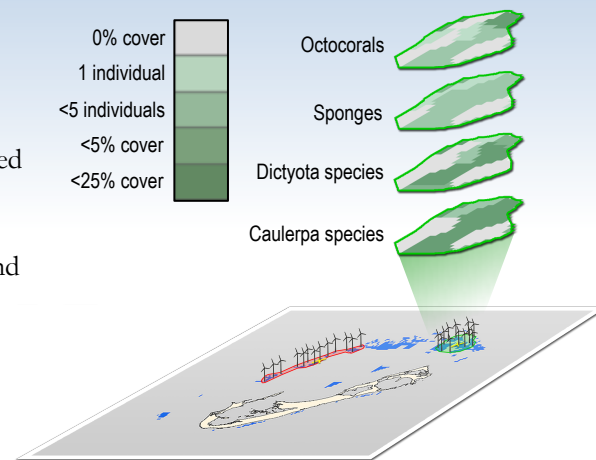


## Spatial post-hoc analysis

Some sectors were not driving factors in determining wind turbine suitability because they are not wholly incompatible with wind turbines, are not protected by law, or insufficient spatial data were available.

The post-hoc analysis examines the overlap between simulated wind farm scenarios and the spatial distribution of these sectors. The boundary of a wind farm is traced around the outermost wind turbines for a specific placement scenario, and the values of each sector contained within this boundary are mapped. This additional information can be used to inform management strategies and mitigation measures.



## Conclusions & Recommendations



### Offshore wind power is economically feasible for Bermuda.

The LCOE for the power producer that we calculated is well below the current cost of energy paid by the Bermuda energy consumer. Even with a substantial markup on a project's LCOE in a negotiated PPA, it is very likely that the actual cost of energy from offshore wind power will be less than the prevailing prices.

### Stakeholder engagement is critical to the success of offshore wind development planning.

Offshore wind development poses some risk of impact to ecological, economic, or social values at all locations on the Bermuda Platform. Our spatial threshold model can facilitate negotiation between stakeholders, energy developers, and decision makers to determine acceptable thresholds of risk and to identify suitable locations for offshore wind energy development. Using this tool in a transparent and iterative way can build trust among stakeholders, thus increasing the likelihood of positive outcomes in the marine spatial planning process.

### Viewshed impacts and risk to migratory birds should be considered in future iterations.

Future work should consider viewshed and avian impacts, which are often identified as major concerns for offshore wind energy development. Explicit integration of viewshed criteria and migratory bird patterns into the spatial planning analysis would help to address these concerns.

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**Calwind group**

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# Offshore wind energy in the context of multiple ocean uses on the Bermuda Platform



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Government of Bermuda

Master's Thesis Group Project Brief

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## Introduction

Bermuda is a British island territory in the North Atlantic, and as a small, remote island, it is heavily dependent upon imported fossil fuels for electricity generation. In 2011, the Government of Bermuda established a set of renewable energy goals to increase its energy security and decrease per capita greenhouse gas emissions. Bermuda's consistent winds and sizable shallow seabed, commonly known as the Bermuda Platform, make offshore wind energy an attractive option to meet its energy goals.



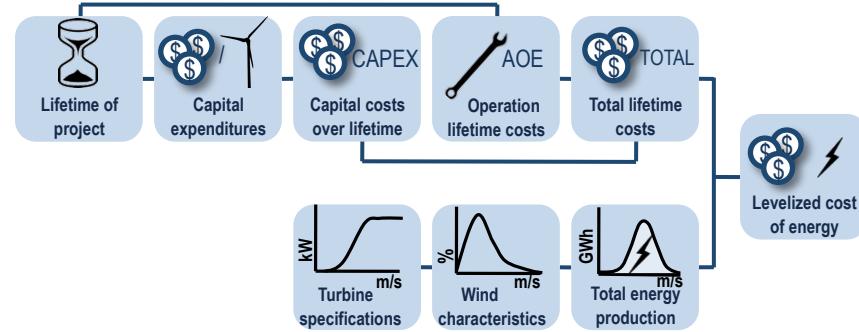
Offshore wind energy development would likely present a risk of impact to the multiple activities and ecological features that occur on the Bermuda Platform. The Platform supports a diverse coral reef ecosystem and ocean uses such as commercial and recreational fisheries, tourism and shipping. Minimizing impacts to these sectors necessitates the use of marine spatial planning in identifying suitable locations for an offshore wind farm. Marine spatial planning is a multi-stakeholder process used for analyzing and coordinating the spatial distribution of ocean activities so as to achieve specified economic, ecological and social objectives. This collaborative process decreases user conflict and project delays, builds trust with affected stakeholders, and helps maintain important ecosystem services. Using marine spatial planning for offshore wind energy development in Bermuda would minimize spatial conflicts while allowing Bermuda to achieve its renewable energy goals.

## Project Objectives

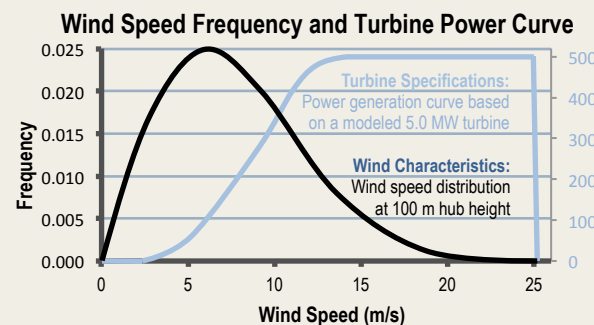
1. Determine the economic viability of offshore wind energy with respect to Bermuda's current energy context.
2. Identify and characterize potential conflicts with ocean uses and ecological features.
3. Develop a spatial analysis model to identify potential locations for offshore wind farms with acceptable risk of impacts.

# Wind Energy Model

We calculated the **Levelized Cost of Energy (LCOE)** in order to determine the economic viability of offshore wind energy. The levelized cost of energy is the price per unit energy from an energy project, and represents the minimum price that would be required in order for the wind developer to cover its costs. To calculate the LCOE, estimates of the total lifetime cost and of the total energy production are required (right).

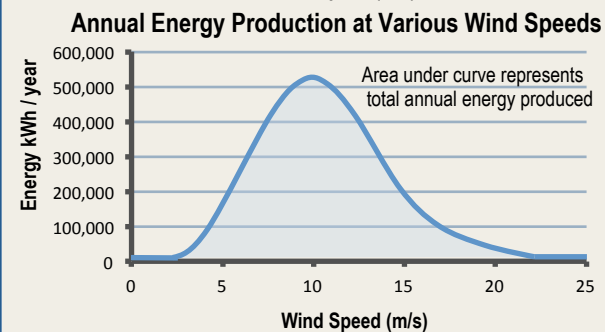


## Wind Energy Production



To determine the total energy production, we used long-term wind data from weather balloons launched from the Bermuda airport. We determined the wind speed at a 100 m altitude to match the hub height of a typical offshore wind turbine in order to create a frequency distribution of wind speeds on the Bermuda Platform (left, top).

A power curve for a modeled 5.0 MW wind turbine was used to calculate the expected annual energy production per turbine (left, top). The power curve for a specific turbine design represents how much power is generated at a particular wind speed. The efficiency of the wind turbine will depend on how well the turbine is matched to the local wind conditions.

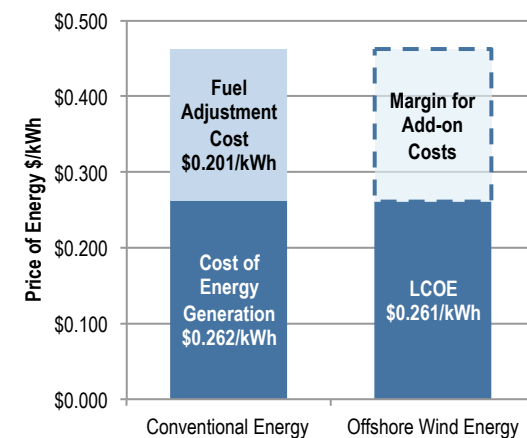


By combining the wind speed distribution and power curves, we obtain the total energy produced at each wind speed (left, bottom). The area under this curve is the annual total energy production.

## Levelized Cost of Energy

Our calculated LCOE for a 100 MW wind farm was \$0.2610/kWh. This value was calculated using the expected annual energy production that was calculated above and cost estimates for capital and annual operating expenditures from a 2012 NREL study.

The price paid by consumers will include add-on costs to account for power purchase agreement (PPA) obligations, intermittency mitigation, and regulatory compliance. The margin between the LCOE and current consumer energy prices leaves significant room for add-on costs while keeping energy prices at or below current rates.



# Spatial Analysis

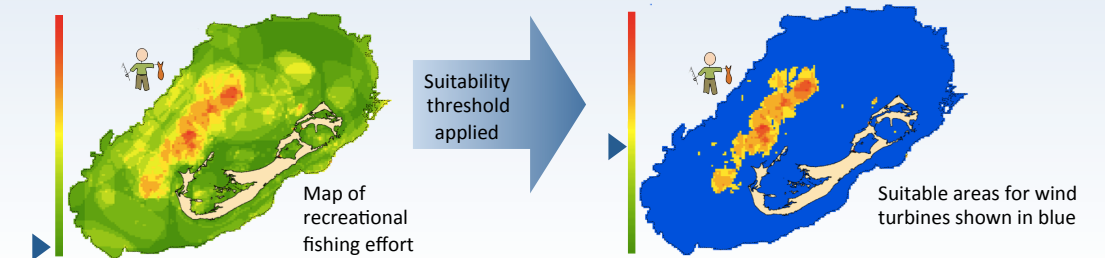
We created a spatial analysis model that determines areas that are potentially suitable for wind turbines. The model consists of three phases: **1) a suitability threshold analysis**, **2) a wind farm optimization analysis** and **3) a post-hoc analysis**. This methodology can identify areas with low risk of impact on the Bermuda platform as part of an iterative multi-stakeholder planning process.

## Suitability threshold analysis

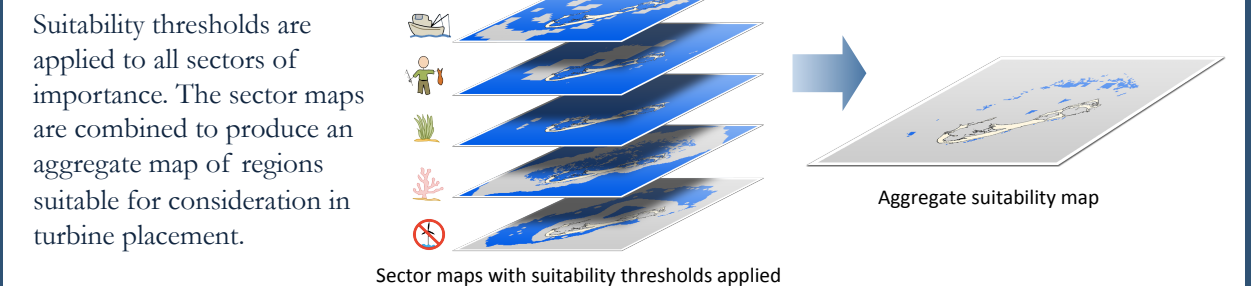
Due to the potential spatial conflict between turbine placement and existing ocean uses and ecological features, an acceptable level of risk of impact would need to be determined. The first phase of the analysis uses spatially explicit data on sectors of importance (right) and defines areas that are deemed suitable for turbine placement by applying a suitability threshold. The suitability threshold determines whether an area is considered for, or excluded from turbine placement based on the value of a sector at that location. This threshold could be set based on a preference to avoid risk of physical or economic impact due to turbine placement.

- ### Sectors of importance
- Commercial finfish and lobster fisheries
  - Recreational finfish and lobster fisheries
  - Reefs
  - Seagrass habitat
  - Exclusion zones (e.g. protected areas, shipping lanes)

### Apply suitability thresholds (example)



### Generate aggregate suitability map



## Wind Farm Optimization Analysis

The wind farm optimization analysis generates wind turbine placement scenarios that (a) meet specified generation capacity, (b) adhere to all suitability criteria, (c) maintain specified inter-turbine spacing, and (d) minimize the distance between turbines to reduce marginal construction and maintenance costs.

The map shows two turbine placement scenarios, centered on two different regions of the Bermuda Platform. The farm outlined in red shows a dispersed pattern of turbines, while the farm outlined in green shows a compact pattern.

