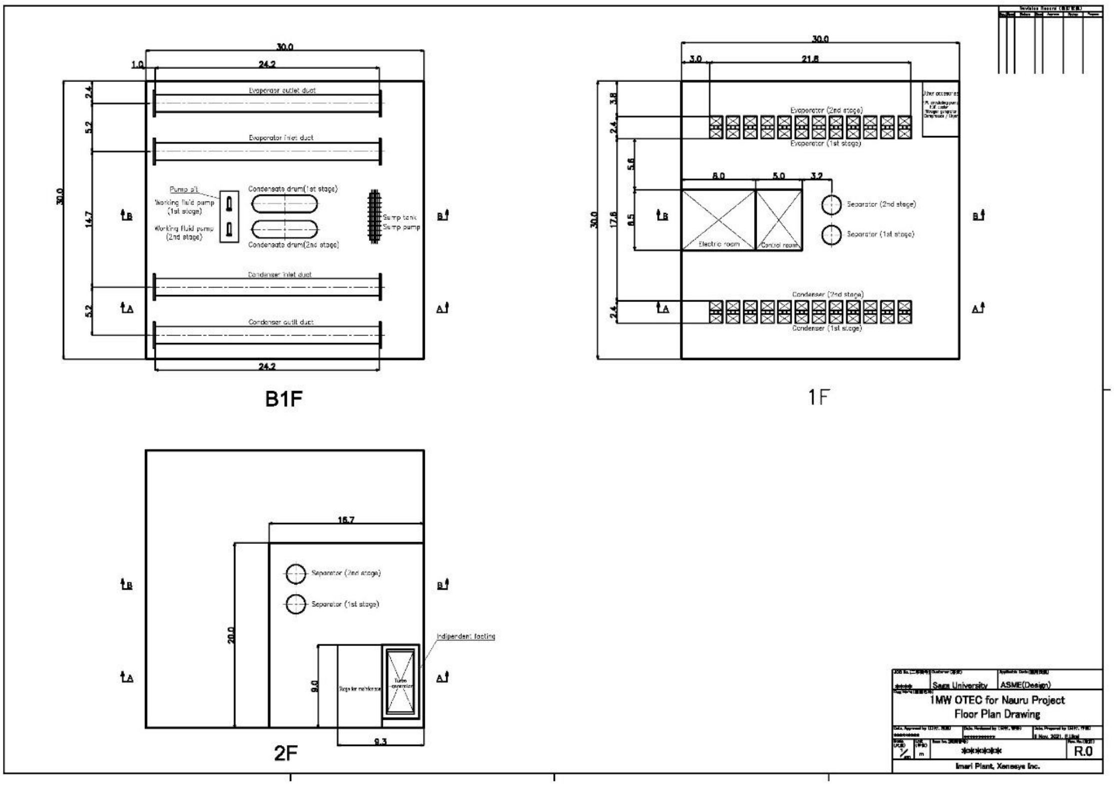


Figure 3.14 Optimized OTEC Facility Floor Plan Overhead View

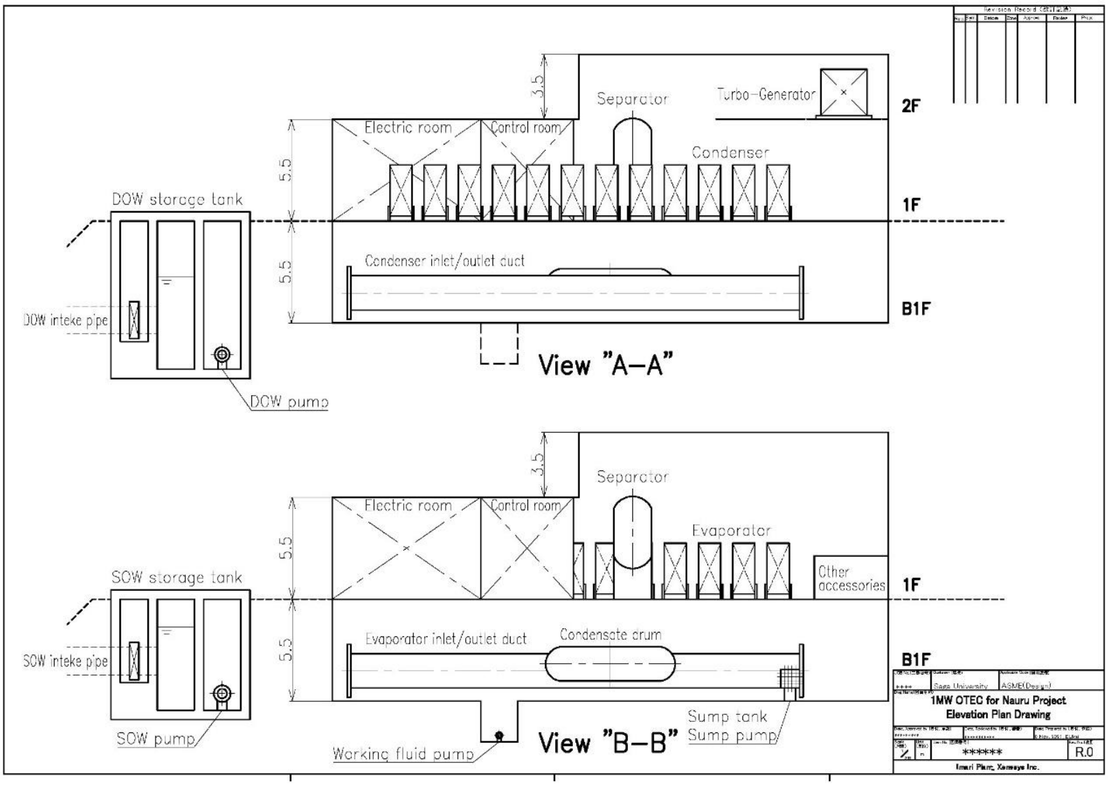


Figure 3.15 Optimized OTEC Facility Drawing Side View

In addition to ocean water pumps, working fluid pumps, automatic control valves, sensors, and other instrumentation will also require electricity. Figure 3.86 illustrates the balance between power generated and internally used based on the design for Nauru. Given the final optimized design, internal consumption will be roughly 307kW with a net output of 1000kW.

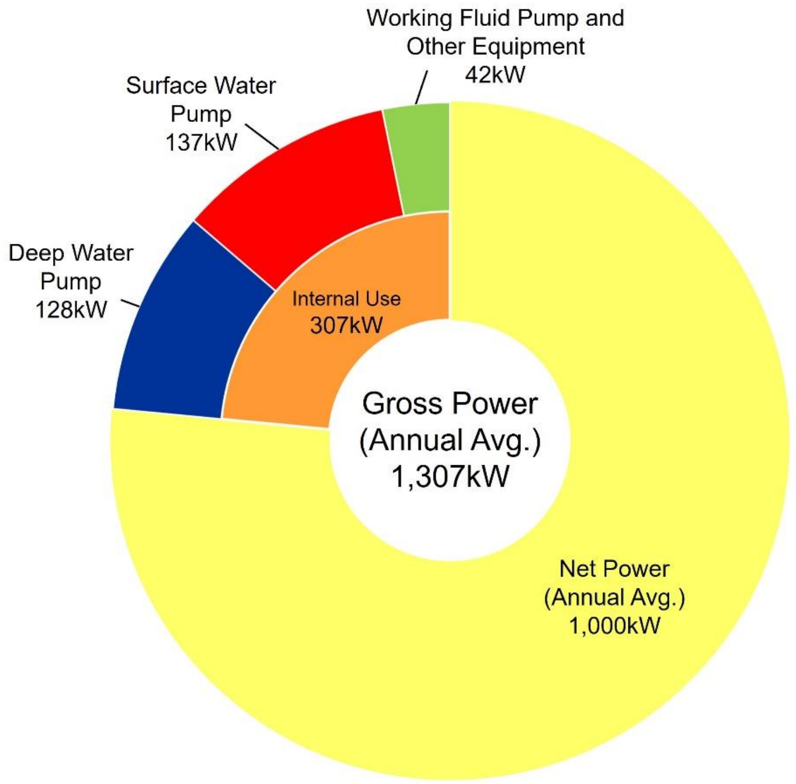


Figure 3.86 Internal Power Estimate for Nauru Case.

3.3.6 Maintenance Considerations

OTEC operation and maintenance is similar to other industrial facilities or power generation facilities, excepting that with OTEC there are generally fewer moving parts and lower operating temperatures. In Japan, the Okinawa Prefecture OTEC Demonstration Facility has provided more than 8 years of operational data including information on costs. As a reference, results from the OTEC Facility, obtained from Okinawa Prefecture's "Demonstration Project of Power Generation Used for Advanced Deep Seawater Utilization," which was completed in FY2018, are summarized along with the corresponding estimates for the Kumejima Model.

Table 3.4. Comparison of OTEC Facility O&M Costs for Kumejima[17].

1000s USD

Item		100kW Class Data	1MW Class Estimate (Kumejima)
Periodic Inspection/ Repair		16.0	84.0
	Turbine Generator	3.3	13.3
	Working Fluid System Equipment	4.1	16.4
	Electrical Equipment and Instrumentation	8.6	54.3
Irregular Inspection / Repair		18.7	29.0
	Corrosion Response	16.2	12.8
	Other	2.5	16.2
Daily Inspection, etc.		13.9	27.9
Other Expenses		1.8	10.5
General and Administrative Expenses			20.0
Total	1000USD/year	50.5	171.4
	USD/kW/year	501.11	167.04

Exchange Rate: 1USD = 113.75JPY

It should be noted that for Nauru, further reduction in maintenance costs may be considered depending on the personnel expenses.

3.3.7 Rough Cost Estimate of the Plant

The approximate cost of this project is estimated as follows.

(1) 1MW OTEC plant cost (main equipment + Desalination Plant + auxiliary equipment, including installation cost)

The cost of the OTEC plant in the initial market is estimated to be 3.3 billion yen (US$30M).

However, if the OTEC market would internationally come to maturity, the cost is expected to reduce to around 2 billion yen (US$18M).

Needless to say, it is required to re-estimate at the stage of full-scale FS.

(2) Construction, civil engineering, and electrical work (other than OTEC): 100 million yen

The roof of the building does not cover the plant. Only the electrical control room has a roof.

(3) Intake pipe construction cost: 3 billion yen (US$27M).

To be exact, a field (incl. seabed) survey is required. The cost may vary significantly depending on the condition of the ocean floor.)

Reference: The cost of an intake pipe of the same scale to be installed on Kumejima in Okinawa Prefecture, which is a reference value, is approximately 8 billion yen (US$73M).

The deep-water intake pipe in Kumejima, Okinawa Prefecture, is planned to be 700m deep and 3.7km long.

The expected length of the intake pipe in the Republic of Nauru is 1.3 km.

(4) Others

Based on the optimized design and plot provided in section 3.3.4. a list of major equipment for the OTEC Plant for Nauru has been developed as seen in summary in Table 3.5.

Table 3.5. Summarized 1MWnet Major Equipment List

Equipment Name	Quantity	Approximate Size / Unit
SOW Pump	3	900mmφ×7mH
DOW Pump	3	800mmφ×9.5mH
Evaporator	24	W0.8m x D1.2m x H2.8m
Condenser	24	W0.8m x D1.2m x H2.8m
Working Fluid Pump	2	0.35mφ x L1.4m
Turbo-Generator	1	W2.5m x L7m x H2.5m (Including seal-gas unit and lubricating oil system)
Separator	2	ID.2.0mφ x H3.9m (TL-TL) t = 18mm
Condensate Drum	2	ID.1.8mφ x L7.0m (TL-TL) t = 21mm
Sump Tank	1	W1m x L5m x H1m

Sump Pump	1	0.2mφ x L0.6m
FW Circulating Pump	2	0.2mφ x L0.6m
FW Cooler	2	W0.4m x D0.4m x H1.0m
Nitrogen Generator	2	W1.2m x D1.0m x H1.8m
Compressor/Dryer	2	
Evaporator Inlet Duct	1	1.8mφx L24.2m
Evaporator Outlet Duct	1	1.8mφx L24.2m
Condenser Inlet Duct	1	1.8mφx L24.2m
Condenser Outlet Duct	1	1.8mφx L24.2m
Note: Sizes listed above are for reference only		

3.4 Challenges and Barriers with References from other Projects

No technical barriers are expected in terms of implementing a 1MW net facility for Nauru through our experience of design work for the Kumejima model which is the same size of OTEC. However, there are risks associated with such large installation projects if not carried out to international standards.

3.4.1 Challenges associated with Intake

There are currently fifteen sites utilizing DOW in Japan [3]. The sites were developed for a variety of purposes, without an overall implementation plan or purpose. Currently, the various locations produce cosmetics, food, aquaculture, and a variety of other items from their ocean water resources. This existing infrastructure, along with further cases listed in Table 3.6, indicate industrial experience in deployment.

Intake pipelines are common component of power plants, with many examples of surface intake in place around the world. Provided industry standards and best practices are met, most potential issues can be averted.

Unique issues associated with the longer pipeline being deployed in deeper water for DOW must be addressed at an early stage. A full feasibility study will examine the issues associated with

DOW deployment to avoid mistakes such as insufficient deployment vessel capacity or insufficient pipeline anchoring. As wave action is a particularly strong force, it is now generally considered best practice for intake pipes to be buried or trenched in near-shore environments to protect the pipes from waves, including irregular occurrences such as rogue waves.

It should be noted that Nauru is home to the first Japanese OTEC pilot plant established by Tokyo Electric Power company in 1981. It was the first OTEC plant to feed power to an operating commercial grid. After successful demonstration, extreme weather events damaged the sea level intake pipes, prohibiting further use. In the Nauru demonstration, the pipes were laid on the seabed without trenching, which exposed them to wave action.

Since this original demonstration, there have been significant improvements in available materials, DOW intake design and construction techniques, and operational know-how developed through long-term demonstration. Techniques now exist that can ensure long-term and generally climate-proof operation. Table 3.6 includes a list of intake pipes in operation including location and operation date.

Table 3.6. DOW Intake Facilities Around the World (Not Comprehensive).

Location	Intake Capacity	Intake Depth	Pipe Length	Installation Date	Notes
NELHA (Hawaii)	.84m^3/s	674m	1.9km	1987	https://nelha.hawaii.gov/wp-content/uploads/2013/05/PIP-Aug-2013.pdf
NELHA (Hawaii)	.19m^3/s	628m	1.8km	1987	https://nelha.hawaii.gov/wp-content/uploads/2013/05/PIP-Aug-2013.pdf
Moroto (Japan)	.011m^3/s	320m,344m	2.7km	1989	http://www.dowas.net/facilities/
Takatsuka (Japan)	.035m^3/s	321m	2.6km	1996	http://www.dowas.net/facilities/
Takaoka (Japan)	.046m^3/s	374m	3.1km	2000	http://www.dowas.net/facilities/
Kumejima (Japan)	.150m^3/s	612m	2.3km	2000	http://www.dowas.net/facilities/
South Korea [7 sites Collectively]	.536m^3/s	Various	Various	From 2000	http://www.dowas.net/paper/pdf/19-2/S3-E.pdf
Yaizu (Japan)	.023m^3/s	270m, 397m		2001	http://www.dowas.net/facilities/
NELHA (Hawaii)	1.8m^3/s	915m	3.1km	2001	https://nelha.hawaii.gov/wp-content/uploads/2013/05/PIP-Aug-2013.pdf

Nyuzen (Japan)	.038m^3/s	384m	3.3km		http://www.dowas.net/facilities/
Iwanai (Japan)	.035m^3/s	300m		2003	http://www.dowas.net/facilities/
Yakumo (Japan)	.041m^3/s	343m	4.4km	2003	http://www.dowas.net/facilities/
Teuchi Bay (Japan)	.005m^3/s	375m	4km	2003	http://www.dowas.net/facilities/
Sado (Japan)	.014m^3/s	332m	3.6km	2004	http://www.dowas.net/facilities/
Namerikawa (Japan)	.023m^3/s	333m	2.6km	2004	http://www.dowas.net/facilities/
Noto (Japan)	.001m^3/s	320m	3.7km	2004	http://www.dowas.net/facilities/
KRISO (South Korea)	.023m^3/s	300m, 500m	3.3km, 4.3km	2005	https://www.kriso.re.kr/menu.es?mid=a20202010000
Rausu (Japan)	.053m^3/s	356m	2.8km	2006	http://www.dowas.net/facilities/
Owase (Japan)	.033m^3/s	415m	12.4km	2006	http://www.dowas.net/facilities/
Intercontinental Hotel Bora Bora (French Polynesia)		914m	2.4km	2006	https://youtu.be/9wtO46Ju4yA
Ito (Japan)	.012m^3/s	800m	4.6km	2008	http://www.dowas.net/facilities/
Tetiaroa (French Polynesia)		960m	2.6km	2012	https://thebrando.com/tetiaroa/tetiaroa-atoll/ and https://www.entrepose.com/en/reference/tahiti-swac-brando-project/
Taaone (French Polynesia)		880m	3.8km	2021	https://www.archyde.com/the-longest-swac-in-the-world-in-assembly-at-papeari-before-being-installed-in-taaone/ and https://www.linkedin.com/in/jean-hourcourigaray-0141001/detail/recent-activity/

4. Fresh-water Production through Desalination

4.1 Background of Freshwater Production on an Island

On Kumejima, two companies produce bottled water products from DOW through reverse osmosis, each company's product is geared to a specific market, and slightly different methods are utilized. Unlike Nauru, Kumejima has sufficient rainfall to meet its own needs or even export water in most seasons and has long had other businesses selling bottled spring water from the island. Due to the limited capacity and high shipping costs for low quantity, the business is self-limiting, and thus is only considered a small part of current DOW operations on Kumejima.

For Nauru, where clean water access has not yet been sufficiently secure, freshwater production through DOW provides significant opportunities for both improving water infrastructure and potentially reducing costs.

4.1.1 DOW Desalination Methods

Ocean water desalination is a separation process of salts from ocean water. Figure 4.1 shows the typical classification of ocean water desalination methods which are thermal distillation and membrane processes.

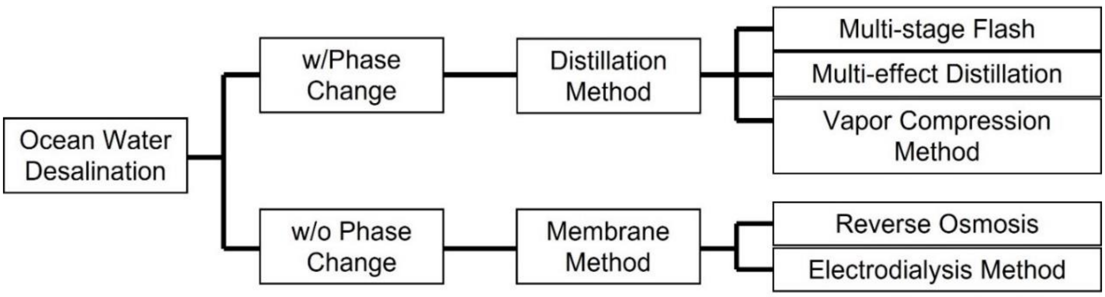


Figure 4.1 Relation between Various Desalination Methods

1) Distillation Method

Distillation Methods are the separation process by evaporating a part of the ocean water, and then condensing the steam. In general, ocean water is heated by a boiler to make a temperature difference between heated ocean water and raw ocean water. The temperature difference is the driving force behind distillation in low pressure conditions. Because it uses the heat of a boiler, combination with power plants are applied specially in the middle east. The quality of freshwater obtained is pure water and requires addition of ions to achieve potabilization or to protect piping. In contrast, Low Temperature Thermal Desalination (LTTD) uses the temperature difference between surface and depth in the ocean, and this process is applicable to multiple use using the effluent of OTEC surface and deep ocean water because both ocean waters maintain temperature difference.

LTTD is the same process as flash desalination; however, the temperature difference between the vaporized ocean water and condenser is limited to the ocean water temperature difference. The surface ocean water (or surface ocean water effluent from OTEC) will be fed to a vacuumed flash chamber, where the pressure is lower than the pressure at the boiling point of the surface ocean water, around 2 kPaA. Surface ocean water at such low pressure has a lower boiling point, so it evaporates (flash desalination). The generated vapor flows into a condenser. In the condenser, DOW provides the low temperature to cool the vapor into a liquid. The system's vacuum pump will remove any non-condensable gases such as Nitrogen and Oxygen contained in the ocean water, any air entering from the atmosphere, and small amount of evaporated steam. Figure shows the LTTD cycle.

LTTD has been studied at the Institute of Ocean Energy, Saga University in multiple test implementations. It is also being deployed to small islands in India by the National Institute of Ocean Technology (NIOT) of India. Currently there are 2 installations in place, with 4 more nearing completions with freshwater output of 150kL/d [20]. In addition, a larger LTTD plant is also in production for the Tuticorin Thermal Power Station [20].

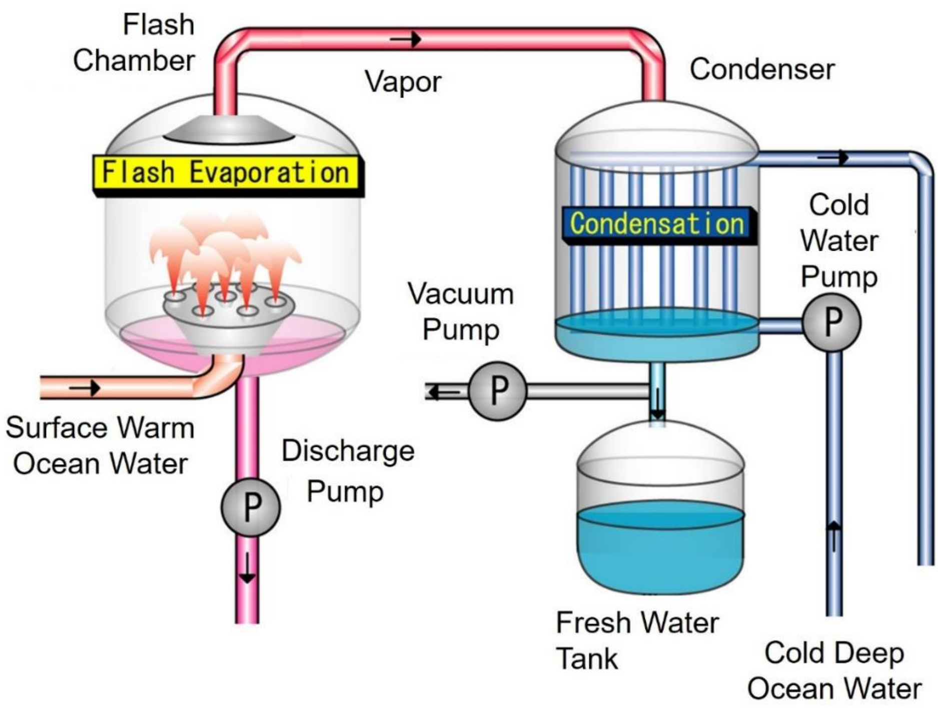


Figure 4.2 Schematic Drawing of LTTD Cycle

A major benefit of LTTD is that only 1-2% of the base ocean water is extracted, so that discharge is only minimally affected compared to a reverse osmosis desalination facility. All non-condensable gasses are also removed through the process however, so aeration prior to discharge may be necessary. A secondary benefit is that the components are simple, significantly simplifying maintenance and operation. Unlike reverse osmosis, specialized membrane maintenance is unnecessary, and pre-treatment can be significantly reduced. A specific case for Nauru will be introduced in section 4.3.

2) Membrane Method

In the case of Reverse Osmosis (RO), surface ocean water is generally used, which has higher concentrations of general bacteria, which causes more biofouling of the RO membrane than DOW [5]. In addition, other contaminants such as micro-plastics and suspended solids must be filtered out to meet RO membrane requirements. In standard RO, the selection of the pre-treatment process needs to meet the ocean water quality in the specific site, and a wastewater treatment process is required for the treatment of the backwash water including coagulants such as ferric chloride. In addition, the brine water, which is concentrated ocean water, will be discharged from the system. For maintenance, frequent replacement and chemical cleaning of the RO membranes, maintenance of the special equipment such as high-pressure pump, booster pump, and energy recovery device are required. These maintenance issues can increase the operational and maintenance costs in isolated locations such as Nauru.

Use of DOW, which is virtually bacteria free due to the dark and cold natural environment can be used with significantly less pre-treatment, and also prolong the interval between necessary RO membrane maintenance. While very cold DOW will require more energy to pump due to the higher density, post-OTEC DOW, which will be warmed during power generation, will mitigate some of any increase in pumping cost.

Depending on final OTEC site placement, post-OTEC DOW can be distributed to existing RO plants by pipes, in which case, only distribution piping to the existing RO plant will be necessary. In case the site is not nearby, additional equipment for desalination may be considered. As with surface water RO, the discharge will have a high salinity, so correct discharge methodology must be considered to mitigate any environmental impact. Compared to an RO Facility without OTEC, post-OTEC water can be utilized to dilute RO discharge and reduce the environmental impact. In the case of cascade or multiple use of ocean water, effluent from SWAC or cold soil agriculture, etcetera could also serve this function.

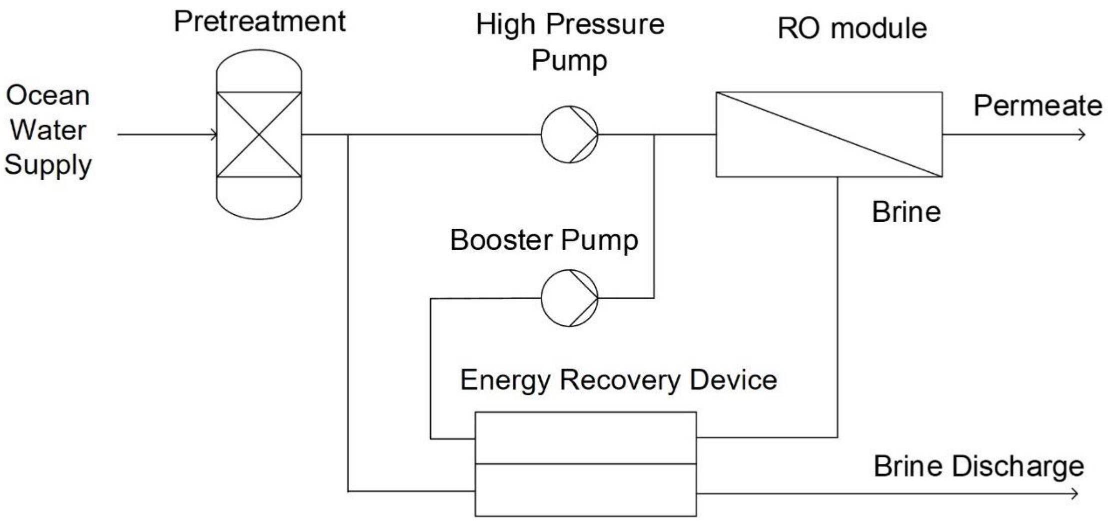


Figure 4.3 Typical RO Desalination Process

On Kumejima, two companies utilize RO with DOW. The benefit to DOW use with RO is that DOW is very clean (virtually bacteria free) and can be utilized without pre-treatment, reducing operating and maintenance costs. A challenge associated with DOW use is that the lower the temperature of ocean water, the higher viscosity, so power consumption may be increased. This can be mitigated through use of post-OTEC DOW water, where the temperature is increased from raw DOW resources.

4.1.2 Comparison of Methods

Table 4.1 Comparison between LTTD and RO Desalination

Category	LTTD	RO
Pretreatment	Deaeration to remove non-condensable gas	Filtration to remove suspended solids and micro-organisms to meet requirements of membranes
Post-treatment	Mineralization	Mineralization
Maintenance	Minimal	Membrane replacement (About 30% per year)
Power Consumption	2-5 kWh/m^3 (Depends on the ocean water temperatures)	5~7 kWh/m^3 (Depends on the water quality and energy recovery system)

	(MSF:10 kWh/m3 including thermal energy)	
Environment Impact	- Negligible salinity change - Lower dissolved oxygen in effluent water due to exposure to vacuum	- Concentrated ocean water (brine) discharge - Wastewater discharge from pretreatment

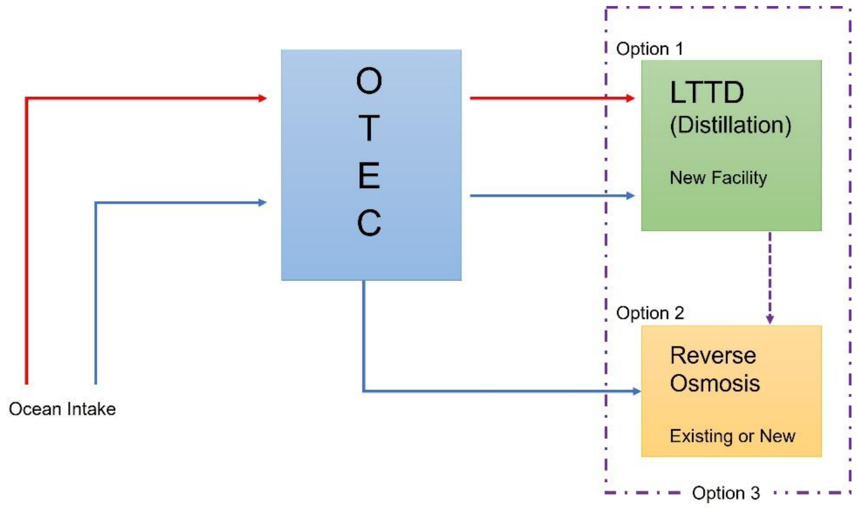
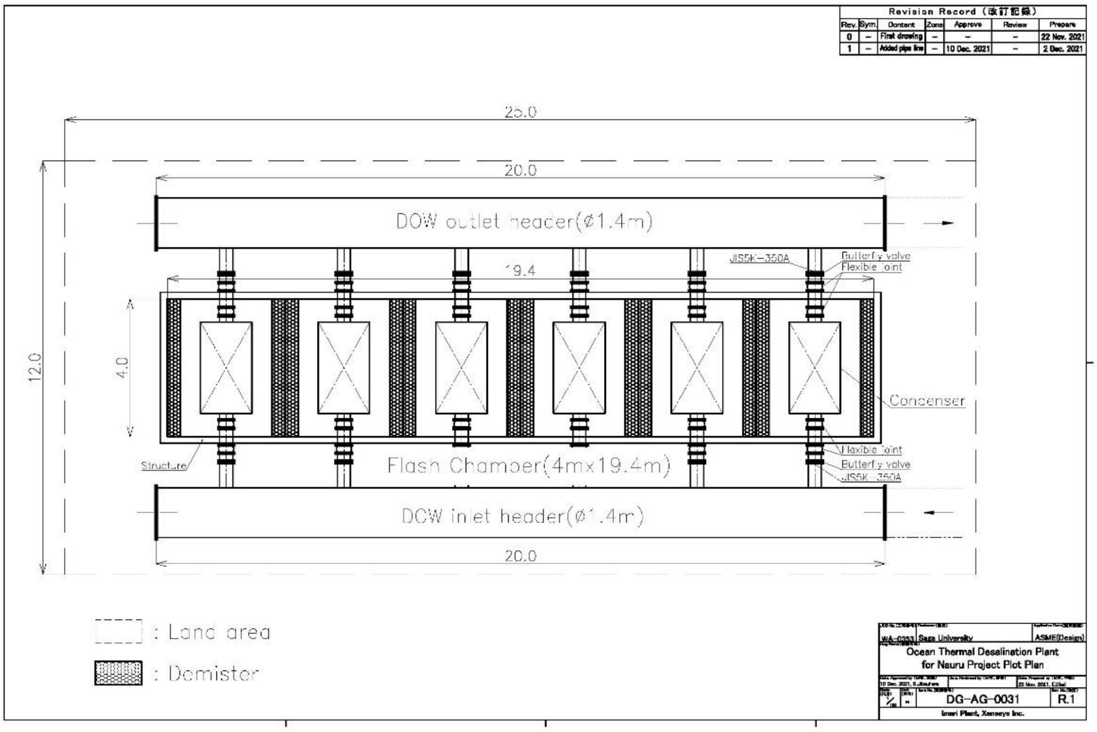


Figure 4.4 Illustration of Options for Increased Water Security on Nauru

4.2 Combining OTEC and LTTD

After providing electricity from an OTEC power plant, the effluent ocean waters can be applied to either the thermal distillation or the membrane separation desalination methods as shown in Figure 4.4. According to a NUC report, in Nauru, the reverse osmosis process is used to produce water. As the effluent ocean waters from OTEC still have thermal energy as a temperature difference of 12.6 °C (As shown Figure 3.213), the LTTD process can be applied. (a) Process Flow Diagram



(b) Schematic Plot Plan

Figure4.5 (a) shows a process flow diagram and (b) schematic plot plan of an LTTD plant producing 23 t/h (Approx. 550 m^3/day) of desalinated water using the effluents ocean water from OTEC. According to a NUC report, the water demand in Nauru is expected about 200000 kL/year, which corresponds to 548 m^3/day by 2025.

In the case of Nauru, the desalinated water produced by LTTD can be transferred and mixed with RO permeate. The advantage of installation of LTTD plant is not only the increase of amount of water production rather than RO alone, but operation that provides; (1) higher quality of produced water; (2) lower environmental impact; (3) lower maintenance cost.

(1) Higher Quality of Produced Water

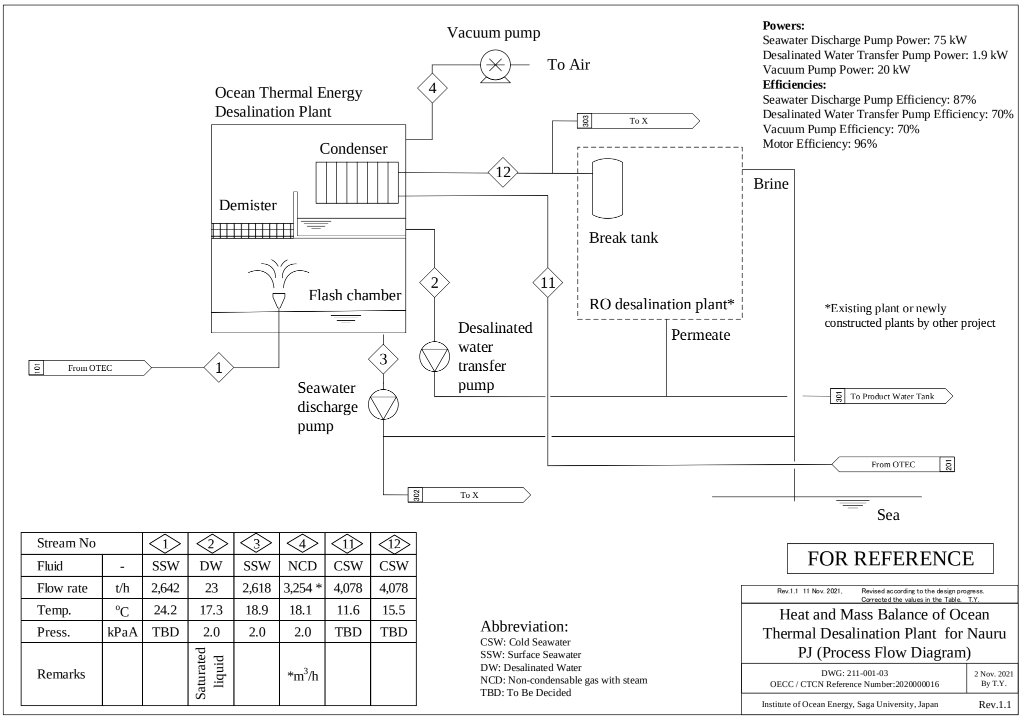
Water produced through desalination needs to meet water quality standards such as WHO standard and Australian water standard. The RO permeate purity depends on the membrane performance and water temperature, where lower ocean water temperature will increase the purity of permeate. The relatively higher ocean water temperature in Nauru is a severe condition in achieving high purity water and may need two-stage filtration. The application of a combination of distillation process and RO is a method to solve the issue of water quality in the product. In the post treatment process, the addition of some deep ocean water, which is a clean ocean water will add some ions to support the adjustment of hardness of produced water.

(2) Lower Environmental Impact

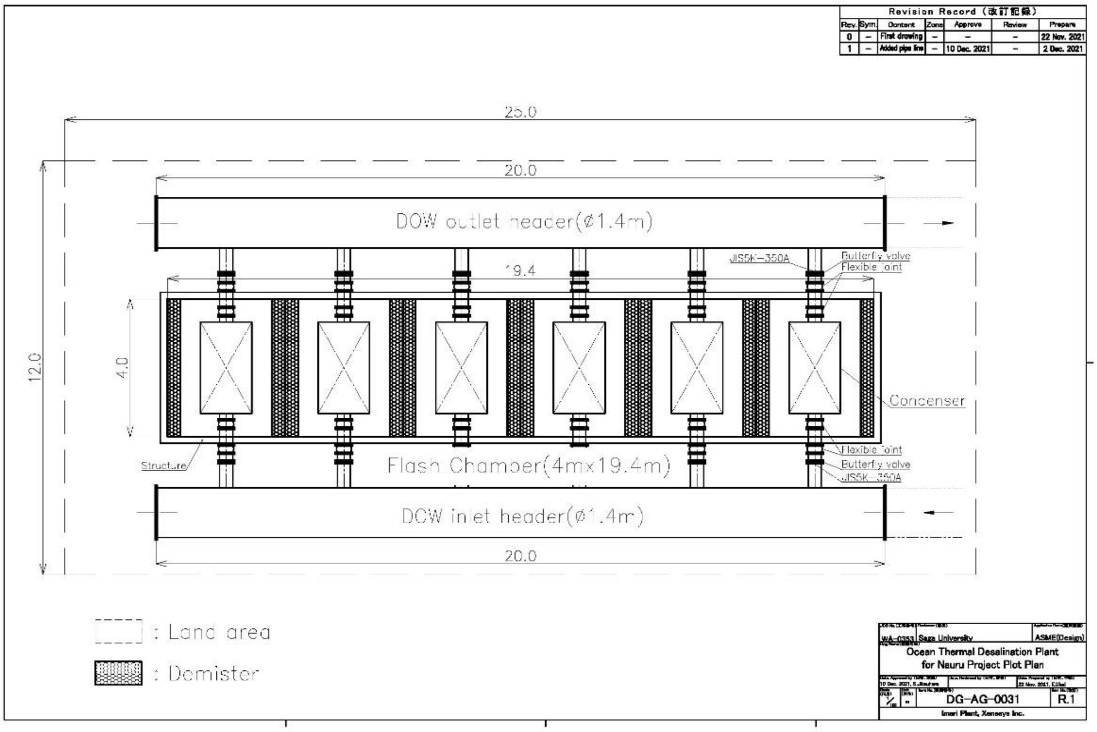
RO membranes require pretreatment processes which require chemicals such as ferric-chloride to coagulate the suspended solids in the ocean water to meet membrane supplier requirement and to avoid the frequent biofouling of the membrane. Whereas the usage of deep ocean water that contains less suspended solid and microorganisms will reduce the load of pretreatment and frequency of chemical cleaning. The deep ocean water after LTTD will be more than 15^{o}C, which is normal condition for RO process in general. Through the increase of LTTD water production, the consumption of chemicals and wastewater discharge from pretreatment will be reduced. In addition, because of high rate of water production approximately 35~50% of the discharge from RO is concentrated ocean water (brine), which is a world-wide issue and will affect the coastal area environment. The combination of LTTD will dilute the brine by mixing the effluent of ocean water from the flash chamber which is almost same ion concentration with original ocean water.

(3) Lower Maintenance Cost

RO membranes are a consumable required to keep the water quality and production flow rate. Usually 30%~50% of the membranes need to be replaced. Whereas the LTTD process does not require consumable components. The usage of surface ocean water for in the flash chamber for the distillation process may cause the biofouling in which will require a periodic cleaning, however, the deep ocean water will not require frequent cleaning. In addition, the RO process requires the periodic and specialized chemical cleaning to remove the biofouling to achieve normal purity of permeate and flow rate of water production, whereas LTTD will generally require less specialized maintenance. Moreover, the utilization of deep ocean water effluent from LTTD will provide a high-quality ocean water that will reduce the load of pretreatment and frequency of chemical cleaning in RO process.



(a) Process Flow Diagram



(b) Schematic Plot Plan

Figure 4.5 Diagram for LTTD Desalination using post-OTEC Ocean Water

5. Deep Ocean Water Cooling (DOW Cooling)

DOW Cooling refers to the cooling of buildings through utilization of the naturally occurring cold DOW resource. Large-scale commercial chillers use energy intensive compressors, fans, and refrigerants to chill fresh water that can then circulate through a building to supply cold to individual spaces. For DOW Cooling, ocean water provides the cold source. DOW is more corrosive to many materials than fresh water, thus after intake, a heat exchanger is used to cool fresh water with DOW. The two liquids never mix, providing the opportunity for the DOW resource to be reused elsewhere or returned to the ocean. The cooled freshwater can circulate in a closed loop, cooling nearby buildings, and reducing the cost of ancillary equipment such as piping and pumps, compared with the cost of materials designed for ocean water.

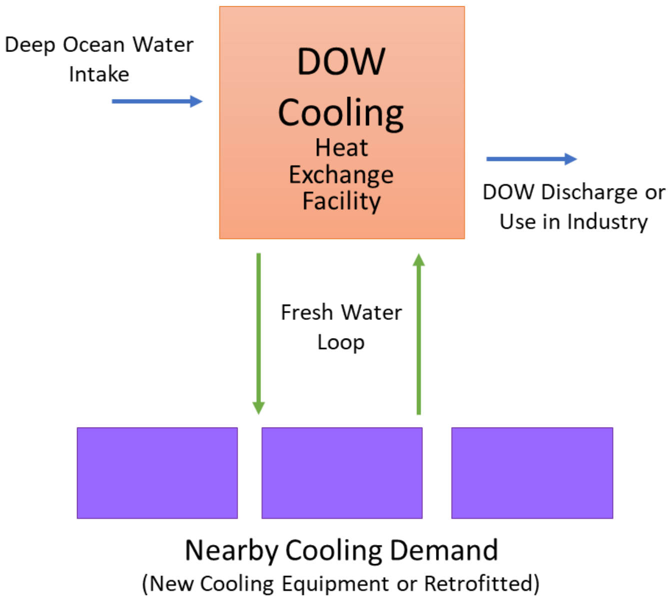


Figure 5.1 Illustration of a Simple DOW Cooling System.

On Kumejima, DOW Cooling is used within the ODRC to cool laboratory and auxiliary buildings with a significant reduction in energy use compared with traditional air conditioning systems. In the case of the main ODRC building, DOW Cooling provides cooling for main air exchange between the building and outside air, while also allowing for the temperature and settings of each room to be individually adjusted.

The graph below illustrates the difference in cooling efficiency between typical air conditioners and DOW-based cooling. Where air conditioners use working fluids to exchange heat from inside to outside, requiring energy-intensive compressors, a DOW system can use the naturally occurring cold water resource from the ocean. While some electricity is still required to move the cooling liquid and air through a system, in the case of Kumejima, the system is about 8 times more efficient. As Kumejima's existing intake was designed for fishery research, higher efficiencies are possible through use of smaller, optimized pumps.

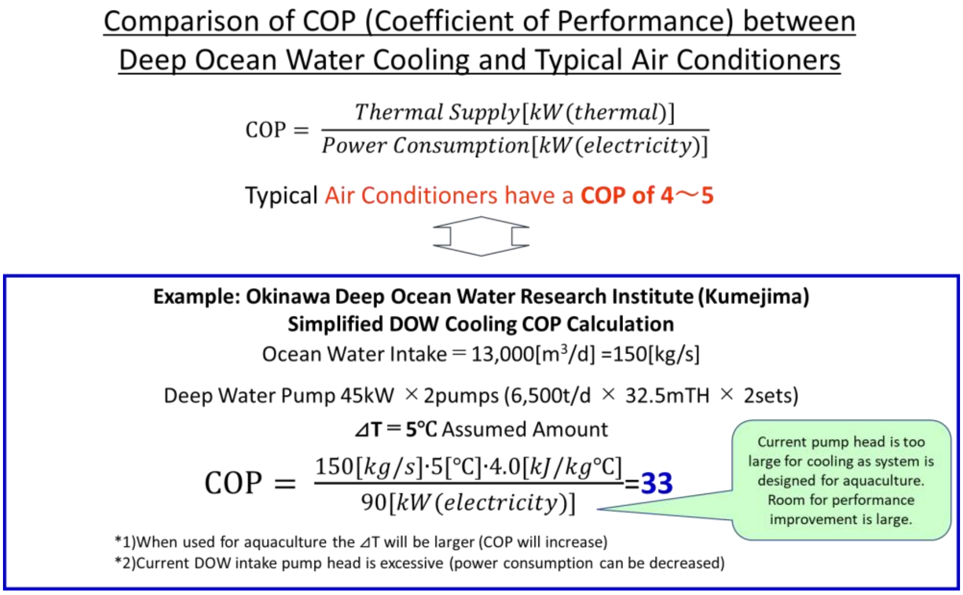


Figure 5.2 Comparison of Simplified COP between SWAC on Kumejima and a Typical Air Conditioner.

While larger-scale implementation has been considered for Kumejima, the distance from ocean water intake to larger cooling demand at hotels, restaurants, and municipal buildings have made it impractical given the limited DOW resource currently available. The same technology has been applied to other uses such as agriculture.

6. The Feasibility of Potential Aquaculture with OTEC

6.1 Background

As part of the pre-feasibility study for an OTEC system applied to Nauru, the technical team will discuss the feasibility of aquaculture and other DOW uses. The feasibility will be assessed in consultation with stakeholders aligning with the National Act on Coastal Fisheries and Aquaculture in Nauru.

In Okinawa, the southern-most prefecture of Japan, there is a remote island with many characteristics and goals similar to Nauru. Kumejima Town, the local government of that island is working on increasing its renewable energy capacity to meet its goal of 100% renewable energy by 2040 [1] through the use of OTEC.

In 2000, Okinawa Prefecture established the Okinawa Deep Ocean Water Research Center (ODRC) on Kumejima Island to promote fishery research and industry. The ODRC utilizes DOW and SOW pipes with capacities of 13,000m3 per day [2] to research new technologies and also sell water to local industries.

Based on the island's more than 20 years of experience in working with DOW resources for both local industry and clean energy, the current situation, progress, and future plans will be outlined as a reference towards implementing ocean energy technologies in Nauru.

6.2 Deep Ocean Water Use on Kumejima

Since 2001, the people of Kumejima have used the available capacity of DOW from a depth of 612m and SOW from a depth of 15m to strengthen existing practices and create new industries accounting for a significant and growing portion and of the total island revenue.

The total revenue from deep DOW related industries has grown up to 24 million USD per year as of the most recent survey in 2016 [4]. (Figure 6.1)

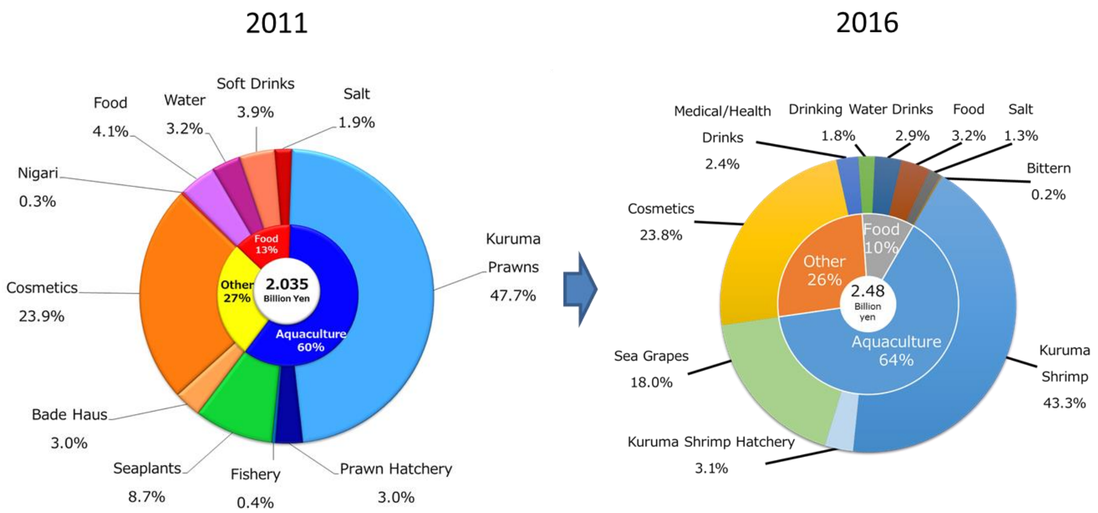


Figure 6.1 Economic Impact of DOW Use on Kumejima.

Local companies on the island purchase water at a price based on the intended use of the water and set by the local government. 98% of DOW sold to industries from the ODRC is used in kuruma prawn (Penaeus japonicas) and sea grape (C. lentillifera) aquaculture. Both industries use clean DOW to regulate temperature and now have the largest market shares in Japan [5].

6.2.1 Kuruma Prawns

In the 1970's Kumejima's Fishery Cooperative began farming kuruma prawns on Kumejima. Since this species of prawn is not endemic to Okinawan waters due to the higher temperature, wild mother prawns were purchased from Kyushu and farmed in ponds around Kumejima. The high temperature of summer months limited the growing season, providing market-available prawns from November to May.

Figure 6.2 Kuruma prawn (Penaeus japonicas) at Epoch Prawn Farm

A variety of factors led to domestic market instability including the intermittence in the availability of wild brood stock, the risk of virus transmitted from wild stock leading to die off, and other risks such as the end of the bubble economy.

Technology researched at the ODRC provided a method for securing prawn seedling availability in Okinawa year-round, leading to stable and secure supply. In addition, the use of DOW allowed for the production of a virus-free brood stock, from which fry are bred. DOW is used at the Okinawa Kuruma Prawn Hatchery located on Kumejima to produce virus-free baby prawns for grow-out at aquaculture facilities throughout Okinawa. The stable supply of baby prawns has enabled Kumejima to produce reliable supplies of prawns. The majority of prawns have traditionally been sold at auction via fish markets throughout Japan. With the onset of the COVID-19 pandemic, suppliers have adapted by diversifying their markets to include more local consumption and direct to consumer options.

Since the grow out ponds on Kumejima do not have access to DOW at capacities enough to cool surface water to the necessary 25 degrees Celsius temperature in summer months, they cannot harvest from June to October. Access to expanded ocean water capacity would enable year-round live prawn cultivation, which would achieve historically higher prices at market and also create a more consistent availability for their customers.

The cold aspect of DOW is used in smaller quantity at the Kumejima Fishery Collective Kuruma Prawn Farm. During processing, live prawns are gradually chilled to calm the prawns, to help limit any injury during process and sorting. Using DOW for this process reduces energy costs from chilling and the cleanliness helps ensure high quality product.

6.2.2 Sea Grapes

Sea grapes are a local Okinawan delicacy with a consistency and taste comparable to caviar. An endemic sea plant, they grow naturally in warm Okinawan waters and can also be found in other locations around the world.

Figure 6.3 Sea grapes (C. lentillifera) at Kumejima Deep Ocean Water Development Company's Farm

Using technology developed at the ODRC and through years of trial and error, the Kumejima Deep Ocean Water Development Company grows sea grapes through onshore aquaculture. Since sea grapes are sensitive to temperature, SOW and DOW are mixed to maintain a constant temperature. Although current production facilities are limited by the daily DOW needed at the warmest time of year, the company has gradually grown to produce around half of the total production in Okinawa. Part of their success is the ability to grow year-round due to the temperature control enabled by ODW and SOW. Other producers in Okinawa are limited to a short growing season. In addition, the Kumejima farm supports the industry overall by providing high quality product under other brand names when other sources become unavailable. Since the other properties of DOW outside of the low temperature, are not needed for sea grape farming, there is potential for increasing the DOW available to other users through cost-effective methods of decreasing the SOW temperature during the summer, such as with post-OTEC SOW.

6.2.3 Cosmetics

A significant and growing portion of Kumejima’s DOW revenue comes from cosmetics, primarily those made by Point Pyuru. Although their water use needs are not large, Point Pyuru uses desalinated DOW as the base of its series of OEM and branded products, returning minerals and adding other local ingredients for its recipes.

The use of DOW provides marketing benefits, low-cost access to minerals and water, and the benefit of relatively a bacteria-free resource. Point Pyuru, a local company, was founded after the installation of the DOW intake and now sells a variety of products to domestic and international markets. They focus on moisturizers, cleansers, amenities, and specialized products such as collagen boosting creams.

Figure 6.4 Point Pyuru’s “Beautiful Kumejiman” line of products.

6.2.4 Agriculture

The ODRC researched the use of DOW in cooling soil for agriculture for more than fifteen years. Okinawa’s warm climate limits the growing season for many plants, requiring most leaf plants to be imported during the summer months. The high cost of transportation from other regions to Okinawa increases the sale price significantly. In the case of spinach, the price can more than double [5].

Yet, through cooling soil, as with DOW Cooling, a heat exchanger is used to cool fresh water with DOW, which then flows through pipes under soil, the roots of leafy plants can be cooled. Spinach normally takes a month and a half to grow, leading to eight harvests per year. In the warm summer months, cooled soil spinach can be harvested after only a month, allowing for ten harvests per year.

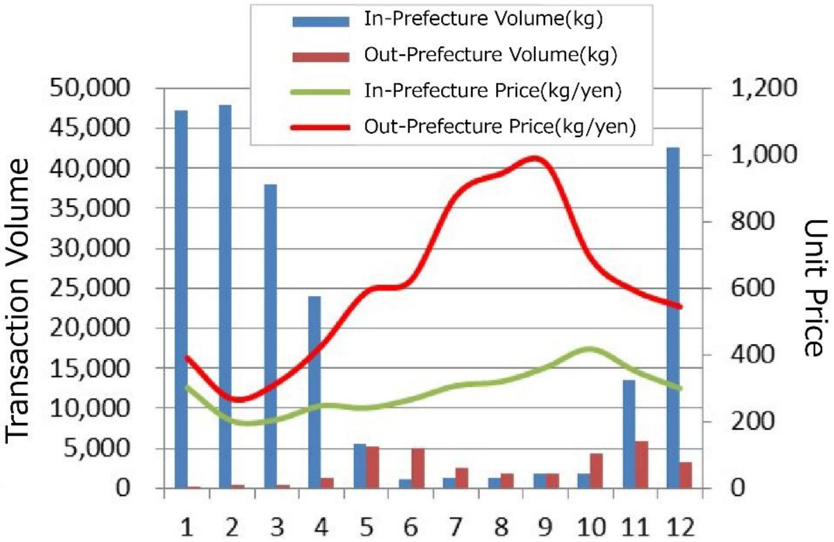


Figure 6.5. Okinawa Prefecture Spinach by Volume and Sales (2009～13) [5]. Okinawa has limited self-sufficiency in summer, but cooled-soil agriculture could provide consistent production instead of the currently limited seasonal harvests.

In order to support the commercialization of such agricultural techniques, in 2014 Kumejima Town built 6 typhoon-resistant green houses to utilize cooled soil agriculture for both local and export use. More recently, the company operating the houses on behalf of Kumejima Town, Rohto

Figure 6.6 Rohto Pharmaceuticals Bioreactor within Kumejima Town Greenhouse

Pharmaceutical, has established new bio-reactor equipment to test use of indirect DOW cooling in algae production. Currently they are producing superfoods and food coloring extracts as a step towards future expansion.

6.2.5 Oysters

General Oyster Co. and its subsidiary GO Farm has been researching oyster production with DOW resources on Kumejima for more than 8 years. Oysters, which are currently not farmed in Okinawa Prefecture, are highly regulated in Japan. While traditionally eaten cooked in Japan, the popularity of raw oyster consumption is growing, though somewhat hindered by the concern for sickness from the chance of eating a contaminated oyster. Complete onshore production of oysters would allow a controlled environment for production of safe raw oysters, but the cost of feed and temperature control are limiting factors.

With Okinawa's warm climate, production of planktonic feed is much easier, and the DOW resource can provide cheap nutrients and cooling. The expanded water capacity of a 1MW-class OTEC plant would provide the roughly 50,000m3 or more per day of ocean water needed for onshore oyster production. GO Farm has established a small-scale hatchery and research center to continue developing its technology and processes under existing ocean water capacities.

6.2.6 Other Products

Additional uses of DOW on Kumejima include salt production, bittern production, fishery preservation, bottled water production, use in food, and spa use. Compared with mainland Japan intake locations, Kumejima's high shipping costs limit the amount of high capacity or large-scale exports, so bulky or heavy products such as bottled water are limited.

In 2015, the Fisheries Civil Engineering Construction Technology Center Institute moved their coral hatchery research operations to Kumejima to take advantage of lower operating costs through cooling SOW during hot summer months in a heat exchanger with DOW. This allows consistent water quality with low-cost temperature control for their work in coral preservation.

7. OTEC and Industry Operability

7.1 Expanding Resource Capacity to Meet Island Needs

With the persistent demand for increased water supply by DOW users on Kumejima, local industry, associations and the town government have been seeking options for increasing the capacity of water available for use. Since simply bringing up more water through the same diameter pipe with stronger pumps is not a viable alternative due to the increase in ocean water temperature through friction and significant increase in pumping costs, it is recognized that new pipelines are required to meet the demand. At the same time, large-scale utility and infrastructure projects can be difficult for island communities to establish alone.

More recently, as the need for accelerated action to counter climate change becomes more accepted, the role of renewable energy in policy outlook has become ever more important. In February 2018, Kumejima Town Mayor Ota announced the island would aim for 100% clean energy [10]. This was followed by a “Zero Carbon City” declaration, the first municipality in Okinawa to announce its goal of going carbon free by 2050 [11]. Kumejima Town’s energy policy was further collected in the “Kumejima Town Energy Vision 2020” which includes OTEC in its roadmap for meeting climate related obligations [1].

7.1.1. Overview of the “Kumejima Model”

The “Kumejima Model” is a concept integrating a system of technologies for utilizing DOW multiple times in a “cascade” from OTEC through to uses such as research, ocean water desalination, expansion of current industry, and the adoption of new industries. The core requirement of the model is access to a larger supply of both DOW and SOW on the scale of 180,000m3 per day. Water from a depth of 700m averages six to seven degrees Celsius [12] providing a resource that can then be re-used after OTEC in a variety of ways. Since post-OTEC DOW is still cold, it can be used for cooled-soil agriculture, area cooling, aquaculture, and other uses. In the case of agriculture and cooling, heat exchangers are also used so that ocean water can then be used again for desalination, cosmetics, and aquaculture. The same water can be used up to four times or more depending on the use.

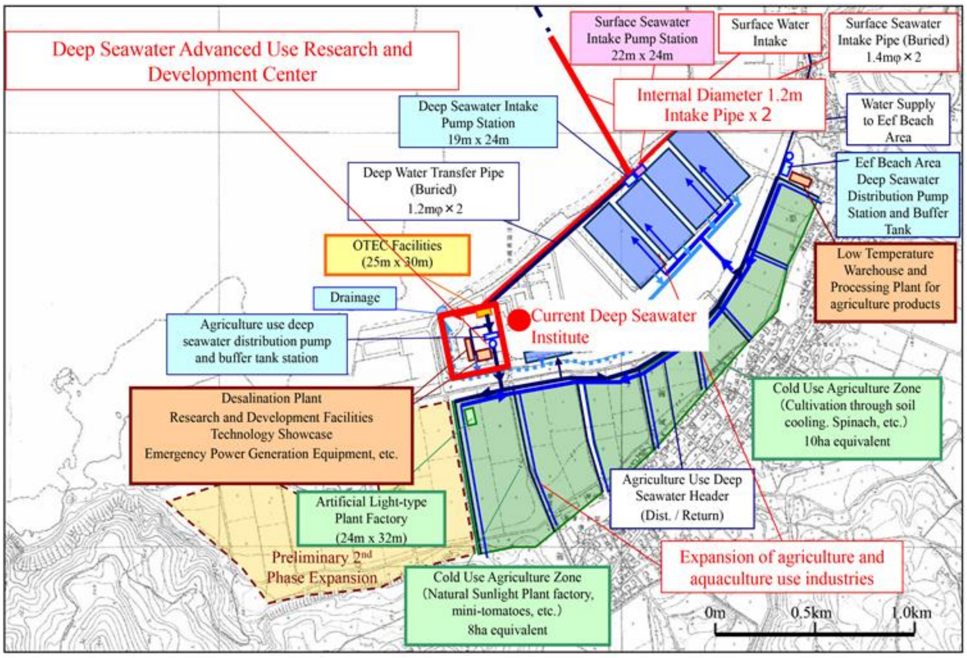


Figure 7.1 Current Kumejima Industries and Future Model Area [13]. New intake pipes provide expanded water resources for model area self-sufficient in power and water

7.1.2. Benefits and Goals

Expansion of intake capacity will supply resources for expansion of existing industries. A pond system for kuruma prawn summer farming would require roughly 28,000m3 of ocean water per day, roughly equivalent to the total current capacity the ODRC, but with a product that can be sold at roughly thirty percent higher prices than in the currently available growing season. The potential for new businesses and operations are vast. A fiscal year 2017 survey conducted by the Okinawa General Bureau examined current and future interest in deploying DOW industries to Kumejima, with further surveys highlighting several companies with concrete plans for expansion when expanded ocean water becomes available.

Throughout the world, there are currently several sites using DOW for a variety of uses from cooling to agriculture. There are, however, yet no large-scale systems integrating the separate uses of DOW for efficient use. Kumejima provides a small-scale working environment to test and refine the integration of technologies and systems which will allow a working model that can be adapted at larger scale for other island communities in Japan and throughout the world.

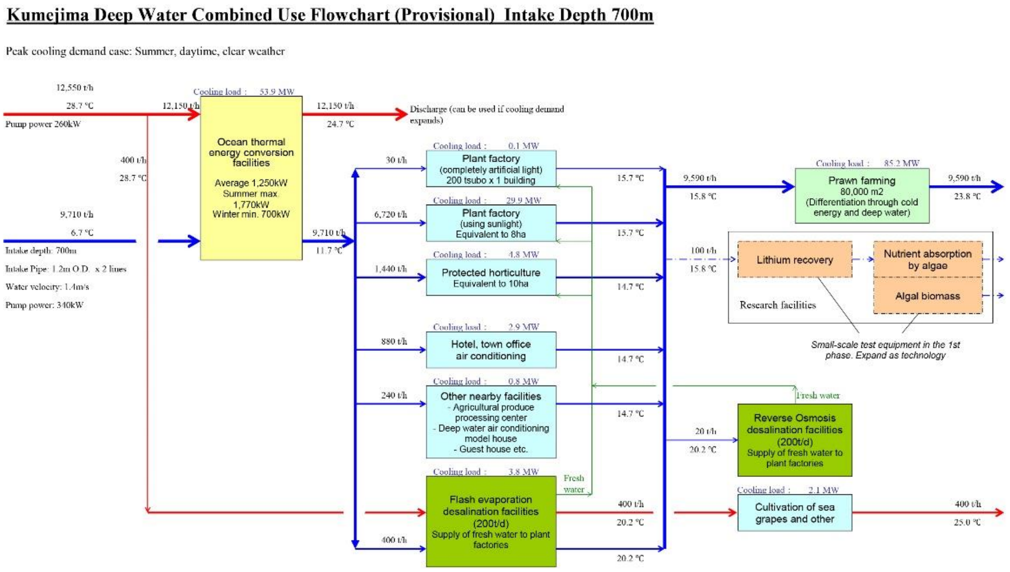


Figure 7.2 Kumejima Model Flow Concept at 700m Depth [13]. Multiple use of the water resource leads to increased efficiency and less waste.

7.1.3. Impediments to Implementation

There are no major technological hurdles to implementing the "Kumejima Model." The need for a new pipeline requires a significant initial investment and is large enough that no single user has been able to privately finance a pipeline for their independent use. Kumejima Town, with funding from the Japanese Government is currently studying implementation of a new intake as a utility. As with other utilities, the initial cost is expected to be partially covered through grants or subsidies, while operating and maintenance costs will be covered by operating income from water sales. This is similar to the implementation of the world's largest DOW intake in Hawaii at the Natural Energy Laboratory of Hawaii Authority (NELHA).

For OTEC, the current development stage is between initial research and commercial investment, which can be a challenging step. With the "Kumejima Model," the integrated system of technologies, most with individually proven track records and existing demand, enables an efficient and economic use of the pipeline investment. In addition, studies such as the initial Feasibility Study done by Kumejima Town, and the FY2017 Economic Survey conducted by the Okinawa General Bureau, provide further evidence and information towards successful implementation.

7.1.4. Impact of the “Kumejima Model”

While the “Kumejima Model” will have a significant impact locally, the potential economic and social benefits pale in comparison to the opportunity to test, demonstrate, and prove the reliability of OTEC and related industries. With OTEC’s potential to provide resilient baseload renewable energy, the “Kumejima Model’s” greatest benefit will be to help move the technologies from developmental to pre-commercial and commercial stages for wider adoption domestically and abroad. Already, the efforts made on Kumejima have been recognized as a viable concept for community development. In Malaysia, under the joint Malaysia Japan Science and Technology Research partnership for Sustainable Development (SATREPS), a “Malaysian Model” is being developed to adapt OTEC to local conditions [14]. For Nauru, differences in location, culture, and customs means that direct adoption of Kumejima’s implementation plan will likely not make sense. Rather, based on the experience of DOW use in Japan, and considering the needs of Nauru, this document will explore possible options towards the creation of a “Nauru Model” to ensure secure, economic, and environmentally sound sources of power, water, and food.

7.2 OTEC and Island Grids

As previously noted, Kumejima Town recently published the “Kumejima Town Energy Vision 2020.” This is a policy document compiled with support of local experts to examine how Kumejima Town can approach its future energy environment and needs. Unlike national or state-level visions in Japan, this document considers the unique situations and challenges on Kumejima. As Nauru shares many similarities in terms of size and power demand, we will briefly outline some of the key points that may inform establishment of future renewable energy in Nauru.

7.2.1. Brief Comparison of Nauru and Kumejima

Table 7.1. Table Comparing Basic and Electricity-related Data in Nauru and Kumejima

	Nauru[15]	Kumejima
Basic Data		
Area	21.1 km2	63.2 km2
Population	~13,000 people	~8,000 people
GDP	US$ 130 million (2018)	US$ 217 million (2017)
Major Industries	Mining (Phosphate Ore)	Agriculture / Fishery/ Tourism
Electricity Related		
Annual Electricity Demand	35,813 MWh (avg. 4.1MW)	50,395 MWh (avg. 5.8MW)
Power Generation Capacity		
DE Power Generation	11.6 MW	16.5MW
Solar Power Generation	0.5MW (2018) -> 6MW (TBD)	2.5MW (2020) -> 6.0MW (2030) -> 9.5MW (2040)
Wind Power Generation	N/A	N/A

As noted above, the while the area of Kumejima island is larger, the population of Nauru is close to the population of Kumejima between 1965 and 1970 [1]. In addition, the annual average electricity demand, and current power generation methods, ie solar and diesel power generation are similar.

The major difference between both islands is in the industrial sector and geographic location compared with potential export markets. These and other considerations will be included in analyzing which components of the Kumejima Model and Kumejima's renewable energy efforts may be applicable.

7.2.2. Current Electricity Situation in Kumejima

Kumejima's Energy Vision 2020 has set a goal of reducing fossil fuel consumption to zero by 2040 [1]. For the island's utility needs, the vision calls for replacing current thermal power plants with solar power generation, OTEC, and energy storage facilities, including electric vehicles.

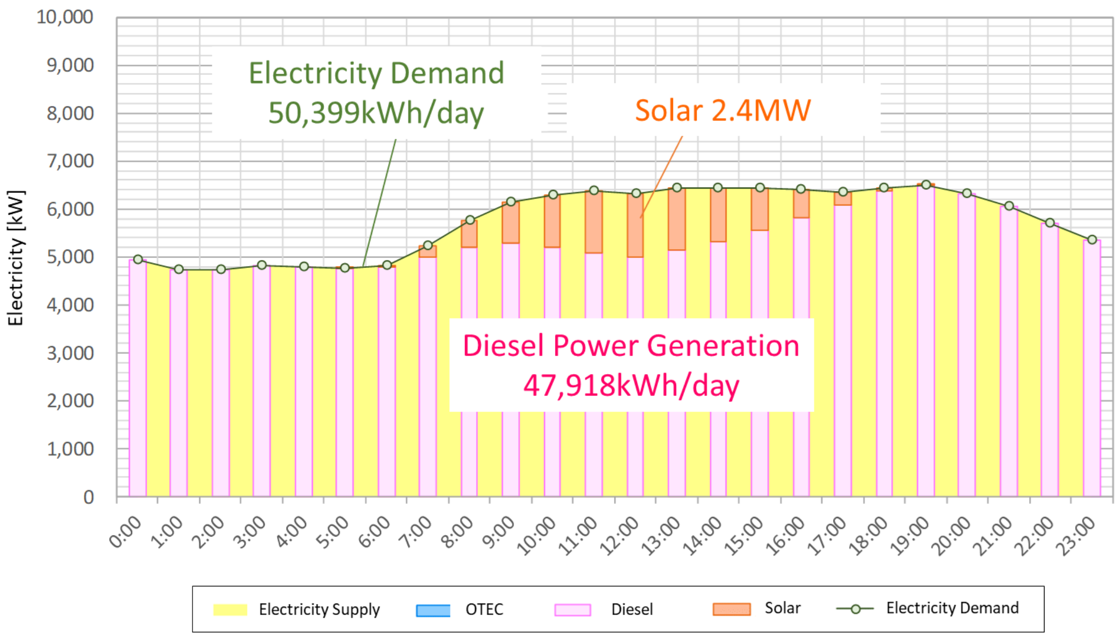


Figure 7.3 Electricity Situation in Kumejima as of FY2020 [1].

As noted in Figure7.3, Kumejima's average electricity demand is 50MWh/day supplied by 47.9MWh/day of diesel power generation and some solar. Due to limitations of Kumejima's islanded grid, the introduction of new renewables has peaked at about 5% of total electricity production.

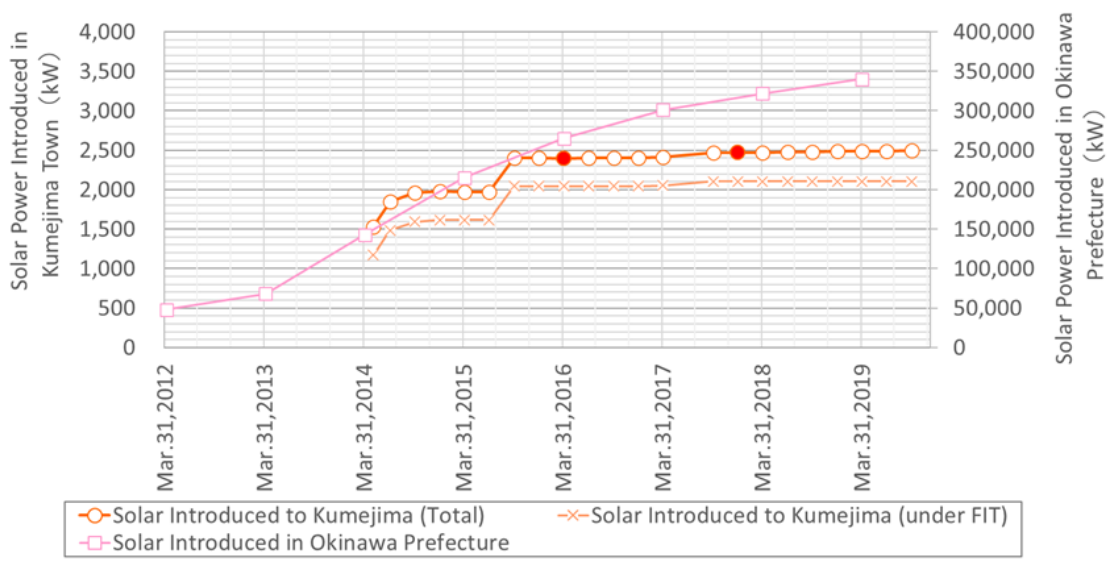


Figure 7.4 Changes in Solar Power Generation Introduction on Kumejima and Okinawa Prefecture [1].

7.2.3. Considering Expansion of Renewable Energy

In order to increase renewable energy and meet the island's renewable energy goals, a variety of renewable energy options were considered in terms of energy cost, technology readiness level, amount that can be introduced to Kumejima, and the suitability for Kumejima. As Kumejima has no geothermal resources, it was not included in the analysis.

Renewable Energy options considered for Kumejima were rooftop solar, field/stand deployed solar, rooftop solar heating, land-based wind, offshore wind, biomass, small hydropower, onshore OTEC, and offshore OTEC.

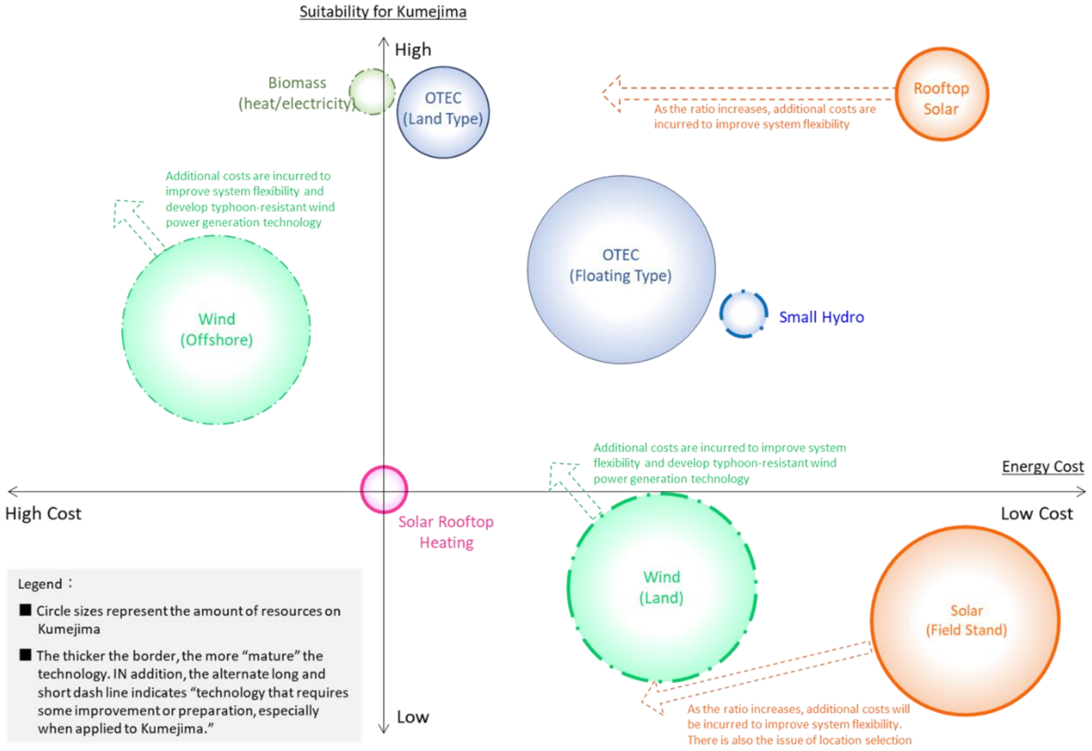


Figure 7.5 Results from Evaluating the Possibility of Introducing Each Renewable Energy Technology on Kumejima [1].

The results of analyzing renewable energy suitability for Kumejima are summarized in Figure 7.5. The circle size represents the amount of resources on Kumejima. Technology maturity is represented by the thickness of the border. Dashed lines represent a need for improvement or special measures before introduction to Kumejima.

For wind, while there are large wind resources, especially in the winter, reinforcing for typhoons and managing volatile output make it a difficult technology to introduce. In the case of solar, both rooftop and larger-scale implementations are possible, however, as installation ratio increases, costs from grid management increase. Land management can also become a significant issue. OTEC is very suitable for Kumejima, though offshore costs are still high as the technology is at pre-commercial stages.

7.2.4. The Kumejima Model's Impact on Kumejima Energy

As seen in Figure, a 1,000kW class OTEC facility would be responsible for supplying approximately 15% of Kumejima's electricity supply with an average power demand of about 6,000kW. Installation is expected around the year 2025, pending the outcome of a detailed planning survey. In addition, solar power generation is expected to increase with support of storage batteries and EV.

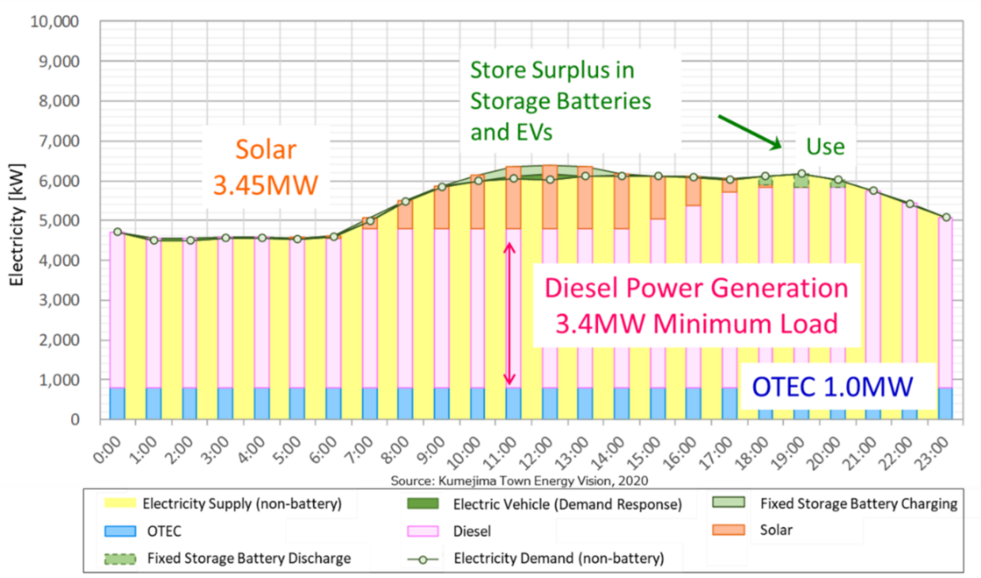


Figure 7.6 Projected Kumejima Town Energy Generation in 2025 [1].

For Nauru, a similar size facility would have a larger impact and allow for larger reduction in diesel power generation, while at the same time limiting any impact on current grid stability or operations.

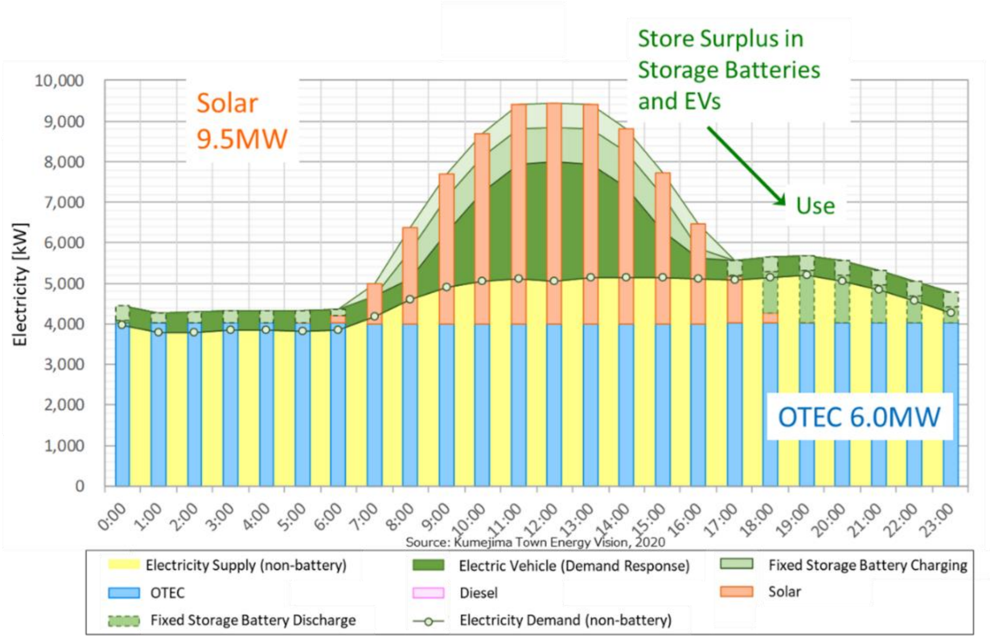


Figure 7.7 Projected Kumejima Town Energy Generation in 2040 [1].

To reach its 100% renewable energy goal, it is expected that an additional 5MW of OTEC power generation capacity will be required along with 9.5MW of solar capacity and technologies for long-term storage and grid management. It should be noted that this refers to the capacity of energy required not just for current electricity consumption, but to replace all fossil fuels including transportation. The Kumejima Town Energy Vision does not include transport to or from the island via ferry or air transportation.

Detailed analysis of this type is outside the scope of the current study, however, given the similar situations on both islands, it is clear that a MW-scale OTEC facility will have dramatic effects in terms of increasing Nauru's renewable energy, decreasing the total amount of imported fuel required to meet the needs of Nauru's people.

7.3 Reliability of DOW Industries and OTEC

Unlike most renewable energies, OTEC's base energy source is a robust buffer and natural storage medium. Both photovoltaic and wind power are considered intermittent as changes in weather such as wind, clouds, rain, sunlight can have dramatic and very fast effects on power production. In the case of OTEC, the energy source is ocean water. While like solar power, the heat energy OTEC uses comes from the sun, it is absorbed and held by the ocean. Water has a higher specific heat, which means more energy is required to change its temperature. This is a beneficial attribute as even large short-term swings in ambient temperature have a relatively small effect on ocean temperature. Figure shows surface and deep ocean temperatures as well as ambient temperature on Kumejima for the week of January 19, 2016. A significant drop in ambient temperature brought snowfall for the first time in 39 years, yet as one might observe, the surface temperature remained stable.

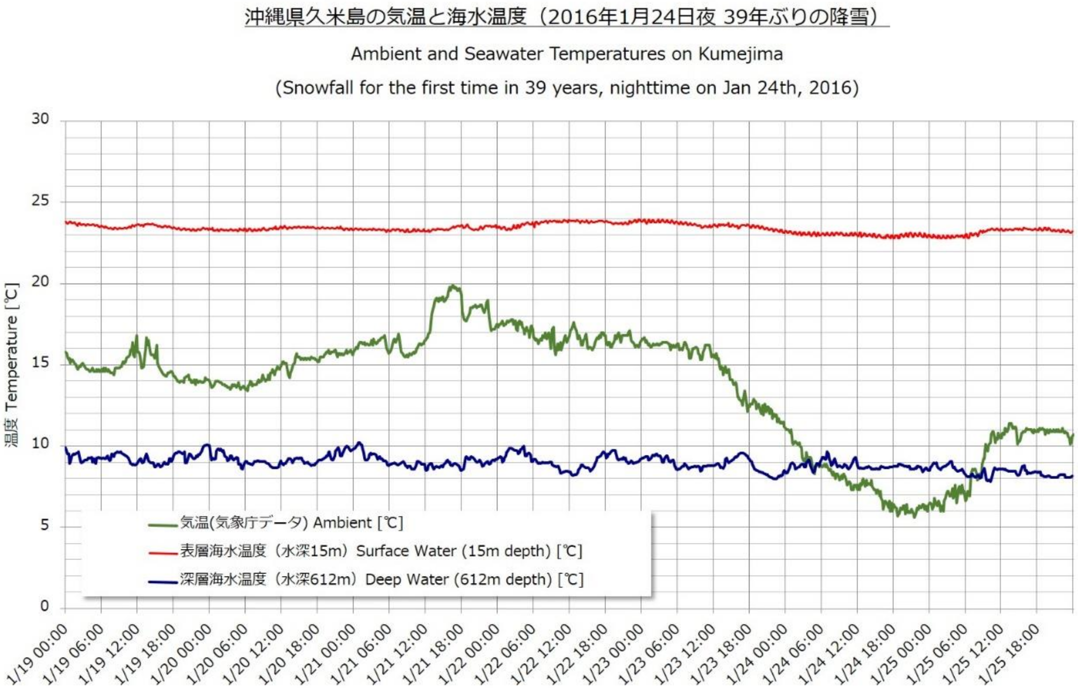


Figure 7.8 Ambient and Ocean Water Temperatures on Kumejima January 19-25, 2016 [17].

In the case of Kumejima, seasonal temperatures swings are quite large, with winter surface temperatures approaching 20°C [12]. Nauru's more stable seasons mean that even in the winter, Nauru will be able to achieve higher power output from similar water flows compared to Kumejima.

In terms of resilience to extreme weather, the NOAA's historical hurricane tracker lists 24 category 1 or higher storms within 60 nautical miles of Kumejima between installation of the intake pipe in 2000 and 2021. Nine storms were recorded since installation of the OTEC facility in 2013[16] as shown in Figure. Provided the intake facilities and OTEC facilities are adequately engineered, the track record on Kumejima shows successful long-term deployment of intake pipe and facilities, and an 8+ year track record for OTEC. For Nauru the same database shows no hurricanes going back to 1945[16].

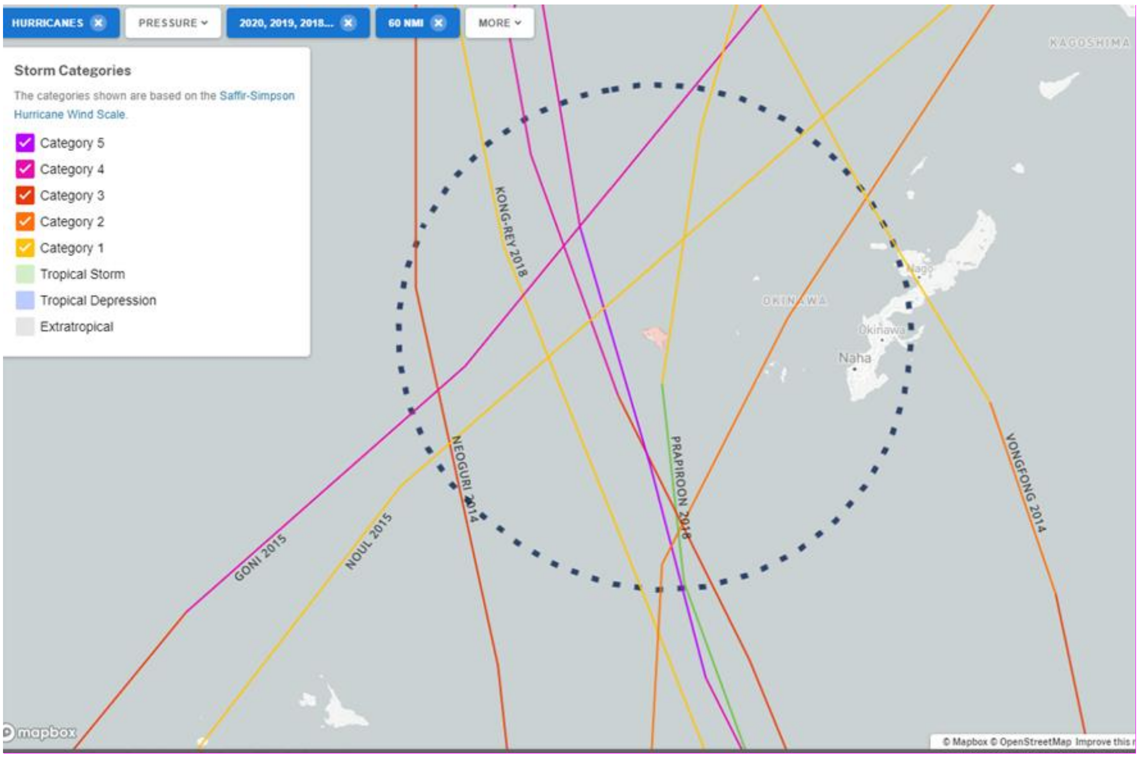


Figure 7.9 NOAA Historical Hurricane Tracks 2013-2020 for Kumejima[16].

While there is little risk from severe weather for Nauru, the ocean is still a difficult if manageable environment. Care must be taken when selecting the type of housing for the OTEC facility to ensure it matches its expected life cycle. Similar care to existing long-term power generation facilities should be sufficient. For the intake pipeline, local currents and wave action must be considered when determining installation methods to ensure safe long-term deployment.

8. Conclusion of technical analysis

8.1 OTEC and Industry Concept for Nauru

While the social, environmental, and economic situations on Nauru are different from Kumejima, the basic concept of multiple and cascade use applied for Kumejima is applicable. In the case of ocean water intake, as with other utilities, the water supply can be approached as a separate business, distributing water and maintaining infrastructure. The OTEC facility will support water temperature adjustments and power generation, while outgoing water provides a resource for downstream use.

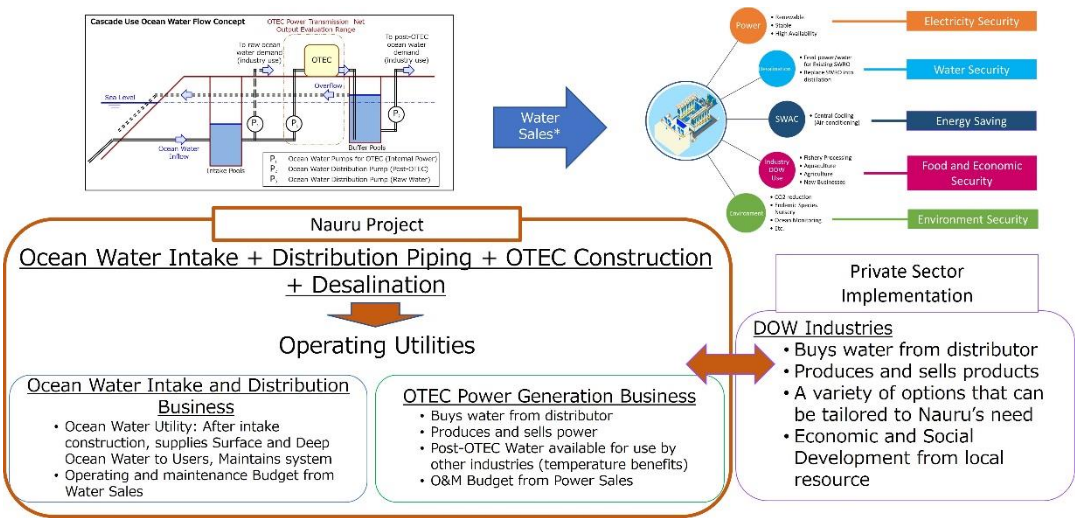


Figure 8.1 Nauru Project Concept

Specific DOW industries will require an organic development from established practices in Nauru along with entrepreneurial initiatives, however we have also summarized considerations in adapting a selection of industries to Nauru.

Based on the initial intake site selection described in section 3.3.2, local consultants surveyed the existing area, selecting two possible sites to implement an OTEC facility. Based on the size requirements determined for each portion of the facility, a site in the Aiwo District next to the Od-N-Aiwo Hotel was chosen for initial concept development. This site is a cleared piece of land with higher potential for agriculture and aquaculture compared to a site nearer the civic center. Figure 8.2. shows the proposed area with elevation overlays. In the nearshore environment, the elevation is less than 10m. Lower elevation areas will require less pumping cost to provide water resources. Within the ten to thirty meter elevation zone, there are unused or underutilized buildings that may be repurposed if provided ocean water resource. The area with elevation of thirty meters or more is not currently considered as sufficient opportunities at lower elevation are available, however, it may be considered for future agriculture or aquaculture development.

Figure 8.2. Aiwa District with Elevation Overlay

Figure 8.3. highlights potential areas nearby to the proposed OTEC site that may be incorporated into a “Nauru Model” of combined OTEC, Desalination, and DOW Industry development.

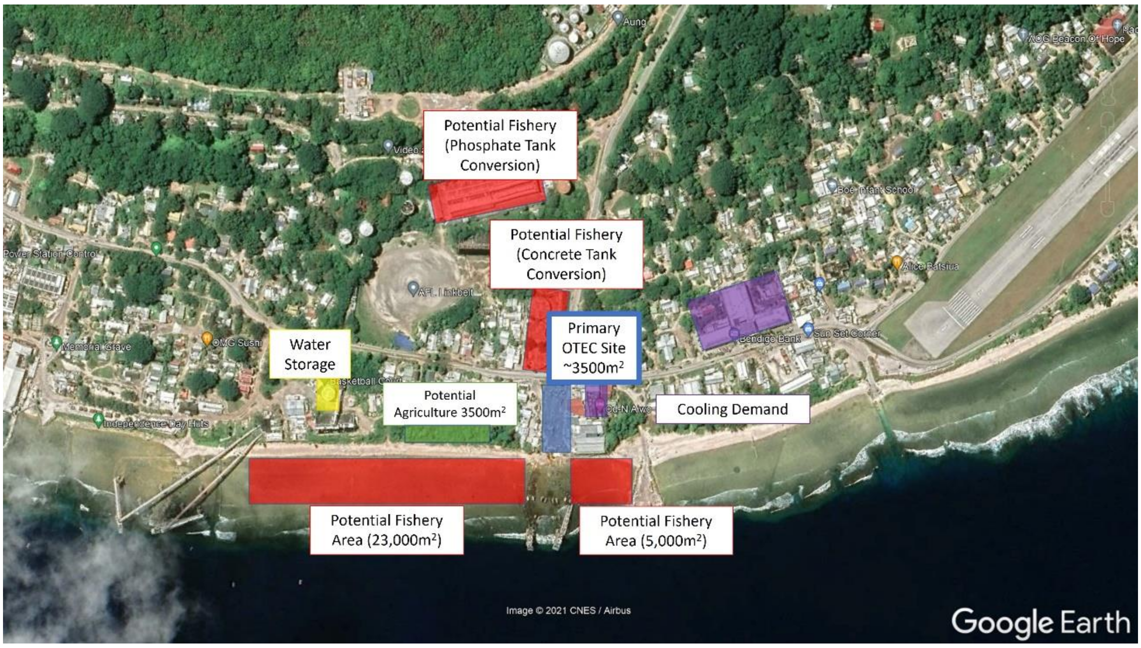


Figure 8.3. Potential Areas around Proposed OTEC Site for Nauru Model

Figure 8.4. illustrates how necessary equipment might fit into the local environment. Based on the plot plans (Figures 3.14 and 3.15) developed for the Nauru OTEC Facility, this site provides enough space. Section 8.2 will consider various applications given the site.

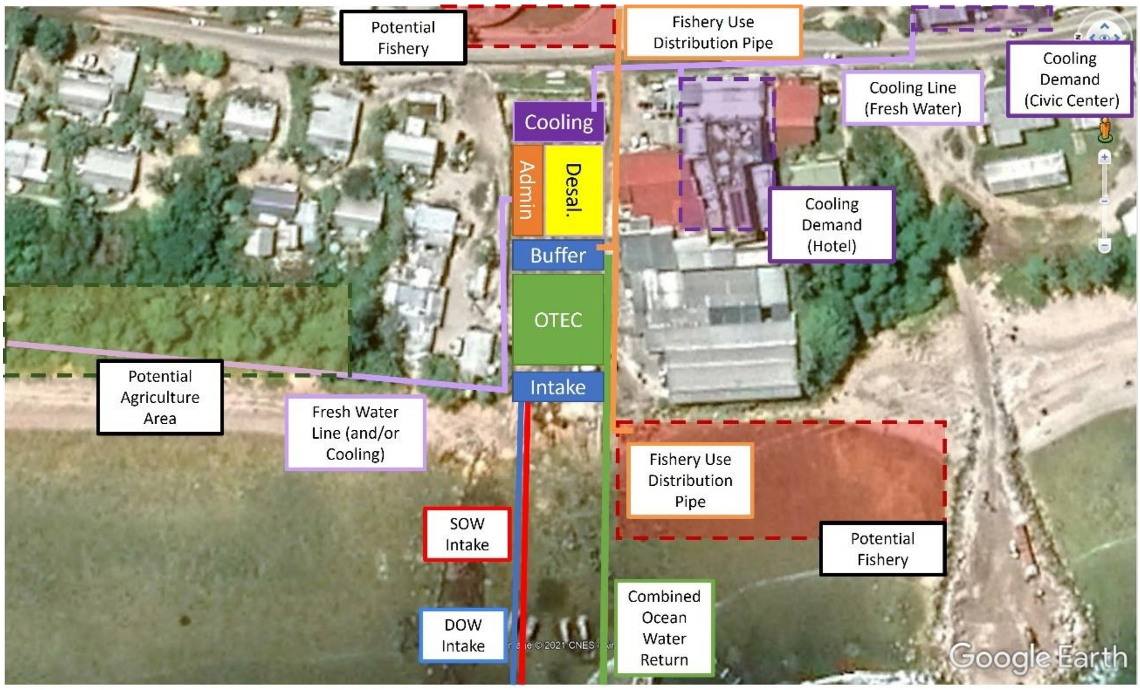


Figure 8.4. Potential Equipment Arrangement for Nauru OTEC Site

In terms of power generation, the proposed OTEC facility will be able to generate clean power with capacity factor near or exceeding 90%. This significant increase in baseload renewable energy will enable NUC to reduce oil imports and reliance on diesel generators, at a time when large-scale solar power generation will introduce challenges to grid stability. The spinning power source OTEC represents, will play a key role in stabilizing the Nauru grid towards meeting the renewable energy goals the Nauru Government has set.

8.2. Considering Adaptation of Various Industries to Nauru

8.2.1. Deep Ocean Water Cooling and Desalination

As noted in section 5, DOW Cooling can significantly reduce the electricity required for cooling. Such systems have been established in several locations around the world. In French Polynesia, two hotels have installed DOW Cooling [18] while a hospital in Tahiti commissioned a new system to cover its cooling demand in 2021[19]. Other examples include small-scale implementation at the Natural Energy Laboratory of Hawaii Authority (NEHLA), and a variation with lake water in Toronto and at Cornel University.

DOW Cooling is also known as Sea Water Air Conditioning (SWAC) or district cooling when using cold sources other than DOW. As with other renewable energies, one disadvantage of DOW Cooling is the higher initial cost from required infrastructure development, which is offset by lower energy costs. In addition, cold water will warm over time and distance through pipes, so proximity of large-scale buildings, or many small buildings with the need and ability to install new cooling equipment will be required. Distribution lines for the fresh water will need to be installed, which will be a significant initial investment, followed by low-cost and environmentally friendly cooling.

With the proposed desalination system providing fresh water, a single system may be used to both deliver cold water resources delivered through the potable water produced from LTTD. While a single LTTD system can meet all of Nauru’s current water use needs, a combined cooling and distribution system could significantly improve water security and availability, relieving water-related stress and increasing resources for alternative fresh-water activities such as agriculture.

For Nauru, implementation of DOW Cooling may significantly reduce energy produced through fossil fuels for cooling, while also providing a resource for expanded availability for cooling, increasing the productivity and comfort of nearby establishments. As the Nauru Utilities Corporation notes, “Extreme temperatures can increase demand for cooling, and the resulting increases in electricity demand can push up fuel and electricity cost.”

Figure 8.5. demonstrates nearby larger-scale cooling demand near the OTEC Site. As an initial step, a cooling distribution line of DOW cooled fresh water can be connected to both the nearby Od-N-Aiwo Hotel and the Civic Center. Examination of each building’s current cooling method will be required to understand the needs for conversion. This distribution line may be extended to serve large-scale cooling demand at buildings surrounding the airport. Smaller-scale buildings nearby may also benefit, however, the cost of converting to a cooling system capable of integrating with the line must be considered.

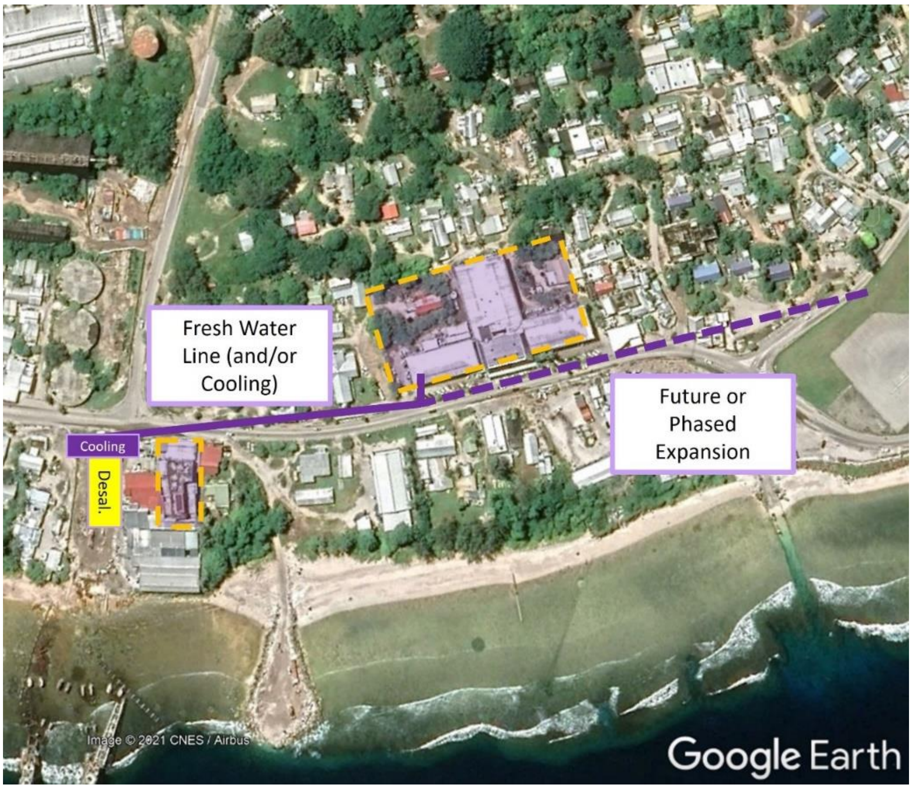


Figure 8.5. Suggested Initial DOW Cooling Line

Nauru’s limited size makes expansion of a DOW cooling system attractive, though it may be difficult and economically challenging to supply all of the island from one system. Still, it may be possible for an integrated infrastructure project to increase supply cooled fresh water for both potable, cooling, and agriculture use. Establishment of such a system would require further study.

8.2.2. Agriculture and Foodstuffs

There are several ways DOW and OTEC can contribute to development or diversification of Nauru's agriculture industry. On Kumejima, efforts have been made to utilize chilled-soil techniques to increase harvests and crop diversity. In addition, DOW may be applied to plant factory and aquaponic implementations. The space available near the OTEC site will be a primary driver of the scale of any agriculture implementation, as will water availability.

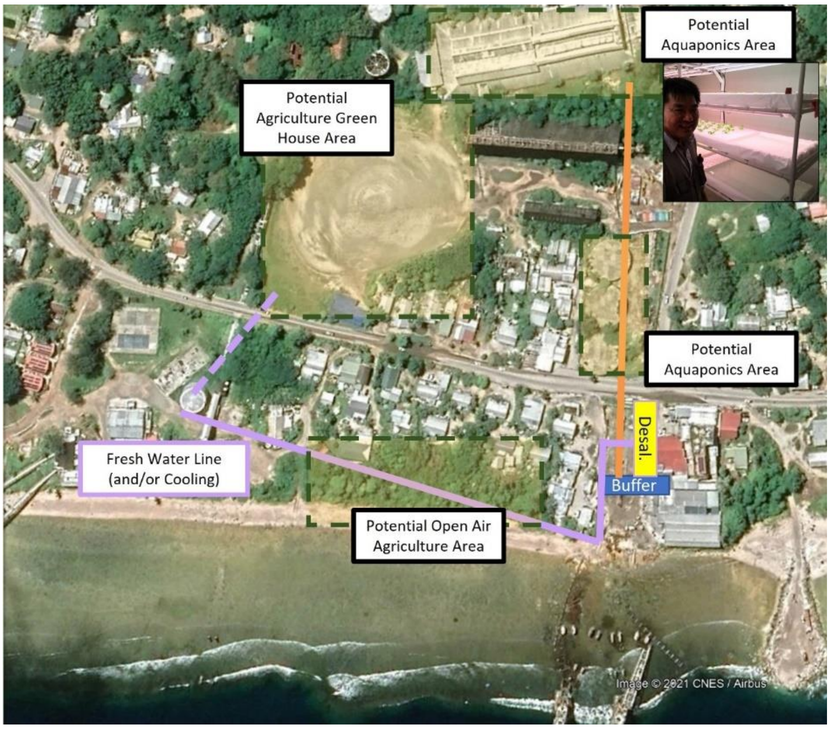


Figure 8.7. Agriculture Potential around OTEC Site

1) Chilled-Soil Agriculture

In chilled-soil agriculture, fresh water is chilled in a heat exchanger with DOW, this cold fresh water then travels through a closed loop system where it passes through beds or trays of soil (pipes embedded within the soil). Cooling plant roots allows some vegetables to grow out of season, allowing for year-round growth and in some cases higher yields. On Kumejima, Spinach was found to grow faster in summer months, with harvest after 1 month instead of the usual 1.5 to 2 months. In addition, heavier plants and even fruits may also benefit from such techniques.

Figure 8.8. Cooled-soil Agriculture Implementation on Kumejima

This type of agriculture requires some significant infrastructure, including the water chilling system and freshwater distribution to nearby farms. In the case typhoon mitigation measures are necessary, greenhouses can be constructed to house these implementations. A significant social advantage of the chilled soil agriculture is that raised beds may be used for some types of leafy vegetables, which can significantly reduce the strain from tending the crops. In addition, the ability to grow out of season, in some cases year-round, may significantly impact the sustainability of diversified diet.

In order to assess the potential for implementation, the area of land available for agriculture near the OTEC site as well as considerations of local food, greenhouse, and labor costs should be considered in a future study. In addition, if a SWAC system is established, the same facility may be able to supply cooled fresh water to both buildings and farms. In the case of the OTEC Site, a large open area near former Phosphate Drying Site may be partially adapted to open or greenhouse agriculture, while a near shore-area may also be utilized.

2) Plant Factory

Plant factories are generally fully enclosed environments with controlled light, water, and nutrients. While the initial cost is high, output quality is also generally high with significant reduction or elimination of pesticides. The potential for use with DOW comes from the reduction in cooling, electricity, and freshwater costs when integrated with OTEC. This technology has been established at sites in Japan and tested with DOW in Hawaii and Kumejima, but is at an early stage of development. Deployment for Nauru would require detailed consideration, however, the existing concrete oil tanks or Phosphate storage facility may be convertible to plant factory for significantly lower cost.

3) Aquaponics

Aquaponics may provide another agricultural alternative for Nauru in the future. Compared to a traditional aquaculture system, DOW can support low-cost temperature control and may also contribute nutrients depending on the salinity acceptable to the plants being grown. Aquaponic use of DOW is at an early stage of testing, but as with plant-factory, existing un-used or underutilized facilities nearby may be able to bootstrap development.

4) Bioreactor Production

Although under recent development on Kumejima, production of superfoods such as spirulina through a small-scale infrastructure project may significantly increase health and wellbeing through production of high-nutrient supplements from a small footprint. It is said that 1g of such phytoplankton-derived supplements can equal the daily nutrient requirements for one person. In a continuous system, as introduced in Figure 6.6. water loss through evaporation is limited, reducing necessary resources.

5) Storage Facilities

For produce storage facilities that rely on traditional cooling techniques, adaptation of SWAC-style technologies can reduce energy use and increase the resiliency and sustainability of the local food supply. As with SWAC, large scale cooling facilities using water circulation can be retrofitted to accept DOW cooled water. If such facilities are not nearby, when future installations are required, they can be designed with DOW cooling capabilities.

Figure 8.9. Fishery Processing Center on Kumejima with large-scale Freezer and Refrigeration Storage

On Kumejima the local fishery processing center is served with DOW which can be used to regulate temperature and process fish and sea plants for sale, transport, or storage. A facility of similar scale would require additional costs, however, the resiliency provided by a large-scale refrigeration and freezer facility would significantly impact food security.

6) Salt and Bittern Production

An additional product that may be produced directly from DOW or potentially from the discharge of a DOW-based desalination plant is salt. Any of the varieties of salt production from ocean water can be used with DOW. The advantage DOW has is the cleanliness of the initial resource, reducing the need for treatment. In addition, the issues regarding micro-plastics in the surface layer are diminished or eliminated for DOW.

As a byproduct of salt production, bittern can be made as a natural mineral supplement, or as an ingredient for tofu production, further increasing local food security. Salt Production can take place in various places nearby the OTEC facility.

8.2.3. Aquaculture and Fishery

While the primary use of DOW on Kumejima is for aquaculture, the vast majority of production is for the domestic export market. Nauru's location and existing shipping restrictions likely make it difficult to produce for export. There are, however, significant ways DOW can contribute to local fisheries, and may even support a gradual increase in production towards future export.

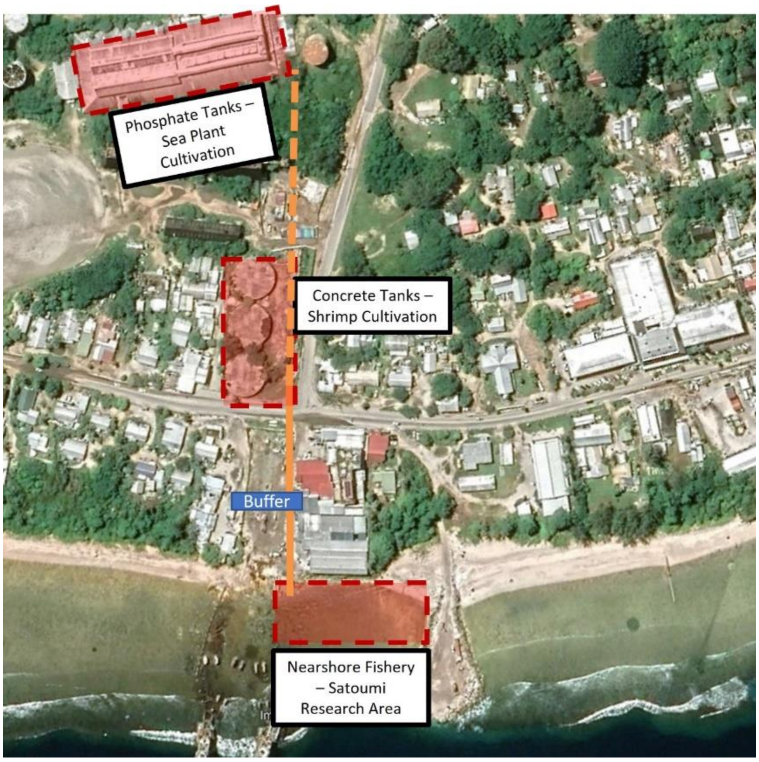


Figure 8.10. Fishery Potential near the OTEC Site

1) "Satoumi"

One approach to fishery for Nauru may be the "satoumi" concept, with DOW as driver for fishery and community development. The Japan Ministry of the Environment describes satoumi as "a coastal area where biological productivity and biodiversity has increased through human interaction [26]." While the overall concept includes increasing sustainable productivity and improving the environment, as a first step, a test area can be established in the nearshore environment.

Actual implementation methods can vary, however, creating a near shore pond would allow for a test area for gradual fishery development on Nauru.

Traditional Nauru pond farming may be applicable for testing with post-OTEC water nutrients and temperature control. In this way, a variety of species can be tested in a scalable approach. As the introduction to “Teachings of Satoumi” states, “Enhancing ecosystem function in the coastal sea by local people closely involving environmental protection and resource management [27].” Care with nutrient rich effluent must be considered, a combination with OTEC discharge may be applicable.

Implementation of the Satoumi concept with DOW would be a world-first approach to fishery, potentially applicable to other island nations.

2) Fishery Processing

One of the largest uses of DOW in Japan by number of implementations is for fishery processing. The cold, clean water can aid in low-cost preservation and preparation of catches, reducing loss in stock and energy use. The natural DOW resource can displace freshwater use at fish processing stations, increasing the water available for other uses. In addition, DOW may be used for ice production, further supporting preservation and reducing freshwater consumption.

The capacity of DOW use for Fishery will depend on the OTEC site and nearby facilities. It may also be used with a SWAC-type system to decrease cooling costs for fishery storage and processing facilities.

3) Fishery Nursery / Research

Another major worldwide use of DOW is for nursery activities. The temperature and cleanliness of DOW is a great resource for working with fish farming, breeding, and nursery activities. Depending on the local fishing methods, nursery activities can support endemic species cultivation, or be used to farm other species onshore. Small-scale aquaculture activities can take place in relatively small space with semi-portable tanks, allowing for gradual development.

Large-scale aquaculture activities would require significant infrastructure, space, and established distribution and market to be successful, or adaptation of offshore aquaculture techniques. DOW may also provide an opportunity to cultivate sea plants and algae for food, feed, or fertilizer use as well. As with agriculture, these initiatives may benefit from utilization of existing nearby infrastructure.

4) Effects on Offshore Fishery

There are no documented negative effects from OTEC to local fisheries, provided OTEC discharge water is handled in an environmentally friendly way. DOW is nutrient rich, which may encourage ocean life to converge near the outlet, a similar effect as a Fish Aggregating Device, however, this is dependent on many factors and in general, the outlet will be designed to limit any impact. During installation of the intake piping, the construction zone may be temporarily cordoned off, however, the impact will be limited and managed. After installation, there should be no effect on local fishing, however, the area where any sub-ocean piping is installed may be unavailable for some fishing practices such as trawling, etc.

8.3 Towards a "Nauru Model"

At its core, the "Kumejima Model" means adapting technologies to achieve sustainable self-sufficiency in water, food, and energy from local resources. As each community has its own needs and situation, an original concept is required to meet these critical goals. For Nauru, need goes past just reducing dependence on oil imports and achieving cleaner power generation. Water security and access to local resources for local development are basic necessities that every community should have access to.

The "Nauru Model," then, is focused on the most critical needs, energy and water, while also laying the foundation, access to deep ocean water, for organic and scalable development and adaptation of industry applicable to and by the people of Nauru. Kumejima's success has come from the participation and ideas of local people working together with experts and government to improve traditional methods and being new endeavors.

As a starting point for implementation in other regional communities with similar needs, Nauru provides a manageable scale for a first of its kind implementation of existing technologies combined in a new way to bootstrap islands quickly towards carbon neutrality and more resilient economic development. A future rigorous feasibility study of the potential identified here should outline a practical method of achieving a groundbreaking development opportunity, not just for the people of Nauru, but for many similar islands and coastal communities.

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II. Socio- Economic and financial analysis [A3.2]

1. Overall approach and methodology

1.1 Approach for the selection of the technology

Under this assignment, the ocean energy technologies identified have been pre-assessed and scored based on a Multi Criteria Decision Analysis (MCDA). This preliminary assessment enabled Nauru's NDE and the consulting team to identify the most relevant technology for Nauru and to maximize the results of the pre-feasibility study for the technology prioritized. In the second step, a pre-feasibility study, based on a list of criteria detailed in the following sections, has been implemented to assess the socio-economic feasibility and the financial viability of each ocean energy technology identified, and to identify the different financing options available for Nauru.

1.2 List of criteria for the multi criteria decision analysis and the selection of one technology

The introduction of ocean technologies in Nauru is supported by Nauru's lack of access to clean, stable energies, as well as Nauru's water scarcity challenge. The technology selected for the pre-feasibility study should thus best address those needs.

To achieve this, a Multi Criteria Decision Analysis (MCDA) has been used. A MCDA, or Multi Criteria Analysis (MCA), is a widely used decision-making analysis which evaluates multiple and sometimes conflicting criteria as part of the decision-making process. MCDA resembles a cost-benefit analysis, but it is easier to apply to decision making when comparisons involve non-monetary units such as environmental impacts of a project.

The MCDA focused on the following criteria:

Table 2 Criteria for MCDA

#	Category	Criteria
1	Potential for energy generation	Generation potential with the technologies
2		Stability of power generation
3	Electricity generation cost	Cost of electricity generation (xx$ / kWh)
4	Co-benefits	Availability of water
5		Agriculture and food availability
6		Reduction of fossil fuel imports
7		Other co-benefits (energy efficiency, development co-benefits)

The information required for the MCDA analysis is provided in section 3 of this report.

1.3 Components of the feasibility study

The overall objective of the assignment is to assess the socio-economic feasibility and the financial viability of the ocean energy technology prioritized, and to identify the different financing options available for Nauru. This is achieved through the delivery of three outputs, namely, (1) the identification of social and economic costs and benefits to the technologies; (2) development of the financial assessment on the viability and profitability of the technologies; and (3) suggestion of the financing options to develop the incoming feasibility study and to introduce the technologies in the country.

In this report, the ocean energy technology selected after the MCDA are assessed according to the criteria detailed in table 2.

Information used for the assessment have been sourced from publicly available documents (e.g. Nauru Energy Road Map), technical pre-feasibility study of the technologies and stakeholder consultations in Nauru. Based on the information, each technology was given a score from 1 (low) to 4 (high). The criteria have been pre-scored by the consulting team, and will be discussed during stakeholders' consultation with key stakeholders in Nauru. Weighting may also be considered depending on the materiality of each criterion for the technologies and the country.

The table below presents the list of criteria and sources of information.

Table 3 Criteria for the pre-feasibility study

#	Category	Criteria
1	Environment	Impacts on flora and fauna
2		Overall environmental impact
3		Waste management capacity
4	Social and economic	Increase of energy security and potential economic development
5		Impact on poverty reduction
6		Potential impacts of land acquisition
7		Increase of water security
8		Impact on agriculture
9		Impact on fisheries
10		Impact on other sectors - tourism and recreation
11		Social acceptance
12	Technical	Ease of construction, operation and maintenance of generation facilities
13		Resilience and durability of generation facilities
14		Reinforcement need of power grid and transmission network
15	Financial	Overall cost of construction (including plant and costs required to strengthen the grid)
16		Operation costs (Operation and maintenance, others)
17		Average amount of electricity generation

2. Pre-selection of one ocean technology

2.1 Potential for energy generation

At global scale, ocean energy has significant resource potential in theory. However, as shown in Table 3, each technology requires certain ocean conditions and therefore not all technologies are appropriate to Nauru. The ocean conditions applicable are tidal amplitude, tidal flow speed, wave height and temperature difference between deep and surface seawater. Considering these conditions, OTEC possesses the largest potential for energy generation among the three ocean technologies.

Table 4 Suitable ocean conditions and geological location for Tidal, Wave and OTEC technologies

	Tidal Energy		Wave Energy	OTEC
	Tidal range	Tidal stream		
Required ocean condition	Mean tidal amplitude should exceed 2.5 meters	Flow's speed to be at least 1.5 to 2 meters per second	Higher wave and strong wind are required	Temperature difference should be around 20 °C between deep and surface seawater
Stability	Not stable	Not stable	Not stable	Stable
Suitable geological location	Coast lines of continents (e.g. west coast of Canada)		Latitudes between 30 and 60 degrees	Tropical regions with latitudes between north and south 30 degrees
Compatibility with Nauru	Not compatible (Tidal amplitude in Nauru: below 1.5 m for 90% of the time)	Not compatible	Not compatible (Nauru's latitude: 0.5 degree)	**Compatible** (Nauru's latitude: 0.5 degree)

Nauru is one of the best locations for an OTEC plant, as it possesses an ideal temperature difference between deep and surface seawater, and as its nearby seabed has a steep inclination. [1] In fact, a small-scale and operational OTEC pilot plant was constructed in Nauru as early as in 1981 by a Japanese electric power company. Just like Kiribati where 1 MW OTEC plant is being built, Nauru theoretically has significant potential to generate electricity with a large-scale OTEC plant, even to the amount covering the whole electricity demand of the nation. However, the larger the generation capacity of a plant becomes, the higher the capital cost to deploy becomes. The next sub-section compares the costs of the three ocean technologies.

2.2 Electricity generation cost

The generation cost, or levelized cost of energy (LCOE) differs by technology. The LCOE depends on several factors, such as the capital expenditure cost (CAPEX), the operational expenditure cost (OPEX) and the potential production of energy. The annual energy produced from an array of devices is calculated based on two key factors – Capacity factor (or load factor) and availability. Increased capacity factor results in a higher Annual Energy Production (AEP) per kW installed.

The following sub-sections will detail the expected LCOE. To better assess the expected LCOE on the long-term, the LCOE will be assessed based on two scenarios: 1. The technology is still nascent and the project is one of the first projects for the technology (first array), 2. The technology is more mature, and more projects have been developed already (second array to commercial scale). The costs and LCOE have been identified in previous research. [2] For all technologies, data is available to some extent for a number of prototypes and planned projects. However, it covers a wide range of technologies as well as a wide range of technology readiness levels and scale. Cost ranges remain thus indicative.

1) Tidal energy

- **CAPEX**

Although tidal energy prototypes have already been launched around the world, such as in Europe, North America and Asia, most grid-connected capacity is located in the United Kingdom. Given the availability of such projects, CAPEX costs are relatively well identified for tidal energy. However, the infrastructure required for each of these projects differed. This leads to wide ranges of CAPEX costs. For example, the cost related to cabling depends on technological choices and different choices may be made for future commercial projects. First array CAPEX costs are estimated between 4,800 to 16,000 USD/kW. In the future, significant cost reduction is anticipated in the areas of installation, grid connection, and project development. This is in alignment with a move to larger arrays, and through process improvements as a result of learning by doing.

- **OPEX**

OPEX costs remain uncertain, as operation and maintenance (O&M) costs differ widely depending on the plant scale, technologies used, location and availability of relevant workforce in the location. The OPEX range for tidal energy is estimated at between 400 to 800 USD/kW for the first array, and may see significant reduction for commercial scale projects, between 200 and 400 USD/kW.

- **Annual energy produced**

Tidal energy capacity factor is estimated between 35 and 42 percent with an annual availability between 75 to 98 percent, with a mean availability increasing with the technology becoming more mature.

- **LCOE**

The LCOE ranges are diverse within the first array deployment, but clear convergence is seen across the tidal energy sector as progression is made towards commercial scale projects. For the first array, it is estimated at between 400 to 725 USD / MWh, while commercial scale projects are likely to achieve an LCOE of approximatively 200 USD / MWh. The breakdown of the LCOE is detailed in the following figure:

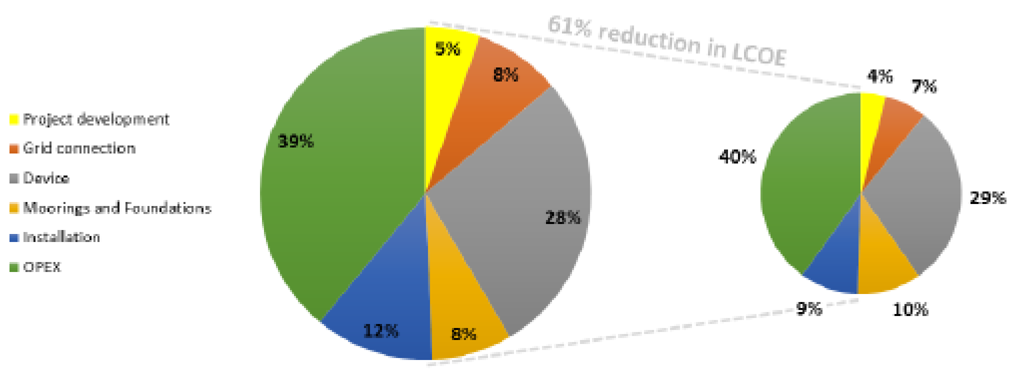

Figure 3: Tidal LCOE percentage breakdown by cost center values at current stage of deployment (Left) and the commercial Target (Right)

2) Wave energy

Full scale demonstration projects for wave energy are already available. The technology has been mainly implemented in the United Kingdom and Europe. As for other technologies, scaling-up wave energy is complex and requires more research and testing.

- **CAPEX**

There is significant variability of CAPEX costs for wave energy across the first pilot projects installed. Surveys conducted to developers also show a significant CAPEX cost range. This may be due to the readiness level of the technology. For first array projects, CAPEX cost could vary between 4,000 and 18,000 USD/kW. Significant costs reductions are expected once commercial scale is achieved, which could result in CAPEX costs between 3,000 to 7,000 USD/kW.

- **OPEX**

OPEX costs remain uncertain, as operation and maintenance (O&M) costs differ widely depending on the plant scale, technologies used, location and availability of relevant workforce in the location. As wave energy plants are located offshore, maintenance is by nature very costly. Current estimations for OPEX costs vary between 130 USD/kW/year to 470 USD/kW/year for first array projects, and may be reduced to 170 USD/kW/year to 380 USD/kW/year for commercial scale projects.

- **Annual energy produced**

The energy production will vary from technology to technology, depending on the geometry, PTO and control strategies. There will also be variation from site to site depending mainly on the resource levels and on the distance to shore and port. Wave energy is expected to have capacity factors of 25 to 35 percent for medium/high resource sites and up to 40% for high resource sites.

Capacity factors is expected to increase with the technology becoming more mature. Annual availability is ranging at 65 to 95% for the first array projects and is expected to reach 95% for commercial scale projects.

- **LCOE**

The LCOE ranges are diverse within the first array deployment, but clear convergence is seen across the tidal energy sector as progression is made towards commercial scale projects. For the first array, it is estimated at between 200 to 700 USD / MWh, while commercial scale projects are likely to achieve an LCOE of approximatively 120 to 480 USD / MWh. Differences can be explained by location and technology factors. The breakdown of the LCOE is detailed in the following figure:

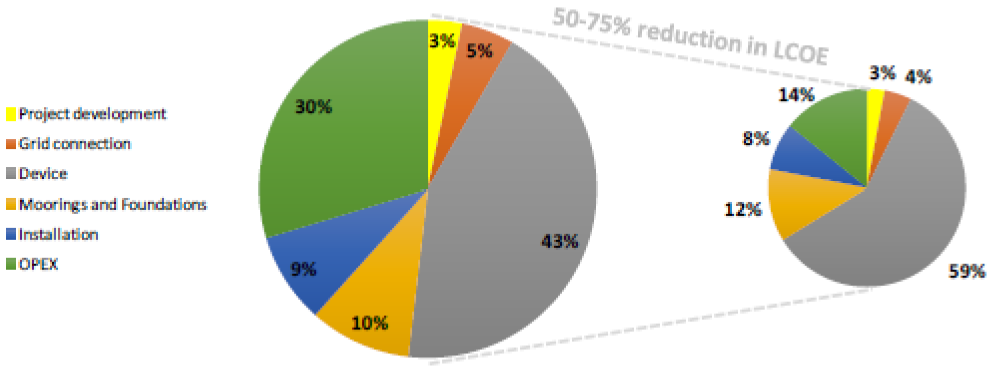

Figure 4: Wave energy LCOE percentage breakdown by cost centre values at current stage of deployment (Left) and the commercial Target (Right)

3) Ocean Thermal Energy Conversion (OTEC)

While OTEC technology is well-known, with several test plants producing power, larger scale plants are yet to be demonstrated. Most of the data available is thus based on technical studies rather than based on actual operational experience.

- **CAPEX**

There is a strong relationship between plant size and economies of scale for OTEC's CAPEX cost. This is largely due to the fact that the fixed cost in constructing an offshore platform and connecting a deep-water OTEC plant back to shore is a significant contributor to total cost. While shore-based OTEC plants have long been considered a stepping stone toward these deep-water platforms, the economics of bringing deep-ocean cold water to shore is in most cases cost-prohibitive.

At small-scale (1 to 5MW), CAPEX costs are estimated between 35,000 to 45,000 USD/kW, while at larger scale (10MW), costs fall at below 25,000 USD/kW.

- **OPEX**

OPEX costs remain uncertain, as those are mainly based on a CAPEX and will most likely depend on other factors as well. OPEX costs are estimated at between 4 to 5 percent of the CAPEX costs, and remain relatively constant across plant sizes.

- **Annual energy produced**

OTEC provides a largely constant power output. As OTEC power production is based on the availability of cold water, there may be some slight variations between seasons, reflecting seasonal changes in surface water temperatures. Typical values for the capacity factor range from 90 percent to 95 percent.

- **LCOE**

The LCOE changes dramatically according to the size of the plant. For plants smaller than 5MW, OTEC's LCOE is estimated at more than 600 USD/MWh. For larger plants, this may fall at approximatively 200 USD/MWh (for a plant of 100MW). As explained above, this is mainly due to the cost of the offshore platform.

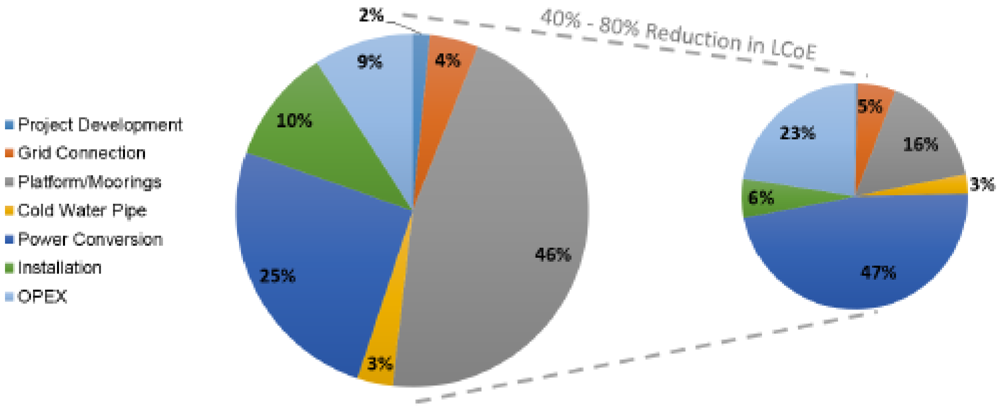

Figure 5: OTEC LCOE percentage breakdown by cost centre values for 5MW plants (Left) and 100MW plants (Right)

Some of those costs may be offset by the by-products provided by OTEC, such as water.

4) Conclusion for the cost

At commercial stage, wave energy and tidal energy are expected to be the most affordable. However, in the next few years, both technologies should remain in the costs provided for the first array and be equivalent to OTEC.

Although OTEC is the most expensive at the production scale expected for Nauru, it also provides an important range of co-benefits, which revenues and economic benefits have not been considered as part of this section.

2.3 Co-benefits

Ocean energy technologies bring several co-benefits and by-products. Those are detailed in the following sub-sections.

Aquaculture

Fisheries is an important industry in island states, either for their national consumption or for exports. However, overexploitation and climate change may reduce the volumes of fish available for commercial fishing. This will have significant consequences on livelihoods, food security and economies. Aquaculture is a way of domesticating and controlling the growth of ocean species. However, it requires energy to power circulation, fish feeders and waste disposal. It also needs power for its infrastructure such as sensors, cameras and lights, and for monitoring and maintenance equipment.

While aquaculture has been implemented near shore, it is also possible to conduct it offshore to facilitate scaling up and economies of scale. Energy needs to be brought to aquaculture platforms in this case. Wave energy is the best adapted ocean energy technology for agriculture, as it is often implemented as an offshore floating structure.

Given that ocean energy is often implemented offshore, As the mooring systems are complex and are currently responsible for roughly 10% of a wave energy converter's capital expenditure, sharing the mooring with aquaculture could reduce these costs by up to 50%. [3] OTEC is well suited for aquaculture as well, as its waste cold water contains valuable nutrients that can be leveraged for fisheries.

Desalination

Fresh water is very scarce in Nauru. Droughts already impact the country heavily in terms of water availability and climate change is expected to exacerbate those impacts. The country already relies heavily on desalination for its fresh water production capacity. Desalinating seawater has become a common practice to produce potable water. Desalination is a process of removing salt and other unwanted content from seawater to provide fresh water for human consumption or agriculture.

Reverse osmosis is the main process of desalination. The process of pressurizing water to direct it through a membrane against its natural flow is energy intensive. About 36% of the operating expenses in a seawater desalination plant come from its energy consumption. A clean energy source is thus essential to provide a continuous supply of fresh water while at the same time limiting additional emissions from the energy sector.

This can be achieved with ocean energy technologies. All technologies provide energy output that be used for desalination. However, ocean energy technologies can be leveraged more efficiently than other sources of clean energy for the desalination process. For example, wave power plants that have their power take-off units on shore deliver high-pressurized water to shore by default. This water can be reused for desalination. Another way to use ocean energy for freshwater production is being evaluated where the step of generating electricity is skipped altogether as pressurized seawater is directly delivered to the reverse osmosis cycle, instead of producing energy. Like wave energy conversion, OTEC also moves water to shore. Depending on the OTEC process, fresh water is produced as a by-product from evaporated warm seawater or it can be obtained through both evaporation and condensation.

Efficient cooling

Cooling is also an energy-intensive process. A majority of cooling technologies are inefficient. Seawater air conditioning (SWAC) can provide efficient cooling and reduce electricity output needs. It is a concept that uses cold water from the depth of the ocean as the refrigerant fluid to cool a freshwater distribution system by means of heat exchangers.

The water that is used in the electricity generation process of OTEC can be re-used in an air conditioning system as post-OTEC deep ocean water is still sufficiently cold for re-use.

2.4 Scoring of ocean technologies in MCDA

This section provides the scoring result of ocean technologies identified based on the introduced MCDA criteria in the previous section. The technologies are scored on a scale from 1 (low) to 4 (high) in each criterion. Each technology can score from 6 (lowest) to 24 (highest).

In terms of generation potential with the technologies, Nauru is a good fit for OTEC plants, having access to ocean with ideal temperature difference between deep and surface seawater. However, Nauru does not have the conditions aligned with the ideal specifications for tidal and wave energy generation.

The stability of power generation is scored based on the capacity factor. Acknowledging that the capacity factor varies depending on the specifics of the site, control strategies and technology development among others, the range of capacity factors for a technology provides a referencing point to compare the three technologies. The capacity factor of tidal is estimated 35 to 42 percent, wave is 25 to 40 percent, and OTEC is 90 to 95 percent. OTEC is the most stable and is ranked the highest on this criterion.

As already discussed in the electricity generation cost section, the cost range of LCOE is provided to each technology under two scenarios. The first array is the cost range when the technology is still nascent. The second array is for the case when the technology is more mature and commercial scale. For the first array, LCOE of Tidal, Wave and OTEC are respectively between 400 to 725 USD/MWh, 200 to 700 USD/MWh, and more than 600 USD/MWh for plants smaller than 5MW. For the second array, these are 200 USD/MWh (Tidal), 120 to 480 USD/MWh (Wave) and 200 USD/MWh (for an OTEC plant of 100MW). Therefore, Wave scores the highest and OTEC scores the lowest score for the LCOE criterion.

Regarding co-benefits, while both Wave and OTEC have potential to produce co-benefits in aquaculture and desalination without additional large-scale investments, Tidal is not expected to have such benefits. Wave and OTEC are thus scored the highest for this criterion. Since OTEC extracts cold water from deep ocean and the water can be used for cooling on land, only OTEC is anticipated to generate co-benefits in efficient cooling. However, it is important to mention that the SWAC technology requires investments in infrastructure to some extent outside of the OTEC plant. Hence, OTEC gains high score and other two technologies attain the lowest score.

In conclusion, OTEC ranks the 1st at the overall score, followed by Wave and Tidal.

Table 5 Scoring summary

#	Category	Criteria	Tidal	Wave	OTEC
1	Potential for energy generation	Generation potential with the technologies	1	1	4
2		Stability of power generation	2	2	4
3	Electricity generation cost	Cost of electricity generation (LCOE)	3	4	2
4	Co-benefits	Aquaculture	1	4	4
5		Desalination	1	4	4
6		Efficient cooling	1	1	3
		Total Score	9	16	21

Based on this assessment, OTEC is chosen as the preferred technology for the pre-feasibility study.

3. Pre-feasibility study

This section provides the details of the pre-feasibility study for OTEC. The objective of the pre-feasibility study is to assess the socio-economic feasibility and the financial viability of OTEC and to provide information for the identification of the financing options available for Nauru. The pre-feasibility study consists of four major components; environmental aspects; social and economic aspects; technical aspects; and financial aspects. Each sub-section below provides the summary of these four components.

3.1 Environmental aspects

Impacts on flora and fauna are evaluated in this sub-section. OTEC technology requires installation of artifacts both on land and in the ocean. The technology utilizes the temperature difference between the sea surface water and the deep seawater – generally at depths below 1,000 meters for electricity generation. The power plant and turbines are planned to be constructed on land, where some levels of environmental impacts on terrestrial flora and fauna during the construction and operation are expected. Ocean Water Intake pipes will be required to intake and discharge ocean water. Studies have shown minimal impact to marine flora and fauna depending on the method of installation and discharge.

Overall environmental impact and waste management capacity are also assessed in this sub-section. The possibility of contamination during the construction and the operation, construction waste and material waste management capacity are detailed below.

Impacts on flora and fauna

The terrestrial and marine ecosystems in Nauru have limited diversity. [4] Several factors are considered as drivers of the island's limited biodiversity including geographical isolation from other Pacific chain of islands, expansion of monocultural plantations, and the decades long open-cast phosphate mining.[5]

Although "the indigenous flora and vegetation of Nauru can be regarded as among the poorest and limited in the world",[6] globally rare species exist in Nauru, as details in Table 5.

Table 6 Rare, threatened, or endangered species in Nauru

#	Category	Name of species	Local name	Description
1	Some of the rare plants	Aidia racemosa	Enga	Limestone forest tree, close to extinction
2		Bruguiera gymnorrhiza	Eõm or etam	Mangrove tree that purifies the water around the anchialine (ponds) where it grows
3		Cerbera manghas	Dereiyongo	Important coastal tree, which is now found only in a few locations in the main settled areas
4		Cordia subcordata	Eongo	Forest tree, probably rare because of the 30% of coastal habitat on the island. The timber is highly valued
5		Erythrina variegata	Eora	Forest tree. Rare due to past removal and loss of forest habitat
6		Hernandia nymphaeifolia	Etiu	Coastal forest tree. Timber was prized for canoe hulls in the past
7		Ochrosia elliptica	Eoerara	Attractive small tree with bright red fruit. Good shade tree.
8		Pisonia grandis	Yangis	A forest tree which is the main rookery species for noddy birds and found mainly along the upper escarpment
9		Thespesia populnea	Itira	Forest tree. Considered the best wood for construction and carving. Also one of the best trees for coastal replanting activities
10		Tournefortia argentea	Deren	Important tree for coastal and beach protection and one of the most important medicinal and multipurpose plants on Nauru
11	Rare, threatened, or endangered terrestrial animals of Nauru	Frigate bird	Fregata spp	Noddy species are both in global decline but Nauru could be a stronghold for these species
12		Nauru reed warbler	Itsirir	Rare species of birds
13		Micronesian black skinks	Emoia arnoensis nauru	New undescribed species
14		Nauru tidal rock bug	Corallocoris nauruensis	Newly discovered micro-moth leaf miner
15	Rare, threatened, or endangered marine species of Nauru	Giant clams, corals, sea turtles		Globally threatened species are all found in Nauru
16		Humphead wrasse	Cheilinus undulatus	Listed in the IUCN Red List of Threatened Species
17		White tip reef shark	Triaenodon obesus	

To conserve these rare species and surrounding ecosystems, actions such as setting priority terrestrial and marine sites for conservation have been proposed. Figure 6 shows the priority sites considered for conservation. The technical analysis of this project suggests potential sites for the OTEC plant in Nauru. Some of the suggested plant sites are close to the priority, however, the selected site is not near a conservation site. The plant will require the installation of large pipes, buried in the near-shore environment. The construction phase could damage coral species, however, mitigation and restoration is possible. Detailed environmental risks brought by the plant on rare species and the ecosystems needs to be comprehensively assessed in a full-fledged feasibility study.

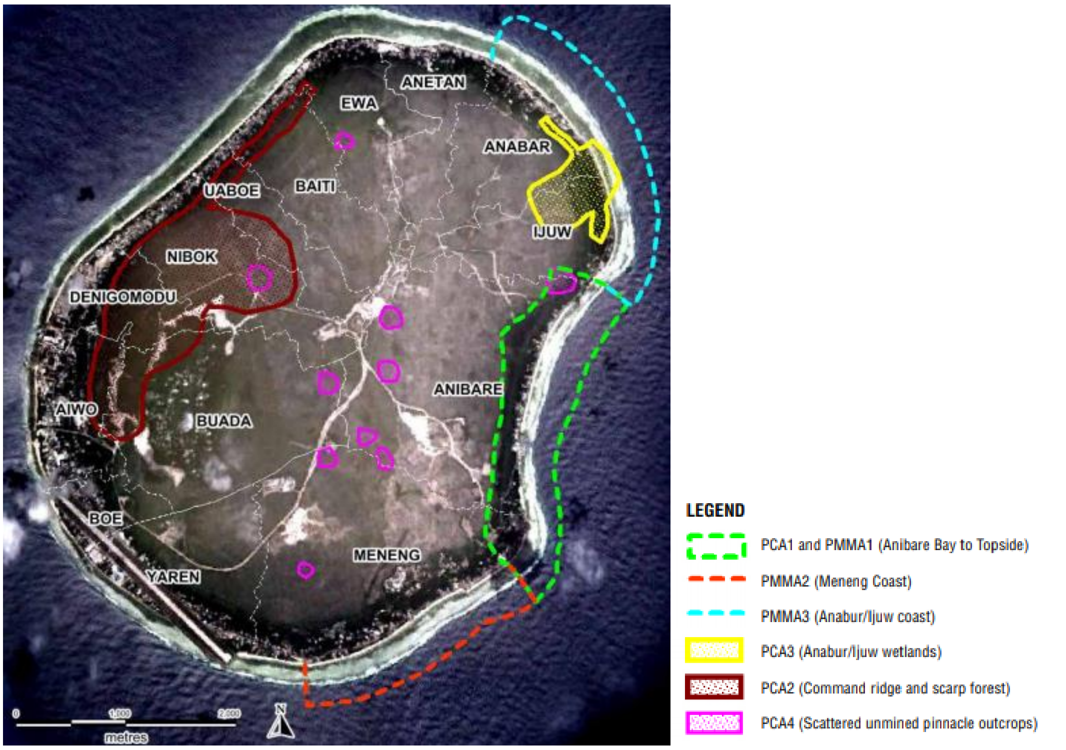

Figure 6 Priority terrestrial and marine sites

Overall environmental impact

Since the construction and operation for a typical OTEC plant do not involve the use of hazardous equipment or chemical materials, the level of air quality disturbance and noise as well as the risk of contamination are expected to be within typical levels of other construction and similar plants. In addition, the construction works are expected to be performed indoors. Therefore, the air quality and noise level are not expected to be significantly be disturbed. However, wastewater and any potential agent of water/soil contamination require proper treatments during the construction and plant operation.

The transportation of construction materials and workers is expected to impact air quality and noise pollution in the communities along the access roads. Especially when using unpaved road, some level of resuspended dust in the air should be anticipated during passage of vehicles. However, the dust resuspension, vehicle emissions, and noise from these vehicle movements are not expected to cause significant levels of environmental disruption nearby communities.

Waste management capacity

Construction waste are likely to be disposed to a landfill managed by the Nauru Rehabilitation Corporation (NRC). The primary mission of NRC is to rehabilitate land destroyed by the phosphate industry. NRC provides waste management services for municipal and industrial waste by utilizing dumped holes created by the mining industry. However, the nation's waste management practices have been lacking for decades.[7] Solid waste management is a key priority in the National Sustainable Development Strategy (NSDS) 2005–2025 and the government has been working on a three-year project to strengthen the country's institutional capacity with the help of the UNEP's Chemicals and Waste Management Programme since 2019.[8] Stricter waste management practices may be enforced to the construction wastes of the OTEC plant after institutional capacity has been strengthened.

The detailed amount of waste will have to be determined during the feasibility study or the detailed engineering design phase of the project. The OTEC plant will serve a useful life of 40 years. After serving its useful life, the turbine, large industrial scale pumps among others would have to be replaced and recycled or disposed of otherwise.

3.2 Social and economic aspects

The OTEC plant is expected to bring multiple social and economic benefits to the nation. The plant is supposed to increase the reliability of electricity supply, which could potentially boost economic activities in the nation. The impact on the island's economy is expected to be wide, including on the cost of electricity for households as well as on macroeconomic indicators such as the rate of population below poverty line. Similarly, co-benefits of the OTEC plant have wider implications not only in increasing water security but in other key sectors including agriculture and fishing. At the same time, the plant could also bring negative impacts on key sectors and provoke negative attitudes from local communities towards new technology such as OTEC. This sub-section summarizes these socio-economic aspects of the OTEC plant.

Increase of energy security and potential economic development

Along with water insecurity, energy insecurity is one of the major sources of vulnerability in Nauru. Energy generation is almost solely dependent on fossil fuels and all the fuels are imported, which means the nation's energy security is susceptible to the price volatility of the international oil market. A large part of the imported fossil fuels are used for the electricity generation. According to the Nauru Energy Roadmap 2018-2020[9], Nauru imported 25.81 million liters of fossil fuels per year in the fiscal year of 2016-17. 9.44 million liters of diesel or 37% of the total imported fuels was used for electricity generation by the Nauru Utility Corporation (NUC) which is the government-owned utility responsible for public electricity and water. 7.44 million liters of diesel or 29% of the total imported fuels was consumed in the retail diesel market and a part of the sold diesel was used for electricity generation by other organizations such as RONPHOS or the phosphate company and the Australian Government's Regional Processing Centres (RPC). The rest proportion of the total imported fuels was used for transport and other activities in the category of retail petrol and aviation. Table 6 summarizes the amount of Nauru's annual fossil fuel imports and its breakdown in 2016-17.

Table 7 Nauru's annual fossil fuel imports in 2016-17

Category	Amount (million liters)	Proportion
NUC diesel	9.44	37%

Retail diesel	7.44	29%
Retail petrol	4.10	16%
Aviation	4.81	19%
LPG	~0.02	0.1%
Total	25.81	-

Expanding renewable energy production is the key strategy for the Nauru Government to achieve its sustainable development by lowering its vulnerabilities, as well as to achieve its climate commitments. In 2014, the government set the energy target as 50% of grid electricity supplied from renewable energy sources by 2020 [10].

However, as of the year 2021, most of the electricity is still generated by diesel power plants. The total renewable energy delivered to the grid during this period was 992 MWh, which represents 2.7% of the energy provided to the grid[11]. In order to achieve the 50% target, way more generation capacity of renewable energy is required and the generated electricity needs to be available for end-users. Considering the relatively low cost and the short period of installation, the government views the solar PV as the main driver to reach the 50% target [12].

The 50% target is now to be achieved by 2030 and the government has another target to achieve 100% of renewable energy by 2050. Nauru expects installing more renewable energy will lead to fewer fossil fuels imports and improving energy security.

Increasing solar PV electricity generation is regarded as the priority measure to achieve Nauru's objectives. However, alternative measures to generate and/or store electricity are required, as solar energy is variable. Therefore, either battery energy storage system or non-variable-susceptible renewable energy sources are essential to realize the renewable energy targets and at the same time reliable electricity supply. Although combining solar PV and battery storage technology is considered as effective approach to supply clean and reliable electricity, thigh battery costs are a significant bottleneck. The technology needs assessment for Nauru mentioned the risk that power generation through solar and battery will become more expensive than power generation through diesel generators if batteries do not achieve significant cost reductions.

As already discussed at the previous section, the OTEC is not susceptible to weather conditions and benefits from a high stability in its electricity generation. The electricity supply by the OTEC will not be influenced by the price volatility of the international oil market. Although OTEC's electricity generation cost is not as low as solar PV, it supplements solar PV due to its stability. Furthermore, various co-benefits are expected in the OTEC including increasing water security.

If the reliability of electricity supply increases with the OTEC plant, the electricity demand may be stimulated. While some large organizations including RONPHOS and RPC generate the electricity on their own with captive capacities, clean and reliable electricity supply may be attractive to them. In addition, new industries might be created based on the availability of new energy sources, such as green hydrogen generation and aquaculture among others. The new port, which is expected to be completed in the next few years, may also enable the installation of new industries and players, attracted by a stable supply of energy. New industries are likely to bring economic development, which potentially leads to further electricity demand increase. The potential economic effects of the OTEC need to be assessed in a full-fledged feasibility study.

Impact on poverty reduction

It likely that the OTEC plant will have a long term impact on poverty reduction. The number of jobs created during the construction and operation of the plant is expected to be limited. However, the increased reliability of electricity supply and various co-benefits of the OTEC is likely to benefit low-income and vulnerable groups through improved energy security, the development of new industries and increased economic opportunities. In the construction and operation phases, measures could be taken to enable the participation and empowerment of the low-income and vulnerable groups.

Tackling poverty is included to the 17 policy objectives in the NSDS 2019-2023 Medium Term Strategic Framework[13]. The government committed to reduce poverty by, among others, "Lowering the share of the population below national basic needs poverty line". A quantitative policy target was also set, with Nauru aiming to decrease the proportion of population below the basic needs poverty line from 24% in 2012/13 to 10% in 2037.

24% of the population of Nauru (16.8% of households) were living below the basic needs poverty line according to the most recent survey in the country (2012 and published in 2013)[14]. Although food poverty was not raised as an issue and access to basic infrastructure such as electricity, water, housing among others was assessed as secured, it is important to emphasize that electricity and water needs are mostly based on fossil fuels, which are imported. Volatility and prices and in supply are significant factors of vulnerability. The OTEC plant is likely to alleviate this.

The report also identified that women, young adults and children as vulnerable groups. Since subsistence fishing provides supplementary protein for many households in Nauru including the poor and vulnerable groups, the potential impact on fishing by the OTEC plant needs to be carefully assessed in the succeeding phase of this project.

The OTEC plant is expected to have the limited direct impact on job creation. The number of temporary jobs created will be roughly 50 during the period of construction for 18 months. The operation phase will require less workers. Although the required number of workers depends on operation standards adopted, the number is expected to be 10 for the roles including direct OTEC and deep ocean water (DOW) intake operations, administration, and maintenance. Additionally, the construction phase will require experienced and skilled supervisors and the operating phase is likely to require some specific expertise as well. While the reopening of the RPC in 2012 created a shift by some from government to higher-paying jobs, such shift will not be seen in the OTEC plant project due to its limited number of involving workers and the required expertise. It is likely that some of these skills will need to be sourced from other countries for the construction phase.

Potential impacts of land acquisition

Based on the technical pre-feasibility study, 900 m2 of land will be required for the OTEC plant on land. This does not include additional intake and distribution facility space, and space under the seabed for pipeline installation. Since the final construction site has not yet been determined, ownership of the land for the site will need to be confirmed during the full-fledged feasibility study. The land acquisition process must be carefully monitored so as not to cause any involuntary resettlement nor physical and economic displacement due to this project.

Increase of water security

Post-OTEC ocean water can produce fresh water as a by-product. A 1MW OTEC plant's capacity can generate 1,000kL/day.

Apart from the water desalination, rainwater and poor-quality groundwater are the sources of fresh water. Whereas the average precipitation is 2,080mm per year, periodic droughts are serious challenges to water security in Nauru. In the driest year recorded, the annual precipitation dropped to only 280 mm [15]. Droughts can last as long as three years and climate change brings further uncertainty to the precipitation pattern of the island. In some locations, groundwater is available but contaminated and not appropriate for drinking. Its main use is for showering, washing, toilet flushing and for lawn and garden irrigation. Prolonged droughts also cause a lowering of the underground freshwater lens, bringing further difficulties in accessing the groundwater. Therefore, the practice of rainwater harvesting from rooftop catchments is widely adopted in the island and it is effective during wet seasons. However, heavy reliance on rainwater to meet water needs is risky especially during droughts or dry seasons.

Hence, Nauru runs five reverse-osmosis units to produce desalinated water. The responsible entity for operation is NUC. The technology needs assessment conducted in 2020 calculated that the total water production capacity of Nauru’s five reverse-osmosis desalination plants is 2,380kL/day. Considering this total capacity, the amount of fresh water that could be supplied by the OTEC plant may have significant impact on water security. When the desalination units are operating at full capacity, the theoretical water production capacity per capita is equivalent to approximately 200L/day. Since the WHO optimal level of water access to eliminate health concerns is 100L/day, the water supply volume itself is not so problematic as long as the production capacity is maintained.

However, as the water desalination is energy intensive, water security In Nauru is closely linked with energy security. The NUC produces about 70% of potable water and distributes for commercial and domestic use in the country. According to the report by IRENA in 2013, the desalination plants consumed around 30% of the electricity generated by the NUC in 2008. If the same ratio is applied to 2021 figures for electricity and fuel use, the amount of electricity used for the desalination would be 13 GWh and the amount of diesel would be 3 million liters each year.

Thus, desalination of salt water is an expensive option for Nauru and susceptible to supply and price volatility of the international oil market. In summary, the positive impact of the OTEC plant is not limited to the mitigation of greenhouse gases emissions but the significantly improved energy and water security.

Impacts on agriculture

Agriculture is a priority sector in Nauru for sustainable development, especially in the context of improving nutrition and food security. One of the key policy objectives is to increase the value of domestic agricultural and livestock production. Nationally cultivated agricultural products are fruit trees including coconut and breadfruit, horticultural products including fruits and vegetables and livestock including poultry and swine.

However, agriculture in Nauru is quite challenging due to three barriers: limited land availability, poor soil fertility and limited access to water. In meeting the national demand, commercial agriculture is not efficient enough. Insufficient local supply leads to the importation of the majority of agricultural commodities from Australia and Fiji. Regarding the first and second barriers, the small island nation inherently lacks abundant agricultural land availability and key elements of soil particularly nitrogen and potassium. Decades-long of open-air mining worsened these challenges. As a result, the available areas for agriculture lie in the narrow coastal belt and the land surrounding Bauda lagoon [16]. To solve these barriers, the government and development agencies have endorsed the use of fertilizer and composting as well as the expansion of aquaculture opportunities.

For water scarcity, the OTEC plant is expected to contribute to lighten the burden by providing fresh water. Since fresh water has been scarce in Nauru, human consumption has been prioritized compared to agricultural use. Contaminated brackish water has been used for agriculture to compensate for water scarcity. Once the OTEC secures certain amount of fresh water for human consumption, the quantity and quality of water for agriculture could also be improved, which will have positive impact on agricultural production.

Impacts on fisheries

Fisheries is also a priority sector for sustainable development due to its contribution to nutrition, food security and economy. For example Nauru collected 73 million USD or roughly 30% of the total national annual revenue in 2019/20 as license fees for foreign fishing boats fishing in the substantial EEZ [17].

Despite its importance for the economy, fisheries do not have consistent production statistics. In addition, the style of measurement and the categorization are not unified. Therefore, recent studies only present indicative estimated figures. In a study from 2014 conducted by the Pacific Community, fishery and economic studies published over two decades were examined to provide estimates. Considering the fact that no fisheries statistical system in Nauru covers the whole range of categories, some categories such as aquaculture and coastal subsistence are likely to be underestimated owing to their minor volume and non-economic nature of the activities. Table 7 summarizes the annual fisheries production in Nauru waters estimated in the study by the Pacific Community [18].

Table 8 Fisheries production estimate in Nauru waters in 2014

Category	Volume (tons)
Aquaculture	0
Freshwater	0
Coastal commercial	163
Coastal subsistence	210
Offshore locally based	0
Offshore foreign based	177,315

Marine fisheries have two distinct components; offshore and coastal. While offshore fisheries are dominated by foreign-flagged vessels, coastal fishing is operated for subsistence purposes and for sale in local markets. The primary target of the offshore fisheries are skipjack and yellowfin, which are intended for foreign canneries. With regard to coastal fishing, there are some commercial fishing, but mostly on a part-time scale. Fish catches are sold only when there is surplus after meeting subsistence needs. The fishing methods differ depending on fishing areas from trolling in the nearshore pelagic waters to cast nets and cast nets in the reef flat, reef crest and surf zones [19].

The potential impact of the OTEC plant is expected to be more significant to coastal fishing if proper damage mitigation measures are not taken. Depending on pipe installation, the pipe may affect dredging if used. Additionally, the OTEC plant will intake and discharge large amount of surface sea water and DOW. In the case of a 1MW size plant, the volume of surface water used is about 240,000m3/day or about 180,000m3/day for DOW. Although the temperatures of surface water and DOW are different (surface: 27.8 degrees Celsius, DOW: 5.9 degrees Celsius), it is possible to discharge water at the same temperature as the surrounding water of the discharging sea zone. In other cases, (100kW OTEC plant in a Kumejima, Japan), the discharge water is returned offshore at 25m depth to limit water temperature variability. As DOW may stay or stagnate near reef if released, DOW is discharged past the reef at a deeper depth. There are no documented negative effects from OTEC to local fisheries in Japan. It is likely that such mitigation practices should be adopted by the plant in Nauru. In light of the significance of the coastal fishing for the Nauru economy and society, further environmental impacts assessment especially in marine ecosystems is essential and should be addressed in the feasibility study.

The impact of the OTEC plant on aquaculture is likely to be positive. Its wastewater contains valuable nutrients. If wastewater is leveraged for aquaculture, aquaculture production potential could improve. Nauru has a long tradition of milkfish farming. Although the practice was on the decline partly owing to the decreased water quality in aquaculture farm ponds including the Buada Lagoon, Nauru and FAO have tried to revitalize the practice [20]. If conditions allow, it may be possible with rich nutrient water from the OTEC plant to farm species with higher value for sale building on the tradition and infrastructure of aquaculture in Nauru. In fact, the Kumejima island where the 100kW OTEC plant is operational develops aquaculture farming of high value marine products such as shrimp, oyster, sea grape among others.

Impacts on other sectors – tourism and recreation

The impact of the OTEC plant may have wider implications on other sectors such as tourism. Diversification of the economy is a key issue for the sustainable development of Nauru. Whereas tourism is key sector for some islands in the South Pacific, the Nauru tourism industry is at an early stage of development. According to the national sustainable development strategy 2019-2030, the number of annual tourists is estimated at less than 1,000. Remoteness, cost of travel, quality of infrastructure and the limited availability of goods and services curtail the motivation of potential visitors. Nonetheless, healthy marine ecosystems including coral leaf are valuable resources to attract tourists and to entertain local people through subsistence fishing which is viewed as a pleasurable social activity that has value beyond just food collection. The breadth of the impact by the OTEC needs to be evaluated in the feasibility study of this project.

Potential conflicts with other sectors operating in oceans need to be identified early on to avoid backlashes. This can be done in the context of marine spatial planning, which is an approach to manage the spatial and temporal distribution of different anthropogenic ocean practices. The potential impacts of the OTEC plant on the key sectors including fisheries, tourism and leisure are covered in this report. However, there may be more sectors to be impacted such as shipping and defense. The full-fledged feasibility study should include these considerations.

Social acceptance

Public acceptability is key for the successful installment of the OTEC plant. International experience shows there are both optimistic and pessimistic views on the public acceptance of ocean energy technologies including OTEC. One of the optimistic views claims that ocean energy technologies are relatively easy to gain social acceptance since many parts of the facilities are submerged and do not impose visual impairments that affect the natural landscape [21]. Another study investigated public acceptability of electricity generation technologies including one of tidal power generation. The study concluded tidal energy was viewed as non-threatening for current and future generations and therefore enjoyed more acceptability. However, the applicability of this conclusion to the OTEC project in Nauru may not be high since tidal and OTEC are different technologies.

On the other side of the spectrum, some research imply that ocean energy is not universally supported, opposition free or exempt from the public acceptance issues faced by other renewable technologies. While the ocean energy technologies are viewed as an opportunity by those focused on global concerns or macroeconomics, they may appear as a threat to those focused on more immediate, localized impacts. The main stakeholder groups expressing concern or opposition in Nauru are likely to be those involved in the fisheries sector as well as the tourism and leisure sector. While no negative impacts on fishing are expected, consideration of the fishery sector's position is a critical factor for social acceptance. In Kumejima, the fishery collective is a strong supporter of OTEC development due to positive benefits for aquaculture operations.

A transparent and comprehensive environmental impact assessment is crucial to mitigate the local concerns. In addition, the distribution of benefits to wider stakeholders and the community involvement are also effective tools for constructive communication with the public. For example, a toolkit for the distribution of benefits from onshore wind farms has been developed by the UK government and identified four different types of community benefit schemes [22].

- ✓ Community funds: a lump sum or regular payment into a fund for the benefit of local residents;
- ✓ Benefits in kind: direct provision for local community of facility improvements, environmental improvements, educational support among others;
- ✓ Local ownership: sharing ownership through personal equity investment opportunities, profit-sharing or part-ownership schemes linking community benefits to project performance;
- ✓ Local contracting and associated local employment during construction and operation.

In the case of Nauru, a direct benefit utilizing fresh water may be an effective and low-cost approach on the delivery of community benefits.

Universal best practices on community involvement include early public involvement, engaging directly with special interest groups, establishing early two-way communication and planning participation. Reliable and robust scientific assessments on the impacts of plants provide the basis of these public engaging practices. Regardless whether the Nauru legislation requires such environmental impact assessments or not, it is desirable to carry out the assessments in the feasibility study of the OTEC project.

3.3 Technical aspects

As the engineering design and simulation aspects of the OTEC is covered in the technical analysis part of this project, this sub-section describes additional technical information in relation with socio-economic aspects. Those are mainly related to ease of construction, operation and maintenance of generation facilities; resilience and durability of generation facilities; and reinforcement need of power grid and transmission network.

Ease of construction, operation and maintenance of generation facilities

According to the engineering design and simulation analysis in this project, the required level of technical specialty for the OTEC plant construction and maintenance in Nauru is not likely to differ from a diesel engine power plant. Since the NUC has run several power plants for decades, Nauru is considered to have the general capacity to construct and run the OTEC.

Nonetheless, some specialists' involvement will be required from outside of Nauru during the design and construction. For instance, at least one specialist supervisor will be needed during construction in each key functions; civil engineering, construction, mechanical engineering, electrical engineering, operation, and instruments and controls. These supervisors will not be necessary during operation once operating team workers will be provided proper technical training. It is desirable to set regular maintenance once a year with specialists.

The industrial scale intake pipes do not require maintenance based on the operational experiences in OTEC projects in Japan. It is ideal to conduct a monitoring survey for the pipes once every several years to a decade.

In general, in case of emergencies the OTEC plant should be programmed to stop automatically and a plant manufacturer or maintenance service provider should fix the problem. The examples of such emergencies are a breakage of intake pipes or a leakage of ammonia which is used in the thermal conversion process, among others. Details of the plant recovery procedure and the scope of responsibility should be determined in contracts with a plant manufacturer or maintenance service provider. However, apart from the fatal accident such as intake pipe damage, the proposed OTEC would not have to stop entirely even when some system component fails because the double rankine cycle based system configuration is applied in this pre-feasibility study. Normally two 500kW turbine/generator sets are in operation and in the case of one 500kW becomes down, another 500kW is still running.

Resilience and durability of generation facilities

Resilience and durability of generation facilities are highly dependent on the engineering design of the generation plant and the design should be discussed in the feasibility study. In general, OTEC plants are less susceptible to weather conditions compared to other technologies. However, there is a risk of breakdown especially in case of extreme weather including king tide and strong wind among others.

Although Nauru does not experience tropical cyclones as the nation is close to the equator, it is subject to strong winds and sea swells from cyclones in other parts of the region [23]. Tropical cyclones occurring elsewhere in the region cause the most extreme waves in Nauru. It is recommended that the OTEC plant design should consider the uncertainty in the effects of tropical cyclones on the wave climate in Nauru, particularly the extreme values and, where possible, build in resilience to cope with increases in extreme wave and weather conditions should they occur.

Reinforcement need of power grid and transmission network

Further research is necessary on whether investment for the reinforcement of the power grid and transmission network is required for the OTEC project with 1 MW generation capacity. For the ADB funded 6 MW solar power plant project, there was no network reinforcement investment. Since the solar plant construction is not yet completed, its actual burden on grid stability is not yet confirmed. According to the preliminary modelling conducted during the preparation of the Solar Power Expansion Plan, there were no critical issues regarding grid stability, provided a sufficiently sized BESS was installed along with necessary control and protection modifications [24]. Similar modeling and studies should be included in the feasibility study to confirm whether grid upgrading is required or not.

4. Financial Analysis

This section provides the results of the financial analysis for a 1MW OTEC plant. The first sub-section provides the general assumptions in terms of costs and revenues. The second sub-section focuses on the different financing options available for infrastructure and the options recommended for this specific project. Finally, the last sub-section details the results of the analysis.

4.1 Assumptions

The assumptions used for the financial analysis, as well as their sources, is detailed in the following tables. The first component of the analysis are the costs.

Table 8: Assumptions related to costs

Category	Item	Cost (USD)	Source
Capital cost	OTEC power plant infrastructure	17,916,331 to 29,561,946	Technical report (consulting team)
	OTEC intake pipe infrastructure	26,874,496	Technical report (consulting team)
	Construction costs	895,817	Technical report (consulting team)
Operation cost	Maintenance cost	1% of capital costs, annualized based on the plant lifetime	IEA, Cost of energy for ocean energy technologies, 2015
	Salaries during operation (average annual income)	6 workers @6,565/annually	2006 HIES
	Land lease cost	900m^2 @6.12/m^2	Official government prices for land lease

At this stage, the consulting team understands that there will not be significant needs for additional transmission infrastructure and water storage infrastructure. Those costs, along with land acquisition for the intake pipe (submarine) and transmission infrastructure are not included in the assumptions and financial analysis.

The OTEC power plant infrastructure, intake pipe and construction costs are based on the actual costs experienced for the Kumejima plant (100kW) in Japan. Those costs have then been adapted to a 1MW plant size. The high cost assumption is based on a “as-is” situation, where costs would not decrease despite the technology being more mature. The low cost assumption is based on the assumption that costs will decrease due to the technology being applied at commercial level.

Land lease costs are based on land prices as of 2021 in Nauru. Maintenance costs are an estimation (5% of the overall capital cost of the plant).

Assumptions for the revenues are mainly based on historic sales and forecast from NUC.

Table 9: Assumptions on revenues

Category	**Item**	**Values**	**Source and comments**
Electricity	Residential lifeline	0.22 AUD / kWh, 18.77% of total output	NUC Business Plan 2021 - 2023
	Residential prepaid	0.47 AUD / kWh, 26.91% of total output	NUC Business Plan 2021 - 2023
	Residential postpaid	0.48 AUD / kWh, 8.14% of total output	NUC Business Plan 2021 - 2023
	Others (Commercial, industrial, government)	0.70 AUD / kWh, 46.18% of total output	NUC Business Plan 2021 - 2023
Water	Residential	8.40 AUD / m^3, provision to total demand (89,550 m^3), 1% annual growth	NUC Business Plan 2021 - 2023
	Commercial/Industrial	11.80AUD / m^3, provision to total demand (88,413 m^3), 0.5% annual growth	NUC Business Plan 2021 – 2023 Includes demand for commercial, industries, tourism and RPC
	Government	15.53AUD / m^3, provision to total demand (20,850 m^3), 0.5% annual growth	NUC Business Plan 2021 – 2023 Includes demand for government and Fire protection.

Both tariff recovery rates have been assumed to be at 80% in the case a private sector stakeholder was involved in the plant operations. The percentage of electricity output used by tariff line is aligned to the current grid usage.

The expected output for the plant is based on the following assumptions:

Table 9: Assumptions related to outputs

Category	Item	Values
Electricity	Installed capacity	1 MW
	Capacity factor	95%
	Total output per year	8,322 MWh
Water	Total output from the plant per year	412,872 m^3

Concerning water provision, it is important to note that the total output from post-OTEC desalination could satisfy the entire country's demand, including losses (forecasted to amount to 242,313 m^3 in 2025). For the purposes of this study, it is assumed that desalination covering demand for the whole country will be produced. In reality, capacity may expand depending on retirement of other capacity or changing needs and location. Incremental potential demand for agriculture and aquaculture is not covered in the financial analysis. It should be further considered in a full-fledged feasibility study to be included.

4.2 Financing options for the OTEC plant

Infrastructure is a capital-intensive asset class, which is generally site and use specific. It involves high sunk costs, and require extensive, advanced planning and long lead times. Infrastructure lifecycle is long – between 20 to 40 years. Infrastructure financing is thus complex, as the development and construction phases do not bring any cash flows, and that cash flows are distributed on a long period of time. In most cases, investments in energy rely on user-pay tariffs for their revenue and may be regulated by a government regulatory agency. The investment characteristics of this asset class, the maturity of national institutions, and the quality of macroeconomic management significantly impact the way infrastructure is financed.

While the public sector provides the majority of infrastructure financing, the private sector is increasingly involved in infrastructure financing. In the energy sector, Public Private Partnerships (PPP) structures may be used, or purely private developers may choose to provide electricity on a contract based approach (PPAs). Private projects generally have long-term contracts for their outputs. PPPs are also generally long-term contracts, under which the private sector constructs the project's assets for the public sector, and raises the required finance. The private sector then operates and maintains the asset for a given number of years, and the public sector either pays for the availability of the asset or the private sector charges end-users to use the asset.

Public and private sector financing differ as the tools used and risk evaluation methods differ as well. Public financing is done though debt instruments – with high levels of debts, countries have more difficulties in borrowing the capital required for the investment, or at a higher financing cost. Private sector entities may have access to debt and equity. In both cases, it is important to understand the options available for financing early in the planning phase.

Given Nauru's challenges in relation with public debt, public financing through debt has not been considered by the consulting team. The options considered include commercial loans, the bond market and private equity. Sources also include concessional financing from IFIs (including, but not limited to, the GCF). The factors considered to choose a preferred option include criteria such as flexibility to accommodate change over the life of the project, the suitability of the expected tenors and interest rates to the requirements of the project's revenues and debt profile and risk and return expectations (risk appetite).

Another important choice lies between corporate and project financing. In a corporate financing, the corporate entity issuing the debt will often have multiple operating assets already generating revenue. Debt provision will thus depend on the entity risk profile, as well as existing cash flows, non-limited to the future asset. A project finance company depends on cash flows generated by a single asset which the project company has the right to operate for a finite period or which it owns but which has a limited lifespan. The major source of project finance will generally be long-term bank loans and bonds in addition to equity. Both loans and bonds are likely to be secured against the project company's assets, while credit evaluation is likely to be based on the future cash flow.

In the case of the OTEC plant in Nauru, it is likely that the structure will be either 100% private-based, or in a PPP agreement to avoid constraints in leveraging debt from the public sector. In both cases, a long-term contract agreement will be required for service provision to NUC in electricity and water. Given the current risk of operating in Nauru, it is likely that project financing will be the preferred option, as the OTEC plant will be the only asset being evaluated for financing. It is also likely that provision of equity will not be the preferred option given the country risk profile. This means that the project company will have to find the majority of its financing in debt.

Debt may be leverage from loan finance of bond finance. Loan finance will be provided by banks – which have the experience to evaluate transactions. Commercial banks also have several regulatory constraints, which might limit the tenor available to the project and require the project company to refinance (prompting refinancing risk). Usually, loans are provided to short tenors, such as 5 to 7 years. In some cases, banks may also accept to finance beyond 10 years, but risk will increase. Some lenders are willing to lend for relatively long tenors of up to 25 years, but usually for lower exposure amounts and only in certain countries where the project assets are of very high quality and cash flows are highly predictable.

Bond financing is a capital market transaction. Bond investors make their investment decisions based on a project bond's merits and credit rating relative to other investment opportunities. Bond investors have fewer restrictions in terms of maturity. Longer tenor project bonds ensure financing costs that are fixed for the life of the project, thus avoiding refinancing risk. Longer payment profiles reduce the amount of each payment, which makes the project more affordable on the authority and end users. Bond value, however, is decided at issuance, where investors decide if investing in a bond with a specific face value (payment at the end of the maturity), maturity and coupons (regular payments) makes sense given the issuance payment.

Bank finance may be combined with bond finance using 'bridge to bond' financing. In this option, commercial banks may lend for a period shorter than the project life on assumption that the project company or issuer will refinance through bond issuance.

To decide whether bonds make sense for the OTEC plant project, considering the risk profile and potential appetite from bond investors. Given the country's risk profile, it is likely that bond issuance may not enable the project company to receive the financing required for the project at an acceptable rate (coupons and face value). This is further detailed in the financial analysis below. While loan finance may bring refinancing risk, its value can be set early in the process, enabling the project company and public authorities to confirm the final project cost.

To avoid refinancing, it is preferable for the project company to request (and achieve) a longer tenor for the project, such as 25 to 30 years. It is likely that commercial banks may not be able to provide such tenor for a project in Nauru. In this case, the involvement of IFIs, including Multilateral Development Banks (MDBs) may be required. The results of the financial analysis provide further insights on the possible expectations for the internal rate of return (IRR), structuring and involvement of MDBs.

4.3 Results of the financial analysis

This sub-section details the results of the financial analysis. Eight scenarios were used for the financial analysis based on the assumptions provided in section 5.1. Those are detailed in the following table:

Table 10: Assumptions of financial analysis

Scenario #	Assumptions	
1	CAPEX	45,686,643 USD
	Interest rate	6.32%
	Financial instruments	Full debt
2	CAPEX	45,686,643 USD
	Interest rate	11.42%
	Financial instruments	Full debt
3	CAPEX	45,686,643 USD
	Interest rate	6.32%
	Financial instruments	Debt (Plant infrastructure, construction) Grant (intake pipeline)
4	CAPEX	45,686,643 USD
	Interest rate	11.42%
	Financial instruments	Debt (Plant infrastructure, construction) Grant (intake pipeline)
5	CAPEX	57,332,258 USD
	Interest rate	6.32%
	Financial instruments	Full debt
6	CAPEX	57,332,258 USD
	Interest rate	11.42%
	Financial instruments	Full debt
7	CAPEX	57,332,258 USD
	Interest rate	6.32%
	Financial instruments	Debt (Plant infrastructure, construction) Grant (intake pipeline)
8	CAPEX	57,332,258 USD
	Interest rate	11.42%
	Financial instruments	Debt (Plant infrastructure, construction) Grant (intake pipeline)

Tenor (30 years) as well as other assumptions does not change across scenarios. The debt volume depends on the scenarios and varies between 1.1 to 1.2 times the cost of CAPEX targeted by the debt instrument.

Interest rates used for the analysis are based on benchmarks provided by EDHECinfra index, which is one the only indexes available for infrastructure financing, and Moody's government bonds (long term) information. The index used for the lower range is the Global private infrastructure debt (Local returns), which is a value-weighted representation of the Global private infrastructure debt market. The value retained is a 10-year return performance. The higher range uses Sri Lanka's performance on the government bond market, as Sri Lanka currently has the highest value for governments bonds in Asia Pacific (out of listed countries). It is likely that interest rate may change depending on the tenor/maturity and financing option chosen.

The result of the analysis is summarized in the following table:

Table 11: IRR results

Scenario #	IRR result (40 years)
1	-0.38%
2	-4.80%
3	**3.98%**
4	**1.67%**
5	-2.50%
6	-6.96
7	**1.12%**
8	-1.94%

Scenario 3 brings the best results, with an IRR of 3.98%. This is achieved by having a grant component on the intake pipeline, which could be considered as public infrastructure. However, this remains significantly lower than return expectations in other markets for infrastructure.

It is important to emphasize that higher interest rate scenarios (#2, 6 and 8) are non-viable. This emphasizes the importance of concessionality in the case the private sector debt approach is considered. Scenario #4 shows that even with a higher interest rate on the plant itself, high concessionality on the intake pipe invest could make the project viable although non attractive to investors (and requiring concessionality elements.

5. Gender analysis

Due to the COVID 19 outbreak since February/March 2020, this pre-feasibility study has been facing difficulties to conduct visit surveys in Nauru to discuss with the Nauruan relevant agencies on gender issues relating the introduction of OTEC technology, and to identify what are "specific needs" of women in communities at potential sites for the OTEC plant. As an alternative to the field visit survey to Nauru, the following studies have been conducted regarding gender issues till December 2021:

1) Literature reviews on issues/limitations on gender mainstreaming in Nauru (findings from available literatures/reports that describe gender issues in Nauru)
2) Online interviews to personnel at 3 relevant institutions.
3) Suggestions regarding issues/facts to be clarified/surveyed during the stage of the coming Feasibility Study to incorporate gender mainstreaming on the prospect OTEC introduction into Nauru.

5.1 Literature Review: national policies and issues raised in the existing literatures/reports

The Nauruan Government's gender mainstreaming policies and issues to promote gender mainstreaming in the various literatures/reports are summarized as follows.

5.1.1 National Level

a) National policies on gender equity

Commitment made by the Nauruan Government regarding gender equality	Ratified Year
Convention on the Elimination of All Forms of Discrimination against Women (CEDAW)	Signed in 2011
A national policy framework on gender equality	Developed in 2014 (and this shows a commitment toward achieving gender equality and empowering women.)

Source: Feasibility Studies Report, Feasibility Studies to inform the Nauru Renewable Energy Road Map, 2020

b) Issues pointed out on the National commitment

Issues Raised	Example Details
• Commitment for gender mainstreaming (CEDAW and national policy framework) by the Government has not yet translated into concrete actions.	• Internal procedures (recruitment, promotion, and training) to enhance gender balance for promoting the national policies is not prepared. • A wider government structure supporting gender equality and mainstreaming across all sectors needs to be prepared.

Source: Feasibility Studies Report, Feasibility Studies to inform the Nauru Renewable Energy Road Map, 2020

5.1.2 In the Energy Sector

Issues Pointed Out/raised
• Gender-mainstreaming capacities and knowledge within the national level energy authorities is not fully informed.
• National energy policy tends to overlook specific needs of women as well as vulnerable groups, particularly to improve access for energy and to enhance gender-mainstreaming capacities.

Source: Feasibility Studies Report, Feasibility Studies to inform the Nauru Renewable Energy Road Map, 2020

5.1.3 Tradition, safeguard, and quality of life

Issues Pointed out/raised
• Special needs and exposure of disadvantaged or vulnerable groups or individuals, including women and children needs to include the issue of safeguards.
• While Nauru is a matrilineal society where women have a strong voice at the family and community level, patriarchal values are evident in policy and laws.
• Key issues influencing quality of life of people are low salaries and cost of goods as well as services & products (electricity, petrol), lack of access to clean drinking water, unemployment, and items becoming unaffordable. • People in the community have different usage of energy/electricity. These vary from household appliances (e.g., electric fans, freezers, and chillers, charging mobile phones, lights, TV, cooking (rice cooker), boiling water, and laundry). • As for most women in Nauru, the biggest benefit would be having access to clean water, 24 hours in a day and thereby improving the health of the family. • From the past project experience, women see the biggest challenges would be maintaining equipment, location of equipment, theft, vandalism, and deteriorating structures. If water supply is insufficient for all households, then there will be competition amongst household for the limited supply.

Source: Nauru's environmental and social safeguard policy and guideline, June 2020, Pacific Women Shaping Pacific Development Nauru Country Plan Summary 2019, UNDP: Nauru SMARTEN Gender Analysis and Action Plan 2019-2020

5.2 Findings and Views Observed on Gender Issues through the Online Interviews (conducted three (3) interviews in the beginning of December 2021)

Based on the understanding acquired through reviewing the available literatures/reports, the on-line interviews to relevant personnel at the government institutions were conducted. In the following table, main points raised and explained as the answers of respondents are summarized.

Institutions that respondents of the on-line interviews belong are the following:

1) Nauru Utilities Corporation (NUC),

2）Department of Women and Social Development Affairs (WASDA), the Nauru Government, and

3）Department of Climate Change, the Nauru Government

Questions	Outlines of Answers Obtained by Online Interviews
1. Some reports describe that the Government agencies have not yet translated gender mainstreaming into practical actions. ・ If this is a situation in Nauru at this moment, what are behind of that, or what is a limitation causing that? ・ What are measures and ways forward for mainstreaming gender into practices/actions?	・ It seems that definition of "gender" is not well perceived/understood in the Nauruan government institutions at this moment in relations with development of electricity and water etc... (it may be not clear even differences of ideas between women's live movement and gender…). ・ Therefore, it is necessary to start increasing awareness regarding what are considerations necessary for gender at first, by holding workshops at <u>both</u> the Government institutions/implementing agencies (raising awareness) and communities (explanation and hearing opinions) levels.
2. Traditional values relating gender issues in the societies of Nauru (general) ・ Women's needs for energy and water, access, and decision making on use/payment of electricity and water at communities/households ・ Is there any barrier causing use of electricity and water at a community level?	・ The Government encourages female recruitment into the Government sector. ・ Before there were more foreigners as the Government employees, but recently more Nauruan women are employed at the public sectors. ・ It is slower (due to cultural value/traditional concept), but it is progressing. As for Nauruan women, delivering/having children is a 'setback' for getting and continuing permanent employment. In tradition taking care of children is women's duties.

	• At households, women mostly decide use and consumption of electricity and water. Therefore, decreasing cost for water and electricity will be a significant impact for families in case the OTEC introduction makes it possible. • 90% of electric fee is for air-conditioning (in offices, air-conditioning is used for 24 hours, and at houses when family members stay home it is used continuously.) • According to NUC, one family (extended family like 5 to 10 persons in one compound) pays for about 300 to 500 Australian Dollars (JY 24,000 to 40,000) average for electricity. • Average water fee may be about 100 to 200 Australian dollars (JY 8,000 to 16,000) average per extended family. (GNI:14,230USD/per head.) • Electric fee is expensive for families, but it is necessary for their live, so they must spend/pay. In case of extended families, they share the cost among the members who have income, so they can manage to pay. • Many women who do not have permanent employment, they have informal jobs such as selling fishes and vegetables. Incomes received from informal job are also important for families to pay expenses for life. • Recently there are more couples to live as core family compering before (changing lifestyles and composition of household). • Water shortage is a major problem in Nauru. Recently drought occurred and water shortage is a keen problem. (In Nauru getting clean water is only by desalinating sea water. (At all houses there are water tanks). • High inflation rate (3.3% in 2018, World Bank) is also a problem in Nauru now.
3. Gender balance, employment, and training in electric and water sectors (Note: According to Department of Women and Social Development, the latest Census (in charge of Statistical Department) was completed in November 2021. During the Feasibility Study, the Census shall be analyzed to update data, information on the economic status and population, and composition of household etc.)	• There are 4 females in the national congress out of 33 seats. • In case of NUC, 33 are female staff (20 % of staff. Total staff numbers are about 160 currently). For administrative areas, there are female sections/ dept heads. Female employers are all for administrative and no one in operation and technical fields in NUC. • In tradition female (girls) seek studies of liberal arts, and not in engineering and technical majors. (In Nauru for tertiary education most go to outside of the country) • There is no female Nauruan certified engineer at this moment, and no girl student studying engineering/technical fields receive by the Government scholarship. • (There are female students studying abroad in engineering fields by their own funds. But in

	most cases, they do not return to Nauru after graduating, and tends to stay outside of the country to have engineering/technical jobs. Students who received the Government scholarship return Nauru after graduating because of the bounds.) ・ There is 1 female certified engineer in Nauru, but she is not a Nauruan.
4. Potential after OTEC introduction and prospect changes	・ At this moment, (respondents said) Nauruan do not have enough knowledge and skills for operating and maintaining the OTEC facilities. It is very necessary to have appropriate training on them as the OTEC introduction is planned. ・ In case that the OTEC application reduce a problem of water shortage (due to recently more happening drought and changing climate) and the excessive cost of electricity (and water), benefit and impact for families and women would be great. ・ For training and employment of the OTEC facilities, it is necessary to encourage to recruit and develop skill/knowledge for female, to increase women's promotion and interests to engineering/technical work areas.

5.3 Ways Forward: Suggestions on what activities and information collection need to be carried out in the stage of the Feasibility Study to corporate a plan on gender mainstreaming into the OTEC Study

With the results of literature/reports reviews and the on-line interviews, surveys and activities that need to be carried in the stage of the coming Feasibility Study are as follows:

Information collection and activities to be conducted to increase awareness on gender mainstreaming at the Government level
・ With the latest Census of Nauru (November 2021), data (population, education level, income level, expenses, household composition etc.) need be updated and clarified to study the feasibility of the OTEC introduction, and associated socio-economic issues.
・ Confirmation/identification on focal persons at the relevant electric agencies
・ Workshop on gender mainstreaming to increase awareness and definitions of gender, and plans to formulate activities/actions ・ Measures (such as workshops or a short training) for enhancing gender-mainstreaming capacities and knowledge at the relevant electric agencies for enabling existing national gender strategies/plans into sectors' actions/practices
・ Existence of gender focal persons in the target community on the OTEC plan

Information collection and studies to be conducted (Opinion hearing at the relevant government institutions and by organizing interviews and focus group discussions at prospect communities of the OTEC introduction)
・ Clarification on needs and access to energy and water (if not good enough, what is behind of the limitation at that time)
・ Status on sufficiency of energy and water (if not good enough, what is behind of them)
・ Women's economic status related to access to energy (if not good status, what are causes?)
・ Participation status of women for decision making on the community issues/households (if not good enough, what are causes?)
・ What are benefits for the prospect communities and females after the OTEC introduced, such as: ・ Safe water availability/sufficiency ・ Decrease in the cost of electricity and water ・ Changes in health/sanitation status by sufficient safe water and decrease in the cost of electricity ・ Prospect of chances for training and employment on the operation and maintenance of the OTEC and related facilities for women/girls, so that women/girls are encouraged to start employment/jobs in technical and operational fields ・ Prospect economic activities and incomes, and prospect for bi-product economic activities as the OTEC introduced.

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III. Stakeholder’s Consultation and survey

3.1 Summary

As part of the deliverables indicated in the Terms of Reference, a Stakeholder’s Consultation has been organized on 29 November 2021 in Nauru. Due to the effects of the COVID-19 pandemic, participants from Japan joined on line.

The aim of the Stakeholder’s Consultation was to present preliminary results obtained in the Pre-Feasibility Study and to exchange opinions with main representatives from different organizations related to the energy and water sectors, as well as those involved with mitigation and adaptation policies and strategies of the country, aiming at gathering the necessary information to understand the direction for this project and to finalize the GCF Concept Note.

The objectives of the Stakeholder’s Consultation were:

- To present main findings of the technical /socio-economic / financial study
- To present GCF concept note (draft)
- To exchange opinions conducive to the preparation of final report and GCF concept note

All organization matters, logistics, and the list of participants (Annex 2) were coordinated with the Nauru NDE. For local participants, the consultation was in a face-to-face format, so the Ministry of Commerce, Industry and Environment facilitated the venue (DCIE Conference Room), which allowed to keep the expenses to the minimum since the conference room is equipped with audio-visual equipment, internet connection, screen, etc., which means that the budget was spent for printing of materials and catering services.

The consultation was divided in 2 sessions. In the first session experts made presentations in relation to the results of the technical and financial analysis; and the second session which consisted in the discussion (consultation) with stakeholders. The consultation’s agenda is attached in Annex 1.

3.2 Inputs obtained in the Consultation and Surveys

In the discussion session, main concerns from the NDE and local stakeholders were focused on issues that need to be considered regarding the potential location of the plant, investment needed for the installation of the plant, and direction / contents of the GCF concept note.

Although there was no objection in relation to the 5 alternative locations and the selected site proposed by the implementation team, more peripheral issues were raised such as the ownership of the land and obtaining the proper authorization for the installation of the plant.

The NDE pinpointed the need to introduce water resources as the main byproduct of this project due to the potential impact that may have for agricultural and aquaculture purposes, and also the provision of drinkable water to the population.

As for the concerns regarding the required investment costs, the experts highlighted that calculations are in a very early stage, and the need to conduct a more detailed analysis in the feasibility study. Nevertheless, it was undeniable that this issue represents one of the main hurdles for this project since it is unknown at this point if the GCF will finance later stages. Moreover, one of the pending activities for the feasibility study is the search for potential investors for this project and a more detailed analysis of income sources.

Finally, in relation to issues raised on the need to relocate people when installing the plant, the CTCN mentioned the need to consider proper social and environmental safeguards in the next phase. On this regard, the experts indicated that although the analysis was focused in the area where the old plant was built, there are other options that can be taken and that needs of people living in nearby areas will be considered as part of the feasibility study.

To support the ideas expressed in the Stakeholder's consultation, a survey was prepared and distributed to participants aiming at obtaining consensus among all stakeholders and set the direction for the upcoming feasibility study and implementation phases.

Although there were 12 stakeholders in the consultation, only 4 participants filled the survey. Here are some of the responses that will be considered in future activities.

Question	%	Responses
3. Do you agree with the idea of promoting the installation of an OTEC plant, following Nauru's objective to increase renewable energy sources?	100	- Impact on natural resources should be taken into consideration.
4. Do you agree that the Ocean thermal energy conversion (OTEC) plant can be considered as the best solution to remove such threat to energy supply for Nauru?	100	- Data from a feasibility study is required in order to evaluate OTEC plant.
5. Provision of drinkable water and food security are deliverables planned for this project as they are directly linked with agriculture and aquaculture activities. Are there any important considerations that should be taken on this regard?		- Cost of water - How the structure of aquaculture activities will be. - Feasibility and impacts of each deliverable needs to be evaluated. - Drinking water quality tests. - Land acquisition and rents. - Water storage.
7. What are the main issues that needs to be considered in order to make the final decision on the location for the plant?		- Social and environmental impacts. - Consultation with communities and social safeguards needs to be considered. - Land tenure issues. - Grid integration
9. Do you agree with the idea of preparing a concept note for the Green Climate Fund in order to access funds to continue with the feasibility study and implementation phase?	100	- Other sources should be considered if it takes time to get the approval from GCF. - Requirements from landowners, access to beaches and social areas need to be considered.
10. Given the considerable amount of investment that is required for the installation of the OTEC plant, can you suggest alternative sources of income that can be considered for this project?		- Commercial aquaculture activities. - Access to loans and required investment needs to be evaluated against the size of Nauru's economy. - Car and shipping container washing. - Water for firefighting.
12. Do you have any suggestion of comment for the implementing entity to consider in this project?		- How the structure of aquaculture activities will be. - What the price of electricity will be in comparison to other energy sources.

It can be concluded that stakeholders at the consultation and survey respondents agreed with the results of the pre-feasibility study, and more importantly, with the introduction of OTEC technology, as the most suitable renewable energy source for Nauru.

Obviously there are some concerns in this regard, mainly in relation to the location of the plant, negotiation with land owners, but most importantly, the social and environmental impacts that the installation of the OTEC plant may pose.

Finally, most of the stakeholders are aware of the extent of financing that the plant will require, and because of that, the financing structure and the impact in the country's economy (and ultimately the population) is another issue that needs to be addressed in the next phase.

The implementation team concludes this report by reaffirming that as the next step, it is definitely necessary to conduct a Feasibility Study where more precise information on the plant location, and most importantly, the investment required to implement this project has to be conducted. The NDE will also need to work with the central government in order to move forward with the adoption / authorization for this project, and the implementation team also needs to work on the verification of technical issues and channeling of financial sources.

IV. Conclusions and Recommendations

4.1 Justification of alternative plan

At the outset of the project the key outcomes of the TA were: 1) desk-based and onsite data collection to validate the appropriateness of the identified sites and to provide technical and economical input to the pre-feasibility study; 2) Conduct socio-economic analysis and pre-feasibility study; 3) Stakeholder consultations; and 4) Synthesize input for GCF concept note.

In the kickoff meeting held on 27 November 2020 with the Government of Nauru, CTCN, and stakeholders, it was recognized that it was not feasible for the implementing entity to conduct onsite data measurements, as indicated in the original work plan due to travel restrictions as a result of the COVID-19 pandemic. The experts from the implementation team have suggested alternative approaches to conduct this pre-feasibility study, and so, the activity related to 'on-site measurement of data', as described in the Terms of Reference, has been replaced by the option of conducting analysis of data obtained from international oceanographic databases and conduction of simulation models.

The methodology followed international research standards and delivered highly reliable outputs. In fact, as a result of this analysis the Nauru Model was created. This methodology would also use countrywide data to analyze multiple potential sites in Nauru in order to determine the best location for the installation of the OTEC plant.

Details of the alternative option were presented to the GCF though a justification document, and the implementing team has waited until the GCF gave the green light to proceed with the alternative analysis.

4.2 Summary of services provided and assumptions for the next phase

4.2.1 Services provided for technology/ site selection and simulation model

a) Selection of most suitable ocean energy technology together with suitable site

Under the pre-defined criteria, evaluation for respective ocean energy technologies was made in terms of suitability to Nauru from different aspects based on data analysis conducted by a simulation model that was developed particularly for this project.

As a result, OTEC has been selected as the most suitable ocean technology for Nauru and the most suitable site was chosen among 5 candidate sites suggested by the simulation model.

b) OTEC Simulation model development

Oceanographic data generated by the simulation model developed for this pre-feasibility study has been accepted instead of actually measuring data onsite because of travel restrictions for due to the COVID-19 pandemic.

The dataset created by the simulation model delivered annual average data in 2020, which means all seasonal variation has been reflected.

When much longer period average data is required in order to reflect the impact of El Nino and La Nina events to SST, the 10 years' average data 2011-2020 (Annex 8) has been available for consideration.

The results of the simulation model provided additional deliverables:

(i) Summary report for simulation model for Nauru (Annex 3)
(ii) Temperature & Salinity data profiles for 5 selected locations (Annex 4)
(iii) Temperature Profile Report (Annex 5)
(iv) Guide on how to visualize the ocean data near Nauru (Annex 6)
(v) Coordinates of the Argo profiles included for this analysis (Annex 7)
(vi) Annual Average for SST (Sea Surface Temperature) from 2011 to 2020 (Annex 8)

Prospect of using the simulation data-base in the Feasibility Study:

- During the development of the simulation model and data gathering for the project, it becomes evident that those deliverables can be used for the full-fledged feasibility study.

- The full-fledged feasibility study to be conducted in preparation of the project implementation will, needless to say, require more precise and long term ocean data. In order to satisfy the requirements as such, a number of data sampling might be necessary over the years considering the difference of seasonal conditions and also the impacts by La Nina or El Nino.
- The database (NetCDF*1) of the 4 dimensional oceanographic data relevant to OTEC (Temperature, Salinity, Velocity, Density) around Nauru in 1km resolution (300km x 360km x 5km depth) is developed not only for the purpose of this pre-feasibility study but also can be used for next phase, particularly in the case of the feasibility study before actual introduction of the OTEC plant in Nauru.

  *1 NetCDF (Network Common Data Form) is a file format for storing scientific multi-dimensional data (variables) such as raised above. Each of those variables can be viewed through a dimension (such as time) in an appropriate user-interface by creating a layer or table view from a NetCDF file.

  NetCDF created for the Nauru project will be available to view in next phases.
- It also becomes evident that the model-based oceanographic data simulation approach for OTEC taken in this project is applicable in other island countries similar to Nauru.

4.2.2 Provided service for OTEC design

a) Overall System Design

The overall system design includes the design of the OTEC plant itself, water production (desalination) system, cooling (air conditioning) system, and provision of resources for aquaculture, agriculture, cosmetics, and so on.

The temperature difference between SOW and DOW can produce not only electricity through OTEC but also fresh water by desalination. This method is called Low Temperature Thermal Desalination (LTTD) which not only produce potable water, but also reduce power consumption compared with the existing RO process desalination. Air conditioning for buildings can be applied using DOW, which will also reduce power consumption. The concept of overall system design for OTEC in the project is based on the DOW multi-use as stated above and it is aiming at securing the resilience for Nauru's infrastructure and economy.

b) Decision of the type of process cycle

The Double Rankine Cycle was selected based in the following characteristics:

- The cost of installing a deep sea water intake facility is estimated to be about three times the cost of an OTEC power generation facility.
- It is important to reduce the cost of the water intake facility in order to reduce the total cost of the system.
- The experts of the project team (Saga University, in Japan) are studying a multi-stage cycle that uses the heat source from seawater in cascade as a method to effectively utilize the heat energy of the heat source seawater that has been taken in.
- Under ideal conditions, if the temperature and flow rate conditions of the heat source are the same, it has been found that the power generation output may be about 1.3 times higher than that of the single stage cycle.

In consideration of the OTEC process cycle features, the design work of for the heat balance diagrams with estimated process values has been conducted. Heat balance diagram for "Single Rankine Cycle" and "Double Rankine Cycle" can be found in Annex No.9

c) Decision regarding the capacity of OTEC

In terms of deciding the capacity for the OTEC plant in Nauru, the energy situation, technology readiness and economic constraints were considered with the Nauru Government in order to get a realistic and achievable introduction of renewable energy.

The Nauru Utilities Corporation (NUC) has provided background information on the current grid needs and expected future renewable energy installation and demands. The NUC noted it could utilize a baseload OTEC plant on a scale of 3-4MW to meet a current peak demand of 5.7MW.

Based on the requirement by NUC and consideration of the existing renewable energy implementation plan, and in order to achieve competitive OTEC power generation costs (compared with diesel) in Nauru, it has been concluded that the capacity of 1MW is the most appropriate for Nauru.

4.2.3 Desalination system coupled with OTEC (LTTD)

Low Temperature Thermal Desalination (LTTD) uses the temperature difference between the surface and depth in the ocean, and this process is applicable for multiple applications using the effluent of OTEC surface and deep ocean water because both ocean waters maintain a temperature difference.

LTTD is the same process as flash desalination, however, the temperature difference between the vaporized ocean water and condenser is limited to the ocean water temperature difference. The surface ocean water (or surface ocean water effluent from OTEC) will be fed to a vacuumed flash chamber, where the pressure is lower than the pressure at the boiling point of the surface ocean water. Surface ocean water at such low pressure has a lower boiling point, so it evaporates (flash desalination). The generated vapor flows into a condenser. In the condenser, DOW provides the low temperature to cool the vapor into a liquid. The system's vacuum pump will remove any non-condensable gases such as Nitrogen and Oxygen contained in the ocean water, any air entering from the atmosphere, and small amount of evaporated steam.

A major benefit of LTTD is that only 1-2% of the base ocean water is extracted, so that discharge is only minimally affected compared to a reverse osmosis desalination facility. All non-condensable gasses are also removed through the process however, so aeration prior to discharge may be necessary.

A secondary benefit is that the components are simple, significantly simplifying maintenance and operation. Unlike reverse osmosis, specialized membrane maintenance is unnecessary, and pre-treatment can be significantly reduced.

After providing electricity from an OTEC power plant, the effluent ocean waters can be applied to either the thermal distillation or the membrane separation desalination methods. According to a NUC report in Nauru, the reverse osmosis process is used to produce water. As the effluent ocean waters from OTEC still have thermal energy as a temperature difference of 12.6°C, the LTTD process can be applied.

According to a NUC report, the water demand in Nauru is expected to be about 200,000 kL/year, which corresponds to 548 m3/day by 2025.

In the case of Nauru, the desalinated water produced by LTTD can be transferred and mixed with RO permeate. The advantage of installation of LTTD plant is not only the increase of amount of water production rather than RO alone, but operation that provides higher quality of produced water, lower environmental impact and lower maintenance cost.

4.2.4 DOW based cooling system analysis

DOW Cooling refers to the cooling of buildings through utilization of the naturally occurring cold DOW resource. Large-scale commercial chillers use energy intensive compressors, fans, and refrigerants to chill fresh water that can then circulate through a building to supply cold to individual spaces. For DOW Cooling, ocean water provides the cold source. DOW is more corrosive to many materials than fresh water, thus after intake, a heat exchanger is used to cool fresh water with DOW.

The two liquids never mix, providing the opportunity for the DOW resource to be reused elsewhere or returned to the ocean. The cooled freshwater can circulate in a closed loop, cooling nearby buildings, and reducing the cost of ancillary equipment such as piping and pumps, compared with the cost of materials designed for ocean water.

4.2.5 Potential Aquaculture with OTEC

As part of the pre-feasibility study for an OTEC system applied to Nauru, the technical team will discuss the feasibility of aquaculture and other DOW uses. The feasibility will be assessed in consultation with stakeholders aligning with the National Act on Coastal Fisheries and Aquaculture in Nauru.

In Okinawa, the southern-most prefecture of Japan, there is a remote island with many characteristics and goals similar to Nauru. In Kumejima Town, the local government of that island is working on increasing its renewable energy capacity to meet its goal of 100% renewable energy by 2040 through the use of OTEC.

In 2000, Okinawa Prefecture established the Okinawa Deep Ocean Water Research Center (ODRC) on Kumejima Island to promote fishery research and industry. The ODRC utilizes DOW and SOW pipes with capacities of 13,000m3 per day to research new technologies and also sell water to local industries.

Based on the island's more than 20 years of experience in working with DOW resources for both local industry and clean energy, the current situation, progress, and future plans will be considered as a reference towards implementing ocean energy technologies in Nauru.

4.3 Lessons learnt

Below are listed experiences, acquired knowledge and practices obtained through the conduction of this project which produced valuable lessons and it is crucial to promote and disseminate those lessons in other island countries:

4.3.1 Technical analysis

- The review of the long-term energy mix roadmap premised on the introduction of OTEC had a great impact so as to change existing renewable energy introduction plan.
- Having determined the way to gather alternative ocean data in a remote basis is crucial for the evaluation of potential energy for OTEC projects. This is a valuable experience that can be shared.
- The simulation method of how to estimate 3 dimensional ocean data with required resolution for Nauru based on global oceanographic data has been developed and it can be replicated to similar small island countries.
- Quantitative evaluation of double Rankine cycle applied to OTEC in comparison to single Rankine cycle has been established, which is another output that can be shared in new projects.
- Desalination by OTEC + LTTD is found to give tremendous advantages in comparison to conventional RO from the economic and environmental perspective which justifies the use of OTEC together with LTTD desalination for similar island countries.

- In addition, it was found that existing RO facilities can increase efficiency by combining with OTEC.
- Additional fresh water will be produced by providing OTEC effluent directly to an RO facility and its operation provides higher quality of fresh water, lower environmental impact and lower maintenance costs in comparison to plants operating only RO facilities.
- Land extension for other renewable energy options such as solar PV or wind power requires huge land areas which might not be available in small island countries. In the case of Nauru, the site area of the recently constructed 6.0MW solar power plant needs more than 0.62MWh/m2. On the contrary, the land extension for a 1.0MW OTEC plant is calculated at 9MWh/m2.
- For the above indicated reasons, for a small island country in the Pacific Ocean region, OTEC is definitely advantageous.
- OTEC's huge amount of discharged deep ocean water (DOW) is found useful for potential agriculture and aquaculture. In reference to the experience of Kumejima island in Japan, which can be considered as a model for Nauru, agriculture and aquaculture proved to be successful. 98% of DOW is sold to business owners, and intake pipes are normally used facilities for those businesses. The initial cost for the intake pipe is huge but if it could be shared with business owners benefiting from DOW, the initial cost burden could be reduced.

4.3.2 Socio-economic and financial analysis

a) Social factors

- Energy and water security can have a strong and direct effect into the Nauruan society, as it can allow for job creation, entrepreneurial activities, and moreover an impact on poverty reduction.
- Energy security means that importation of fossil fuels will be reduced, and so, it may eliminate one of the main sources of pollution which is directly linked with respiratory illnesses affecting the population.
- While the country is engaging in efforts to promote gender equality, the energy sector needs to address this issue since gender mainstreaming initiatives are scarce, let alone issues related to vulnerable groups.

- Access to energy and water would have a strong relation to gender issues at the community level by improving health of family members, and by increasing the possibilities of women to access to more economic activities.
- Land acquisition and ownership are some of the main issues that a country needs to take care of for an OTEC project. The most suitable locations for the plant are not necessarily the most suitable for the communities, so negotiations and safeguards needs to be considered.

b) Economic factors

- From the socio-economic perspective, introduction of OTEC technology would bring multiple social, economic, and environmental benefits to the country. Among the direct outputs we can mention an increase in the reliability of electricity supply, which means to elimination of energy insecurity, it can potentially boost economic activities, and can also provide an increase in water security that has direct implications into agriculture and fishing activities.
- In that sense, the Kumejima model proved that it is feasible to start new economic activities and in the case of Nauru, the provision of desalinated water is directly linked with agricultural activities, aquaculture and livestock, aquaculture, provision of refrigeration, and others that the country may consider in order to diversify its economy.
- A major benefit for the country would be the reduction in the importation of fossil fuels that erodes the country's financial resources. Needless to say, this will also help to achieve goals set in Nauru's NDC as well as their energy roadmap which aims at increasing renewable energy sources.

c) Environmental factors

- Through the introduction of OTEC technology, a secure provision of energy and water can allow the country to tackle the high vulnerability to climate change in different ways. Given the similarity to most island countries, if this project succeeds to get to the implementation stage, it could become a model project to be replicated in countries in need of reliable energy and water sources.

- Energy security may eliminate one of the main sources of pollution in the form of fossil fuels imports.
- The component of water security is directly linked with adaptation goals since drinkable water sources are scarce in Nauru. Similarly, desalinated water can be used for agricultural purposes.
- With the possibility to create healthy ecosystems, the country can stimulate ecotourism initiatives, which is another area from where the country can benefit.

d) Financial factors

- The fact that OTEC is a relatively new technology makes it difficult to get accurate information on capital and operational costs involved for the construction of an OTEC plant. This pre-feasibility study served as a source to compile the basic information for this project, but it will be necessary to conduct a feasibility study in order to determine more precisely the required amount of investment for the installation of the plant.
- It is a fact that the installation of an OTEC plant will require considerably more amount of investment in comparison to other renewable energy sources. Therefore, the financing structure is obviously one of the main concerns for a country such as Nauru which has limited options in acquiring new loans of debt instruments, while getting grants for the total of the project is highly unlikely.
- At the moment, there are no cash flow sources aside from the tariffs charged for the provision of electricity and water. The country will need to be creative in order to develop new cash flow sources and make this project sustainable in the long term.
- Financing options through public private partnerships (PPP) structures and the involvement of partners from the financial sector needs to be planned carefully. This activity will also be conducted in the feasibility study.
- The scale of the investment does not justify the project compared to Solar PV and battery cost without providing more arguments. The project needs to go beyond energy provision and provide an overall resilience model centered on OTEC.
- Justifying the investment in the plant by mitigation impact is likely to be insufficient, as Nauru’s overall emissions are marginal. Nauru is highly vulnerable to climate change – including in water supply and food security – a project targeting these vulnerabilities will be more bankable for GCF.

- In terms of preparation of a GCF concept note, it is essential that discussions with AEs can take place at some point to develop a concept note that is bankable for AEs (eg. which takes into account the needs of the country and the capacities/mandate of the AE).
- OTEC is not only a source of energy – it should also enable the building of more resilient livelihoods in Nauru.

4.4 Recommendations

4.4.1 Technical analysis

This pre-feasibility study has been formulated before the start of the COVID-19 pandemic but conduction of this project has started when travel restrictions were already put in place. Since an unprecedented situation took place, the Nauruan government requested the implementing entity to think on alternatives which forced the team to request a project extension and make additional efforts in order to find solutions and collaborators.

Although it is still unknown how the situation of the pandemic will evolve. It is recommended that countries might need to consider different options in new projects regarding measurement of data on site. The analysis of global oceanic data with existing software is one option.

Below there is a list of other recommendations:

a. Nauru's land area is small and vulnerable to the effects of climate changes such as coastal erosion and rising sea levels.
   The urgency of removing the cause of climate change and shifting residents living in coastal areas to higher ground is increasing, but it might be challenging to solve such difficulties. Two options might be considered: (1) replacement of fossil fuel usage with renewable energy and (2) securing large land in the hills in such a small island country for relocation of a number of residents living in coastal areas.

[Recommendation]:

When it comes to land security in terms of renewable power generation, OTEC is most suitable in comparison to solar PV or wind power in Nauru and other similar island countries in the

Central Pacific Ocean region, because OTEC's necessary land area is smaller than to other technologies, OTEC is about 9.2MWh/m2 whereas Solar power is 0.57MWh/m2, which means solar PV in Nauru needs land of 16 times bigger than OTEC. (A 6.0MW solar plant in Nauru needs 2.17ha.)

b. Most of the daily necessities in particular diesel or petroleum depend on imports and are easily affected by external factors such as prices and exchange rate fluctuations in Nauru or other nearby island countries.

[Recommendation]:

Since Nauru is an isolated island country relying heavily on fossil fuels that are imported from overseas countries. In the unlikely event that oil imports are stopped for some reason, there could be a danger that the national social economy might collapse. If most of the necessary energy resources can be supplied domestically, energy security can be maintained.

Nauru is blessed by being surrounded by the ocean and it has been proved that for Nauru, OTEC technology can provide a stable power supply, so it (ocean energy) can replace fossil fuel as a base load power source. Moreover, grid electricity supplied from OTEC could replace fossil fuels with electricity for electric vehicle (EV) in the near future and energy security can be achieved without concerns of energy cutoff.

c. The country tends to be dry due to the decrease in precipitation caused by the influence of the La Niña phenomenon, which reminds us that water security is crucial not only for Nauru but also for Pacific island countries.

[Recommendation]:

For island countries, fresh water security is dependent on desalination from sea water. Fresh water produced by desalination is supplied mainly for human consumption and irrigation. The desalination processes applied at the moment is through Reverse Osmosis (RO) or by distillation and those methods consume large amount of electricity or fossil fuels with significant amount of emissions and energy cost, which means that from the perspective of environmental and economic impact, both the RO and distillation are not recommendable.

The implementing entity recommends Low Temperature Desalination as a better alternative because it consume far less amounts of electricity and no fossil fuel at all. Our recommendation is to supply DOW and SOW (both are effluent of OTEC) to the LTTD facility as different temperature waters can produce fresh water.

Required electricity by LTTD desalination is only powered for vacuum pump, discharge pump, and fresh water transfer pump and the required amount of electricity is part of the OTEC output, which means no extra cost is needed because OTEC fuel is ocean energy.

It is also to be noted that a 1MW OTEC DOW and SOW effluent could have capacity to produce 1,000m3/day which is far more than total demand forecast in 2025 according to the NUC report in Nauru.

4.4.2 Socio-economic and financial analysis

[Recommendations]:

- The main recommendation for countries that want to engage with OTEC technology is to consider the high amount of investment that will be required. In that sense, it would help if the applicant country has different sources of revenues that can be used as sources of cash flow that can easy financial burdens from loans.
- At the same time, it is recommended to fully consider the multiple benefits that OTEC technology can provide, and always present it as a project with mitigation and adaptation components.
- Since ocean technologies analyzed in this study, aside from OTEC have been already assessed, the focus should have been solely for OTEC technology which is the only viable option for Nauru.

Annexes

Implementing Entity:

Overseas Environmental Cooperation Center, Japan (OECC)

Annex 1: Stakeholder's Consultation Agenda

Stakeholder's Consultation on Technical / Socio-Economic / Financial analysis

Date: 29 Nov 2021 (Monday)

Venue: DCIE meeting room / @Zoom online

Organized by: Ministry of Commerce, Industry and Environment

Supported by: Overseas Environmental Cooperation Center, Japan (OECC)

Time (VUT)	Time (JST)	Context	Presenter
14:30-15:00	11:30-12:00	Registration	
Introductory remarks			
15:00–15:15	12:00-12:15	Introduction and housekeeping announcement (5min) **Opening remarks** (5min*2)	Moderator: Abraham Aremwa • Mr. Reagan Moses Secretary for Climate Change and National Resilience / NDE Nauru • Mr. Makoto Kato, Project Manager, (OECC)
Presentation of main results obtained in the feasibility study and Consultation session			
15:15–15:25 15:25-15:45	12:15-12:25 12:25-12:45	Revisiting activities conducted in the Pre-Feasibility Study (10min.) Main results obtained in the Technical Analysis (20min.)	Mr. Jiro Ogahara (OECC) • Prof. Yasuyuki Ikegami (IOES) • Prof. Takeshi Yasunaga (IOES) • Mr. Benjamin Martin (Xenesys)
15:45-16:05	12:45-13:05	Main results obtained in the Financial Analysis (20min.)	Mr. Samuel Alterescu (DTFA)
16:05 -16:20	13:05-13:20	Introduction of proposal for the GCF Concept Note (15min.)	Mr. Samuel Alterescu (DTFA)
16:20–16:35 16:35–17:00	13:20-13:35 13:35-14:00	**Q&A** (15min.) **Inputs by stakeholders** (25min.)	Moderator: Abraham Aremwa Facilitated by: Makoto Kato (OECC)

Time (VUT)	Time (JST)	Context	Presenter
17:00–17:10	14:00-14:10	Main conclusions of the stakeholder consultation (10min.)	Mr. Jiro Ogahara (OECC)
17:10–17:20	14:10-14:20	**Closing remarks** (5min.*2)	• Mr. Reagan Moses Secretary for Climate Change and National Resilience / NDE • Mr. Makoto Kato Project Manager, (OECC)

Annex 2: Stakeholder’s Consultation List of Participants

No.	Name	Title	Department/SOE/ NGO
1.	Mr. Reagan Moses	Secretary/ NDE	DCCNR
3.	Mr. Jay Udit	Secretary	MoJ
4.	Mr. Midhun Ajaykumar (online)	Director	DCCNR - Energy
5.	Ms. Evalyne Detenamo	Acting Director	DCCNR - Energy
8.	Mr. Carmine Piantedosi	CEO	NUC
9.	Mr. Ali Mohammed	GMO	NUC
10.	Mr. Apenisa Manuduitagi	RE&M	NUC
11.	Mr. Credence Halstead	(tbc)	NRC
13.	Mr. Kemp Detenamo	(tbc)	NPA
14.	Mr. Being Yeeting	Advisor	NFMRA
15.	Mr. Tyrone Deiye	Consultant	NGO
16.	Mr. Haseldon Buramen	Consultant	NGO
17.	Mr. Anton Jimwereiy	Consultant	NGO
18.	Mr. Abraham Aremwa	Consultant	JAG (OECC)
19.	Ms. Marilyn Deireragea	Leader	Justice and Border Control
20	Mr. Vanic Dabe	RE Team Leader	NUC
21.	Mr. Being Yeeting	Fisheries Advisor	NFMRA
22.	Mr. Sambit Nayak (online)	Climate Change Specialist	CTCN
23.	Ms. Clara Landeiro (online)	Climate Change Specialist	CTCN
24.	Prof. Yasuyuki Ikegami (online)	Project Coordinator	Saga University
25.	Prof. Takeshi Yasunaga (online)	Ocean Energy Specialist	Saga University
26.	Mr. Benjamin Martin (online)	Analyst	Xenesys
27.	Mr. Samuel Alterescu (online)	Energy Economics Specialist	Deloitte Tohmatsu Financial Advisory LLC
28.	Mr. Goro Tamaru (online)	Analyst	Deloitte Tohmatsu Financial Advisory LLC
29.	Ms. Rie Kawahara (online)	Gender Specialist	R-Quest
30.	Mr. Kuniaki Makiya (online)	Secretary General	OECC
31.	Mr. Makoto Kato (online)	Project Manager	OECC

32.	Mr. Jiro Ogahara (online)	Project Coordinator	OECC
33.	Mr. Shigeo Aoki (online)	Technical Advisor	OECC
34.	Ms. Kisato Nagakuro (online)	Researcher	OECC
35.	Mr. Abraham Aremwa	Local Expert	JAG Engineering

Annex 3: Summary Report for Simulation Model for Nauru

1. Selected 5 potential sites with justifications

Selection criteria:

1. Depth: The desired depth was chosen to be within 500 to 1000m, since the designs for OTEC are usually found within this range.
2. Distance to the shore: We are prioritizing sites that are in closer distance to the shore to reduce initial costs.
3. Distance to the main districts: As final selection criteria, the distance to the districts of enigomodu, Aiwo, Boe and Meneng were considered. These are the most populated areas in Nauru, and having OTEC closer to the distribution points will reduce project costs.

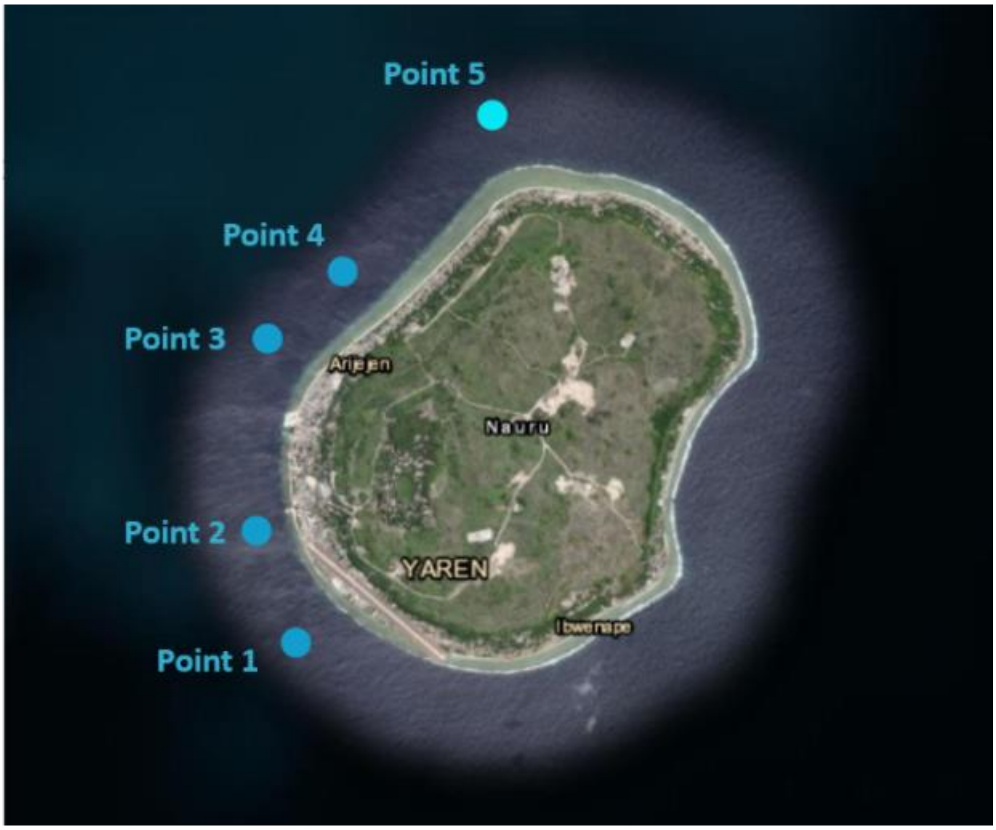


Figure 1. Location of the 5 sites in relation to Nauru.

(i) Power generation potential by ocean-energy based technology (OTEC, Wave, Tide) around all over Nauru

1. Wave:

The area surrounding Nauru has a wave energy flux that varies between 7.5 and 10.5 kW/m, which are low in comparison to the South Pacific where more than 30 kW/m can be found. Aside of the low wave energy potential, the areas with higher energy flux are very distant from the island, which means that only offshore wave energy converters (WECs) could be considered for energy harnessing, onshore and nearshore WECs are not suitable.

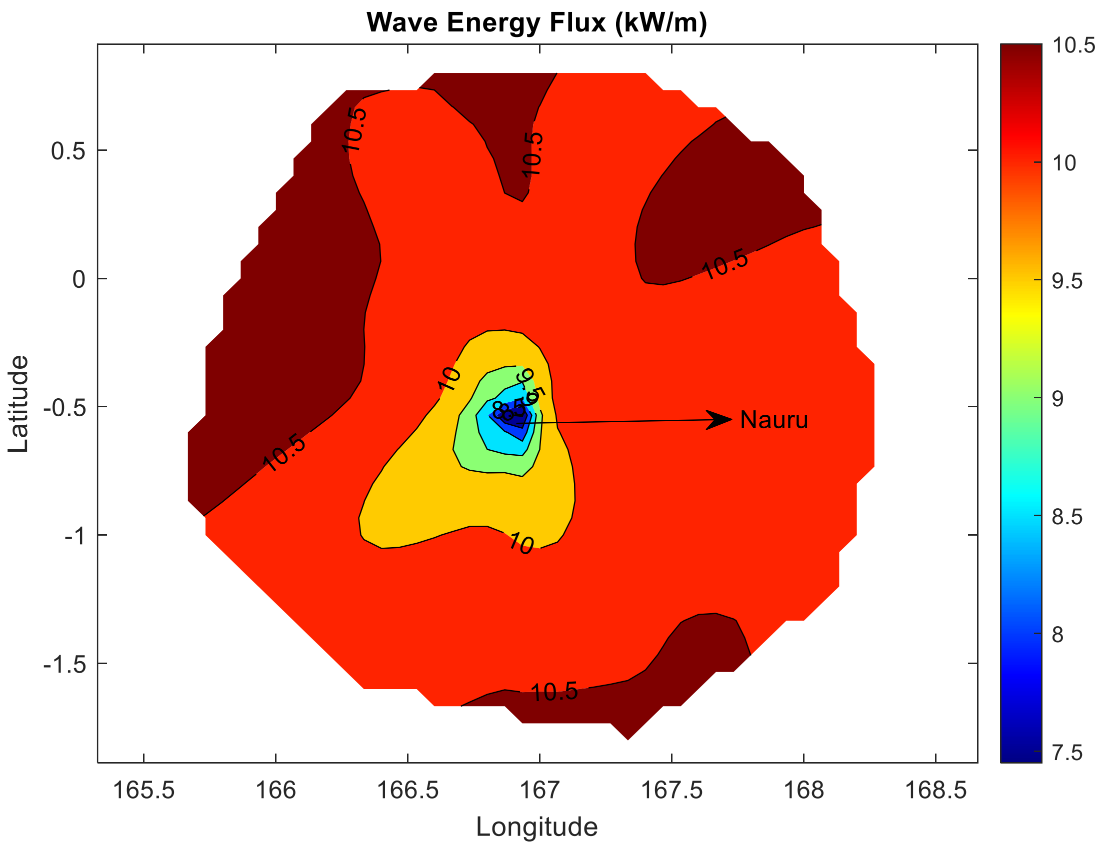


Figure 2. Wave energy flux (kW/m) near Nauru.

2. Current:

At 50m depth, the current speed varies between 0.2 and -0.9 m/s. The kinetic energy was estimated at 50m depth to estimate the current energy density near Nauru. According to the results in the images below, energy varies from 0 to 1.8 kW/m2. There are two hot spots for ocean current energy close to the island, one in the Southeast and one in the Northwest; at both locations it is possible to find the maximum of 1.8 kW/m2.

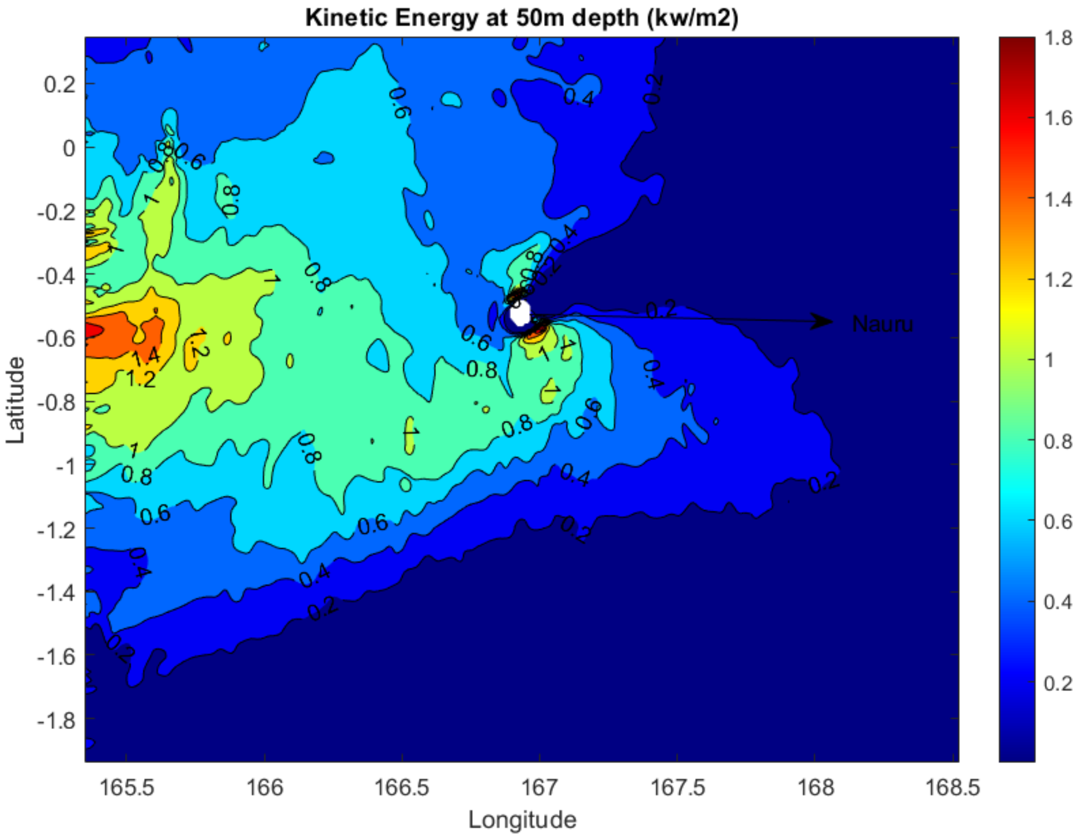


Figure 3. Kinetic energy at 50m depth near Nauru in kW/m2.

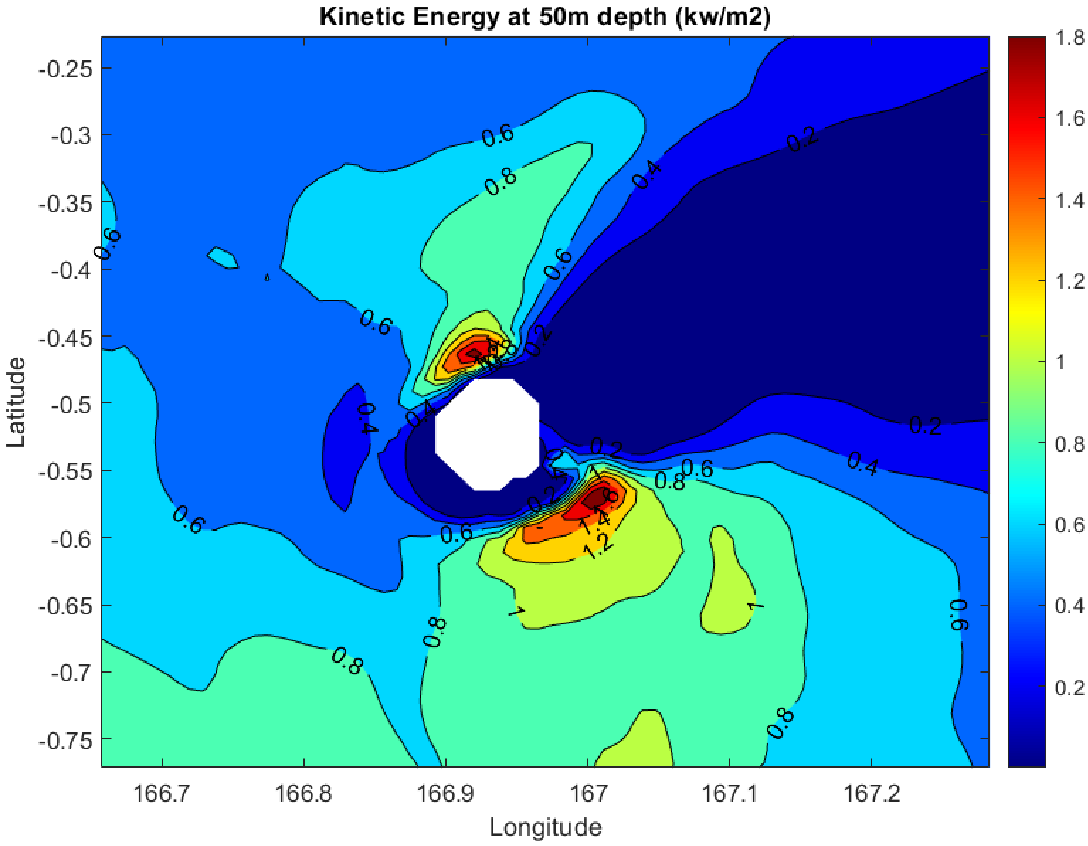


Figure 4. Kinetic energy at 50m depth zoomed at the island area in kW/m2.

3. Thermal:

Nauru is located near the Equator, where temperature difference is significantly high due to high surface temperatures. Power density was estimated using the temperature difference between 0m and 700m, and the results can be seen at the plot below. The area surrounding Nauru shows values close to the 2.15 – 2.20 W/m2 range, with the South, North and East having the highest values. Nevertheless, the difference in power density near Nauru is rather small.

F

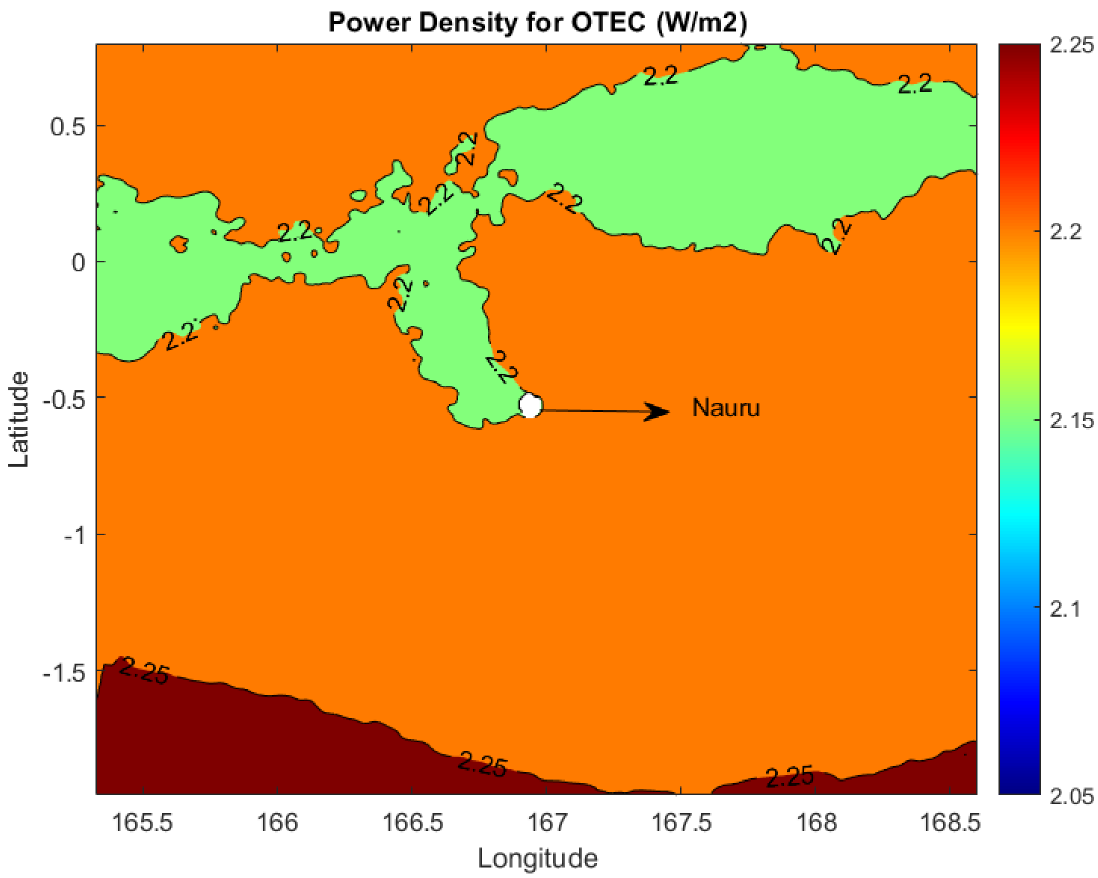


Figure 5. Power density for Ocean Thermal Energy Conversion near Nauru (W/m2).

(ii) Explanation of the simulation model and how it has been used to estimate ocean energy potential

The process of creating the Nauru model was divided into three stages (see figure 8 for a simplified schematic):

1. Obtain temperature, salinity, velocity and surface elevation data from the HYCOM database for the Nauru domain. The domain has dimensions 1080x900km and the data obtained was for the whole year of 2020. HYCOM is a global ocean model with 9km resolution.

2. Use ROMS (Regional Ocean Modeling System) to create a 3km model for the Nauru domain, using the HYCOM data for boundary and initial conditions.

3. Use the output from the 3km model as boundary/initial conditions to further downscale it to 1km, again using ROMS. This time, the domain was 360x300km centered in Nauru, and the shape of the island was better defined. The figures below show the 1km grid that was used for the model containing bathymetry data, when we zoom into the island the island representation seems much clearer. Final temperature profiles are obtained from the 1km model (Nauru Model).

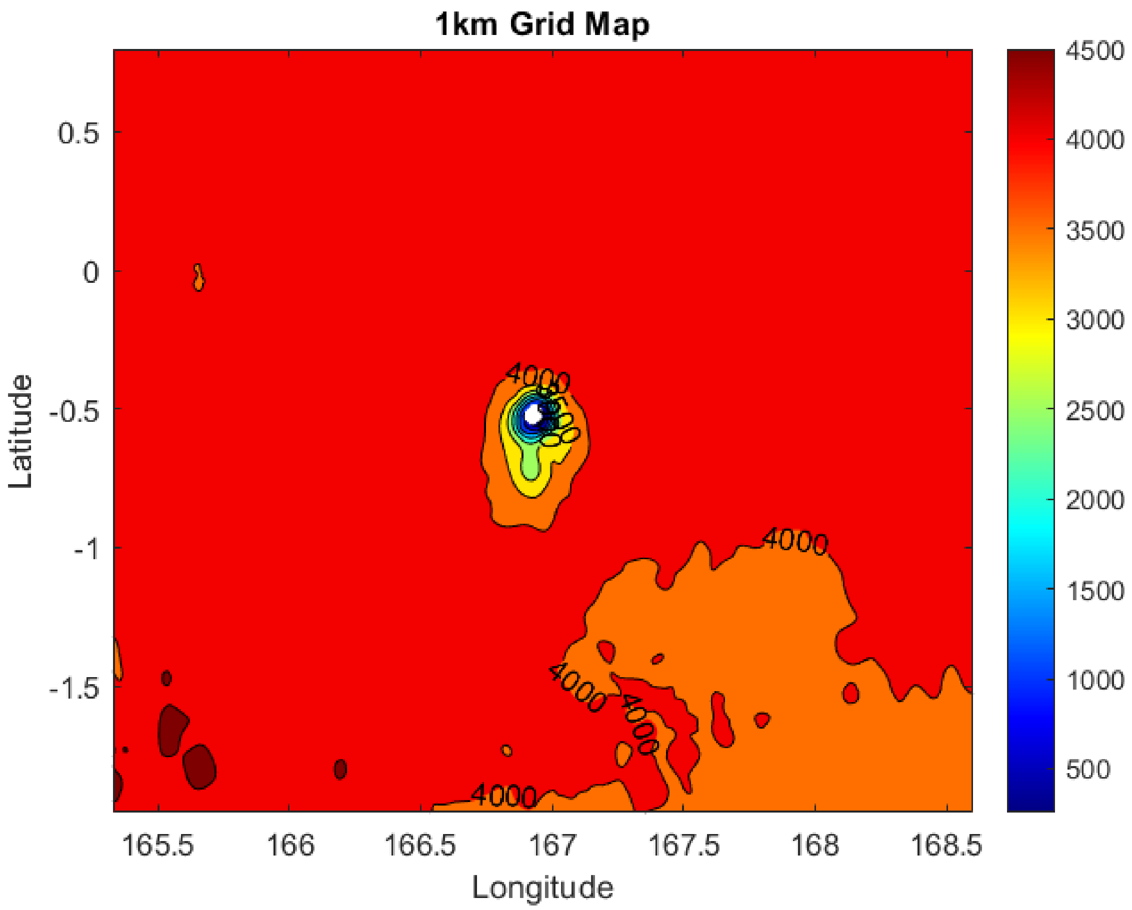


Figure 6. Bathymetry data in the 1km grid for Nauru, full domain.

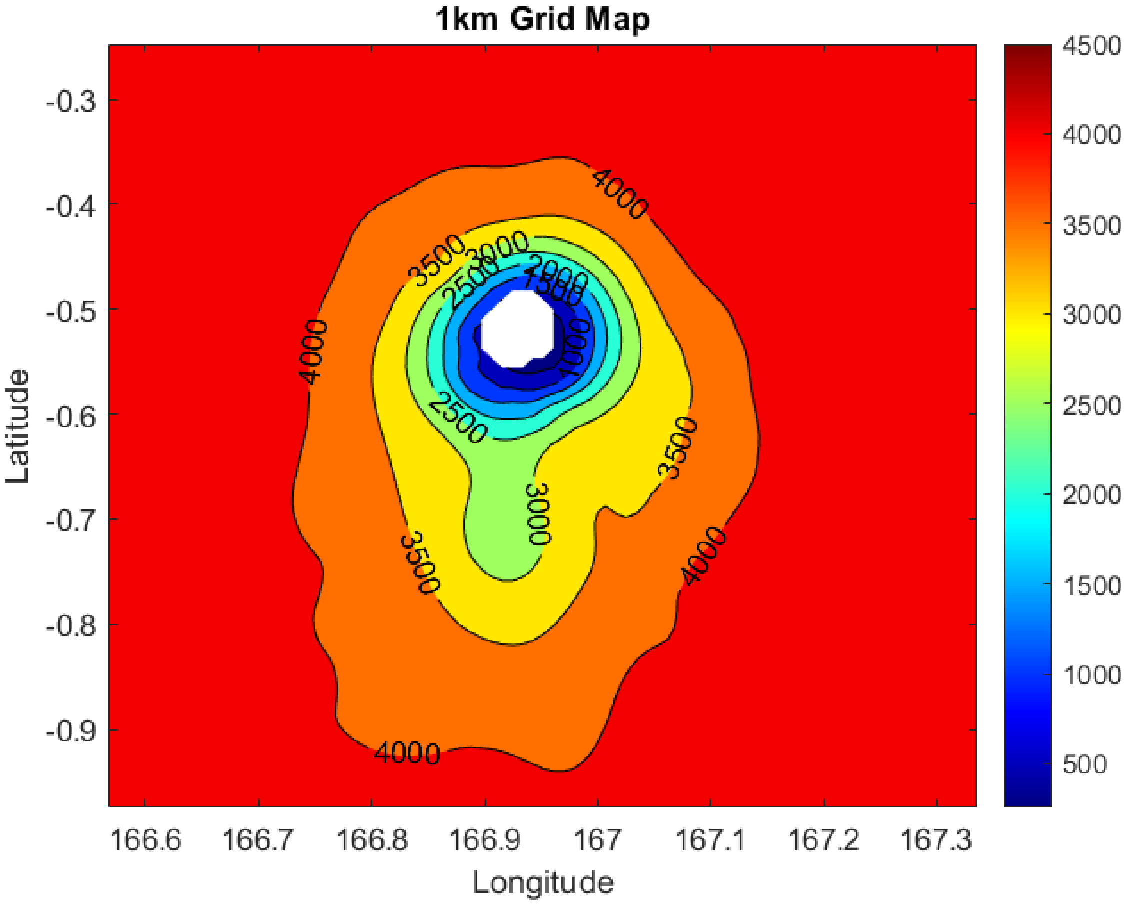


Figure 7. Bathymetry data in the 1km grid for Nauru, zoomed into the island area, which is represented by the color white.

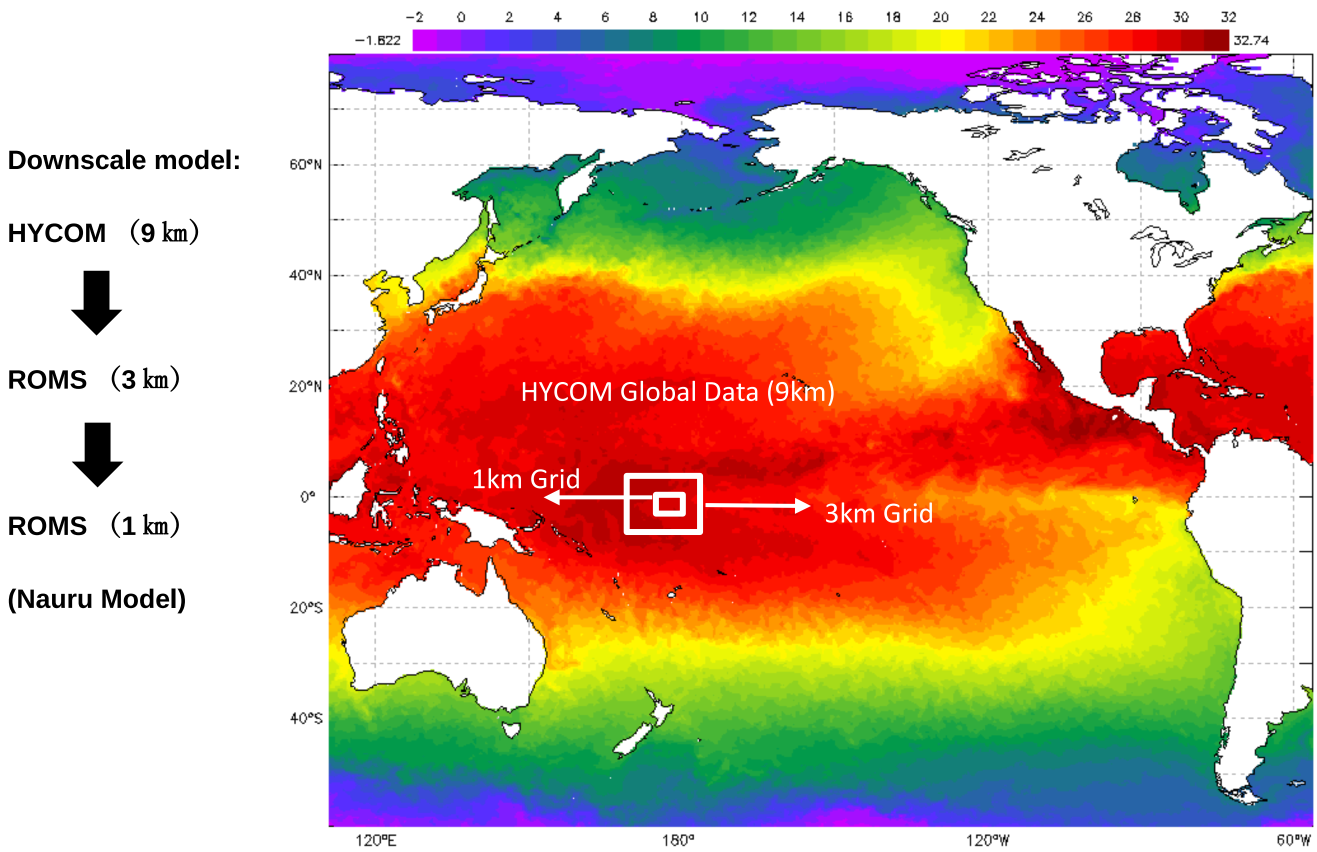


Figure 8. Schematic of the Nauru model: It starts with the HYCOM data with 9km resolution (background map in the figure), then ROMS is used to downscale it to 3km resolution (outer square), and, lastly, ROMS is used again to downscale from 3km to 1km resolution (inner square).

(iii) Information used in the model: Location (longitude/latitude), numerical data set and profiles for temperature, and Salinity for each candidate sites (5 points) with the specified template

1. Sites Coordinates

Point 1: 166.9104104°E 0.5519202°S

Point 2: 166.9064007°E 0.5398911°S

Point 3: 166.9074354°E 0.5193250°S

Point 4: 166.9154549°E 0.5111762°S

Point 5: 166.9311058°E 0.4942318°S

2. Temperature Profiles

The plots below represent the temperature average in degrees Celsius for each site. According to the results, there is surface temperature variation between sites, with point 5 having the highest temperature (29.43) and point 1 having the lowest (28.59). At higher depths the profiles are very similar, which means that surface temperature will be a more important variable to consider when choosing a site.

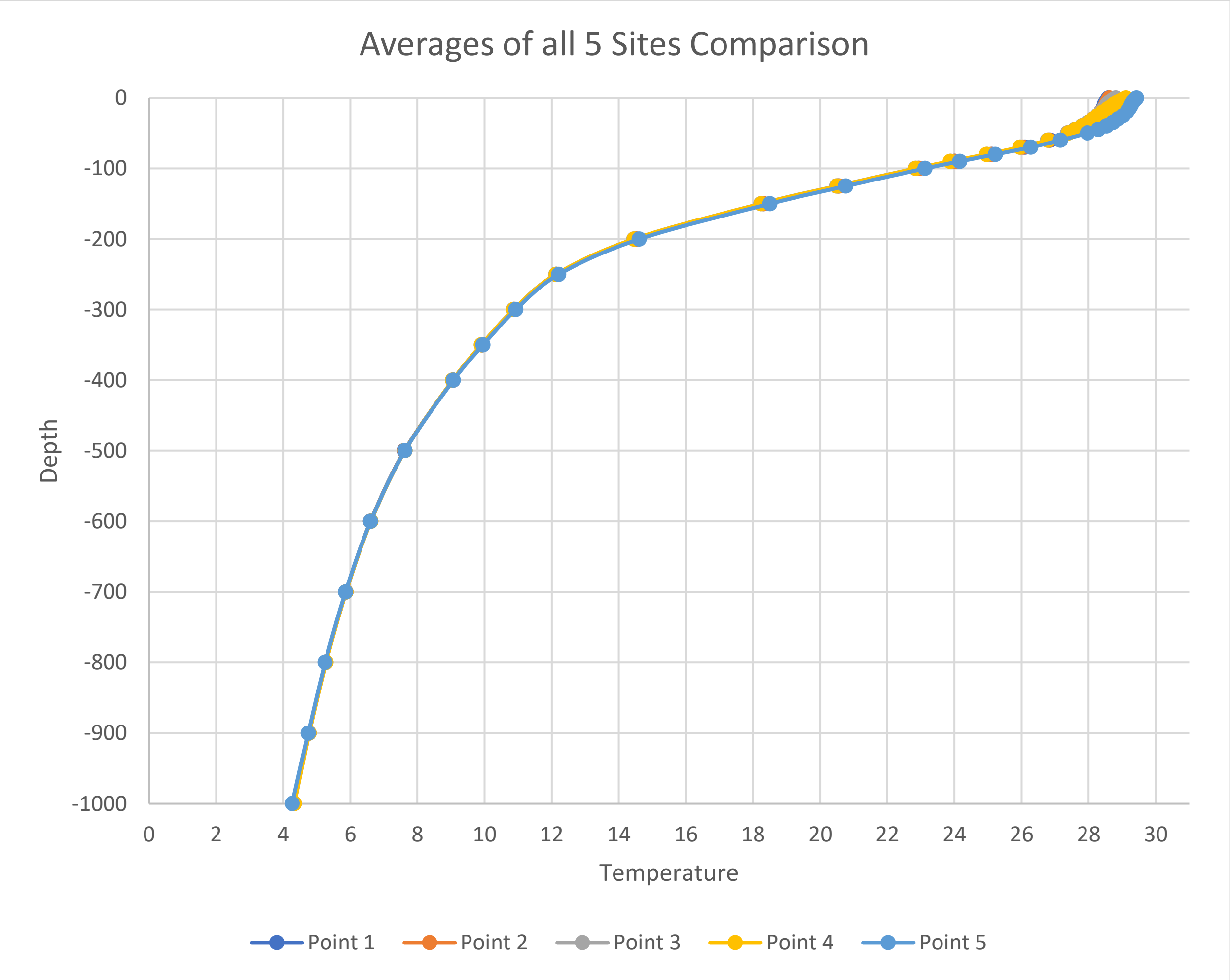


Figure 9. Average temperature profiles in degrees Celsius for each site compared with each other.

3. Salinity Profiles

The plots below represent the salinity average in PSU for each site. According to the results, there is a large variation of surface salinity between the sites, which can vary from 34.84 at point 5, to 35.04 at point 1. Aside of that, there is also a visible difference in salinity from 0m to 150m, as well as from 500m to 1000m. Point 5, in the North of the island, seems to have particularly distinct characteristics when it comes to salinity profile, with lower salinity values at shallow and deep areas.

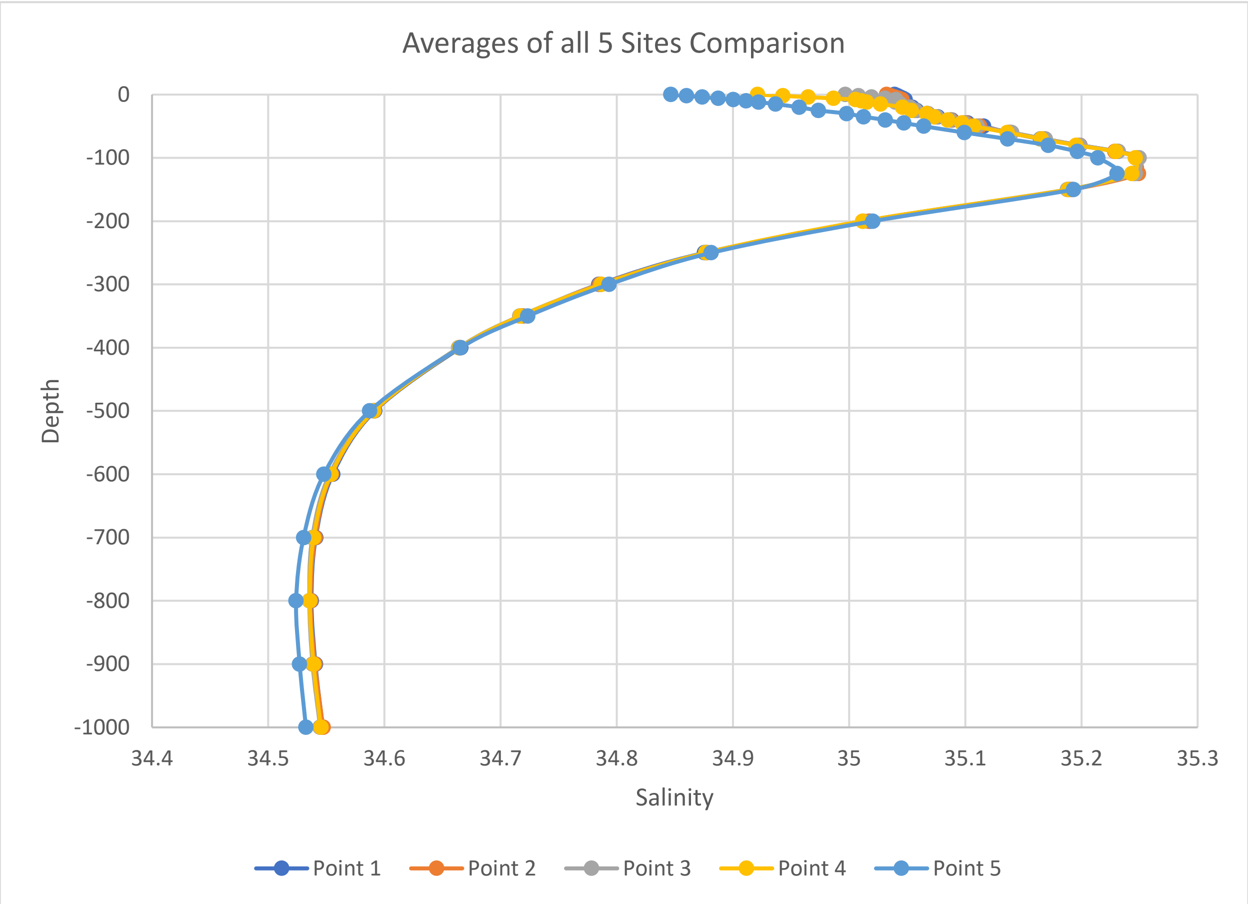


Figure 10. Average salinity profiles in PSU for each site compared with each other.

6.3 To supply the software package that enables to interactively display data at any point from land to horizontal distance of 20 km for following parameters (depth, temperature, salinity, density, flow velocity / direction, difference between surface water temperature and water temperature, energy potential).

In order to display the variables in geographical coordinates GIS packages were used, since they allow the user to visualize spatial data in layers using a basemap and useful tools, such as ruler to measure distance. Both ArcGIS and QGIS have been used, which are similar software in terms of capacities, nevertheless, QGIS is free and open source.

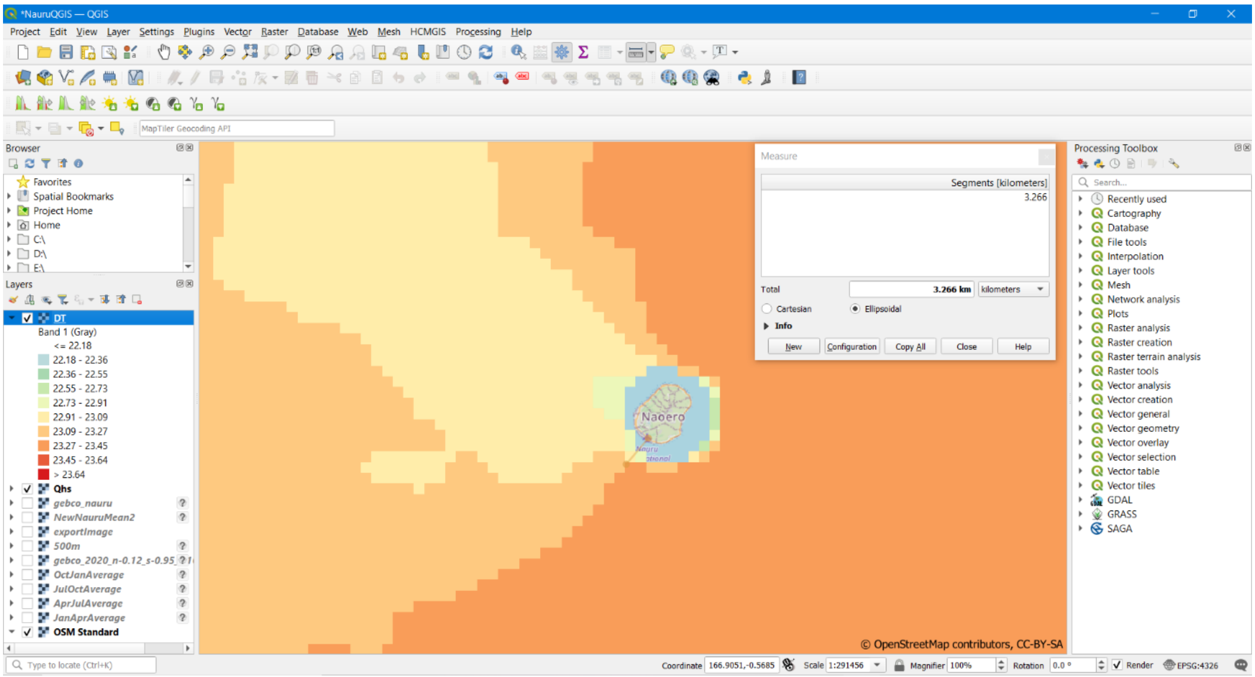


Figure 11. QGIS screen display.

Example: The image above shows how QGIS can be used to display the temperature difference at 700m depth surrounding Nauru in a raster format. The distance between the airport area and the closest grid point with 24 degrees’ difference is being measured in km.

Annex 4: Temperature & Salinity Data Profiles at 5 selected locations

Temperature data

Point 1		Point 2		Point 3		Point 4		Point 5	
Latitude	0.5560438° S	Latitude	0.5593551° S	Latitude	0.5192888° S	Latitude	0.5095206° S	Latitude	0.4923848° S
Longitude	166.9073475° E	Longitude	166.9048640° E	Longitude	166.9057746° E	Longitude	166.9139700° E	Longitude	166.9302780° E
Distance (km)	0.86	Distance (km)	0.48	Distance (km)	0.65	Distance (km)	0.86	Distance (km)	1.02
Depth (m)	809	Depth (m)	754	Depth (m)	647	Depth (m)	573	Depth (m)	749
DT (20m - 700m)	21.89133	DT (20m - 700m)	21.91176	DT (20m - 700m)	21.90791	DT (20m - 700m)	21.97885	DT (20m - 700m)	22.60514

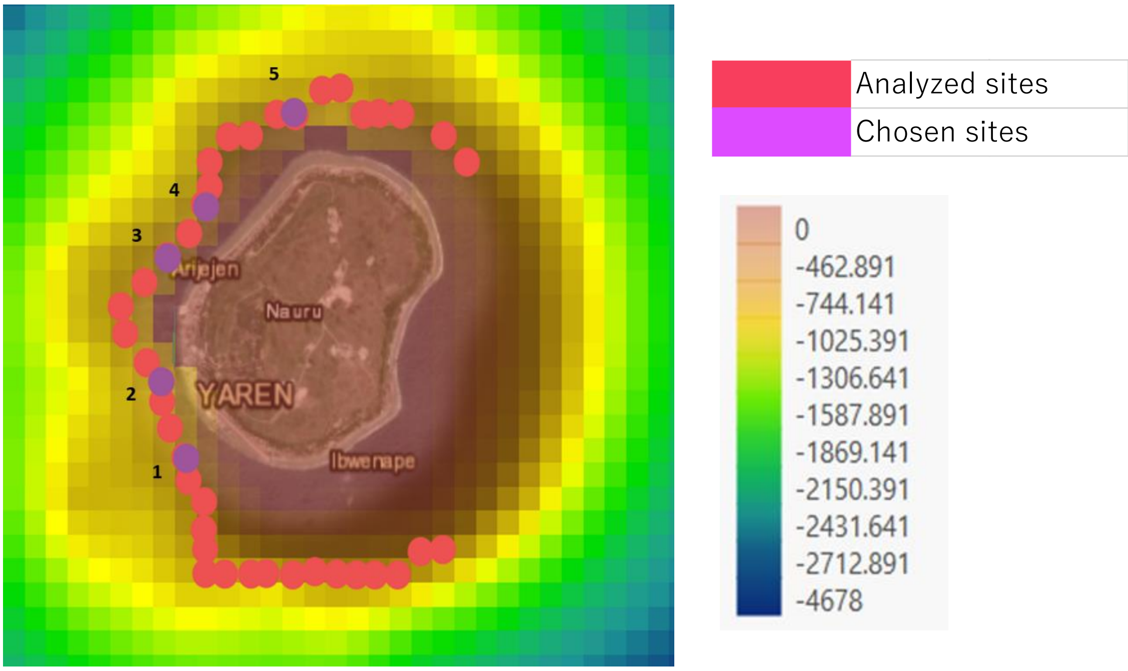
Point 1	Temperature (C)		
Depth (m)	Minimum	Average	Maximum
0	27.96306	28.59095	29.21883
-2	27.93554	28.56268	29.18983
-4	27.90801	28.53442	29.16082
-6	27.88048	28.50615	29.13182
-8	27.85636	28.48065	29.10494
-10	27.84999	28.46956	29.08914
-12	27.84362	28.45848	29.07333
-15	27.81898	28.42785	29.03672
-20	27.76046	28.36064	28.96082
-25	27.68225	28.27413	28.86601
-30	27.56287	28.14413	28.7254
-35	27.44375	27.98969	28.53563
-40	27.28624	27.82227	28.35829
-45	27.11544	27.62475	28.13407
-50	26.94007	27.39783	27.85559
-60	26.52833	26.85834	27.18835
-70	25.92798	26.10355	26.27912
-80	25.07746	25.12477	25.17207
-90	23.91543	24.00538	24.09533
-100	22.76358	22.93148	23.09937
-125	20.69984	20.54212	20.38441
-150	18.73568	18.31414	17.89261
-200	14.93468	14.51368	14.09268
-250	12.46862	12.13926	11.8099
-300	11.09356	10.88053	10.66749
-350	10.07241	9.931683	9.790958
-400	9.159105	9.062614	8.966124
-500	7.646769	7.612538	7.578308
-600	6.600084	6.605439	6.610794
-700	5.869127	5.868946	5.868765
-800	5.293673	5.26703	5.240387
-900	4.826703	4.767416	4.708129
-1000	4.416861	4.328201	4.239541

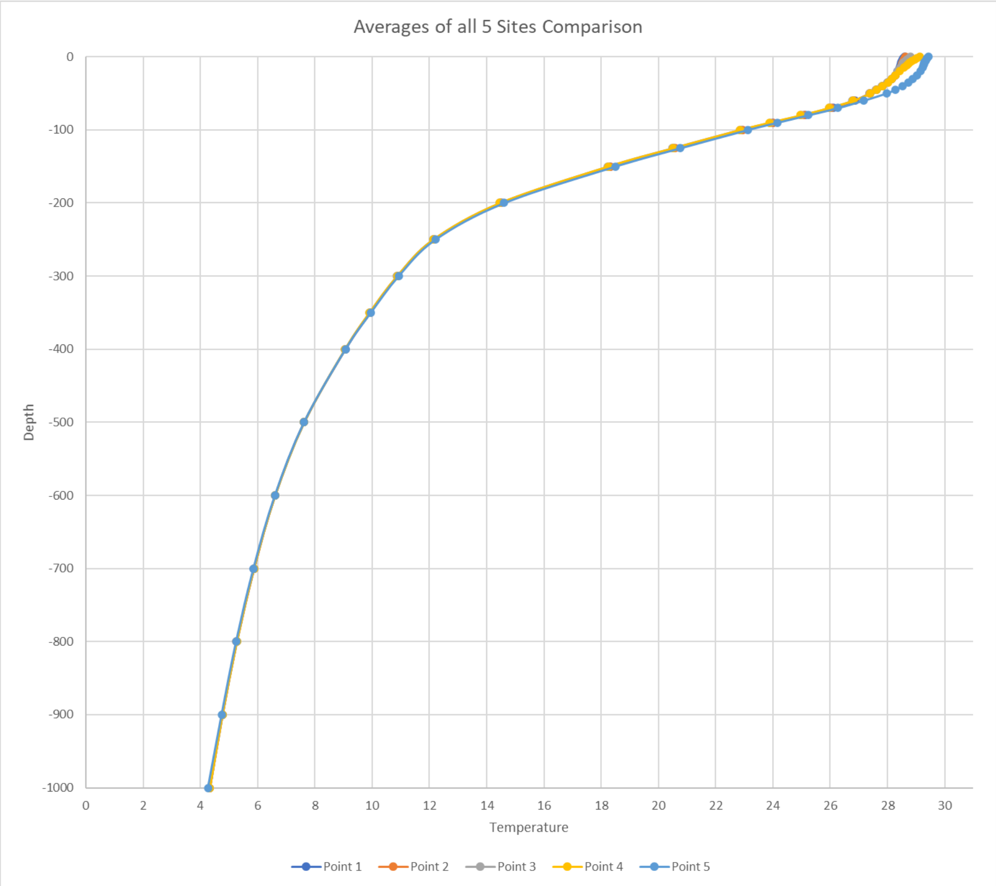
Point 2	Temperature (C)		
Depth (m)	Minimum	Average	Maximum
0	27.97509	28.62284	29.27059
-2	27.95783	28.5973	29.23676
-4	27.94057	28.57175	29.20293
-6	27.9233	28.5462	29.1691
-8	27.90721	28.52209	29.13696
-10	27.89717	28.50533	29.11349
-12	27.88714	28.48858	29.09002
-15	27.85456	28.44709	29.03962
-20	27.78539	28.36672	28.94805
-25	27.7084	28.28064	28.85288
-30	27.59961	28.14373	28.68785
-35	27.46719	27.9947	28.52221
-40	27.28844	27.80949	28.33055
-45	27.09597	27.60075	28.10553
-50	26.9009	27.37355	27.84621
-60	26.45969	26.81875	27.17781
-70	25.81745	26.03769	26.25794
-80	25.02869	25.08874	25.14879
-90	23.95042	24.01214	24.07386
-100	22.81528	22.95055	23.08582
-125	20.72141	20.57608	20.43075
-150	18.73999	18.31809	17.8962
-200	14.93252	14.51345	14.09438
-250	12.48523	12.15463	11.82404
-300	11.08916	10.88077	10.67237
-350	10.05774	9.925755	9.793769
-400	9.147143	9.055515	8.963887
-500	7.655382	7.619671	7.58396
-600	6.598876	6.60396	6.609045
-700	5.873638	5.870038	5.866439
-800	5.296183	5.265991	5.235799
-900	4.829308	4.766517	4.703726
-1000	4.416746	4.325566	4.234386

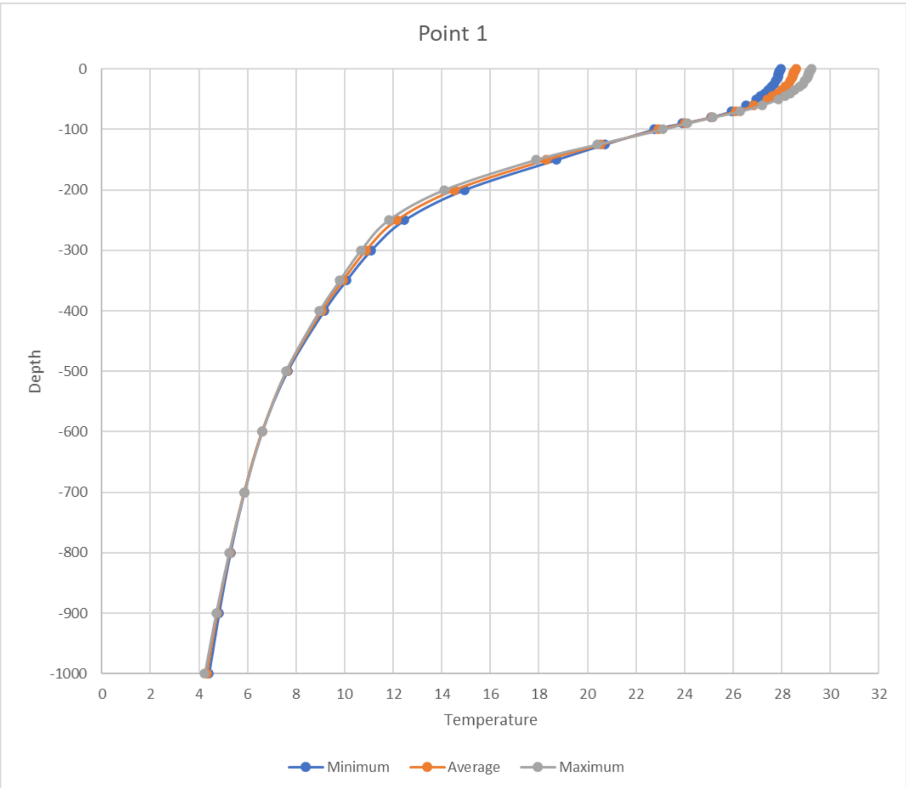
Point 3	Temperature (C)		
Depth (m)	Minimum	Average	Maximum
0	28.20132	28.80762	29.41393
-2	28.13099	28.74475	29.3585
-4	28.06067	28.68187	29.30308
-6	27.99034	28.619	29.24765
-8	27.92868	28.56206	29.19544
-10	27.91518	28.53812	29.16106
-12	27.90168	28.51418	29.12668
-15	27.85927	28.46037	29.06147
-20	27.78265	28.36233	28.94201
-25	27.72975	28.27628	28.8228
-30	27.60633	28.14452	28.6827
-35	27.48426	27.99436	28.50445
-40	27.30076	27.80379	28.30683
-45	27.11032	27.59593	28.08153
-50	26.93961	27.38139	27.82317
-60	26.4415	26.77751	27.11352
-70	25.73185	25.9534	26.17496
-80	24.88279	24.97837	25.07394
-90	23.80393	23.89928	23.99463
-100	22.73466	22.84232	22.94999
-125	20.63894	20.48534	20.33175
-150	18.65121	18.22964	17.80808
-200	14.86623	14.45395	14.04168
-250	12.45787	12.12971	11.80155
-300	11.07071	10.86587	10.66103
-350	10.02165	9.90237	9.783088
-400	9.138407	9.052123	8.965839
-500	7.667234	7.626927	7.58662
-600	6.612876	6.612736	6.612595
-700	5.874745	5.872281	5.869817
-800	5.303273	5.272977	5.242681
-900	4.833245	4.77267	4.712095
-1000	4.42055	4.334794	4.249038

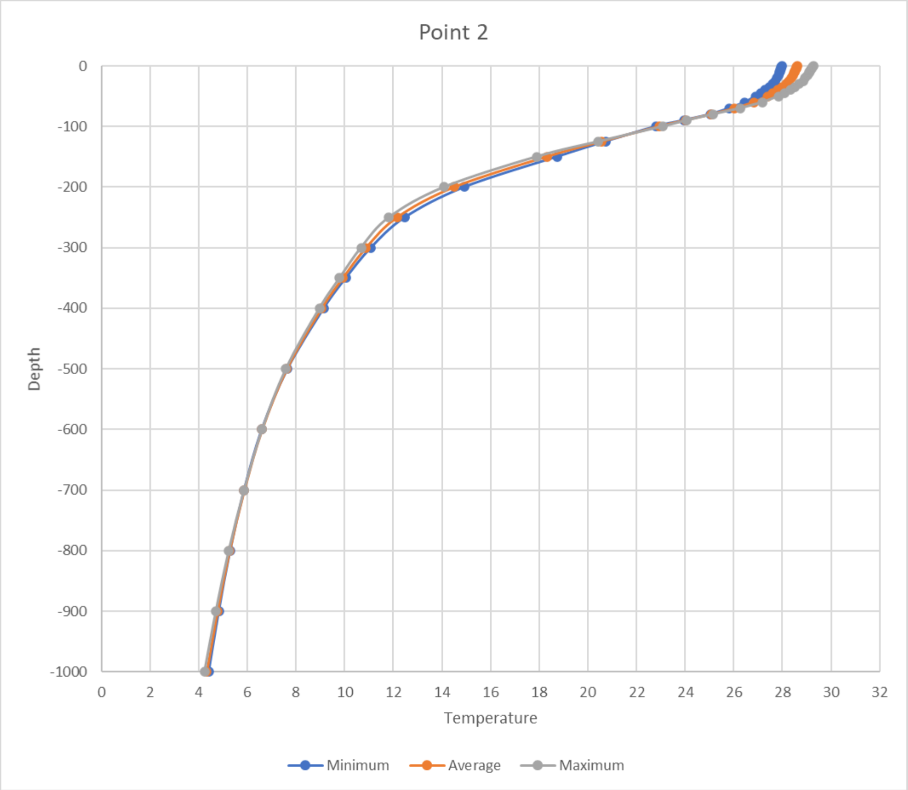
Point 4	Temperature (C)		
Depth (m)	Minimum	Average	Maximum
0	28.42934	29.11648	29.80361
-2	28.35622	29.0318	29.70739
-4	28.2831	28.94713	29.61116
-6	28.20997	28.86245	29.51493
-8	28.14369	28.78292	29.42215
-10	28.11518	28.73176	29.34835
-12	28.08666	28.68061	29.27455
-15	28.00518	28.58583	29.16649
-20	27.85201	28.42167	28.99134
-25	27.73547	28.28355	28.83164
-30	27.58416	28.15522	28.72628
-35	27.49132	28.01255	28.53377
-40	27.32682	27.82046	28.3141
-45	27.14829	27.61411	28.07993
-50	26.98369	27.40733	27.83097
-60	26.46893	26.7959	27.12287
-70	25.72054	25.95588	26.19123
-80	24.78026	24.96292	25.14557
-90	23.75834	23.87389	23.98945
-100	22.73885	22.84689	22.95492
-125	20.67933	20.50981	20.3403
-150	18.66779	18.23877	17.80975
-200	14.86589	14.45596	14.04603
-250	12.46462	12.13283	11.80104
-300	11.08042	10.8732	10.66599
-350	10.02595	9.906162	9.786371
-400	9.138878	9.053435	8.967991
-500	7.665679	7.625035	7.584391
-600	6.612378	6.612685	6.612993
-700	5.873156	5.871234	5.869313
-800	5.303298	5.27247	5.241642
-900	4.831754	4.771625	4.711495
-1000	4.420875	4.334973	4.249072

Point 5	Temperature (C)		
Depth (m)	Minimum	Average	Maximum
0	28.70738	29.42776	30.14814
-2	28.6732	29.39112	30.10903
-4	28.63902	29.35447	30.06992
-6	28.60485	29.31783	30.03081
-8	28.57452	29.28519	29.99586
-10	28.56237	29.2715	29.98062
-12	28.55023	29.2578	29.96537
-15	28.52128	29.22213	29.92298
-20	28.46479	29.1415	29.81821
-25	28.40406	29.02909	29.65412
-30	28.32893	28.87516	29.42139
-35	28.23667	28.72498	29.21329
-40	28.12876	28.53247	28.93619
-45	27.93849	28.28591	28.63333
-50	27.64469	27.96574	28.28679
-60	26.81503	27.16069	27.50635
-70	26.02312	26.27613	26.52913
-80	24.94987	25.22237	25.49486
-90	23.89741	24.15494	24.41248
-100	22.95036	23.12237	23.29438
-125	20.94585	20.76584	20.58584
-150	18.91797	18.50157	18.08518
-200	15.03455	14.61301	14.19147
-250	12.56276	12.21487	11.86699
-300	11.16311	10.92959	10.69606
-350	10.08922	9.956699	9.824174
-400	9.158187	9.072433	8.98668
-500	7.663074	7.625017	7.58696
-600	6.602806	6.605848	6.60889
-700	5.85965	5.856799	5.853947
-800	5.281867	5.250295	5.218724
-900	4.803927	4.745425	4.686924
-1000	4.349958	4.26791	4.185861

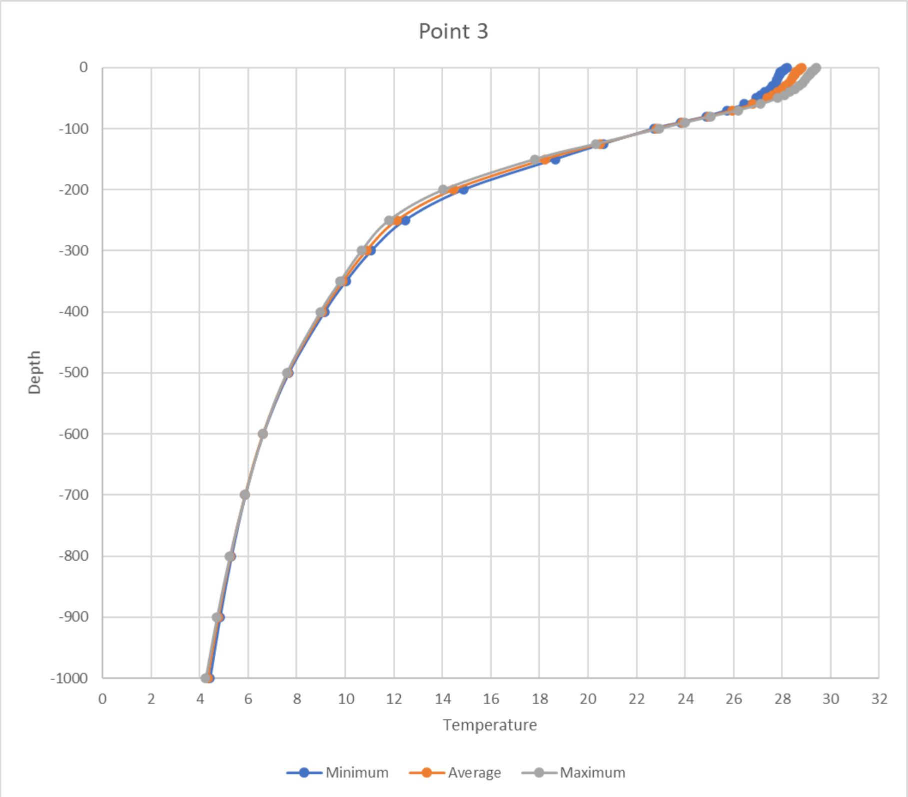



Averages of all 5 Sites Comparison
Depth
Temperature
0
-100
-200
-300
-400
-500
-600
-700
-800
-900
-1000
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Point 1
Point 2
Point 3
Point 4
Point 5

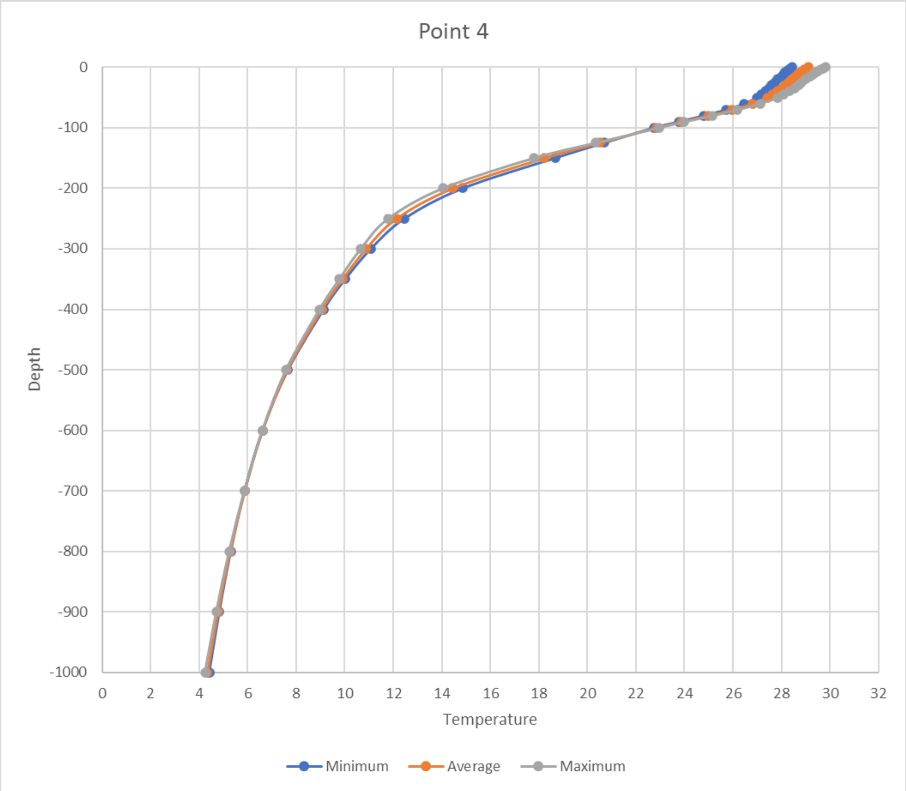

Point 1
Depth
Temperature
0
-100
-200
-300
-400
-500
-600
-700
-800
-900
-1000
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32
Minimum
Average
Maximum

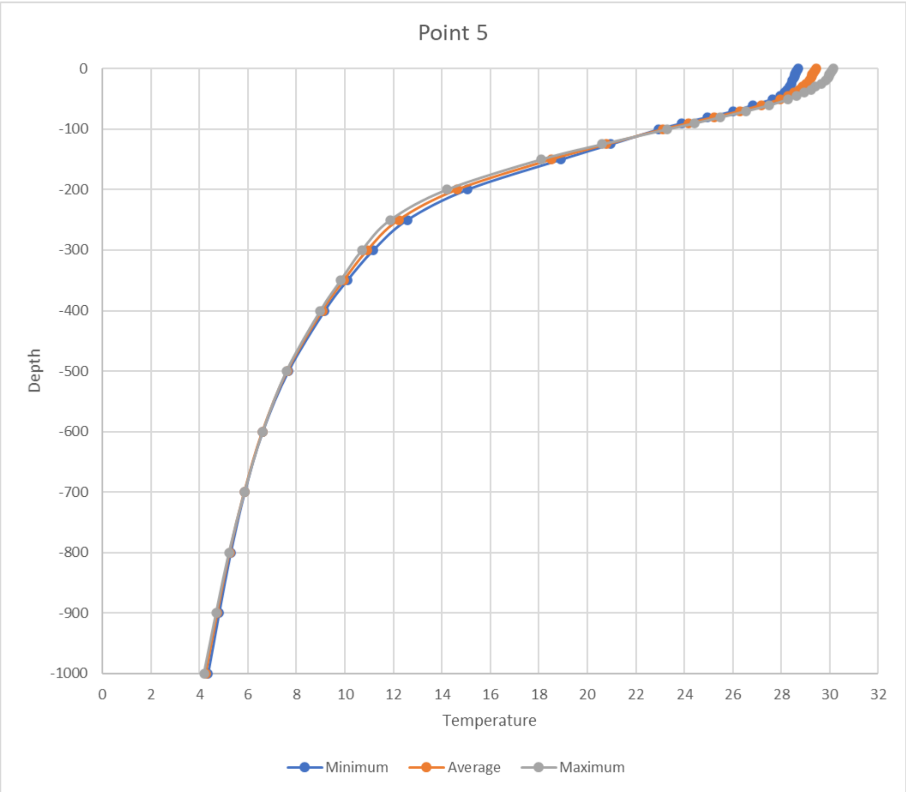


Point 2
Depth
Temperature
0
-100
-200
-300
-400
-500
-600
-700
-800
-900
-1000
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32
Minimum
Average
Maximum



Point 3
Depth
Temperature
0
-100
-200
-300
-400
-500
-600
-700
-800
-900
-1000
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32
Minimum
Average
Maximum


Point 4
0
-100
-200
-300
-400
-500
-600
-700
-800
-900
-1000
Depth
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32
Temperature
Minimum
Average
Maximum


Point 5
0
-100
-200
-300
-400
-500
-600
-700
-800
-900
-1000
Depth
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32
Temperature
Minimum
Average
Maximum

Salinity Data

Point 1		
Latitude	0.5560438	158
Longitude	166.90734	173
Distance (km)		0.86
Depth (m)		809
DSalt (20m - 700m)		0.648912

Point 1	Salinity (PSU)		
Depth (m)	Maximum	Average	Minimum
0	35.17986	35.03922	34.89858
-2	35.18139	35.04159	34.90179
-4	35.18292	35.04395	34.90499
-6	35.18445	35.04632	34.9082
-8	35.18575	35.04822	34.9107
-10	35.18588	35.04769	34.9095
-12	35.18602	35.04716	34.90831
-15	35.18821	35.04933	34.91045
-20	35.19253	35.05436	34.91619
-25	35.19548	35.05808	34.92068
-30	35.20319	35.06731	34.93144
-35	35.2113	35.0764	34.94149
-40	35.22391	35.08845	34.95298
-45	35.2368	35.10205	34.9673
-50	35.24845	35.11577	34.98308
-60	35.26925	35.13761	35.00597
-70	35.29859	35.16469	35.0308
-80	35.33409	35.19866	35.06323
-90	35.37391	35.23103	35.08815
-100	35.39322	35.24914	35.10507
-125	35.3809	35.24562	35.11034
-150	35.30945	35.18959	35.06973
-200	35.08429	35.01831	34.95232
-250	34.91006	34.87564	34.84121
-300	34.80118	34.78455	34.76792
-350	34.72588	34.7192	34.71251
-400	34.66741	34.6657	34.664
-500	34.59293	34.59167	34.59041
-600	34.55703	34.55553	34.55403
-700	34.54361	34.54093	34.53824
-800	34.54043	34.53724	34.53404
-900	34.54308	34.54068	34.53828
-1000	34.54799	34.54693	34.54587

Point 2		
Latitude	0.5593551	157
Longitude	166.90486	172
Distance (km)		0.48
Depth (m)		754
DSalt (20m - 700m)		0.650827

Point 2	Salinity (PSU)		
Depth (m)	Maximum	Average	Minimum
0	35.17645	35.0323	34.88816
-2	35.17764	35.03575	34.89387
-4	35.17883	35.0392	34.89958
-6	35.18002	35.04265	34.90529
-8	35.18114	35.0454	34.90967
-10	35.18189	35.04453	34.90717
-12	35.18264	35.04366	34.90468
-15	35.18506	35.04613	34.9072
-20	35.18978	35.05216	34.91455
-25	35.19412	35.05671	34.91931
-30	35.20066	35.06691	34.93317
-35	35.20977	35.07485	34.93994
-40	35.22245	35.08773	34.95301
-45	35.23535	35.10043	34.9655
-50	35.24758	35.11241	34.97724
-60	35.27216	35.13932	35.00647
-70	35.30094	35.16799	35.03504
-80	35.33095	35.1983	35.06566
-90	35.36842	35.22875	35.08908
-100	35.38922	35.24821	35.10719
-125	35.38635	35.24926	35.11218
-150	35.31418	35.19145	35.06871
-200	35.08335	35.01694	34.95054
-250	34.91292	34.87796	34.843
-300	34.80189	34.78528	34.76867
-350	34.72492	34.71897	34.71301
-400	34.66545	34.66469	34.66394
-500	34.59035	34.59112	34.5919
-600	34.55313	34.55464	34.55616
-700	34.53895	34.54046	34.54196
-800	34.53567	34.53651	34.53734
-900	34.53993	34.54024	34.54056
-1000	34.5465	34.54732	34.54815

Point 3		
Latitude	0.5192888	155
Longitude	166.90577	172
Distance (km)		0.65
Depth (m)		647
DSalt (20m - 700m)		0.650354

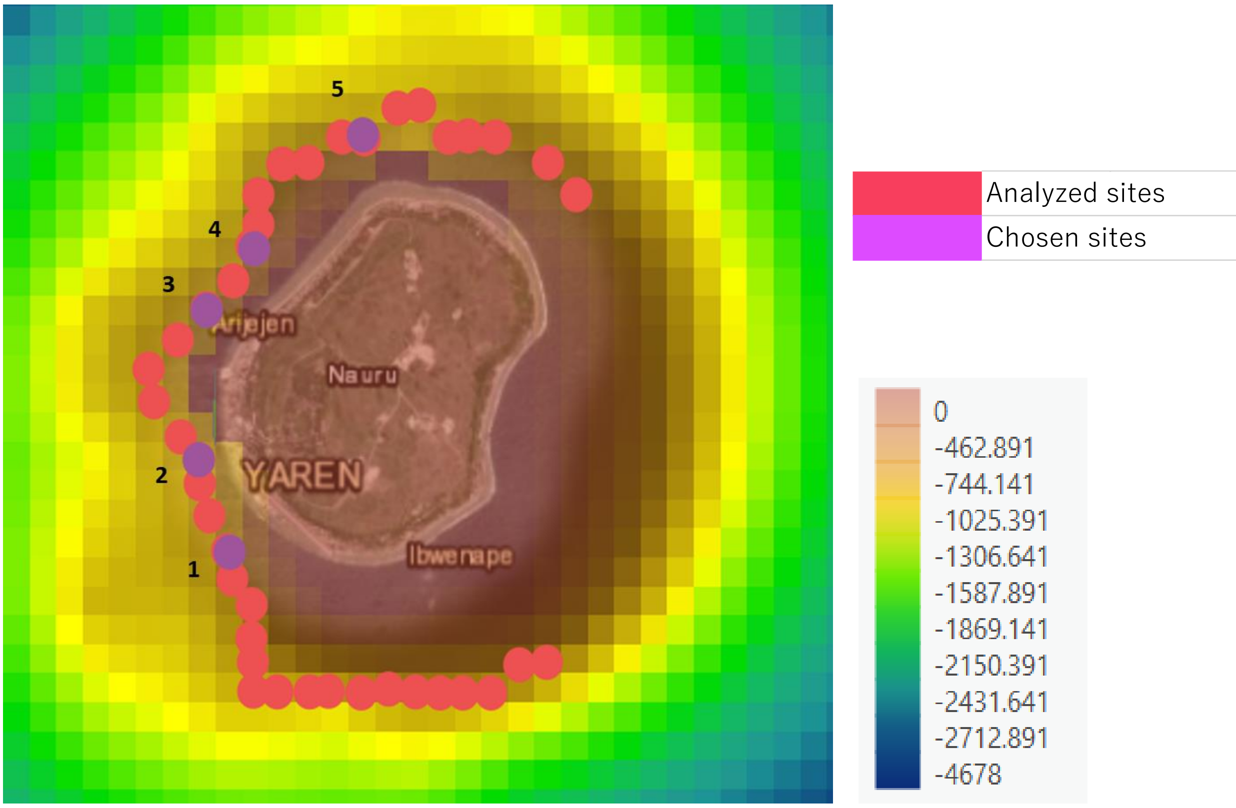
Point 3	Salinity (PSU)		
Depth (m)	Maximum	Average	Minimum
0	35.16014	34.99679	34.83343
-2	35.16495	35.00812	34.8513
-4	35.16975	35.01946	34.86916
-6	35.17456	35.03079	34.88703
-8	35.17872	35.04037	34.90203
-10	35.17928	35.04019	34.90111
-12	35.17984	35.04002	34.90019
-15	35.18244	35.04403	34.90562
-20	35.18798	35.05254	34.9171
-25	35.19316	35.05709	34.92101
-30	35.20145	35.06822	34.93499
-35	35.21	35.07533	34.94067
-40	35.22127	35.0868	34.95233
-45	35.23282	35.09908	34.96533
-50	35.24359	35.11029	34.97698
-60	35.27313	35.14	35.00687
-70	35.30377	35.16887	35.03397
-80	35.33449	35.19806	35.06163
-90	35.37367	35.23177	35.08986
-100	35.39328	35.24979	35.10629
-125	35.38254	35.2465	35.11046
-150	35.31008	35.18806	35.06604
-200	35.07676	35.01213	34.94751
-250	34.91108	34.87688	34.84267
-300	34.80127	34.78643	34.77158
-350	34.72036	34.71649	34.71262
-400	34.6633	34.66377	34.66424
-500	34.58866	34.5901	34.59155
-600	34.55191	34.55286	34.55382
-700	34.53763	34.53794	34.53825
-800	34.53438	34.53541	34.53645
-900	34.53709	34.53817	34.53926
-1000	34.54308	34.54469	34.54631

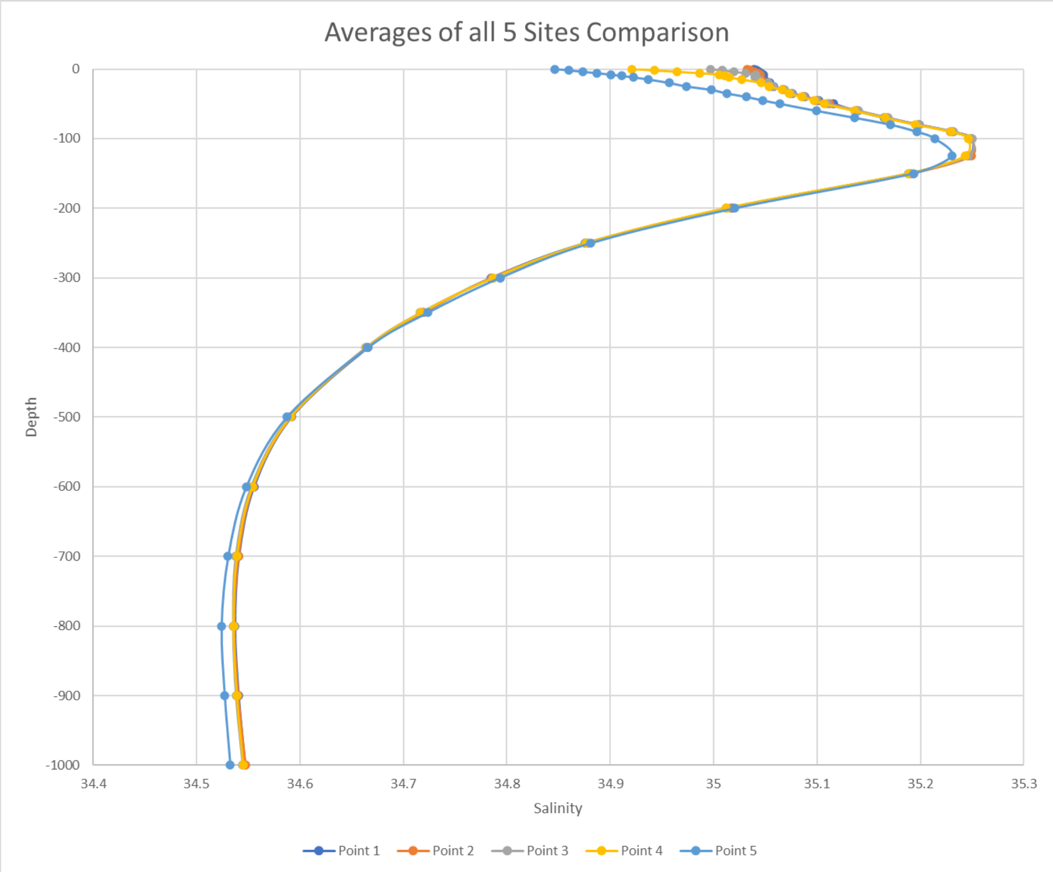
Point 4		
Latitude	0.5095206	154
Longitude	166.91397	172
Distance (km)		0.86
Depth (m)		573
DSalt (20m - 700m)		0.644291

Point 4	Salinity (PSU)		
Depth (m)	Maximum	Average	Minimum
0	35.13904	34.92129	34.70353
-2	35.14608	34.94302	34.73995
-4	35.15312	34.96475	34.77637
-6	35.16016	34.98648	34.81279
-8	35.16648	35.00561	34.84475
-10	35.16882	35.01045	34.85208
-12	35.17116	35.01529	34.85941
-15	35.17606	35.02712	34.87819
-20	35.18462	35.04599	34.90735
-25	35.19174	35.05346	34.91517
-30	35.20259	35.06665	34.93072
-35	35.20947	35.07303	34.93658
-40	35.21969	35.08487	34.95005
-45	35.23027	35.09706	34.96384
-50	35.24007	35.10723	34.9744
-60	35.27075	35.13624	35.00173
-70	35.3022	35.16542	35.02865
-80	35.33729	35.19546	35.05364
-90	35.37335	35.22953	35.0857
-100	35.39253	35.24634	35.10016
-125	35.38061	35.24343	35.10625
-150	35.31377	35.18886	35.06396
-200	35.07567	35.01176	34.94786
-250	34.91126	34.87664	34.84202
-300	34.8018	34.78687	34.77195
-350	34.72129	34.71712	34.71294
-400	34.66456	34.66452	34.66449
-500	34.59064	34.59085	34.59107
-600	34.55447	34.5541	34.55373
-700	34.54033	34.53904	34.53775
-800	34.53737	34.53581	34.53425
-900	34.54005	34.53896	34.53788
-1000	34.54528	34.5453	34.54532

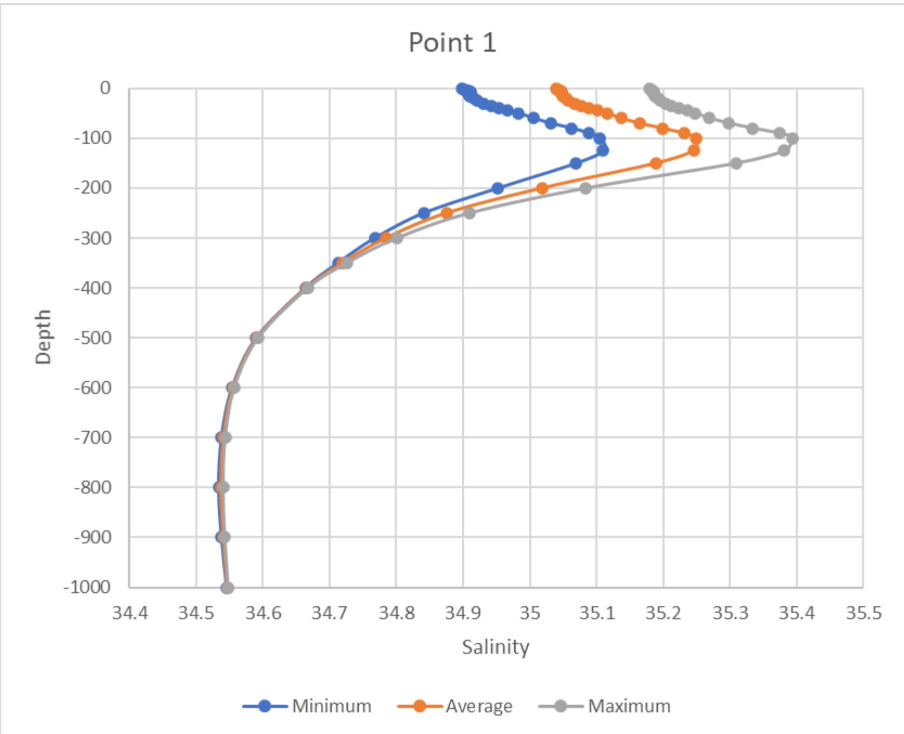
Point 5		
Latitude	0.4923848	152
Longitude	166.93027	174
Distance (km)		1.02
Depth (m)		749
DSalt (20m - 700m)		0.616483

Point 5	Salinity (PSU)		
Depth (m)	Maximum	Average	Minimum
0	35.10904	34.84647	34.58389
-2	35.11178	34.86006	34.60834
-4	35.11451	34.87365	34.63279
-6	35.11725	34.88724	34.65724
-8	35.12021	34.90037	34.68053
-10	35.12422	34.91127	34.69832
-12	35.12823	34.92217	34.71612
-15	35.13424	34.93678	34.73932
-20	35.14463	34.95693	34.76924
-25	35.15525	34.97362	34.79199
-30	35.16407	34.99789	34.83171
-35	35.17226	35.0125	34.85274
-40	35.17902	35.03131	34.8836
-45	35.18831	35.04726	34.90621
-50	35.20156	35.06427	34.92697
-60	35.2382	35.09933	34.96046
-70	35.27495	35.13635	34.99775
-80	35.31966	35.17133	35.02301
-90	35.34764	35.19644	35.04524
-100	35.36308	35.21427	35.06546
-125	35.37331	35.23065	35.088
-150	35.32387	35.19326	35.06265
-200	35.0913	35.02044	34.94958
-250	34.91883	34.88136	34.84388
-300	34.80884	34.79336	34.77788
-350	34.72598	34.72338	34.72078
-400	34.66192	34.66527	34.66863
-500	34.58333	34.58728	34.59122
-600	34.54461	34.54796	34.55131
-700	34.52815	34.53042	34.53269
-800	34.5237	34.52405	34.52439
-900	34.52782	34.52706	34.5263
-1000	34.53185	34.53248	34.53311

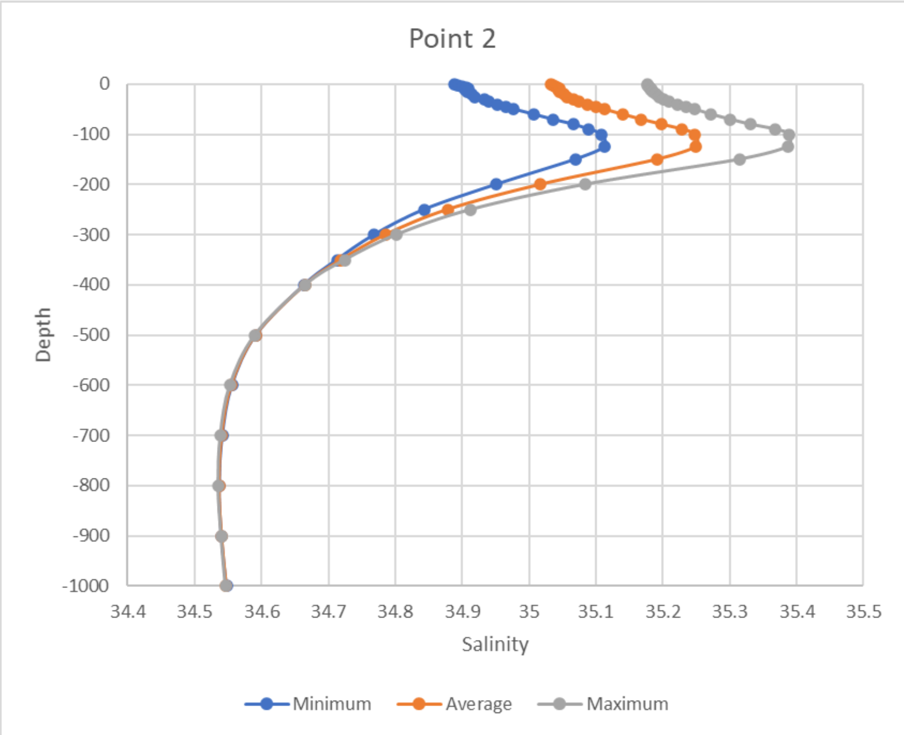


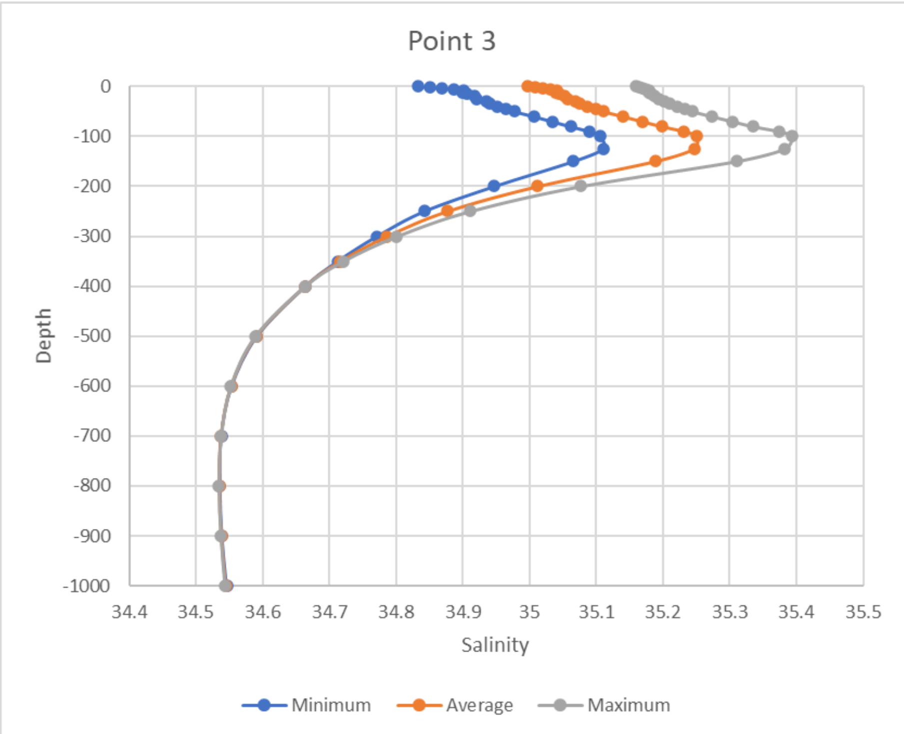


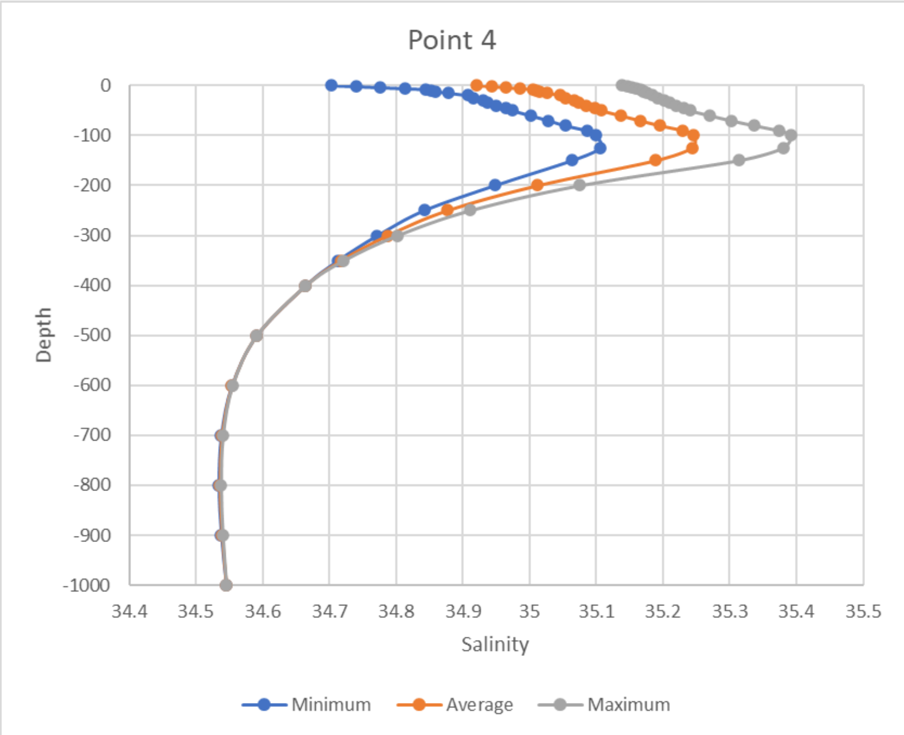
Averages of all 5 Sites Comparison
Depth
Salinity
0
-100
-200
-300
-400
-500
-600
-700
-800
-900
-1000
34.4
34.5
34.6
34.7
34.8
34.9
35
35.1
35.2
35.3
Point 1
Point 2
Point 3
Point 4
Point 5

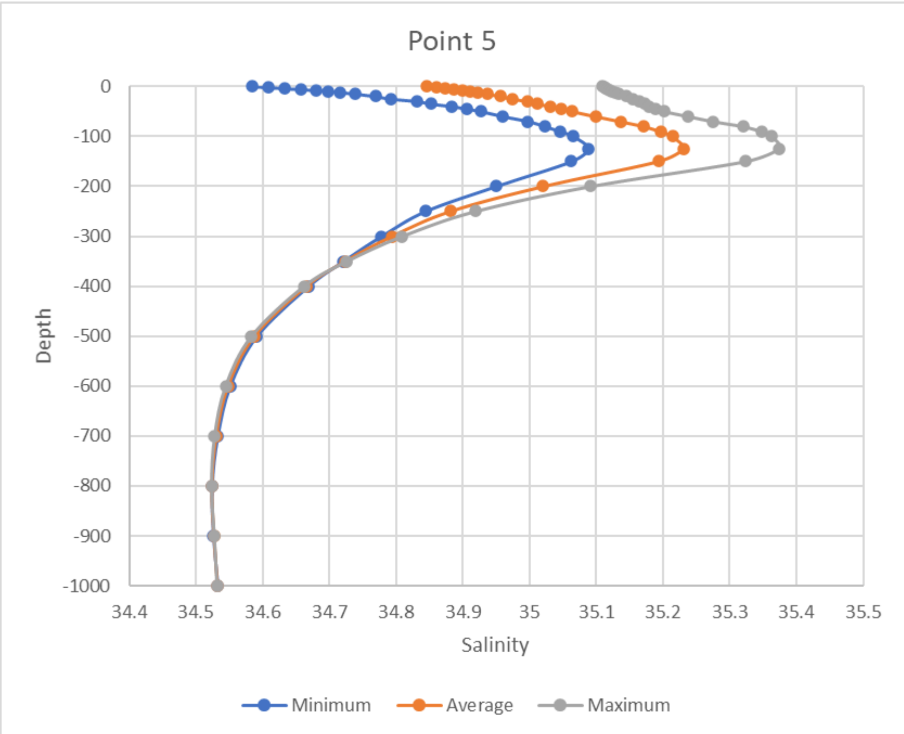


Point 1
Depth
Salinity
0
-100
-200
-300
-400
-500
-600
-700
-800
-900
-1000
34.4
34.5
34.6
34.7
34.8
34.9
35
35.1
35.2
35.3
35.4
35.5
Minimum
Average
Maximum


Point 2
Depth
0
-100
-200
-300
-400
-500
-600
-700
-800
-900
-1000
34.4
34.5
34.6
34.7
34.8
34.9
35
35.1
35.2
35.3
35.4
35.5
Salinity
Minimum
Average
Maximum


Point 3
Depth
0
-100
-200
-300
-400
-500
-600
-700
-800
-900
-1000
34.4
34.5
34.6
34.7
34.8
34.9
35
35.1
35.2
35.3
35.4
35.5
Salinity
Minimum
Average
Maximum


Point 4
0
-100
-200
-300
-400
-500
-600
-700
-800
-900
-1000
Depth
34.4
34.5
34.6
34.7
34.8
34.9
35
35.1
35.2
35.3
35.4
35.5
Salinity
Minimum
Average
Maximum


Point 5
0
-100
-200
-300
-400
-500
-600
-700
-800
-900
-1000
Depth
34.4
34.5
34.6
34.7
34.8
34.9
35
35.1
35.2
35.3
35.4
35.5
Salinity
Minimum
Average
Maximum

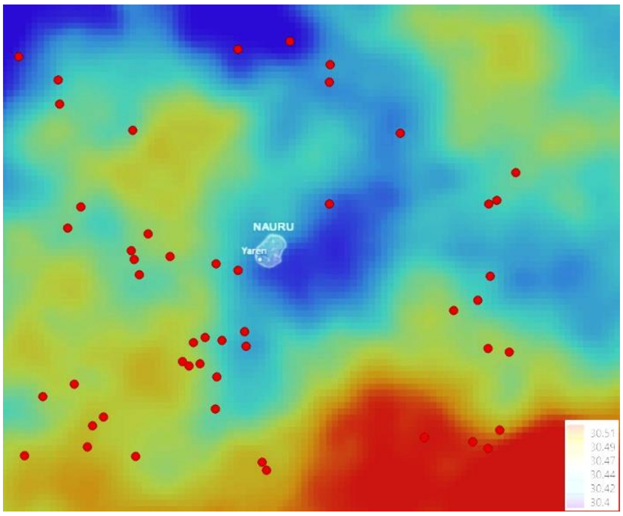
Annex 5: Temperature Profile Report

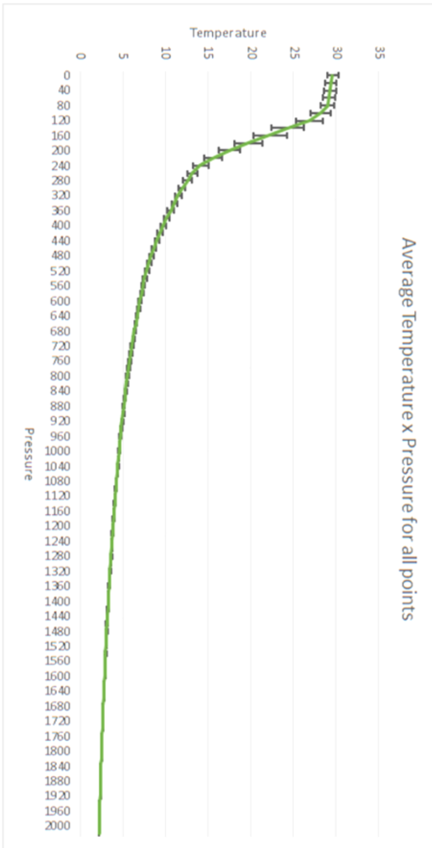
The Argo profiles available within the domain 112 km by 92 km surrounding Nauru were downloaded (62 profiles) and the mean temperature profile was obtained. Data covers a period from 2001 – 2021.

From the surface to the thermocline, the temperature difference is noticeable (relatively large standard deviation), which can be attributed to spatial and temporal (seasonal and daily) variations. However, below the thermocline between 400 m and 2000 m, the standard deviation of the temperature is small.

At the surface, the temperature is around 29.6 $\pm$ 0.64 degrees. The temperature between 400 m and 1000 m ranges from 9.8$\pm$0.34 degrees to 4.6$\pm$0.12 degrees. That gives the temperature difference between the surface and the deep water at 400 m to 1000 m in the range of 19.8 $\pm$ 0.98 degrees to 25 $\pm$ 0.76 degrees (neglecting the independence of the variation).

Near the coast, the thermocline depth may change but the temperatures of both the mixed layer water near the surface and the water below the thermocline may not change much. The details will be revealed by the high-resolution model that is under preparation.





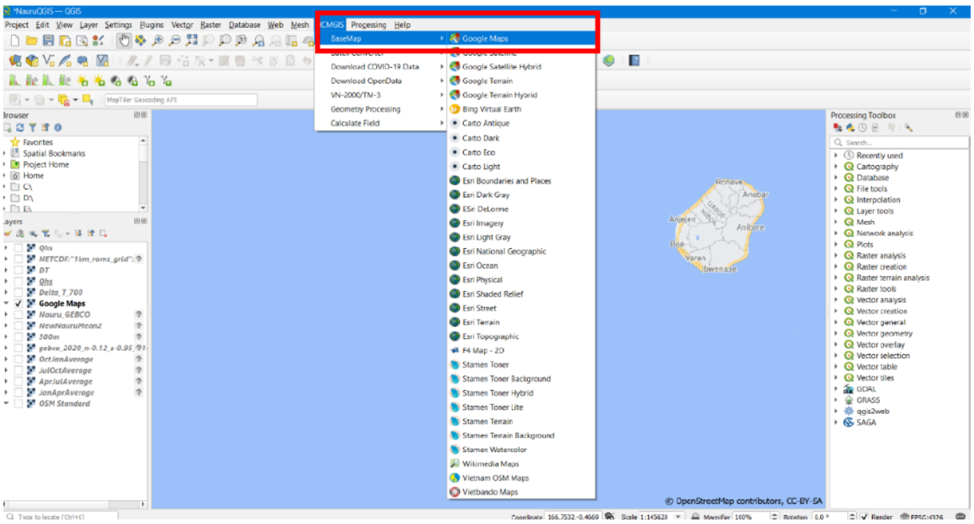
Left: Coordinates of the Argo profiles included for this analysis. Background is satellite-derived SST in degrees Celsius. The spatial variation of SST is 0.1 degrees. Right: Mean temperature profile in degrees Celsius versus Pressure in decibars. Pressure is assumed to be depth.

Annex 6: Guide on How to Visualize the Nauru Files

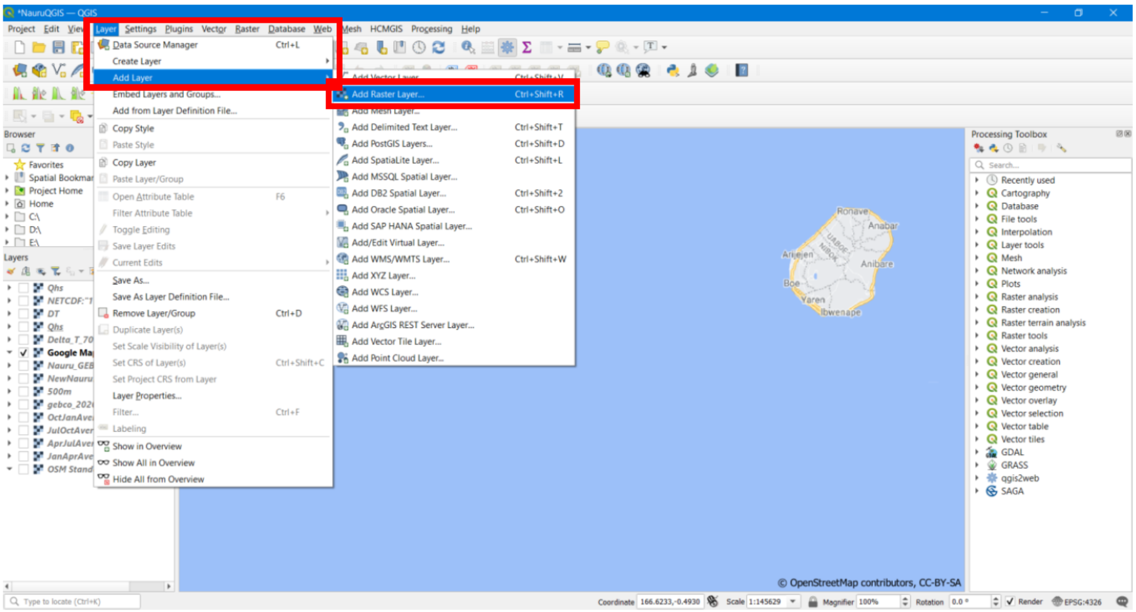
1. The Nauru Model outputs, as well as GEBCO and MURSST data are saved as GeoTIFF files (*.tif) and are called Nauru files in this document. They can be read by most GIS software. The file extension is .tif, but it is not an image file; it contains the physical variable in a binary format. Image files are provided in .jpg format.

2. QGIS is recommended for visualization since it is a free software that is fairly easy to use. Please **download QGIS** from here: https://qgis.org/en/site/forusers/download.html
Follow the instructions depending on which platform you use (Windows, macOS, Linux).

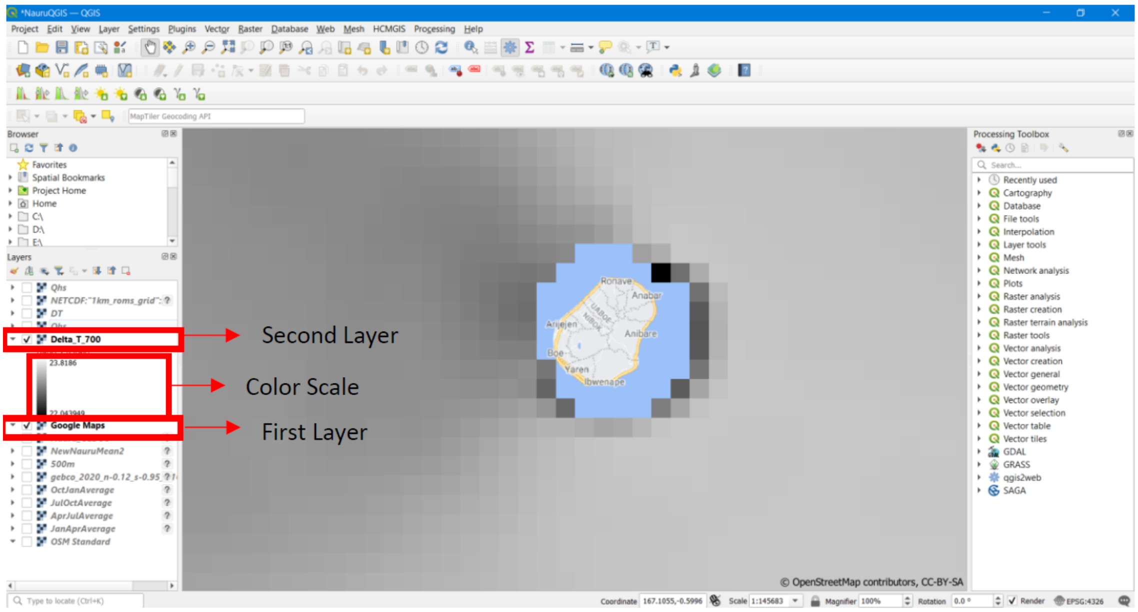
3. To have a better understanding of where Nauru is, we need to add a basemap to our map. Basemap is similar to what you see on Google Maps, for example. **Install a basemap plug-in called HCMGIS**. Click on Plugins > Manage and Install Plugins. When the new window opens, type HCMGIS in the search field, select it, and click on “Install”. When the plugin is installed, you will see a new option in the top bar saying HCMGIS. Use it to select the basemap you would like to add to your layers. Here, I am selecting Google Maps.



4. **Open the TIFF file as a raster** layer. To do that, click on Layer > Add Layer > Add Raster Layer.
Browse and select the file you would like to visualize on the “Source” field. In this example, I will show the temperature difference data at 700m depth (Delta_T_700.tif)

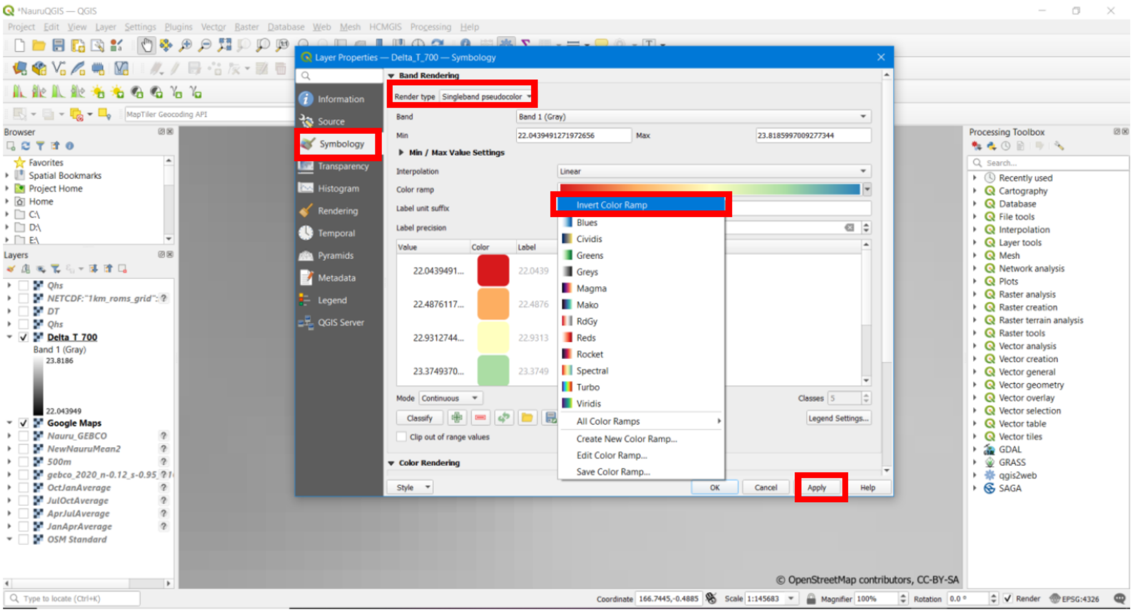


5. The **TIFF file is now a layer in our map** and you can see it in the “Layers” section in the left of the window. As you can see, you can have multiple layers open, and you will **check the boxes of the ones you would like to see on the map**, and uncheck the boxes of the ones you would like to hide. In this example, I am choosing to only see the Delta_T_700 layer and the basemap layer (Google Maps).



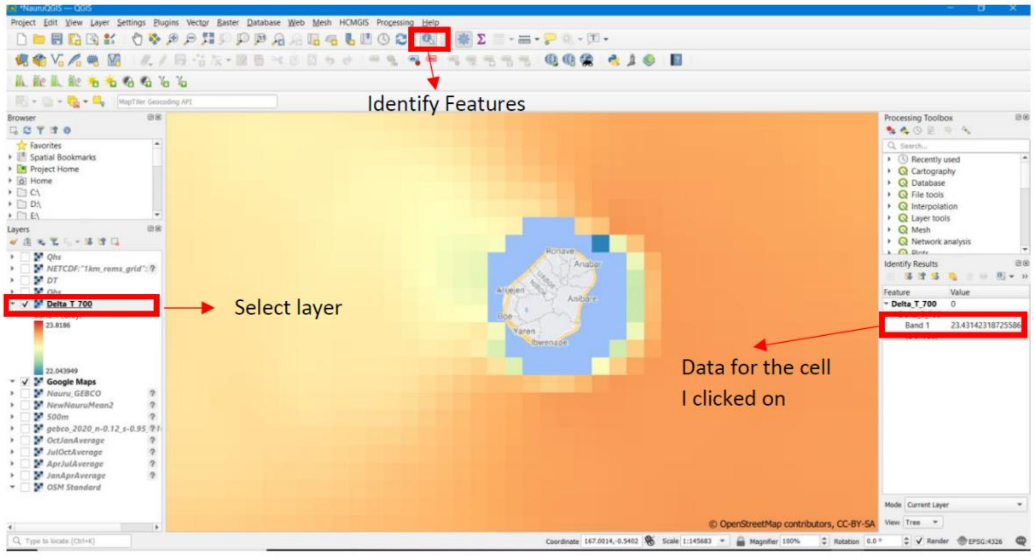
6. By standard, the image will open on a gray scale, where it is difficult to visualize how different those values are from each other. **Double click on the color scale to make**

changes. In this example we will use a “Singleband Pseudocolor” type of color range with the standard linear interpolation. Since this color scheme assigns red to low values and blue to high values, we invert the color scheme to make it easier to understand in the map. You can also change the minimum and maximum values of the range, change the interpolation type, the color ramp, or the label precision.

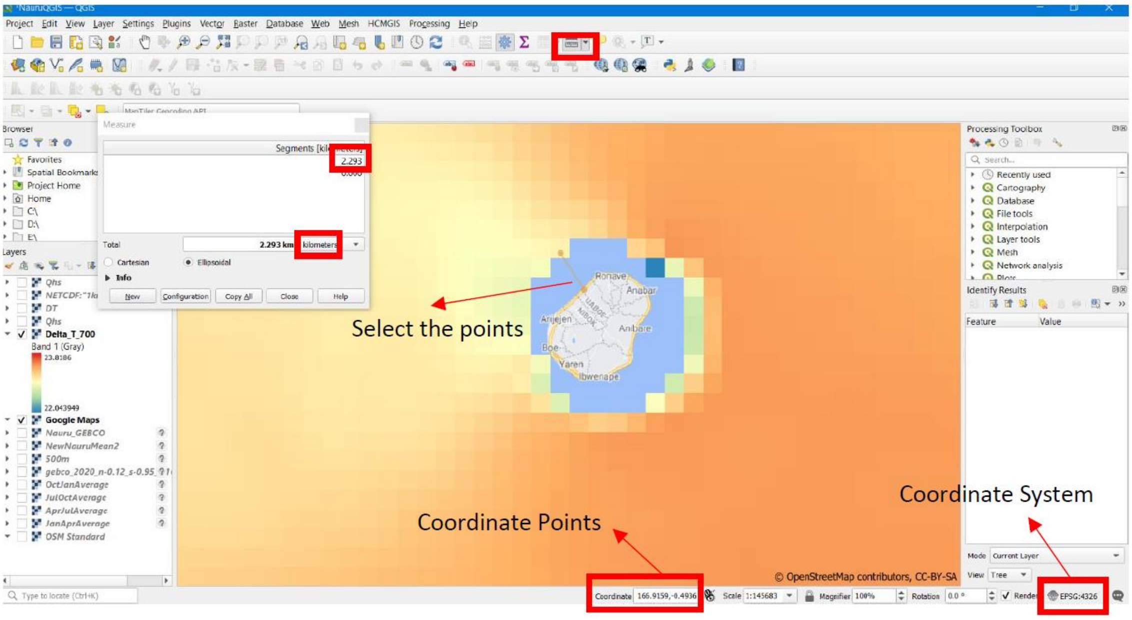


7. We can now see the Delta_T_700 data on our map. In QGIS, you can click on the layer you would like to inspect, then **click on the “Identify Features” button to find the value in each cell**. Here, I clicked on a random cell in the Delta_T_700 layer and I can now see the value for temperature difference in that specific spot. Another important factor is that since we can visualize multiple layers, their order is important to know which ones should be on top. Because my Delta_T_700 layer is before “Google Maps” in the “Layers” box, I can

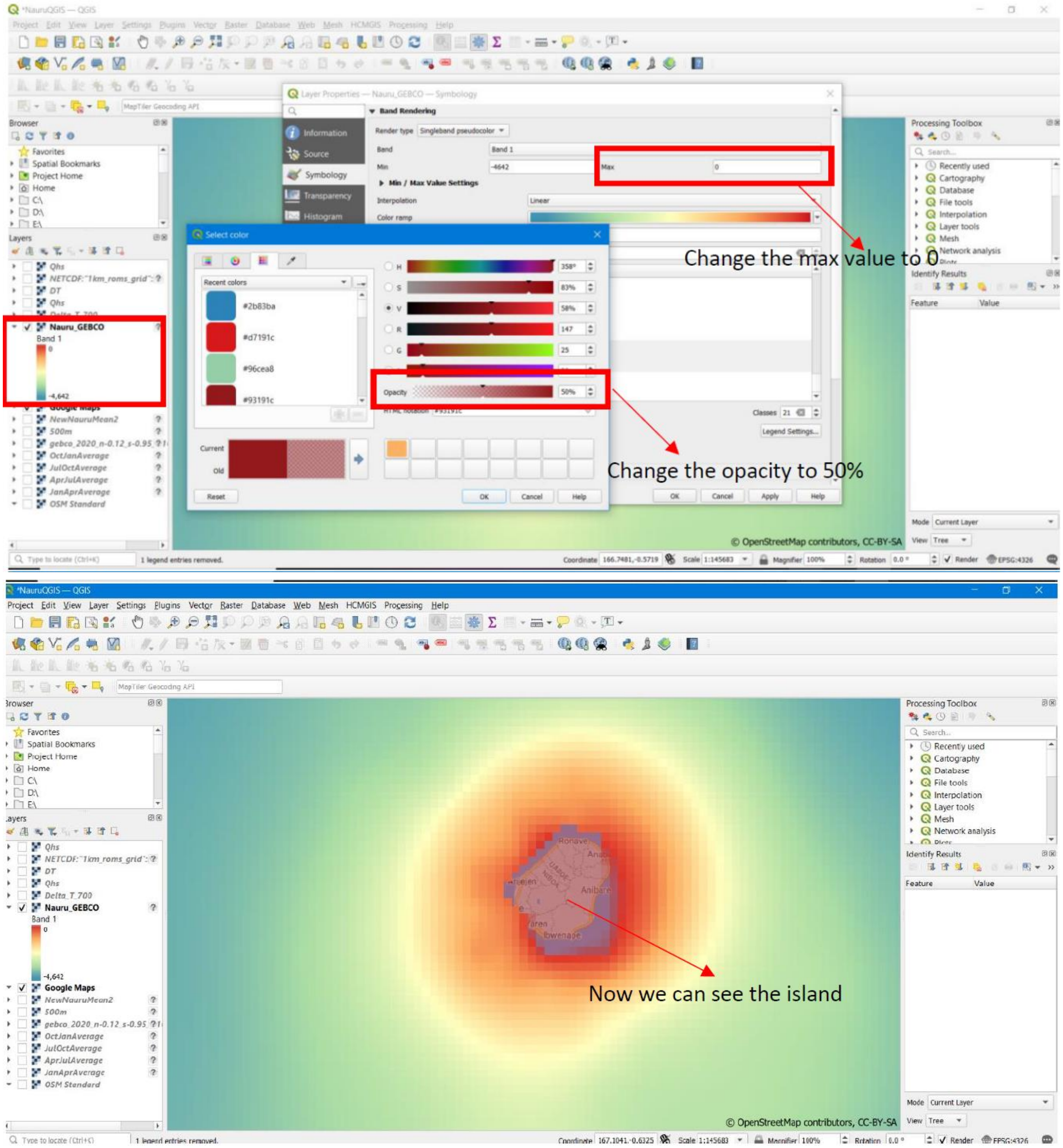
visualize it on top of the basemap. You can hold and drag layers up and down to change their order.



8. Lastly, you can also measure distances nn the map. Click on “Measure Line”, change the unit to the one of your preference (here we are using kilometers) and select the points to measure the distance between them. In this example, I am measuring the distance between the coast of Nauru and one of the closest grid points, which is 2.293 km. In this case, the empty areas in my map are the land area of Nauru and also the areas that have depths lower than 700m. You can visualize the coordinates and the geographical system in the bottom bar.

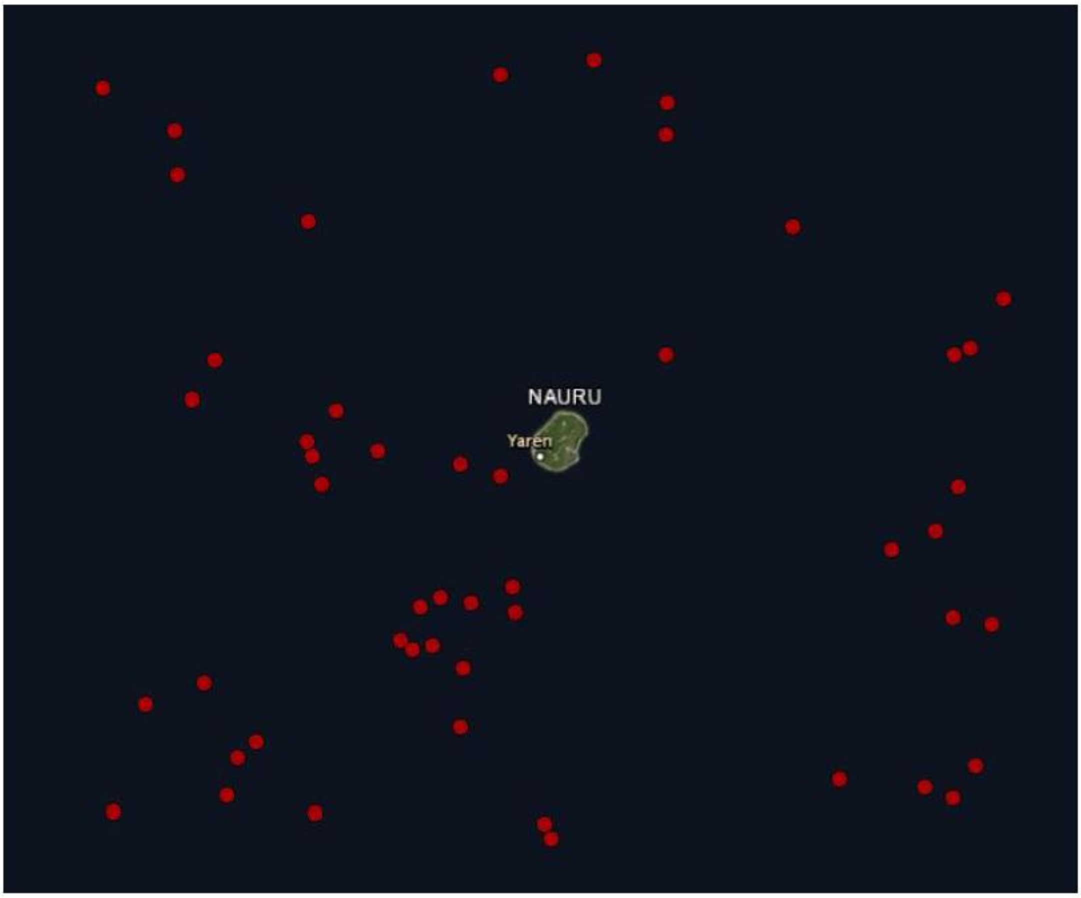


9. Sometimes the map we would like to see does not have an empty area where the island is. For example, the Nauru_GEBCO layer has elevation data for the full domain. If we open this layer and change the color scale, we will not be able to see where Nauru is. One way of solving this issue is **adding transparency**, another possible solution is changing the color scale to start from zero to negative, hiding the positive values where land is. In summary, you can add transparency by doubleclicking the color you want to change or **change the minimum/maximum of the color ramp**.

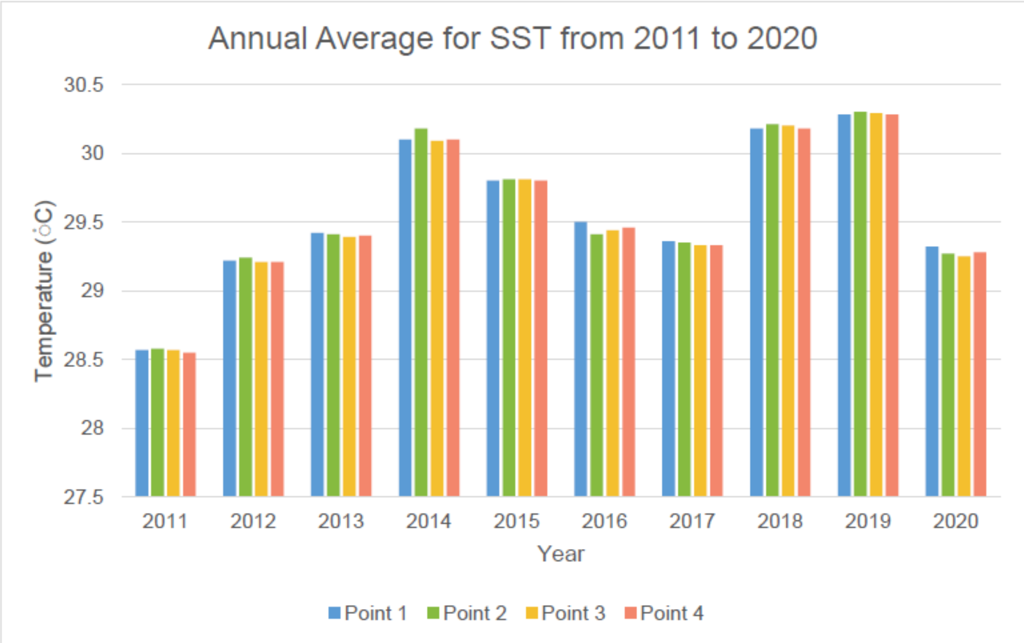


10. You can save your current project or you can keep adding layers of data to visualize in the map.

Annex 7: Coordinates of Argo profiles near Nauru

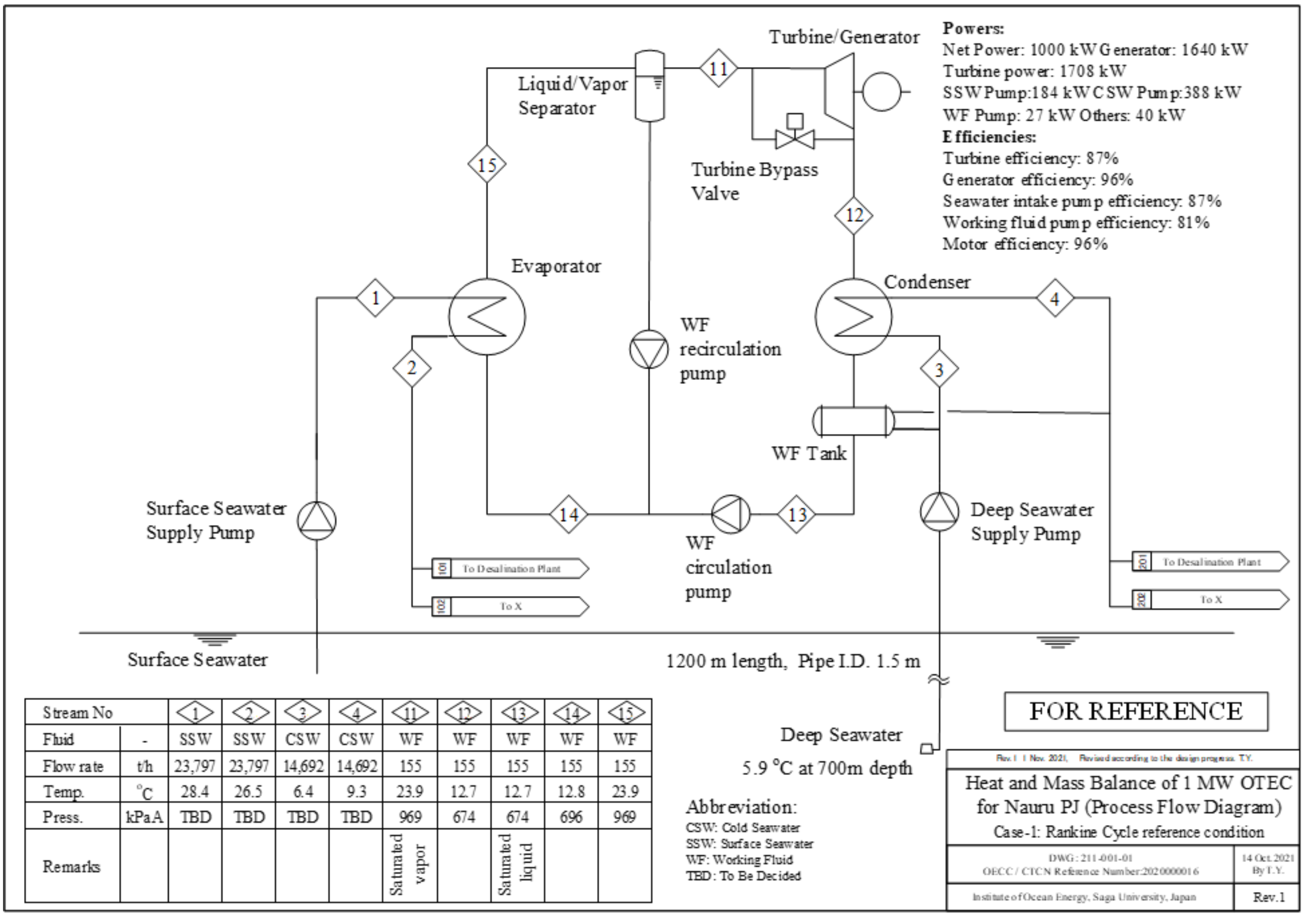


Annex 8: Annual Average SST 2011-2020



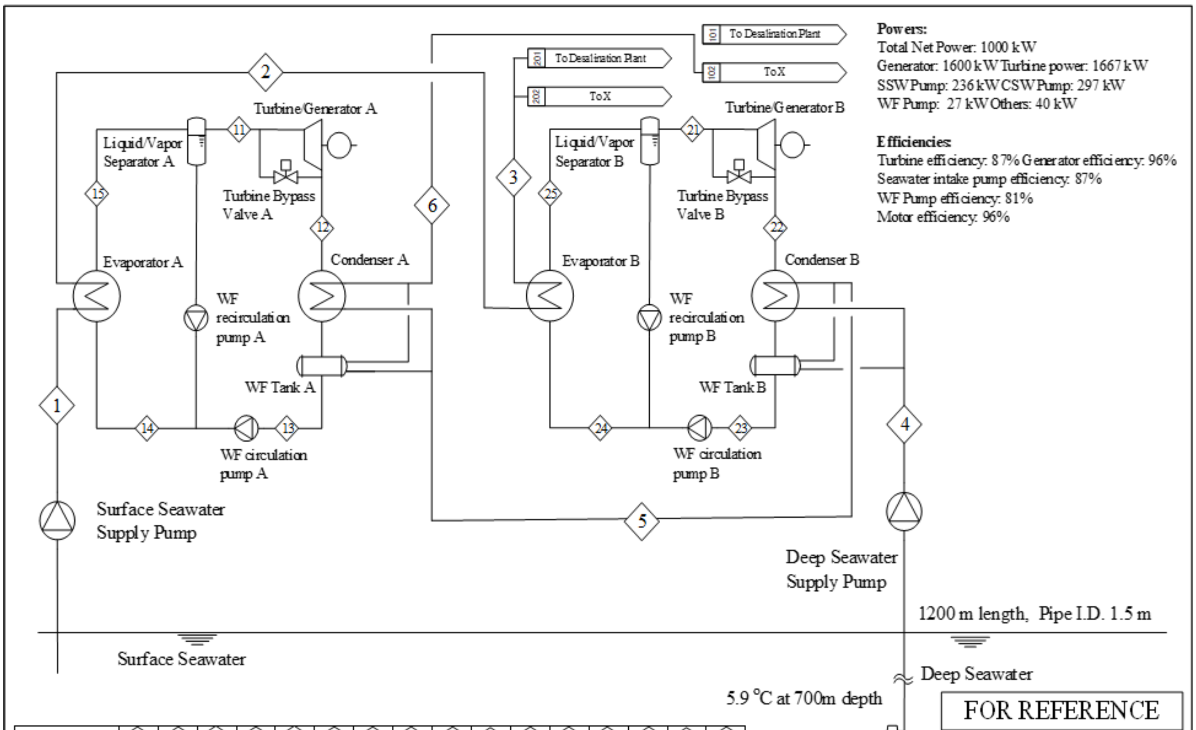
Annex 9: Single and double Rankine cycle diagramm

■1MWnet OTEC Single stage Rankine cycle Heat balance diagram



Stream No		1	2	3	4	11	12	13	14	15
Fluid	-	SSW	SSW	CSW	CSW	WF	WF	WF	WF	WF
Flow rate	t/h	23,797	23,797	14,692	14,692	155	155	155	155	155
Temp.	°C	28.4	26.5	6.4	9.3	23.9	12.7	12.7	12.8	23.9
Press.	kPaA	TBD	TBD	TBD	TBD	969	674	674	696	969
Remarks						Saturated vapor		Saturated liquid		

■1MWnet OTEC Double stage Rankine cycle Heat balance diagram



Stream No		1	2	3	4	5	6	11	12	13	14	15	21	22	23	24	25
Fluid	-	SSW	SSW	SSW	CSW	CSW	CSW	WF	WF	WF	WF	WF	WF	WF	WF	WF	WF
Flow rate	t/h	13,170	13,170	13,170	12,307	12,307	12,307	83	83	83	83	83	83	83	83	83	83
Temp.	°C	28.4	26.6	24.7	6.4	8.3	10.2	24.1	13.6	13.6	13.7	24.1	22.1	11.9	11.9	12.0	22.1
Press.	kPaA	TBD	TBD	TBD	TBD	TBD	TBD	975	695	695	975	975	917	656	656	917	917
Remarks								Saturated vapor		Saturated liquid			Saturated vapor		Saturated liquid		

Abbreviation:
CSW: Cold Seawater
SSW: Surface Seawater
WF: Working Fluid
TBD: To Be Decided

Rev.1 1 Nov. 2021, Revised according to the design progress. T.Y.

Heat and Mass Balance of 1 MW OTEC for Nauru PJ (Process Flow Diagram)

Case-2: Double-Stage Rankine Cycle reference condition

DWG: 211-001-02
OECC / CTCN Reference Number:2020000016

14 Oct. 2021 By T.Y.

Institute of Ocean Energy, Saga University, Japan

Rev.1