Evaluation Ocean Thermal Energy Conversion Bahamas

Energy Audit Report

The Caribbean Community Climate Change Centre (CCCCC)

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ABBREVIATIONS

BPL	Bahamas Power & Light
CCCCC	Caribbean Community Climate Change Centre
CC-OTEC	Closed Cycle OTEC
EU	European Union
GCCA	Global Climate Change Alliance
IG	Imperial Gallon
IGPD	Imperial Gallon Per Day
LCOE	Levelised Cost of Energy
NPV	Net Present Value
NRW	Non-Revenue Water
OC-OTEC	Open Cycle OTEC
OTEC	Ocean Thermal Energy Conversion
PV	Photovoltaic
RO	Reverse Osmosis
SDC	Seawater District Cooling
SWAC	Seawater Air Conditioning
SWRO	Seawater Reverse Osmosis
WSC	Water and Sewerage Corporation

PREFACE

Witteveen+Bos has been commissioned by the Caribbean Community Climate Change Centre (CCCCC) to perform a feasibility study for Ocean Thermal Energy Conversion (OTEC) in the Bahamas.

The project aims to evaluate the feasibility of OTEC pairing with SWRO plants and its combination with Solar District Cooling (SDC), solar thermal and/or solar PV to contribute to the decarbonization of the water supply in The Family Islands.

There are four deliverables from this project:

1. Inception Report - based on an inception meeting with local stakeholders and partners.
2. Assessment Report - bench-level assessment of the Water Resources of the Bahamas, regarding the inverted geothermal conditions from existing SWRO wells to support OTEC.
3. Energy Audit Report - energy efficiency audit of existing SWRO facilities and implications for OTEC pairing.
4. Conceptual Design Specifications for SWRO-OTEC pairing system.

This document is the third deliverable, Energy Audit Report.

The CCCCC has received financing for this project from The European Union through the GCCA+ programme toward the cost of the project titled 'Enhancing Climate Resilience in CARIFORUM Countries' and applied part of the proceeds towards this consultancy project.

The Global Climate Change Alliance Plus (GCCA+) is a European Union flagship initiative helping the world's most vulnerable countries address climate change.

OTEC is an emerging technology that requires research and scaling-up effort. We are pleased to assist in the development of this technology in the Bahamas.

EXECUTIVE SUMMARY

Freshwater in Family Islands is mostly produced from Seawater Reverse Osmosis (SWRO) plants. The process is highly energy intensive. The energy comes from the power grid, which is still mostly generated by diesel power plants. In this report, we assess the energy consumption of SWRO plants operated the majority by Veolia on behalf of the Water and Sewerage Company (WSC) in the Family Islands. Further, we assess the cost-benefit analysis of Ocean Thermal Energy Conversion (OTEC) as an energy source for the SWRO plants. The Bahamas is utilizing cold saline groundwater for District Cooling from underground at 1000 ft depth. Though there is not yet evidence that the reverse geothermal conditions continue deeper, it is useful to evaluate the cost and benefits of OTEC to determine the attractiveness to further investigate this. In this study, we assess the cost-benefit of implementing OTEC for 3 SWRO locations in the Family Islands.

Energy efficiency

The energy consumption of the SWRO plants is in the range of 2 - 4 kWh/m^3 produced, with an average of 3,65 kWh/m^3 produced. This is within the range of typical installations with the same configurations. In Eleuthera, all SWRO plants have utilized this energy recovery technique. The energy efficiency was calculated for the volume produced, not delivered. Non-Revenue Water (NRW) has been reported to be close to 50 %, of which a large part occurs during distribution. Focusing on NRW reduction would significantly increase overall energy efficiency.

Cost-benefit analysis

The cost-benefit analysis has been performed on three SWRO locations, determined in the previous Assessment Report (Witteveen+Bos, 2022). The locations are Lower Bogue, Naval Base, and Cockburn Town. In each location, we design an OTEC system to supply 100% electricity demand of the SWRO plants. As alternative mature renewable energy options, we also assessed the implementation of solar PV, wind turbine, or their combinations at each location. The concept design has resulted in the following system for each location:

Table 1 Selected technology for each location

Location	OTEC system	Alternative
Lower Bogue	500 kW OC-OTEC	1500 kW wind turbine and 11.4 MWh Li-ion battery
Naval Base	350 kW CC-OTEC	2000 kWp, and 7.9 MWh Li-ion battery (charge)
Cockburn Town	60 kW CC-OTEC and SDC	350 kWp Solar PV and 1.4 MWh Li-ion battery

In the analysis, we have estimated the capital cost and operating costs. The benefit of OTEC installation comes from selling electricity for the SWRO plants at the cost of $0.2/kWh. For Open Cycle (OC) OTEC, fresh water is also generated and valued at $9.3/1000 imperial gallon (IG) at Lower Bogue. Seawater District Cooling (SDC) benefit comes from the energy saving for cooling.

Table 2 Cost-benefit analysis results

System	Lower Bogue	Naval Base	San Salvador
OTEC	**OC-OTEC 500 kW**	**CC-OTEC 350 kW**	**CC-OTEC 60 kW**
NPV (30 years, r = 4%)	-$15,193,000	-$23,694,000	-$10,248,000
NPV/capital cost ratio	-0.34	-0.85	-1.1
LCOE ($/kWh)	0.37	0.57	1.11
SDC			

System	Lower Bogue	Naval Base	San Salvador
NPV (30 years, r = 4%)	-	-	$579,000
NPV/capital cost ratio	-	-	0.52
Alternative	**1500 kW wind turbine and 11.4 MWh Li-ion battery**	**2000 kWp, and 7.9 MWh Li-ion battery (charge)**	**350 kWp solar PV and 1.4 MWh Li-ion battery**
NPV (30 years, r = 4%)	-$3,913,000	-$3,773,000	-$789,000
NPV/capital cost	-0.16	-0.21	-0.24
LCOE ($/kWh)	0.24	0.26	0.27

The results show that the OTEC for electricity generation alone is not yet cost-effective. But the combination with freshwater generation increases the business case significantly. The 500 kW OC-OTEC in Lower Bogue produces additional freshwater capacity equal to 40% of the current SWRO plant capacity. The LCOE is almost 40% lower than the case of without freshwater production at Naval Base.

The SDC in San Salvador gives a positive NPV with an NPV/capital cost ratio of 0.35. Combining SDC with OTEC increases the business case. In San Salvador, the LCOE of OTEC improves from 1.24 to 1.11 $/kWh. In this case, only 25% of cold water is utilized due to low demand quantity. Higher utilization of cold water would give a better business case.

The results suggest that the OTEC business case is greatly enhanced when combined with freshwater generation and providing cooling. However, this analysis is based on the assumption that cold water (< 7°C) water is available at a depth of 1 km. Therefore we suggest performing a test well to a depth where the water has a temperature difference of plus or minus 20ºC compared to shallow saline groundwater and confirming this cold water availability. And since OTEC is a developing technology, it is also wise to start with a smaller scale for piloting. In the next report, we will provide design specifications for 30 kW open cycle OTEC in Lower Bogue. While in Naval Base and Cockburn Town, we will provide the design specification for wind and/or solar PV with batteries.

1

INTRODUCTION

The Bahamas is a potential area for implementing Ocean Thermal Energy Conversion (OTEC). It has a semi-tropical climate that creates sufficient temperature differences between the surface and deep ocean water. OTEC requires a minimum 20 °C difference between warm surface water and cold deep ocean water.

Instead of using deep ocean water, the project's Beneficiary came up with the idea of using saline groundwater as the cold-water source. There has been evidence that the groundwater gets colder with depth, at least for a few hundred feet. Groundwater is already being used by Sea Water Reverse Osmosis (SWRO) plants in the Bahamas to produce potable water. This opens up an opportunity to pair OTEC with SWRO plants.

Witteveen+Bos has been commissioned by the Caribbean Community Climate Change Centre (CCCCC) to perform a feasibility study of OTEC pairing with the SWRO plants in the Family Islands. This Energy Audit report is the third of four deliverables from this assignment. This report aims to assess the current cost of the SWRO operation and to present the cost-benefit analysis for implementing OTEC at three pilot locations.

In this chapter, we elaborate on this project's background and objective.

1.1 Previous report

The second report (Assessment Report) provides a bench-level assessment describing the OTEC enabling conditions and several alternative renewable energy technologies. In the report, it was recommended to:
- Elaborate in the next phase of this project closed cycle OTEC for the SWRO plant location Bogue, Eleuthera, using solar thermal for the realization of the required 20 °C difference between the cold and the warm feed flow. If space is limiting the size of the Solar Thermal, a smaller OTEC in combination with one or more wind turbines can be considered. Battery storage capacity to be adjusted to the combination of wind and OTEC. And OTEC with solar thermal heating should be compared to alternative electricity generation options.
- Elaborate open cycle OTEC with minimal battery storage capacity for the SWRO plant location Cockburn Town with SDC using OTEC and investigate the opportunity to supply clean water from OTEC in this location.
- Elaborate on the next phase of this project on solar PV and storage with batteries for the SWRO plant location at Naval Base.

1.2 Study objective

This study aims to:
- Evaluate the energy efficiency and cost of the on-grid SWRO plants in the Family Islands.
- Assess the cost-benefit of OTEC implementation at the three recommended locations (see 1.1) in the Family Islands and provide technical guidance on public-private institutional arrangements and a framework for medium-large scale OTEC.

1.3 Reading guide

This report is structured as follows. Chapter 2 evaluates the current cost of the on-grid SWRO plants. This establishes a baseline for the next chapter. Chapter 3 provides the cost-benefit analysis of implementing OTEC or other renewable energy alternatives. In Chapter 4, we draw conclusions and provide recommendations for the framework for medium and large-scale implementation of OTEC and the private institutional arrangements for OTEC implementation in the Bahamas.

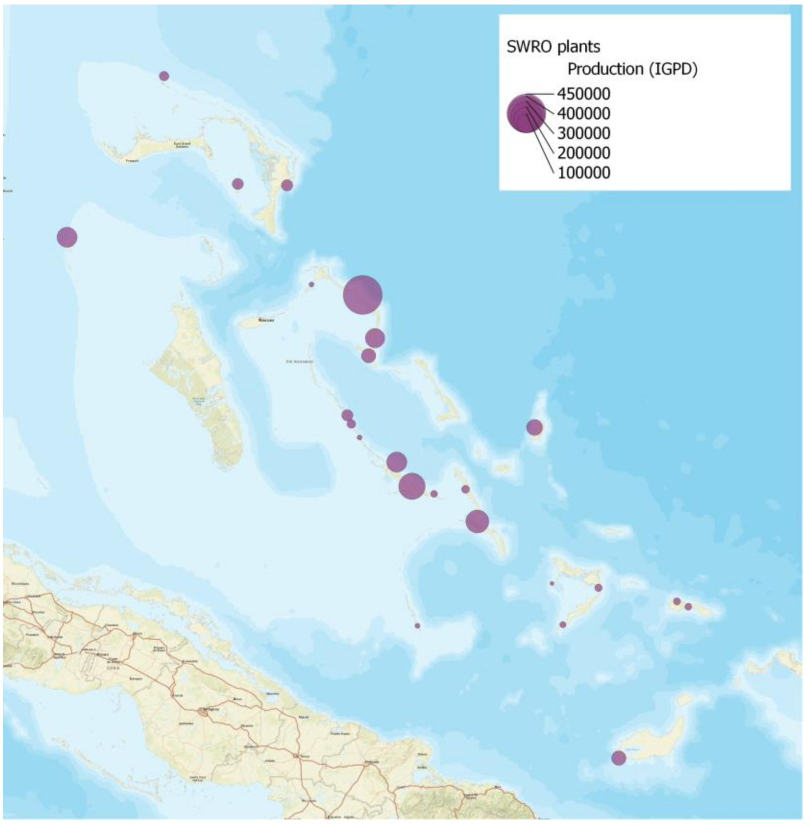
2

ENERGY AND COST ASSESSMENT OF ON-GRID SWRO PLANTS

Most potable water in the Family Islands is produced by SWRO plants. SWRO plants process saline groundwater into standard potable water. The use of saline groundwater is expected to increase due to a shortage of freshwater sources. Currently, there are 25 SWRO plants that supply potable water to the distribution networks in the islands. The capacity of these so-called on-grid SWRO plants ranges from 2,500 to 650,000 IGDP. Figure 2.2 illustrates the plants in the maps and indicates their capacity.

In this chapter, we assess the energy and costs of these on-grid SWRO plants. Other than these plants, there are SWRO plants owned by private sectors that do not supply water to distribution networks. These plants are not within the scope of this study.

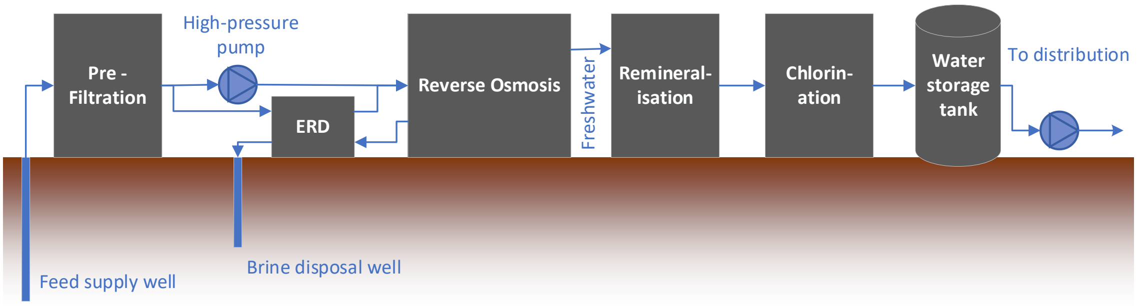
Figure 2.1 25 SWRO plants in the Family Islands and their production capacity



2.1 Processes in a SWRO plant

SWRO plants in the Family Islands use saline groundwater as the water source. The saline water is processed into potable water through several treatment steps. Figure 2.2 shows the typical processes of SWRO plants in the Family Islands.

Figure 2.2 Typical desalination process flow in SWRO plants in the Bahamas



The processes involved are as follows:

1 Water extraction:
   - Saline groundwater is abstracted from Feedwater Supply Well, typically 300ft deep, by a submersible or above-ground pump. Figure 2.3 (a) shows a supply well with a submersible pump.

2 Pre-filtration:
   - The extracted water goes to the Cartridge Filter units. The Cartridge filters within each housing unit remove all sediments above 5 microns in size. Figure 2.3 (a) shows an example of the units.

3 Reverse Osmosis:
   - The pre-filtered seawater is supplied to High-Pressure Booster Pumps before being supplied to Reverse Osmosis units. The reverse osmosis unit contains semi-permeable membranes that require high pressure to allow for separation. The membrane allows water molecules to permeate while blocking solids molecules. The unit produces desalinated water and brine solution. Figure 2.3 (c) shows high-pressure pumps and membrane units.

4 Energy recovery unit:
   - The brine stream leaving the Reverse Osmosis (RO) unit is still under high pressure. This energy is recovered by an energy recovery unit employing pressure exchange technology. The high-pressure energy from the hydraulic pressure is transferred directly from the brine stream to the seawater feed stream. This increases the pressure of the seawater feed pressure. The pressurized water goes back into the system. Figure 2.3 (d) shows the energy recovery devices.

5 Brine disposal:
   - The brine stream is discharged to the Brine Disposal Well onsite. Desalinated not meeting the standards is also disposed to this disposal well. Figure 2.3 (e) shows the brine disposal well.

6 Remineralization:
   - The desalinated water from the Membrane units flows to the Calcium Carbonate Contactor, where it is re-mineralized. Figure 2.3 (f) shows the remineralization unit.

7 Chlorination
   - The remineralized water is injected with Chlorine from the Chlorine Generator Feed System for disinfection.

8 Storage tank and distribution:
   - After post-treatment, the water is collected in water storage tanks for distribution. The water is distributed to the Distribution Network via the Distribution Pumps. Figure 2.3 (g) and (h) show the storage tank and distribution pump, respectively.

Figure 2.3 Facilities in a typical SWRO plant

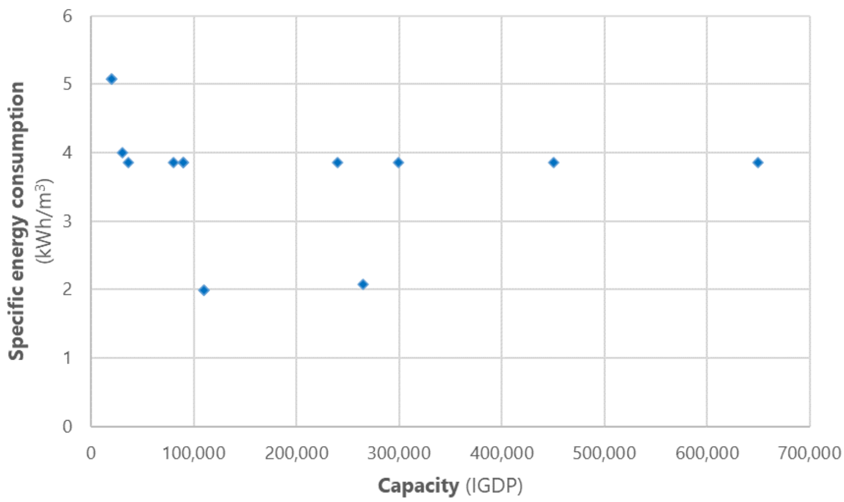
(A) supply well with a submersible pump
(B) pre-filtration unit
(C) high-pressure pump and reverse osmosis unit
(D) energy recovery unit
(E) brine disposal well
(F) remineralization unit

2.2 Energy consumption and efficiency

Energy consumption

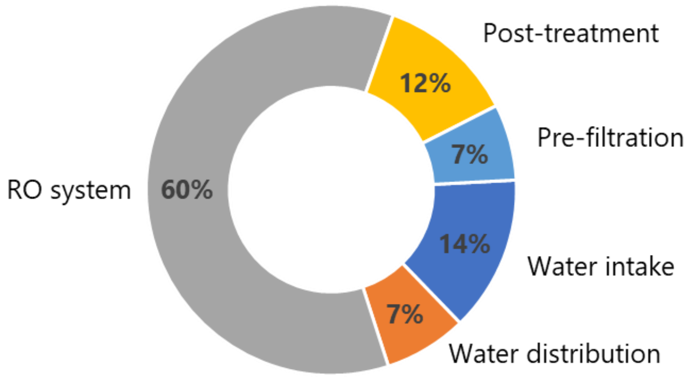
The specific energy consumption of 14 SWRO plants in the Family Islands ranges from 2 to 5 kWh/m^3 by design, with an average of 3.65 kWh/m^3. The data for 2 kWh/m^3 need to be validated since this is considered very low for a SWRO plant.

Figure 2.4 Specific energy consumption of 14 SWRO plants in Family Islands



No data is available on the plants' actual energy consumption breakdown. Figure 2.5 shows the breakdown for a typical SWRO plant.

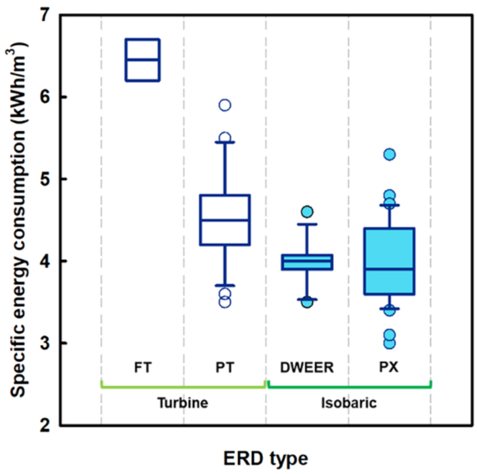
Figure 2.5 SWRO energy consumption components (Pinto, 2020)



The process that consumes the most energy is the RO process. In the past, the energy consumption required is 8 kWh/m^3. Nowadays, energy recovery is usually employed. It reduces energy consumption significantly to just above 4 kWh/m3. Together with membrane improvement and pumping improvement, the energy consumption of RO process reduces to 2.5 kWh/m3.

The specific energy consumption depends on many factors, such as RO configuration, energy recovery device used, and plant size. Kima et al. have investigated specific energy consumption from 70 SWRO plants dataset. The energy consumption based on the energy recovery device is shown in Figure 2.6.

Figure 2.6 Specific energy consumption based on energy recovery device (Kima, parka, Ryook Yangb, & Honga, 2019)

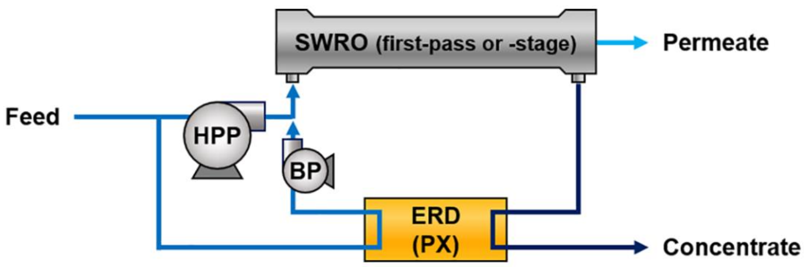


In Eleuthera, most of the plants used the PX-type energy recovery device. Their energy consumption falls within the range of 3.5 to 4.2 kWh/m^3. Therefore the energy consumption of SWRO plants is within this range. Except for one location in Colonel Hill has slightly higher specific energy consumption, and three sites have very low specific energy consumption of around 2 kWh/m^3 at Deadman's Cay, Bennett's Harbour, and New Bight.

Energy efficiency measures

The RO process has the highest energy-saving potential since it is the most energy-intensive step. The membrane for SWRO requires a high-pressure feed. There are several energy recovery technologies to reduce energy consumption. One of the technologies is pressure exchange. In Eleuthera, we observed that three plants (Naval Base, Tarpum Bay, and Waterford) already utilize this energy recovery technology.

Figure 2.7 Energy recovery illustration



There are several energy efficiency measures can be considered for SWROs in Family Islands:

1 The high-pressure pump for RO process is the highest energy consumer. When the existing pumps have almost reached their lifetime, it is worth investigating the use of more efficient pumps. The pump also needs to be operated on an efficient operating range based on its specifications/pump curve.
2 Another significant energy efficiency measure is using the latest innovative membrane technology called Closed Circuit Reverse Osmosis. When treating seawater, it uses just enough power to overcome the water's osmotic pressure, resulting in a record low energy consumption of 1.45 kWh/m^3. It is worth investigating the use of the technology in the existing installation and/or future SWRO plants.
3 Another potential is using Variable Frequency Drive (VFD) for pumps. Based on our observations in Eleuthera, the distribution pump has not employed VFD. Use of VFD can reduce energy consumption and also reduce pressure peaks in the distribution system.
4 One of the significant measures is NRW reduction. In Eleuthera, the NRW is reported to be as high as 50 %. Reduction of NRW will decrease water production and, therefore, a reduction in energy

consumption for pumping and RO operations. Any improvement in NRW would reduce energy consumption per volume of delivered water.

Energy source
In the Family Islands, the electricity needed for SWRO plants comes from power grid managed by Bahamas Power & Light Company (BPL). Most plants have backup diesel generator. Figure 2.6 shows a backup power generator in a container at one of the sites in Eleuthera. The following sites do not have any backup generator: Simms (Long Island) Duncan Town (Ragged Island), Snug Corner (Acklins), Salina Point (Acklins), Abraham's Bay (Mayaguana), Pirates Well/Betsy Bay (Mayaguana), Long Cay (Long cay).

Figure 2.8 Diesel backup power generator

2.3 Desalination cost

The freshwater purchase price in the Family Islands ranges from 9.2 to 25 $/1000 IG (2.0 - 5.5 $/m^3), with an average of 20.3 $/ 1,000 IG. The water tariff for residential customers in the islands is around $6.00/ 1,000 IG. The tariff has not been revised since 1971. Table 2.1 shows the purchase price and the shortfall compared to tariff on each SWRO location in Family Islands.

Table 2.1 Purchase price and shortfall compared to customer tariff

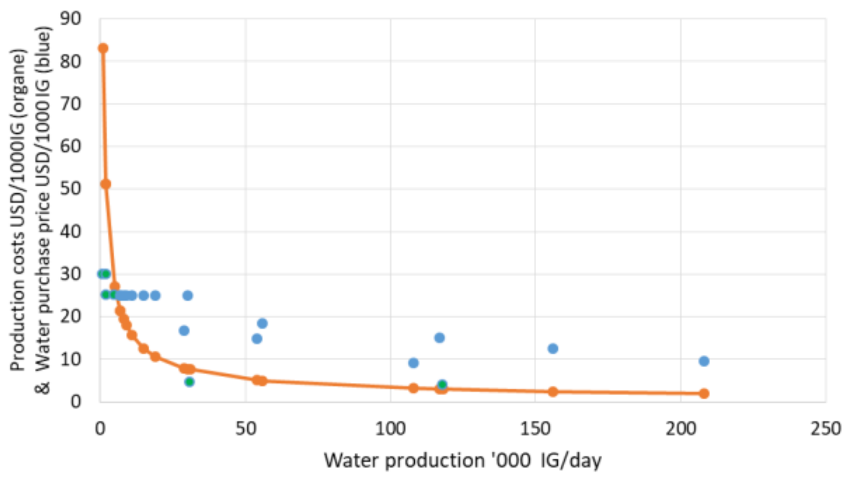
Location	System Capacity (IGPD*)	Usage (IGPD)	Purchase Price/1,000 IG	Shortfall in price compared to tariff /1000 IG
Grand Cay, Abaco	20,000	19,000	$25.00	$19.00
Moores Island, Abaco	35,000	32,000	$16.65	$10.65
Masons Bay/Snug Corner, Acklins	14,000	9,000	$25.00	$19.00
Salina Point, Acklins	14,000	6,000	$25.00	$19.00
Long Cay, Crooked Island	2,500	2,000	$30.00	$24.00
Lower Bogue, Eleuthera	650,000	600,000	$9.30	$3.30

Location	System Capacity (IGPD*)	Usage (IGPD)	Purchase Price/1,000 IG	Shortfall in price compared to tariff /1000 IG
Naval Base, Eleuthera	450,000	450,000	$9.34	$3.34
Waterford, Eleuthera	90,000	65,000	$14.83	$8.83
Tarpum Bay/ Rock Sound, Eleuthera	240,000	120,000	$9.20	$3.20
Current Island, Eleuthera	3,000	2,000	$30.00	$24.00
Georgetown, Exuma	298,800	242,000	$9.54	$3.54
Williams Town, Exuma	8,000	6,000	$25.00	$19.00
Staniel Cay, Exuma	41,000	25,000	$25.00	$19.00
Black Point, Exuma	14,000	15,000	$25.00	$19.00
Farmers Cay, Exuma	3,000	3,000	$25.00	$19.00
Sweetings Cay, Grand Bahama	6,500	6,000	N/A	N/A
Matthew Town, Inagua	90,000	80,000	$19.34	$13.34
Deadman's Cay, Long Island	160,000	160,000	$14.75	$8.75
Simms, Long Island	20,000	11,000	$25.00	$19.00
Cockburn Town, San Salvador	80,000	70,000	$13.86	$7.86
Duncan Town, Ragged Island	2,500	2,500	N/A	N/A
Pirates Well, Mayaguana	20,000	8,000	$25.00	$19.00
Abrahams Bay, Mayaguana	20,000	7,000	$25.00	$19.00

*IGPD: Imperial Gallons Per Day

The purchase price is considerably high since desalination water typically costs 0.5 - 1.00 $/m^3 (Salinas-Rodriguez, 2021). Hydrocensiel has reported that the purchase price of desalinated water is too high compared to the production costs. It was suggested that WSC renegotiate the purchase price with the contractors. Moreover, the purchase cost does not include the electricity cost. WSC pays for the electricity bill separately at cost.

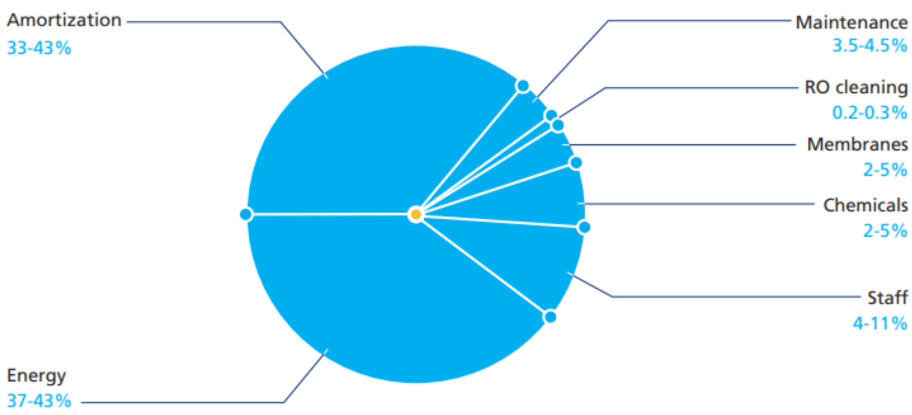
Figure 2.9 Water purchase price vs production cost (Hydroconseil, 2019)



Cost components

Figure 2.8 shows the typical cost components for a seawater reverse osmosis plant. The two largest components are amortization (capital cost) and energy cost, 33-43 % and 37-43 %, respectively.

Figure 2.10 Production costs in seawater reverse osmosis plants (Sanz , 2020)



Energy component cost in the Bahamas

In the Bahamas, the electricity cost ranges from 0.51 to 1.29 $/m3, equaling 9 - 17 % of the purchase cost. Table 2.2 shows the calculated electricity cost per m^3 in each SWRO location based on an electricity price of $0.2/kWh.

Table 2.2 Electricity cost per m^3 at each SWRO plant in Family Islands

No	Island	Plant location	Plant Capacity (IGPD)	Electricity cost USD/1,000 IG	Electricity cost USD/m^3*
1	Abaco	Moore's Island	36,000	4.4	$0.98
2	Andros (South)	KEMPS BAY	30,000	4.6	$1.01
3	Cat Island	Bennett's Harbour	110,000	2.3	$0.51
4	Cat Island	New Bight	110,000	2.3	$0.51
5	Crooked Island	Colonel Hill	20,000	5.8	$1.29
6	Eleuthera	Lower Bogue	650,000	4.4	$0.98
7	Eleuthera	Naval Base	450,000	4.4	$0.98
8	Eleuthera	Tarpum Bay	240,000	4.4	$0.98
9	Eleuthera	Waterford	90,000	4.4	$0.98
10	Exuma	George Town	298,800	4.4	$0.98
11	Inagua	Matthew Town	90,000	4.4	$0.98
12	Long Island	DEADMAN'S CAY	265,000	2.4	$0.53
13	Long Island	SIMMS	20,000	5.8	$1.29
14	San Salvador	Cockburn Town	80,000	4.4	$0.98

*Electricity price: $0.2/kWh

3

COST-BENEFIT ANALYSIS

This chapter presents the cost benefit analysis (CBA) of OTEC implementation at three locations in the Family Islands. To understand the full potential, we performed the analysis on the full-scale installations (i.e., not a pilot scale). In addition, we compare the OTEC performance to that of solar PV and/or wind power as alternative renewable energy generation.

3.1 Site locations

In the previous report, we chose three locations for the analysis in agreement with the Beneficiary. The chosen sites are:

1 Lower Bogue, Eleuthera.
2 Naval Base, Eleuthera.
3 Cockburn Town, San Salvador.

Figure I.1 to Figure I.3 in Appendix I show the aerial view of the sites and area boundary of WSC.
The relevant data of the sites is presented in Table 3.1

Table 3.1 Site information

Site	Lower Bogue	Naval Base	San Salvador
Design capacity	650,000 IGPD (2,960 m^3/day)	450,000 IGPD (2,050 m^3/day)	80,000 IGPD (360 m^3/day)
Annual energy consumption (kWh/day)	11,414	7,902	1,404.8
Power consumption rating (kW)	476	329	59
Well depth	extraction well: ~300 ft (~150 m) brine injection well: ~150 ft (~50 m)	extraction well: ~300 ft (~150 m) brine injection well: ~150 ft (~50 m)	extraction well: ~300 ft (~150 m) brine injection well: ~150 ft (~50 m)
Extracted water temperature	27 °C	27 °C	27 °C
Current water extraction rate* (m^3/day)	6,000	4,000	700
Extraction well capacity (m^3/day)	19,200	19,200	19,200
Estimated available extraction well capacity (m^3/day)	6,000	4,000	700
Cooling demand	not available	not available	708,000 W**
SWC area	1,012,500 ft^2 (94,142 m^2)	1,040,250 ft^2 (96860 m^2)	1,326,000 ft^2 (122,915 m^2)

Available area not covered by trees and building	1000 m^2	21000 m^2	850 m^2
Water quality issue	high iron content	-	-

* Calculated from freshwater production capacity. Typically, 40% - 50% of freshwater is produced from seawater desalination (Salinas-Rodriguez, 2021).

** Assumption: 236 rooms with an average 30 m^2 size. 100 W/m^2 demand cooling.

3.2 Methods

The parameter to evaluate the weighted cost-benefit is Net-Present Value (NPV). In this report, we select a period of 30 years since OTEC has technical lifetime of 30 years or longer. A positive NPV_{30} means the benefits outweigh the costs over a period of 30 years. Additionally, we calculate the Levelised Cost of Energy (LCOE) of the generated electricity.

The costs consist of capital and operating costs. The benefit comes in revenue from sales of generated electricity and desalinated water (if any), and greenhouse gas (GDG) reduction. The GHG emission reduction is calculated but is not monetized.

The costs and benefits of OTEC system at each location is compared to other mature renewable energy alternatives: wind, solar PV or their combination.

As the starting point for the analysis, we draw the conceptual design of the OTEC installation and the alternative renewable energy generation (solar PV and/or wind), as described in the next section.

3.3 Concept design

3.3.1 Design assumptions

We have taken the following assumptions:

1. 6 °C cold water is available at 1000 m below ground level

The Assessment Report (Witteveen+Bos, 2022) concluded that there is not enough information to confirm the availability of <6 °C cold water underground. There has been evidence of inverse geothermal for 300 m depth, but it is not known until which depth it continues to get colder. It has been reported that at 2200 m depth the temperature is approximately 51 °C. Therefore it is not yet clear until which lowest temperature can be achieved by underground well. A pilot well and monitoring must therefore be performed to determine the availability of cold (or hot) water at a deeper level.

If the cold-water source is unavailable, it is possible to increase the surface water temperature to > 47 °C to achieve the minimum 20 °C difference with the current groundwater well (27 °C). However, this design is not efficient. OTEC requires an enormous volume of water, and only approximately 3 % of the energy from the water is utilized. Furthermore, solar thermal collectors need a large area to achieve the required heating. For example, a 10 kW OTEC requires a 60,000 m^2 area of solar thermal to heat 0.052 m^3/s surface water from 27°C to 47°C.[1]

There is no OTEC option without the availability of <6°C cold water or > 47°C source. Solar thermal collector is not energy- and space efficient to elevate the temperature to 20 °C difference.

[1] Heating requirement: 110,000 kWh/day. Solar irradiance: 5.4 kWh/m2 per day. Overal efficiency: 0.48. Spacing 30 %

2. The current diesel generator available as backup power

OTEC has high operating availability (over 90%). However, the availability of existing diesel generators is still useful, considering that OTEC technology is a developing technology. A diesel generator is available to enable maintenance and unplanned downtime. A diesel generator has a low CapEx and therefore does not burden the financial performance. Biodiesel could be used to reduce the environmental impact. In the future, when large batteries are cheaper, the diesel generator can be replaced by a battery.

3.3.2 Technology Selection

In this CBA, all locations were assessed for OTEC implementation. But we also provide alternative renewable energy for each location, either solar PV, wind turbine, or their combination.

OTEC technology selection

There are two types of technology considered for OTEC: Open Cycle OTEC (OC-OTEC) and Closed Cycle OTEC (CC-OTEC). OC-OTEC has a higher investment cost but produces freshwater in addition to electricity. CC-OTEC only produces electricity. OC-OTEC is, therefore, suitable for locations where freshwater demand has not yet been met or will not be met in the near future.

We, therefore, selected OC-OTEC for Lower Bogue since it has the biggest freshwater demand in Eleuthera and is projected to grow since it is the main tourist destination in Eleuthera. In both Naval Base and Cockburn Town, we proposed CC-OTEC. These locations can benefit from the lower investment cost of CC-OTEC.

OTEC combinations

The cold water used by OTEC can be utilized for other applications, such as seawater district cooling, water supply to the aquarium, and cosmetics.

There are no aquariums near the three locations. Therefore, this option is not considered. In Okinawa, Japan, deep seawater is also sold as a cosmetic product. There is an opportunity to apply the same for the Bahamas. But we have left out that options since it is a marketing strategy rather than an actual product.

The only location that has cooling demand nearby is Cockburn Town. Compared to the other locations, this site is close to cooling demand. In less than 500 m, a resort called Club Med Columbus is located. Therefore, we proposed to evaluate SDC in this location.

Alternative Renewable generation options

As an alternative to OTEC, we proposed solar PV and/or wind turbines. Both are relatively more mature renewable energy technologies. All three locations have comparable solar irradiance, as shown in Table 3.2. The wind speed is higher in Naval Base and Cockburn Town.

Table 3.2 Solar irradiance for the three sites (Solargis, 2023)

	Direct Normal Irradiation (kWh/m^2)	Global Horizontal Irradiation (kWh/m^2)	Diffuse Horizontal Irradiation (kWh/m^2)	Specific Output (kWh/kWp)
Lower Bogue	1897.9	1941.7	720.4	1671.5
Naval Base	1988.8	1989.5	689.8	1708.7
Cockburn Town	1847.5	1955.3	756.6	1668.0

Table 3.3 Wind speed data at two different elevations: 50 m and 100 m

	Average speed (50 m)	Average power density (50 m)	Average speed (100 m)	Average power density (100 m)
Lower Bogue	4.55 m/s	111 W/m^2	5.33 m/s	153 W/m^2
Naval Base	5.91 m/s	255 W/m^2	6.49 m/s	298 W/m^2
Cockburn Town	5.93 m/s	219 W/m^2	6.71 m/s	283 W/m^2

If only solar PV were to supply all the electricity, the areas required per location are: 27,500 m^2, 19,000 m^2, and 3,500 m^2 for Lower Bogue, Naval Base, and Cockburn Town, respectively. As shown in table 3.1, the available area is 1,000 m^2, 21000 m^2 and 21,000 m^2. There is enough space for solar PV at Naval Base and Cockburn Town, but not at Lower Bogue.

If the space is available, we suggest using solar PV than wind due to higher development cost and risk with wind installations. With the restriction in space availability, we have opted for:
- 100 % wind in Lower Bogue.
- 100 % wind in Naval Base.
- 100 % solar PV in Cockburn Town.

3.3.3 Design criteria

The conceptual design is based on the criteria mentioned below.

General criteria that apply for both OTEC and the alternative system:
1. The energy system (OTEC or the alternative) shall supply power to meet 100 % demand. We aim for a continuous non-intermittent electricity supply and no peak supply to and from the electricity grid, to not damage the electricity grid.
2. The installation must be located within the desalination plant area if possible, and no forest areas are to be utilized for renewable energy facilities.
3. Able to withstand 200 mph wind speed (Category 5 hurricane).

The conceptual design is based on the below criteria:
1. OTEC is utilizing saline groundwater.
2. A separate new extraction well is designed for OTEC to make the drinking water extraction independent on the electricity supply from OTEC and to reach sufficient low or high temperatures. The well extracts water at a depth of 1,000 - 1,500 m.
3. The return water is injected into a new well at a depth where the groundwater temperature is equal to the water injected.

3.3.4 Design results

The OTEC and solar PV systems have been designed to supply 100 % electricity demand of the SWRO plants. Since solar PV and wind turbines do not generate electricity on a continuous basis, battery is provided with a capacity to back up for 1-day of consumption without any generation from solar and wind.

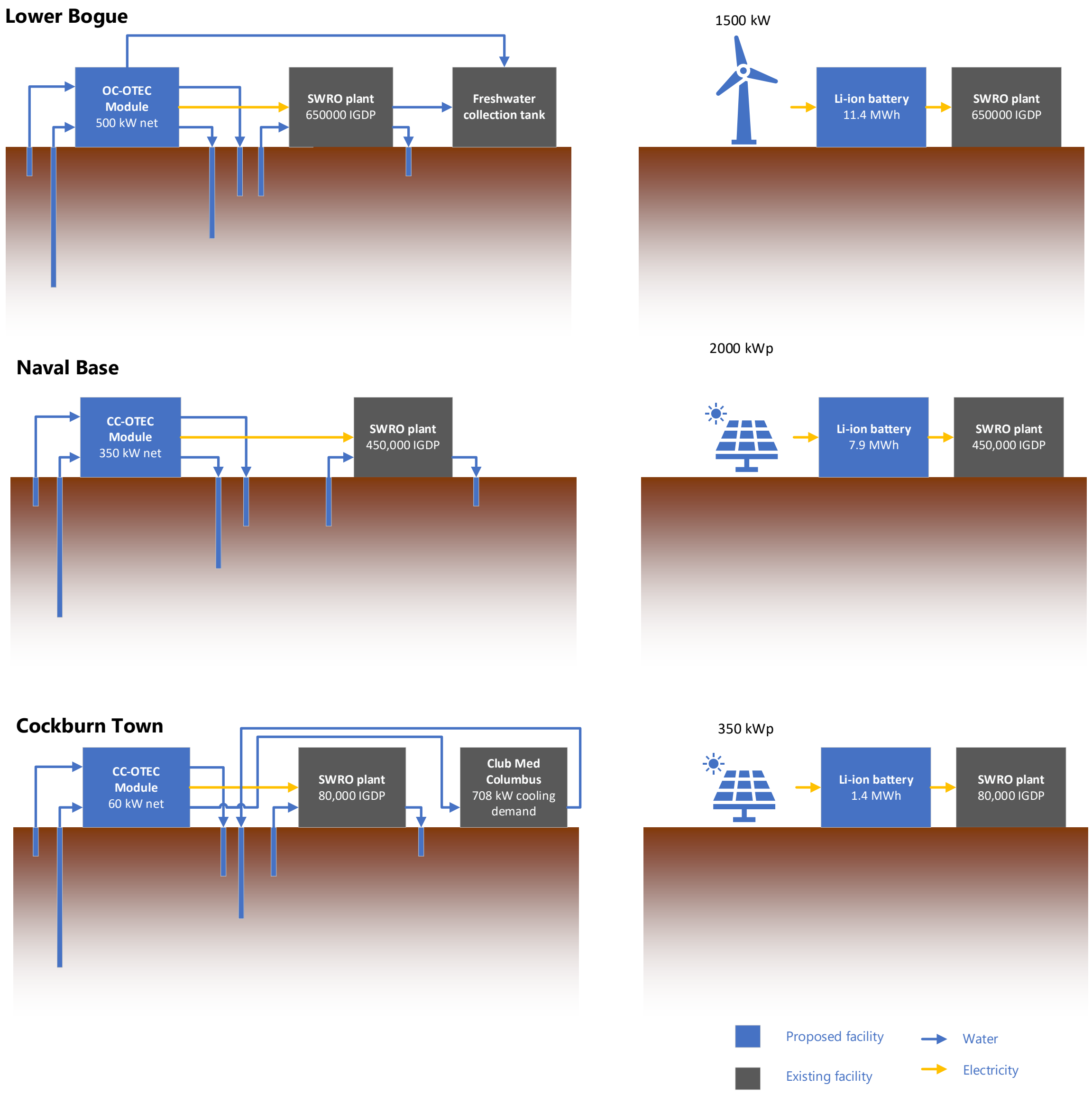
It has resulted in the following sizes for each location.

Table 3.4 OTEC plant and solar PV sizing results

	Lowe Bogue	Naval Base	Cockburn Town
OTEC	500 kW-net OC-OTEC	350 kW-net CC-OTEC	60 kW-net CC-OTEC + SDC
Alternative	1500 kW wind turbine and 11.4 MWh Li-ion battery	2000 kWp, and 7.9 MWh Li-ion battery (charge)	350 kWp and 1.4 MWh Li-ion battery

The systems are illustrated in figure 3.1.

Figure 3.1 Conceptual design of OTEC at the three locations and the alternative solar PV



In the design, we have taken the following assumptions and considerations for OTEC:
- A cold-water flow rate of 2.7 cubic meters per second is required per MW-net (Vega, 2014).
- The optimal warm-water flow rate is about 1.9 times the cold-water flow rate (Vega, 2014).
- Cold water and warm water well must be sized large enough to limit the overall losses of the pumping (<30 % gross electricity production) (Vega, 2014).
- 2,300 m^3/day of freshwater is produced per MW OC-OTEC (Vega, 2014).

The OTEC process has been simulated in Aveva Process Simulation, and the equipment is sized accordingly. The well and equipment size are tabulated in table 3.5.

Table 3.5 Well and OTEC module component size

Components	Lower Bogue	Naval Base	San Salvador
Wells			
Cold water extraction wells	5 x 18" wells, 1000 m.b.g.l	3 x 18", 1000 m.b.g.l	1 x 18", 1000 m.b.g.l
Cold water injection wells	5 x 18" wells, 1000 m.b.g.l	3 x 18", 500 m.b.g.l	1 x 18", 500 m.b.g.l
Warm water extraction wells	3 x 18", 50 m.b.g.l	2 x 18", 50 m.b.g.l	1 x 18", 50 m.b.g.l
Warm water injection	3 x 18", 100 m.b.g.l	2 x 18", 100 m.b.g.l	1 x 18", 100 m.b.g.l
Submersible pump cold water intake	5 x 16 kW, @1100 m^3/h	3 x 20 kW, @1100 m^3/h	4 kW, 600 m^3/h
Submersible pump warm water intake	3 x 26 kW, @3000 m^3/h	2 x 10 kW, @3000 m^3/h	2 kW, 1100 m^3/h
Injection pump cold water	5 x 8 kW, @1100 m^3/h	3 x 10 kW, @1100 m^3/h	2 kW, 600 m^3/h
Injection pump warm water	3 x 16 kW, @3000 m^3/h	3 x 5 kW, @3000 m^3/h	1 kW, 1100 m^3/h
*m.b.g.l = meter below ground level			
OTEC Module			
Flash evaporator	3 kPa(abs)	N/A	N/A
Turbogenerator	650 kW	450 kW	80 kW
Condenser	10205 m^2 exchange area	4000 m^2 exchange area	800 exchange area
Vacuum pump	3 kPa(abs), 1248 m^3/s	N/A	N/A
Evaporator	N/A	3208 m^2 exchange area	800 m^2 exchange area
Working fluid feed pump	N/A	10 kW	2 kW

3.4 Capital and operating costs

3.4.1 OTEC

The capital cost has been estimated based on the main equipment specification in table 3.5. Additionally, the following costs are added to arrive at the total installed cost:
- Other mechanical and in-plant pipes: 20 % of the main equipment cost.
- Electrical and instrumentations: 30 % of the main equipment cost.
- Civil works: 20% of the main equipment cost.
- Indirect costs: 20 % of the total equipment and civil works costs.
- Contingency: 25 %.

Table 3.6 Capital cost for OTEC system

Components	Lower Bogue	Naval Base	San Salvador
Wells	$18,371,000	$11,155,000	$3,794,000
OTEC Module	$6,414,000	$4,999,000	$1,765,000
Other mechanical and in-plant pipes	$1,434,000	$1,099,000	$370,000
Electrical and instrumentations	$2,151,000	$1,648,000	$556,000
Civil works	$1,434,000	$1,098,000	$370,000
Indirect costs	$2,438,000	$1,867,000	$630,000
Contingency	$8,060,000	$5,466,000	$1,871,000
Total installed cost	**$40,304,000**	**$27,334,000**	**$9,359,000**

The operating cost of the OTEC installation is assumed at 1.4 % of the capital cost (Ruud Kempener, 2014).

3.4.2 Alternative: Solar PV and/or Wind

The capital cost for the solar PV/wind system is shown in Table 3.7.

Solar PV
As for the Solar PV system, the total installed cost for the Bahamas area is 3,000 $/kWp for the design that withstands 200 mph hurricane winds. Solar PV has a lifetime of > 30 years

Wind
The total installed cost of onshore wind for commercial size in the United States is 4,300 to 3,540 for sizes 100 kW to 1.5 MW. The operating cost is 35 $/kW/yr. (NREL, 2022) We have added 20 %, considering the logistics.

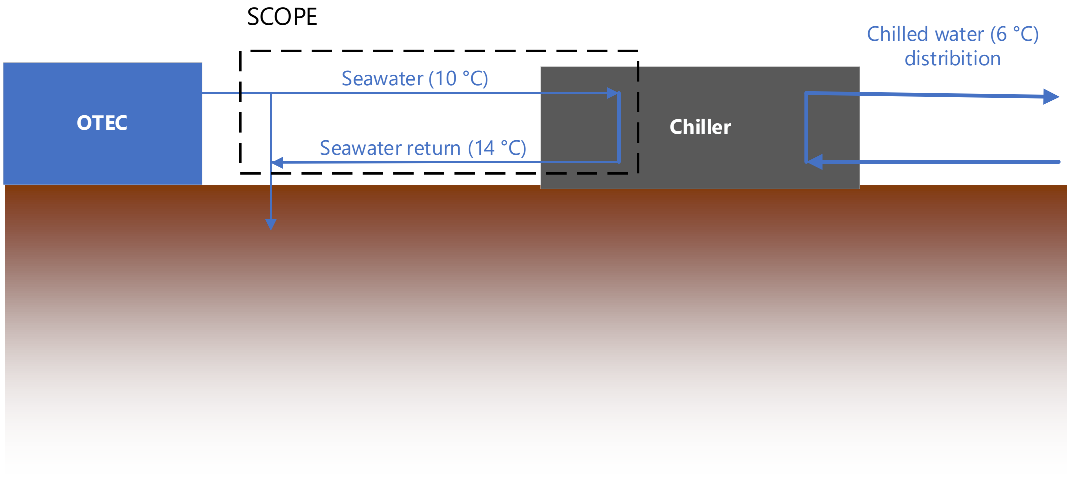
Battery
The battery cost for the size range is 510 $/kWh (Ramasamy, et al., 2022). The battery cost is based on US Market (2022) with an additional 10 % considering the logistics. The battery has a lifetime of approximately 10 years. The cost of replacing the battery every 10 years must be accounted.

Table 3.7 Capital cost of Wind/Solar PV system

Component	Lower Bogue	Naval Base	San Salvador
PV system total installed cost	-	$5,542,000	$1,053,000
Wind	$6,372,000	-	-
Battery	$5,821,000	$4,069,000	$744,000
Total	**$12,193,000**	**$9,240,000**	**$1,797,000**

SDC
In Cockburn Town, SDC is paired with the CC-OTEC. The CC-OTEC is paired. Figure 3.2 shows the scope of SDC installation. Here we assume the scope is delivering the chilled water to the central chiller. The distribution to the rooms and cottages is the scope of the user. Therefore, the main components for the SDC installation are the pipeline and pump.

Figure 3.2 Scope of SDC installations



To deliver 0.04 m^3/s seawater, 8-inch pipe is delivered, the cost of underground pipe is $910 per meter. 1 km pipeline is required to deliver the seawater from the desalination site to the resort without passing through airport runway, as shown in figure 3.3. The operating cost is assumed at 1 % capital cost.

Figure 3.3 Pipe routing for SDC

3.5 Benefit

OTEC installation produces electricity. For OC-OTEC, freshwater is also generated. The electricity generated by the OTEC installation is valued at 0.2 $/kWh (commercial rate in the Bahamas). The freshwater is valued at 9.3$/1000 IGPD or $2.0 $/m^3.

The benefit of using cold water for SDC in Cockburn Town is calculated by electricity savings. The use of cold water reduces 81 % of the electricity requirement of the chiller. This is equal to 66 kW power saving.

The benefit calculation result is shown in table 3.8.

3.6 Financial performance

The output of the financial performance is NPV. The following assumptions have been taken for the financial calculations:
- Interest rate of 1.5 - 4% is expected for a sustainable project in the Bahamas. Interest rate of 4% has been chosen.
- General inflation rate of 1.5%
- Financial period: 30 years.
- OTEC lifetime: >30 years.
- Solar PV lifetime: >30 years.
- Battery lifetime: 10 years.

Table 3.8 Financial performance OTEC and Solar PV at each location

	Lower Bogue	Naval Base	San Salvador
OTEC system	**OC-OTEC 500 kW**	**CC-OTEC 350 kW**	**CC-OTEC 60 kW (excl. SDC)**
Annual electricity generation (kWh)	4,166,110	2,884,230	512,752
Annual fresh water production (m^3)	423,807	N/A	N/A
Emission reduction (ton CO2e/year)	1,296	897	159
Capital cost	$43,409,000	$27,822,000	$9,602,000
Operating cost	$434,000	$390,000	$ 134,000
Revenue from electricity production/year	$841,000	$613,000	$105,000
Revenue from water production	$882,000	N/A	N/A
NPV (30 years, r = 4%)	-$15,193,000	-$23,694,000	-$10,248,000
NPV/capital cost ratio	-0.34	-0.85	-1.1
LCOE ($/kWh)	0.37	0.57	1.11
Alternative system	**1500 kW wind turbine and 11.4 MWh Li-ion battery**	**2000 kWp, and 7.9 MWh Li-ion battery (charge)**	**350 kWp and 1.4 MWh Li-ion battery**
Annual electricity generation (kWh)	4,166,110 kWh	2,884,230	512,752

	Lower Bogue	Naval Base	San Salvador
Capital cost	$12,193,000 at year 0 + $5,821,000 at year 10 + $5,821,000 at year 20	$9,612,000 at year 0 + $4,069,000 at year 10 + $4,069,000 at year 20	$ 1,797,000 at year 0 + $744,000 at year 10 + $744,000 at year 20
Operating cost	$ 38,000	$ 26,000	$ 5,000
Revenue from electricity production per year	$ 833,000	$ 576,000	$ 102,550
NPV (30 years, r = 4%)	-$3,913,000	-$3,773,000	-$789,000
NPV/capital cost	-0.16	-0.21	-0.24
LCOE ($/kWh)	0.24	0.26	0.27

In all there locations, the benefit does not out weight the costs for the OTEC system nor the wind/solar system. All system has negative NPV. Compared to OTEC system, the solar PV/wind systems give a better (lower) NPV/capital cost ratio.

Table 3.9 provides the financial performance of the SDC at Cockburn Town. The analysis shows a positive NPV, therefore it is financially attractive to combine SDC with OTEC at Cockburn Town.

Table 3.9 Financial performance SDC at Cockburn Town

Location	San Salvador
Available cooling capacity	2796 kW
Cooling demand	700 kW
Capital cost	$ 1,111,000
Operating cost	$ 17,000
Revenue	$ 116,000
NPV (30 years, r = 4%)	$ 396,000
NPV/capital cost	0.35

3.7 Discussions

3.7.1 Capital cost

The capital cost estimates on this study result in specific cost ($/kW) as shown in Table 3.10. The specific costs are compared to a literature correlation.

Table 3.10 Specific cost comparison to literature

OTEC capacity	This result	Cost correlation by Vega [1] converted to present day cost
500 kW_{net}	$86,800/kW (Open cycle)	$88,700 (Closed Cycle)
350 kW_{net}	$67,700/kW (Closed Cycle)	$103,000 (Closed Cycle)
60 kW_{net}	$155,000/kW (Closed Cycle)	$215,400 (Closed Cycle)

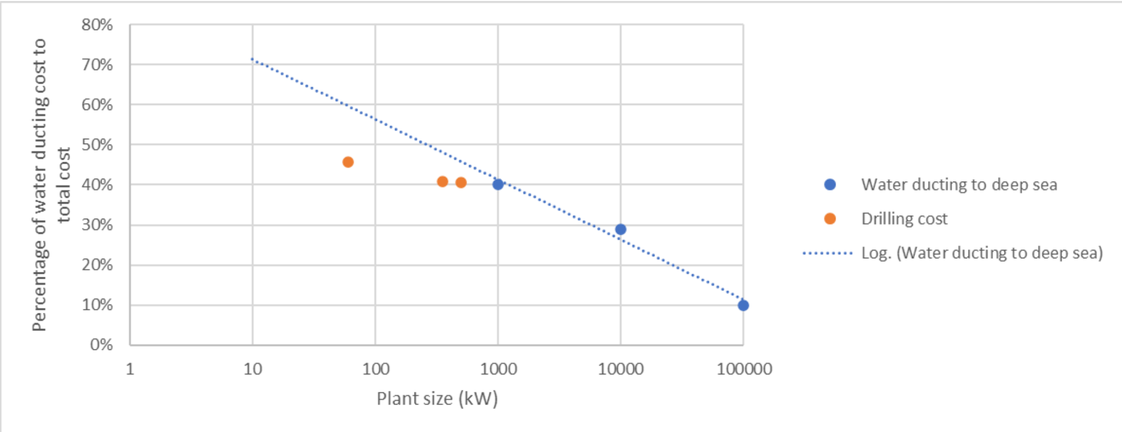
The comparison shows that the specific cost is lower than the literature values. The cost correlation from Vega assumes offshore platforms or long- and large diameter pipes into the deep sea. The use of wells instead of long water ducting to the deep sea could be the contributing factor.

It should be noted that Vega's cost correlation does not correlate for installations below 1 MW. Therefore it may not be perfectly valid to use this cost correlation.

Figure 3.4 shows the percentage of water ducting or wells cost relative to the total costs. The data percentage of water ducting for 1 MW, 10 MW, and 1000 MW was obtained from literatures. They seem to have logarithmic correlation. Using the logarithmic correlation, it is expected that at 500 kW, 350 kW, and 60 kW, the water ducting cost would contribute to 45 %, 48 %, and 60 % respectively. These are higher than percentage cost of onshore wells, which are around 40 to 46 %.

The cost of onshore wells is expected not to scale by plant size. A larger OTEC requires more quantity of wells. The well diameter is limited by availability of common bore size and also by the ground porosity.

Figure 3.4 Water ducting or wells cost percentage to total cost



3.7.2 Sensitivity Analysis

In this section, we provide the sensitivity analysis of the data input and assumptions on the resulting NPV. The lower and higher range of the values are provided based on the following arguments:

- The interest rate for sustainable projects is 1.5 - 4% in the Bahamas. 8% is chosen for higher value as the extreme scenario.
- Capital cost sensitivity within ±30 %.
- Desalinated price as low as 1 $/m3 has been reported in other countries. The maximum price in the Bahamas is 4.55 $/m3.
- Electricity price is between 0.15 - 0.40 $/kWh.

Figure 3.5 shows the sensitivity chart for the case at Lower Bogue. It is observed that the capital cost is highly sensitive for an OTEC project since it is a high-capital-cost project. Three out of five high scenarios result in positive NPV.

Figure 3.5 500 kW OC-OTEC at Lower Bogue

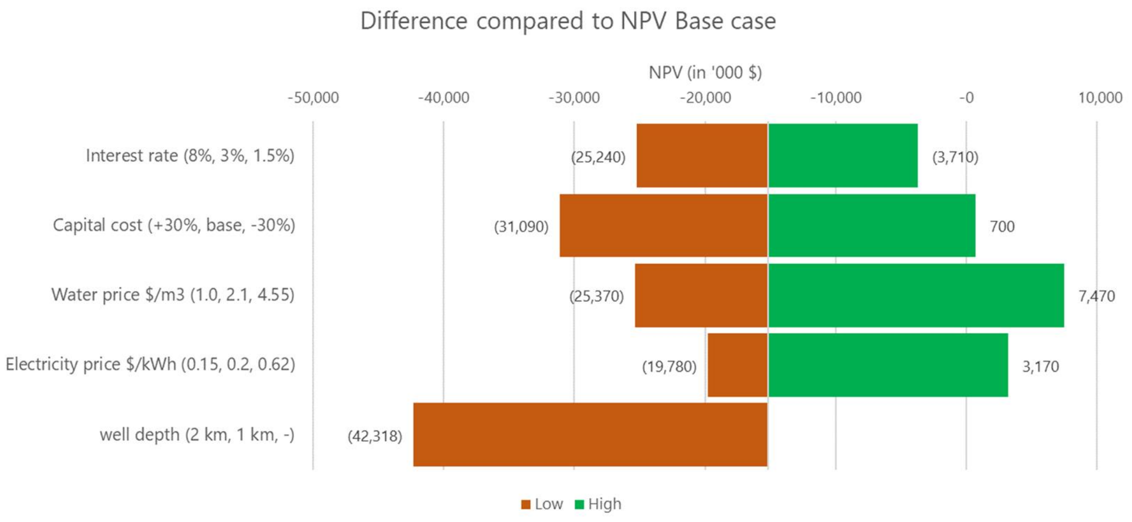


Figure 3.5 and Figure 3.6 show the sensitivity analysis for Naval Base and Cockburn Town locations. A high scenario for electricity price would make a positive NPV for Naval Base, but not Cockburn Town. In Cockburn Town, the specific capital cost and operating cost are high due to smaller scale.

Figure 3.6 350 kW CC-OTEC at Naval Base

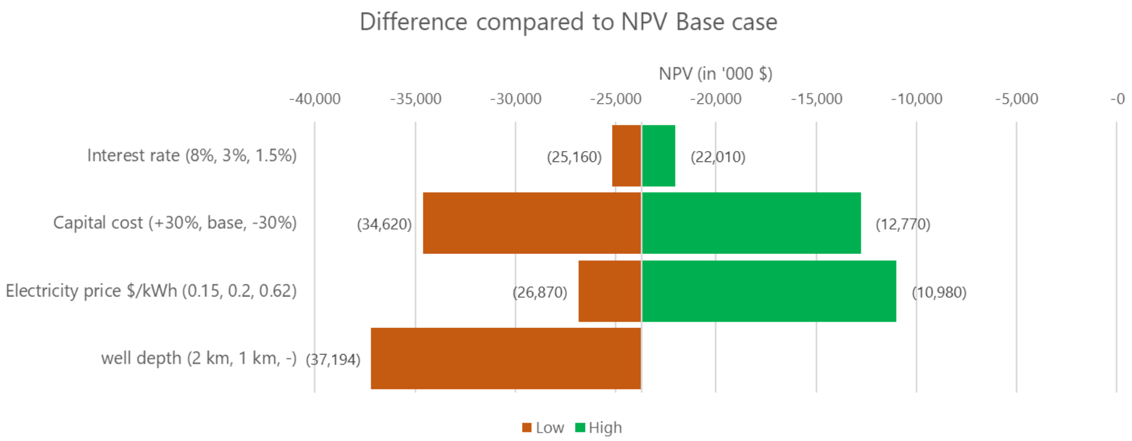
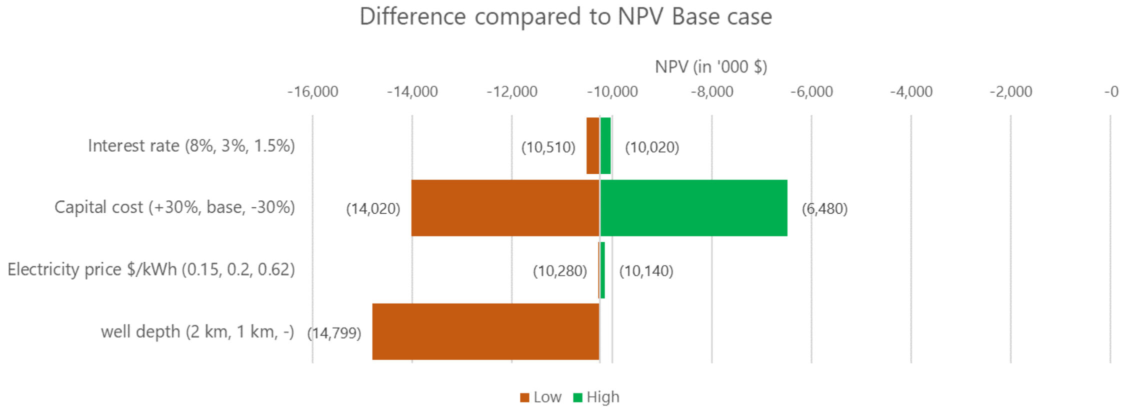


Figure 3.7 60 kW CC-OTEC at Cockburn Town (excl. SDC)



4

CONCLUSIONS & RECOMMENDATIONS

4.1 Conclusions

The conclusions are divided into two groups: energy efficiency & cost assessment of on-grid SWRO plants, and cost-benefit analysis of OTEC.

Based on the energy efficiency/cost assessment of on-grid SWRO plants, we have concluded the following points:

1 The energy consumption of the SWRO plants is in the range of 2 - 4 kWh/m^{3,} with an average of 3,65 kWh/m^3 of water produced. This number is within the range of the typical SWRO plant.
2 In Eleuthera, all SWRO plants have recovered energy from high-pressure Concentrate.
3 NRW has been reported to be close to 50 %. Focusing on NRW would increase overall energy efficiency.
4 Electricity cost for the SWRO plants is paid at-cost price to the SWRO contractors by WSC. This condition eliminates the incentive for the SWRO contractors to improve energy efficiency.

Based on the cost-benefit analysis in Chapter 3, we observed that:

1 The availability of cold (<7°C) or hot (>47°C) water is important since the alternative of heating up the shallow saline groundwater to create the 20°C temperature difference is not efficient and not space- and cost-effective.
2 The cost-benefit analysis at three locations does not support OTEC implementation. All three locations result in negative NPV. Compared to Solar PV/Wind with battery, the case in Lower Bogue is almost as competitive because of utilizing fresh water from OC-OTEC technology. The results are summarized in table 4.1.

Table 4.1 Cost-benefit analysis results

System	Lower Bogue	Naval Base	San Salvador
OTEC	**OC-OTEC 500 kW**	**CC-OTEC 350 kW**	**CC-OTEC 60 kW**
NPV (30 years, r = 4%)	-$15,193,000	-$23,694,000	-$10,248,000
NPV/capital cost ratio	-0.34	-0.85	-1.1
LCOE ($/kWh)	0.37	0.57	1.11
SDC			
NPV (30 years, r = 4%)	-	-	$579,000
NPV/capital cost ratio	-	-	0.52
Alternative	**1500 kW wind turbine and 11.4 MWh Li-ion battery**	**2000 kWp, and 7.9 MWh Li-ion battery (charge)**	**350 kWp solar PV and 1.4 MWh Li-ion battery**
NPV (30 years, r = 4%)	-$3,913,000	-$3,773,000	-$789,000
NPV/capital cost	-0.16	-0.21	-0.24
LCOE ($/kWh)	0.24	0.26	0.27

3 Producing fresh water from OC-OTEC improves the business case significantly. But the case at Lower Bogue still gives a negative business case with a water price of $9.3/1000 IG. In some other locations, the water purchase price is higher, at $25/1000 IG.
4 SDC increases the business case of OTEC:
   - Combining SDC with OTEC increases the benefit of the project. But the cooling demand must be within the vicinity of the OTEC installations. Furthermore, the cooling demand must be close together, preferably in a high-story building. Such buildings are rarely found in the Family Islands.
5 Sourcing cold water from groundwater has some benefits. For OTEC using deep ocean water, either long pipelines or offshore platform is required. For onshore OTEC, a pipeline of around 2 km is required since the deep ocean water is normally far from the shore. For offshore OTEC, an offshore platform offshore is required. Both options are expensive. Groundwater well is found to be comparably expensive. A large well diameter is required to limit the high energy consumption of the pump due to friction losses.
   In the CBA, 500 kW OTEC installation already requires 5 wells with 18" diameter. This requirement could be a limiting factor for larger-size OTEC. A larger diameter well is a lot more expensive than a standard well size. Moreover, care should be taken to ensure that the ground structure is not impacted by pumping large amounts of water in and out.
6 There are side benefits of OTEC, such as selling deep seawater as a cosmetic product and tourist attraction for OTEC facility. These options were not investigated in this study, but they could be promising.

4.2 Recommendations

Piloting and implementation of medium-large scale OTEC
The cost-benefit analysis shows that using OTEC has a better business case by combining it with freshwater production, using OC-OTEC technology. As OTEC is a developing technology, we suggest doing a pilot project in one location first. North Eleuthera is a good location considering ease of access and freshwater demand. In our next report, we will elaborate on the design specifications for locations in North Eleuthera with 30 kW OC-OTEC. The two other projects, we suggest applying solar PV. This we will elaborate in the next Design Specifications report.

A test well is first needed to confirm the availability and depth of <7°C or > 47ºC groundwater. A well needs to be drilled to approximately 3000 feet or maybe even 6000 feet, and appropriately tested. Pumping tests and geophysical logs need to prove that similar high transmissivities occur in the rock formation. If the test well drilled to this depth proves this contention to be correct, wells can be used to provide the cold/warm water needed for the OTEC installation in the Bahamas.

Funding needs to be made available to drill the appropriate deep test well and carry out the necessary pumping tests and geophysical logging.

After a pilot at one location, the OTEC can be scaled to many other locations in the Bahamas to provide non-intermittent clean energy.

Technical guidance on private-public partnership
Based on the cost-benefit analysis, it is clear that OTEC producing electricity alone does not appear likely to be profitable. Integration with other side products is needed, such as SDC and freshwater production. These products of OTEC are currently managed by different parties.

In the Bahamas, the SWRO plant is owned by a mostly private party, mostly Veolia. Water distribution is managed by a government institution, namely WSC. Meanwhile, the electricity is produced and managed by BPL in Family Islands.

Presently, groundwater wells have been drilled for water production. OTEC technology opens up opportunities for utilizing groundwater for district cooling and power generation. The well's requirement for OTEC is, however, more demanding. It needs to be drilled for about 3,000 ft; a lot deeper than the typical groundwater plant for desalination plants. Presently groundwater is abstracted at 300 ft. In New Providence, a 1000 ft well has been utilized for district cooling. The well for OTEC needs to be sufficiently large to enable extracting large volumes of water without too high energy consumption for pumping. The depth and large size characteristics of the well make the cost for OTEC expensive.

Aside from the well, OTEC modules also require high investment, mainly due to the nature of the low efficiency of the technology and the requirement to process large volumes of water. Compared to Solar PV (without battery, the capital cost can be 5 times more to deliver the same annual electricity generation.

For high-capital investment, cooperation between the private and the government parties, and funding from the international institution may be needed. All parties could be in benefit from such cooperation:

- Private SWRO operators/Veolia: continuity of water business.
- BPL: generation of clean non-intermittent energy.
- WSC: decarbonization of the water sector, additional power supply capacity from OTEC plant.
- Bahamas government: decarbonization of water and energy sector. Pioneering OTEC technology.
- International organization: use knowledge from the Bahamas to develop in other countries.

New wells are needed for OTEC. Therefore WSC is not bound to the current operator of SWRO plants. However, Veolia has shown interest in investing in a water production facility in the Bahamas. Therefore Veolia as a private partner is a strong argument.

5

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Appendices

APPENDIX: PLOT AREA OF 3 SWRO LOCATIONS IN THE BAHAMAS

Figure I.1 R.O. Plant site Bogue, Eleuthera (Water and Sewerage Corporation, 2022)

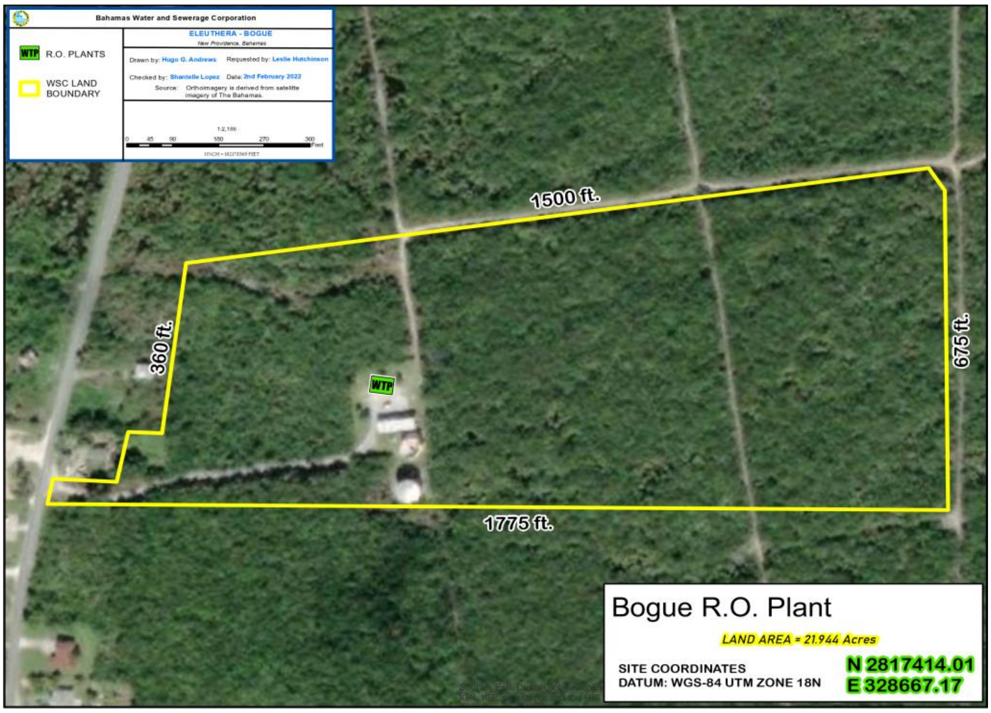


Figure I.2 R.O. Plant site Naval Base, Eleuthera (Water and Sewerage Corporation, 2022)

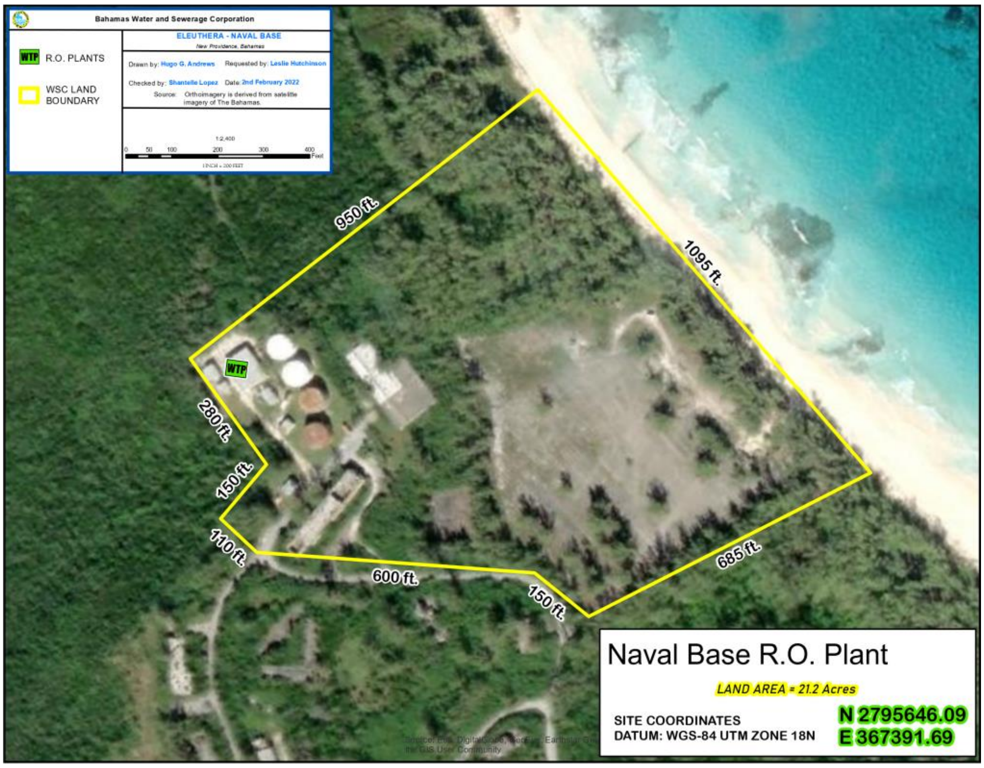
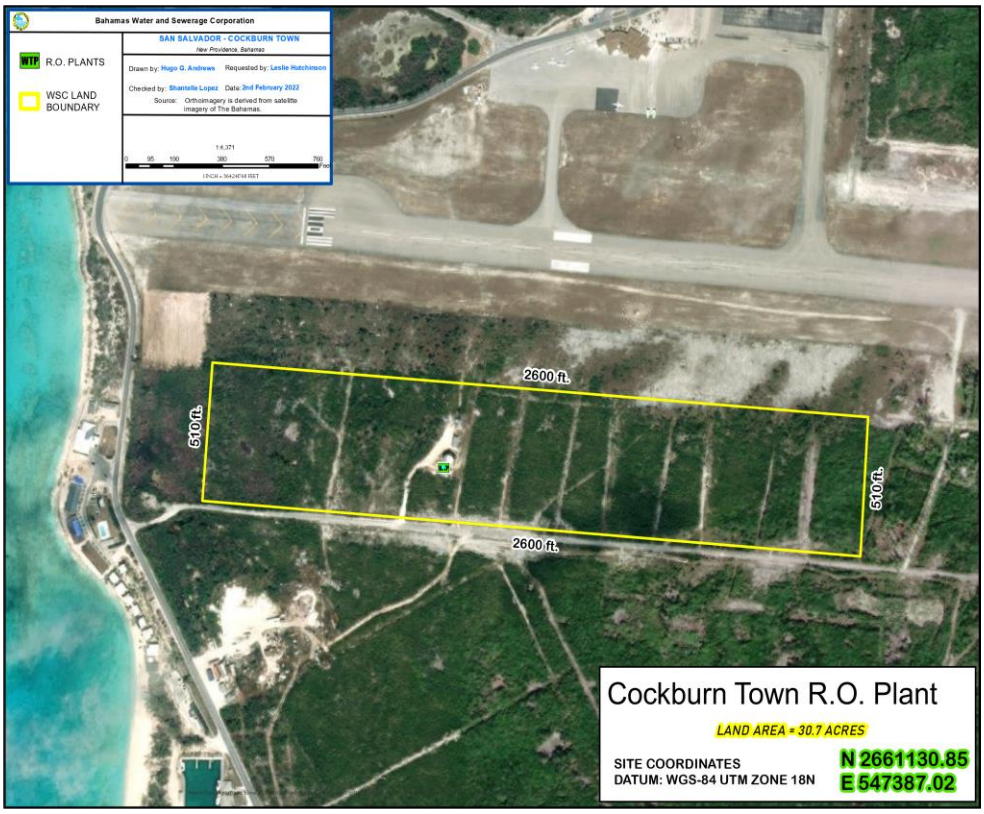


Figure I.3 R.O. Plant site Cockburn Town, San Salvador (Water and Sewerage Corporation, 2022)



II

APPENDIX: CASH FLOW

Table II.1 Cash Flow Open Cycle OTEC 500 kW at Lower Bogue

Year	Capex (k$)	Operational cost (k$)	Revenu (k$)	Total cash flow (k$)	Present value cash flow (k$)
0	(40,305)	(403)	1,715	(38,993)	(38,993)
1	-	(403)	1,715	1,312	1,249
2	-	(403)	1,715	1,312	1,190
3	-	(403)	1,715	1,312	1,133
4	-	(403)	1,715	1,312	1,079
5	-	(403)	1,715	1,312	1,028
6	-	(403)	1,715	1,312	979
7	-	(403)	1,715	1,312	932
8	-	(403)	1,715	1,312	888
9	-	(403)	1,715	1,312	846
10	-	(403)	1,715	1,312	805
11	-	(403)	1,715	1,312	767
12	-	(403)	1,715	1,312	730
13	-	(403)	1,715	1,312	696
14	-	(403)	1,715	1,312	662
15	-	(403)	1,715	1,312	631
16	-	(403)	1,715	1,312	601
17	-	(403)	1,715	1,312	572
18	-	(403)	1,715	1,312	545
19	-	(403)	1,715	1,312	519
20	-	(403)	1,715	1,312	494
21	-	(403)	1,715	1,312	471
22	-	(403)	1,715	1,312	448
23	-	(403)	1,715	1,312	427
24	-	(403)	1,715	1,312	407
25	-	(403)	1,715	1,312	387
26	-	(403)	1,715	1,312	369
27	-	(403)	1,715	1,312	351
28	-	(403)	1,715	1,312	335

Year	Capex (k$)	Operational cost (k$)	Revenu (k$)	Total cash flow (k$)	Present value cash flow (k$)
29	-	(403)	1,715	1,312	319
30	-	(403)	1,715	1,312	303
				Net Present Value	(18,830)

Table II.2 Cash Flow Closed Cycle OTEC 350 kW at Naval Base

Year	Capex (k$)	Operational cost (k$)	Revenu (k$)	Total cash flow (k$)	Present value cash flow (k$)
0	(27,335)	(383)	577	(27,140)	(27,140)
1	-	(383)	577	194	185
2	-	(383)	577	194	176
3	-	(383)	577	194	168
4	-	(383)	577	194	160
5	-	(383)	577	194	152
6	-	(383)	577	194	145
7	-	(383)	577	194	138
8	-	(383)	577	194	131
9	-	(383)	577	194	125
10	-	(383)	577	194	119
11	-	(383)	577	194	114
12	-	(383)	577	194	108
13	-	(383)	577	194	103
14	-	(383)	577	194	98
15	-	(383)	577	194	93
16	-	(383)	577	194	89
17	-	(383)	577	194	85
18	-	(383)	577	194	81
19	-	(383)	577	194	77
20	-	(383)	577	194	73
21	-	(383)	577	194	70
22	-	(383)	577	194	66
23	-	(383)	577	194	63
24	-	(383)	577	194	60
25	-	(383)	577	194	57
26	-	(383)	577	194	55
27	-	(383)	577	194	52
28	-	(383)	577	194	50
29	-	(383)	577	194	47
30	-	(383)	577	194	45
				Net Present Value	(24,156)

Table II.3 Cash Flow Closed Cycle OTEC 60 kW at San Salvador

Year	Capex (k$)	Operational cost (k$)	Revenu (k$)	Total cash flow (k$)	Present value cash flow (k$)
0	(9,359)	(131)	105	(9,385)	(9,385)
1	-	(131)	105	(26)	(25)
2	-	(131)	105	(26)	(23)
3	-	(131)	105	(26)	(22)
4	-	(131)	105	(26)	(21)
5	-	(131)	105	(26)	(20)
6	-	(131)	105	(26)	(19)
7	-	(131)	105	(26)	(18)
8	-	(131)	105	(26)	(18)
9	-	(131)	105	(26)	(17)
10	-	(131)	105	(26)	(16)
11	-	(131)	105	(26)	(15)
12	-	(131)	105	(26)	(14)
13	-	(131)	105	(26)	(14)
14	-	(131)	105	(26)	(13)
15	-	(131)	105	(26)	(12)
16	-	(131)	105	(26)	(12)
17	-	(131)	105	(26)	(11)
18	-	(131)	105	(26)	(11)
19	-	(131)	105	(26)	(10)
20	-	(131)	105	(26)	(10)
21	-	(131)	105	(26)	(9)
22	-	(131)	105	(26)	(9)
23	-	(131)	105	(26)	(8)
24	-	(131)	105	(26)	(8)
25	-	(131)	105	(26)	(8)
26	-	(131)	105	(26)	(7)
27	-	(131)	105	(26)	(7)
28	-	(131)	105	(26)	(7)
29	-	(131)	105	(26)	(6)
30	-	(131)	105	(26)	(6)
				Net Present Value	(9,783)

Table II.4 Cash Flow SDC at San Salvador

Year	Capex (k$)	Operational cost (k$)	Revenu (k$)	Total cash flow (k$)	Present value cash flow (k$)
0	(1,112)	-	-	-	-
1	-	(17)	116	(1,112)	(1,112)
2	-	(17)	116	100	95
3	-	(17)	116	100	90
4	-	(17)	116	100	86
5	-	(17)	116	100	82
6	-	(17)	116	100	78
7	-	(17)	116	100	74
8	-	(17)	116	100	71
9	-	(17)	116	100	67
10	-	(17)	116	100	64
11	-	(17)	116	100	61
12	-	(17)	116	100	58
13	-	(17)	116	100	55
14	-	(17)	116	100	53
15	-	(17)	116	100	50
16	-	(17)	116	100	48
17	-	(17)	116	100	46
18	-	(17)	116	100	43
19	-	(17)	116	100	41
20	-	(17)	116	100	39
21	-	(17)	116	100	38
22	-	(17)	116	100	36
23	-	(17)	116	100	34
24	-	(17)	116	100	32
25	-	(17)	116	100	31
26	-	(17)	116	100	29
27	-	(17)	116	100	28
28	-	(17)	116	100	27
29	-	(17)	116	100	25
30	-	(17)	116	100	24
				Net Present Value	396

Table II.5 1,500 kW wind turbine at Lower Bogue

Year	Capex (k$)	Operational cost (k$)	Revenu (k$)	Total cash flow (k$)	Present value cash flow (k$)
0	(12,193)	0	0	(12,193)	(12,193)
1	0	0	833	833	794
2	0	0	833	833	756
3	0	0	833	833	720
4	0	0	833	833	685
5	0	0	833	833	653
6	0	0	833	833	622
7	0	0	833	833	592
8	0	0	833	833	564
9	0	0	833	833	537
10	(5,821)	0	833	(4,988)	(3,062)
11	0	0	833	833	487
12	0	0	833	833	464
13	0	0	833	833	442
14	0	0	833	833	421
15	0	0	833	833	401
16	0	0	833	833	382
17	0	0	833	833	364
18	0	0	833	833	346
19	0	0	833	833	330
20	(5,821)	0	833	(4,988)	(1,880)
21	0	0	833	833	299
22	0	0	833	833	285
23	0	0	833	833	271
24	0	0	833	833	258
25	0	0	833	833	246
26	0	0	833	833	234
27	0	0	833	833	223
28	0	0	833	833	213
29	0	0	833	833	202
30	0	0	833	833	193
				Net Present Value	(5,152)

Table II.6 2000 kW Solar PV at Naval Base

Year	Capex (k$)	Operational cost (k$)	Revenu (k$)	Total cash flow (k$)	Present value cash flow (k$)
0	(9,612)	0	0	(9,612)	(9,612)
1	0	(29)	577	548	522
2	0	(29)	577	548	497
3	0	(29)	577	548	474
4	0	(29)	577	548	451
5	0	(29)	577	548	430
6	0	(29)	577	548	409
7	0	(29)	577	548	390
8	0	(29)	577	548	371
9	0	(29)	577	548	353
10	(4,070)	(29)	577	(3,521)	(2,162)
11	0	(29)	577	548	321
12	0	(29)	577	548	305
13	0	(29)	577	548	291
14	0	(29)	577	548	277
15	0	(29)	577	548	264
16	0	(29)	577	548	251
17	0	(29)	577	548	239
18	0	(29)	577	548	228
19	0	(29)	577	548	217
20	(4,070)	(29)	577	(3,521)	(1,327)
21	0	(29)	577	548	197
22	0	(29)	577	548	187
23	0	(29)	577	548	178
24	0	(29)	577	548	170
25	0	(29)	577	548	162
26	0	(29)	577	548	154
27	0	(29)	577	548	147
28	0	(29)	577	548	140
29	0	(29)	577	548	133
30	0	(29)	577	548	127
				Net Present Value	(5,217)

Table II.7 350 kW Solar PV at San Salvador

Year	Capex (k$)	Operational cost (k$)	Revenu (k$)	Total cash flow (k$)	Present value cash flow (k$)
0	(1,798)	0	0	(1,798)	(1,798)
1	0	(5)	103	97	93
2	0	(5)	103	97	88
3	0	(5)	103	97	84
4	0	(5)	103	97	80
5	0	(5)	103	97	76
6	0	(5)	103	97	73
7	0	(5)	103	97	69
8	0	(5)	103	97	66
9	0	(5)	103	97	63
10	(745)	(5)	103	(647)	(397)
11	0	(5)	103	97	57
12	0	(5)	103	97	54
13	0	(5)	103	97	52
14	0	(5)	103	97	49
15	0	(5)	103	97	47
16	0	(5)	103	97	45
17	0	(5)	103	97	43
18	0	(5)	103	97	40
19	0	(5)	103	97	39
20	(745)	(5)	103	(647)	(244)
21	0	(5)	103	97	35
22	0	(5)	103	97	33
23	0	(5)	103	97	32
24	0	(5)	103	97	30
25	0	(5)	103	97	29
26	0	(5)	103	97	27
27	0	(5)	103	97	26
28	0	(5)	103	97	25
29	0	(5)	103	97	24
30	0	(5)	103	97	23
				Net Present Value	(1,037)