Offshore Wind Power Suitability along Florida’s Atlantic Coastline

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All maps projected in NAD 1983 Florida State Plane East

Introduction

While offshore wind power has become commonplace in Europe, it is only beginning to be considered in the United States, predominantly along the southern coast of Cape Cod. In 2012, the National Renewable Energies Laboratory (NREL) carried out a study characterizing the feasibility of offshore wind power along the entirety of the United States coastline, except for Florida, Alabama, and Louisiana, for which there was insufficient data. This project’s aim is to supplement the 2012 study by determining suitable locations for an offshore wind farm along Florida’s Atlantic coastline. This project will focus on the state’s eastern (oceanside) coastline due to the predominant east-to-west wind currents. To determine a suitable location, various spatial data sets will be utilized to narrow down possible project areas, and other data sets will be used to determine the suitability of regions within these project areas for offshore wind farms.

Methodology

This project was conducted in two phases. The first created an area over which a wind farm would be feasible, based on proximity to deep water ports and the coastline, bathymetry, and annual wave height. The second phase involved a cost-benefit analysis over these areas, comparing the potential profits based on extrapolated wind speeds, and the potential costs of building wind turbines based on the depth of the seafloor.

In order to determine the feasible project area, a base area was first created using basic editing tools around the extent of the area being analyzed. Then, a 15-mile buffer around each deep water port, and one with a 5-mile radius from the coastline (Map A). These buffered areas were removed from the base area.

To determine the wind speeds at 90 meters, sea-level wind speed data was obtained from 13 National Oceanographic and Atmospheric Administration (NOAA) weather buoys positioned along the Florida coastline. Using Equation 1 shown below, the annual wind speeds during the year of 2014 at sea level was extrapolated to 90 meters of altitude, the height that potential wind turbines would be built to. Then, a spline interpolation was used to build a rasterized wind speed model (Map B) covering much of the potential project area. The base area polygon was then cut to match the size of the available wind speed data.

Equation 1: Wind Speed Interpolation to 90m

For wind speed measurement Uz at height z, this series of equations was applied twice: first where α = z and λ and again where α= 10 and λ = 90 to determine wind speed at 90m.

$$U_* = \sqrt{(0.61 + 0.063U_\alpha)\cdot 10^{-3}} \cdot U_\alpha$$

$$U_\lambda = U_z + \frac{U_*}{0.4} \cdot ln\left(\frac{\lambda}{z}\right)$$

A bathymetry raster for Florida’s dataset was obtained from NOAA (Map C). This raster was first used to limit the base area polygon; as offshore wind farms are currently only feasible within 60 meters of depth. After the base area had been determined, the bathymetry dataset would be used to apply a depth-based cost analysis to the final feasibility study.

The final data set that was considered is annual significant wave height, available from NREL (Map D). First, all areas with an annual wave height of over 2 meters were selected, and converted into a separate layer. Using the clip tool, these areas were removed from the base area. What remained of the base area polygon is the final area that would be analyzed for feasibility of a wind farm (Map E).

To convert the interpolated wind speeds into a cost-based raster, the available power to be generated was determined using Equation 2 shown below (Map F). This assumed a 90-meter blade length, and a 45% turbine conversion efficiency, both of which are industry standard values. Then, the resulting raster was multiplied by the price of electricity per kWh in Florida (11.7 ¢/kWh), and extrapolated over a 20-year turbine life expectancy. This resulted in a raster of available profits per lifetime kW produced from each site.

Equation 2: Estimating Power Output

Assuming a power coefficient $C_p = 0.45$ and rotor sweep area $A = \pi(90)^2$ m², and given air density $\rho = 0.0765$ lb*ft^{-3} and conversion constant k = 0.000133, power output P in kW can be found based on ambient wind speed V in mph.

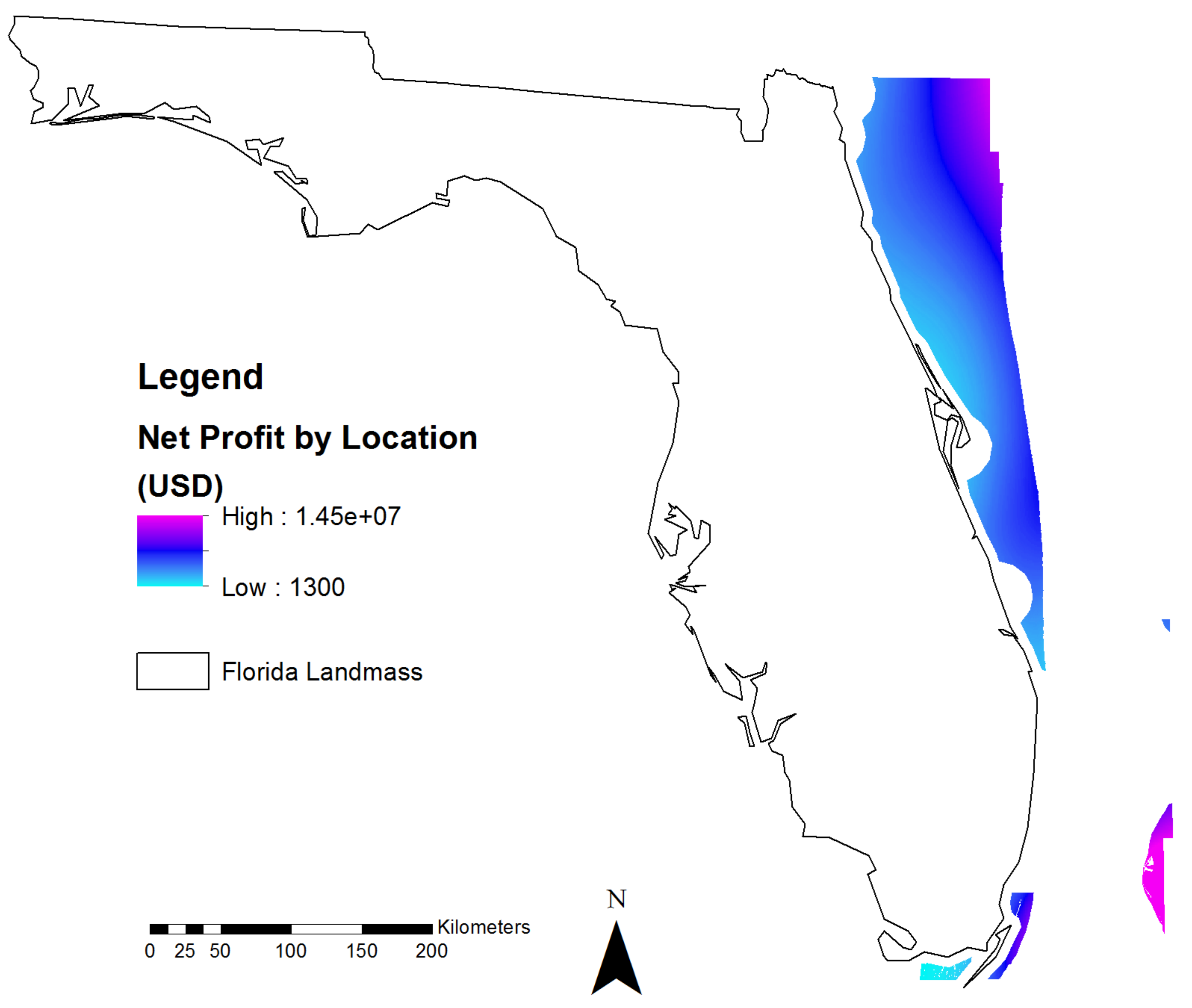
$$P = kC_p\frac{1}{2}\rho AV^3$$

To convert the bathymetry data set into a cost-based raster, a 2014 NREL Wind Cost Analysis was used to determine a cost per meter depth per kilowatt over the estimated turbine life of 20 years. An estimated cost of 136.7$ per m depth per kW was multiplied by the bathymetry raster to result in a cost-by-depth raster per lifetime kW produced by the turbine.

To complete the cost-benefit analysis over the feasible project area, the cost raster was subtracted from the profits raster to result in an overall net profit raster.

Results & Discussion

A brief analysis of the final cost-analysis map (top right) shows the most profitable areas for wind farm construction in purple, and the least profitable in light blue. The two most profitable wind farm locations are in the northeastern portion of the map, somewhat far off the coast of Jacksonville, and immediately off the coast of Miami in the southern portion of the map. The northeastern region is not only bigger in area than the southern one, it is farther away from land and less visible to people residing along the nearby coastline. So, this northeastern region can be considered the optimal location for a wind farm per this feasibility study.

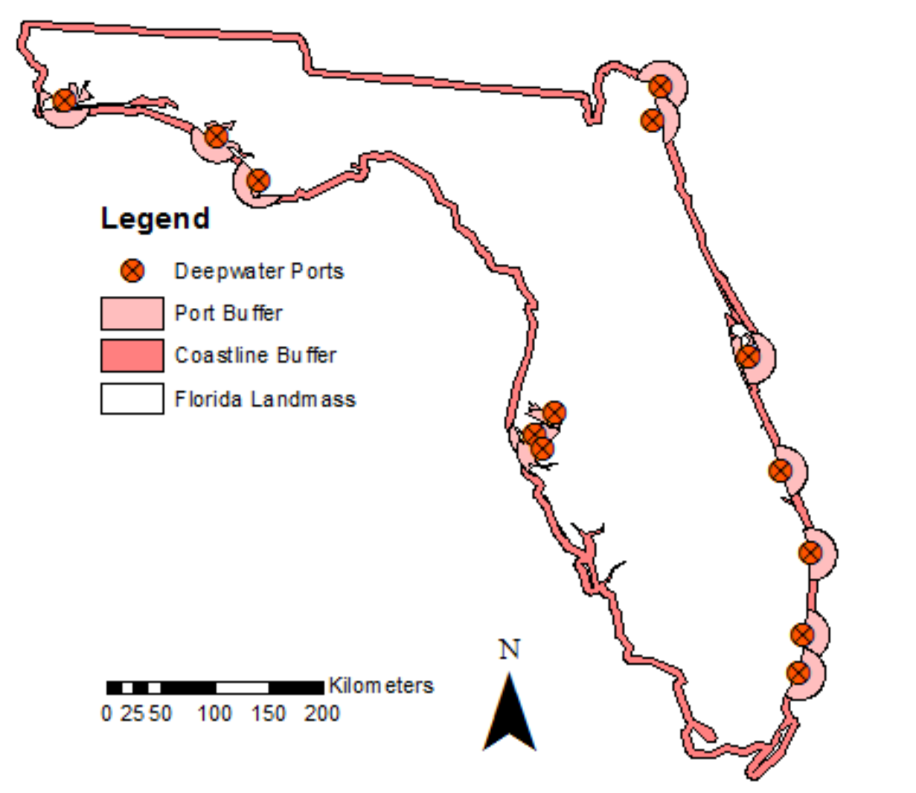


The main limiting factor in the data analyzed here was the cost-by-bathymetry model. The initial NREL analysis was carried out for a turbine at a depth of 15 meters, and while the application of NREL’s analysis used in this project assumes a linear depth-cost ratio, that is by no means guaranteed. A more in-depth cost analysis would be required for a more complete study.

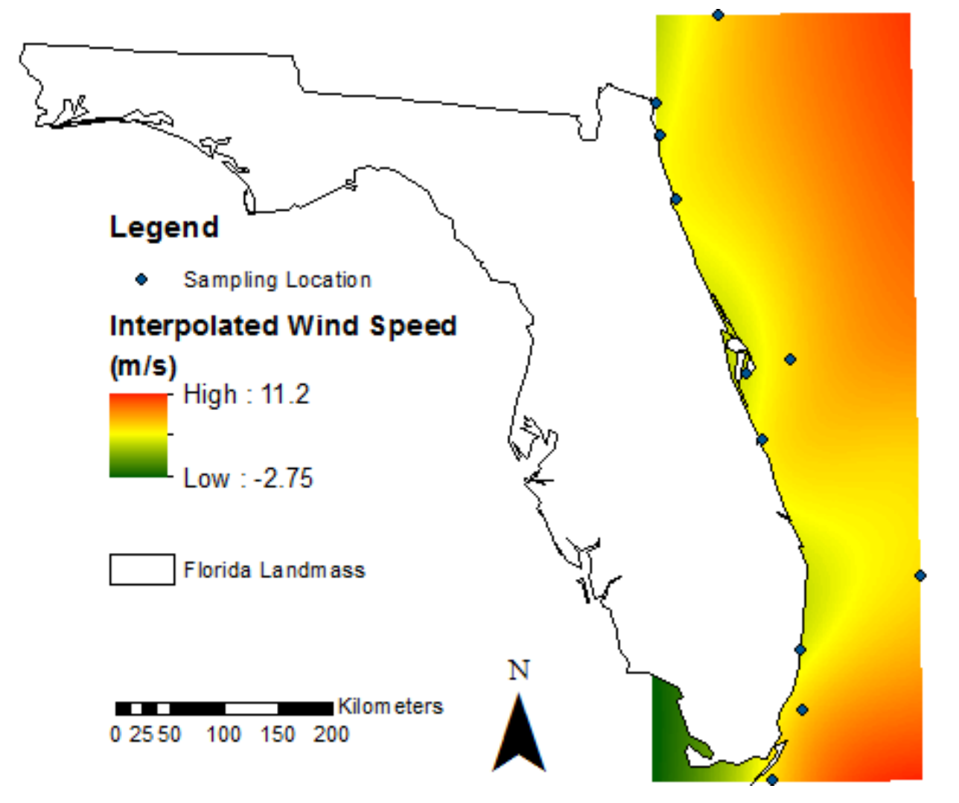
This study focused on four major factors, but a more in-depth analysis, which would result in a more detailed feasibility study, would include additional physical layers, including bedrock type and ocean current speed. In addition, locations of protected marine habitat were not available, so these areas were not excluded from this analysis. These layers would be necessary for a full analysis.

If a wind farm were to be built, several factors must be considered specifically for the Floridian environment. The first is that, due to a steep continental shelf, there is a limited amount of space over which grounded turbines can be built. Floating turbines, while not commonplace yet, are in development and would help solve this problem. In addition to depth restrictions, these turbines need to be designed to withstand hurricane-force winds. This final design implication is crucial: Floridian wind is not a sustainable investment until the turbines themselves can handle a hurricane.

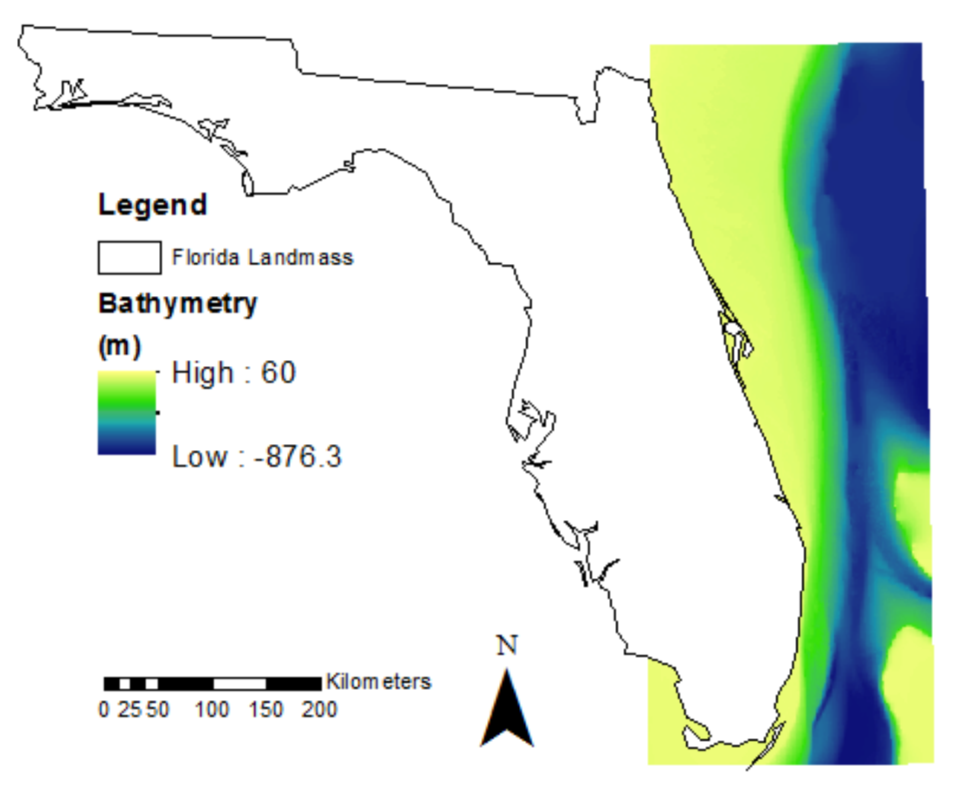
A: Buffers around Coast and Ports



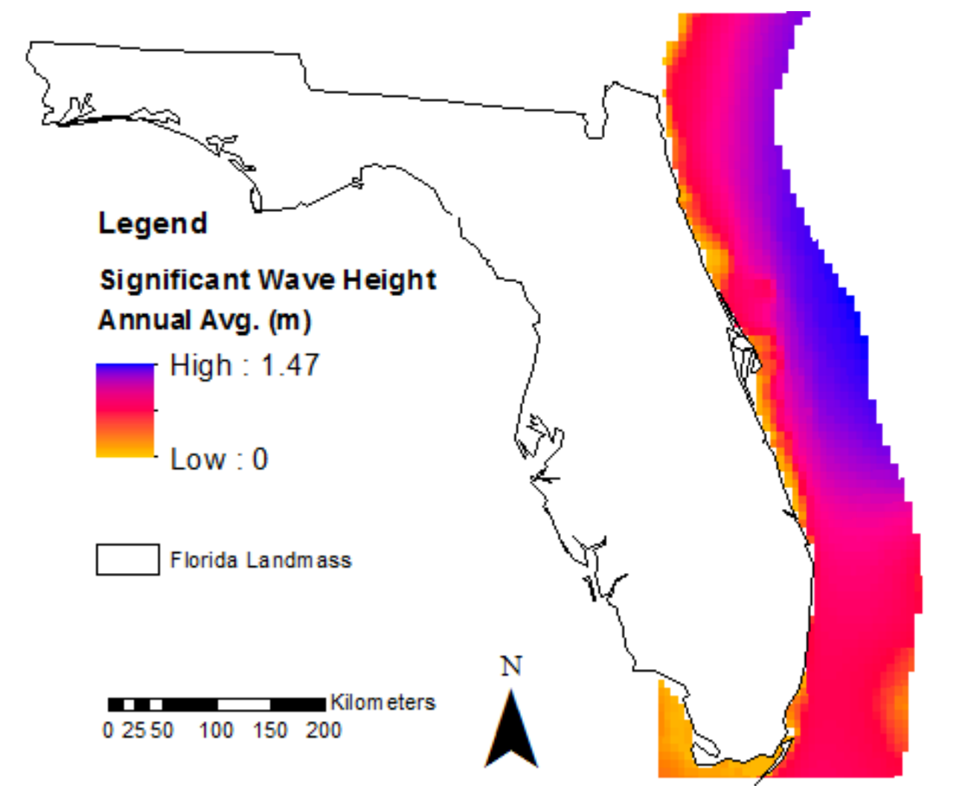
B: Wind Speed at 90 m



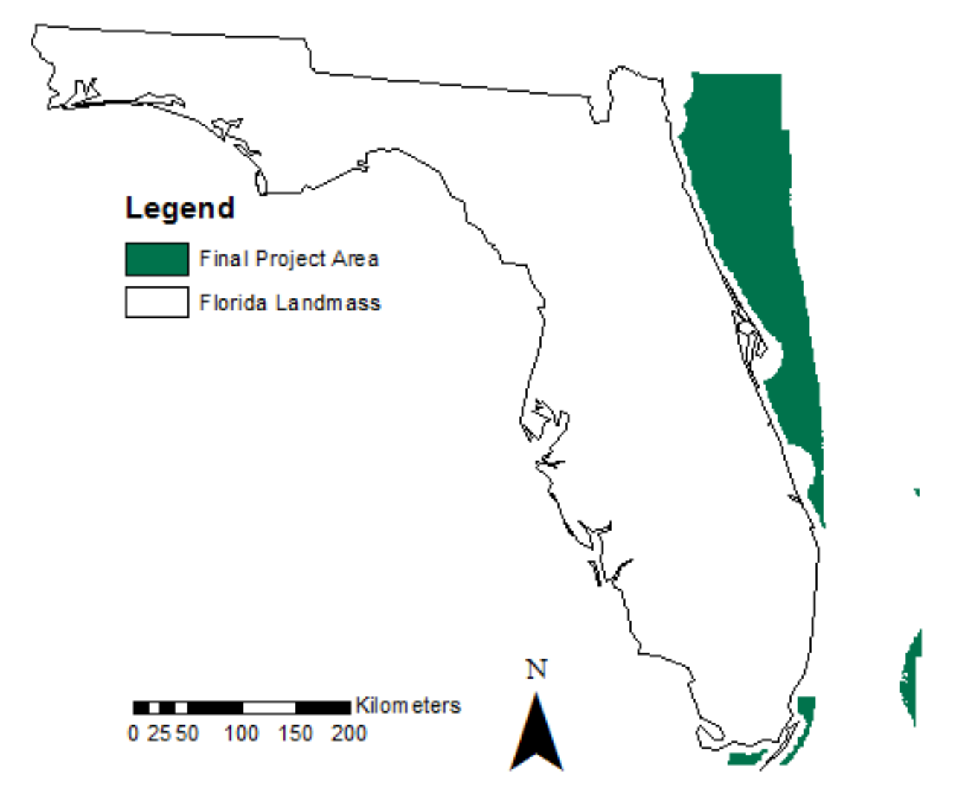
C: Bathymetry



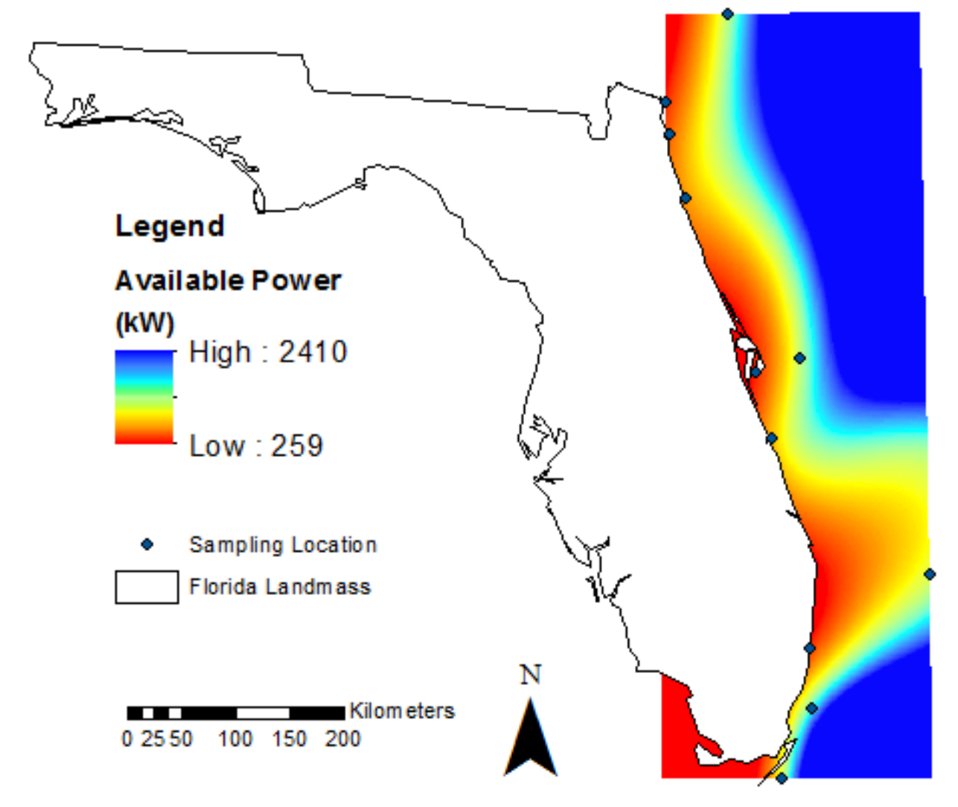
D: Wave Height Data



E: Final Base Project Area



F: Possible Power Generation



References

Drennan, W. M. “On Parameterizations of Air–sea Fluxes.” Atmosphere-Ocean Interactions - WIT Transactions on State of the Art in Science and Engineering 2 (2006): 01-33. Google Scholar. Web. 19 Oct. 2016.

“How to Calculate Wind Power Output.” Windpower Engineering & Development. WTWH Media, 26 Jan. 2010. Web. 05 Dec. 2016.

Data Sources

National Oceanographic and Atmospheric Administration
National Renewable Energies Laboratory
Florida Department of Environmental Protection