Renewable energy siting - revised February 2024

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Contents

Introduction

The purpose of this analysis is to find areas of Bermuda's waters that are suitable for further exploration for siting of offshore wind, solar and wave energy systems. Any site that is being considered for siting of renewable energy systems would need a full environmental impact assessment, including surveys of benthic habitat.

This analysis does not consider the routing of cables connecting the renewable energy system to land, which would most likely also require environmental impact assessment due to the high coverage of ecologically sensitive habitats on the Bermuda platform.

The following technologies will be considered:

- Offshore wind (fixed)
- Offshore wind (floating)
- Floating solar PV
- Wave power

Only areas on the Bermuda platform, excluding the Challenger and Argus seamounts are considered. The seamounts are assumed to be too far from land to be economically feasible for energy system installation.

This is a revised version of the report, **February 2024**, using information from the updated literature review by Rocky Mountain Institute and feedback solicited by Sarah Brooks from experts. This version also incorporates minor changes that have been made to proposed zones, and some minor corrections to existing zones, specifically the seasonally protected areas and grouper boxes.

This table summarizes the criteria used for mapping site suitability.

Data	Criteria type	Offshore wind (fixed)	Offshore wind (floating)	Floating solar PV	Wave power
Minimum depth (m)	Suitable area	0	15	2	0
Maximum depth (m)	Suitable area	60	1300	1300	1300
Protected areas	Excluded area	✓	✓	✓	✓
Black grouper and hind spawning aggregations + 1km buffer	Excluded area	✓	✓	✓	✓
Seasonally protected areas	Excluded area	✓	✓	✓	✓
Ferry and shipping lanes + 0.5nm buffer	Excluded area	✓	✓	✓	✓
Submarine cables + 50m buffer	Excluded area	✓	✓	✓	✓
Seagrass index values - upper 50% of values	Excluded area	✓	✓	✓	✓
Coral cover - upper 25% of values	Excluded area	✓	✓	✓	✓
Coral diversity - upper 25% of values	Excluded area	✓	✓	✓	✓
Mapped reef areas (algal vermetid and lagoonal patch reefs) - buffered 100m	Excluded area	✓	✓	✓	✓
Inner horizontal surface - 6.1km radius of airport	Excluded area	✓	✓		
Outer horizontal surface - excluded for turbines above 150m height	Excluded area	✓	✓		
Avian Zones	Excluded area	✓	✓		
Lagoon and nearshore areas	Excluded area				✓
Distance from shore - min. 50m	Excluded area			✓	
Distance from shore - max. 15 km	Excluded area			✓	
Macroalgae >50% cover (remote sensing data)	Excluded area			✓	
Coral cover - lower 75% of values	Suitability index	✓	✓	✓	✓
Coral diversity - lower 75% of values	Suitability index	✓	✓	✓	✓
Wrecks heatmap	Suitability index	✓	✓	✓	✓

Data	Criteria type	Offshore wind (fixed)	Offshore wind (floating)	Floating solar PV	Wave power
Distance from shore - cost of cabling (increases further from shore)	Suitability index	✓	✓	✓	✓
Visual impact - decreasing with distance from shore	Suitability index	✓	✓		
Inside/ outside rim reef	Suitability index		✓	✓	
Levelized cost of energy (LCOE)	Suitability index	✓			

Methods

Depth limitations

Each energy generation technology has different depth limitations. The limits we are going to use are from a literature review by RMI which was updated in July 2023:

Energy generation type	Minimum depth (m)	Maximum depth (m)
Offshore wind (fixed)	0	60
Offshore wind (floating)	50	300
Floating solar PV	2*	1300
Wave power	0	1300

*Floating solar also needs to be at least 50m from the shoreline to account for the surf zone and tidal range. This criteria will be used to define the shallowest depths since this will result in minimum depths greater than or equal to 2m in almost all areas, and because the 2m minimum depth is not accurately mapped.

It is important to note that depth limits vary depending on the technology used for energy generation, e.g. fixed wind monopiles can potentially be installed in depth ranges of 0 - 70m, whereas jackets and tripods are limited to 25 - 60m. Renewable energy technology is developing fast and the depth ranges are constantly expanding.

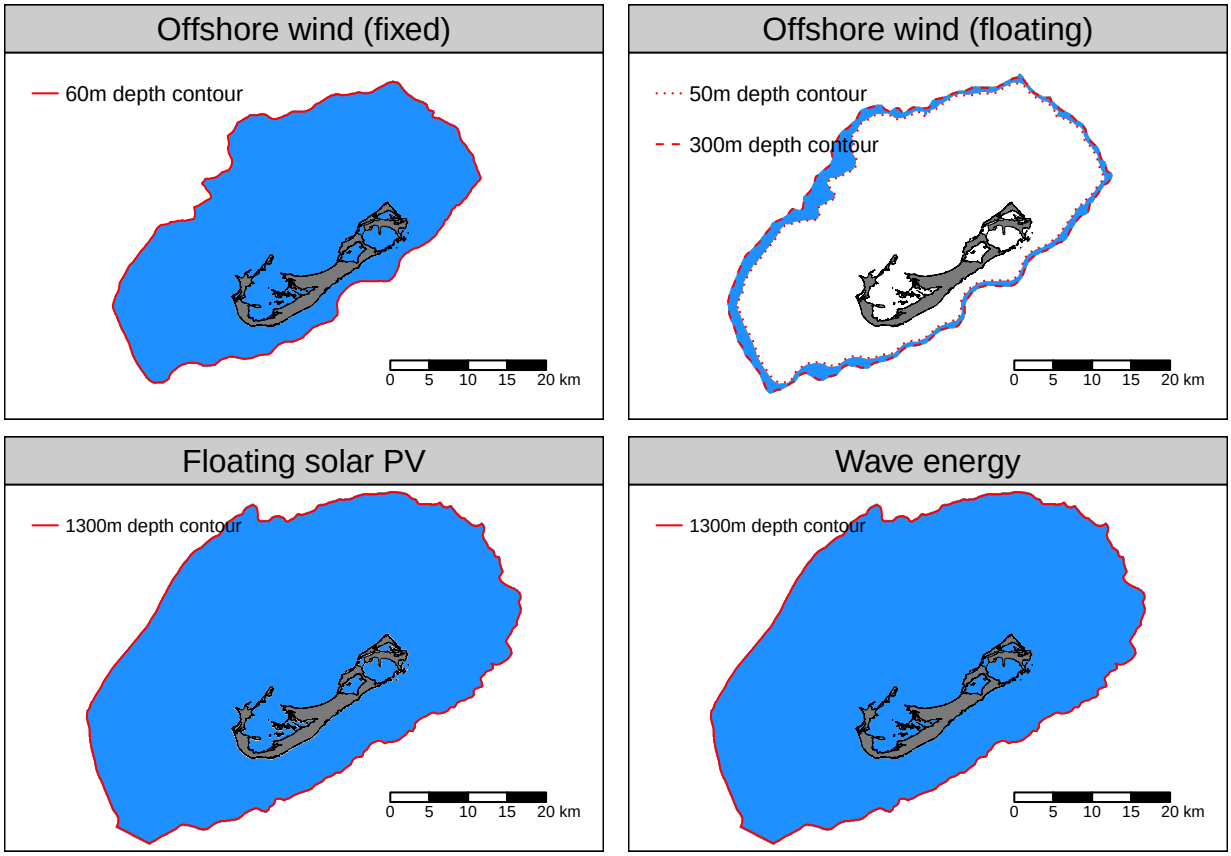

Figure 1: Energy platform installation suitable areas according to depth limitations only.

Floating wind energy is only currently economically feasible and used in the 50 - 300m depth range shown above. However, it should be technically feasible to deploy it in depths as deep as 1300m.

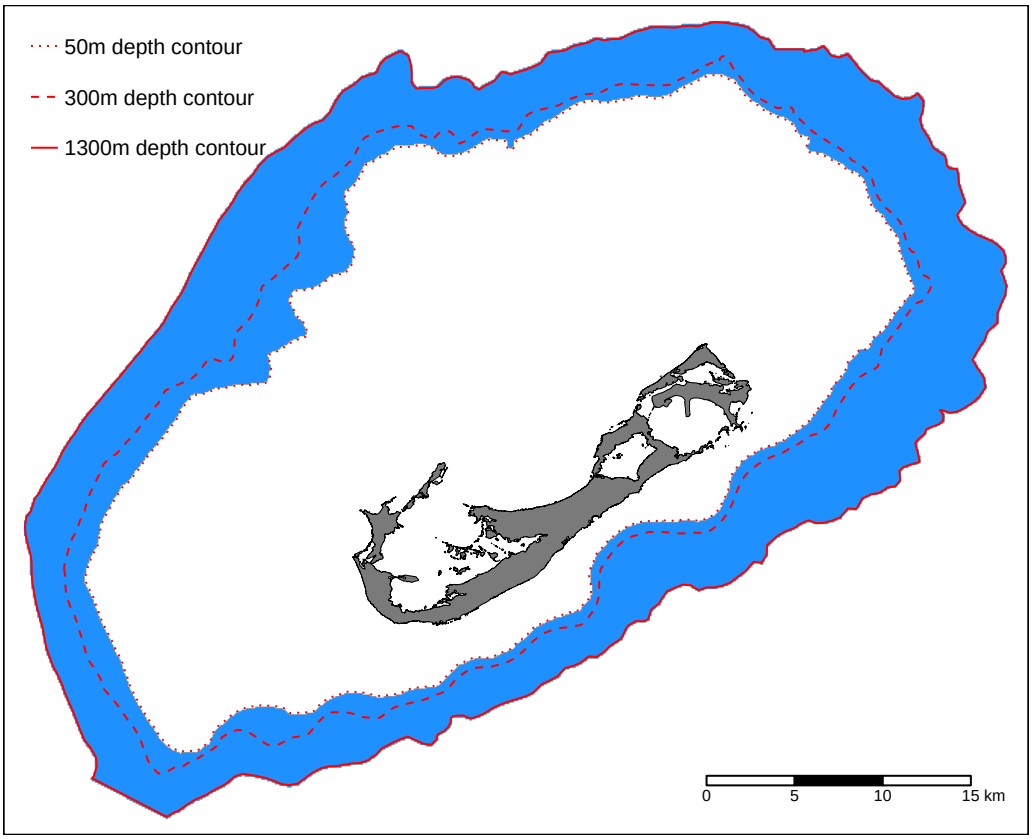

Figure 2: Floating offshore wind depth limits that are technically feasible for installation

Areas excluded

The following areas are not suitable for the siting of any energy platforms.

Proposed MSP zones

Under the most recent MSP proposals (as of 13 December 2023) the renewable energy installations will be prohibited in some areas.

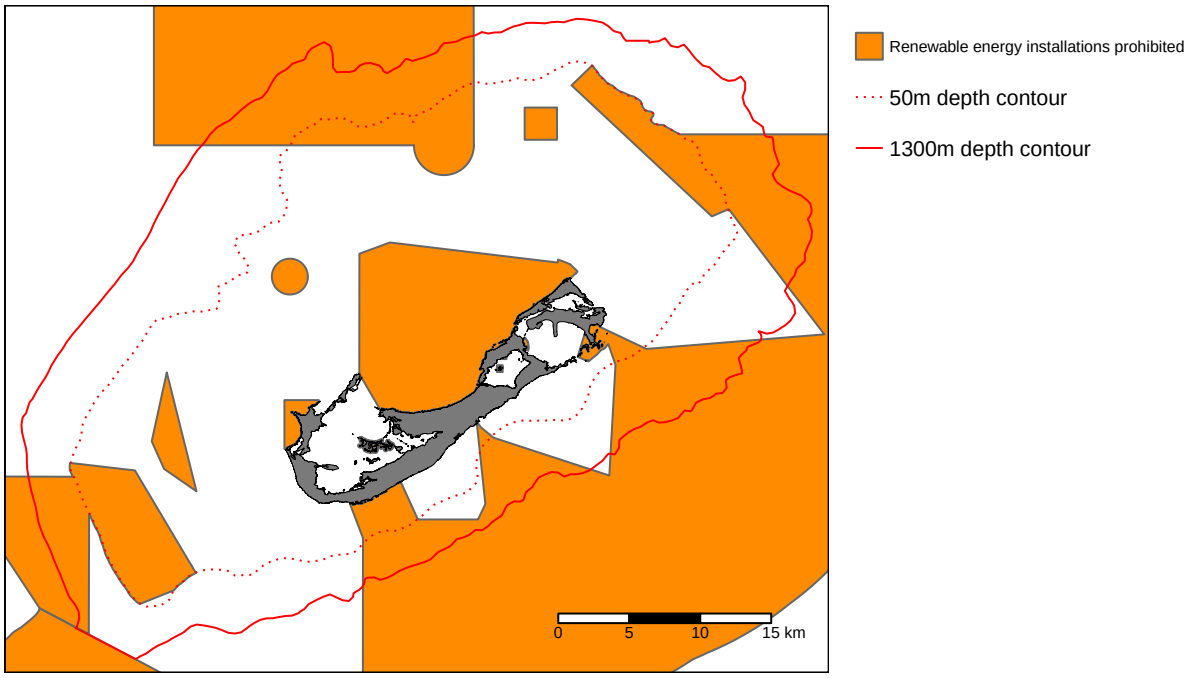

Figure 3: Proposed areas where renewable energy installations would be prohibited

Protected areas

Areas that have some protection would not be suitable for energy platform siting as the installation and operation of the platform would disturb or destroy the habitats and species that are protected.

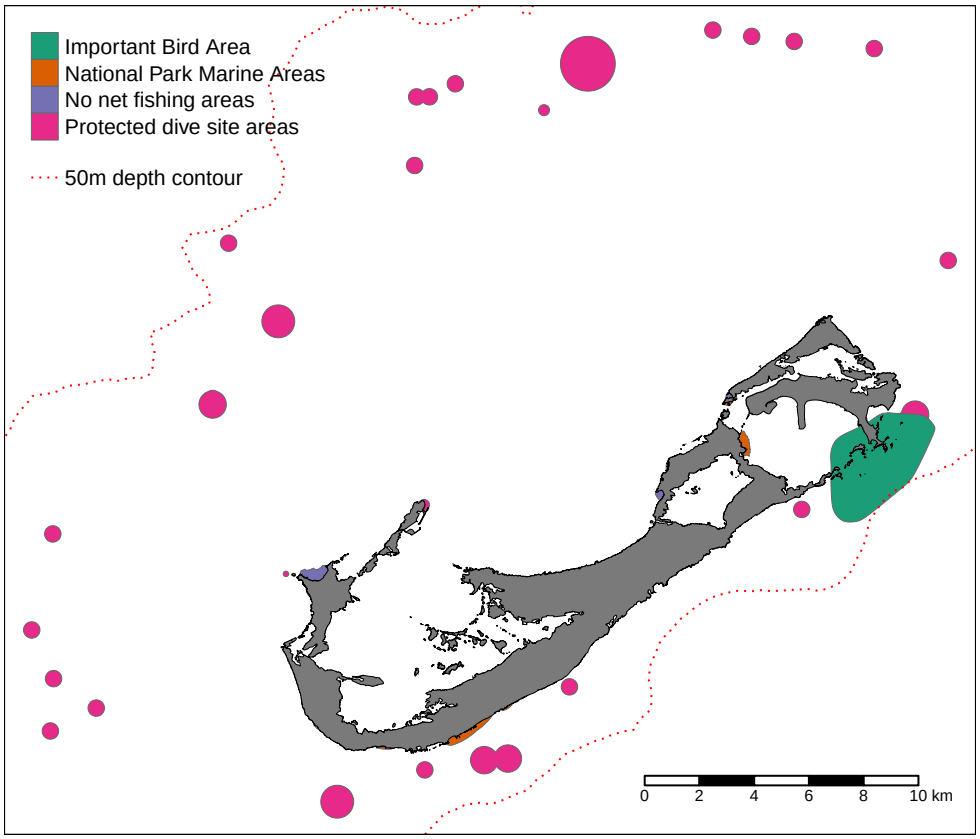

Figure 4: Protected areas to be excluded as suitable areas for energy platform siting.

Spawning aggregation sites and seasonally protected areas

Installation and operation of energy platforms in spawning aggregation areas could have significant impact on fish populations using those sites. To minimize this impact, and given that there are so few known grouper and red hind spawning aggregations in Bermuda, these areas and and the surrounding area to a distance of 1km will be excluded as suitable area for energy platforms.

In addition, the Seasonally Protected Area (see map) will also be excluded as suitable areas for energy platforms. This exclusion criteria has support from both the Department of Environment and Natural Resources and the Regulatory Authority.

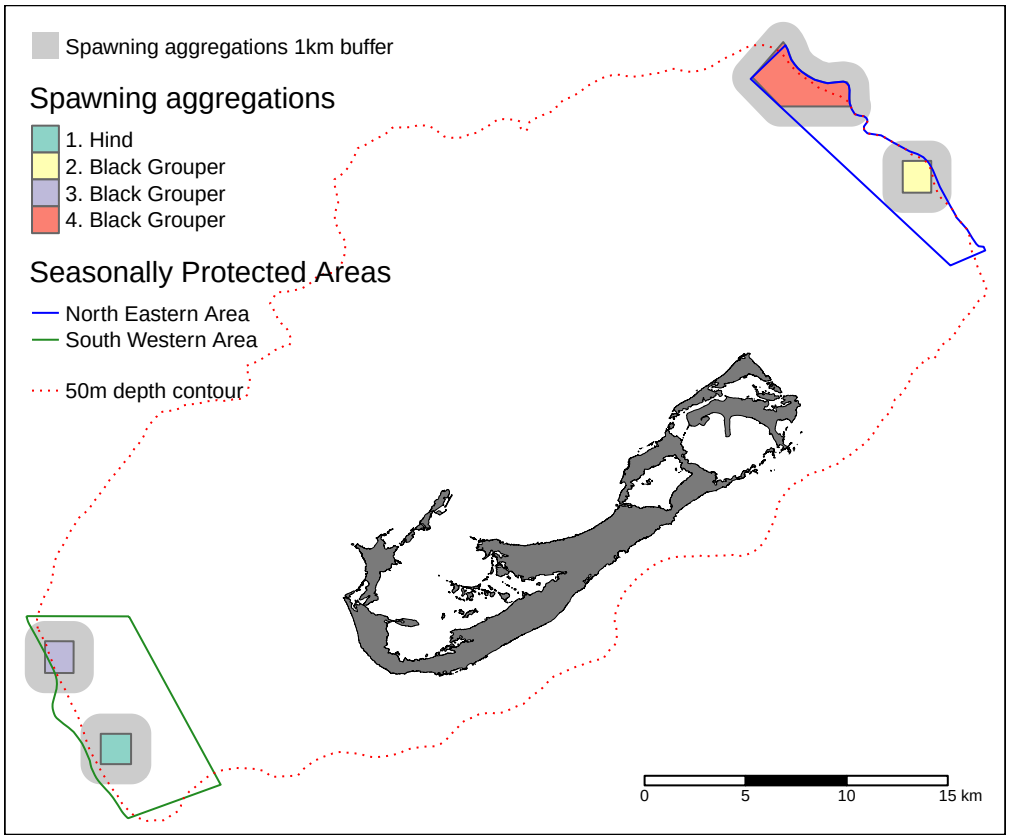

Figure 5: Fish spawning aggregation areas, buffer zone to 1km and seasonally protected areas.

Shipping and ferry lanes

Above water and even below water energy platforms are likely to be incompatible with shipping lanes. The shipping lanes were buffered to a distance of 0.5 nm, i.e. areas within 0.5 nm (926 metres) of the shipping lanes are considered unsuitable for energy platform installation. The 0.5 nm distance was chosen using information in a UK Maritime and Coastguard Agency Marine Guidance Note (MGN 543). 0.5 nm is the minimum tolerable distance of a wind turbine boundary to a shipping route (range of distances is 0.5nm - 3.5nm). Note that we are not taking into account the width of the shipping route, which should also be considered, but is dependent on the sizes and numbers of vessels using the shipping lanes, as well as other considerations.

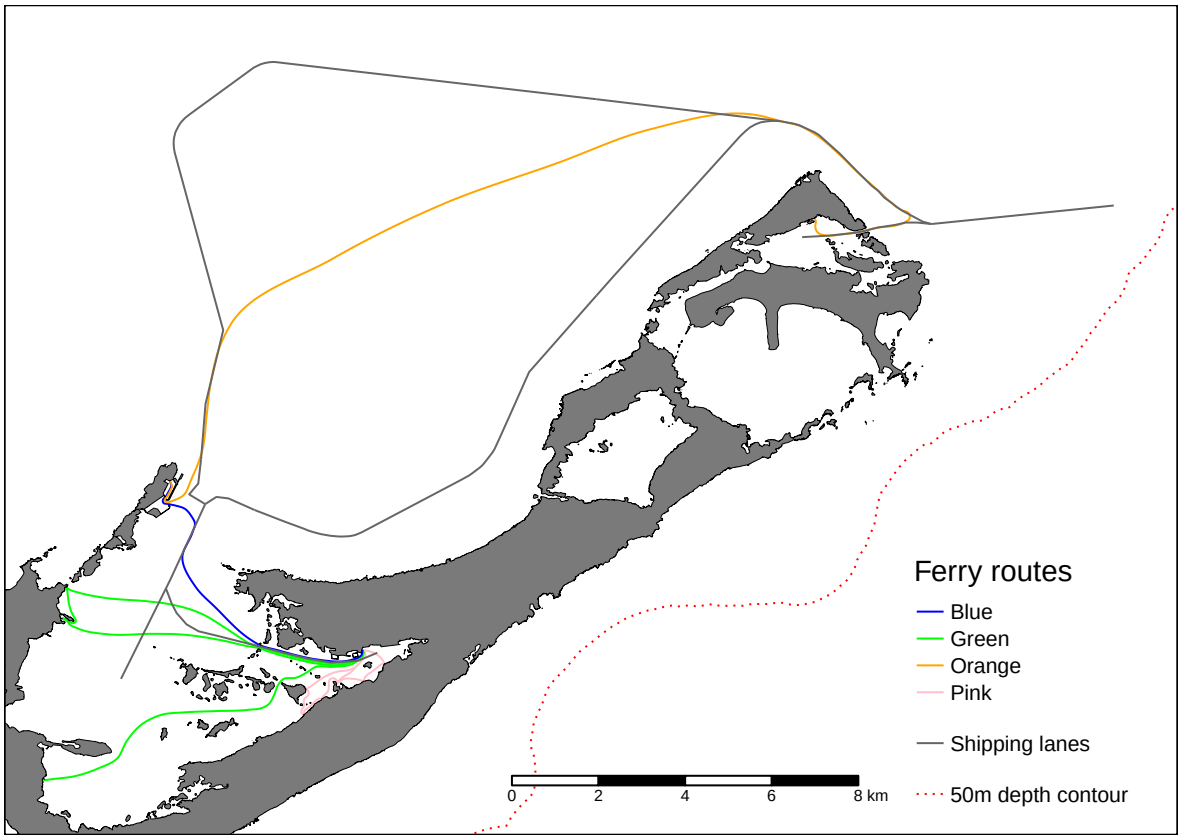

Figure 6: Shipping and ferry lanes

The Orange ferry route is not used, so was not used in this analysis.

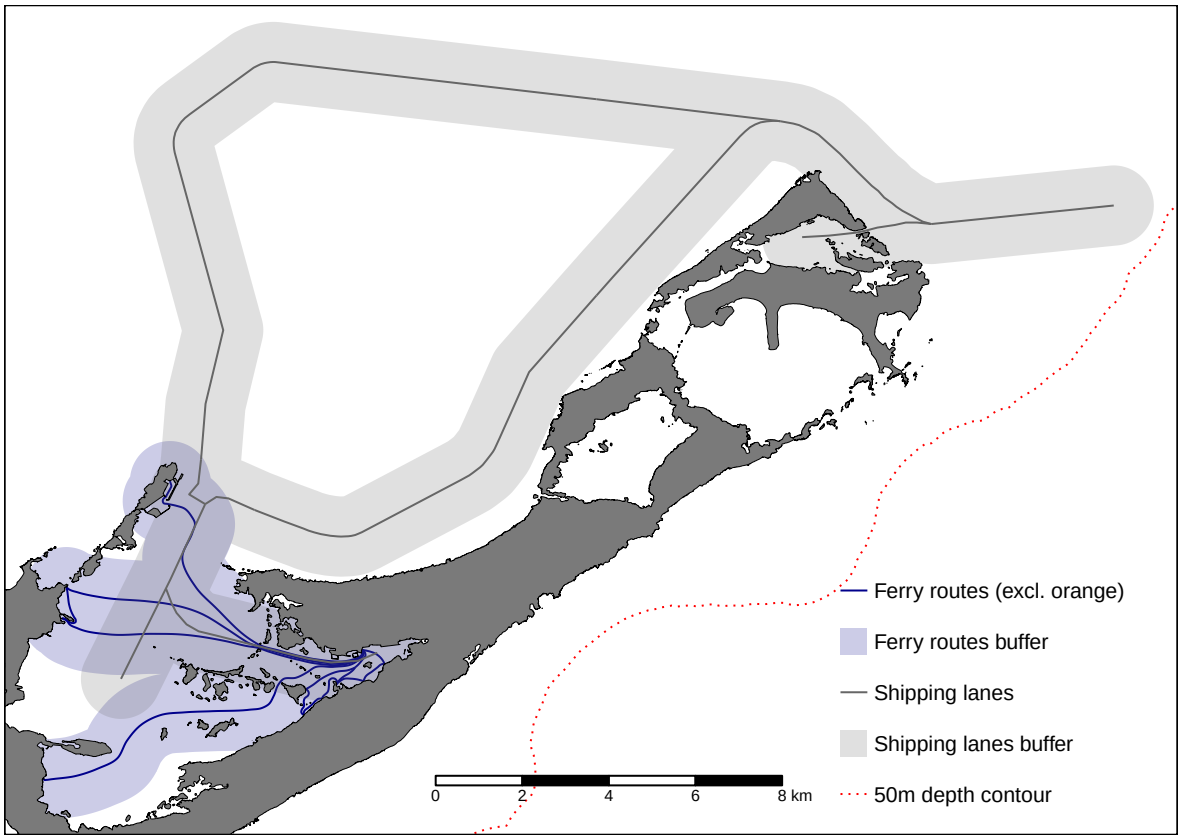

Figure 7: Shipping and ferry lanes buffered; not suitable for energy platform siting

Submarine cables

Areas where existing cables are laid are assumed to be unsuitable for energy platforms due to the need to access them and the potential for damaging them during platform installation. All cables were buffered to a distance of 50m to avoid a platform being placed too close, i.e. areas to 50m distance around cables excluded as suitable area for energy platform siting.

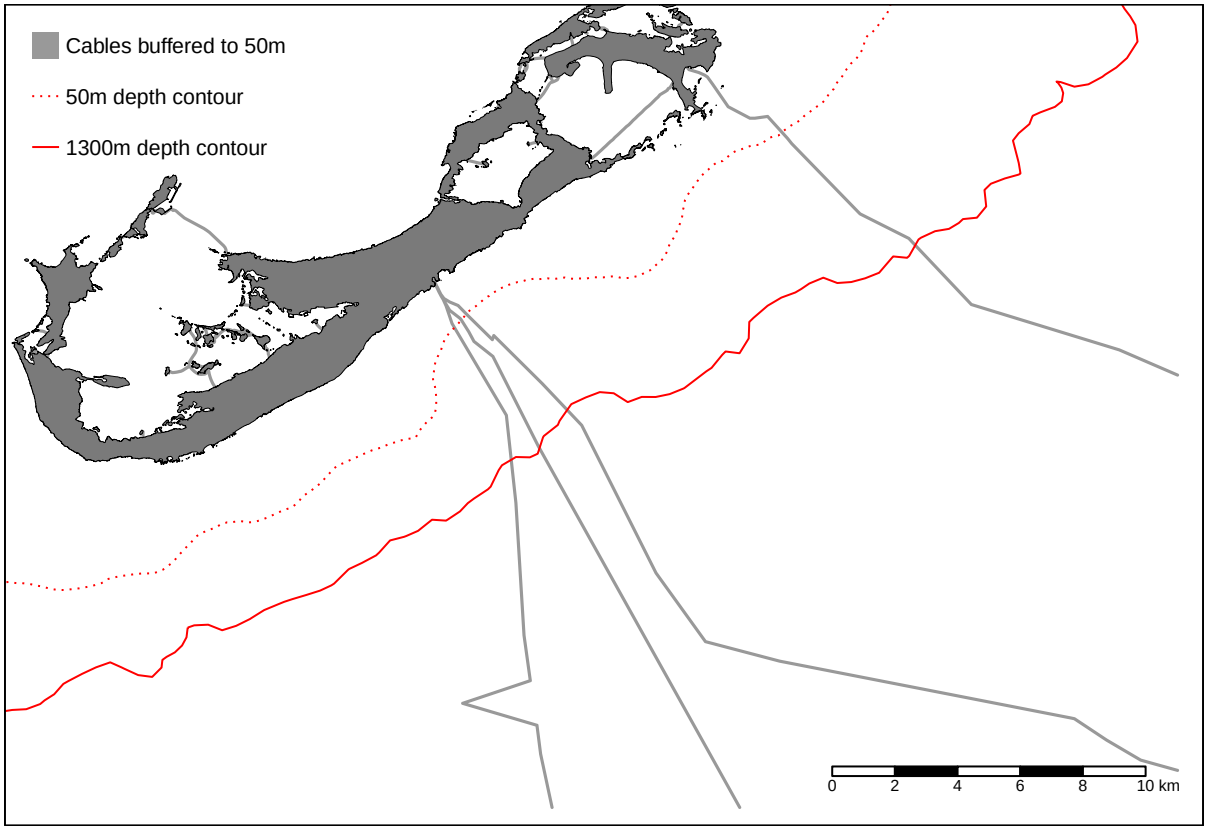

Figure 8: Submarine cable areas to be excluded as suitable areas for energy platform siting

Fishing

Wind and solar energy platform installation areas will likely become inaccessible to fishers due to the hazards associated of navigating near the platforms. Wave energy platforms may not be so restrictive in terms of access since they are submerged, however, the operation of the wave turbines is likely to interfere with fish populations.

Following comments from the Steering Committee and other stakeholders, fishing data were **not** used to exclude areas as being suitable for energy platform installation. This was because there were concerns the fishing heatmaps were not accurate for some areas, and the energy installations areas may not need to be off-limits to all fishing activity.

Before any renewable energy project is approved, a full impact assessment should be done to evaluate the potential impacts on fishers and other ocean users.

Sensitive habitats

Seagrass Placing structures on seagrass will destroy the habitat. Given the considerable loss of seagrass in Bermuda, the conservation and restoration of the remaining areas is of high importance. Using the seagrass index that was created for the prioritization (see separate document for methods on how this was created), we will assume that the top half (50%) of seagrass index values are areas that are not suitable for energy platform siting. These are areas where seagrass is most likely to be found based on the data we have available. The remaining values will be re-scaled 0 to 1 and used in the index of site suitability.

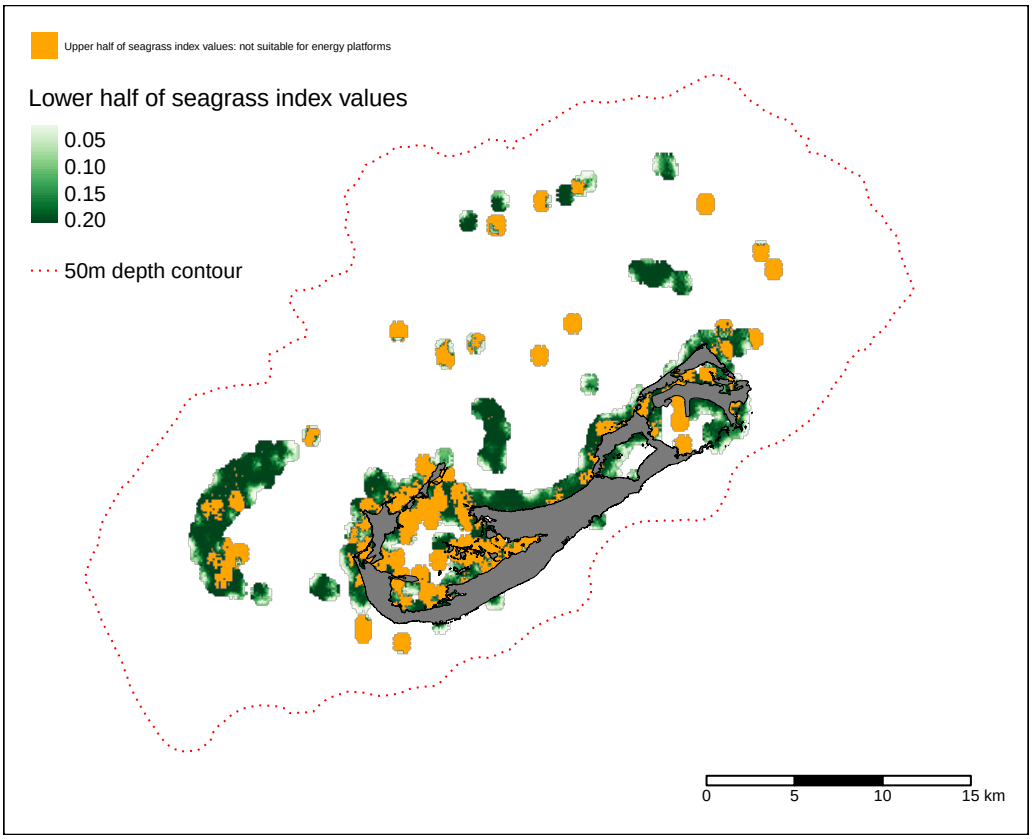

Figure 9: Seagrass areas

Coral

Coral cover As with seagrass, placing structures on coral will destroy habitat. However, there may be space between reef patches that is suitable for attaching structures. We will therefore assume only the upper 25% of coral cover values are unsuitable for energy platform siting. The remaining 75% of values will be used in the index of site suitability. Data is from Bermuda Reef Ecosystem Analysis and Mapping Programme (BREAM) and has been interpolated.

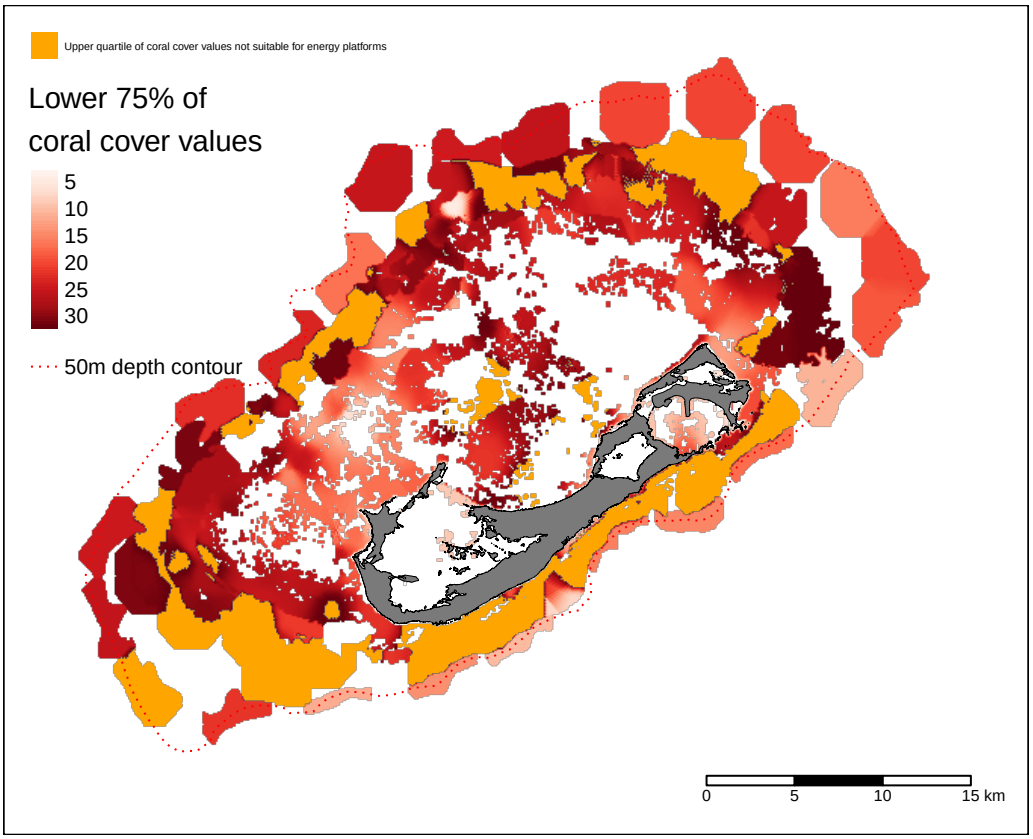

Figure 10: Coral cover

Coral diversity (species richness) We will also assume that high diversity (number of coral species) areas will want to be avoided, so the upper 25% of coral diversity (species richness) values are classified as unsuitable for energy platform siting. The remaining 75% of values will be used in the index of site suitability. Data is from Bermuda Reef Ecosystem Analysis and Mapping Programme (BREAM) and has been interpolated.

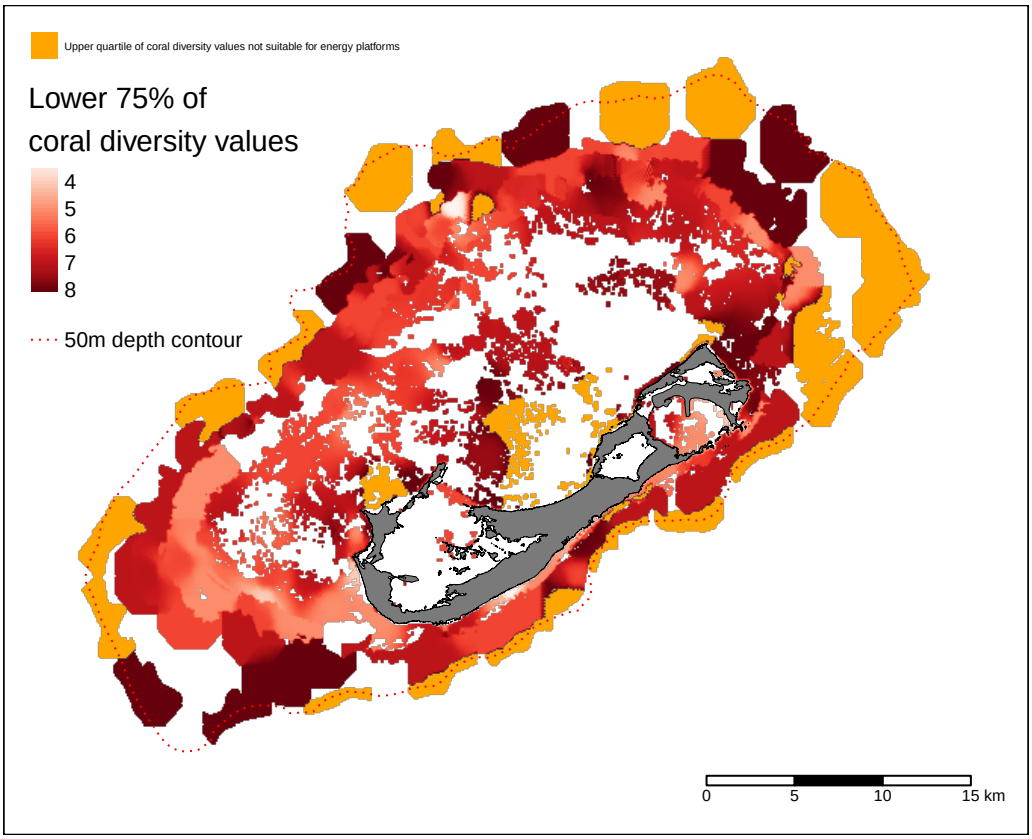

Figure 11: Coral diversity (species richness)

Patch reefs Where locations of patch reefs are accurately mapped, these, and the area around them to distance of 100m, should be excluded as locations available for siting. Patch reefs were mapped by Dr Murdoch using satellite imagery and so are only available for shallow areas where reefs are visible in the images.

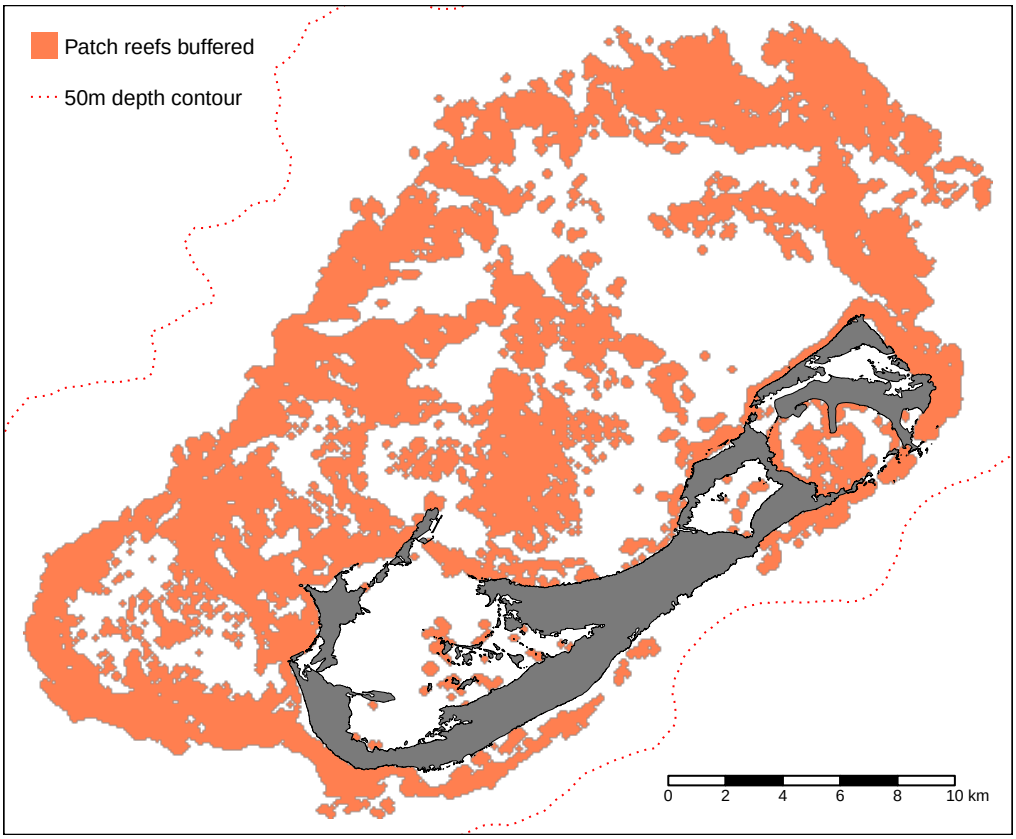

Figure 12: Patch reefs and 100m area surrounding them.

Wind energy specific criteria

Airport obstacle limitation surfaces

Exclusion areas The inner horizontal surface and the airport approach surface sections 1 and 2 (see map) will be treated as excluded areas for wind energy platforms due to the restrictions on structures within these areas.

The inner horizontal surface is defined in the Bermuda Plan 2018 as: "Surface is contained in a horizontal plane at an elevation of 50.5m. The outer limit of the surface is formed by circles of radius 4000m centered on each end of the runway strip, and joined by common tangents parallel to the runway centerline to form a racetrack pattern."

There are 3 sections to the approach surface, extending out a total distance of 15km from the runway strip ends. Definitions from the Bermuda Plan 2018:

- Approach surface section 1: "Commencing at both ends of the runway strip from an elevation of 18 feet; inner edge length 280 m diverging at a rate of 15% on either side; surface extends to a length of 3,000 m from end of runway strip with a slope of 50:1 or 2%"
- Approach surface section 2: "Commencing at the end of the Approach Surface Section 1 in both directions of the runway; inner edge length diverging at a rate of 15% on either side; surface extends to a length of 3,600 m from end of Approach Surface Section 1, with a slope of 40:1 or 2.5%"

- Approach surface horizontal plane: "Commencing at the end of the Approach Surface Section 2 in both directions of the runway; inner edge length diverging at a rate of 15% on either side; surface extends horizontally to a length of 8,400 m from end of Approach Surface Section 2"

Using these definitions the approach surfaces have been mapped (see separate Methods document "Airport Control Zones"). We can calculate the start and end heights of each approach surface:

Surface	Start height (m)	End height (m)
Approach surface section 1	5.5	65.5
Approach surface section 2	65.5	155.5
Approach surface horizontal plane	155.5	155.5

Since most commercial wind turbines are more than 150m tall, approach surfaces sections 1 and 2 are not suitable for wind turbine placement.

Height restricted areas The outer horizontal surface is defined in the Bermuda Plan as: "150 m above aerodrome elevation within a radius of 15,000 m of the centre of the airport for Code number 3 or 4 runway"

The construction of any structures above 150m in height is forbidden within the outer horizontal surface, which rules out many of the commercially available offshore wind turbines. Similarly, the approach surface horizontal plane, which is 155.5m high, would not be limited in the types of wind turbines that could be placed there.

Full details of how the inner and outer horizontal surfaces were created is available in a separate methods document.

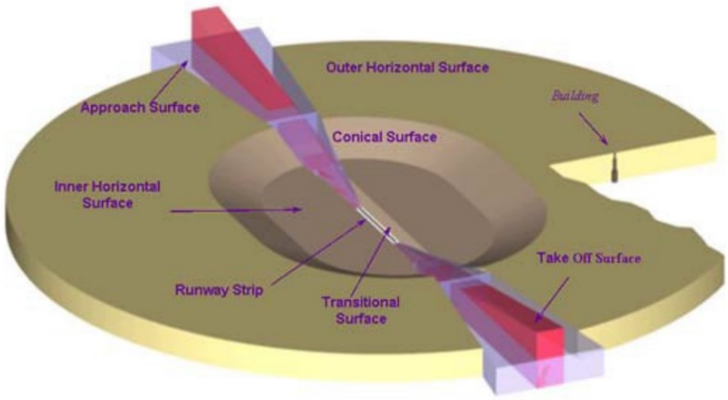

Figure 13: Obstacle limitation surfaces.

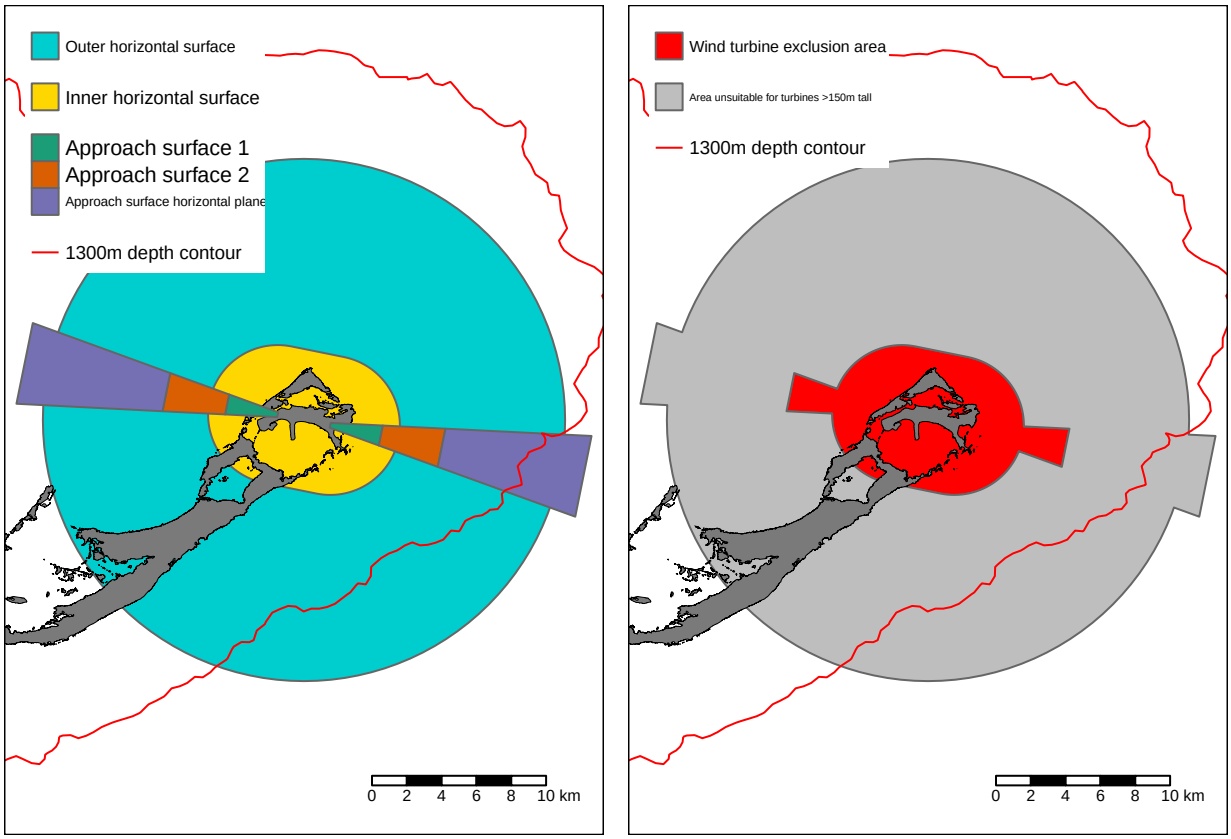

Figure 14: Airport horizontal surfaces. Inner horizontal surface is unsuitable for wind turbines. Outer horizontal surface cannot have structures over 150m in height, which rules out most commercially available wind turbines. For the purposes of this analysis, the entirety of the approach zones were categorised as unsuitable for wind turbines.

Avian zones

These areas come from a BREN School of Environmental Science and Management student project report, Offshore wind energy in the context of multiple ocean uses on the Bermuda platform, and were identified by the Department of Conservation Science as important for courtship activity, food foraging and nesting access. Following the approach in that study, these zones are excluded as potential areas for wind energy siting.

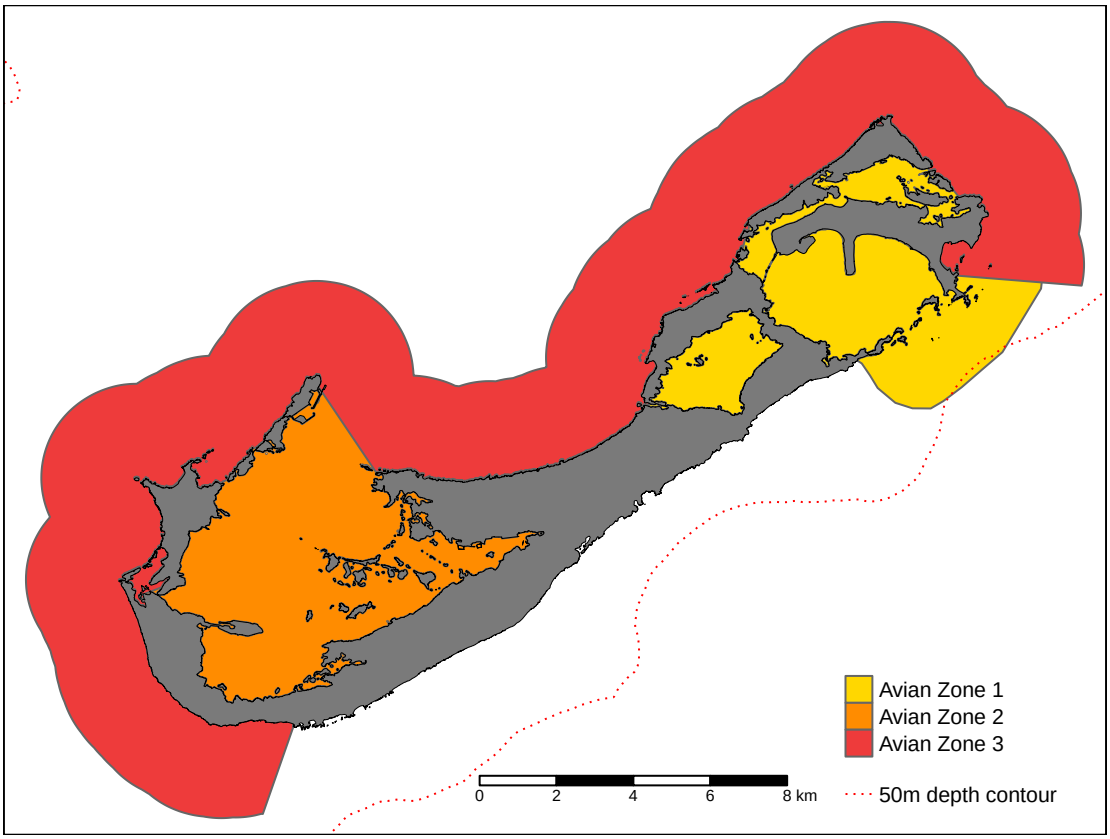

Figure 15: Avian Zones; not suitable for wind energy platform siting

Visual impact

The visual impact of wind turbines diminishes as a function of distance to shore as quantified in Sullivan et al. 2013 (see Figure).

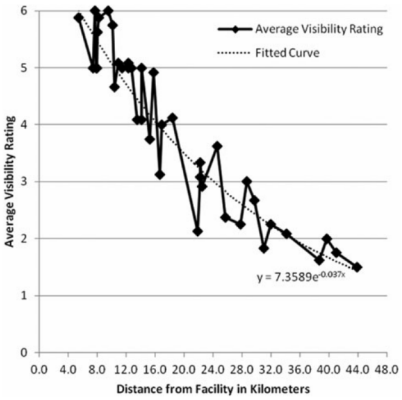

Figure 8. Offshore wind facility visibility-distance curve for 39 daytime observations of 11 offshore wind facilities in a variety of lighting conditions. The average visibility rating (y-axis) decreases as a function of increasing distance from the facilities (x-axis).

Figure 16: Offshore wind facility visibility-distance curve (Figure from Sullivan et al. 2013)

Within this paper, they further suggest the following visual impact categorization based on distance from shore:

- 0 - 8km: High
- 8 - 13km: Moderate
- 13 - 24km: Low
- 24km and above: Insignificant

Potential wind turbine locations will have a site suitability criteria overlaid using this categorization.

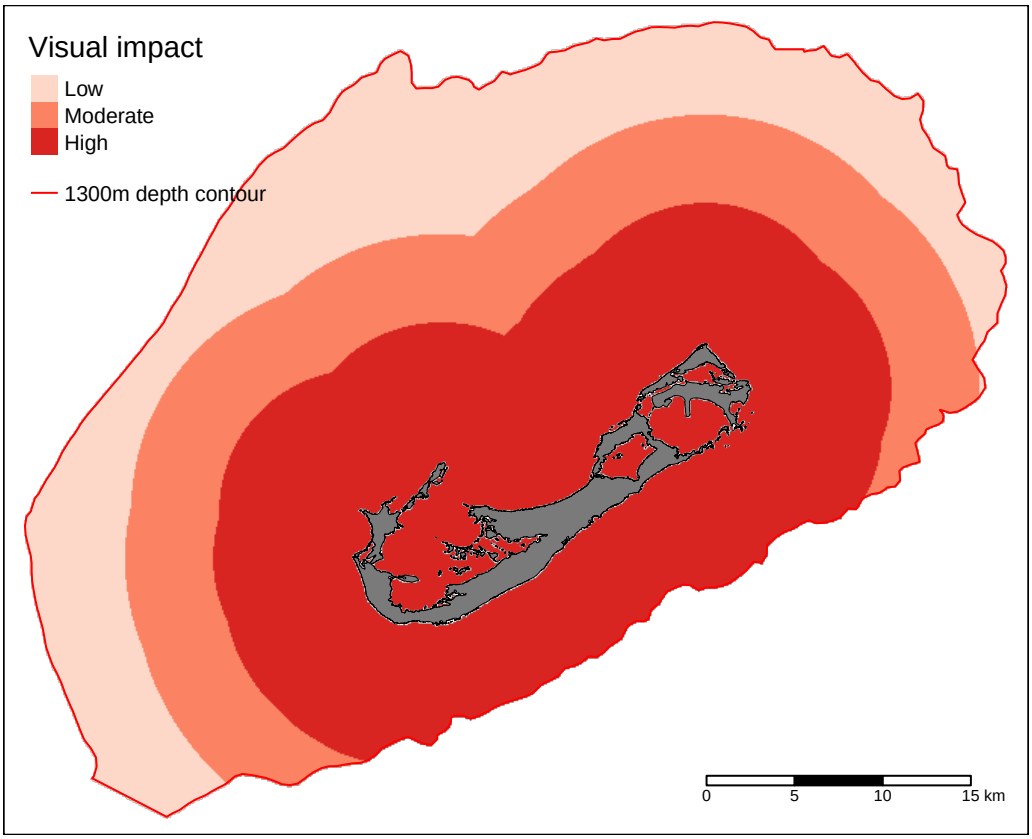

Figure 17: Map of relative visual impact of wind turbines.

Levelized Cost of Energy (LCOE) - fixed wind only

A map of the Levelized Cost of Energy (LCOE) for fixed wind energy technology was provided by BVG Associates and Greenrock. A full report detailing the methods of the LCOE calculation is available via this link: https://www.greenrock.org/projects/offshore-wind

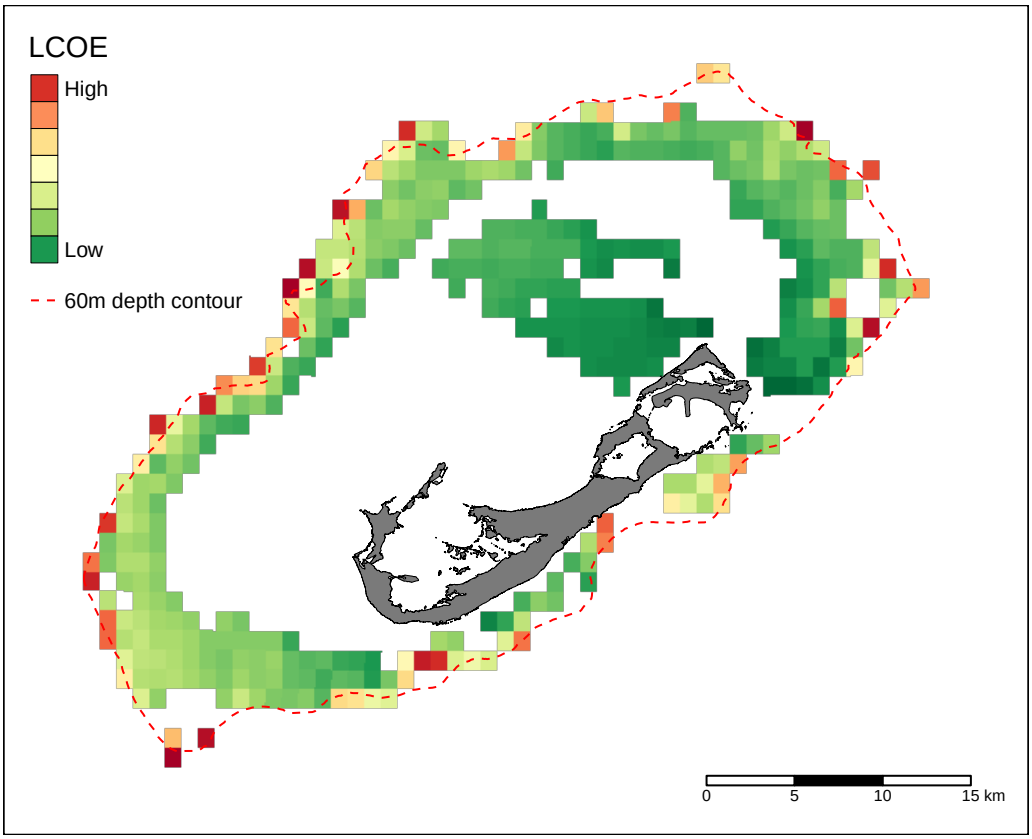

Figure 18: Levelized cost of energy (LCOE) for fixed wind energy (Data from BVG Associates)

Floating solar energy specific criteria

Maximum distance from shore

Maximum current operating distance from shore is 15km, so any areas beyond this distance will be excluded.

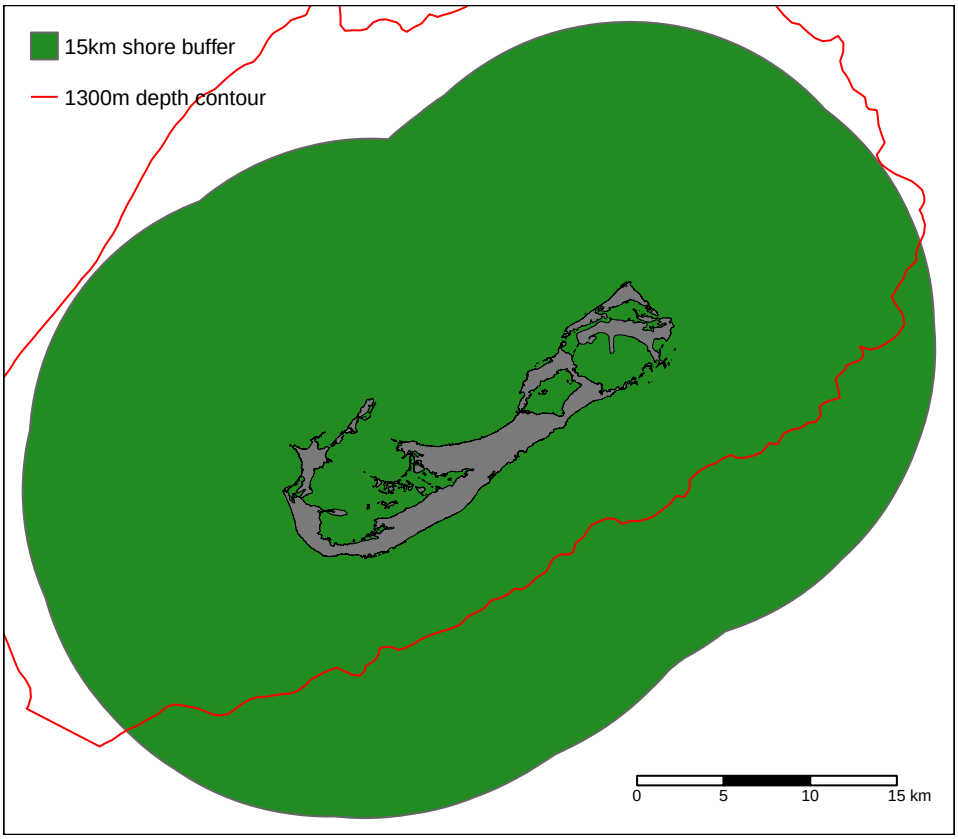

Figure 19: Area within which solar energy platforms must be placed.

Photosensitive habitats

To avoid placing floating solar panels over photosensitive habitats, which could be severely impacted by shading, high macroalgae cover areas will be excluded. These are defined as any area with over 50% macroalgae according to remote sensing habitat data provided by Dr Eric Hochberg. This is in addition to the exclusion of patch reefs and the areas around them to 100m, which is done for all technologies.

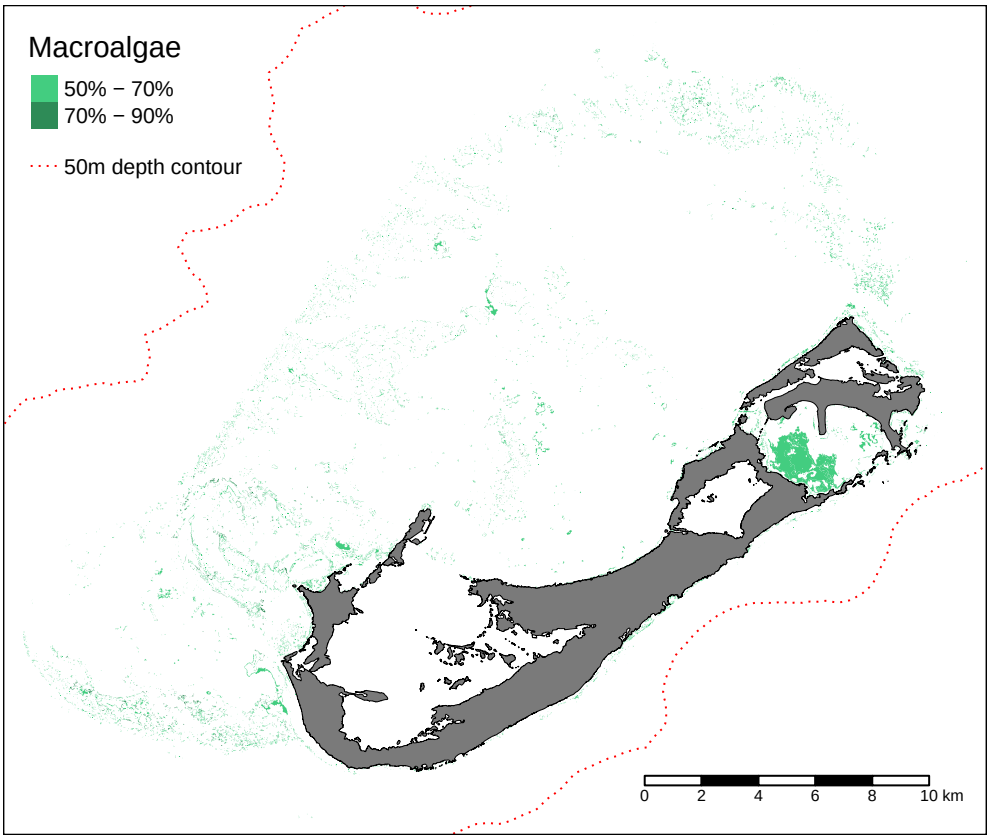

Figure 20: Photosensitive areas unsuitable for solar energy platforms

Wave energy specific criteria

Suitable wave energy

Wave energy installations need a suitable amount of water movement to function. Therefore areas which are highly sheltered, such as bays and lagoons will likely be unsuitable sites. All habitat zones (see map) within the rim and main terrace reef will therefore be excluded as suitable areas for wave energy:

- bays and coast
- Madracis reef
- Montastraea reef
- Diploria-Porites reef
- Castle Harbour Madracis
- Algal Vermetid reef

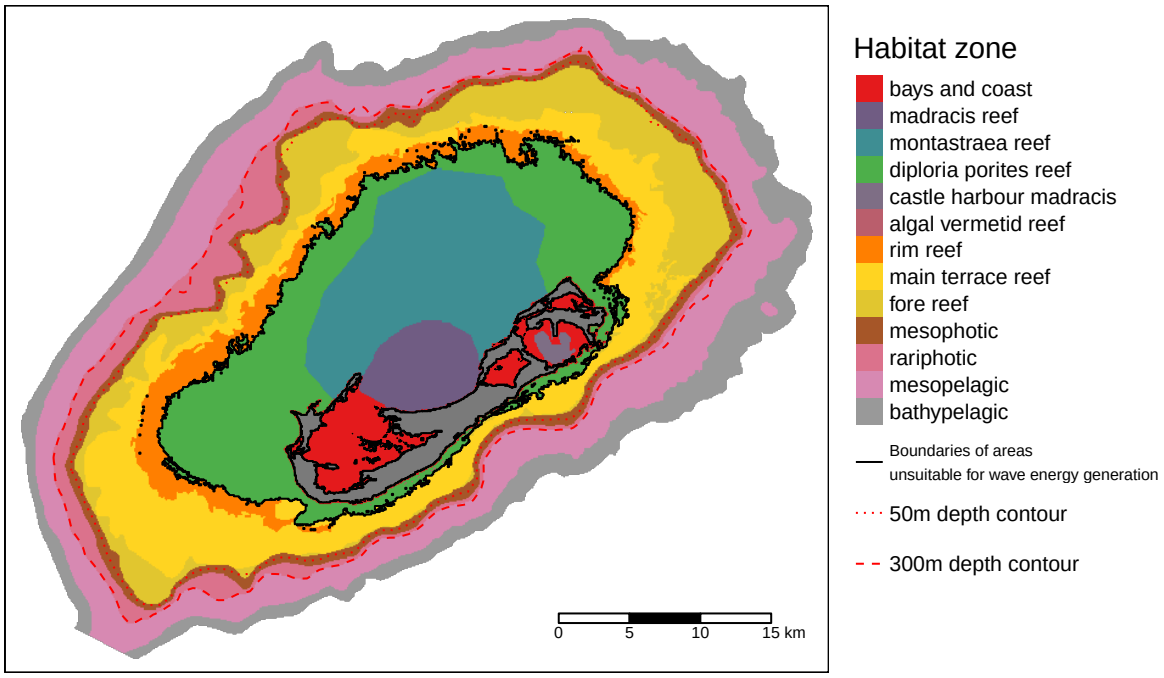

Figure 21: Habitat map showing the lagoon and nearshore zones not suitable for wave energy platform siting

Floating technology specific criteria

For floating wind and floating solar, areas inside the rim reef are suitable, and areas outside only partially suitable. This is based on the literature finding that the maximum wave height before catastrophic failure is 17m for floating wind, and 13m for floating solar. Bermuda Weather Service wave forecast data for outside Bermuda's reef is:

- An average annual wave forecast height of 5.5ft (1.7m)
- A maximum mean wave forecast height of 12ft (3.7m)
- An absolute highest forecast height of 35ft (10.7m)

Although technology has been demonstrated to withstand waves of over 10.7m (which is the maximum forecast wave height for outside Bermuda's reef according to Bermuda Weather Service), the optimal wave height for these technologies is 0m.

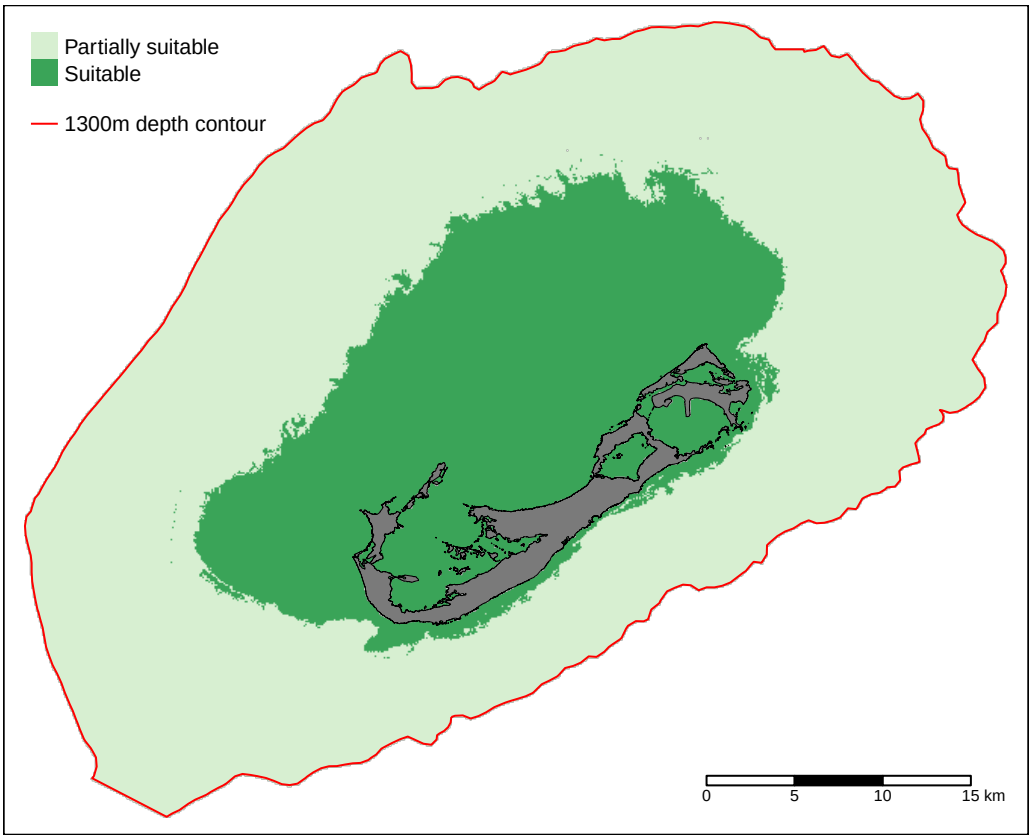

Figure 22: Floating technology areas suitability due to wave energy

Index of site suitability - all technologies

In addition to the technology specific site suitability criteria, the following data will be used to create an index of site suitability for areas that have not been removed as potential sites:

- Coral cover - lower 75% of values
- Coral diversity (species richness) - lower 75% of values
- Wrecks heatmap - heatmap of wrecks, indicating number of wrecks in an area. Provided by Philippe Rouja.
- Distance from shore - the further a site is from shore, the more costly it will be for cabling which is a significant expense (based on feedback from Annie Glasspool).

All data have been scaled 0-1 and values have been inverted, so that the highest original values are now the lowest and vice versa. This was done so that the higher values represent areas potentially more suitable for energy platform siting, and lower values the areas least suitable.

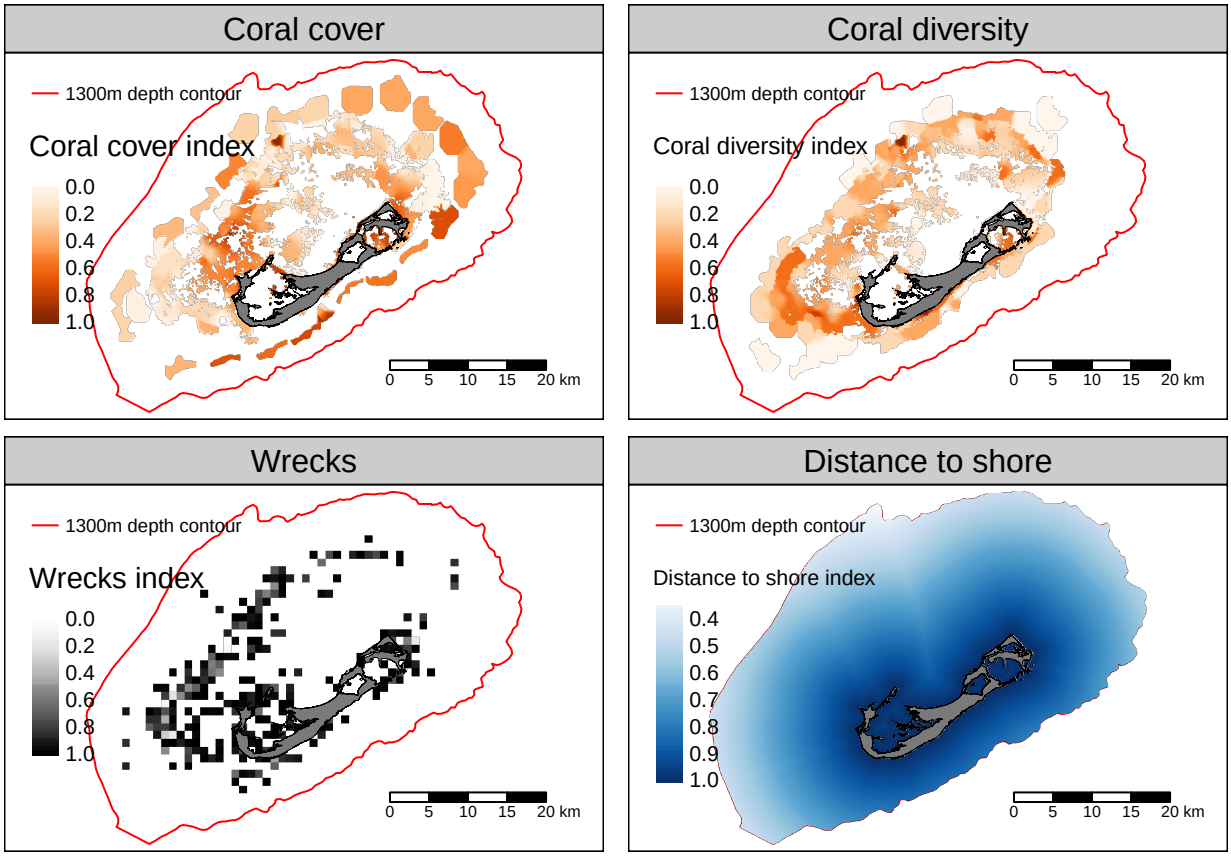

Figure 23: Components of the site suitability index. Each component is scaled 0 - 1, with higher values representing areas potentially more suitable for energy platform siting, and lower values the areas least suitable. Only areas with data are shown.

The final index used to assess site suitability for areas that have not been excluded is the sum of these indices. This is the sum of the above data maps. Areas within the 1300m depth contour (area of interest) that do not have any data in one of the maps will be treated as follow:

- Wrecks - no data areas area assumed to have no wrecks and are therefore given a value of 1
- Coral cover and diversity - areas that do not have coral cover or diversity data are broken into three types:

1. Areas of rim, fore and main terrace reef, and mesophotic reefs down to 150m depth. These are areas within known reef habitat zones, but which we have no coral cover or diversity data for. Habitats down to depths of 150m are known to still have coral cover and higher diversity of organisms than areas beyond this depth (Stefanoudis et al. 2019a, b). These areas will be given a score of 0.5.
2. Areas beyond 150m depths. Although there are still diverse fish and benthic communities beyond 150m depth, these is minimal Scleractinian coral cover and much fewer fish species compared to shallower depths. These areas will be given a score of 0.8.
3. Lagoon areas. Areas within the lagoon that are not mapped patch reefs. Assuming that these should be sand or other non-coral habitat, they will be given a score of 1.

The lack of data for these areas underscores the importance of undertaking preliminary environmental surveys of any area that is being scoped for renewable energy platform siting, regardless of the suitability score.

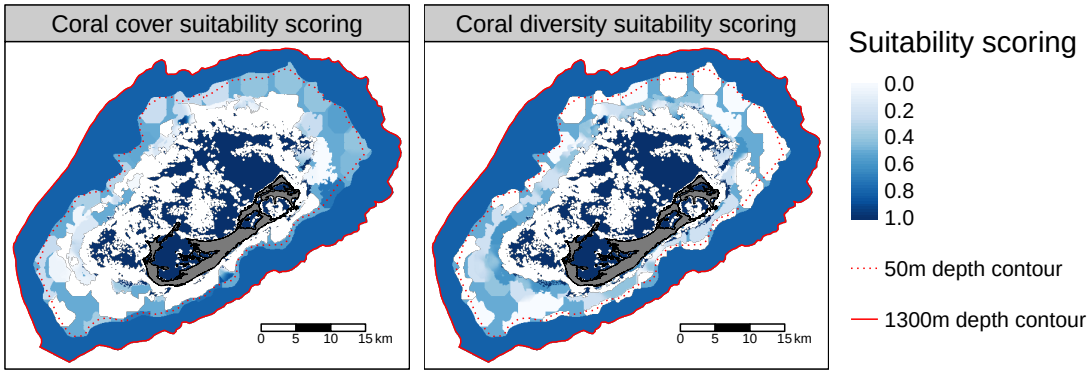

Figure 24: Suitability scoring for coral cover and diversity; showing scoring for areas outside the bounds of modelled coral cover and diversity. Areas without data are either mapped patched reefs or areas of high coral cover or diversity, all of which area excluded as suitable areas for renewable energy platform siting (see earlier sections).

Results

Sites for further investigation

This shows the areas for each technology that could be suitable for further investigation. These maps show the suitable depths for each technology with areas defined as not suitable for siting removed.

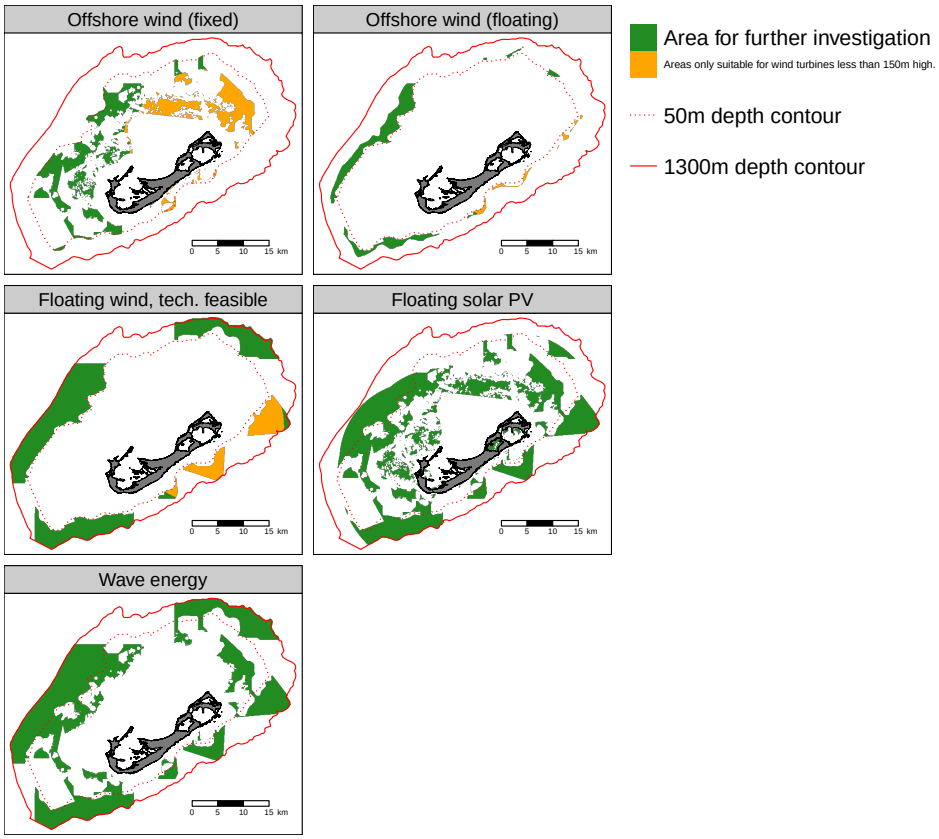

Figure 25: Areas suitable for further investigation as energy platform installation sites.

Sites for further investigation with site suitability index

The following maps show areas that could be suitable for further investigation for energy platform installation, with site suitability index criteria applied. All maps show suitability scores on a scale of low to high, broken into 8 quantiles, meaning that each colour represents 1/8th of all the data values.

Offshore wind (fixed)

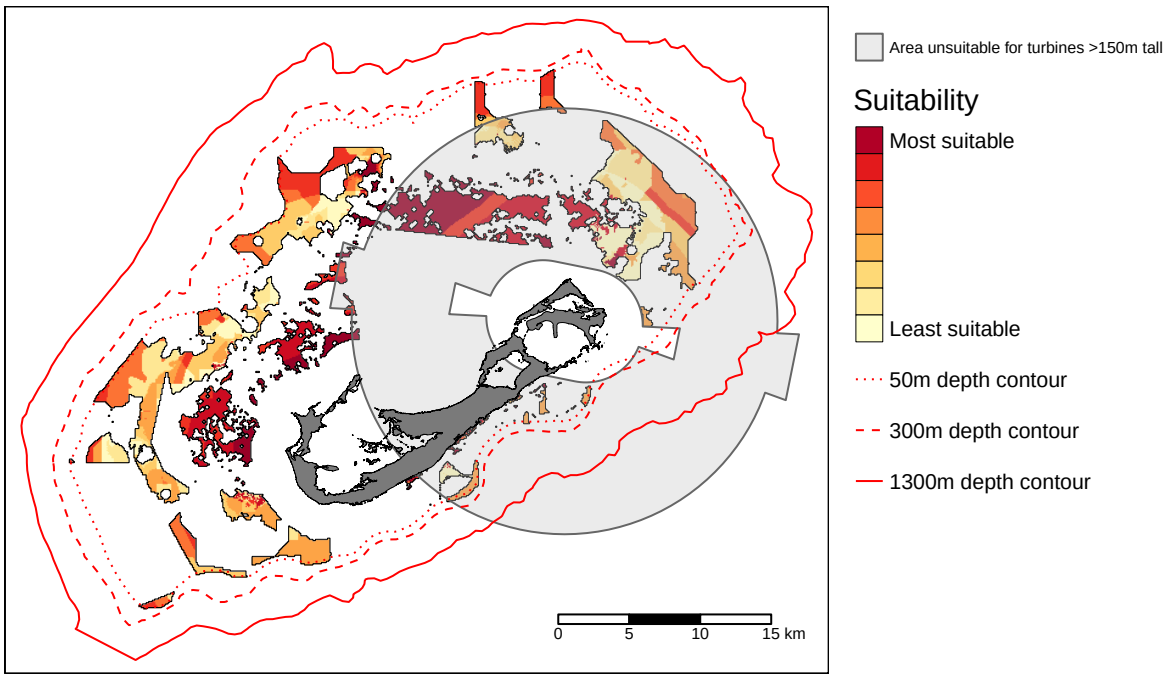

Figure 26: Areas suitable for further investigation as fixed wind energy platform installation sites with site suitability index

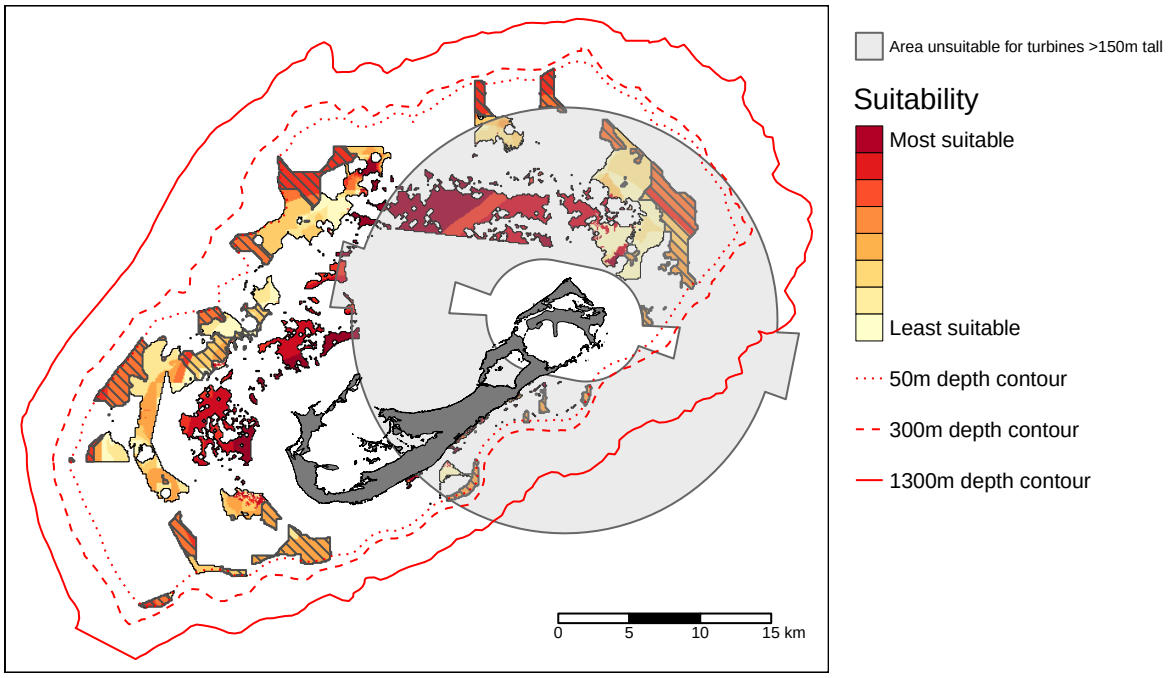

Figure 27: Areas suitable for further investigation as fixed wind energy platform installation sites with site suitability index. Hatched areas areas are areas where reef may exist but we do not have coral cover or coral diversity data available, so suitability scoring for these areas should be treated with caution.

Offshore wind (floating)

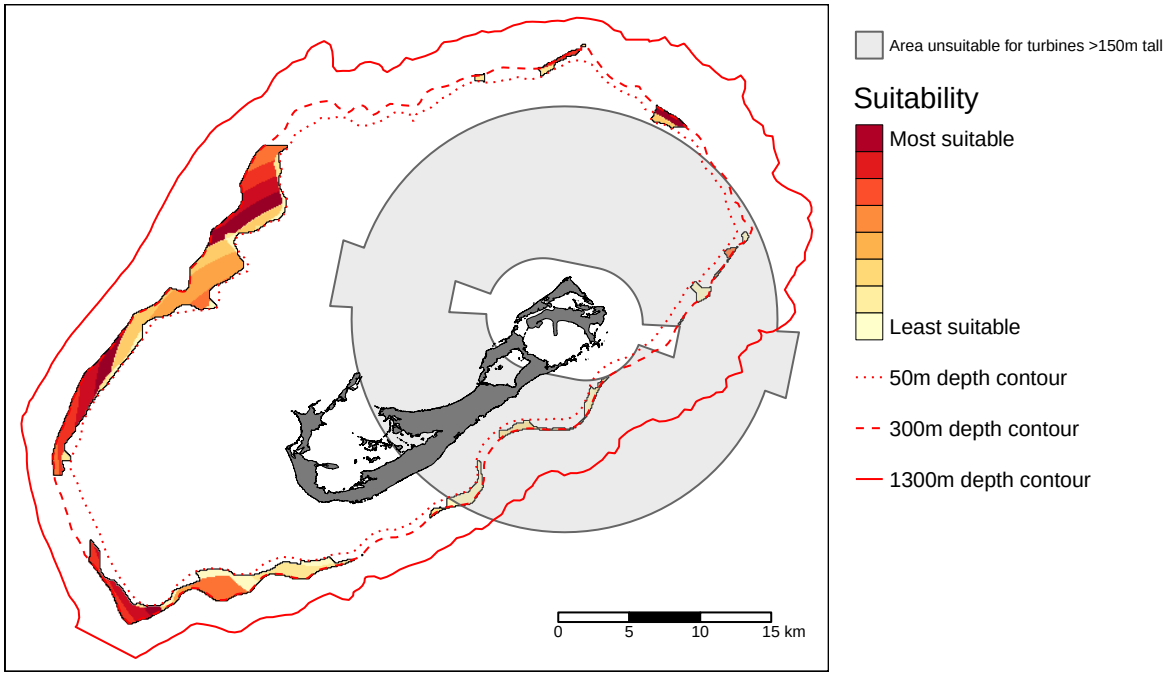

Figure 28: Areas suitable for further investigation as floating wind energy platform installation sites with site suitability index

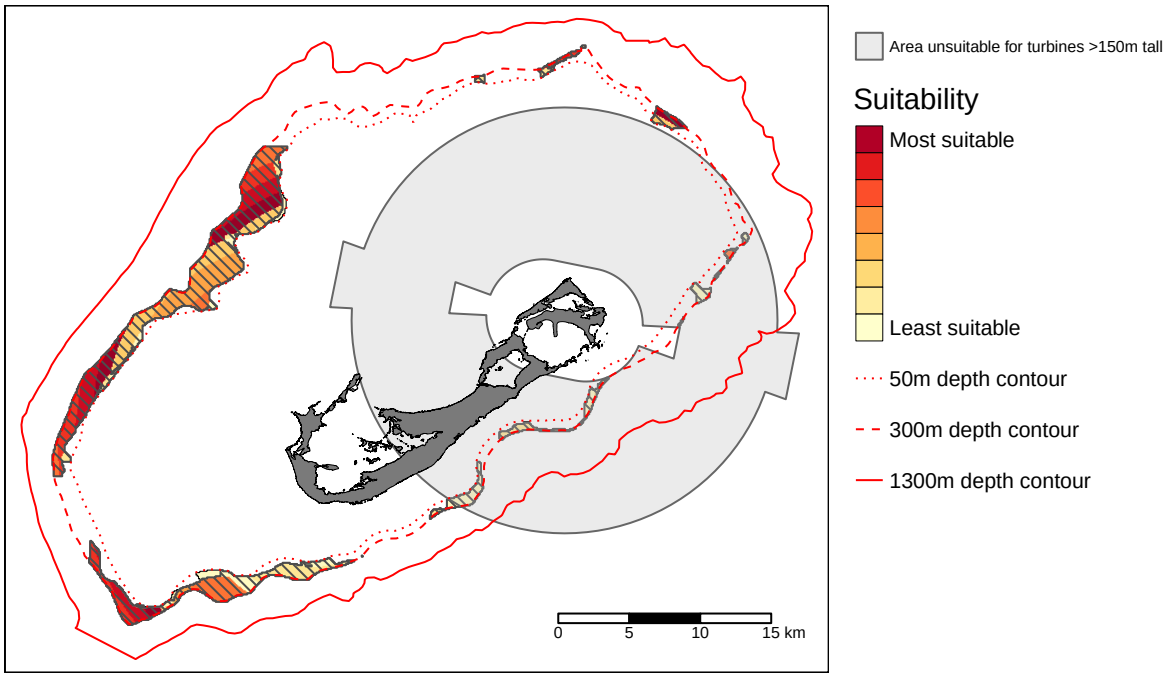

Figure 29: Areas suitable for further investigation as floating wind energy platform installation sites with site suitability index. Hatched areas areas are areas where reef may exist but we do not have coral cover or coral diversity data available, so suitability scoring for these areas should be treated with caution.

Offshore wind (floating) - technically feasible areas

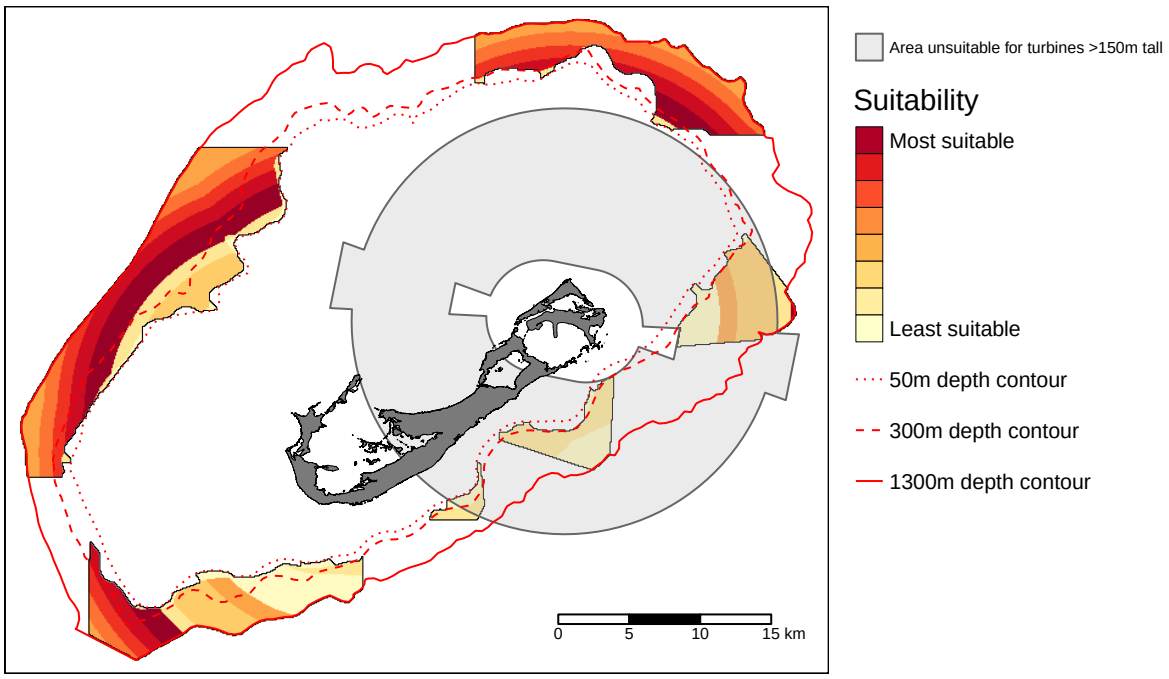

Figure 30: Areas suitable for further investigation as floating wind platform installation sites with site suitability index. This includes water depths that are currently considered technically, but not economically, feasible for installation.

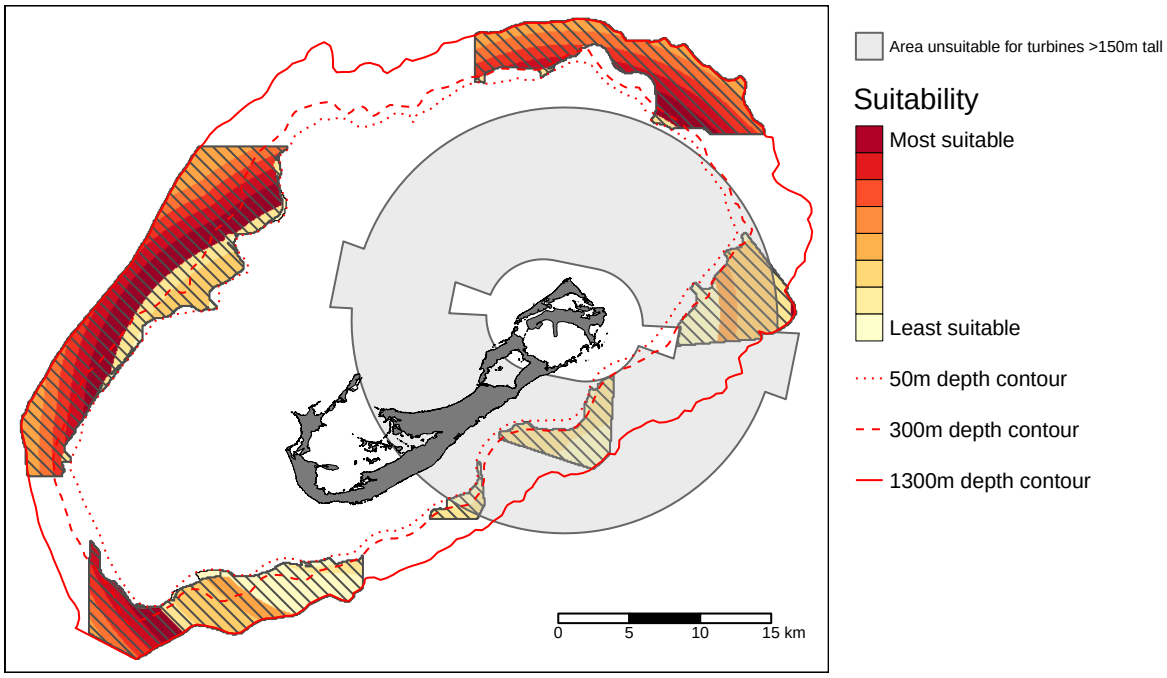

Figure 31: Areas suitable for further investigation as floating wind platform installation sites with site suitability index. This includes water depths that are currently considered technically, but not economically, feasible for installation. Hatched areas areas are areas where reef may exist but we do not have coral cover or coral diversity data available, so suitability scoring for these areas should be treated with caution.

Floating solar PV

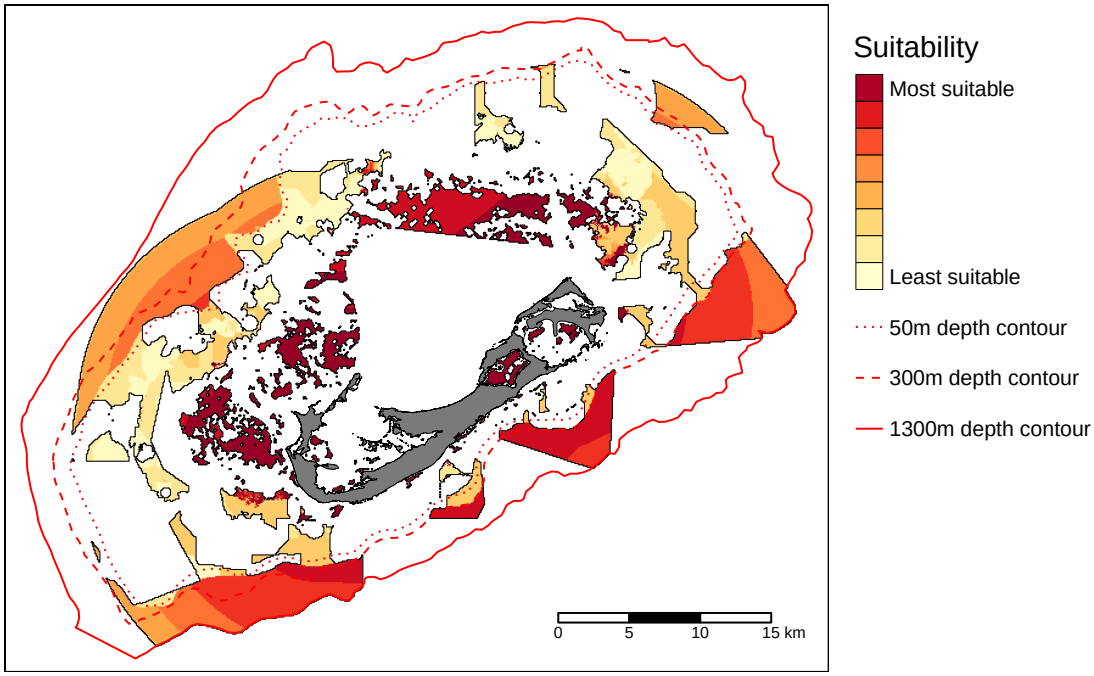

Figure 32: Areas suitable for further investigation as floating solar energy platform installation sites with site suitability index

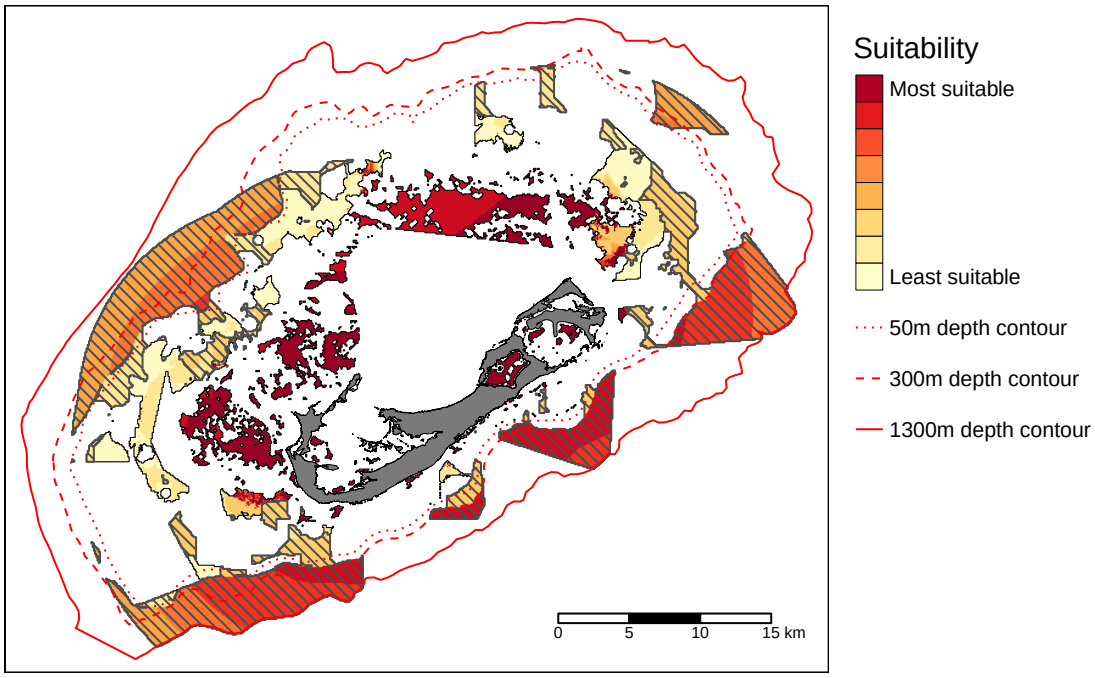

Figure 33: Areas suitable for further investigation as floating solar energy platform installation sites with site suitability index. Hatched areas areas are areas where reef may exist but we do not have coral cover or coral diversity data available, so suitability scoring for these areas should be treated with caution.

Wave power

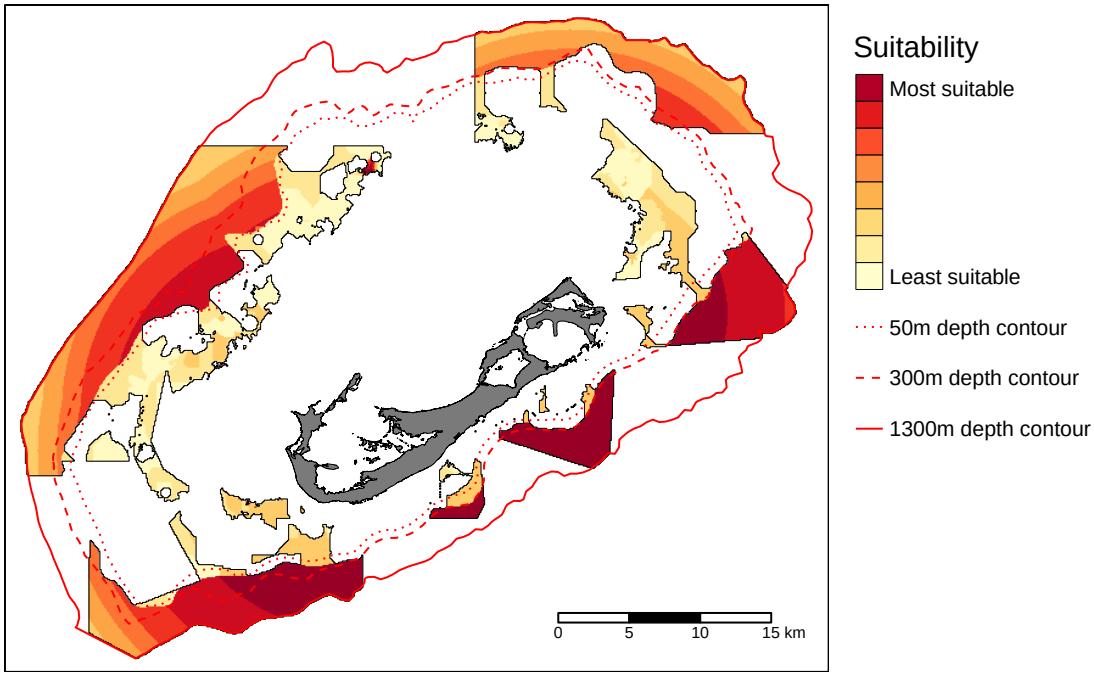

Figure 34: Areas suitable for further investigation as wave energy platform installation sites with site suitability index

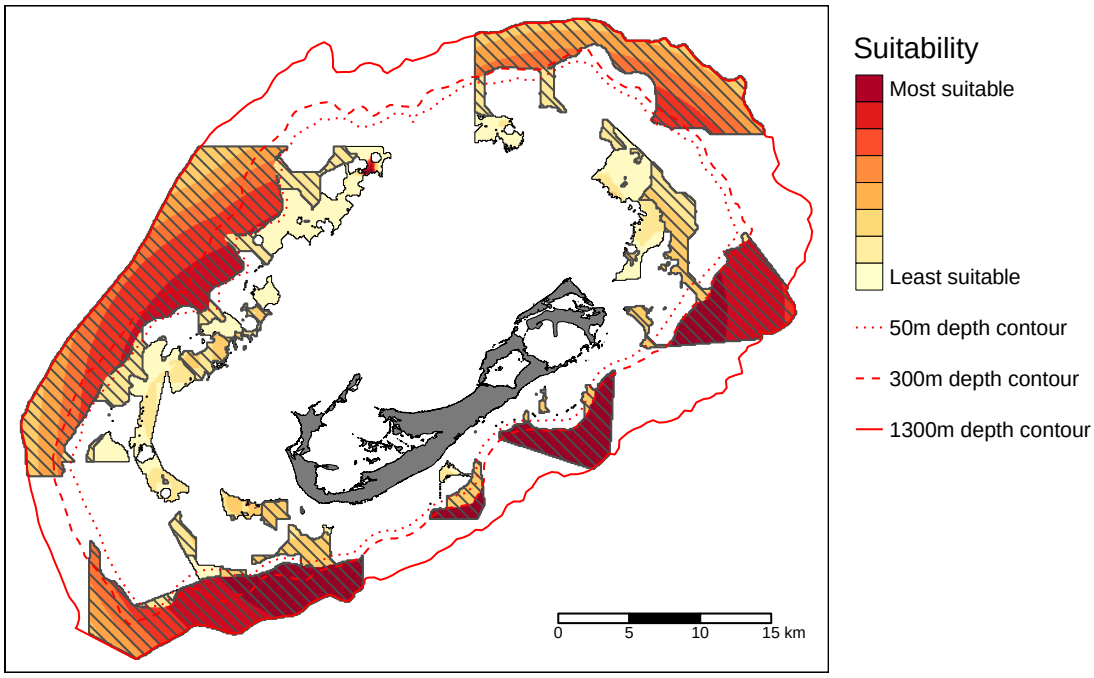

Figure 35: Areas suitable for further investigation as wave energy platform installation sites with site suitability index. Hatched areas areas are areas where reef may exist but we do not have coral cover or coral diversity data available, so suitability scoring for these areas should be treated with caution.

Fixed wind suitable areas with LCOE applied

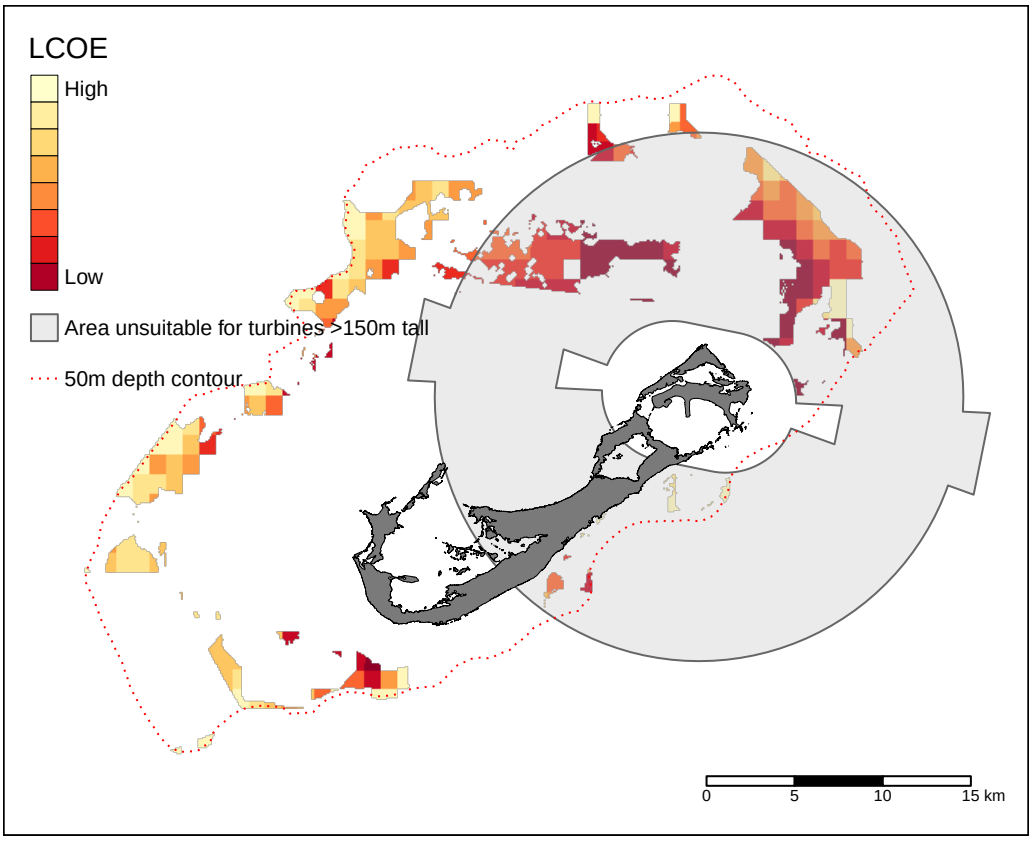

Figure 36: Areas suitable for further investigation as fixed wind energy platform installation sites with LCOE applied (does not include site suitability index)