Evaluation Ocean Thermal Energy Conversion Bahamas

Assessment Report

The Caribbean Community Climate Change Centre (CCCCC)

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LIST OF ABBREVIATIONS

BPL	Bahamas Power & Light
CCCCC	Caribbean Community Climate Change Centre
CDB	Caribbean Development Bank
EU	European Union
GCCA	Global Climate Change Alliance
GCF	Green Climate Fund
GWP	Global Warming Potential
IG	Imperial Gallon
IGPD	Imperial Gallon Per Day
MoW	Ministry of Works
MTP	Mean Tangible Production
NDP	National Development Plan
NRW	Non-Revenue Water
OPM	Office of the Prime Minister
OTEC	Ocean Thermal Energy Conversion
PDMU	Programme Development and Management Unit
PV	Photovoltaic
RO	Reverse Osmosis
SDC	Seawater District Cooling
SDG	Sustainable Development Goal
ST	Solar Thermal
SWAC	Seawater Air Conditioning
SWRO	Seawater Reverse Osmosis
TRL	Technology Readiness Level
WSC	Water and Sewerage Corporation

EXECUTIVE SUMMARY

The government of the Bahamas is investigating implementing OTEC technology for providing clean energy for the Bahamas' water sector. Witteveen+Bos has been commissioned by CCCCC to investigate the feasibility of this plan. This report is the second deliverable of the project that provides the results of the assessment of enabling environment for OTEC technology in the Bahamas.

OTEC Enabling environment

The OTEC implementation is influenced by aspects as follows: geography, demography, economy, climate ambitions, geohydrological conditions, climate change and water resource vulnerability, water sector conditions, stakeholders, and funding.

The government of the Bahamas has set the target to achieve 30 % renewable energy production by 2030. The number in 2018 was still 0.22 %. This ambition would surely support the development of OTEC technology.

One of the important enabling factors for OTEC in the Bahamas is the availability of cold and warm water sources (around 20 °C difference). As a tropical country, the Bahamas has warm water at the seawater surface and cold water on the deep sea. There has been an indication that the deeper the well, the colder the groundwater. We investigated the potential subsurface temperature decrease. Based on our investigation, there is insufficient information that the 20 °C temperature difference requirement for OTEC application on saline groundwater can be established by just drilling deeper than the current wells in the Bahamas.

Based on expert judgment, the porosity and permeability of the muddy deep-water sediments are considered rather low and therefore probably unsuitable for OTEC.

With this finding, in the next project phase we will investigate the use of solar thermal to increase the temperature difference of the extracted groundwater flows to be used for OTEC.

Clean energy for the SWRO plants

The current water supply is energy intensive because of using saline water as the source. OTEC implementation would supply steady clean energy. Alternatively, wind and solar both on land and in the sea are seen to be good financial competitive options considering the solar irradiance and wind speed in the Bahamas area. Tidal and wave power were also investigated. It is found that tidal and wave power are not favourable for the Bahamas.

As it is recommended that solar and wind are to be used it seems very logical to closely cooperate with BPL as in that way the existing grid can be used and where needed upgraded to improve reliability. The emergency energy supply could then be maintained and fuelled with biofuels or from locally at the RO plant installed batteries.

PREFACE

Witteveen+Bos has been commissioned by the Caribbean Community Climate Change Centre (CCCCC) to perform an OTEC feasibility study for the Bahamas (with consultancy contract number CONTRACT# 69/2022/EU-GCCA/CCCCC).

The project aims to evaluate the feasibility of OTEC and its combination with SDC, solar thermal and/or solar PV to contribute to the decarbonisation of the water supply in the Bahamas (Family Islands).

We are expected to complete four deliverables under this contract:

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

Goal of this report

This Assessment Report is the second deliverable of the project. The purpose of this Assessment Report is to provide the results on the review of the enabling environment for the development and promotion of OTEC technology in the Bahamas. This report is the second deliverable from the project 'Evaluation Ocean Thermal Energy Conversion Bahamas' (hereinafter referred to as The OTEC Project).

The report is based on the following:

- Interview and site visits from the inception phases
- Literature analysis

Project framework

The Caribbean Community Climate Change Centre (CCCCC) has received financing from The European Union through the GCCA+ programme toward the cost of the project titled 'Enhancing Climate Resilience in CARIFORUM Countries' and intends to apply part of the proceeds towards a Consultancy for 'An evaluation of Ocean Thermal Energy Conversion'.

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

1

INTRODUCTION

1.1 Background

The project is situated in the Bahamas, a country in the north of Cuba and East of Florida. The project focuses on renewable energy for the water supply in the Family Islands, the islands that make up the Bahamas with the exception of New Providence Island, where the capital and largest city, Nassau, is located and Grand Bahama Island, where Freeport is located.

Figure 1.1 Map of the Bahamas

The Bahamas consists of over 700 islands, although 95 % of the population live on 7 islands with main population centres concentrated on New Providence and Grand Bahama [Paho, 2007]. The Bahamas has already experienced impacts from changes in climate, including sea level rise, coastal erosion and drought. The country, like the rest of the Caribbean region, also has a history of struggles against major impacts from destructive storms and hurricanes. In 2017, the Bahamas was hit by two consecutive Category 5 hurricanes, Irma and Maria, causing damage to infrastructure and evacuation of affected islands [Acaps, undated].

Water supply Family Islands

The public water utility in the Bahamas, the Water Sewerage Corporation (WSC), is the main water supply operator in the country; however, some other operators cover limited areas. WSC supplies New Providence and 24 Family Islands and Cays. It has historically played a major role in structuring the water sector, having both operational and regulatory responsibilities. The WSC is, however, not able to provide water services to every Bahamian citizen. It also suffers from an insecure financial situation, and provides unequal levels of service for various reasons, including differing sources of supply, availability, and age of infrastructure. There are different tariffs for residential and non-residential customers. The tariffs also differ by location, broken down into New Providence, Major Family Islands (Exuma, Eleuthera, Abaco and San Salvador) and the other Family Islands [Hydroconseil, 2019].

The water infrastructure consists of more than 50 standalone systems, most of which include pumping stations, storage tanks, mains and pipes, and some also include pressure tanks. The two water sources used by the WSC are well fields and saline groundwater treated with Reverse Osmosis (RO) plants. So far, the RO plants have been considered as having little environmental impact. Still, in fact, this is not the case as they consume a lot of energy. Moreover, the grid power in the Bahamas comes from fuel generators using diesel and Heavy Fuel Oil as an energy source [Hydroconseil, 2019].

Due to overuse and climate change (resulting in increased seawater intrusion), well fields utilising sweet water are being replaced by RO using saline groundwater. The use of RO plants is leading to the increasing involvement of the private sector, as the RO plants are mainly (if not all) managed by private operators contracted by WSC. Veolia/SUEZ is the main operator for the WSC RO facilities.

In the Table below, the main reasons for interruptions of the water supply are presented.

Figure 1.2 Main reasons interruptions of the water supply [Hydroconseil, 2019]

Origin	Most likely reason	Examples	Possible improvement
Power outage	Low quality of BPL power Absence or failure of back-up generator	North Eleuthera, North Andros	Investment
Age or inadequate quality of old pipes	Old pipes or poor procurement of old pipes	5,000 feet of low-quality grey conduit PVC along Samuel Guy Street in Spanish Wells Drainage fittings in Russell Island	Procurement requirements
Improper installation of pipes	Previous lack of works supervision	Millionaire's Road on Harbour Island Glass Window Bridge	Better works oversight (now addressed)
Pressure surges	Pumps pushing directly into distribution lines	A vast majority of WSC networks are not gravity-fed	PRV, pressure tanks or elevated tank (even small capacity)

OTEC as a source of renewable energy for the water supply system

The Office of the Prime Minister (OPM) of the Bahamas and the Water Sewerage Company (WSC) have identified Ocean Thermal Energy Conversion (OTEC), utilizing saline groundwater instead of Ocean water as a promising option to replace diesel as a source of electricity generation in combination with the Reverse Osmosis water treatment systems utilising Saline groundwater. In some cases, solar energy using PV might be considered an additional or even better option. Together with OTEC, Seawater District Cooling (SDC) is considered a promising alternative to common air conditioning systems utilizing diesel powered electricity as a source. Both OTEC and SDC in combination with the existing RO plants are to be investigated in this project. Thus, the water supply system of the Family Islands of the Bahamas should become energy neutral.

During the inception phase of this project, WSC and OPM together with the Consultant Witteveen+Bos from The Netherlands, also identified other interesting renewable energy sources as an alternative or add-on for OTEC and PV:
- Wind energy

- Solar thermal energy
- Wave energy
- Tidal energy

To elaborate on the most promising options for renewable energy, three WSC water supply locations were identified (see Table 1.1)

Table 1.1 Pilot locations identified

Location	Current MTP	Current Peak	WSC Proposed New MTP	WSC Proposed new Peak Capacity	Notes
North Eleuthera	525 IG	600 IG	600 IG	750 IG	New Well needed, additional storage tank, power conditioning
Central Eleuthera	350 IG	400 IG	450 IG	600 IG	Additional Storage tank
San Salvador	64 IG	80 IG	90 IG	120 IG	Backup generator to be added

1.2 Reading guide

The report starts in chapter 2 with an explanation of the principles of OTEC Technology and options and ideas for combining it with water treatment and district cooling on The Family Islands. In chapter 3 the political, legal, institutional, financial and environmental conditions in The Family Islands for OTEC are described. In chapter 4 the technical enabling environment is described to combine water treatment with OTEC, PV, and other potential sources of renewable Energy. In chapter 5 the conclusions and recommendations towards the development and implementation of a renewable energy infrastructure combined with the water treatment and supply system are discussed.

2

OTEC TECHNOLOGY

Ocean Thermal Energy Conversion (OTEC) is a technology that uses ocean thermal gradient between cooler deep and warmer shallow or surface seawaters to produce electricity. The advantages of OTEC include being able to provide electricity on a continuous (non-intermittent) basis, while also providing cooling without electricity consumption. The capacity factor of OTEC plants is around 90 % - 95 %, one of the highest for all renewable power generation technologies. Although the efficiency of the Carnot cycle is very low (maximum 7 %), it does not impact the feasibility of OTEC as the fuel is 'free'. Open cycle OTEC (OC-OTEC) is one of the OTEC types. Other types of OTEC include closed-cycle (CC-OTEC), Kalina cycle, and hybrid system OTEC.

The total worldwide capacity of OTEC installed is only 0.23 MW (see Figure 2.1). The OTEC technologies are all still mainly in the research and development stages. Several barriers still need to be overcome, and work on these technologies is therefore conducted mainly in research institutes and universities. Nevertheless, the first OTEC test plants were developed in the late 1970s, starting with a 15 kW offshore barge in Hawaii in 1979 and followed by several land-based plants in Nauru in 1982 and in Hawaii in 1987 and 1993. Demonstration projects have continued to be conducted in France (La Réunion), Hawaii, India, Japan and the Republic of Korea, with many of them investigating additional functions such as SWAC, desalination or aquaculture [IRENA 2020].

Figure 2.1 The scale of OTEC compared to total ocean energy deployment

2.1 Principles

OTEC systems extract heat from surrounding seawater by evaporating a working fluid. The resulting high-energy vapour is then used to drive a turbine, thereby producing electricity. Finally, the fluid is condensed by use of the cold seawater. The main difference between CC- and OC-OTEC lies in the working fluid used in the system, the different cycles are shown in Figure 2.2. CC-OTEC uses a refrigerant like ammonia with a low boiling point in a closed-loop system, whereas the working fluid in an OC system is seawater.

2.1.1 Open-Cycle

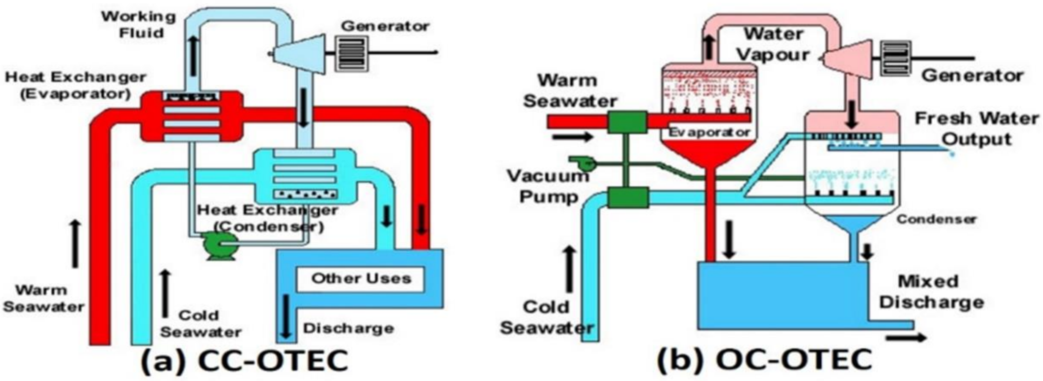
In OC-OTEC, warmer seawater is flash evaporated at below atmospheric pressure to produce steam. The low pressure is achieved by the use of a vacuum pump, powered by the gross electric output of the OTEC system. The low-pressure steam spins a turbine to generate electricity. The steam leaving the turbine is then condensed by the colder seawater. This condensate is desalinated and can therefore be used for irrigation or drinking water. The cold water used in the condensation leaves with a temperature of around 46°F (8 °C) and may additionally be used for air-conditioning purposes. If there exists no practical use for desalinated water or cold seawater for cooling then the condensation step may be omitted, saving costs on a large heat exchanger.

OC-OTEC has a high potential in the Bahamas due to the scarcity of local freshwater resources. Drinking water is primarily produced from groundwater, which is desalinated through reverse osmosis. OC-OTEC could provide an economic benefit and save energy on running an RO plant.

2.1.2 Closed-Cycle

Warm surface water is used to provide heat to a working fluid with a low boiling point. The heat increases vapour pressure, which is used to drive a turbine. The working fluid vapour is subsequently condensed by deeper cold water and pumped back into a closed system. Another major difference with OC-OTEC is the smaller size required of the ducts and turbines. Its heat exchangers require less surface area as well for effective heat transfer. CC-OTEC offers a more efficient use of the thermal resource.

Figure 2.2 Closed (a) and Open (b) Cycle OTEC

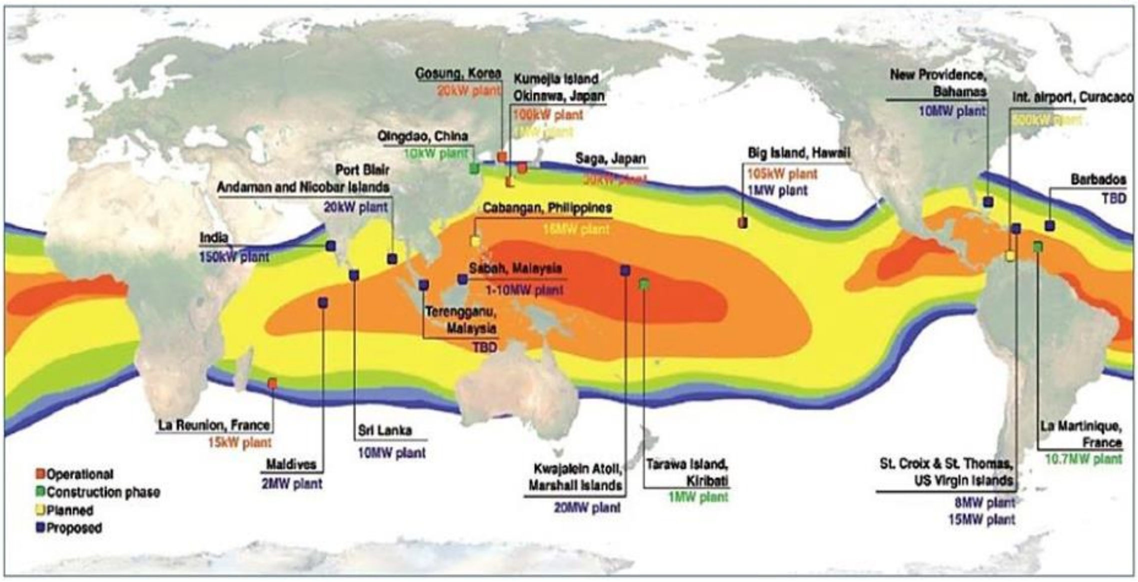


2.2 Technology status

Technology readiness

Closed-cycle OTEC is feasible up to 10 MWe and is expected to be scalable to over 100 MWe with further research in the near future [NOAA, 2009]. Modular scaling is proposed as an alternative, through combining multiple lower-capacity systems. OTEC technology is still in its infancy, making it difficult to estimate the economic potential for commercial use [Langer e.a. 2020]. The map below indicates OTEC projects in varying stages of development, from proposed to operational.

Figure 2.3 OTEC plants worldwide [Petterson and KimCan, 2020]



2.3 Saline groundwater as a source of OTEC

OTEC requires a temperature gradient in a medium to generate electricity, but it is not required for this medium to be seawater. Instead, groundwater could be used as a substitute for seawater, as long as there exists a large enough temperature difference between the warm and cold source. In general, groundwater temperature increases with depth and offers a stable temperature gradient. An advantage of using groundwater instead of seawater is that the system is not exposed to the hydrodynamic forces of the ocean.

Situation in the Bahamas

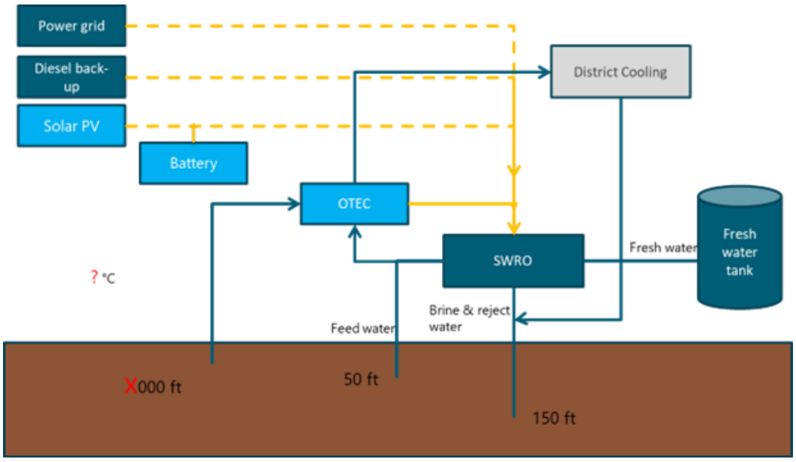
The sea between the Islands of the Bahamas cannot be used as a source for OTEC in the Bahamas, as it is too shallow to contain a large enough difference between surface and bottom temperatures.

The use of OC-OTEC with saline groundwater would align well with the current drinking water production in the Bahamas. The desalinated condensate can be used to alleviate SWRO plants in drinking water production. In the Bahamas, geothermal conditions are inverted, meaning that groundwater temperature in fact first decreases before it starts increasing.

2.4 Technological Challenges

The technological challenges for OTEC using saline groundwater are considered much less than in case of using water from the ocean as the infrastructure is more simple and the water quality and environmental conditions are more stable. The main challenge in the situation of the Bahamas will be the question of how to establish a temperature difference. In sections 3.3 and 3.4 we elaborate on the geological conditions, geohydrological conditions, and available information to answer the question if a difference of 20ºC or higher can be established using water from different depths. If a temperature difference of 20ºC or more can be established, the system can be designed as presented in Figure 2.4.

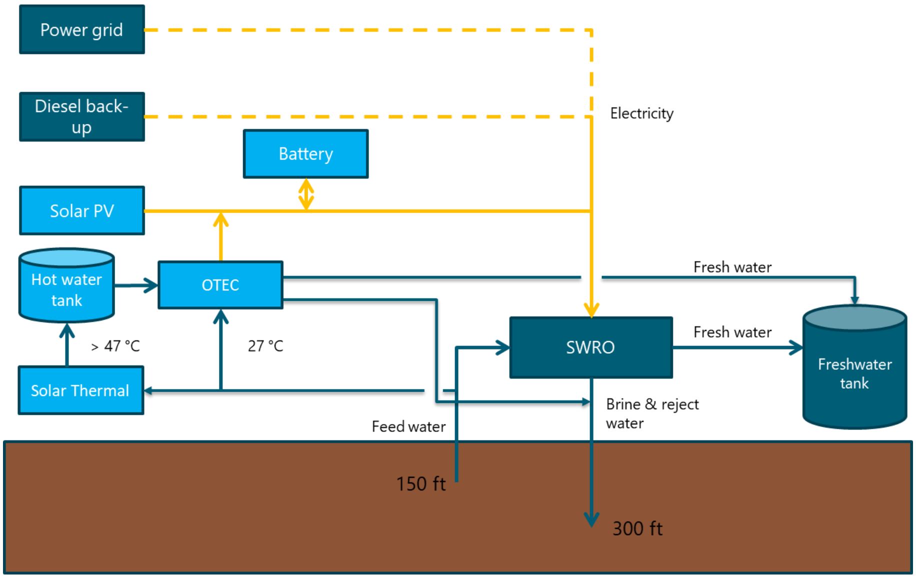
Figure 2.4 Combination OTEC/SDC and SWRO



2.5 Combination with solar thermal heating

In case the 20 °C temperature difference requirement cannot be established, solar thermal heating can be applied as shown in Figure 2.5 to increase the temperature difference. In appendix II Solar Thermal Technology Options are presented.

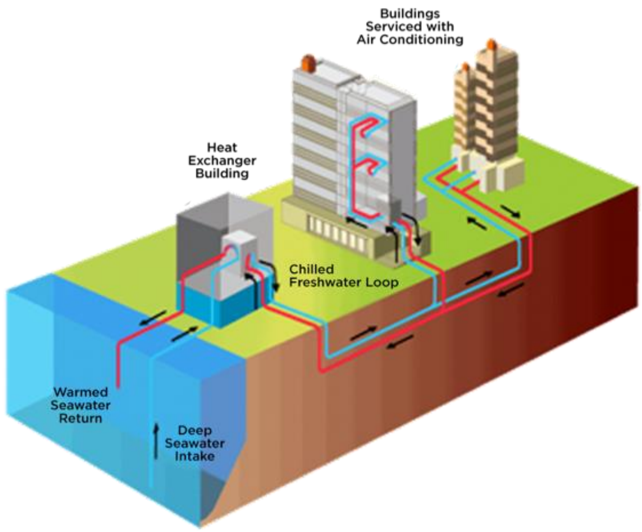
Figure 2.5 OTEC combination with solar thermal heating



2.6 Combination with SDC/SWAC

In the OC-OTEC, cold water is used to condensate the steam leaving the turbine. The cold water used for the condensation is typically pumped from a depth of around 1000 ft, where it has a temperature of around 41°F (5 °C). After it has been used, the cold water remains at a low enough temperature, around 46°F (8 °C), to be used for seawater air conditioning (SWAC) or Seawater District Cooling (SDC).

Figure 2.6 SWAC (source: otecorporation.com)



2.7 Other products from OTEC

In Kumejima, Japan the team of the Bahamas experienced that OTEC provides the opportunity to develop other commercial activities like aquaculture and cosmetics [WSC, 2022]. If OTEC is going to be applied this could be a nice add on. However this opportunity is not typical for OTEC as the source of the cosmetics are the water and the salts in the ocean or saline groundwater in combination with controlled conditions (temperature, water quality). Any other technology producing steam and concentrating the salts is considered applicable. So we do not further consider this as a typical add on. However, when developing OTEC it is recommended to consider improving the business case by additional commercial activities as developed by the Japanese in Kumejima.

3

REVIEW OF OTEC/SDC ENABLING ENVIRONMENT FOR THE BAHAMAS

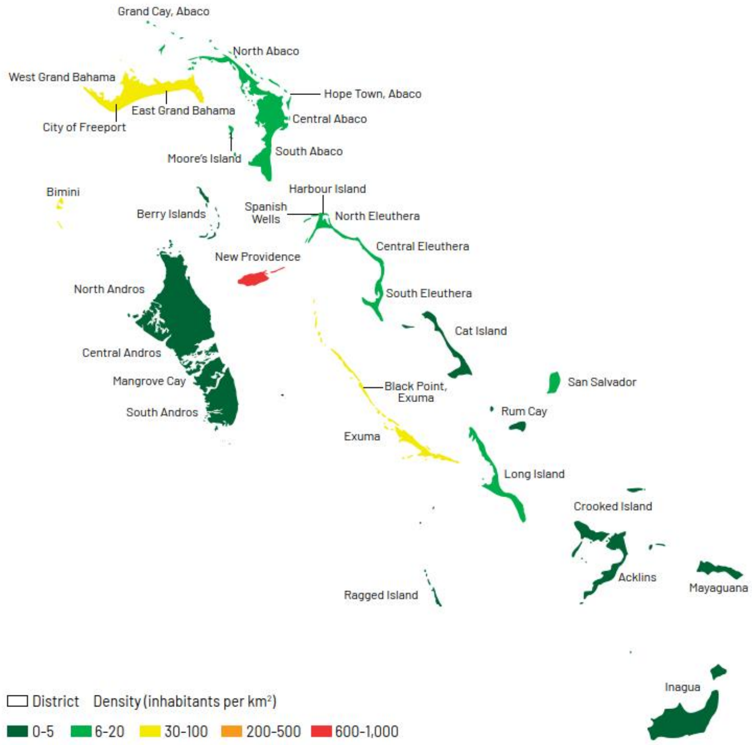
In this chapter we provide a review of OTEC and SDC enabling environment in the Bahamas with a focus on the Family Islands. The enabling environment includes geology and hydrogeology conditions, energy and water market, legislation, institutional and environmental aspects.

3.1 Geography, demography and economy

The Bahamas is an archipelago of over 700 islands and cays, situated just 80 km off the coast of Florida. It is considered a high-income country, with an estimated GDP per capita in 2019 of USD 29,0151, which has decreased in recent years and is expected to further contract due to the impacts of COVID-19 and Hurricane Dorian in 2019. Its economy relies heavily on two sectors, tourism and financial services, both vulnerable to external shocks. The population of the Bahamas, of almost 390 thousand people, is dispersed over a vast archipelago, though 70 per cent are on the island of New Providence, home to the capital of Nassau (see Figure 3.1).

This low population density and the geographical condition (many Islands) make it necessary that local small scale reliable renewable energy systems are to be developed in combination with the local water supply systems. OTEC utilising groundwater in principle provides a very constant and reliable amount of electricity. Therefore, it seems a very suitable technology. On the other hand, the small scale might result in very high costs for the produced electricity.

Figure 3.1 Bahamas Population Density, 2019 (in inhabitants per km^2) [United Nations, 2020]



Although the country belongs to the very high human development category, inequalities hinder the full inclusion of its benefits. Around 16 per cent of its population are migrants, mostly of Haitian origin. The population is ageing, and this will have significant implications in terms of social benefits, healthcare and labour force [United Nations, 2020].

The Bahamas is a constitutional monarchy with a bicameral parliament. It is considered a stable democracy where political rights and civil liberties are generally respected. Its multiparty political system is dominated by the Progressive Liberal Party (PLP) and the Free National Movement (FNM). While its institutions are considered accountable and the legal system of the Bahamas relatively strong (the country ranks 29 out of 180 countries according to Transparency International Corruption Perception Index19), challenges are evident when it comes to equal treatment of all population within its territory20, regulatory quality, and rule of law (as evidenced by declining World Governance Indicators (WGI) data over time. Likewise, the Rule of Law index developed by World Justice Project21 shows a downward trend, ranking the Bahamas as 34th out of 37 High Income Countries [United Nations, 2020].

In the Bahamas many second homeowners from other countries have large estates. These second homeowners very often possess their own water supply system with wells and large storage tanks. The amount and capacity of these systems is unknown. However, most of them are also connected to the water supply system of WSC for back up and peak water supply.

If the Bahamas want to utilize renewable energy for the total water supply in the Family Islands, focus should be on the dispersed private water systems as well. A programme should be developed to get a better view of the number, locations and capacity of these private water systems.

3.2 Climate ambition (SDG Affordable and Clean Energy)

The National Development Plan (NDP) Vision 2040 is the country's long-term strategy for economic growth, social transformation and environmental resilience, though it is not (yet) formally adopted by the Government of the Bahamas. It is based on four interrelated pillars, namely:

1. GOVERNANCE - ensures the principles of transparency and accountability at national and local government levels.
2. SOCIAL POLICY - promotes the concept people centred development by facilitating access to quality health care and education and addresses issues of poverty and discrimination.
3. ENVIRONMENTAL SUSTAINABILITY AND RESILIENCE - fosters greater integration between modernization and infrastructure development and the natural environment.
4. ECONOMIC POLICIES - promotes inclusive growth built on improved productivity and social safety nets and eliminates inequalities and discrimination.

The country is an active participant in many multilateral environmental treaties. While it submitted a National Biodiversity Strategy and Action Plan to the Convention for Biodiversity (CBD) in 1999, this has not been updated since. This is an area where urgent action is opportune. Similarly, the Bahamas has not updated its key environmental law since 2000 [United Nations, 2020].

The government has set for itself a very ambitious target of 30 % of renewable energy production and consumption by 2030 (starting from a baseline of 0.22 per cent in 2018) in line with SDG 7 and the country's commitment under the UN Paris Agreement on Climate Change. It is difficult to identify a trend with respect to the country's CO_2 emissions, showing sharp peaks and deep troughs. The most recent data is from 2016, when the country emitted 4.7 metric tons per capita, down from 7.8 metric tons per capita in 2013, but only slightly down from the 5.0 metric tons per capita reported in 2011. The strategies comprise the enhancement of the regulatory framework and expanding solar energy solutions in Family Islands [United Nations, 2020].

WSC states in their corporate strategy for 2023 that they have a focus on financial and environmental stewardship by taking the following steps (with respect to The Family Islands):

- Increase the number of customers by 5 % by investing in the extension of the distribution system.
- A draft legislation to govern the sector is to be developed and both an independent Economic Regulator (URCA) and Environmental Regulator (DEPP) are to be established.
- Continue energy efficiency activities inclusive of the transition to electric vehicles and solarization of WSC facilities in the Family Islands.
- Establish a comprehensive, resourced, Family Island NRW Programme [WSC, 2022].

Veolia (Suez), the main operator of the water supply systems has stated for the previous COP26: 'Veolia is preparing to double its commitments for reducing GHG emissions while reinforcing its reputation as the leading partner for its customers' low carbon and resilience strategies' [Veolia.com].

As both the government and WSC mention solarization as a focal point, a joint undertaking seems logical to change the energy supply system from diesel powered to solar powered. It is recommended that OPM, Bahamas Power & Light (BPL), as the operator of the energy supply on behalf of the government together with WSC and Veolia develop a joint programme for a reliable and renewable future energy supply for the water supply system and the total energy system. OTEC and other renewable energy systems can be elements in the future energy system together with PV.

3.3 Geology of the Bahamas

The Bahama Banks consist of a carbonate platform with a thickness greater than 4.5 km (ca. 15,000 feet) [Schlager et al., 1984]. The carbonate platform stretches across the entire Bahama Archipelago but does not vary systematically across the Bahama Archipelago, with sediment presenting a more or less mud-dominated lithology (see Figure 3.2), due to discontinuous sedimentation through time, specific islands orientation, variable wind and oceanic currents, etc. [e.g. Carew and Mylroie, 1997; Harris et al., 2015; Weij et al., 2019].

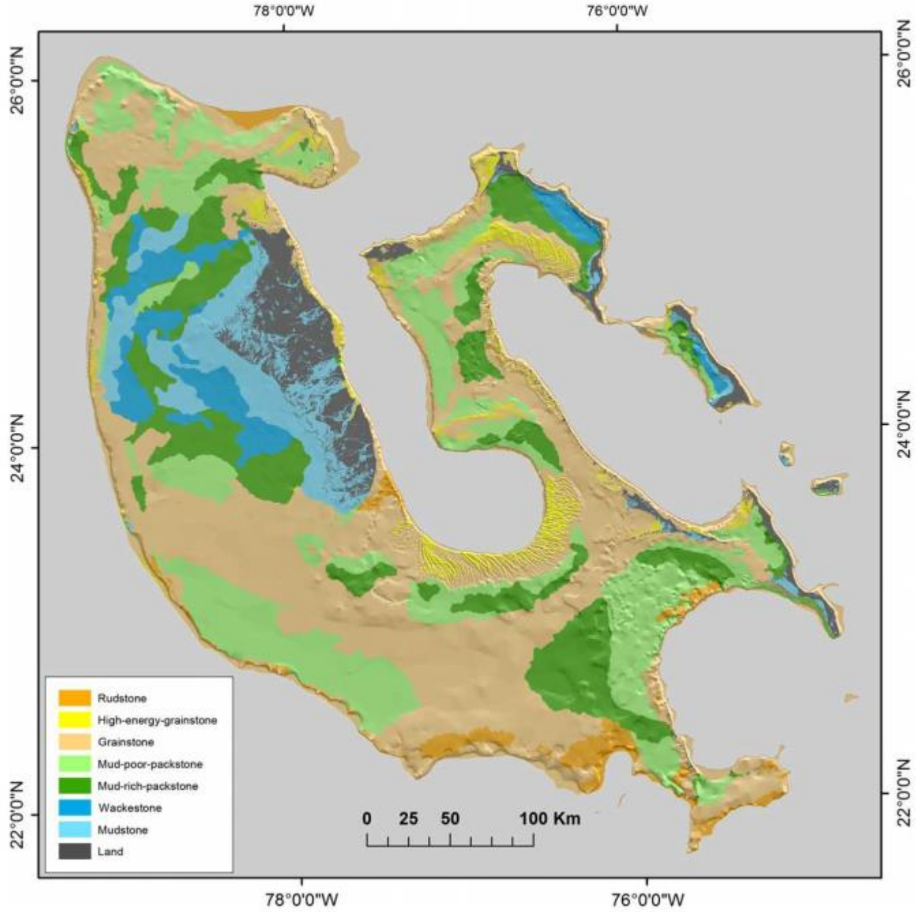
Consequently, it is rather challenging, and potentially wrong, to set up a uniform geological model across the Bahama Banks.

Overall, the carbonate platform has been accumulating since at least the Cretaceous [Schlager et al., 1984]. Following a marine flooding during the Albian/Cenomanian, recorded in the sedimentary succession at a depth of approximately 1900 - 2700 m (ca. 6000 - 8900 feet), the area formed a deep-water basin, where deep-water chalks were deposited [Schlager et al., 1988; Epstein and Clark, 2009]. After the Eocene/Oligocene, at a depth of approximately 1500 m (ca. 5000 feet), the area became shallower and formed a deep-water slope where deep-water chalks were sporadically disturbed by coarser-grained gravity flows. **Based on expert judgment, the porosity and permeability of these muddy deep-water sediments are rather low and therefore probably unsuitable for OTEC**.

Starting from the Miocene, at a depth of approximately 1200 m (ca. 4000 feet), the area consisted of a high-energy reef margin, made of mudstones to various skeletal grainstones and floatstones [e.g. Eberli et al., 1997; Mylroie et al., 2012]. After the Miocene/Pliocene boundary, at a depth of approximately 300 - 550 m (ca. 1000 - 1800 feet), the reefal sediments covered a wide range of lithofacies from wackestones, floatstones, rudstones, grainstones to boundstones. Following the onset of glacio-eustatic sea-level variations at the beginning of the Pleistocene, at a depth of approximately 75 - 100 m (ca. 250 - 330 feet), the Bahama Banks underwent numerous cycles of reef platform extensions [e.g., Carew and Mylroie, 1997; Eberli et al., 1997]. Carbonate sequences accumulated during interglacial floodings and were separated by erosional surfaces formed during glacial regressions. The regressive sequences displayed reefal, peri-reefal, beach and terrestrial settings with sediments covering a wide range of lithofacies from mudstones, floatstones, rudstones, packstones to boundstones [e.g. Carew and Mylroie, 1997; Eberli et al., 1997]. After the Pleistocene/Holocene boundary, at a depth of approximately 40 - 60 m (ca. 130 - 200 feet), mostly mudstones and packstones were deposited in alternation with aerial sediments following subaerial exposure [e.g. Beach and Ginsburg, 1980; Carew and Mylroie, 1997].

This entire reefal to peri-reefal succession dated from the Miocene to the Holocene is known to present high porosity and permeability. This may lead to the creation of local sinkholes of approximately 100 - 200 m deep (ca. 300 - 600 feet), also called blue holes [e.g. Carew and Mylroie, 1997]. Such sinkholes are often used as freshwater supply in the Bahamas, as the rainfall percolates through the ground and becomes trapped into them [Falkland, 1991]. On the other hand, this reefal to peri-reefal succession is locally susceptible to be partly dolomitized due to infiltration of saline ground water [Whitaker and Smart, 1993]. **This may lead to reduced porosity and permeability, with sediments that might consequently be less suited for OTEC**. Unfortunately, both phenomenas are particularly difficult to map. Therefore, in addition to the great geological variability of the carbonate platform across the entire Bahama Archipelago, it is particularly challenging to predict the lithology and associated porosity and permeability at a specific location or depth. **Acquisition of local data is consequently advised before the implementation of OTEC at a given project area**.

Figure 3.2 Sedimentary distribution through space for the Bahamas Platform [Harris et al., 2015]



3.4 Hydrogeology conditions of the Bahamas

Reverse geothermal gradient

Under normal geological conditions, groundwater temperature increases with depth. However, due to the extraordinary geology and location of the Bahama Banks, there exists a reverse geothermal gradient, as indicated by temperature logs [Cant, 2012]. According to Cant, this gradient is caused by subsurface penetration of cold Atlantic seawater'. This means that the groundwater temperature decreases with increasing depth. At approximately 183 m depth, the groundwater temperature has been found to be approximately 21.5 degrees C [Cant, 2012]. The temperature measurements from deep boreholes have thus shown a similar decrease in temperature over depth to that of the surrounding ocean. Projections have been made that the groundwater temperature at approximately 1000 m could reach up to 6 degrees C [Ardaman and Associates Inc., 2013]. These projections are, however, based upon the thermal gradient between shallow groundwater and groundwater at a depth of 183 m and the assumption that the gradient will be similar between 183 m and 1000 m depth. There are no measurements below a depth of 183 m.

Ocean temperature gradient

The temperature gradient in the ocean has been measured in the deep sea approximately 2.6 km southwest of New Providence Island, also called the 'Tongue of the Ocean' [Philips et al., 2019]. These measurements show a clear decline in temperature with increasing depth (see Figure 3.3). The measured ocean temperature at a depth of 700 m is approximately 10 degrees C, compared to approximately 27 degrees C at the surface [Philips et al., 2019; Arias-Gaviria, Osorio, Arango-Aramburo, 2020]. At 180 m the ocean temperature is indeed close to 21 degrees C (comparable with groundwater temperature at this depth). These findings are in line with historic ocean temperatures as measured at Montego Bay, Jamaica [Arias-Gaviria et al., 2020].

The measured monthly temperatures at Montego Bay show that the ocean temperature at 1000 m is approximately 5 degrees C (Figure 3.4).

Figure 3.3 Temperature measurements in the deep sea southwest of New Providence Island. Retrieved from [Philips et al., 2019]

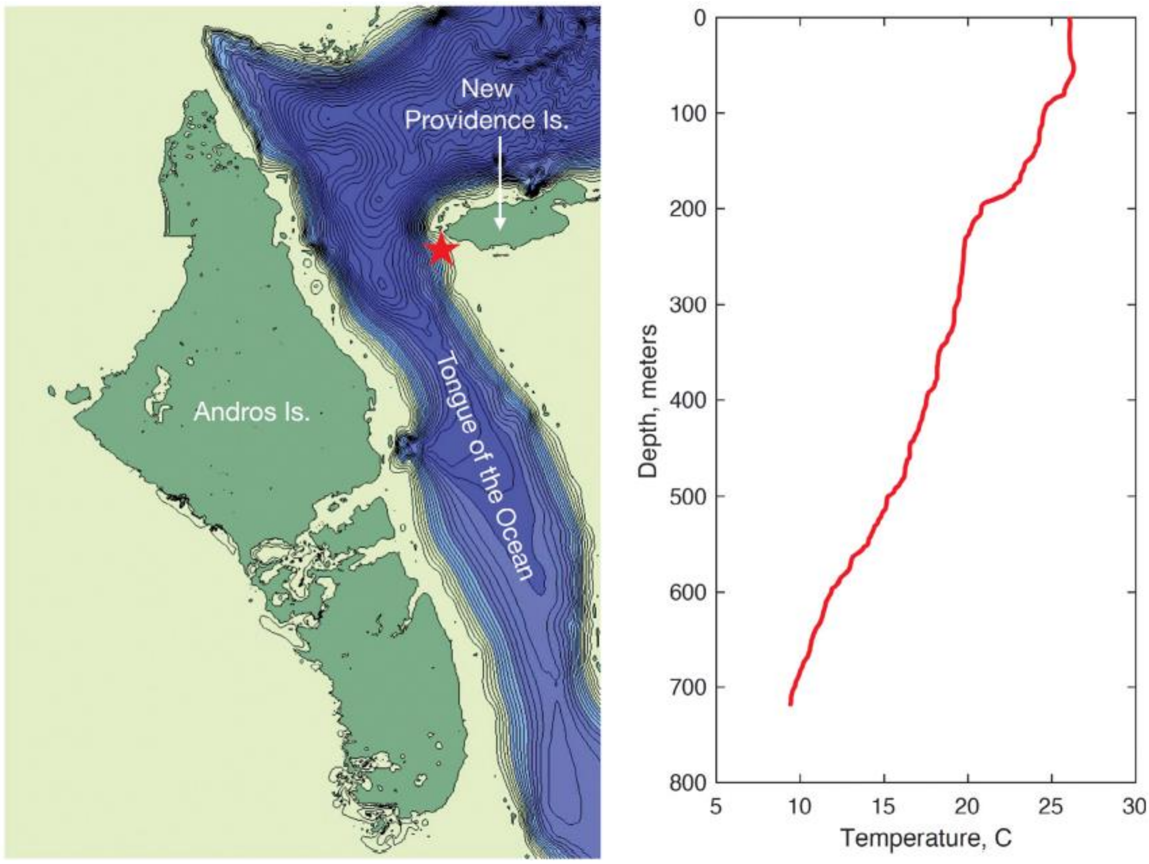
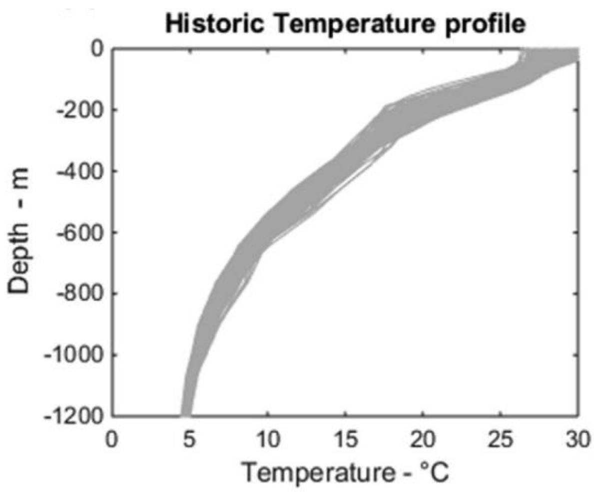


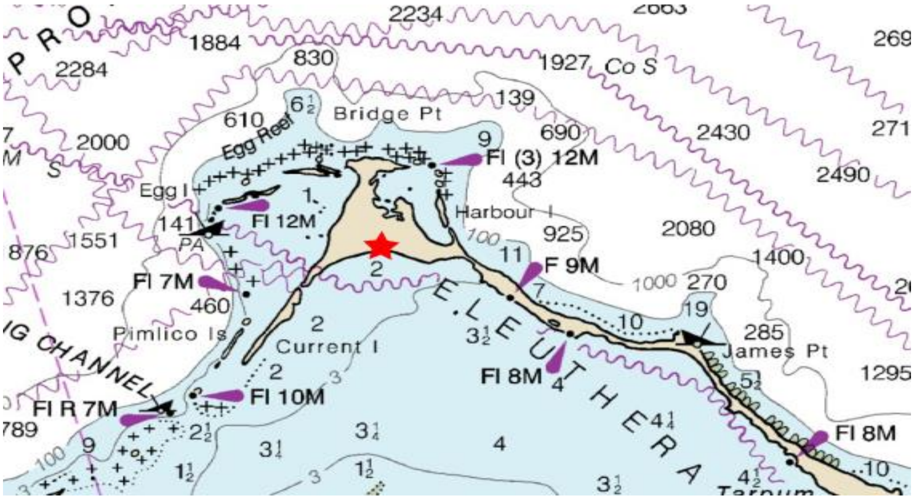
Figure 3.4 Monthly measured temperature profiles at Montego Bay, Jamaica. Retrieved from [Arias-Gaviria et al., 2020]



Ocean depth

The Bahamian Archipelago is characterised by sharp drop offs into deep oceans (> 1000 m) after only a few kilometres of very shallow sea [Philips et al., 2019; Buchan, 2000]. The Eleuthera Island has similar drops, with depths up to 4000 m only tens of kilometres away from the ocean shoreline. The deep sea is thus extremely close to the Eleuthera Island as can be seen in Figure 3.5. At Lower Bogue in the northern part of Eleuthera, the ocean depth is approximately 1700 m at a mere 11 km [NOAA, 1984].

Figure 3.5 Water depth in fathoms. 1 fathom is equal to 1.83 m. Retrieved from [NOAA, 1984]. The red start indicates the proposed groundwater OTEC system

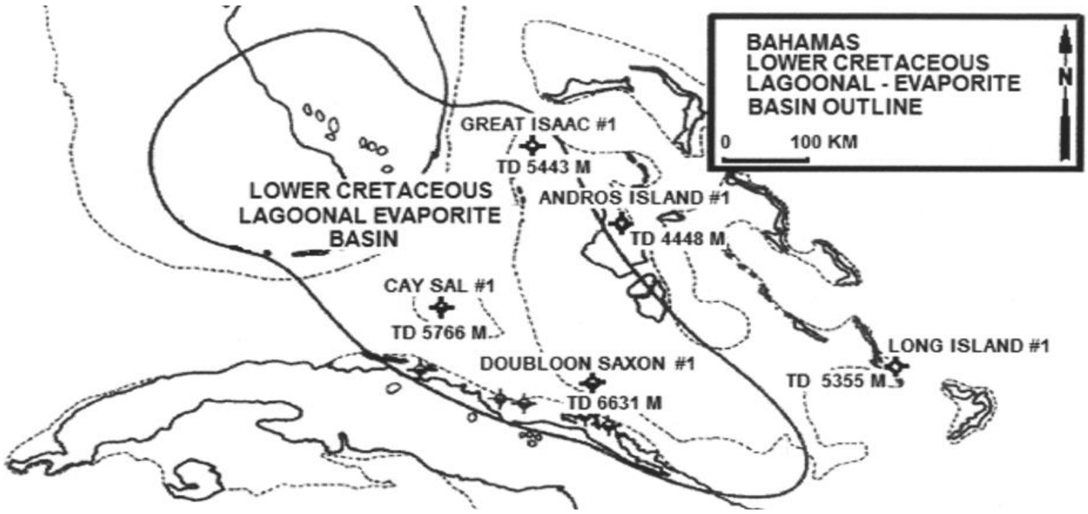


Temperature at larger depths

The reverse geothermal gradient found by Cant [Cant, 2012] is only applicable up to a certain depth (as stated, based on a measured groundwater temperature at a depth of 183 m). Epstein and Clark [Epstein and Clark, 2009] have reported temperatures in numerous deep wells at large depths (Figure 3.6). They reported a temperature of 51 degrees C at approximately 2200 m depth (Cay Sal deep well), and up to 182 degrees C at 8534 m depth (Long Island deep well). There appears to be variation in the temperature along the depth, since the Cay Sal deep well has measured a temperature of 142 degrees C at approximatively 8200 m. Extrapolation of these measured groundwater temperatures at greater depths will lead to a temperature of 26 degrees C at a depth of 1000 m (Figure 3.7).

This larger temperature at greater depths may influence the temperature at lesser depths. It is however unclear where the balance and transition lie between the cold groundwater, fed by the deep ocean and the warm ground water, fed by the heat of the Earth's core.

Figure 3.6 Location of deep test wells in the Bahamas. Retrieved from [Epstein and Clark, 2009]



Expectations for the groundwater temperature

Based on the measured groundwater temperature profile up to approximately 183 m, the (similarity to the) temperature gradient in the ocean and the proximity of the deep ocean to the Bahamian Islands, it can be expected that the groundwater temperature at 1000 m is approximately 5 degrees C. In combination with the warm shallow ocean temperatures of approximately 27 degrees C, this would be ideal for OTEC, which requires a temperature difference of at least 20 degrees C.

It is however unknown how the higher temperature at greater depth (approximately 51 degrees C at 2200 m) affects the groundwater temperature at 1000 m depth. It is unclear where the transition from cold to warm groundwater begins and consequently, if groundwater of 5 degrees C can be expected at a depth of 1000 m.

As can be seen in Figure 3.7, the expected groundwater temperature lies somewhere between 5 and 26 degrees C, based on extrapolation of both the measured shallow and deep temperatures. The groundwater temperature at 1000 m depth at the proposed groundwater OTEC location at Lower Bogue depends on two things. Firstly, the temperature is affected by the water (and consequently heat) flux from the deep ocean, transporting cold water to the proposed OTEC location at 1000 m depth. Secondly, the temperature is affected by the heat flux resulting from the upwards heat flux of the Earth's core. An overview of measured temperatures and described fluxes can be found in Figure 3.8.

Figure 3.7 Measured groundwater temperature (blue dots), with gradient (blue line), with extrapolations to a depth of 1000 m, based on shallow measured temperature (at 0 and 183 m depth), red dashed line, and based on deep measured temperature (2200 m and 8534 m depth), grey dashed line

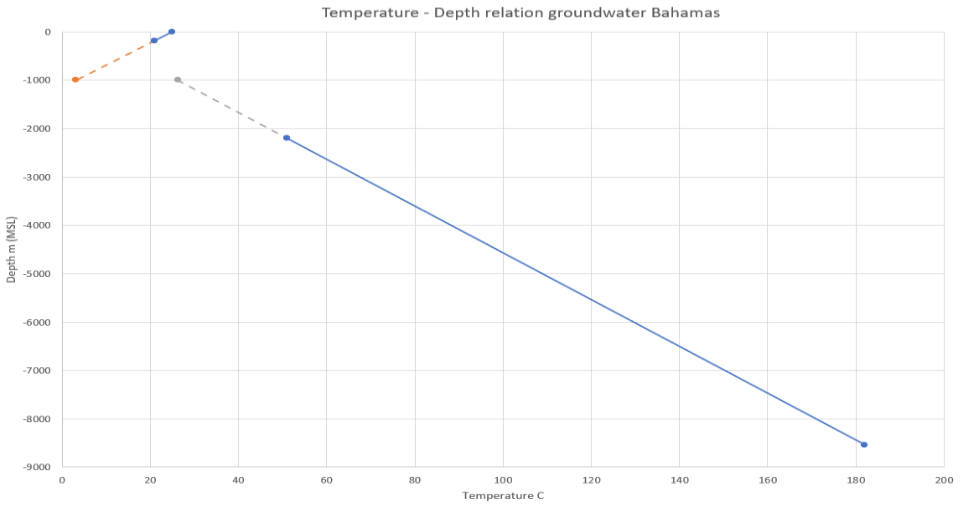
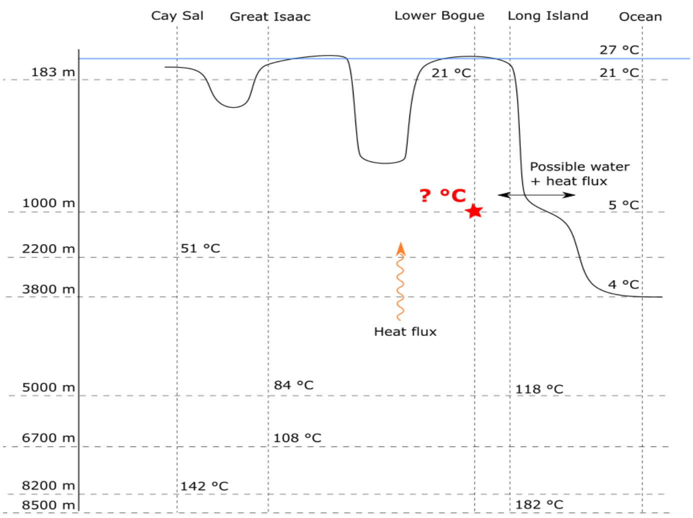


Figure 3.8 Indicative overview of measured temperatures at various depths. The red star indicates the proposed location of the groundwater OTEC system on the WSC locations in Eleuthera. The blue line indicates mean sea level. The black line indicates land surface level (above the blue line, the islands) and ocean floor level (below the blue line). It can be seen that the ocean floor drops to a level of 3800 m below mean sea level. Temperature at this depth is expected to be 4 degrees Celsius



Challenges in the groundwater temperature

The remaining challenge therefore is the fact that there is no deep well at the proper depth (approximately 1000 m) available to confirm the expectations. A measurement at a depth of 1000 m is necessary to evaluate the groundwater temperature and therefore the success of OTEC utilizing saline groundwater (without additional heating by e.g. solar thermal).

Available deep groundwater

It has been shown that there are cavern systems present at larger depths (approximately 120 - 180 m) [Cant, 2012]. These systems have a far greater hydraulic connectivity than when there is no cavern system. Depending on whether such a system is present, the transmissivity of these zones can vary significantly and therefore the connectivity with the ocean can be expected to be location dependent. How much water can be transported through these caverns is unclear, although it has been reported that there are large (but unquantified) volumes of saline water moving through the subsurface caverns [Whitaker and Smart, 1990; Whitaker, 1992]. The capacity of the location specific aquifer has to be estimated based on measurements.

In order to make an estimation of the sustainable discharge that is achievable from a deep well, an aquifer pumping test can be performed. In this test, the drawdown and recovery of the groundwater heads as a result of groundwater extraction are measured. A proposal of such a study has already been made [Cant, 2011].

Summary: There are indications that the groundwater temperature gradient is similar to the temperature gradient of the surrounding ocean. To a certain depth, this would mean that the groundwater temperature at 1000 m could be approximately 5 degrees C. However, measurements at 2200 m depth show a temperature of approximately 51 degrees C. Extrapolation of groundwater temperature at greater depths will lead to a temperature of 26 degrees C at a depth of 1000 m.

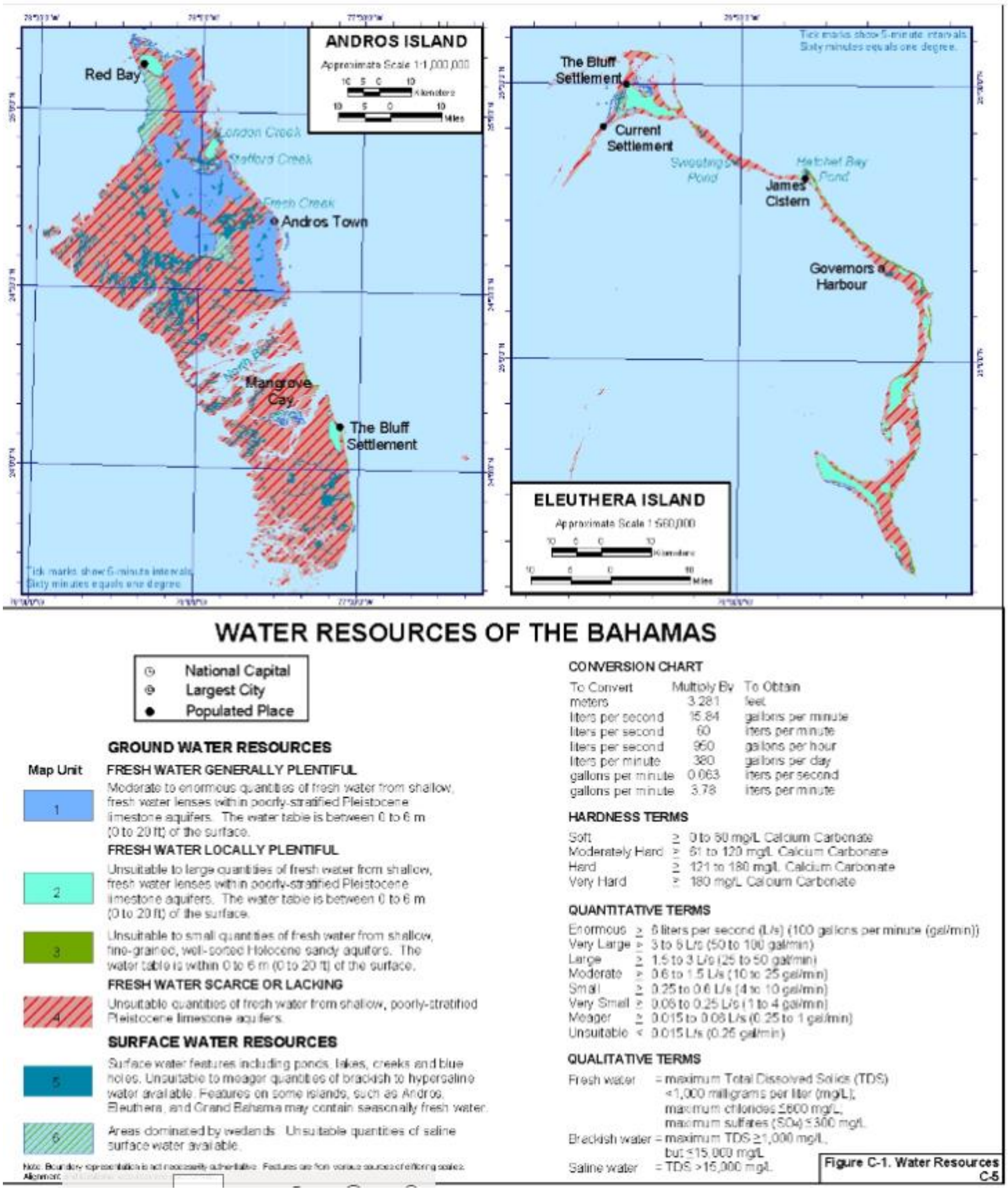
It is unclear if and how the higher temperatures at greater depth will affect the groundwater temperature at 1000 m depth. **It is recommended to perform a groundwater temperature measurement at depths between 183 and 1000 m to evaluate the groundwater temperature and therefore the success of OTEC utilizing saline groundwater (without additional heating by e.g. solar thermal).**

The aquifer capacity seems to depend largely on the presence of cavernous systems. This greatly affects the transmissivity and connectivity of the systems and consequently influences the discharge that can be achieved from the deep well. This means that the aquifer capacity is location dependent. **It is therefore recommended to perform an aquifer pumping test to estimate the achievable discharge from a deep well.**

Freshwater resources

Freshwater resources are finite and vulnerable in the Bahamas. The extent of freshwater resources is limited to very fragile freshwater 'lenses' in the shallow karstic limestone aquifers. The 'freshwater' is actually derived from precipitation and lies on top of the shallow saline water as a 'lens', less than 5 feet from the surface of the ground. The Bahamas Land Resources Survey, 1969-1975, was the first major assessment conducted to identify and profile the water resources in the Family Islands. In 2004, the US Army Corps of Engineers implemented a second assessment and produced maps of water resources in the main islands [USACE, 2004]. This report highlighted the very limited extent and fragility of the freshwater lenses, as well as the difficulty of operating well fields. Over-abstraction of the limited freshwater reserves is the main concern. Over-abstraction can cause saltwater intrusion into the freshwater aquifer, meaning that well fields must be permanently abandoned or left for numerous years in order to recover.

Figure 3.9 Water resources Bahamas (Andros Island and Eleuthera Island). Retrieved from [USACE, 2004]



The thickness of freshwater lenses depends on the geological conditions of the islands and the size of the islands. At larger islands, there is usually a thicker freshwater lens.

The principal aquifer on most Bahamian islands is the Pleistocene-aged Lucayan Limestone. The aquifer is comprised of poorly-stratified, oolitic limestone. The freshwater bodies in this unit are known as Ghyben-Hertzberg lenses. The base of the Lucayan Limestone is accepted as the maximum thickness to which a freshwater lens can develop.

Figure 3.10 Hydrogeological conditions and freshwater lenses. Retrieved from [USACE, 2004]

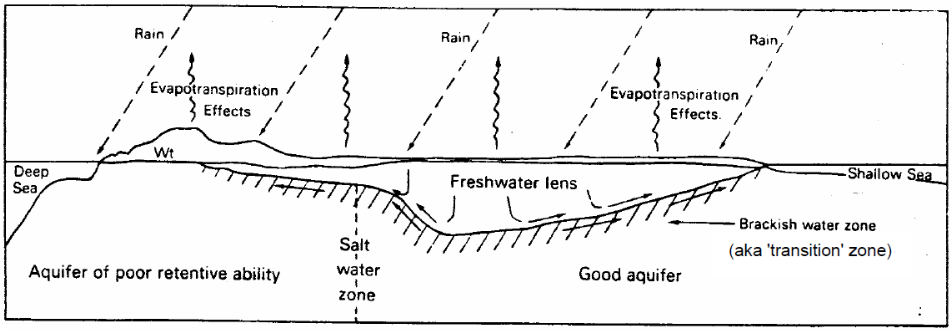


Table 3.1 Thickness and depth measurements of the Lucayan Limestone. Retrieved from [USACE, 2004]

Location	Average thickness of Lucayan Limestone (m/ft)	Depth (below mean sea level) to base of Lucayan Limestone (m/ft)
Andros Island and Great Bahama Bank	43 / 141	43 / 141
Long Island	40 / 131	38 / 125
San Salvador	35 / 115	32 / 105
Hogsty Reef	>21 / >69	>31 / >102
Great Inagua	29 / 95	28 / 92
Crooked-Acklins Bank	25 / 82	21 / 69
Grand Bahama Island and Little Bahama Bank	24 / 79	21 / 69
Mayaguana	10.5 / 34.4	3 / 10

Deep borehole drilling in areas where freshwater lenses occur could lead to contamination of these lenses. Proper protection of the freshwater lenses during operations is necessary.

3.5 Climate change and water resource vulnerability

Climate change is leading to:
- Fall in precipitation
- Rise in sea level
- Rise in air temperature

The fall in precipitation will have a direct impact on the recharge rate and on the condition of the freshwater lenses. Furthermore, the rise in the daily intensity of rainfall will also affect the recharge rate as the infiltration rate is lower during intense rain. The rise in air temperature will also have an impact on the recharge rate as the evaporation will increase.

The rise in sea levels may be the parameter that has the greatest effect, but the quantitative impact is very difficult to estimate due to the multiple impacts on water resources, including:
- Reduction of land and proportional reduction of the recharge rate
- Increase in storm surges, leading to saltwater intrusion into the land / surface water and contamination of the well fields

Higher pressure-head of the seawater and accelerated seawater intrusion [Hydroconseil, 2019].

3.6 Water sector

The Commonwealth of the Bahamas has initiated a process to ensure sustainable water supply services to 100 % of the population, in line with Sustainable Development Goal #6 (SDG6) and the National Development Plan (NDP). Hydroconseil together with WSC developed a strategy which is aligned with SDG6 as it aims to improve the access to water of the population and, above all, the sustainability of services. The solutions to reduce water leaks aim to increase water efficiency and reduce withdrawals. It is also linked to the National Development Plan as it includes measures to improve WSC governance, modernise the water infrastructure, and reduce the impact of the water supply service on the natural environment and especially water resources [Hydroconseil, 2019].

Therefore, this strategy forms a good basis for this project seeking for renewable energy sources, reducing the impact of energy.

Financial situation

WSC has a poor financial performance, which could be explained by four main reasons:
- An increase in operational costs linked to the development of desalination
- Excessively low water tariffs
- Decreasing capital investment in infrastructure
- High and rising levels of non-revenue water (NRW)

In the Family Islands, the average tariff in 2014 covered only 30 % of WSC's operating costs. The transition to a water sector dominated by RO plants has a direct impact on operating costs. Due to its high reliance on energy, desalination is much more expensive than other alternatives. As the current price paid by WSC for diesel powered electricity is between USD 0,20 to USD 0,32 per kWh a significant cost saving is possible by the transition to renewable energy sources which have cost prices lower than USD 0.10 up to USD 3.00 per kWh. However, this requires an initial investment in renewable energy production facilities, for which SWC does not have the funding available.

Another cost saving option with impact on energy consumption is reduction of NRW. It should be possible to reduce NRW from the current 30-50 % (average UFW rate for all facilities is 37 %.) to 5-7 %. These values are common in countries with good maintenance practices like Denmark, Singapore, Japan, The Netherlands and Germany. **It is recommended to combine a NRW programme to a renewable energy programme for the water sector. In that way oversized renewable energy production and oversized investments can be prevented.**

Energy supply

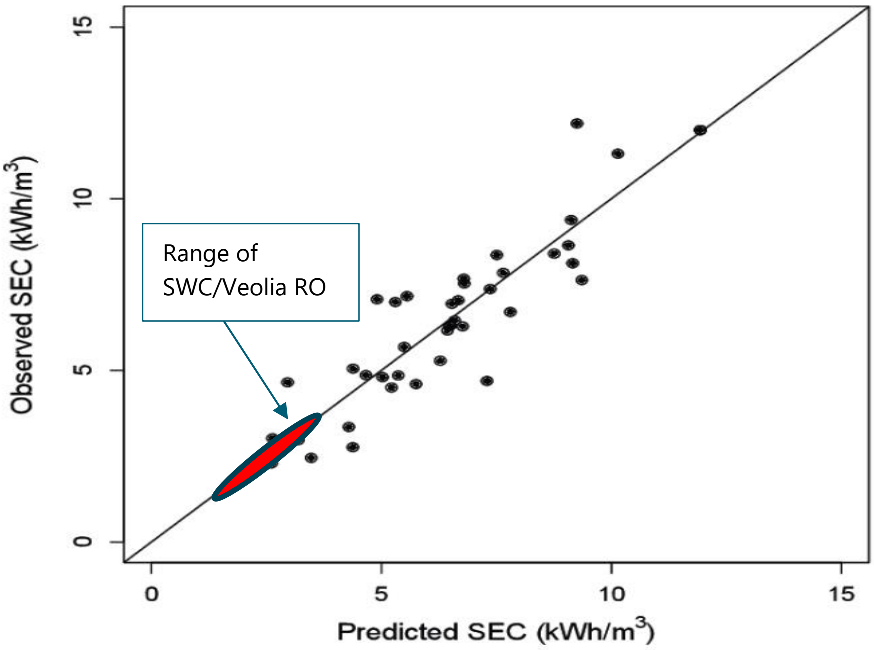
Veolia (Suez) uses both energy from the electricity grid operated by BPL and on-site back-up generators using diesel as a source for their water treatment facilities. In several RO locations operated by WSC/Veolia the diesel generator is the main source as there is no grid available or as the grid is very unstable. BPL uses also diesel as an energy source for their electricity production.

In Table 3.2 the electricity consumption for the WSC/Veolia RO facilities is shown. It can be seen that smaller facilities have a higher specific energy consumption per IG of water treated. The specific consumption is very low for small scale desalination (see indication in Figure 3.11) This is not a surprise as Veolia (Suez) applies pressure recovery in their RO systems. **So not much is to be expected from energy efficiency measures in the water treatment plants.**

Table 3.2 Electricity Consumption WSC/Veolia RO facilities

ISLAND	PLANT LOCATION	PLANT CAPACITY	POWER CONSUMPTION	ELECTRICITY COST	ELECTRICITY PRICE	ELECTRICITY/WATER
		IGPD	kWh/day	USD/month	USD/kWh	kWh/IG
ABACO	Moore's Island	36.000,00	632,16	$6.068,74	$0,32	0,0176
ANDROS (SOUTH)	KEMPS BAY	30.000,00	545,00	$5.275,60	$0,32	0,0182
CAT ISLAND	Bennett's Harbour	110.000,00	1.000,00	$9.734,40	$0,32	0,0091
	New Bight	110.000,00	1.000,00	$9.734,40	$0,32	0,0091
CROOKED ISLAND	Colonel Hill	20.000,00	462,00	$4.497,29	$0,32	0,0231
ELEUTHERA	Lower Bogue	650.000,00	11.414,00	$68.484,01	$0,20	0,0176
	Naval Base	450.000,00	7.902,00	$47.412,01	$0,20	0,0176
	Tarpum Bay	240.000,00	4.214,40	$25.286,41	$0,20	0,0176
	Waterford	90.000,00	1.580,40	$15.171,85	$0,32	0,0176
EXUMA	George Town	298.800,00	5.246,93	$31.481,58	$0,20	0,0176
INAGUA	Matthew Town	90.000,00	1.580,40	$15.171,85	$0,32	0,0176
LONG ISLAND	DEADMAN'S CAY	265.000,00	2.500,00	$24.336,00	$0,32	0,0094
	SIMMS	20.000,00	462,00	$4.497,29	$0,32	0,0231
SAN SALVADOR	Cockburn Town	80.000,00	1.404,80	$13.486,09	$0,32	0,0176

Figure 3.11 Specific Energy Consumption small scale desalination operations [Stillwell and Webber, 2016]



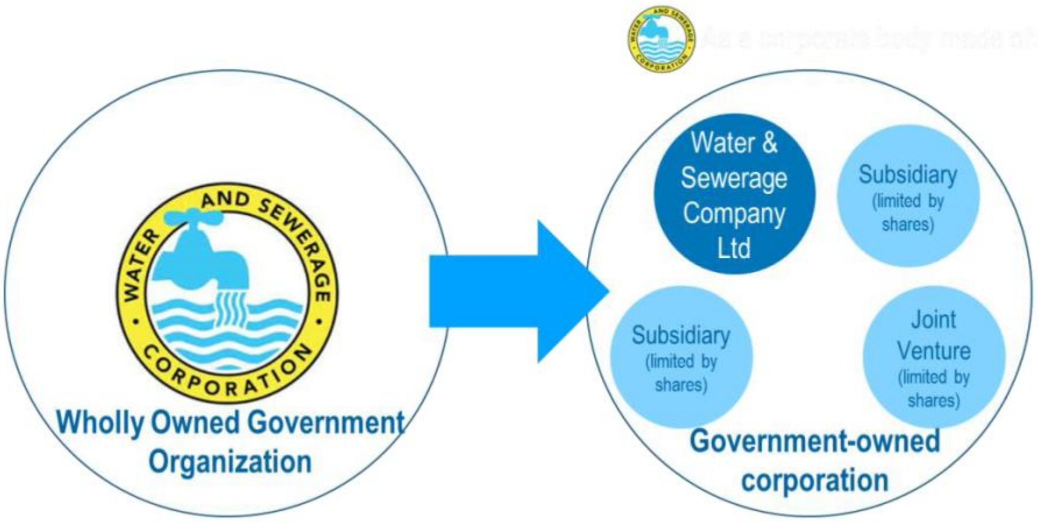
3.6.1 Institutional set up

Water
In order to improve the situation of the water and sanitation sector, three bills were submitted in 2016, which the Government/Parliament is still discussing:
- Water and Sewerage Services Regulation Bill (2016)
- Environmental Regulatory Authority Bill (2016)
- Water and Sewerage Services Bill (2016)

The adoption of these bills, which has been delayed up to now, depends on the political agenda. One of the WSC's main problems – in addition to its financial situation and its economic model – is its lack of autonomy from the government. The Water and Sewerage Services Bill would create a new water supply company to supplement the WSC: The Water Sewerage Company Limited. The WSC would remain a corporate body with functions and powers until these functions and powers are transferred to the Water Sewerage Company Limited. The WSC would be discharged from its regulatory functions. The Water Sewerage Company Limited would become a state-owned company for which the government retains majority ownership. Wholly-owned subsidiary companies limited by shares will then be incorporated. The Water Sewerage Company Limited will be a wholly-owned subsidiary of the WSC.

The following diagram illustrates the new institutional set-up of the WSC, as previously proposed [Hydroconseil, 2019]:

Figure 3.12 The corporatization of the WSC



This structure seeks to provide financial stability and guarantee greater autonomy to the WSC. It would introduce performance indicators and rules from the private sector into the management of a government-owned corporation. Nevertheless, the WSC would still rely on the Ministry to appoint its Board members. The new functions of the WSC would be as follows:
New primary functions of the WSC within its area of supply:
- Monitoring the water and sewerage system
- Securing a safe affordable, coordinated, reliable and environmentally sustainable system of water and sewerage services to all consumers
- Formulating and executing plans for the modernisation, development and extension of the water and sewerage systems

Establishing this Water Sewerage Company Limited with sufficient budget and powers to set an investment programme for renewable energy sourcing in motion seems necessary to reach 30 % renewable energy sources in the Water Sector in line with the national goal of the Bahamas Government.

3.6.2 Environmental Impact

Water resources
No Environmental Impact assessment studies were available to the team for the water treatment facilities of WSC in The Family Islands.
The RO installations are thought to extract water from below the sweet and brackish water lenses and inject water below the extraction level. However, no geohydrological models are available showing if this assumption is correct. **As the sweet water and brackish water lenses are very limited in size and as especially the availability of sweet water below the surface is important for the vegetation, it is recommended that geohydrological analysis is performed when planning and realizing additional extraction for OTEC and SDC.**

Another risk to the groundwater resources, which is also mentioned in the Hydroconseil report is the number of septic tanks owned by private house owners. Also, no information is available on the exact locations of these tanks and the impact on the groundwater system.

Impact of diesel-powered electricity production
Human health, our environment and global climate are all affected by diesel emissions.

Human Health
Exposure to diesel exhaust can lead to serious health conditions like asthma and respiratory illnesses and can worsen existing heart and lung disease, especially in children and the elderly. These conditions can result in increased numbers of emergency room visits, hospital admissions, absences from work and school, and premature deaths.

Environment
Emissions from diesel engines contribute to the production of ground-level ozone which damages crops, trees and other vegetation. Also produced is acid rain, which affects soil, lakes and streams and enters the human food chain via water, produce, meat and fish. These emissions also contribute to property damage and reduced visibility.

Global climate
CO_2 emission from one litre of diesel fuel is 2.68 kg. With an assumed consumption of 0.4 l diesel per kWh, and using the total annual energy consumption figure (14,580 MWh/year), derived from the figures in Table 3.2, the total diesel consumption for the water treatment in The Family Islands per year is estimated to be about 1.3 million IG. And as a result, 1.6 million kg of CO_2 is emitted.

3.7 Demand for cooling

In nearly all locations near RO facilities of WSC the cooling demand is low and not very close. The reason in general is that hardly any high-rise resorts or other objects to be cooled are found. Also, no big urban areas with many houses concentrated in a small area are found. So cooling is only considered interesting in specific locations. Therefore Open OTEC is considered less interesting for The Family Islands and WSC than closed cycle OTEC. Only the WSC RO Plant in San Salvador was considered a prospective location for Open OTEC due to the proximity of the Club Med Resort and the possibility of providing them with very cool seawater for air-conditioning but this would require them to replace their current air-conditioning system [WSC, 2022].

3.8 Involvement of Stakeholders

The critical stakeholder organisations in this project are:
- The Office of the Prime Minister (Government of the Bahamas- OPM
- The Department of Environmental Planning & Protection (DEPP)
- Ministry of Works (MoW)
- Water and Sewerage Company (WSC)
- Bahamian Power and Light (BPL)

For all of them the realisation of the National Development Plan (Vision 2040) and meeting SDG goals is the reason to support the introduction of renewable energy sources into the water supply system.
WSC and BPL are also to realize the programme to change from diesel powered electricity to renewable energy powered systems. In BPL the knowledge about energy systems is available. However, the experience with OTEC or other ocean based innovative technologies is not available. If OTEC is selected to be part of the future renewable energy system, it is recommended to cooperate with the Institute of Ocean Energy (IOES) of Saga University in Imari. This institute seems to have the most advanced and hands on knowledge on OTEC. In order to increase the knowledge within the Bahamas it is recommended also to involve staff of the stakeholders above and of the University of the Bahamas (UB), the Bahamas Technical & Vocational Institute (BTVI), Cape Eleuthera and Unesco (Inter Governmental Hydrological Program). As OTEC is still in the R&D phase it seems logical to give the first project in the Bahamas a pilot status. The same applies to wave energy. If only PV and wind on land is selected it is recommended to cooperate with developers who already established similar facilities in the Caribbean.

Another important stakeholder is Veolia (Suez) which operates the majority of the RO facilities and does this in an energy efficient manner. Veolia is a multinational with enough money to invest in renewable energy and extensive knowledge in both RO and the energy systems that power their water treatments. Moreover, they have a clear ambition to contribute to the SDG's. So, it is recommended to start investigation if and how Veolia can be a partner in the development of OTEC and other renewable energy sources.

The many owners of private RO systems are also a group of stakeholders with generally enough money and political influence that can benefit for cooperation in the project and vice versa. Maybe some of them are interested to invest in the renewable energy production, not only for the water sector, but for the entire Bahamas.

It is recommended to make a stakeholder analysis for each separate location as other neighbouring facilities and their operators might be interested to cooperate in the development if they also can benefit. An example is the airstrip near the RO facility in San Salvador. They probably also need electricity and other renewable aviation fuels in near future. They have a lot of space on one hand available, but also restrictions to other activities.

In all locations in The Family Islands renewable electricity form the Grid is also to be established. The project for the Water Sector provides the opportunity to cooperate with BPL to install solar and wind in any location on shore and offshore near the grid and thus increase the options for solar PV and wind as energy source for the water supply, especially in situations where available space at the WSC locations is the limiting factor.
It is therefore recommended to cooperate with BPL in identifying the best locations on every Family Island for installation of PV and Wind both onshore and offshore.

3.9 Funding

The amount of funding for solar is the lowest compared to other renewable energy technologies, around USD 850 per kWp installed capacity [IRENA, 2021]. With 1 kWp an average electricity production of 4.4 - 4.9 kWh can be expected in the Family Islands (see 4.5.1). Based on the average daily energy consumption for all facilities in Table 3.2 and keeping in mind that only during 8 (December) -12 (June) hours per day this solar electricity is produced, it is estimated that in total between 15 and 25 million USD needs to be invested. In this figure no investment in the electricity transmission system and in energy storage is foreseen. So, it is very likely that this figure will be much higher in order to establish a robust energy supply system.
WSC does not have the funds to invest this amount of money, not even when this investment is spread over a period of 10 years. **So, cooperation with private investors and if possible International Financing Institutions is necessary.**

3.10 Challenges and barriers introduction Renewable energy on small Islands

IRENA [IRENA, 2020] has identified in their 'Innovation outlook ocean energy technologies' the following list of challenges and barriers for the deployment of renewable energy technologies on Small Islands:

- **Technology:**
  - Manufacturers target relatively large devices; such high capacities may not be needed on small islands
  - Little available information on local geotechnical seabed conditions
- **Infrastructure:**
  - Low-quality grid infrastructure (new / improved infrastructure needed)
  - Dispersed market
  - Lack of trained personnel
  - Limited energy services and deployment and maintenance equipment
  - Constraint or non-technical local supply chain
  - Challenging to transport components and equipment to the remote islands
  - Lack of data, knowledge and resources for resource and environmental assessments

- **Financial:**
    - Lack of capital for high upfront costs
    - High operation costs due to remoteness
    - Highly subsidised fossil fuel plants
- **Regulatory and Policy:**
    - Consent delay and high bureaucracy in permissions
    - Lack of legal framework and policies
    - Revenue support mechanisms often not available
- **Environmental:**
    - Little experience with seismic activity in the area
    - Concerns regarding megadiversity that prevails in many tropical regions
- **Socio-political:**
    - Weak awareness and knowledge of technology by all involved stakeholders (governments, end users, investors, etc.)
    - Lack of social acceptability and community readiness
    - Potential issues with sharing oceans, particularly interference with the local fishing industry

Most if not all of these challenges and barriers apply to this project.

4

ASSESSMENT OF CURRENT SWRO FACILITIES

4.1 Introduction

The water infrastructure managed by the Water and Sewerage Corporation (WSC) in the Family Islands consists of more than 50 standalone systems, most of which include pumping stations, storage tanks, mains and pipes, and some also include pressure tanks. The two water sources used by the WSC are well fields and Reverse Osmosis (RO) plants.

4.2 SWRO and water supplies

The final report and interim information sheets of Hydroconseil [Hydroconseil 2018 and 2019] provide a very thorough overview of the technical and institutional situation of the water supply and also wastewater treatment facilities in the Family Islands. Most of the facilities are operated by Suez (Veolia) on behalf of WSC. WSC is responsible for operation and maintenance of the clean water storage, pumping and transport and distribution of the water. Non-Revenue Water level is extremely high, average 37 % and up to 50 %. Most of the losses are in the storage and distribution system, which in most cases is operated and maintained by WSC. In appendix IV some pictures of the 4 RO sites visited in Eleuthera are presented to illustrate the bad condition of tanks and pumps.

4.3 Overview of locations

The information sheets in the interim report of Hydroconseil contain a comprehensive overview of all water treatment facilities and connected distribution areas.

4.4 General description of the process and responsibility

In general, two main water treatment processes can be seen in The Family Islands as presented in Figure 4.1, utilizing sweet groundwater resources and the RO based systems. The pressure tank and storage tank in Figure 4.1 are not always included in the water treatment and supply system.
In general, the system in Figure 4.1, utilizing sweet groundwater is more vulnerable to climate change and to other risks, like pollution from Industries, agriculture and septic tanks. The wells are less deep than both extraction and injection wells in the RO based water treatment system.

Figure 4.1 Water treatment and water supply from sweet groundwater

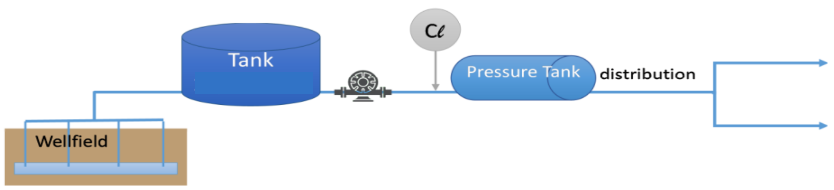
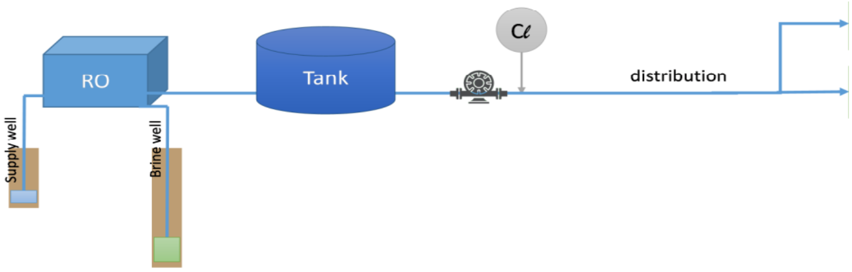


Figure 4.2 Water treatment and water supply from saline groundwater



Because of the limited sweet water resources and the more vulnerable situation WSC is gradually replacing the sweet water well based system with the RO based system. For the assessment of OTEC and other renewable energy source options we will therefore focus on the RO based facilities. These have a much higher relative energy consumption and thus, with the introduction of a renewable energy source, also have a greater impact on the reduction of diesel consumption and carbon dioxide emissions.

4.4.1 Wells

Perform aquifer pumping tests to estimate the achievable discharge from the current wells utilised for RO to see whether the capacity can be increased to feed both the RO and the OTEC/SDC.

4.4.2 Storage and Distributions

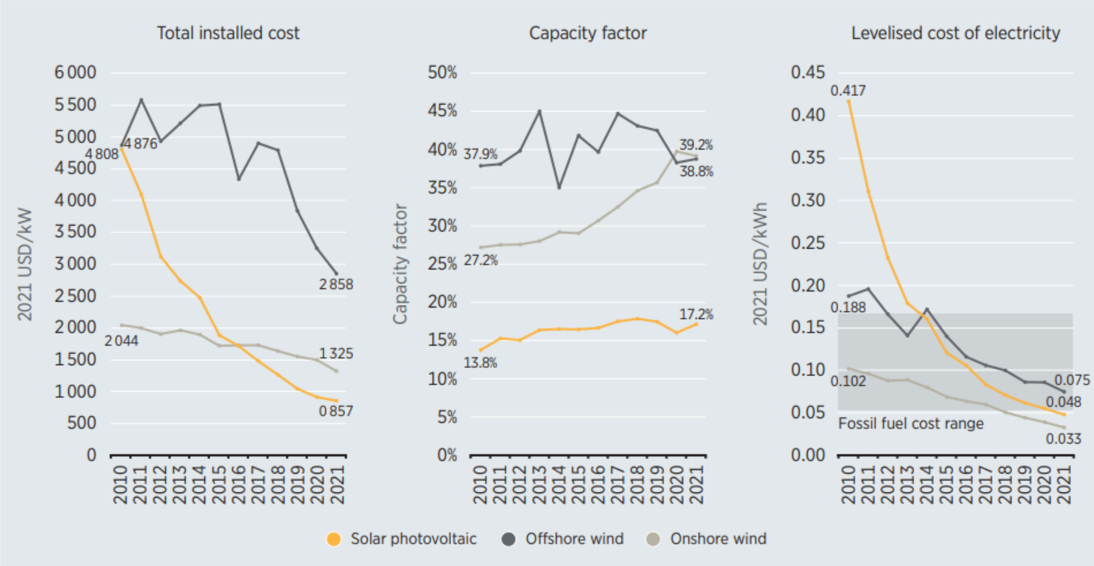
It is not known if the energy consumption figures for the different locations also include the energy for the distribution pumps. For each RO location a reliable energy balance has to be established. This might require installation of additional electricity meters on the pumping stations if the electricity consumption is not recorded.

As the pumps are in most locations old and in bad condition it is recommended to replace the current distribution pumps with energy efficient frequency-controlled pumps. This will also contribute to the required reduction of pressure peaks as indicated by Hydroconseil [Hydroconseil, 2019].

4.5 SWRO and alternative renewable energy sources integration

Costs
According to a world-wide study on the cost development of wind and solar energy it is clear that WSC will be able to save a lot of money on energy costs by switching from diesel to wind or solar powered electricity. According to the study, the levelized cost of wind and solar powered electricity (see Figure 4.3) is significantly below the current price of USD 0,20 to USD 0,32 for the current diesel-powered electricity.

Figure 4.3 Costs of wind and solar powered electricity production [IRENA, 2021]



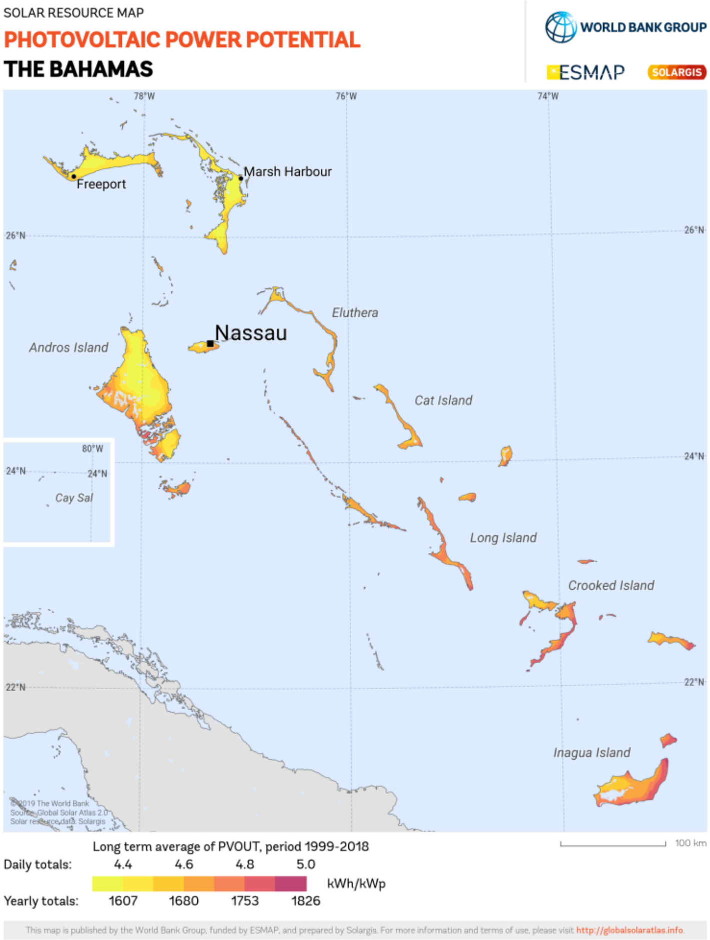
4.5.1 Photovoltaic (PV) solar panels on land or buildings

Photovoltaic (PV) solar panels can be installed on the roof of buildings if the construction of the building is strong enough, or on land or on water. In 4.5.2 we discuss PV on water.
On average (as a general "rule of thumb") modern PV panels will produce maximum 8 – 10 watts per square foot of solar panel area. This figure will be used to assess the maximum available PV capacity at the RO locations of WSC.

Reliability and availability

The Bahamas has an average daily solar potential between 4.4 and 4.9 kWh/kWp [Global Solar Atlas, 2022]. This means that in combination with the 8-10 watts per square foot installed capacity it is possible to produce 35-49 Wh per square foot per day on average. This means that 20.4 to 20.8 square feet are needed to produce 1 kWh per day.

Figure 4.4 Solar potential in kWh/kWp the Bahamas [Global Solar Atlas, 2022]



Available land per location

WSC performed a Photovoltaic Assessment in April 2022 [WSC, 2022].
The results of this assessment are presented in Table 4.1. The three proposed locations for a first application of renewable energy technology are in bold printing.

Table 4.1 Power consumption for RO plants on the Family Islands [WSC,2022]

ISLAND	PLANT LOCATION	PLANT CAPACITY (IGPD)	POWER CONSUMPTION PER DAY (kWh/day)	ELECTRICITY COST PER MONTH	HOURS OF OPERATION/ TYPE OF PLANT	AVAILABLE RESULTANT AREA (sq. ft.)
Cat Island	Bennett's Harbour	110,000	1,000.00	$9,734.40	24 HRS. R.O PLANT	131,186
	New Bight	110,000	1,000.00	$9,734.40	24 HRS. R.O PLANT	479,288
Crooked Island	Colonel Hill	20,000	462.00	$4,497.29	24 HRS. R.O PLANT	133,950
	Lower Bogue	**650,000**	**11,414.00**	**$68,484.01**	**24 HRS. R.O PLANT**	**636,127**

ISLAND	PLANT LOCATION	PLANT CAPACITY (IGPD)	POWER CONSUMPTI ON PER DAY (kWh/day)	ELECTRICITY COST PER MONTH	HOURS OF OPERATION/ TYPE OF PLANT	AVAILABLE RESULTANT AREA (sq. ft.)
Eleuthera	**Naval Base**	**450,000**	**7,902.00**	**$47,412.01**	**24 HRS. R.O PLANT**	**528,188**
	Tarpum Bay	240,000	4,214.40	$25,286.41	24 HRS. R.O PLANT	26,998
	Waterford	90,000	1,580.40	$15,171.85	24 HRS. R.O PLANT	25,424
Exuma	George Town	298,800	5,246.93	$31,481.58	24 HRS. R.O PLANT	35,455
Inagua	Matthew Town	90,000	1,580.40	$15,171.85	24 HRS. R.O PLANT	11,434
Long Island	Deadman's Cay	26,5000	2,500.00	$24,336.00	24 HRS. R.O PLANT	55,939
	Simms	20,000	462.00	$4,497.29	24 HRS. R.O PLANT	47,364
San Salvador	**Cockburn Town**	**80,000**	**1,404.80**	**$13,486.09**	**24 HRS. R.O PLANT**	**607,225**
South Andros	Kemps Bay	30000	545.00	$5,275.60	24 HRS. R.O PLANT	151,416

Below the aerial photograph is presented of the 3 proposed locations for the first application. Based on this information we assess the available land and PV capacity for each of the three locations:

- At Bogue, Eleuthera, the RO plant is surrounded by forest. Though the area owned by WSC is rather large (636,217 sq. ft), only a small area around the RO plant is available for PV panels. It is estimated that only 32.000 sq.ft. is available if PV panels are installed both on land not covered by forest and on the roof of buildings. The daily electricity supplied will be between 1.2 and 1.6 MWh. So, this covers around 10 % of the total energy consumption of the RO plant.
- At Naval Base, Eleuthera, the RO Plant is bordered by a rather large area (estimated to be about 220.000 sq.ft.) of land available for PV panels on land. PV panels can also be placed on the RO building and around the RO plant and pumping station (estimated to add another 24.000 sq.ft.). The daily electricity supplied will be between 9.5 and 11.9 MWh. So this covers around 150 % of the total energy consumption of the RO plant.
  It is recommended to develop PV for Naval Base in the conceptual design phase for this project as this is considered a technical (and financial) very feasible option. As the available land is exceeding the surface needed for the electricity generation of WSC alone, **it is recommended to cooperate with BPL** to see whether this location it is beneficial to develop additional capacity for other consumers in the area.
- The RO Plant Cockburn Town, San Salvador is completely forested. It is bordered by the local air strip, that seems to offer enough space for installing PV panels on land. Only 35,000 sq.ft is needed to cover the electricity consumption of the RO plant. However, there are a number of challenging issues regarding aviation and solar power. All of the issues that arise can be mitigated once the problems they cause are quantified. These include:
  1) Obstacle limitations
  2) Reflection of sunlight for flight crews
  3) Controllers and airside drivers
  4) Access routes for fire and rescue vehicles
  5) Interference with CNS equipment and meteorological equipment
  6) Electro-magnetic interference from DC-power sources (including inverters)

PV is considered a feasible option in this location. If PV is to be installed in this location **it is recommended to closely cooperate with the airstrip operator.** A mutual benefit is expected as it is very likely they also need renewable electricity sources for their facilities and as they probably can financially benefit from a change to solar powered electricity

Figure 4.5 R.O. Plant site Bogue, Eleuthera [WSC,2022]

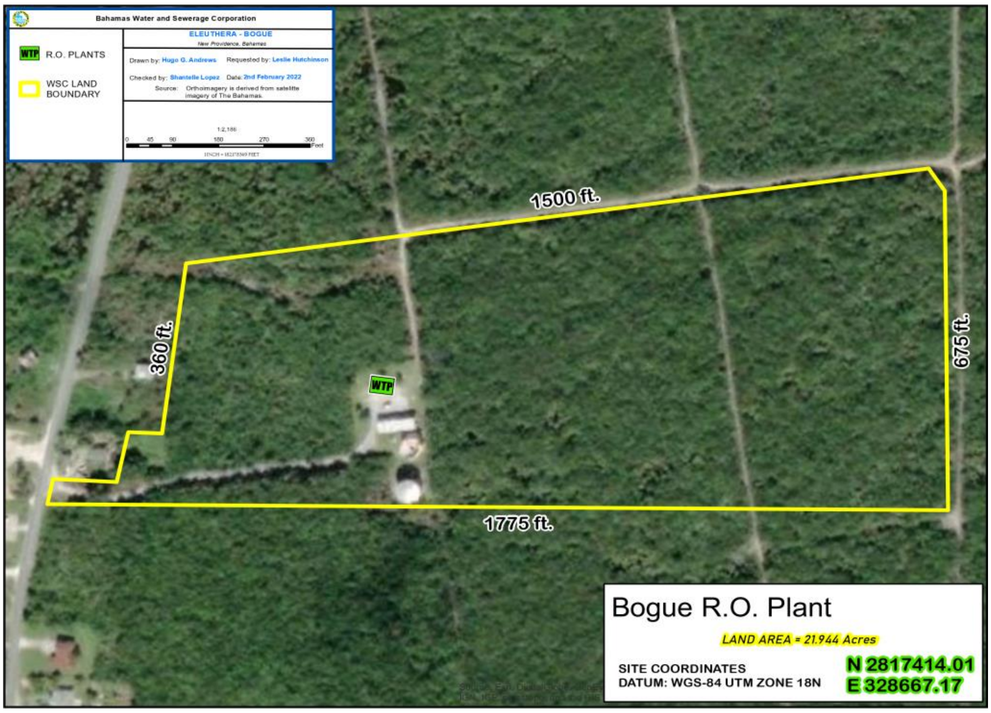


Figure 4.6 R.O. Plant site Naval Base, Eleuthera [WSC,2022]

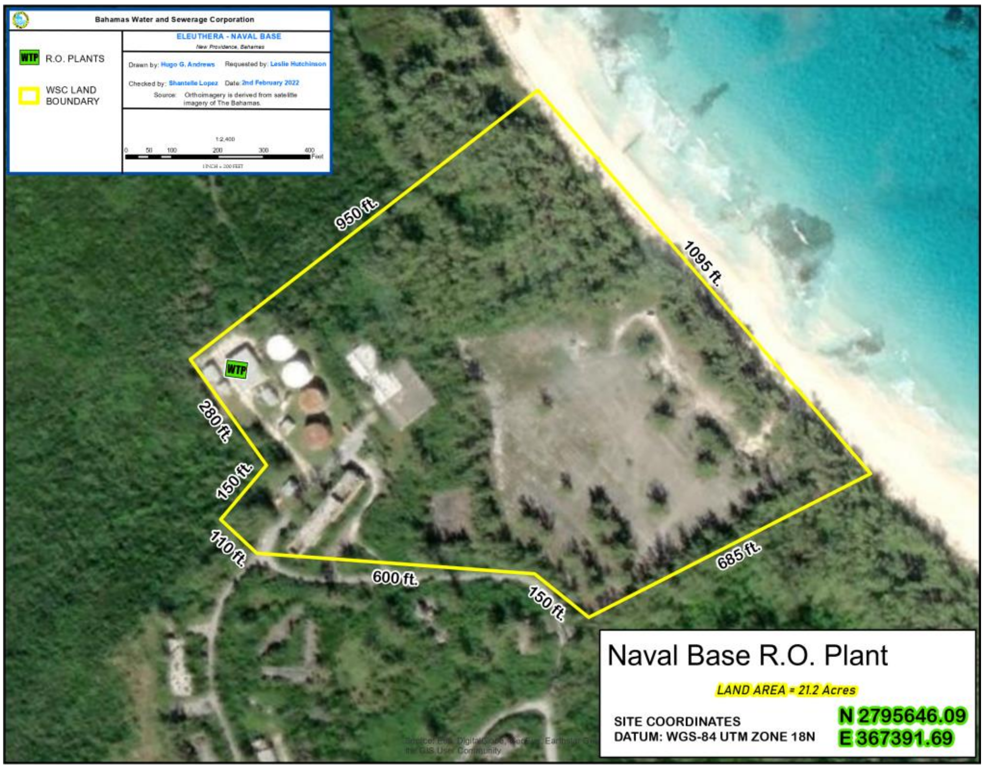
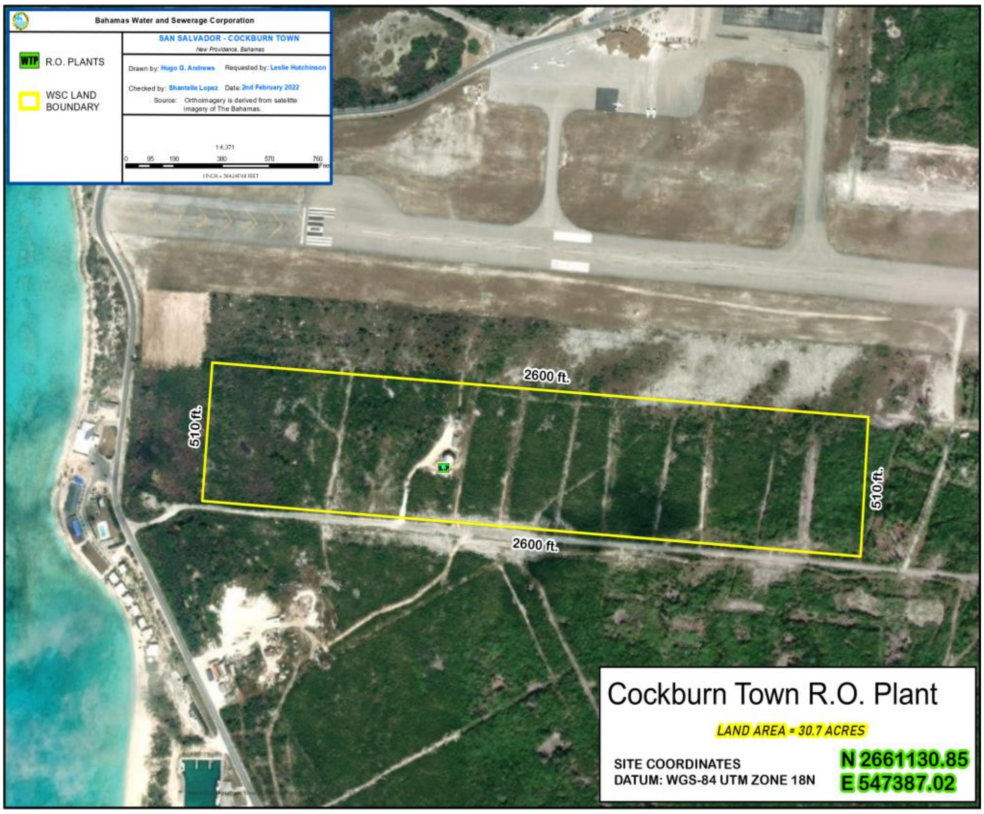


Figure 4.7 R.O. Plant site Cockburn Town, San Salvador [WSC,2022]



4.5.2 PV on water

Technology analysis

Solar PV on lakes is a proven technology, however, solar PV at sea is a lot more challenging due to higher waves and salt water. It is expected that in 2025 the application is commercially available Norwegian company Ocean Sun has successful pilots in Norway (100 kW installation, see figure) and Singapore. They want to scale up to 100-metre diameter floats with a capacity of 1 MW (1.3 MW/ha) that should also be able to withstand higher waves [Bjørneklett, 2018].

Figure 4.8 100 kW PV panels at sea in Norway [Bjørneklett, 2018]

Off the coast of Scheveningen, the Netherlands in 2019 the ' first floating solar power plant at sea has been established. Six partners have been working together on the project: Energieonderzoek Centrum Nederland (ECN now part of TNO), Maritime Research Institute Netherlands (MARIN), Utrecht University, energy company TAQA from the United Arab Emirates, and initiator Oceans of Energy from Leiden. The solar park would be 15 km off the coast, be 2,500 square metres in size, generate 50 MW. With a lifetime of 15 years, the cost of energy of this pilot project comes to EUR 3.54/kWh. However, this is the first large-scale project of this type [Cobouw, 2018].

Large-scale floating supports at sea could eventually match the price of foundations on land. However, heavy inverters may make the floating construction more expensive. Long cable distances can make grid connection for offshore solar PV so expensive that this technology cannot compete with onshore solar PV. A prerequisite for economic feasibility of offshore PV therefore is that it takes place close to the coast, or that it is co-coupled to the grid connection of offshore wind. The inverters can then be placed in the wind turbine, or themselves directly connected to the inverter of the wind turbine [Witteveen+Bos, 2019].

Considering the situation in the Bahamas floating PV can be most likely applied on the West side of the Islands. However, the situation with Hurricanes that can come from any side of the Island makes that a thorough study is first needed on the effects and mitigating measures for coping with Hurricanes.

Ecological, social and spatial compatibility and synergies

When applying solar panels (PV systems) at sea, the same potential effects on water quality play a role as when applied to lakes, ponds and other fresh inland waters. Due to the water movements in the sea the effects will not be observable in most applications. Only in large-scale applications in lee parts of coastal waters, adverse effects on water quality can be expected. A positive effect of floating PV systems at sea is that the floating structures provide habitat for various animal species. The structures themselves can act as floating reefs and add valuable ecological functions. The magnitude of this ecological effect can be enhanced by making smart choices in the design of the PV systems [Witteveen+Bos, 2019].

4.5.3 Wind energy

Wind power has grown rapidly since 2000, driven by R&D, supportive policies and falling costs. Global installed wind generation capacity – both onshore and offshore – has increased by a factor of 98 in the past two decades, jumping from 7.5 GW in 1997 to some 733 GW by 2018 according to IRENA's data. Onshore wind capacity grew from 178 GW in 2010 to 699 GW in 2020, while offshore wind has grown proportionately more, but from a lower base, from 3.1 GW in 2010 to 34.4 GW in 2020. Production of wind power increased by a factor of 5.2 between 2009 and 2019 to reach 1412 TWh [www.irena.org/Energy-Transition/Technology/Wind-energy].

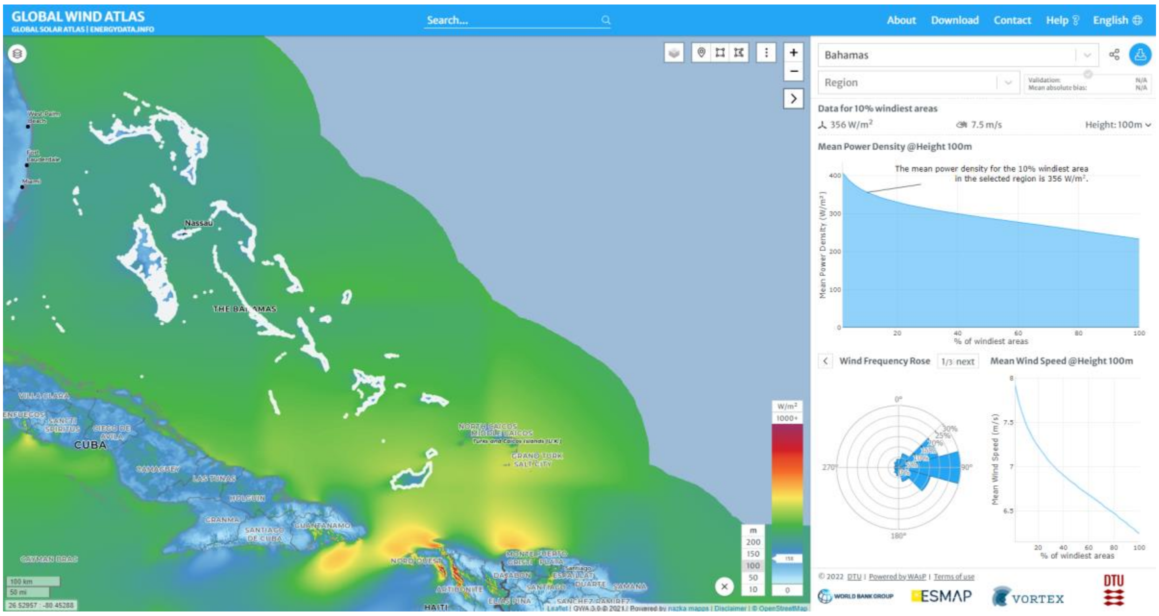
As the technology has improved and scaled up, costs have fallen and capacity factors have risen. Between 2010 and 2020, the global weighted-average levelized cost of electricity (LCOE) of onshore wind fell by 56 %, from USD 0.089/kWh to USD 0.039/kWh. Over the same period, the LCOE of newly commissioned offshore wind projects fell by around half (48 %) [www.irena.org/Energy-Transition/Technology/Wind-energy].

Wind turbine capacity has increased over time. Today's new wind power projects have a turbine capacity in the 3-4 MW range onshore and 8-12 MW offshore.

The amount of power that can be harvested from wind depends on the size of the turbine and the length of its blades. The output is proportional to the dimensions of the rotor and to the cube of the wind speed. Theoretically, when wind speed doubles, the wind power potential increases by a factor of eight.
In Figure 4.9 it can be seen that the windpower is around 350 W/m^2 for the 10 % windiest areas in the Bahamas at an elevation of 100 m. The windpower at 200m elevation for the 10 % windiest areas in the Bahamas is 531 w/m^2. A rule of thumb for feasible wind energy projects is that the average wind speed should be above 4 m/s. In the entire Bahamas the average wind speed is above this threshold value. In the 3

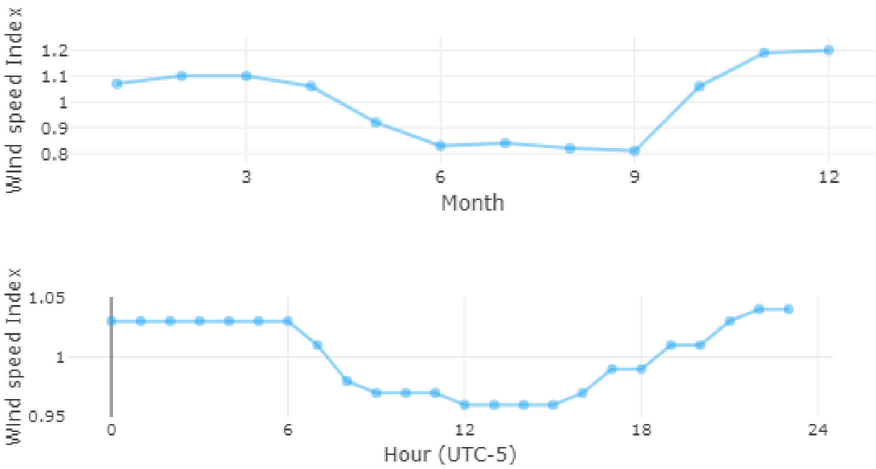
RO locations to start renewable energy the average value is about 6-7 m/s. As a result a Turbine Type of 126 m high with an installed capacity of 3.45 MW will produce average about 0.8-1 MWh.

Figure 4.9 Wind power in the Bahamas (Global Wind Atlas, 2022)



In Figure 4.10 it can be seen that year-round wind energy is available with a variance of 20 %. What also can be seen is that wind energy is higher during the night. Thus this provides a nice complementary energy source to PV.

Figure 4.10 Wind speed variance by month and hour (Global Wind Atlas, 2022)



4.5.4 Wave and tidal energy

In Figure 4.11 it can be seen that the installed capacity of tidal energy is much bigger than that of wave energy. Though several technological options are applied for both types of energy, one technological option is applied in most cases:

- Horizontal axis for Tidal Energy
- Oscillating body for Wave Energy

The current LCOE for tidal energy can be estimated to be between USD 0.20/kWh and USD 0.45/kWh and for wave energy to be between USD 0.30/kWh and USD 0.55/kWh. With the least optimistic projections (EC Trajectory), the targeted USD 0.11/kWh should be reached with a deployment of 20 GW, which can be anticipated in the early- to mid-2030s. The more recent study, however, shows a much more optimistic image presenting USD 0.11/kWh already at less than 100 MW of deployed cumulative capacity, which can be expected in around 2022 for tidal and in 2024 for wave [IRENA, 2020]. Of course these figures very much depend on the local circumstances (e.g. wave and tidal current power).

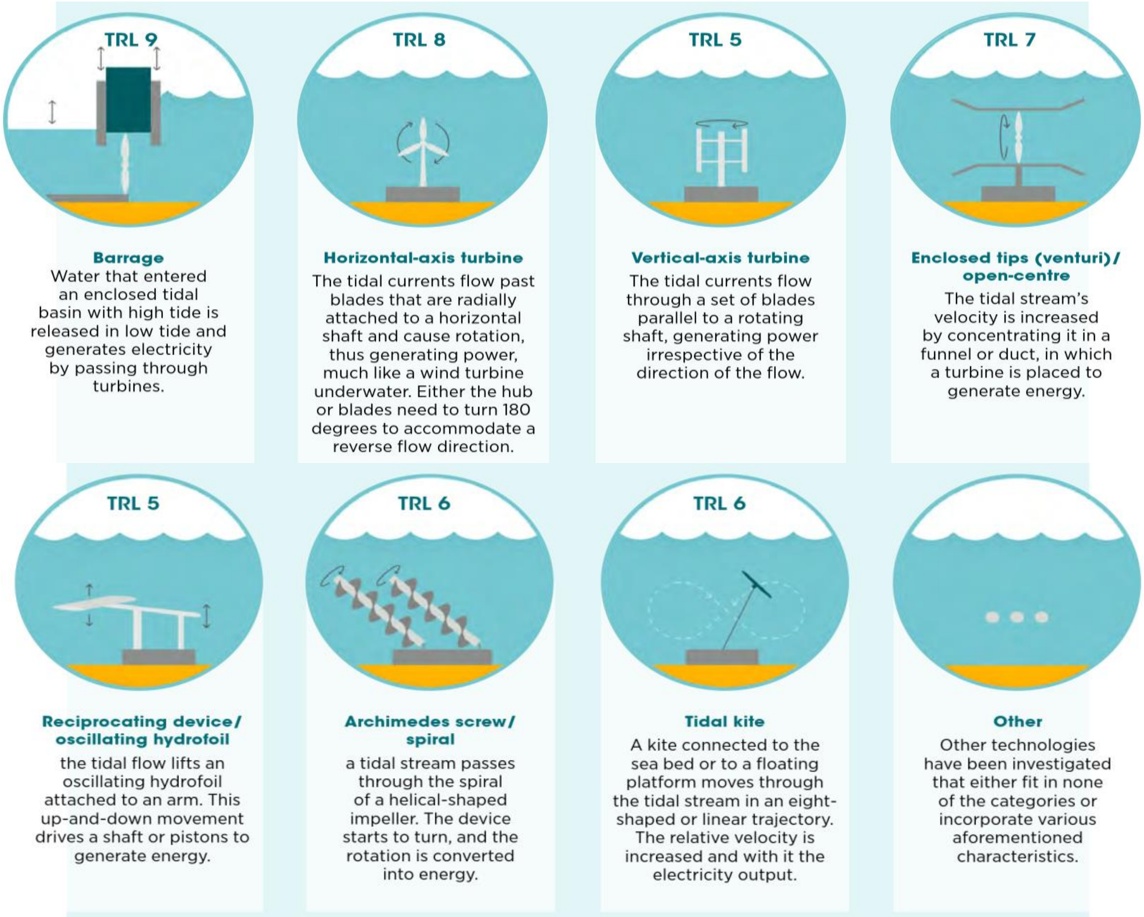
With these financial figures these technologies can become competitive with diesel powered electricity, however wind and solar are cheaper.

Figure 4.11 Projected capacity and number of project developers by technology

Tidal Energy

In Figure 4.12 different tidal energy technologies are presented and the technology readiness level of these technologies. It can be seen that most of the technologies are not yet commercially available. Several technologies to make use of tidal currents are under investigation, and although a convergence towards horizontal-axis turbines has been observed in recent years, other technologies that may greatly increase the global resource potential is also being pursued. Whereas a few years ago a single tidal turbine had a capacity of only 100 kilowatts (kW), turbines of 1.5 MW have now been successfully deployed by a handful of deployers, and they are being scaled up further.

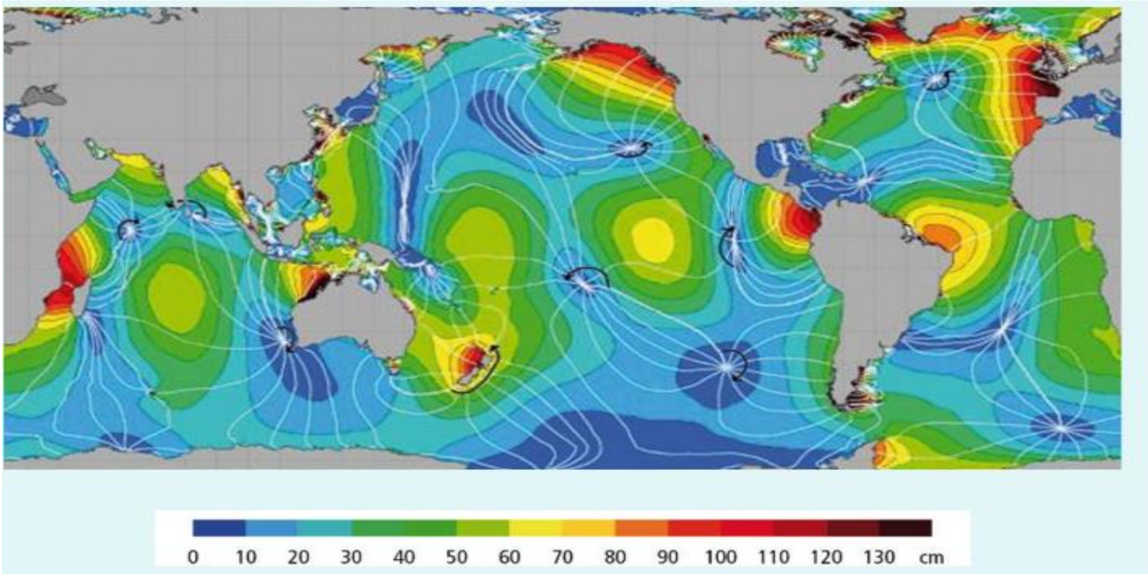
Figure 4.12 Tidal Energy Technologies [IRENA, 2020]



In Figure 4.13 it can be seen that the water level differences due to tidal forces in the Bahamas are below 60 cm. Tidal currents are strongest in regions with high tide ranges but are further enhanced by the topography. This is particularly the case in narrow straits or between islands, where the streams are naturally funnelled and speed is thus enhanced.

Favourable conditions are not very likely in the Bahamas and therefore Tidal Energy is not considered as the most favourable renewable energy source.

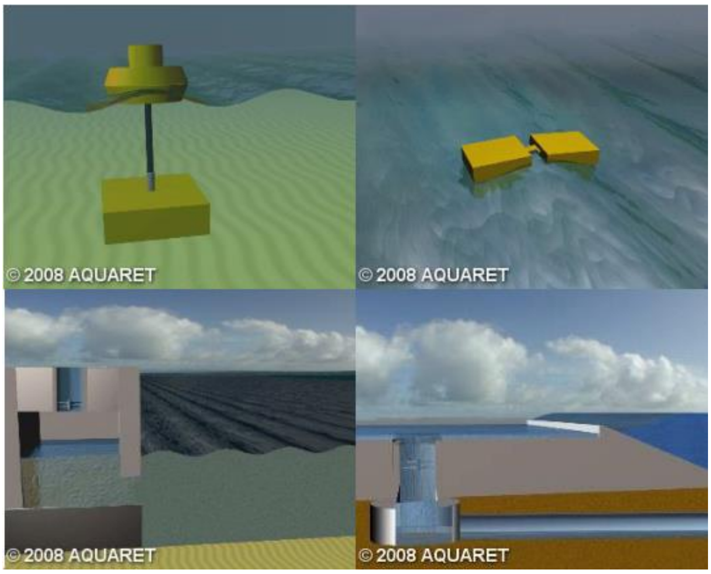
Figure 4.13 Global distribution of water level differences due to tidal forces [Lewis et. Al. 2011]



Wave Energy

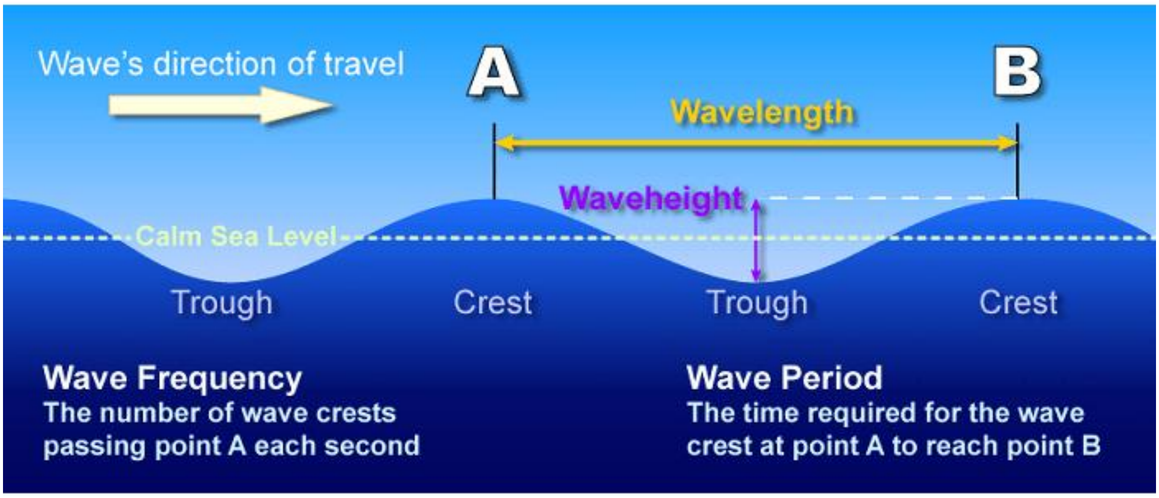
A wave energy converter can be used to extract wave energy from rapidly changing water levels. There are many different techniques for extracting wave energy. Some examples of techniques are floats that are vertically oscillating or hinged, air chambers in water barriers and capping the waves with return flow through a turbine, as shown in Figure 4.14.

Figure 4.14 Wave Energy Techniques [Aquaret, 2008]



The power of wave energy depends on the wave height, the period between two waves (see Figure 4.15, the energy efficiency of the waves and the length of the wave energy converter (and also on water density and g-value).

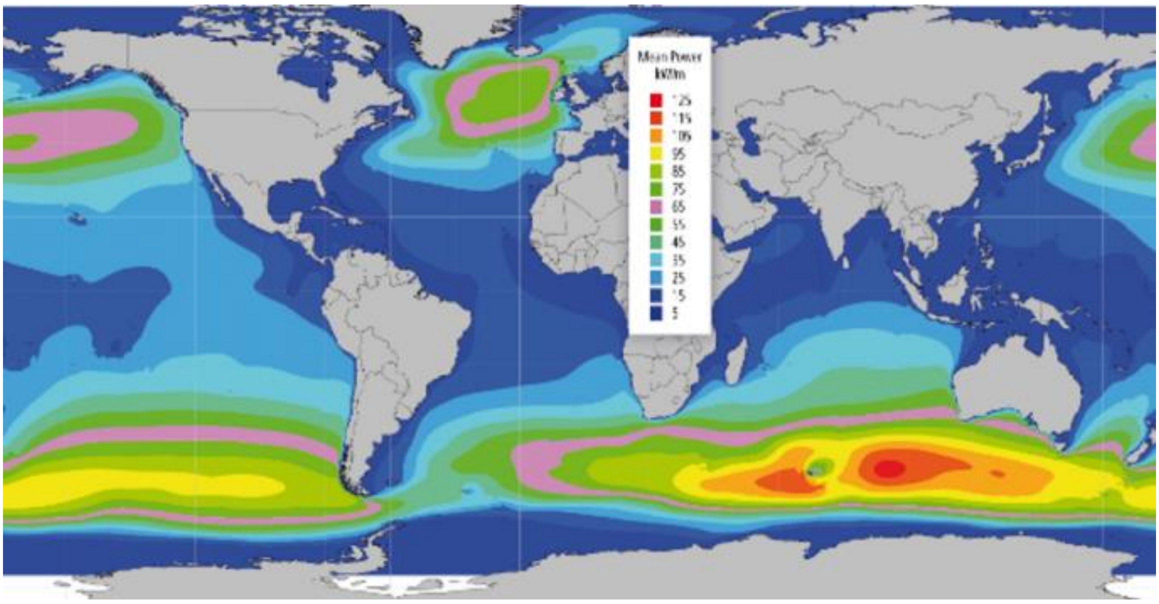
Figure 4.15 Wave characteristics used for wave energy analysis [www.offshoreblue.com]



A major difference with tidal energy is that with tidal energy a clear ranking can be made of locations with reasonable conditions near certain barriers, moderate conditions in estuaries and poor conditions in the open sea. For wave energy, there is some ranking, further out to sea the waves are slightly higher, however, conditions as a whole classify as poor.

In Figure 4.16 it can be seen that the Bahamas are in a region with the lowest wave power level. **Therefore wave power is not considered one of the most favourable options for renewable energy**.

Figure 4.16 Global distribution of wave power level (kW/m)[IRENA, 2020]



4.5.5 Energy Storage and Grid stability (batteries)

Energy storage has the potential to contribute to the stable and efficient operation of the electricity grid, especially with the increasing proportion of renewable generation. Electricity generated from renewable resources is dictated by resource availability – that is, when the sun is shining or the wind is blowing. However, the demand for renewable electricity is governed by factors that do not often align well with the availability of this intermittent resource.

Energy storage technologies therefore provide us with an opportunity to store renewable electricity for later use, thereby matching generation to demand. They also have a wide range of other potential applications, such as managing peak demand and power quality at various levels throughout the electricity network, providing backup power and shaping customer usage in response to tariffs.
To provide such a wide range of applications, energy storage systems require a similarly wide range of characteristics [CSIRO, 2015].

Energy storage technologies are available in many different forms, each of which has different ways of storing energy and using power. For example, pumped hydro systems store energy using water movement driven by pumps, flywheels store energy using mechanical momentum, and thermal systems store energy as heat. In Appendix A of the report prepared by CSIRO 'Electrical Energy Storage: Technology Overview and Applications'. Prepared for the Australian Energy Market Commission a detailed description of the technologies in Figure 4.17 can be found.

Figure 4.17 Energy Storage technologies

Mechanical energy storage	Thermal energy storage	Electrical/electrochemical energy storage	Chemical energy storage	Load coordination
• Pumped hydro Storage • Compressed air energy storage • Flywheel energy Storage	• Hot water storage • Molten salt energy storage • Phase-change material storage	• Supercapacitors • Superconducting magnetic energy storage • Batteries • Fuel cells	• Hydrogen • Synthetic natural gas • Other chemical compounds e.g. ammonia, methanol	• Load shaping/ smart appliances (e.g. hot water, pool pumps)

It is recommended to make storage of electricity part of the development of renewable energy supply as it is needed to provide sufficient balancing capacity between electricity supply and demand.

5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusions

The low population density and the geographical condition (many Islands) make it necessary that local small scale reliable renewable energy systems are to be developed in combination with the local water supply systems.

The energy efficiency of the RO systems operated by Veolia (Suez) is very good. No significant energy saving options are expected.

OTEC utilising groundwater in principle provides a very constant and reliable amount of electricity. Therefore it seems a very suitable technology, however OTEC is still in the R&D phase.

There is insufficient information that the 20 °C temperature difference requirement for OTEC application on saline groundwater can be established by just drilling deeper than the current wells in the Bahamas.
Based on expert judgment, the porosity and permeability of the muddy deep-water sediments are considered rather low and therefore probably unsuitable for OTEC.

Solar thermal heating can in theory be applied to increase the temperature difference between the warm and the cold feed flow to OTEC. In that way OTEC on shallow saline groundwater might be a feasible option.

PV followed by wind energy on shore has the lowest costs per kWh compared to alternatives like OTEC and Wave energy. However, battery costs are expected to be significantly higher with solar and wind than using OTEC, because of the larger storage capacity required.

Closed cycle OTEC is considered a more applicable technique compared to open cycle OTEC as in hardly any location the need for cooling water is big enough.

Other commercial activities like cosmetics production and aquaculture may be interesting, but are not considered typical for OTEC and are therefore not further considered in this study.

With respect to the three selected RO locations for a first application of renewable energy the following conclusions are made:
- At Bogue, Eleuthera there is insufficient space near the WTP to produce all the required electricity using PV.
- At Naval Base, Eleuthera there is sufficient space near the WTP to produce all the required electricity using PV.
- At Cockburn Town there is insufficient space near the WTP to produce all the required electricity using PV. However, area around the bordering airstrip offers more than enough space.

If the Bahamas want to utilize renewable energy for the total water supply in the Family Islands, focus should be on the dispersed private water systems as well. A programme should be developed to get a better view of the number, locations and capacity of these private water systems.

Establishing the Water Sewerage Company Limited, as proposed by Hydroconseil, with sufficient budget and powers to set an investment programme for renewable energy sourcing in motion seems necessary to reach 30 % renewable energy sources in the Water Sector in line with the national goal of the Bahamas Government. As the investments will exceed the budget of WSC by far, cooperation with private investors and if possible International Financing Institutions is considered necessary.

The Bahamas is located in a region with the lowest wave power level. Therefore, wave power is not considered one of the most favourable options for renewable energy.

Considering the situation in the Bahamas with the Ocean on the east side of the most eastern Islands and a shallow sea on the west side of all Islands, floating PV can be most likely applied on the west side of the Islands. However, the situation with Hurricanes that can come from any side of the Island makes that a thorough study is first needed on the effects and mitigating measures for coping with Hurricanes.

5.2 Recommendations

Combine a NRW programme to a renewable energy programme for the water sector. In that way oversized renewable energy production and oversized investments can be prevented.

Replace the current distribution pumps with energy efficient frequency-controlled pumps. This will also contribute to the required reduction of pressure peaks as indicated by Hydroconseil.

As the sweet water and brackish water lenses are very limited in size and as especially the availability of sweet water below the surface is important for the vegetation, it is recommended that geohydrological analysis is performed when planning and realizing additional extraction for OTEC and SDC.

Make a stakeholder analysis for each separate location as partners can be site specific (e.g., aviation authorities for the location on San Salvador).

Elaborate in the next phase of this project closed cycle OTEC for Bogue, Eleuthera, using solar thermal for realisation of the required 20ºC 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 Cockburn Town with SDC using OTEC and investigate the opportunity to supply clean water from OTEC in this location.

Elaborate in the next phase of this project solar PV and storage with batteries for the Naval Base.

In all locations in The Family Islands renewable electricity form the Grid is also an issue. The project provides the opportunity to cooperate with BPL to install solar and wind in any location on shore and offshore near the grid and thus increase the options for solar PV and wind as energy source for the water supply, especially in situations where available space is the limiting factor.

Perform a groundwater temperature measurement at depths between 183 and 1000 m to evaluate the groundwater temperature and therefore the success of OTEC utilizing saline groundwater (without additional heating by e.g. solar thermal).

Perform aquifer pumping tests to estimate the achievable discharge from a deep well and from the current wells utilised for RO to see whether the capacity can be increased to feed both the RO and the OTEC/SDC.

Make storage of electricity part of the development of renewable energy supply as it is needed to provide sufficient balancing capacity between electricity supply and demand.

Appendices

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II

APPENDIX: SOLAR THERMAL TECHNOLOGY OPTIONS

Solar thermal power systems use concentrated solar energy

Solar thermal power/electric generation systems collect and concentrate sunlight to produce the high temperature heat needed to generate electricity. All solar thermal power systems have solar energy collectors with two main components: *reflectors* (mirrors) that capture and focus sunlight onto a *receiver*. In most types of systems, a heat-transfer fluid is heated and circulated in the receiver and used to produce steam. The steam is converted into mechanical energy in a turbine, which powers a generator to produce electricity. Solar thermal power systems have tracking systems that keep sunlight focused onto the receiver throughout the day as the sun changes position in the sky. Solar thermal power plants usually have a large field or array of collectors that supply heat to a turbine and generator. Several solar thermal power facilities in the United States have two or more solar power plants with separate arrays and generators.

Solar thermal power systems may also have a thermal energy storage system component that allows the solar collector system to heat an energy storage system during the day, and the heat from the storage system is used to produce electricity in the evening or during cloudy weather. Solar thermal power plants may also be hybrid systems that use other fuels (usually natural gas) to supplement energy from the sun during periods of low solar radiation.

Types of concentrating solar thermal power plants

There are three main types of concentrating solar thermal power systems:
- Linear concentrating systems, which include parabolic troughs and linear Fresnel reflectors
- Solar power towers
- Solar dish/engine systems

Linear concentrating systems

Linear concentrating systems collect the sun's energy using long, rectangular, curved (U-shaped) mirrors. The mirrors focus sunlight onto receivers (tubes) that run the length of the mirrors. The concentrated sunlight heats a fluid flowing through the tubes. The fluid is sent to a heat exchanger to boil water in a conventional steam-turbine generator to produce electricity. There are two major types of linear concentrator systems: parabolic trough systems, where receiver tubes are positioned along the focal line of each parabolic mirror, and linear Fresnel reflector systems, where one receiver tube is positioned above several mirrors to allow the mirrors greater mobility in tracking the sun.

A linear concentrating collector power plant has a large number, or *field*, of collectors in parallel rows that are typically aligned in a north-south orientation to maximize solar energy collection. This configuration enables the mirrors to track the sun from east to west during the day and concentrate sunlight continuously onto the receiver tubes.

Parabolic troughs

A parabolic trough collector has a long parabolic-shaped reflector that focuses the sun's rays on a receiver pipe located at the focus of the parabola. The collector tilts with the sun to keep sunlight focused on the receiver as the sun moves from east to west during the day.
Because of its parabolic shape, a trough can focus the sunlight from 30 times to 100 times its normal intensity (concentration ratio) on the receiver pipe, located along the focal line of the trough, achieving operating temperatures higher than 750°F.

Parabolic trough linear concentrating systems are used in one of the longest operating solar thermal power facilities in the world, the Solar Energy Generating System (SEGS) located in the Mojave Desert in California. The facility has had nine separate plants over time, with the first plant in the system, SEGS I, operating from 1984 to 2015, and the second, SEGS II, operating from 1985 to 2015. SEGS III–VII (3–7), each with net summer electric generation capacities of 36 megawatts (MW), came online in 1986, 1987, and 1988. SEGS VIII (8) and IX (9), each with a net summer electric generation capacity of 88 MW, began operation in 1989 and 1990, respectively. SEGS 3, 4, 5, 6, 7, and 8 all ceased operation in 2021, leaving only SEGS 9 in operation as of December 31, 2021.

In addition to the SEGS 9, the other parabolic-trough solar thermal electric facilities operating in the United States as of December 2021, and their net summer electric generation capacity, location, and year of initial operation are:

- Solana Generating Station: a 296 MW, two-plant facility with an energy storage component in Gila Bend, Arizona, which started operating in 2013
- Mojave Solar Project: a 275 MW, two-plant facility in Barstow, California, which started operating in 2014
- Genesis Solar Energy Project: a 250 MW, two-plant facility in Blythe, California, which started operating in 2013 and 2014
- Nevada Solar One: a 69 MW plant near Boulder City, Nevada, which started operating in 2007

Linear Fresnel reflectors

Linear Fresnel reflector (LFR) systems are similar to parabolic trough systems in that mirrors (reflectors) concentrate sunlight onto a receiver located above the mirrors. These reflectors use the Fresnel lens effect, which allows for a concentrating mirror with a large aperture and short focal length. These systems are capable of concentrating the sun's energy to approximately 30 times its normal intensity. Compact linear Fresnel reflectors (CLFR)—also referred to as concentrating linear Fresnel reflectors—are a type of LFR technology that has multiple absorbers within the vicinity of the mirrors. Multiple receivers allow the mirrors to change their inclination to minimize how much they block adjacent reflectors' access to sunlight. This positioning improves system efficiency and reduces material requirements and costs. A demonstration CLFR solar power plant was built near Bakersfield, California, in 2008, but it is currently not operational.

Solar power towers

A solar power tower system uses a large field of flat, sun-tracking mirrors called heliostats to reflect and concentrate sunlight onto a receiver on the top of a tower. Sunlight can be concentrated as much as 1,500 times. Some power towers use water as the heat-transfer fluid. Advanced designs are experimenting with molten nitrate salt because of its superior heat transfer and energy storage capabilities. The thermal energy-storage capability allows the system to produce electricity during cloudy weather or at night.
The U.S. Department of Energy, along with several electric utilities, built and operated the first demonstration solar power tower near Barstow, California, during the 1980s and 1990s. In 2021, there were two solar power tower facilities operating in the United States:

- Ivanpah Solar Power Facility: a facility with three separate collector fields and towers with a combined net summer electric generation capacity of 393 MW in Ivanpah Dry Lake, California, which started operating in 2013
- Crescent Dunes Solar Energy Project: a 110 MW one-tower facility with an energy storage component in Tonapah, Nevada, which started operating in 2015

Solar dish/engines

Solar dish/engine systems use a mirrored dish similar to a very large satellite dish. To reduce costs, the mirrored dish is usually composed of many smaller flat mirrors formed into a dish shape. The dish-shaped surface directs and concentrates sunlight onto a thermal receiver, which absorbs and collects the heat and transfers it to an engine generator. The most common type of heat engine used in dish/engine systems is the Stirling engine. This system uses the fluid heated by the receiver to move pistons and create mechanical power. The mechanical power runs a generator or alternator to produce electricity.

Solar dish/engine systems always point straight at the sun and concentrate the solar energy at the focal point of the dish. A solar dish's concentration ratio is much higher than linear concentrating systems, and it

has a working fluid temperature higher than 1,380 °F. The power-generating equipment used with a solar dish can be mounted at the focal point of the dish, making it well suited for remote locations, or the energy may be collected from a number of installations and converted into electricity at a central point.
There are no utility-scale solar dish/engine projects in commercial operation in the United States.

III

APPENDIX: RO LOCATIONS WSC/SUEZ/VEOLIA

III

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Table III.1 RO Locations WSC/Suez/Veolia

Island	Plant location	Plant capacity (igpd)	Power consumption per day (kwh/day)
ABACO	Moore's Island	36000	632,16
ANDROS (SOUTH)	KEMPS BAY	30000	545,00
CAT ISLAND	Bennett's Harbour	110000	1000,00
	New Bight	110000	1000,00
CROOKED ISLAND	Colonel Hill	20000	462,00
ELEUTHERA	Lower Bogue	650000	11414,00
	Naval Base	450000	7902,00
	Tarpum Bay	240000	4214,40
	Waterford	90000	1580,40
EXUMA	George Town	298800	5246,93
INAGUA	Matthew Town	90000	1580,40
LONG ISLAND	DEADMAN'S CAY	265000	2500,00
	SIMMS	20000	462,00
SAN SALVADOR	Cockburn Town	80000	1404,80