BERMUDA OCEAN PROSPERITY PROGRAMME

FOR THE DEVELOPMENT OF BERMUDA'S BLUE ECONOMY STRATEGY – PHASE 1 REPORT:

OCEAN RENEWABLE ENERGY

Global Market Assessment + Local Economic Assessment + Industry Expert Analysis

ROCKY MOUNTAIN INSTITUTE

UCLA IoES

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Bermuda's Blue Economy Draft Strategy will outline recommended activities and areas for investment for the sustainable use of Bermuda's ocean resources in order to support economic growth, improve livelihoods, and increase jobs while maintaining the health of ocean ecosystems. The Draft Strategy will begin with a focus on Bermuda's fishing industry, ocean renewable energy, and blue tourism.

This Phase 1 report on Bermuda's Ocean Renewable Energy includes a global market assessment, local economic assessment, and industry expert analysis. Its recommendations will be discussed and refined with stakeholder feedback, and will then undergo an economic analysis that will be incorporated into the Blue Economy Draft Strategy. The Blue Economy Draft Strategy will be a single document combining the recommendations and economic analyses for fisheries, ocean renewable energy, and blue tourism over a 10-year time horizon (2022 – 2032). The final recommendations in the Blue Economy Draft Strategy will not be legally binding, but are intended inform policy and investment decisions going forward.

The research begun in 2019 was conducted within the confines of the global COVID-19 pandemic; the recommendations across industries may change due to the shape of recovery progress in Bermuda and it is the intention of this research and these reports to add to the conversation in order to create opportunity and flexibility within those recovery efforts.

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EXECUTIVE SUMMARY

As Bermuda explores opportunities to address the island's energy needs, it is imperative to explore ocean renewable energy in addition to options on land. This chapter reviews ocean renewable energy first through a broad global assessment of available technologies, and then in the specific context of Bermuda, in order to consider which options best meet the island's priorities while being both technically and commercially viable today.

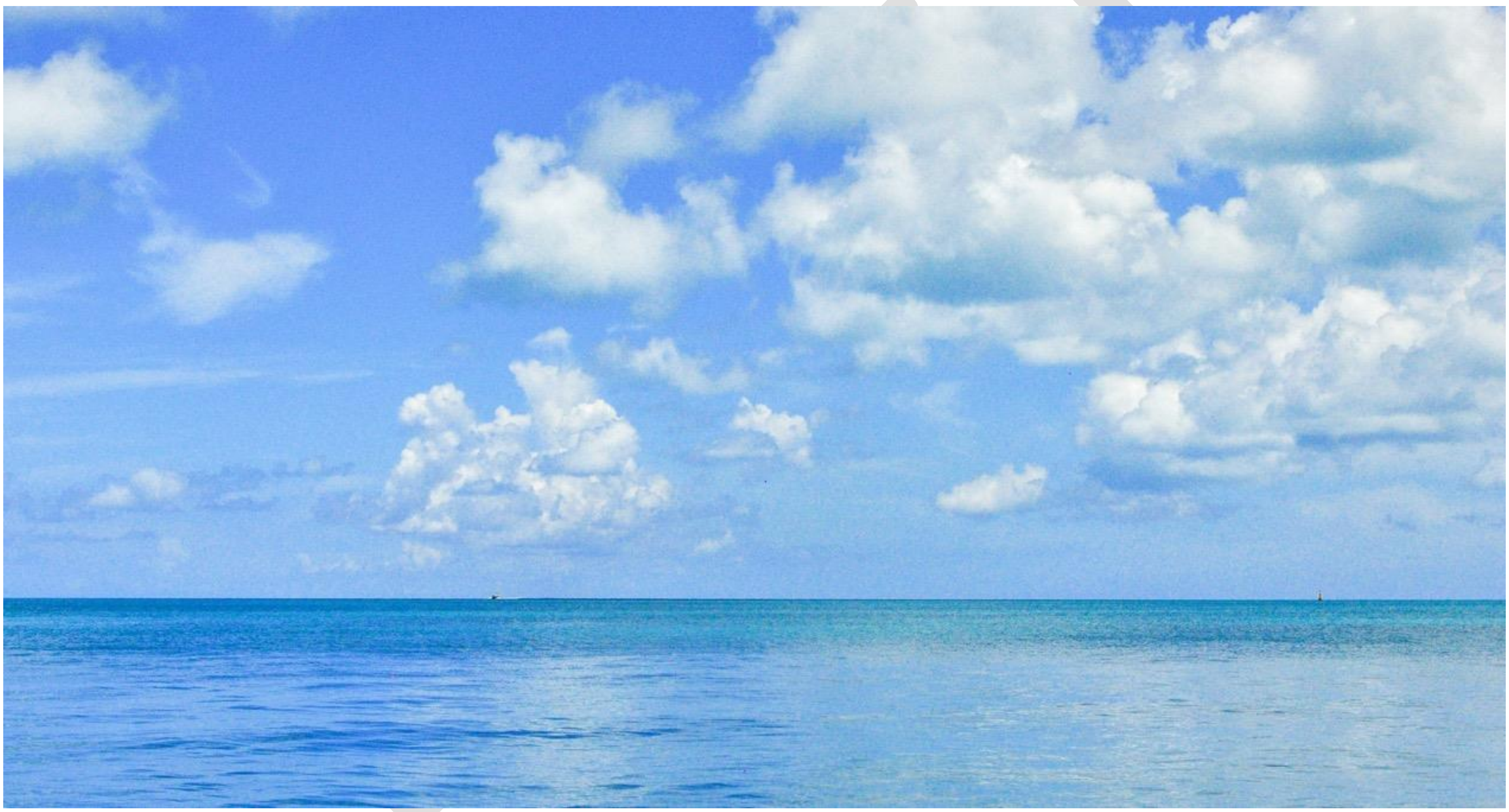
This assessment and analysis have resulted in the following recommended near-term actions for Bermuda:

1. **Implement a Feasibility Study for Offshore Wind:** In line with its 2019 Integrated Resource Plan, Bermuda should proceed with the initial implementation steps for a 60+ megawatt offshore wind farm, which includes conducting a detailed feasibility study containing technical, environmental, economic, and political components.
2. **Floating Solar PV Over the Next Decade:** Bermuda should next consider floating solar photovoltaics (PV) as the highest potential resource option after offshore wind, and with potential to be implemented together in the same location. Cost and technology developments should be monitored prior to adoption.
3. **Maintain Stakeholder Engagement in Monitoring Developing Technologies:** Bermuda can further capitalize on local marine energy resources by considering wave power, tidal power, and ocean thermal energy conversion (OTEC) power as components of the long-term energy mix. Maintain active stakeholder engagement as designated agencies monitor technological milestones and collect environmental data in the short-term to confirm potential viability would be the first step as these technologies are improving rapidly.

Offshore wind is likely the most near-term viable option for ocean renewable energy in Bermuda, given its well-established record globally and the opportunity to tailor a specific solution to meet Bermuda's local conditions. For example, a floating option is likely better suited to Bermuda than an option that is fixed to the sea floor. The resilience of the equipment itself is also an important consideration so that it contributes to a more resilient overall electricity system in Bermuda, able to withstand and recover quickly from external shocks.

Floating solar PV is also likely to be a good near-term option, as more projects are being deployed globally in the marine environment (compared to the majority of floating solar projects today that are located in freshwater locations). As costs continue to come down and the ability of marine-based floating solar is further demonstrated to be able to withstand regular saltwater conditions as well as storm situations, this technology could provide a significant electricity resource in Bermuda.

Finally, other options such as wave power, tidal power, and ocean thermal energy conversion (OTEC) have been tested so far in demonstration projects, but have very limited or no commercial deployment. It is worth keeping a pulse on these technologies as they may continue to mature and see their costs become more certain and competitive; the recommendation is for Bermuda to establish a diverse committee to monitor these and any other potential options for ocean renewable energy that may become good options for Bermuda in the future.



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Introduction

At approximately $0.43/kilowatt-hour(kWh), Bermudians pay one of the highest electricity rates in the world, due largely to Bermuda's dependence on imported fossil fuels. [1,i] Even with an average annual income of $89,000, roughly 5% of Bermudians' incomes go to paying monthly electricity bills – a long held source of frustration for residents.[ii] Historically, space constraints have been one of the greatest hindrances to major changes to the energy industry, including the transition away from imported fossil fuels. At roughly thirty-three square kilometers, Bermuda does not have sufficient land to dedicate to new energy generation.[iii] The introduction of marine renewable resources is therefore central to achieving cost reductions for ratepayers and energy independence for the island.

Because the renewable energy industry in Bermuda is still in its infancy relative to tourism and commercial fishing, our approach to this analysis centered around assessing the feasibility of introducing new technologies to the island, instead of analyzing existing areas for enhancement. For this study, we considered marine-based renewable resources due to land constraints and in recognition of the BOPP's underlying focus on ocean conservation and economic development. We acknowledge there is ongoing analysis of land-based photovoltaic (PV) feasibility by another party and therefore omitted this technology from our analysis. The five marine energy resources that we examined are wave power, tidal power, ocean thermal energy conversion (OTEC), offshore solar, and offshore wind.

Figure RE1 illustrates predominant global energy resources with asterisks denoting which resources we cover in this report.

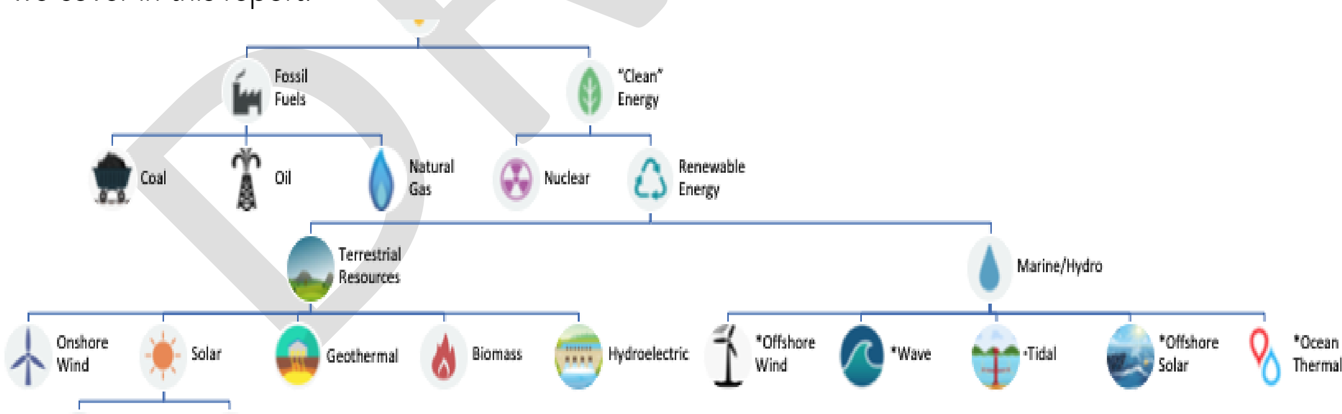


Figure RE1: Global Energy Resource Types

[1] Throughout our research, we encountered two different figures for average residential electricity rate: $0.39 and $0.42. We chose to reference the rate as $0.39 throughout this report, as that is how it is stated on the electric utility's (BELCO) website.

Global Market Assessment

Investments in renewable energy have been increasing at a rate faster than energy demand. From 2004 to 2015, renewable energy investments increased by over 600% globally.[iv] As renewable energy grows, countries around the world are determining if they should invest and if so, in which technologies. To develop relevant hypotheses for Bermuda, it is imperative to understand the global trends that are impacting the development of new electricity capacity and the eventual adoption of renewable energy.

Demand Analysis

Globally, over the last decade, energy demand has increased, and it is expected to continue to grow substantially into the future, as shown in Appendix RE1.[v] As energy consumption grows, there is continual pressure to reduce the costs associated with energy.

Beyond population growth, some of the global trends that are driving this increase in energy consumption include an increase in standard of living in developing economies and the rapid industrialization of China in the twenty-first century.[vi] Energy demand is also largely a reflection of economic growth. Because China and India have been among the fastest-growing economies for the last decade, they have been major contributors to a rise in the world's energy demand.[vii]

Alternatively, in areas where there is low growth in energy demand, the population tends to be in decline. This trend is especially evident in Russia, where the population has been shrinking for several years.[viii] Slowing regional demand growth can also be attributed to recent achievements in energy efficiency, such as the replacement of old physical assets with more efficient ones and the replacement of less efficient fossil fuel generators with more efficient renewable systems.[ix] It is expected that continued innovation in renewable energy technology and growing concern over climate change will cause demand for renewables to rise while conversely, demand for fossil fuels will fall.

Supply Analysis

Renewables represent 26% of all global energy generation – a figure that has climbed rapidly in recent years largely due to broader policy support, improved capacity factors, innovations in battery storage, and substantial cost reductions in wind and solar technologies.[x] Within the renewable energy sector, hydroelectric power accounts for 60% of generation, wind 20%, solar PV 9%, biopower 8.4%, and geothermal, concentrated solar power, and ocean power together comprising the remaining 1.5%.[xi] Many countries have recently seen wind and/or solar resources overtake coal and gas as the cheapest energy resource types, as depicted in Appendix RE2.[xii]

Northern Europe has traditionally been the leader in developing and deploying renewable energy resources, but some of the world's most populous countries are also on track for renewables to dominate their energy mixes in the coming decades. China and India, for example, are projected to achieve 60% renewable energy generation by 2050.[xiii]

Relevant Industry Trends

Declining Renewable Energy Costs: Climbing consumption, coupled with increasingly apparent symptoms of climate change have prompted many nations to invest more in renewable energy. Technological innovations that have amounted from these investments have allowed the LCOE (levelized cost of energy – a standard metric to measure energy costs) of some renewable resources to dip below that of fossil fuels in recent years, as shown below in Appendix RE3. A 2019 McKinsey report predicts that in the next five years alone, new-build wind and solar systems will be cost competitive with existing fossil fuel generators in some countries.[xiv]

Renewable Energy in the Caribbean: Reliance on imported oil is a common theme in the greater Caribbean region. As a whole, 90% of the Caribbean's energy supply comes from imported oil.[xv] This makes the region especially vulnerable to fluctuations in oil prices and helps explain why on average, electricity rates in the Caribbean are exorbitantly high at $0.34/kWh.[xvi] To combat this economic burden, several Caribbean nations have taken strides toward incorporating renewable energy into their energy mixes.[xvii]

With an abundance of sunshine, solar energy has long been a favorite for many Caribbean islands. Across the entire Caribbean region, installed solar capacity is estimated to be over 225 megawatts (MW).[xviii] Although solar PV is the fastest growing source of energy for many Caribbean islands, land limitations will continue to be a pervasive barrier across the region.[xix] In part to address this barrier and also because of the various benefits available from an electricity system that is more distributed in location rather than utilizing a small number of central generating plants, many islands are pursuing opportunities to install solar PV on land areas, as canopies over parking lots, and on rooftops – in particular those located at critical infrastructure.[xx]

Many islands are also looking beyond solar PV for increased renewables penetration and additional resilience benefits from diversifying the types of resources they rely on. Dominica is on track to start construction on a 7 MW geothermal system that has the potential to power 23,000 homes, accounting for 90% of its population.[xxi] Should this project reach commercial operation, it will serve as a model for other countries in the local region with abundant geothermal resources such as St. Lucia, St. Vincent, and St. Kitts and Nevis.[xxii] Outside of geothermal solutions, Barbados has fostered a sizeable solar water industry since the 1970s, with more than 50,000 units installed on the island.[xxiii] The estimated energy savings from these solar water heating systems are approximately 200 million kWh per year, which has allowed the island to reduce carbon emissions and fuel import costs.[xxiv] Hydro resources are also being utilized in Caribbean countries that have options available, including St. Vincent, Dominica, and Belize.

Finally, while offshore wind has yet to be introduced to the Caribbean region, there are currently nine Caribbean islands with commercial-scale onshore wind facilities.[xxv] Many of these islands are Dutch territories, which directly reflects the Netherlands' position as one of the leaders in the global wind industry. Jamaica has also aggressively invested in onshore wind in recent years, with one wind farm in operation and another under development.

Though the Caribbean region is relatively small, natural resources vary immensely from island to island. Knowing this, the renewable energy solution that works for one nation cannot necessarily be prescribed to the entire region.

Marine-Based Energy Resources

The five marine energy resources we researched and analyzed are wave power, tidal power, ocean thermal energy conversion (OTEC), offshore solar, and offshore wind. In our analysis of each technology, we considered the background of the technology, its technological maturity, commercial viability, installed use cases, the match to Bermuda's natural resources, impact to the external environment, and projected LCOE.

Wave Power

Wave energy converters (WECs) capture and convert wave kinetic energy into electricity. Wave power technology is still in the early stages of development with many different design concepts in testing. The wave energy industry is still in a pre-commercial stage[xxvi]. Many of the programs are still in their infancy stage and funded by various governmental organizations. It appears that larger players in the energy market are waiting for the technology to sort itself out before investing. The most common WEC is known as a point absorber, which resembles a buoy that sits atop the waves (see Figure RE2 for visual rendering).[xxvii] Below the buoy is a cabling component, which is commonly compared to that of floating wind turbines.[xxviii] In order to generate sufficient power, WECs are clustered together to form a single system. The generating capacity of a single WEC has not been officially established but is thought to be up to roughly 30 kW in its current state.[xxix]

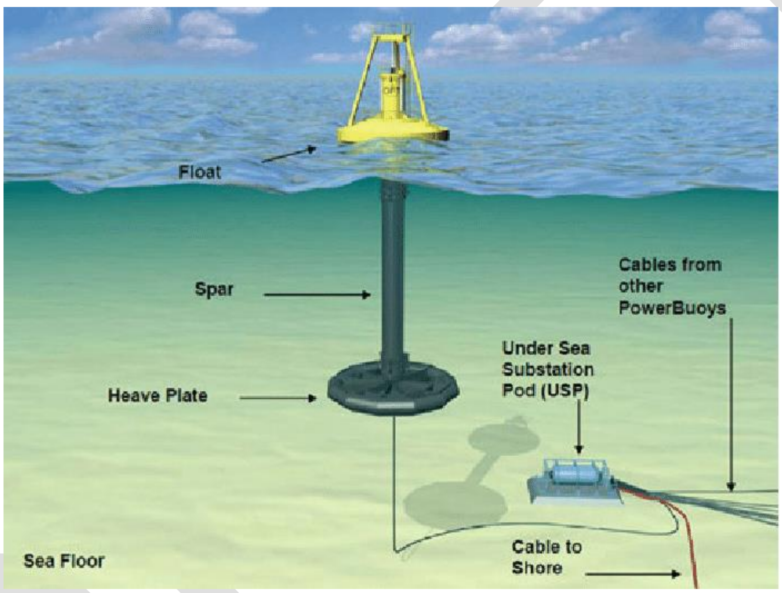


Figure RE2: Wave Power Point Absorber[xxx]

While wave energy testing has only been underway for less than a decade, many nations have made considerable investments in developing this technology. The most sophisticated test site is located in Orkney, Scotland, which is renowned for having one of the strongest wave regimes in the world.[xxxi] Outside of the U.K., research and development is underway in places like South Korea, the Pacific Northwest of the United States and Hawaii.[xxxii] Successful demonstration projects have taken place in various geographies, however commercial implementation has not yet been achieved.[xxxiii] Naturally, the most important determinant of wave power's economic feasibility is the wave resource, which refers to the consistency and power of waves in a given area.[xxxiv]

One of the benefits of waves as an energy resource is that they are much more predictable than solar and wind.[xxxv] While wind tends to die down at night in coastal regions, wave power is much more consistent and generally experiences only slight lulls in the morning.[xxxvi] In terms of durability, WECs are designed to withstand storms. Ahead of a storm, WECs can be detached from their moorings and towed to land or completely submerged underwater for the duration of a storm. This is an especially important consideration for Atlantic island nations, which are starting to see more frequent and more devastating storms with the acceleration of climate change.

While the installation phase of wave power systems tends to create a displacement effect by which fish and marine mammals temporarily vacate the region to avoid disturbances, wave energy systems have thus far had very little impact on their local environments.[xxxvii] The preeminent concern with regards to environmental impact is acoustical output, but so far, WECs are known to generate very little sound. Additionally, because WECs sit atop waves, making them low-lying, viewshed impact is negligible.[xxxviii]

Tidal Power

Tidal power is a source of renewable energy that is "produced by the surge of ocean waters during the rise and fall of tides."[xxxix] Optimal conditions for high tidal energy generation are high currents that are typically formed by a significant difference in tidal range across a narrow constriction.[xl] Tidal power technology typically requires current strength in the 4-6+ knot range.[xli] There are two main types of tidal energy technology: tidal range and tidal stream.[xlii] Tidal range is the more mature of the two and functions like a hydroelectric dam, trapping the tide and then releasing it to generate power.[xliii] Tidal stream, alternatively, harnesses energy from tides via fully submerged turbines, which are similar in concept to wind turbines. See Figures RE3 and RE4 for renderings of a tidal range power system and a tidal stream power system.

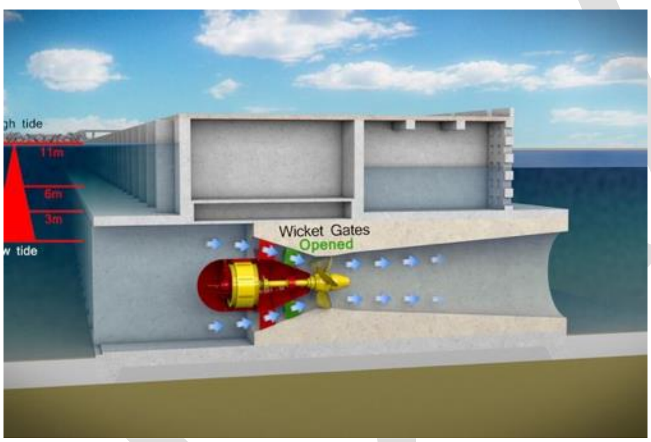


Figure RE3: Tidal Range System[xliv]

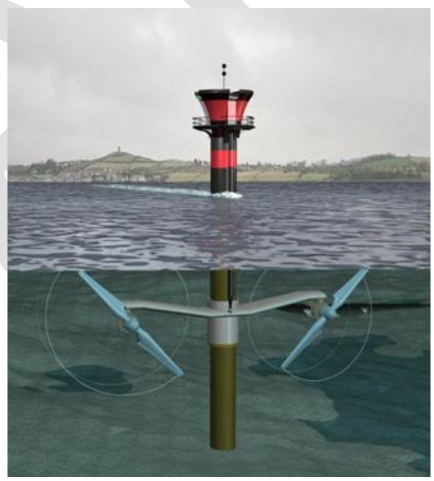


Figure RE4: Tidal Stream System[xlv]

In France and Korea, tidal range power plants, which bear resemblances to hydropower dams, are already in operation.[xlvi] Systems for harnessing tidal currents (tidal stream), however, are in a much earlier phase of development with the first commercial arrays now operating in the UK.[xlvii] Many geographic regions possess strong currents, but like wave power, the key factors contributing to the feasibility of tidal power are a "sufficiently energetic resource and cost-effectiveness relative to competing forms of generation."[xlviii] Ocean Energy Systems (OES) estimates that the first commercial-scale tidal system will have an LCOE in the range of $0.13-0.26/kWh (see Appendix RE4 for details).[xlix] However, this estimated LCOE increases both directly and in the size of the range when considering a smaller scale project appropriate for an island context; the Turks and Caicos Islands Resilient National Energy Transition Strategy (R-NETS) completed in 2019 included an initial investigation of tidal power options, but did not include this resource for in-depth scenario analysis due to the uncertainty in commercialization timeline and cost at the necessary project scale.[l]

Acoustical impact from tidal projects is minimal during commercial operation with all measurements to date suggesting that acoustic emissions would be substantially lower than those of a vessel.[li] Beyond acoustics, there are also environmental concerns pertaining to the potential for marine animals to collide with the underwater turbines.[lii] Although there is little evidence of these collisions occurring with operational systems to-date, much is still unknown about the risk that tidal systems could present to marine species in the long-term.

Ocean Thermal Energy Conversion

Ocean Thermal Energy Conversion (OTEC) is a process that uses natural temperature differences between the surface and deeper areas of the ocean to generate electricity. As shown in Figure RE5, the process uses the structure of a traditional heat exchanger. There is an intake pipe deep in the ocean that draws in cold water and another intake close to the surface which carries warm water. The temperature differences vaporize the working fluid, which passes through a turbine and generates electricity. The electricity is then transported to shore. The generation is consistent throughout the day and night.

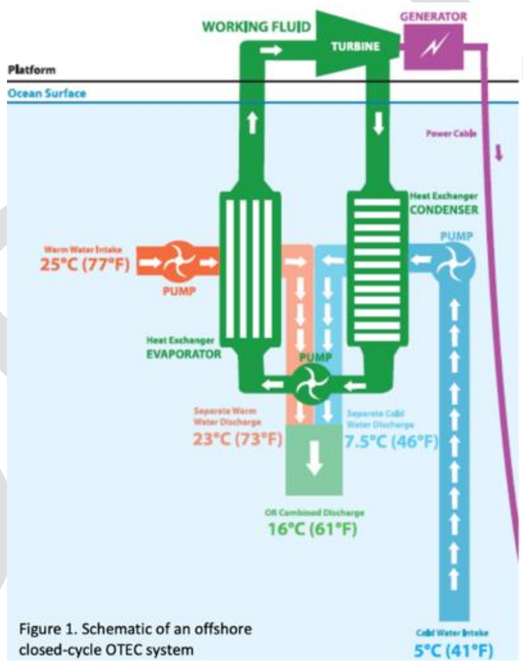


Figure RE5: Typical Structure of an OTEC Plant[liii]

Commercial viability for OTEC is still relatively unknown. There are research and development hubs in Hawaii.[liv] A commercial scale offshore plant is predicted to be capable of producing energy at an LCOE of roughly $0.20/kWh. Per discussions with Makai Engineering, the recommended minimum efficient scale of an OTEC plant is around 100 MW. The installation of the plant requires significant capital expenditure, as there is a great amount of equipment and piping necessary to be transported and submerged at the final location. In order to reach the depths required for a 1000M cold-water intake, it is estimated that the OTEC plant would need to be 10-12km offshore. The corresponding transmission lines from the OTEC facility to shore would be similar to offshore wind or solar at the same sea level. There are also operational challenges related to the fouling within the closed-loop system, like there are in most heat-exchanger systems. As the system runs, debris builds up within the piping and efficiency loss occurs. For many of these reasons, along with a preliminary LCOE estimate ranging up to $0.84/kWh for an OTEC plant at an appropriate scale for an island system, the Turks and Caicos Islands Resilient National Energy Transition Strategy included an initial review of OTEC options but did not pursue further detailed analysis through specific scenarios.[lv]

For an OTEC system to reach commercial viability, the minimum temperature difference between areas must be at least twenty degrees Celsius.[lvi] A greater difference in temperature between the cold and warm intakes will increase the electricity generation potential of the OTEC plant. Without a consistent temperature difference between surface and deep ocean temperatures, the electricity generation potential is greatly diminished, although there are other potential applications. The temperature difference can be utilized for Sea Water Air Conditioning (SWAC), which does not require actual vaporization of the working fluid.

The external environmental impact of large scale OTEC plants is still mostly unknown and subject to the location selected. There is a significant opportunity for fish and other living organisms to be entrained within the intake pipes.[lvii] Due to the sometimes drastic temperature difference during the heat exchange (up to twenty degrees Celsius) and the high speeds of intake, entrainment mortality is possible. The large OTEC plants may act as fish aggregating devices, potentially increasing the anticipated impact to fisheries. Additionally, the large volumes of water required for a commercial scale OTEC plant will have potentially adverse effects on the ocean environment due to the upwelling and redistribution of ocean water. Finally, there is a working fluid, often ammonia, which could be detrimental to the ocean environment if it were to leak. The disruptions to the ocean environment can be mitigated stationing the plants away from points of dense biodiversity. Design improvements and safety precautions will mitigate the severity of any working fluid loss.

Floating Solar

Floating solar is very similar to land-based solar electricity generation technologies (see Figure RE6 for example installation). There are currently both inland[lviii] floating PV (FPV) (on lakes and other freshwater bodies) and offshore floating PV. The World Bank estimated in 2018 that inland PV has an installed capacity of 1.1 Gigawatts and top-end estimates of the total world potential are 400 Gigawatts (GW).[lix] A more recent review by the Bermuda Regulatory Authority identified around 350 operational floating PV systems with a total capacity of around 2.6 GW. A list of high profile projects (Figure RE6) show that projects with greater than 1 megawatts are exclusively located in reservoirs and lakes.

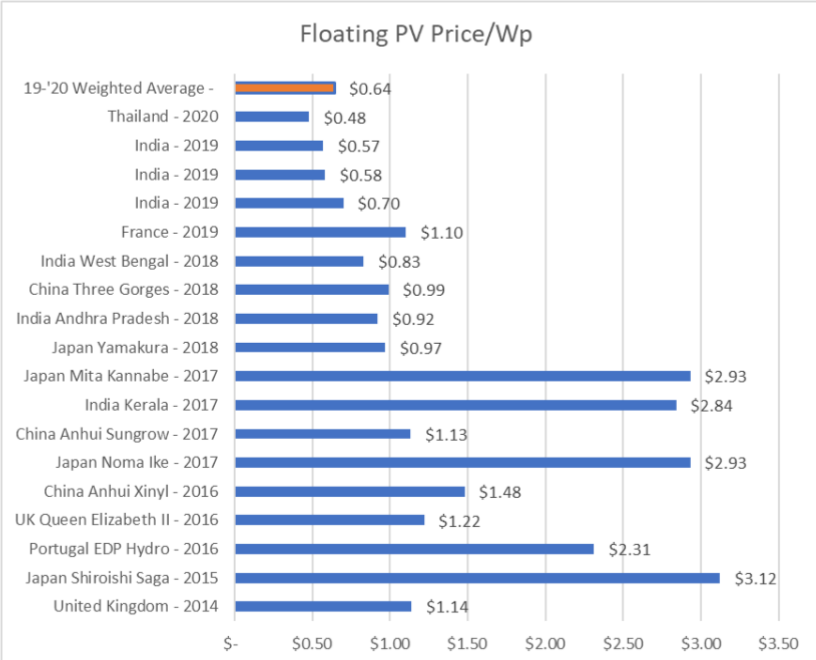


Figure RE6: CAPEX of inland floating solar projects

The initial capital investments required for floating solar are 10-15% higher than typical ground-mounted solar,[lx] and can be as much as 50 times higher.[lxi] Our research has found that in 2020, projects have been very competitive with ground-mount solar PV. Floating PV (FPV) is quickly improving in scale, cost, and technological advancements. Compared to other marine based technologies, it is the most cost competitive. As the technology and engineering advances, resiliency improves and costs decline; relative to offshore wind and floating offshore wind, FPV will offer lower complexity, lower soft costs, higher scalability, and lower capital risk.

TABLE B.1. A comparison of capital investments: Floating vs. ground-mounted photovoltaic systems

CAPEX component	FPV 50 MWp ($/Wp)	Ground-mounted PV 50 MWp ($/Wp)
Modules	0.25	0.25
Inverters	0.06	0.06
Mounting system (racking)*	0.15	0.10
BOS**	0.13	0.08
Design, construction, T&C	0.14	0.13
Total CAPEX	0.73	0.62

Source: World Bank Group, ESMAP, and SERIS 2019.

Figure RE7: CAPEX comparison of traditional ground mount PV and inland floating PV

Depending on the size, location, and complexity, FPV project total investment costs ranged on average between $0.70-$0.80/Watt-peak (Wp) in 2019 and $0.80/Wp and $1.20/Wp in 2018. In 2020, project costs were as low as $0.48/Wp. The 2019 global weighted average for ground mount solar was $0.995/Wp.

Per a 2019 World Bank study, on a per watt-peak basis, FPV capital expenditure remained on average US$0.10 higher than ground mounted PV projects under similar conditions (see Figure RE7). Improved economies of scale and competition will begin to improve FPV competitiveness. This has been proven in both 2019 and 2020, as costs have declined to $0.74/Wp in 2019 and again to $0.48/Wp in 2020 for specific projects. Similarly, the levelized cost of energy is now competitive with ground mount solar PV due to the higher energy yields and improved efficiencies provided by FPV systems (estimated at 10-15%).

It is important to note that much of FPV cost components are the same as those of ground mount solar PV. The slightly higher cost, on average, is due to higher costs of floats, anchoring, mooring, plant design, and higher administrative and environmental hurdles related to accessing water bodies. Cost of floats and other equipment is expected to drop as scale of deployment increases.

Further higher installation costs are offset by slightly lower operating costs. The experience curve for offshore solar is very similar to the experience curve for conventional solar, so there are not any expected exponential improvements in efficiency. However, by optimizing solar panel arrays for ocean environments, it is reasonable to assume incremental gains in efficiency and durability. As scale increases, costs will decline.

Figure RE8: Image of Oceans of Energy Project in North Sea

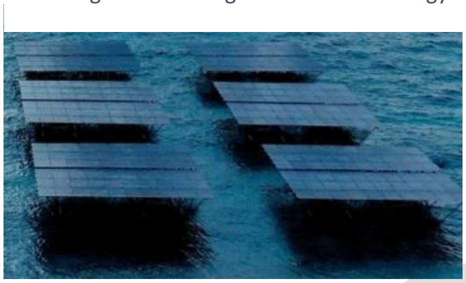


Figure RE7: Image of SolarSea Project

Operations are minimally impacted by wave excitation – a relevant study demonstrated that wave motion and direction have an influence on performance, but the effect is very small. This is likely to decrease further as designs improve.[lxii] A recent Oceans of Energy project in the North Sea demonstrated the ability of a floating solar installation to survive through a storm that experienced waves up to 5 meters; this particular system was designed to have the panels ride under the water after the waves reach a certain height, increasing the resilience of the overall system through storm and hurricane events.[lxiii] The developer claims that the modular system is capable of withstanding rough sea conditions (up to 13 meter high waves).[lxiv] Another initiative, SolarSea, was specifically developed for tropical marine region. The system claims to be commercially viable and is operational for up to 30 years on the sea surface.[lxv]

Offshore options in saltwater environments require additional considerations to either protect or update some components as they are continuously exposed to salt. The same demonstration project mentioned above utilized equipment that is sealed from direct salinity impacts, while considering that the ability of the solar modules to be washed over by waves may help to avoid build-up of salt; additional testing and assessment will be required to understand the impact of saltwater environments on offshore floating solar plants.

Impact to fish due to shadowing effect is minimal, since tidal currents continually renew the seawater underneath the platforms.[lxvi] However shadowing can have negative impact to coral reefs.[lxvii] Since the height of solar panels is negligible, there is effectively no impact to onshore or offshore sightlines.

Figure RE9: Offshore Solar Facility[lxviii]

We note that there is currently higher risk associated with FPV projects because of the lower level of maturity of FPV concept/technology. We believe that the significant growth and investment in FPV will resolve these concerns. In 2015, FPV system global capacity was 65 MW. This has since grown to 3.0 GW in 2019 and is expected to grow rapidly (+1 GW to 3 GW) each year over the next several years.

Offshore/Marine Floating Solar PV

Similar to offshore floating wind farms, marine floating solar PV farms are a new application of existing-proven technologies. Much of the technology is borrowed from oil and gas industry and ground mount solar PV industry. Pairing marine solar PV with wind farms is a growing trend as it offers greater energy yields and shared costs using the same space. Given the rapid growth in development of inland and marine FPV, and the strong applicability to Bermuda, this sector should be closely monitored and studied over the next few years.

Offshore wind farm and marine FPV technologies draw on the expertise and developments of offshore oil and gas platforms, offshore wind, and other maritime technologies. The Seychelles recently developed a utility scale marine-based marine FPV that Bermuda should consider. The Seychelles project was developed under a power purchase arrangement which minimizes the risks to the off-taker. The power purchase cost for the energy produced by the 4 MW FPV power plant is $9.5c per kWh. As more projects are developed, economies of scale will kick in. A recent assessment of cost for marine FPV in the Netherlands is expected to be $0.06/kWh by 2030 and $0.05/kWh in 2050. Several national research entities and industry initiatives are actively engaged in formulating recommended best practices and guidelines regarding floats, sites, permitting, energy yield estimations, anchoring and mooring, and technical requirements, among others, for both onshore, nearshore/maritime, and offshore FPV.

The resiliency of mooring and the floaters for FPV platforms has been enhanced in the past several years. Oceans of Energy's floating PV concept has been engineered to handle 13-metre-high waves. The existing platform has survived several storms with wave heights up to 5 meters. Although this adds to the cost for the pilot project (50 kW), they anticipate a decline in costs as they achieve scale. The company is currently pursuing 2 larger scale initiatives: the first being a 1 MW offshore FPV plant in the North Sea supporting and offshore platform and connected to a windfarm (located 15km offshore), and the second being a 200 kW plant in the Philippines (up to 1.5km offshore).

Offshore Wind

While we believe that all of the marine renewable energy technologies covered within the report have merit, it is clear from both independent research and Bermuda's Integrated Resource Plan (IRP) that offshore wind energy represents a significant and immediate opportunity in Bermuda. Therefore, in this report, it is addressed in additional detail beyond the consideration given to more nascent technologies.

Offshore wind farms are typically stationed 8-24 km offshore and commonly have generating potential of 100+ MW. [lxix] Compared to other marine-based renewable resources, offshore wind is more mature with the first large-scale project entering commercial operation in Denmark in 1991.[lxx] Europe has been the historical leader in offshore wind development, claiming roughly 83% of all installed offshore wind capacity to date.[lxxi] Burdened by climate change, land constraints and rising fossil fuel costs, more and more nations are starting to see offshore wind as a necessary component of their future energy mixes.[lxxii] Until recently, offshore wind remained out of reach for many regions of the world due to prohibitive costs and restrictive design requirements pertaining to ocean depth.[lxxiii] It was not until the last three-to-four years that technological innovation, improvements in supply chain and logistical synergies in Northern Europe have allowed for cost reductions and entry into new markets.[lxxiv]

In order to meet the ambitious renewable energy goals set forth in the Paris Climate Accord, installed offshore wind power capacity must be at least 228 GW by 2030, which would represent a tenfold increase from 2018.[lxxv] At $0.06/kWh in 2018, the levelized cost of energy (LCOE) for onshore wind is already competitive with fossil fuels and is predicted to drop by an additional 50-66% by 2050.[lxxvi] Due to higher costs associated with marine-based construction, as well as reduced predictability of offshore wind speeds, the LCOE for offshore wind is much higher than that of onshore wind at $0.13/kWh in 2018. By 2050, however, the global LCOE for offshore wind is projected to be $0.03-$0.07/kWh.[lxxvii] This predicted cost reduction is expected to result as a continuation of existing trends: as developers become more experienced and thus better at de-risking projects, development costs have gone down.[lxxviii] Other elements that factor into cost reductions include improved capacity factors, improved turbine technology, lower costs of capital, and economies of scale across the value chain.[lxxix]

Large-Scale Turbines

One of the most notable changes in turbine technology over the years has been a drastic increase in turbine size, which has led to higher generating capacity per turbine. In 2018, the average rated capacity of offshore wind turbines was 5.5 MW.[lxxx] That same year, Vestas unveiled a 10 MW capacity turbine with 164-meter diameter blades.[lxxxi] Turbine generating capacity is expected to reach up to 20 MW by 2030.[lxxxii] Although the 10+ MW turbines have yet to be put into practice, they are anticipated to have high capital expenditure costs per MW, but lower overall energy costs due to lower per MW costs for foundations and installation.[lxxxiii] With the ability to operate high-capacity wind farms using fewer turbines, maintenance costs and some environmental impact is anticipated to be lower than current rates.[lxxxiv] However, viewshed impact will be greater and impact on avian species is yet to be determined.[lxxxv]

Floating Platforms

Another recent technological advancement in the offshore wind industry is the introduction of floating foundations. Most offshore turbines sit atop fixed-bottom foundations, making it necessary for wind farms to be sited at depths of generally no greater than 60 meters.[lxxxvi] Floating platforms allow for an alternative to this depth restriction. Various design concepts for floating platforms were borrowed from the oil and gas industry.[lxxxvii] They are revolutionary in the wind industry because they help broaden the offshore market, offer easier setup, may have lower costs in the long-run and have less of an impact on sea life. Many regions of the world, such as Asia and North America harbor powerful offshore wind resources but have been unable to tap into the offshore wind market due largely to having deep bathymetries. Floating platforms allow turbines to sit in waters with depths of greater than 60 meters.[lxxxviii] They also allow projects to be situated further from land in order to capitalize on stronger winds. Finally, because offshore wind turbines have traditionally been mounted on the seabed, they sometimes disrupt marine life, especially during the construction phase. Floating turbines are tethered, rather than mounted, to the sea floor giving them far less volume and therefore causing less interference with marine life.[lxxxix] For a visual comparison of existing platform designs, see Figure RE11.

There are several utility-scale floating offshore wind farms currently in operation. The first being the 30 MW floating wind farm off of Hywind Scotland, and another 25 MW project successfully connected the first of three 8.4 MW wind turbines on 31st December 2019. Although still in its early commercial viability stage, floating wind farms have overcome concerns regarding the stability of the platforms and durability of the mooring lines in turbulent waters and as the blades spin. Specifically, the Wind Float prototype has operated uninterruptedly over five years, while surviving extreme weather conditions including waves up to 17 meters tall and 60-knot winds.[xc] Another downside of projects that require floating platforms is the higher transmission costs associated with being further from land.[xci] Transmission is already a considerable cost barrier for many wind projects so siting a project too far from land could repel prospective developers.

Figure RE10: Photo Showing Floating Platform in 17 Meter Waves

Because of the extensive water depths some thirty miles offshore, it is likely that the only viable offshore wind possibilities for Bermuda are the use of floating wind turbines. Floating wind turbines are typically recommended for water depths up to 1,000 meters. Although there is no technical limitation on the depth potential for floating turbines, the cost increases for every additional distance from shore and meter of depth. Furthermore, since floating wind platforms are still in the precommercial and pre-utility scale phase, there are many other considerations to address.

Some advantages of floating wind turbines include the following:

- Flexible installation process (turbines can be assembled on or near shore with the assembled plant then towed to its final destination).
- The size of the ballast or floater can vary depending on the water depth.
- Floating wind turbines can be relocated for major maintenance or sold and transported fairly easily.

- There is no limitation on the turbine size, which can lead to reduced levelized cost of electricity by taking advantage of larger scales.
- Turbines can be positioned within areas with the most favorable wind profiles.
- The platforms can use gravity anchors for tethers and/or mooring lines rather than more expensive and technically challenging pile driven fixtures.
- They offer reduced installation cost and complexity compared to installation of fixed foundations.

However, given that large scale use of floating wind turbines is relatively new to the industry, the cost is still relatively higher due to the higher interconnection costs and limited scale of production. To get a complete picture of a project's cost and complexity, it is important to not only consider the distance to shore, but also the distance to critical infrastructure, distance to service ports, typical weather conditions (wave heights), along with the travel distance to manage operation and maintenance.

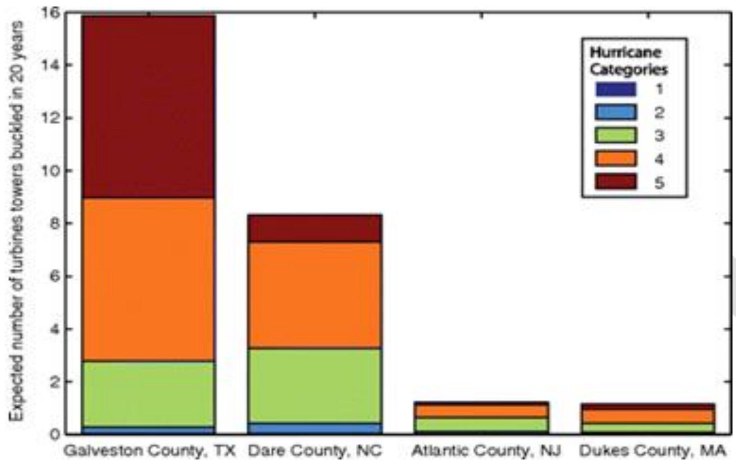
Figure RE11: Fixed vs. Floating Turbine Platforms[xcii]

Hurricane Impacts on Offshore Wind

One of the major risks affecting offshore wind farms is hurricane impact. Most wind turbines are designed largely according to the international standard (IEC 61400-1) that is generally based on European and North American conditions. Proceedings of the National Academy of Sciences (PNAS)[xciii] quantified the hurricane risk to offshore wind turbines using data from the impact on ocean equipment during various Atlantic and Gulf Coast hurricanes along with other predictive models; results are shown in Figure RE12. A review of this and several other studies show that there is a very substantial risk that a Category 3 and higher hurricane can destroy half or more of the turbines at some locations. The most significant failure modes can include loss of blades and buckling of the supporting tower.[xciv]

According to the Official Atlantic Hurricane Database (started in 1851), only nine landfalls have occurred in Bermuda.[xcv] On average, Bermuda experienced a significant tropical cyclone once every six years. However, in recent years, there has been an increase in both the frequency and intensity of storms making direct landfall with the eye partially or fully going over the island with five storms with intensity ranging from category 1 to 3 occurring within the past six years. Figure RE13 shows the Atlantic hurricane alley, including Bermuda's position.

To successfully develop sustainable and resilient offshore resources, the risk from hurricanes to offshore wind turbines should be assessed and understood. Due to the small number of offshore deployments in the Atlantic hurricane belt, there is limited data available to analyze the potential impact. The lessons learned from Eastern Asia typhoons and the experience of high wind prone areas like the North Sea may be helpful in understanding the potential impact of hurricanes on Atlantic based wind farms.



PNAS Chart showing the expected number of turbine towers that buckle in a 50-turbine wind farm over a 20 y period

Figure RE12: Results of study of potential wind turbine damage during hurricane force winds.

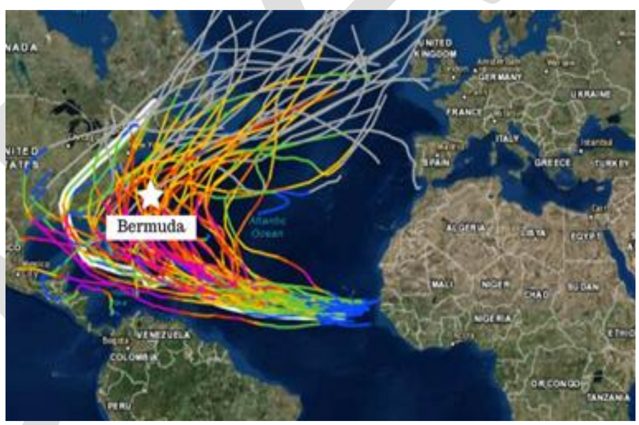


Figure RE13: Map of hurricane alley indicating Bermuda's position[xcvi].

There are several critical components responsible for a wind turbine's ability to withstand storms. These parts include the foundation, towers, blades, nacelle (housing), and control systems (yawing). The tower accounts for roughly 10% of the capital of the wind turbine unit, but it one of the most significant causes of failures during storms. Because the tower supports the housing unit and blades of the wind turbine, its failure is the most catastrophic. As such it is critical that considered systems have design capabilities with reinforced steel or other design characteristics that will increase resiliency. Other key factors include:

1. Shortened or structurally reinforced turbine blades (less weight, improved maneuverability, easy transport, and less wind surface).

2. Yaw control with the ability to turn the nose into the wind.
3. System must contain UPS battery pack with converter as an emergency power supply.
4. Foundations must be structurally sound. Some recommendations include:
    a. Twisted Jacket Foundation[xcvii]
    b. Floating wind foundations as discussed above (for seas deeper than 25 meters); considered more typhoon and earthquake resistant than conventional fixed-bottom designs.
5. Yaw control regulation of blades responding to wind direction.
6. Yaw systems apply hydraulic brake mechanism instead of slider brake mechanism.
7. Yaw systems should have planetary gearboxes instead of worm gearboxes.
8. Downwind turbine designs that allow blades to be more flexible. This design allows blades to bend in high winds reducing the risk of tower damage.

Given the significant risks posed to wind farm developments in East Asia, the Atlantic, and the Gulf of Mexico, there are a number of companies that have developed anti-hurricane/typhoon wind turbines, structures and blades. Hurricane class wind turbines are a newly developing technology for the offshore wind industry. Some newly developed turbines include:

1. GE 4.2-117 typhoon class turbine is being built to survive wind speeds of up to 128 mph (57 m/s). The relative power rating of the 4.2-117 is 4.2 MW.
2. Lockheed Martin Segmented Ultralight Morphing Rotor (SUMR)[xcviii] wind turbine is currently being tested for wind speeds up to 200 mph. These blades are still in the early development phase. The Advanced Research Projects Agency-Energy (ARPA-E) research team is aiming to design a 50-megawatt turbine that can -
    a. Reduce the levelized cost of offshore wind energy by as much as 50 percent by 2025.
    b. Fold and stow in hurricane-force winds.
    c. Morph or deform downwind into the direction of the flow (similar to palm trees during a storm).
3. Dongfang Electric (DEC) prototype 10 MW (B900A) offshore anti-typhoon wind power unit developed for the Fujian Xinghua Bay Wind Farm (Phase II).
4. ENERCON E-82 WECs (rated for wind forces of up to 90 m/s).[xcix]

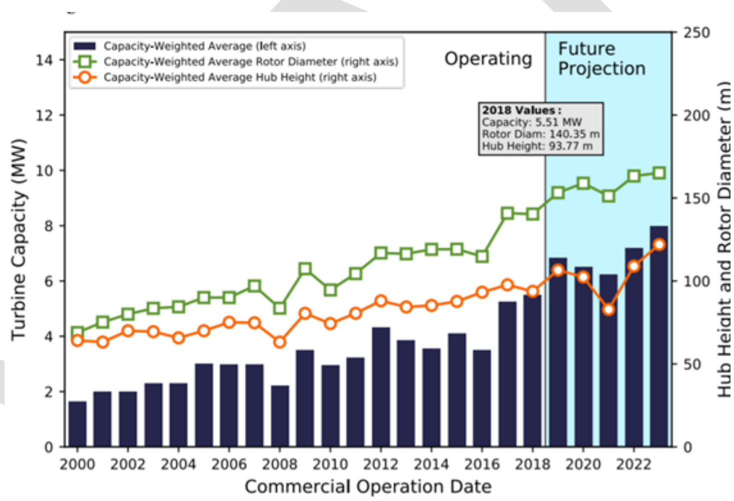
Subsea Cable, Transmission and Interconnection Considerations for Offshore Wind Energy

In addition to considering foundation type and designing for resilience, another critical component of nearshore and offshore wind energy is the system to interconnect the turbines and supply electricity to land. In this context, a nearshore is assumed to be less than 15 miles away from the shore. A near shore wind farm in Bermuda would fall within 100-200 meters water depth. This could be done with a direct high voltage alternating current (HVAC) connection to an onshore substation. This arrangement reduces the overall capital cost and future operation and maintenance cost. Whereas, if the offshore wind farm is finally located more than 20 miles from the shore, there is a high likelihood that it will require having an offshore substation.

Given the strong sentiments around visual interference or not-in-my-backyard (NIMBY) proponents, it is necessary to analyze the related distances required from the shore to mitigate the related objections. A study conducted by MIT has shown the relative distances needed to reduce the visual interference. This study was conducted with a turbine blade size of 90 meters plus a tower height of approximately 65 meters, for a total height of 155 meters. For a frame of reference, it is noted that 5 MW turbine blades are typically 100 meters in length. The larger the turbine capacity, the longer the blades (e.g. A 10 MW turbine can carry blades lengths up to 200 meters).

It was determined that the distance from shore for the turbine's blade tips and hub to be invisible at a height of 155 meters was 28 miles and 21 miles (respectively).

In recent years, there has been a continued drive toward large scale turbines to reduce the levelized cost of energy. Given the high upfront infrastructure and deployment cost required to develop offshore wind farms, to maximize the investment returns, developers have migrated to larger turbines with increased blade lengths. Figure RE14, published in the US Department of Energy 2018 Offshore Wind Technologies Market Report, shows the gradual increase in the average offshore turbine heights and blade lengths. The report concludes that "the larger capacity turbines generally yield lower balance-of-plant costs, fewer and faster installations, and lower maintenance, as well as more energy per unit of area. Recent cost information also indicates that in addition to these project cost-scaling benefits, unit turbine costs may not be rising with turbine capacity."



Offshore wind turbine rating, hub height, and rotor diameter

Figure RE14: Capacity and size of offshore wind turbines over time.

Addressing not in my backyard (NIMBY) concerns in Bermuda introduces several potential challenges, but also opportunities. The first and most obvious challenge is the increased interconnectivity challenges and increased transmission costs (long-distance undersea cabling), deeper water levels (over 4,000 meters), limits to the type of tower support infrastructure that could be involved, and increased challenges to maintain and operate facilities located greater than 20 miles offshore. However, by locating the wind farm some 30 miles offshore presents less interference with commercial shipping activities (including fishing), avoids impacting nearshore wildlife, fishing grounds, coral and seabed, as well as the tourism ecosystem. Figure RE15 shows a 30 mile radius around Bermuda to demonstrate where wind turbines would sit if they were located at that distance from shore.

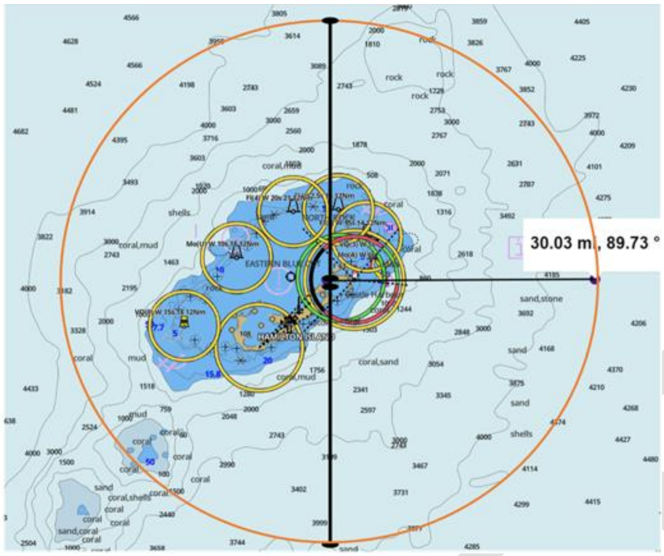


Figure RE15: A 30-mile radius around Bermuda, indicating distance where an offshore wind farm would not be visible.

The electrical grid connection is a critical part of the windfarm development process and cost. These costs include both offshore and land-based infrastructure to connect the wind power plant to the electricity grid. Interconnection cost can account for as much as 15-30% of capital costs associated with offshore wind farms. These costs can vary significantly based upon a large number of other variables including sea floor substrate, distance to shore, and depth.

A compact nearshore wind farm would minimize costs to the developer due to a decreased amount of cable, cable routing effort, and transit time during construction and maintenance. Buried-insulated-three-core copper or aluminum cables are typically used for subsea array collector systems.

In addition to the main transmission line and substations, developers must consider reliability and redundancy in the planning of the interconnection. Although having redundancy increases the cost substantially, it improves the plant's resiliency and avoids future costly opportunity losses due to a single point of failure. These cables are designed for a long life, but the seabed is a hostile environment. Although cables may be buried, the seafloor currents can expose the buried cable over time. This causes cables to drift, causing strain which can create breaks or shorts. Cables may also suffer electrical damage caused by arcing if the cable insulation fails.

Considerations for the seabed conditions and depths must be made when selecting the cable type and size and whether the cable will be buried or laid. These considerations include the amount of vessel traffic, the risk of storm damage, the nature of the seabed or bedrock (rock, coral, sand, mud, etc.), and water depth.

The sizing of the undersea and array cabling is highly dependent on the size of the wind farm, project developers and operators are increasing the use of 66-kV array cable technology rather than the conventional 33-kV. The higher voltage offers important life cycle cost-efficiency benefits, such as the possibility of reducing the number of offshore substations, decreasing the overall length of installed cables, and minimizing electric losses. When combined with floating solar, 66-kV also provides scale and per kWh cost reductions.

Several risks related to cables that should be considered and evaluated include:

- Floating Wind - Motion of cable may cause damage – solutions include dynamic cables
- Structural integrity of the base
- Damage from frequent storms that often times relocate cables along the ocean bed
- Boating activities that may sever the cable
- Damage to seabed and related marine environment
- Electromagnetic interference and impact on marine life
- Cable burial disruption to ocean floor

The connection of the wind farm to the network may bring about an increase in voltage and frequency distortions. The interconnection and balance of power requirement should be assessed during the detailed design stages in partnership with the local utility company. Possible solutions include those used for other intermittent sources of energy such as solar PV where the energy management and/or storage systems (EMSS) can be paired with a combination of traditional generation facilities (diesel or gas based) and storage (battery or hydrogen). It is vital that energy storage be part of the consideration in the energy planning process as the increased loads driven by the need to achieve scale (described under cost considerations) and the system imbalances it will introduce be fully explored. Grid code connection conditions reviewed and approved by the utility will be necessary at the connection point with the onshore grid. It is possible that the wind turbine operational capabilities are sufficient to address grid code compliance issues without additional equipment, but the appropriate studies must be done.

Cost Considerations for Offshore Wind

Turbine costs are estimated to be as much as 35% of the total capital cost for an offshore wind project. Due to the limited number of manufacturers, prices are typically independently negotiated for each project. One of the most significant price determinants is the scale of the project, where the larger the size of the project, the lower the project cost per capacity. Some other pricing factors include delivery costs (to staging port), warranty period (typically 5 years), availability guarantees, turbine attributes (e.g., turbine rating, drivetrain topology, resiliency considerations, etc.), and timing. Figure RE16 shows a typical breakdown of the capital costs for an offshore wind project.[c]

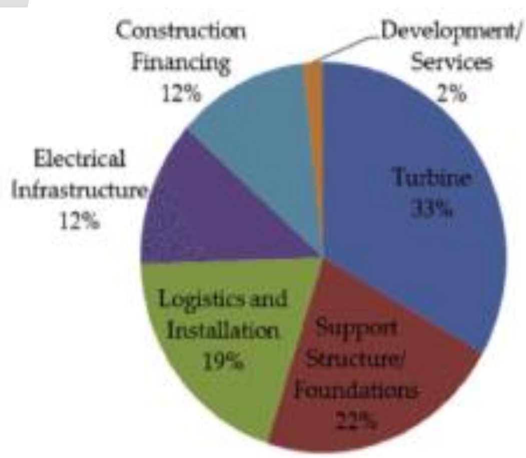


Figure RE16: Offshore wind farm capital cost breakdown.

Capital expenditure costs have declined rapidly over the last few years. This has been driven primarily by technological advancements and the growing scale of wind plants in Europe and Asia. The chart in Figure RE17 shows the costs (levelized cost of electricity or LCOE) published between 2009 and 2020. This chart shows a downward trend between 2010 and 2020 overall for offshore wind, which has seen a 50% decline in cost from 2015 to 2018. Costs are projected to decline to roughly $0.080/kWh by 2020. This is mainly due to the scale-up in turbine size, which now averages over five megawatts. LCOE can be a difficult metric to use for wind farms due to the number of varied factors that impact these computations (e.g. the production capacity and wind speed). Most computations use an average wind speed of 10 meters per second (m/s). Wind speeds vary significantly by region and are very site and height specific. Therefore, it is critical that proper meteorological studies are conducted to determine the wind profiles of potential wind farm zones. This will enable developers to select the appropriate turbine for the specific zone. Turbines are classed by three main parameters: the average wind speed, extreme 50-year gust, and turbulence.

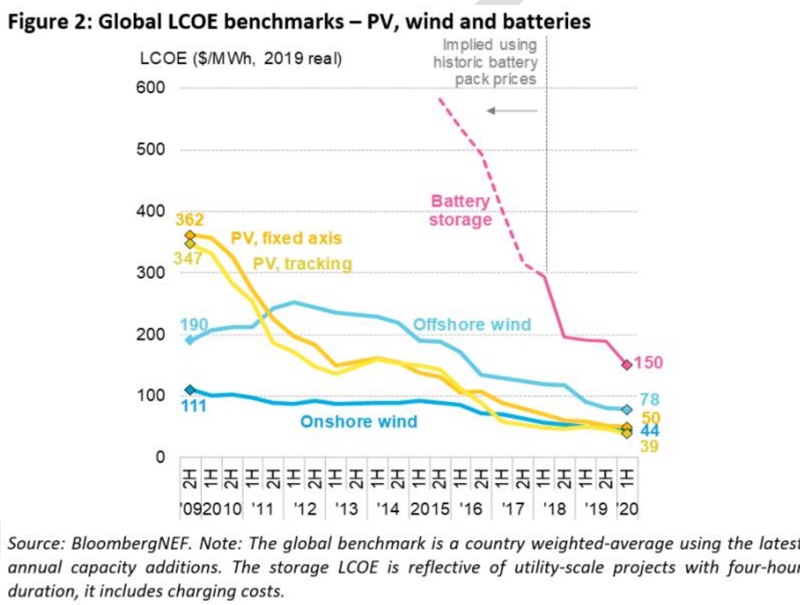


Figure RE17: Offshore wind farm capital cost breakdown.

A 2018 Bloomberg New Energy Finance (BNEF) analysis of global capacity-weighted average capital expenditure (CapEx) showed a cost of $1,500/kW for offshore wind in 2015. This declined to $750/kW in 2019 and is projected to decrease to $650/kW by 2025 (representing a more than 50% decline). This is the most aggressive projected decline shown in Figure RE18, which also includes other projections. These other models suggest a more modest 10% decline.

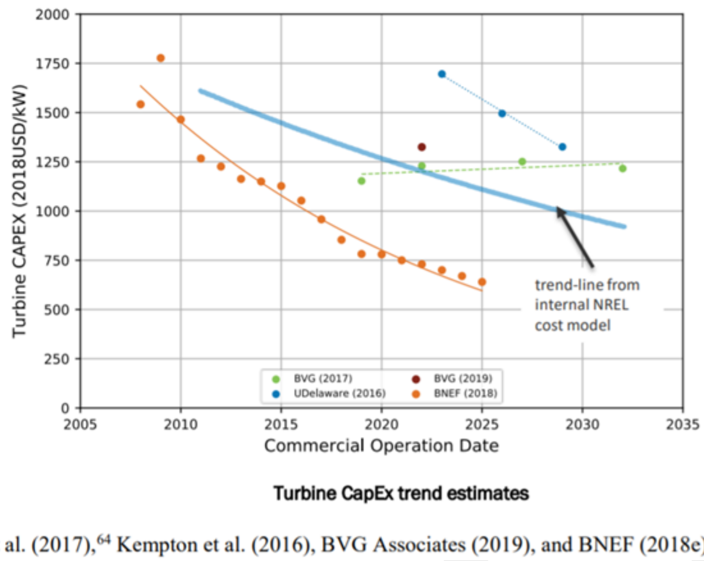


Figure RE18: Offshore wind farm capital cost projections through 2035.

There are several factors that will influence the CapEx costs including spatial conditions (e.g., water depth, distance to port, point of interconnection, wave height of sites that affect technical requirements of installing and operating a wind farm), project size, supply chain, demand and supply conditions (e.g., components, vessels, and skilled labor), etc. However, the general trend suggests that costs will decline aggressively as turbine size/scale expands and commercial production increases. This rapid cost decline is partially due to breakthroughs in other industries using the same technologies, i.e. onshore wind (blade, generator and pole technologies) and use of offshore drilling. And the global market is more mature than the U.S. market. As the number of utility scale projects increase, producers can reinvest profits into capital and process improvements; this will further reduce production costs and improve competitiveness.

The highest commercially available turbine rating is expected to grow from 9.5 MW in 2018 to 15 MW or higher over the next decade. Using higher-rated turbines for a given project size reduces the number of turbines to be installed and serviced, effectively decreasing the unit costs for balance-of-station ($/kW) and operating and maintenance (O&M) activities ($/kW/year). In addition, industry experts and turbine manufacturers suggest that higher turbine rating may not necessarily result in an increase in turbine CapEx ($/kW); turbine manufacturers have reportedly been able to increase turbine rating without increasing the unit cost of the turbine ($/kW). Through continued innovations, such as the use of lightweight materials, advanced manufacturing methods, systemwide load control, and economies of scale in production and delivery, turbine manufacturers may be able to offset other cost increases caused by upscaling and anti-typhoon and hurricane improvements.

Operational expenditures required to operate and generate power typically contribute between 20% and 30% of life cycle costs for offshore wind projects, depending on site characteristics. The strongest drivers are distance from the O&M port, accessibility due to ocean conditions (e.g., wave height), and turbine rating (i.e. fewer, larger turbines suggest lower O&M costs per megawatt)[ci]. Similar to the trends in CapEx, as the average turbine size increases, the average per kW operational cost will decline. Figure RE19 shows the average price decline in $/MW-hour (MWh) relative to the turbine/wind farm capacity.[cii]

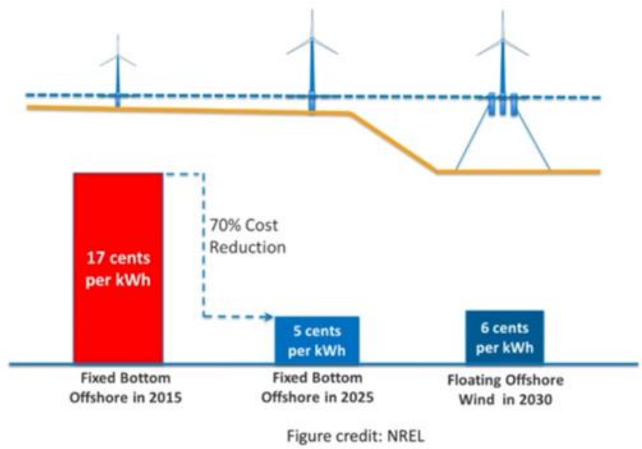


Figure RE19: Offshore wind farm projected per kWh cost decreases with turbine size and installation year.

To optimize costs recent offshore wind buys in the US Northeast, used several strategies to successfully reduce costs. Some key policy design elements[ciii] to de-risk offshore wind procurement included:[civ]

1. Reduce siting risks to find and approve suitable offshore lease areas and land for onshore facilities,
2. Acquiring leases and permits at different levels of government prior to going to market,
3. Eliminating unnecessary soft costs related to development (conducting pre-feasibility studies including wind and other meteorological assessments),
4. Identifying project-ready interconnection points,
5. Formation of an Intergovernmental Task Force,
6. Formation of fisheries and habitat working groups to inform the work,
7. Prescreening offshore wind siting areas that could easily be auctioned off for leasing,
8. Achieving adequate scale (larger wind farm capacity attracts competitive pricing and produces a lower levelized cost of energy in $/MWh),
9. Using a price-finding mechanism such as a reverse auction to mix public and private risk,
10. Sharing initial costs to participate in the auction,
11. Creating long-term revenue certainty through purchase agreements for developers with the lowest price,
12. Reduce permitting risks associated with satisfying environmental, viewshed, shipping and other local concerns,
13. Reduce interconnection risks to ensure there's a place for power to flow and agreements with the utility to accept power within a specific criterion,
14. Facilitated transmission access with the local utility,
15. Making investments to support access through a grid infrastructure study,
16. Design/assemble hybrid turbines from best in class technologies suitable for the Bermuda zone requirements (blade type (⅔ bladed), blade manufacturer, fixed base design, floating platform,

cabling, anchoring/mooring systems optimized for water depths, wave and wind environment, and

17. Study and select generators designed for smart offshore grids.
18. Site projects in areas with lower water depths (less than 200 meters),

This often results in undertaking multi-year studies focused on gathering baseline data to inform the development process.

Local Economic Assessment

Current Energy Mix

As of October 2020, outside of small residential and commercial PV systems (which account for about 5.817 MW of energy production on the island), Bermuda is 100% powered by imported fossil fuels.[cv] Heavy fuel oil and diesel-powered generators make up the bulk of this roughly 567.8 GW per hour per year in energy demand.[cvi]

Bermuda has made efforts in the past to diversify its energy mix: relevant policy and legislation has been developed and Bermuda's first utility scale 6 MW solar PV facility has been developed, due to be commissioned January 2021. In 2008, local researchers deployed a buoy off Bermuda's south shore to collect data on the wave resource with the goal of determining whether a wave energy system would suit Bermuda's wave regime. While the wave regime demonstrated promising potential,[2] the project was ultimately suspended due to a combination of bureaucratic inertia and a lack of advancement in wave energy technology.[cvii] Bermuda's south shore has since been reserved for subsea fiberoptic cables for the telecommunications industry.[cviii]

Bermuda Energy Demand

Bermuda's 2019 Integrated Resource Plan includes a base case projection of electricity demand remaining relatively flat and decreasing slightly over the period from 2020 to 2040. Several sensitivity cases were also modeled to test the impact of higher or lower projected growth in electricity demand, as well as potential uptake of energy efficiency, distribution generation, and electric vehicles.[cix]

Emissions and Environmental Considerations

In 2017, energy generation accounted for approximately 77% of greenhouse gas (GHG) emissions in Bermuda (see Figure RE20 for a comparison of GHG emissions across every sector).[cx] While GHG emissions have remained relatively stable over the last decade, overall pollution levels are expected to drop in the near term with the retirement of nine diesel engines.[cxi] Eight older engines were retired in November 2020[cxii] and four more efficient duel fuel generators that utilize heavy fuel oil instead of diesel were commissioned in March 2020. While heavy fuel oil is considered a dirtier fuel than diesel, the higher stacks used with the new engines help ensure that less sulfur is introduced to the atmosphere, thereby creating a net decrease in local air pollution levels.[cxiii]

[2] The specific findings from this data could not be shared with us at this point in time, as an agreement has yet to be signed between BOPP and the research team.

The broader introduction of renewable energy in Bermuda has the potential to further curtail greenhouse gas emissions from the energy sector. Aside from biomass, emissions from renewable resources are effectively zero. This, combined with the prospect for energy independence and cost reductions, makes renewable energy attractive for many in Bermuda. When selecting which technologies to pursue, it is important to first consider the availability of specific resources in Bermuda. Figure RE21 outlines Bermuda-specific metrics for each of the five resource types we considered in this analysis.

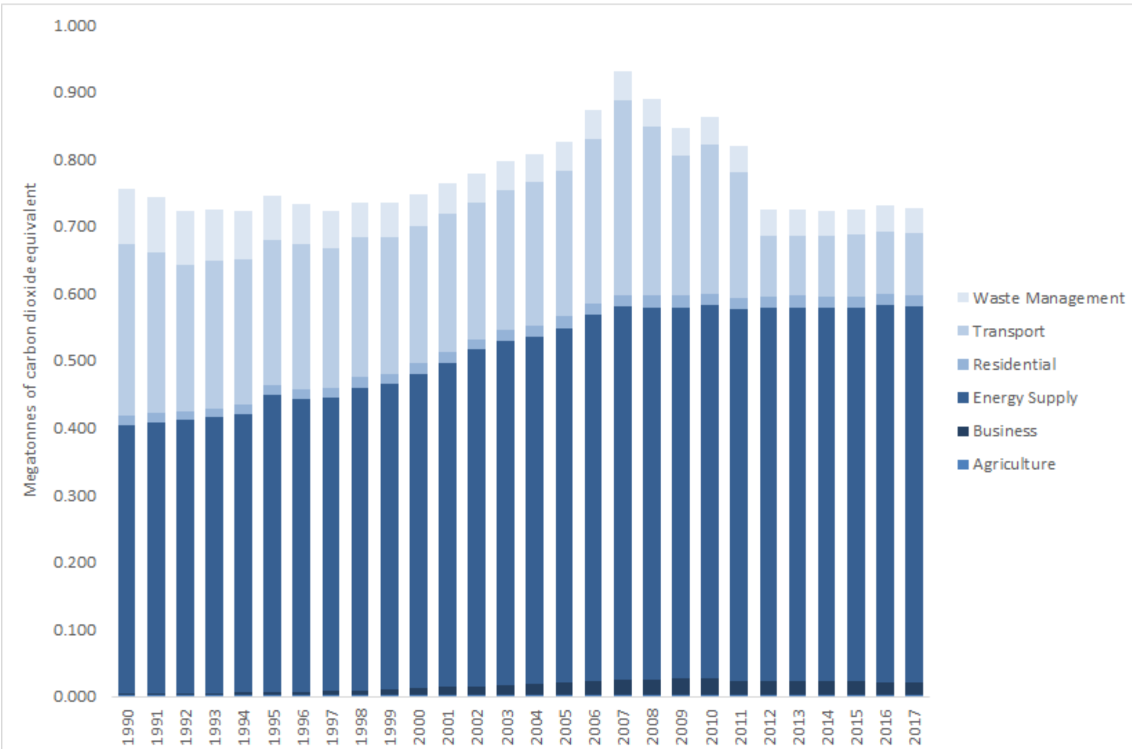


Figure RE20: Bermuda Greenhouse Gas Emissions (1990-2017)

Resource Type	Measurement	Location
Average Wind Speed (m/s)	8.702[cxiv]	Across Bermuda Platform
Average Wave Height (m)	1.8[cxv]	Outside reef
Average Tidal Range (m)	0.85[cxvi]	St. George's Island
Ocean Temperature Difference (degrees Celsius)	13.2-24.9	15-20KM off platform
Avg. Daily Sunshine (hrs)	7[cxvii]	Hamilton

Figure RE21: Marine-Based Energy Resource Measurements in Bermuda

The figures in Figure RE21 represent readings from various locations in the waters surrounding the island and do not necessarily reflect the optimum location for the corresponding energy technology, but they serve as good baseline indicators of feasibility. Robust data sets for wind speeds and wave heights are known to exist, however, they were not made available to us for this analysis.

Electrical Grid & Brownout Risk

Bermuda's electrical grid can be broken up into two components: (1) generation and (2) transmission and distribution (T&D). T&D is solely owned by Bermuda's only electrical utility, BELCO, and portions of it are in severe need of an upgrade due to aging infrastructure. All transmission infrastructure is underground, which helps in avoiding storm damage, however, nearly 40% of BELCO's underground cables are over 50 years old, putting them well beyond their useful lives.[cxviii] To address this, BELCO is currently taking a phased approach to replacing the transmission grid.[cxix] Unlike transmission, most distribution is above-ground.[cxx] In some instances during storms, unmanaged vegetation has crossed electrical wires, interfering with electrical distribution further downstream.

Some stakeholders expressed concerns over increased distributed energy resource (DER) penetration causing further brownouts. At the current level of DER saturation, this does not present a risk, however, it is likely that substantial upgrades to the distribution grid will need to be made once DER penetration meets a certain threshold.[cxxi]

Trends and Recent Changes

Incentives

Bermuda has several key initiatives underway to incentivize the adoption of renewable and energy efficient technology. First, there is no import tariff on renewable energy equipment.[cxxii] From the perspective of renewable energy developers and installers on the island, this is a critical component to making projects economically possible.[cxxiii] The Government also offers a tiered rebate on residential PV systems, which is based on system size.[cxxiv] This is designed to incentivize the uptake of small solar systems on the residential level.

IRP

The Integrated Resource Plan (IRP) was published by the Regulatory Authority of Bermuda (RAB) in 2019 as a follow-up to the Electricity Act of 2016.[cxxv] It originated as a proposal from BELCO and was adapted by the RAB to reflect an extended period of public and expert consultation. Notably, the IRP is considered a living document so future iterations are expected with changing economics and as more local data becomes available.

Some of the key drivers for the IRP included climate change, energy security, electricity affordability, a desire for increased competition in the generation market, and the planned retirement of 150 MW of generation in the current fleet.[cxxvi] Eight potential new generation scenarios were evaluated in accordance with these drivers. Four scenarios included an option for liquified natural gas (LNG). Natural gas is largely viewed as an intermediary between carbon-intensive fossil fuels and renewable resources, as it provides the same reliability as coal but emits 50-60% less carbon dioxide.[cxxvii] Bermuda, however, currently has no liquified natural gas facilities on the island and is reluctant to invest in LNG infrastructure. The general response from the public regarding the LNG proposal was that LNG represented a long-term investment in fossil fuels, which contradicts the global trend of renewable energy adoption. Additionally, an LNG plant would necessitate the continued importation of foreign resources, which fails to fulfill the objective of energy security under the 2016 Electricity Act.[cxxviii]

Beyond the special considerations associated with natural gas, the eight scenarios were evaluated on the basis of their contribution from renewable generation in 2035, greenhouse gas emissions, expected costs, diversity of supply sources, energy security and overall environmental sustainability.[cxxix] Given these criteria, Scenario 1D (50 MW of biomass, 21 MW of solar PV, 60 MW of offshore wind) was ultimately selected, with a projected procurement timeline depicted in Figure RE22. To prepare for the offshore wind component, the RAB is currently queuing up for an offshore wind feasibility assessment.

Though all three facets of this energy mix (solar, wind, biomass) are considered renewable resource types, biomass generation in Bermuda would entail burning wooden pellets, which would result in some carbon dioxide emissions.[cxxx] Additionally, wooden pellets are not produced locally in Bermuda so a biomass power plant would necessitate the continued importation of fuel, departing with the IRP's stated goal of energy independence.[cxxxi]

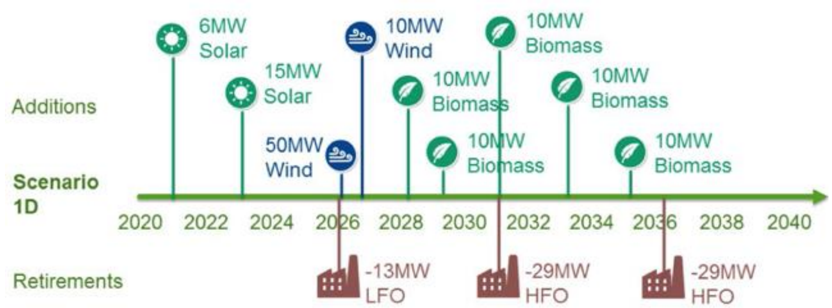


Figure RE22: Future Energy Procurement Timeline[cxxxii]

In our analysis, we sought to move beyond the scope of the 2019 IRP in order to better inform future versions of the plan. We also aimed to optimally incorporate the BOPP's mission of ocean prosperity and environmental sustainability.

Airport Solar PV Project

The 21 MW solar PV component of the IRP includes a 6 MW solar system located on an old, discussed runway next to the airport.[cxxxiii] Planning and development have been underway since 2016 and it is slated for commercial operation in 2020, which will mark the first utility-scale renewable energy system on the island. [cxxxiv] One of the biggest incentives for pursuing this project was the economic component. Costs starting as low as 10.3 cents per kWh, this project created jobs for Bermudians.[cxxxv] More specifically, 45% of the laborers used to develop the project were required to be from the local market. The Developer was also required to commit to employing a local Bermudian company to carry out operation and maintenance of the Facility.[cxxxvi] As the first large-scale renewable energy system on the island, this project helped illuminate some of the challenges and rewards associated with land-based renewable energy development.

Key Stakeholders

Bermuda Electric Light Company (BELCO): BELCO is Bermuda's only electric utility and its core business is to supply Bermudians with electricity. While it owns the majority of large-scale generating systems on the island, the Electricity Act of 2016 and the 2019 IRP opened generation up to the competitive marketplace. On the transmission and distribution side of the grid, BELCO operates as a monopoly, as there is no economic benefit for other utilities to compete in such a small market.[cxxxvii]

Commercial Fishing Industry: Commercial fishers are likely to be at least temporarily impacted by offshore renewable energy development and should therefore be included in early project planning.

Department of Energy: The Department drives energy policy and legislation development in Bermuda, spearheads educational efforts on topics surrounding energy and energy conservation, and provides project support and advice to other Government Ministries and Departments on new energy projects..

Department of Planning: The Department of Planning oversees land use on the island and works to ensure that construction projects are planned in such a way that accounts for the economic, environmental and social needs of Bermuda.[cxxxviii] It will be crucial to get buy-in from the Department of Planning in order to clear the initial hurdles of developing renewable energy projects.

Independent Power Producers (IPPs): Most renewable energy projects are developed, managed and operated by experienced IPPs. An IPP is usually selected through a competitive bidding process or auction. Once an IPP is awarded a project, it works with the utility to negotiate a Power Purchase Agreement (PPA), which dictates the rate at which it will be paid over the course of typically 20 or more years.[cxxxix]

Ratepayers: Bermudians have historically been subject to some of the highest electricity rates in the world.[cxl] This, combined with a general desire for energy independence and concerns about climate change have led Bermudians to be largely supportive of renewable energy on the island, as communicated in a 2010 survey in which 58.75% of those polled expressed at least some support.[cxli] Beyond cost considerations, ratepayers are also impacted by electricity reliability. It is therefore important to plan for a long-term energy mix that can withstand daily and seasonal variations.

Regulatory Authority of Bermuda (RAB): The RAB is the entity that developed the 2019 Integrated Resource Plan and is the only body responsible for regulating the electricity sector.[cxlii] It will also oversee feasibility studies as they pertain to large scale, bulk generation (over 500 kw) renewable energy projects. The RAB is therefore central to designing a feasibility assessment process that provides a clear set of guidelines for prospective players, as well as accurately gauges the practicality of future renewable energy projects, given cost and environmental considerations.

PEEST Framework – External Factors

In order to assess how likely key stakeholders would be to consider and implement recommendations, it is important to weigh the external factors. The PEEST framework provides insight into this likelihood and allows for the crafting of recommendations that are both fundamentally sound and likely to meet Bermuda's unique dynamics.

Political and Legal

The Bermudian Government has been generally supportive of exploring the feasibility of deploying renewable energy on the island. Switching from full dependence on fossil fuels to a more balanced energy portfolio has its political risks and implications. Currently, the Government of Bermuda has a tax levied on imports of fossil fuels and exempts technology related to renewable energy from import duty. Key stakeholders within the Government recognize that this tax revenue would be greatly reduced and eventually eliminated if there was a transition to renewable, on-island energy resources.

Economic

The transition to fossil fuels will ultimately be driven by economic factors. Currently, Bermuda has extremely high energy costs, partially due to the costs and taxes associated with importing fossil fuels. In order for renewable energy to be adopted in Bermuda, there is an expectation that there will be immediate savings to the consumer. In a transition to renewable energy, the country would be less susceptible to external economic factors that might impact the price or supply of fossil fuel imports. While immediate economic savings is the primary objective, energy independence through diversification and reduction in reliance of imported fuels would have long-term economic stability impacts for Bermuda.

Environmental

The report will not focus on the broader impact of a global transition from fossil fuels to renewable energy, however it is acknowledged that the following principles are relevant to global and local acceptance of renewable energy. Considering its Mid-Atlantic location, Bermuda has a disproportionately high likelihood of being impacted by the effects of climate change (e.g., hurricanes) despite being a relatively minor producer of carbon emissions compared to the global economy. While it is difficult for global change to be tied to specific local changes, it is a small albeit important first step towards broader acceptance of renewable energy when small island nations like Bermuda adopt renewable energy. Additionally, the introduction of renewable energy on the island would inevitably lead to a reduction in water and air pollution levels because most renewable energy types are zero-emissions resources. The exception to this is biomass, which emits some carbon dioxide as a biproduct of burning organic material.[cxliii] Finally, the deployment of new energy generators will inevitably lead to some degree of disruption to Bermuda's natural environment. While renewable energy resources generally have low interference with local environments, it is will be important for Bermuda to assess each project's unique impact, especially as it pertains to protected avian and marine species. This assessment will help Bermuda better ascertain the benefits and risks associated with each individual project.

Social

There are two major competing social themes at play regarding renewable energy adoption in Bermuda. The first is the previously described pride associated with the country's natural resources. In general, Bermudians are concerned about global climate change, interested in transitioning to renewable energy locally, and passionate about responsible stewardship of the ocean resources.[cxliv] The second is a widespread concept familiar to many areas where renewable energy has been pursued – NIMBYism, an acronym that stands for "Not In My Backyard." There is worry that when development of renewable energy infrastructure begins with site selection, there may be pushback from people who utilize that site or have it within their viewshed.

Technological

The widespread adoption of renewable energy globally has depended significantly on the development of new technologies to make the replacement of fossil fuels economically viable. Each distinct technology has its own innovation curve in which the technology exponentially improves. Along with the technological innovation curve, there is also a production scale that allows for the manufacture of said technology in a more efficient manner. As mass manufacturing of the technology occurs, there are continued incremental improvements in both the cost (decrease) and quality (increase) of the product. As each technology matures, the improvements diminish and the technology reaches its steady state efficiency.

For nascent technologies examined in this report, there were assumptions that innovation curves similar to more widely adopted technologies, such as ground-mounted solar, would be followed. In reality, there are certain limitations unique to individual technologies and the actual innovation curves must be monitored closely to determine the right time for Bermudian investment. One common sentiment that was expressed in our interviews was that Bermuda does not want to be the guinea pig for new renewable energy technologies. To address this concern, we attempted to build that sense of risk-aversion into our recommendations.

Opportunity Assessment

This section will analyze the technologies detailed in the global assessment and reconcile each technology with Bermuda's unique requirements in order to determine the technology's viability for implementation.

We have compiled the relative strengths and weaknesses of each technology across the categories of technological maturity, commercial viability, existing use cases, match with Bermuda's natural resources, impact to the external environment and global LCOE (see Figure RE23). We believe each of these categories should be considered in the evaluation of any technology's feasibility.

Renewable Energy Technology	Technological Maturity	Commercial Viability	Match for Bermuda's Natural Resources	Impact to External Environment	LCOE (actual vs. *projected*)[3]	Global Installed Base
Offshore Floating Wind	◕	◕	●	○	$0.15/kWh[cxlv]	55 MW[4]
Offshore Wind	●	●	◕	◔	$0.132/kWh[cxlvi]	27.56 GW[cxlvii]
Wave Power	○	◔	●	○	*$0.12-0.47/kWh*[cxlviii]	>20 MW[cxlix]
Tidal Power	◔	◔	◔	◔	*$0.13-0.28/kWh*[cl]	>1 GW[cli]
Ocean Thermal Energy Conversion (OTEC)	◔	◔	○	◔	*$0.15-0.28/kWh*[clii]	105KW (max for one site)
Inland Floating Solar	◕	◑	◑	○	*$0.06/kWh*[cliii]	1.1 GW[cliv]
Offshore Solar	◑	◔	◕	○		Negligible

Notes: Rankings represent relative strength. Key to range is found in Appendix G3.
Projected LCOE are italicized.

Figure RE23: Marine Renewable Energy Opportunity Matrix

To build upon the technological maturity element of Figure RE23, the timeline below (Figure RE24) approximates global commercial viability across each of the five technology types addressed in this report. Projections for tidal energy, OTEC, offshore solar and wave energy are difficult to calculate, as their relatively nascent states pose many development risks. Nonetheless, the projected timing reflects an assimilation of opinions from industry experts. Though offshore wind is still in its infancy compared to onshore wind, we considered it to be "mature" because commercial-scale viability has already been demonstrated through operational projects around the world. Additionally, "stretch" indicates an optimistic approximation for commercial viability while "target" shows a more conservative estimate.

[3] For a more detailed breakdown of LCOE across wave, tidal and OTEC resources, see Appendix RE4.
[4] As of August 2020, there are 2 utility scale floating solar farms in operation. There is over 5 GW in the pipeline for commissioning in 2021.

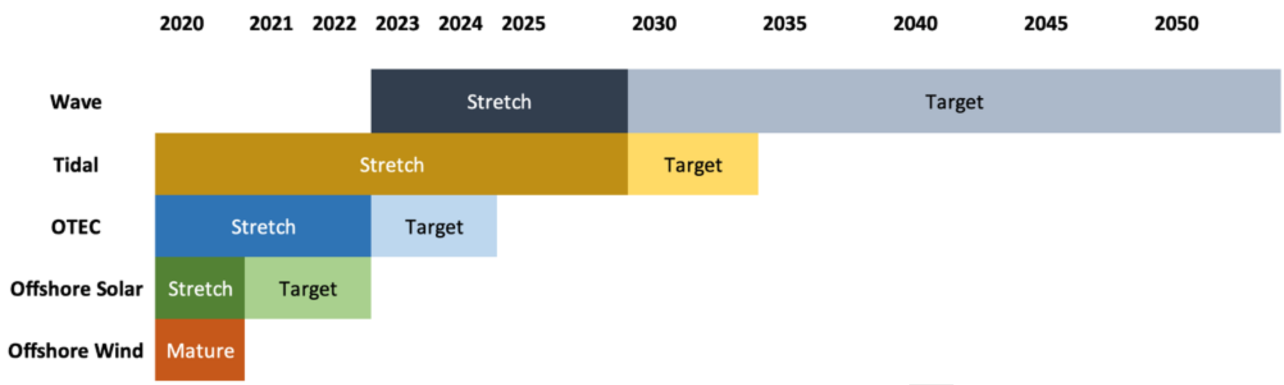


Figure RE24: Marine Renewable Energy Maturity Schedule

These synthesis materials allowed us to formulate a set of recommendations that prioritizes pursing offshore wind technology first, and then moving to address the other technologies in sequence, as they prove themselves in other international markets. We began by calculating a LCOE for 2020 for offshore wind. Building on a 2014 study from University of California, Santa Barbara (UCSB), we calculate the rate to $0.1814/kWh (for full details on calculation, see Appendix RE5).

We then populated an opportunity matrix for offshore wind (Figure RE25) that matches that used for the two other blue economy industries. This matrix allows the reader to compare input factors against one another with favorable conditions noted in green and unfavorable conditions in red. Yellow is used for categories that require caution or have mixed conditions. The matrix demonstrates the potential of offshore wind installation to create jobs, lower electricity rates and move to a cleaner source of energy in Bermuda. Further it will allow Bermuda to increase its independence by reducing importation of fossil fuels. We therefore recommend that Bermuda move forward with the offshore wind component of the IRP by conducting a comprehensive feasibility study with specific goals and steps outlined in the subsequent section.

Category	Criteria	Evaluation*
Economic Impact	Estimated # of Full-Time Jobs Created/MW (Construction Phase)	12-30[clv]
	Estimated # of Full-Time Jobs Created/MW (Operational Phase)	1.2[clvi]
	Bermuda-specific LCOE, Relative to Fossil Fuels	Low (est. $0.1814/kWh)
Energy Demand & Availability	2018 Total Consumption (kWh)	567,827,000[clvii]
	2018 Total Consumption per Capita (kWh)	8,876[clviii]
	2017-2018 Total Growth in Consumption	-2.90%[clix]
	Offshore Wind Share of Caribbean Market	0%
	Local Market Trend	Rapid growth projected[clx]
Potential	Differentiators	Extensive continental shelf, potentially higher wind speeds, relative to other Caribbean nations
	Quality of Infrastructure	Distribution grid in need of upgrade
	Average Wind Speed on Platform (m/s)	8.7
Risk	Resource Viability Risk	Medium
	Technology Risk	Low
	Ability to Withstand Hurricanes	Up to Category 4 (<156 mph wind speeds)[clxi]
	Environmental Impact	Low (EIA to determine/assess this)
Local Interest	Government Interest in Growth	High
	Local Enthusiasm for Offshore Wind	TBD via Feasibility Study

*Please see Appendix G1 for further description of evaluation categories

Figure RE25: Offshore Wind Opportunity Assessment in Bermuda

Recommendations

The recommendations outlined in this section build upon the existing renewable energy capacity increase that is underway through planning initiatives like the Integrated Resource Plan (IRP) and the Department of Energy's biannual Energy Summit. There are two recommendations which we believe will be the most impactful in strategically and efficiently advancing the industry:

- In line with its 2019 Integrated Resource Plan, Bermuda should proceed with the initial implementation steps for a 60+ MW offshore wind farm by conducting a detailed feasibility study containing technical, environmental, economic and political components.
- Capitalize on local marine energy resources by considering wave power and offshore solar PV as components of Bermuda's long-term energy mix. Appoint a committee to monitor technological milestones and collect environmental data in the short-term to confirm potential viability.

Each are described in detail subsequently.

Recommendation #1

Implement Feasibility study of Offshore Wind Farm

In line with its 2019 Integrated Resource Plan, Bermuda should proceed with the initial implementation steps for a 60+ MW offshore wind farm by conducting a detailed feasibility study containing technical, environmental, economic and political components.

The central function of a feasibility study is to identify the potential risks and rewards of a proposed project before substantial capital is committed to the project's development. Not only does a feasibility study tell the procuring party whether a project is viable, it should communicate the constraints and signal economics to prospective developers to inform the competitive bidding process. We recommend the following high-level considerations to the RAB in conducting its first offshore wind feasibility study:[5]

Technical

- Collect meteorological data to determine average wind speed and consistency. To get a conservative estimate, it is generally recommended that, depending on total project size, two to eight meteorological towers be deployed for one to three years.[clxii] The 2014 UCSB Wind Study recommended that this data be collected on the reef to the northeast of the island. There was some speculation expressed by our interview subjects, however that the waters to the west of the island would be more suitable for a wind farm, due to stronger winds and lower viewshed impact due to low population density.[clxiii] It is therefore recommended that Bermuda collect meteorological data at multiple locations for comparative analysis. Alternative to traditional meteorological towers, floating LIDAR stations could potentially be used to capture data at a variety of hub heights and various offshore locations around Bermuda.[clxiv]
- Determine preliminary layout for inter-turbine waking and turbine placement locations, distance to shore and energy production estimate. Wind developers typically leverage this information as inputs for internal financial models.[clxv]
- Consider technical feasibility/turbine selection study and technology options. While large (10+ MW) turbines offer exciting opportunities for future projects, we recognize that Bermuda may not want to take on the risk of serving as a testbed for newer technologies.[clxvi] Given that it generally takes one to three years to conduct a feasibility study, large-scale turbine technology will still be in its relative infancy, so we recommend that Bermuda only consider mature offshore wind turbine technology in the 8 MW and below range.
- Explore different foundation designs. Like large-scale turbines, floating foundations offer more optionality to the worldwide offshore wind market. Though floating platforms are critical to offshore wind on an industry-wide basis, Bermuda's extensive continental shelf yields relatively shallow waters (~20 m) on which traditional fixed-bottom foundations can be constructed. We

[5] Our recommendation embodies prevailing aspects of existing offshore wind feasibility studies, as well as concerns expressed in our interviews with wind energy experts.

therefore recommend that Bermuda pursue one of the more mature fixed-bottom designs, depicted in Figure RE11.

- Explore hurricane resilience (storm surge and induced weather phenomena) and other considerations specific to the Bermuda environment (including corrosive impact of salt water).
- Establish clear guidance on how the project is expected to interconnect to the grid.[clxvii] This is an important determinant of overall cost and will help BELCO both understand the extent of necessary grid upgrades and incorporate them into its existing plan.
- Conduct operations and maintenance study.
- Conduct installation and logistics study.

Environmental

- Conduct an Environmental Impact Assessment (EIA) to assess potential risks posed to avian and fish species. This is an especially important consideration with regards to the Cahow – a critically endangered Bermudian bird species.[6] The Environmental Impact Statement (EIS), the output of the EIA, should address impact both during construction and while the project is operational. See Appendix RE6 for a detailed example of an EIS from Massachusetts's Cape Wind Energy Project.[clxviii]
- Determine water depth and take wave measurements.
- Conduct a seabed analysis to evaluate the suitability of certain technology foundation requirements.
- Evaluate future impacts to meteorological conditions, including wind direction and speed, from climate change.

Economic

- Identify placement constraints from shipping lanes and boating activities and well as economic impact to associated industries. An offshore wind farm in the order of 60-100 MW will likely have at least a temporary impact on other marine-based industries in Bermuda, such as commercial fishing and tourism. It is therefore important to evaluate the magnitude of these impacts before construction begins and include relevant stakeholders in the planning process.
- Forecast costs and revenue. This is critical to determining a project's overall viability and attracting competitive bids.

Political

- Identify regulatory requirements and challenges.
- Solicit local stakeholder input and examine potential community pushback, including considerations pertaining to viewshed impact. At roughly eight kilometers out (as proposed in the UCSB report), an offshore wind farm would be visible on the horizon from the shore. While Bermudians are generally supportive of the introduction of renewable energy, commercial-scale wind projects have been known to spawn NIMBYism.[clxix] Bermuda should be mindful of

[6] Personal Interview: While the EIS will ultimately determine whether wind turbines would adversely impact the Cahow, turbines typically have lower rates of bird collisions than high-rise glass buildings. Birds of prey are disproportionately killed by wind turbines, as they tend to be looking at the ground for prey while flying, instead of straight ahead. Because the Cahow is not a bird of prey, it can be reasonably assumed that they would not be at significant risk for turbine collision.
"How Do Wind Turbines Kill Birds?" LiveScience. Purch. Accessed February 23, 2020. https://www.livescience.com/31995-how-do-wind-turbines-kill-birds.html.

this risk and develop a plan to best educate Bermudians on the benefits, challenges and expected impacts of an offshore wind farm.

- Provide a clear delineation of stakeholders involved and how they will be involved in the process moving forward. A strong foundation for this was established through the consultation process in advance of the 2016 Electricity Act.

Recommendation #2

Consider Floating Solar PV Over the Next Decade

After offshore wind, Bermuda should next consider floating solar PV (FPV) as a high potential resource option within the next decade, and with a possibility for both technologies to be implemented together in the same location.

Offshore Solar in Bermuda

Bermuda's 5.095 MW of installed rooftop solar, plus its nearly finished 6 MW of ground-mounted solar at the Airport PV Project collectively demonstrate that solar PV is a viable renewable energy resource on the island. Since the yield for offshore solar is not markedly different from that of terrestrial-based solar, Bermuda should consider installing floating solar panels in parallel to utilizing available land and built environment space for PV installations.

Among the ocean renewable energy options available, offshore solar is technologically most mature following offshore wind. Countries like Singapore and the Netherlands have already demonstrated that offshore solar is a commercially viable technology and have installed offshore solar systems of their own.[clxx] The Seychelles also recently developed a utility scale marine-based FPV which should be reviewed for applicability to the Bermudian context (and is described in greater detailed earlier in the section on Floating Solar).

Floating solar is much younger in its development than offshore wind. Most installations thus far focus on inland locations, whereas Bermuda likely would be considering offshore locations for its installations. As such, it presents higher risk at this current date (2021) but is rapidly evolving such that within the next decade it is likely to have a stronger track record and improve economic viability. Our recommendation is that Bermuda actively monitor these developments.

To minimize spatial impact, Bermuda should consider combining siting for an offshore solar system with that of its anticipated offshore wind farm. The coupling of the two projects would also present an opportunity to reap the benefits of economies of scale by combining the systems' cabling components. There are also potential environmental concerns if the platforms are installed over coral reefs which rely on sunlight to thrive, so the optimal location will need to balance these and other potential benefits and tradeoffs. Other island nations have placed floating solar installations over sandy bottom to avoid this consequence.[clxxi]

Recommendation #3

Maintain Stakeholder Engagement in Monitoring Developing Technologies

Bermuda can further capitalize on local marine energy resources by considering wave power, tidal power, and OTEC as components of the long-term energy mix. Bermuda should maintain a committee to monitor technological milestones and collect environmental data in the short-term to confirm potential viability. This responsibility lies with the Regulatory Authority and the consultative process outlined within the Integrated Resource Plan allows for stakeholder input. The Electricity Sandbox, established in 2020, can be utilized as new technologies are considered and tested within Bermuda's waters.

Bermuda's land constraints pose substantial limitations to terrestrial renewable energy development. In order to preserve Bermuda's agricultural land and optimize the use of its extensive ocean resources, we performed a preliminary evaluation of four emerging marine renewable energy technologies: wave power, tidal power, and ocean thermal energy conversion (OTEC). We examined pilot projects around the world, talked to scientists experimenting with these technologies and compared LCOE estimations. After assembling data across the four resource types and contextualizing it to fit Bermuda, we determined that wave power and offshore solar (discussed above) show promising long-term potential in Bermuda while tidal power and OTEC do not appear to be economically feasible in the long-term.

Wave Power in Bermuda

In Bermuda, the wave regime pales in comparison to that of the North Atlantic (see Appendix RE7 for global comparison), but after a cursory review, one expert we spoke to believes that the nearby waves' high level of consistency and average height of 5.5 feet make energy extraction possible once wave power technology matures.[clxxii] Additionally, unlike other renewable energy technologies, a wave power system is not expected to impact protected Bermudian species, such as the Cahow and would likely garner public support, given its minimal viewshed impact.

Though wave power cannot currently compete with other renewable resources, industry experts are optimistic about its eventual scalability. Conservative estimates put commercial viability at 10-30 years out, while ambitious estimates place it at three to five years.[clxxiii] Of all the wave energy pilot programs in development around the world, the Hawaii Natural Energy Institute project serves as the best proxy for Bermuda, given Hawaii's similarity to Bermuda in terms of its consistent wave resource and steep bathymetry.[clxxiv] An alternative proposal was submitted as part of Bermuda's Integrated Resource Plan process in 2019 that focused on wave energy; while this proposal is tailored to the Bermuda context and demonstration projects in other locations are cited, no evidence is given of completed commercial projects.[clxxv]

In terms of costs, Ocean Energy Systems (OES) projects LCOE for the first commercial-scale wave project to be \$0.12-\$0.47/kWh. This is higher than that of more mature resource types like wind and solar and the large possible range leads to increased uncertainty, but will likely follow the same cost reduction trends over time and make electricity rates on the island more affordable for Bermudians.[clxxvi] Given the favorable environmental conditions in Bermuda, coupled with the uncertainty surrounding the scalability timeline, we recommend that Bermuda take a conservative approach as it monitors economic and technological achievements in wave power. Utilization of the Electricity Sandbox will allow private sector partners to explore feasibility within Bermuda's waters.

Tidal Power in Bermuda

While tidal power exhibits promise for many regions of the world, several industry experts we talked to expressed that Bermuda's tides make tidal energy impractical.[clxxvii] More specifically, the amplitude of tidal constituents around Bermuda are consistently negligible (less than 4-6 knots) with a 2.49 foot average range.[clxxviii] This kind of tidal resource would likely yield significant cost prohibitions. Bermuda's weak currents combined with the uncertainty surrounding the risk of animal collision leads us to recommend that Bermuda abstain from pursuing tidal currents as a generating resource. Although Bermuda's position is quite different from other islands, the Turks and Caicos Islands did come to a similar conclusion when exploring tidal power options in their 2019 Resilient National Energy Transition Strategy.[clxxix]

Ocean Thermal Energy Conversion in Bermuda

The optimal conditions for OTEC are not met in Bermuda year-round, but the summer months meet the twenty-degree difference threshold. A detailed breakdown of the optimum temperature difference is detailed in Figure RE26. Additional investigation into suitable sites may prove to be beneficial, as there are warm water stream jet streams which may bring warmer surface water.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Bermuda[clxxx]	17.8	17.2	17.8	19.2	23.3	25.9	28.4	28.1	26.4	24.2	21.1	18.3
Avg. Deep Ocean Temp.[clxxxi]	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
Difference	13.8	13.2	13.8	15.2	19.3	21.9	24.4	24.1	22.4	20.2	17.1	14.3
OTEC Viable?[7]	NO	NO	NO	NO	NO	YES	YES	YES	YES	YES	NO	NO

Figure RE26: Offshore Temperature Delta[8]

This table demonstrates that the required twenty-degree difference threshold is not met most of the year and therefore Bermuda should not pursue OTEC for electricity production. However there are additional applications of OTEC which may be worth exploring at a smaller scale. This includes sea water-based air conditioning which uses a very similar system design as an OTEC plant, but there is no vaporization (or turbine) within the process so it does not require as great a temperature difference.[clxxxii] An additional benefit of installed OTEC technology (like any other fixed infrastructure

[7] Goal of difference set to twenty degrees based upon the below source:
Finney. Ocean Thermal Energy Conversion. Guelph Engineering Journal, (1), 17 - 23. ISSN: 1916-1107. ©2008.

[8] Analysis completed by UCLA Anderson, utilizing given temperatures and stated optimal temperature difference.

in the ocean) is its ability to serve as a fish aggregation device by attracting fish, which is enhanced by the nutrient circulation resulting from the technology.

Stakeholders for Inclusion

We recommend that the RA include the perspectives of the following stakeholders as it continues to evaluate emerging energy technologies. Each party possesses both a critical knowledgebase and serves a specific function that is pivotal to ensuring the successful implementation of any new energy technology not included in the existing IRP.

Stakeholder	Rationale
Bermuda Department of Energy	As the authority on energy policy in Bermuda, the DOE must be an active stakeholder in every aspect of the evaluation process in order to develop legislation and policies that serve to bolster new technology deployment.
Regulatory Authority of Bermuda	As the curator of the IRP, the RAB is most knowledgeable about how the addition of another energy technology would impact the dynamic of the planned energy mix.
International Technical Experts	Because all prototyping and pilot projects are being conducted overseas, it is critical to engage scientists and technology developers from around the world to best understand the technology types' level of readiness and compatibility with the Bermudian locality. Bermuda would likely find it especially instructive to talk to researchers in parts of the world with environments most comparable to Bermuda, like Hawaii.
BELCO	Bermuda's electric utility is best positioned to convey the required steps for retrofitting the grid to accommodate additional DERs, like wave energy and offshore solar systems.
Other impacted stakeholders as needed	Our report and the BOPP overall are designed to promote a collaborative approach to sustainably and responsibly using ocean resources. In order to meet this standard, we recommend that many community stakeholders, including those involved with commercial fishing and tourism be consulted prior to installation planning for any major offshore marine energy investment.

Figure RE27: Proposed Stakeholders on Review Committee

In various discussions with Bermudian Government stakeholders, we discovered a comprehensive process within the Department of Planning that was designed for a collaborative approach to land zoning and policy. We would recommend utilizing a similar process for marine resource allocation.

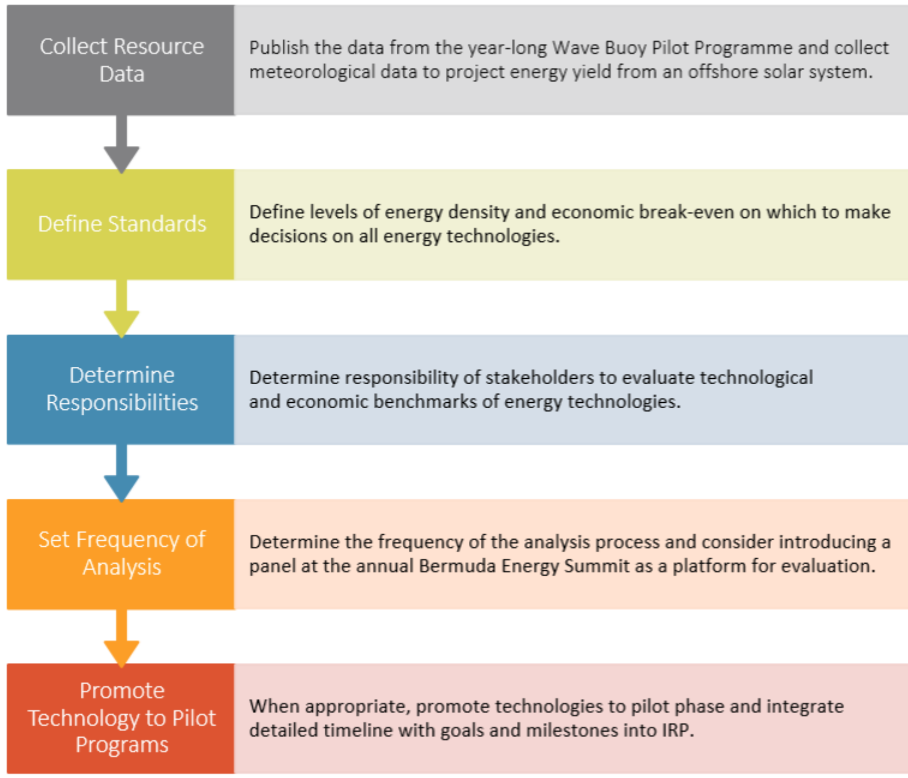


Figure RE28: Proposed Viability Evaluation Process

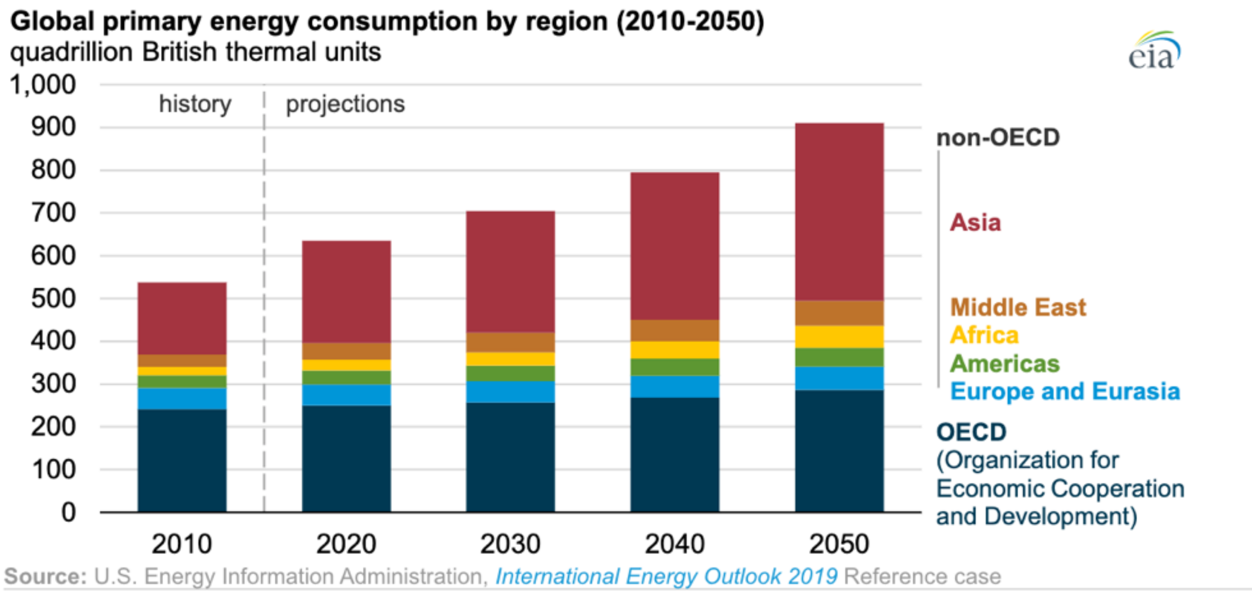
Conclusion

Improvements to Bermuda's energy costs have great potential economic impact for other industries within Bermuda. By investing in renewable energy, Bermuda can create opportunities for cost savings while promoting a responsible, sustainable energy supply that will result in greater Bermudian independence from imported fossil fuels. To grow the renewable energy industry in Bermuda, it is clear from its land constraints that marine-based resources present the most viable opportunities. Of these resources, only offshore wind is currently feasible for Bermuda, however, wave power and offshore solar show promising long-term potential, given Bermuda's natural resources. With time and international investments, these nascent technologies will continue to improve in cost, generating capacity and efficiency. In order to work towards a diversified renewable energy mix, Bermuda will need to broaden the scope of its IRP and consider emerging energy technologies. The implementation of such technologies will allow Bermuda to gain synergies with planned infrastructure upgrades and further optimize marine space by potentially combining the siting and cabling components of two different energy systems. Including active stakeholder participation as new technologies emerge will be critical for sufficient evaluation of renewable energy technologies in the years to come.

This report addresses only the conception consideration of renewable technologies without a closer review of infrastructure siting. A spatial analysis will occur in parallel with future BOPP workstreams related to marine spatial planning.

Appendices

Appendix RE1: Energy Consumption by Region[9]



[9] "Today in Energy." US Energy Information Administration. Accessed February 23, 2020. https://www.eia.gov/todayinenergy/detail.php?id=42342.

Appendix RE2: Cheapest Energy Generation Technology by Country[10]

Cheapest Energy Generation Technology By Country

2014

Coal	Gas	Wind	Solar
Belgium	Algeria	Denmark	
Bulgaria	Argentina	Germany	
Chile	Australia	Uruguay	
China	Brazil		
France	Canada		
Greece	Egypt		
India	Israel		
Indonesia	Mexico		
Italy	Peru		
Japan	Philippines		
Malaysia	Russia		
Morocco	Saudi Arabia		
Poland	U.S.		
South Africa	UAE		
South Korea			
Spain			
Thailand			
Turkey			
U.K.			
Vietnam			

2019

Coal	Gas	Wind	Solar
Indonesia	Algeria	Argentina	Australia
Japan	Belgium	Brazil	Chile
Malaysia	Bulgaria	Canada	Egypt
Philippines	Greece	China	France
Poland	Russia	Denmark	India
South Korea		Germany	Israel
Thailand		Mexico	Italy
Turkey		Morocco	Saudi Arabia
Vietnam		Peru	South Africa
		U.K.	Spain
		U.S.	UAE
		Uruguay	

Note: Reflecting the cheapest benchmark project for each technology and market.
Source: BloombergNEF New Energy Outlook

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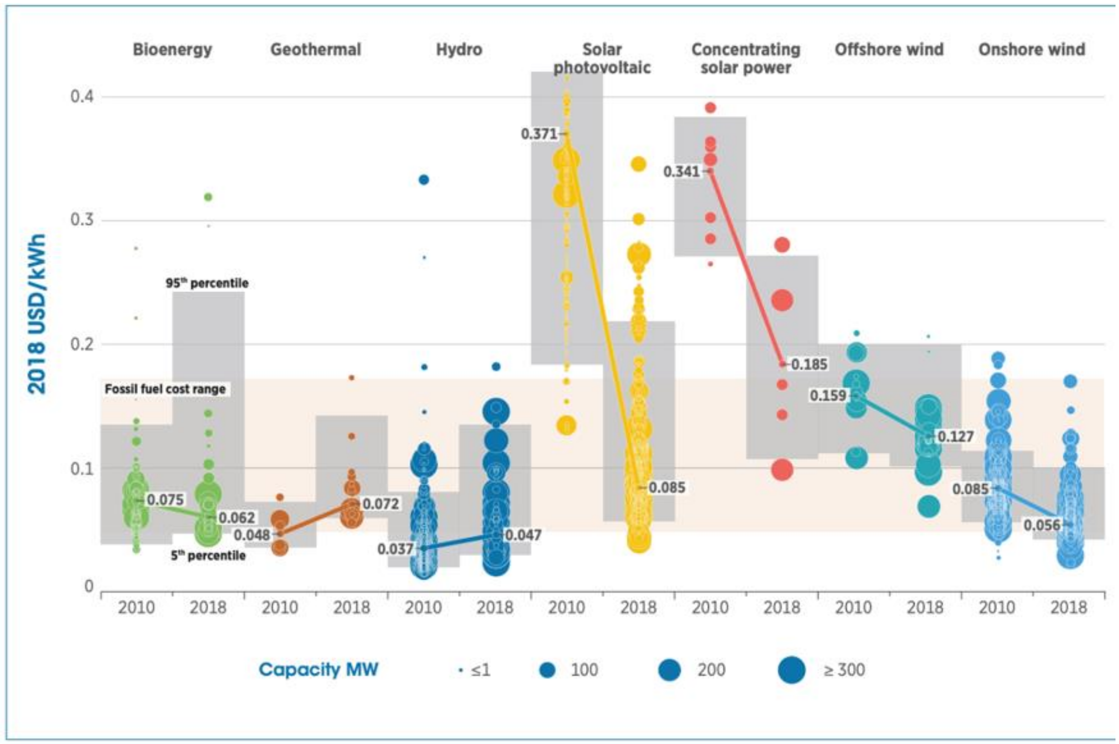
Appendix RE3: Global Levelized Cost of Energy (LCOE) of utility-scale renewable power generation technologies, 2010-2018[11]



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Appendix RE4: Summary LCOE for each Marine Energy Technology, by each Stage of Deployment[12]

Deployment Stage	Variable	Wave		Tidal		OTEC	
		Min	Max[1]	Min	Max	Min	Max
First array / First Project[2]	Project Capacity (MW)	1	3 [3]	0.3	10	0.1	5
	CAPEX ($/kW)	4000	18100	5100	14600	25000	45000
	OPEX ($/kW per year)	140	1500	160	1160	800	1440
Second array/ Second Project	Project Capacity (MW)	1	10	0.5	28	10	20
	CAPEX ($/kW)	3600	15300	4300	8700	15000	30000
	OPEX ($/kW per year)	100	500	150	530	480	950
	Availability (%)	85%	98%	85%	98%	95%	95%
	Capacity Factor (%)	30%	35%	35%	42%	97%	97%
	LCOE ($/MWh)	210	670	210	470	350	650
First Commercial-scale Project	Project Capacity (MW)	2	75	3	90	100	100
	CAPEX ($/kW)	2700	9100	3300	5600	7000	13000
	OPEX ($/kW per year)	70	380	90	400	340	620
	Availability (%)	95%	98%	92%	98%	95%	95%
	Capacity Factor (%)	35%	40%	35%	40%	97%	97%
	LCOE ($/MWh)	120	470	130	280	150	280

[12] "International LCOE for Ocean Energy Technology." OES|IEA. Accessed February 23, 2020. https://www.ocean-energy-systems.org/news/international-lcoe-for-ocean-energy-technology/.

Appendix RE5: LCOE Calculation for Bermuda

In 2014, a team of researchers from the University of California, Santa Barbara (UCSB) published a report that outlined the feasibility of an offshore wind farm in Bermuda. The researchers identified two general regions of the Bermuda Platform that would be most conducive to a wind farm of up to 100 MW, given resource availability, environmental impact and viewshed considerations.[13] Due UCSB report, we assumed the same selected sites in our LCOE calculations

In addition to siting specific locations, the UCSB researchers also calculated a levelized cost of energy (LCOE) of $0.261/kWh,[14] which is substantially lower than the $0.39/kWh rate paid by residential consumers.[15] The LCOE does not take into account the PPA rate that would be negotiated between the wind developer and BELCO, however, given the $0.13 difference between the calculated LCOE and current rates paid by consumers, the UCSB researchers determined that an offshore wind farm would most likely lower prices for Bermudians significantly.

Because several years have elapsed since the publication of the UCSB report, we updated the 2014 calculation to reflect the global 30.5% decline in the global offshore wind LCOE:

Global 2014 LCOE[16] = $190/MWh = $0.19/kWh

Global 2019 LCOE[17] = $132/MWh = $0.132/kWh

Delta = $0.058/kWh = 30.5%

Bermuda 2020 Estimate = $0.261*(1-.305) = **$0.1814/kWh**

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13 Amrhein, Alisan, Gregg, Darrell, Hoang, Tinya, Madhusudanan, Rahul and O'Hara, Casey. "Offshore Wind Energy in the Context of Multiple Ocean Uses on the Bermuda Platform." University of California, Santa Barbara. March 2014. https://www.bren.ucsb.edu/research/2014Group_Projects/documents/BermudaWind_Final_Report_2014-05-07.pdf.

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Appendix RE6: Summary of Environmental Impacts for Cape Wind Energy Project[18]

Table E-1

Summary of Impacts

Resource	**Impacts**	
	Construction Impacts	***Operation Impacts***
Regional Geologic Setting	minor	minor
Noise	*Onshore:* minor *Offshore:* minor *Underwater:* minor	*Onshore:* negligible *Offshore:* negligible *Underwater:* negligible
Oceanography	*Currents:* negligible *Waves:* negligible *Salinity:* negligible *Temperature:* negligible *Sediment Transport:* minor *Water depth/bathymetry:* minor	*Currents:* minor *Waves:* negligible *Salinity:* negligible *Temperature:* negligible *Sediment Transport:* minor *Water depth/bathymetry:* minor
Climate and Meteorology	minor	negligible
Air Quality	*Public Health:* negligible *Visibility:* negligible *Emissions:* minor	*Public Health:* negligible *Visibility:* negligible *Emissions:* minor (beneficial to climate change)
Water Quality	minor	negligible (with the exception of spills)
Electric and Magnetic Fields	negligible	negligible
Terrestrial Vegetation	negligible to minor	negligible to minor
Coastal and Intertidal Vegetation	negligible to minor	negligible (negligible to minor for repairs, depending on location)
Terrestrial and Coastal Faunas other than Birds	negligible to minor	negligible (minor for migratory bats)
Avifauna	*Terrestrial Birds:* Raptors - negligible Passerines - minor *Coastal Birds:* negligible to minor *Marine Birds:* minor to moderate Pelagic Species - minor Waterfowl and Non-Pelagic Water Birds - moderate	*Terrestrial Birds:* Raptors - negligible. Passerines – minor to moderate. *Coastal Birds:* negligible to moderate *Marine Birds:* negligible to major Pelagic Species - minor Waterfowl and Non-Pelagic Water Birds - moderate
Subtidal Offshore Resources	*Soft-Bottom Benthic Invertebrate Communities:* minor *Shellfish:* minor *Meiofauna:* minor *Plankton:* negligible	*Soft-Bottom Benthic Invertebrate Communities:* minor *Shellfish:* minor *Meiofauna:* minor *Plankton:* minor
Non-ESA Marine Mammals	*Acoustical Harassment:* minor *Vessel Strikes:* minor *Vessel Harassment:* minor *Temporary Reduced Habitat:* minor *Turbidity:* negligible to moderate (due to pile driving) *Pollution/ Potential Spills:* minor	*Acoustical Harassment:* negligible *EMF:* negligible *Pollution/ Potential Spills:* minor to moderate *Vessel Strikes:* minor *Vessel Harassment:* minor *Fouling Communities:* negligible to minor

Table E-1 Summary of Impacts		
Resource	**Impacts**	
	Construction Impacts	***Operation Impacts***
Fisheries	*Finfish:* minor *Finfish (juveniles)*: minor *Demersal Eggs and Larvae: minor* *Commercial & Recreational Fishing/Gear:* minor	*Commercial & Recreational Fishing/Gear:* negligible to minor *Sound and Vibration:* negligible to minor *Vessel Traffic:* minor to moderate *EMF:* negligible *Lighting:* negligible/none *Alterations to Waves, Currents, Circulation:* negligible *Habitat Change:* minor *Displacement of Prey:* none
EFH	*Benthic/Demersal:* minor *Water Column:* negligible to minor *SAV/Eelgrass:* negligible to minor	*Benthic/Demersal:* minor *Water Column:* negligible to minor *SAV/Eelgrass:* negligible to minor
T&E	*Sea turtles:* negligible to minor *Cetaceans:* negligible to minor *Avifauna:* negligible to minor *Eastern Cottontail Rabbit:* negligible	*Sea Turtles:* negligible to minor *Cetaceans:* negligible to minor *Avifauna:* minor to moderate *Eastern Cottontail Rabbit:* negligible
Urban and Suburban Infrastructure	negligible to minor	negligible
Population and Economics	minor	minor
Environmental Justice	Negligible (i.e., not a disproportionately high impact on minority or low income populations)	negligible (i.e., not a disproportionately high impact on minority or low income populations)
Visual Resources	minor	moderate Impacts on Shore (Major impacts on-water in close proximity to proposed action)
Cultural Resources	minor	Pending on the outcome of Section 106 process
Recreation and Tourism	minor	minor
Competing Uses of Waters and Seabed	minor	minor (except for impacts to Figawi Race which are moderate)
Overland Transportation Arteries	minor	negligible
Airport Facilities and Aviation Traffic	negligible to minor	minor
Port Facilities and Vessel Traffic	minor	*Ship, Container and Bulk Handling Facilities:* negligible *Cruise Ship Traffic:* negligible *Ferry Operations:* minor *Marinas and Recreational Boating:* minor to moderate *Commercial fishing:* minor to moderate *Search and Rescue:* negligible *Ice:* negligible
Communications: Radar, EMF, Signals, and Beacons	minor	minor (moderate for radar)

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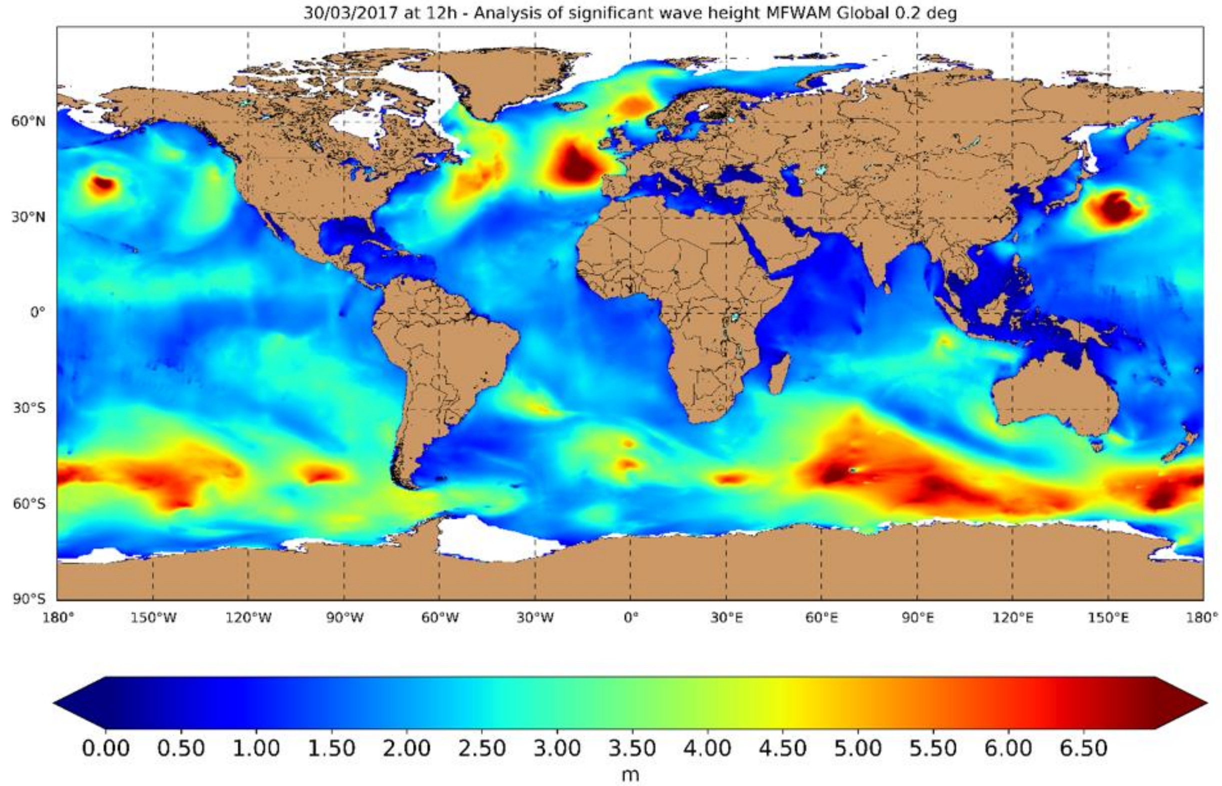
Appendix RE7: Global Wave Heights[19]



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