Submarine Cable Analysis for Marine Renewable Energy Development

Contents

1 Background

Demand for abundant and diverse resources in the oceans is growing, necessitating marine spatial planning. To inform development of Marine Hydrokinetic (MHK) and Offshore Wind (OSW) resources, DOE has asked NREL to identify — and mitigate where possible — the competing uses between MHK/OSW technologies and subsea power/telecoms cables. The first step in this work is to identify and quantify the overlap between the MHK/OSW resource availability and existing cable routes. Several publicly available data layers are available that identify cable routes (e.g. MarineCadastre.gov currently hosts an offshore cables geographical information system (GIS) data layer) and MHK/OSW resource density (MHK Atlas, Wind Prospector). The cable route linear features, however, do not indicate the setback distance necessary to accommodate subsea cable maintenance requirements. Preliminary work was done within NREL to evaluate the influence of subsea cable setback distance on the overlap with MHK/OSW for the west coast of the U.S (Amante, Kilcher, Roberts, & Draxl, 2016). Industry reports (Communications Security, Reliability and Interoperability Council IV, 2014, 2016) from the International Cable Protection Committee (ICPC) of the North American Submarine Cable Association (NASCA; n-a-s-c-a.org) advise on setback distances that inform this analysis.

2 Methods

2.1 Study Area and Submarine Cables

The study area included the 200 nm extent of US waters downloaded from MarineRegions.org[1] and overlapping the offshore cable data layer available through MarineCadastre.gov.[2] See Figure **??**.

TODO: add citations to bibliography:

- MarineRegions.org > Exclusive Economic Zones Boundaries (EEZ), version: World EEZ v9 (2016-10-21, 123 MB). Suggested citation:

  - Flanders Marine Institute (2016). Maritime Boundaries Geodatabase, version 1. Available online at http://www.marineregions.org/. Consulted on 2017-04-25.

- MarineCadastre.gov cable metadata

See Table **??**.

2.2 tbl_eez-usa

Territories within the United States exclusive economic zone (EEZ).

Territory	Area (km2)
Alaska	3,682,912
East	932,351
Guam	208,234
Gulf of Mexico	1,553,288
Hawaii	2,474,715
Johnston Atoll	442,443
N Mariana Islands	763,626
Palmyra Atoll	353,670
Puerto Rico	172,958
US Virgin Islands	38,275
Wake Island	406,970
West	824,679

TODO:

- python - Shapely polygons crossing the antimeridian - Geographic Information Systems Stack Exchange
- r - Use different center than the prime meridian in plotting a world map - Stack Overflow
- ogr - How to change shapefile longitude from -180 - 180 to 0 - 360? - Geographic Information Systems Stack Exchange
- sf::st_transform not honoring +lon_wrap · Issue #280 · edzer/sfr
- Moving The Earth (well, Alaska & Hawaii) With R | rud.is
- Administrative Maps and Projections in R - AriLamstein.com
- Mapping Data in R · Adam Olson
- Mapping All Fifty U.S. States
- fiftystater/make_mapfile.R at master · wmurphyrd/fiftystater

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[1] MarineRegions.org US exclusive economic zone (EEZ) data, version World_EEZ_v9_20161021

[2] MarineCadastre.gov cable metadata: https://coast.noaa.gov/dataservices/Metadata/TransformMetadata?u=https://coast.noaa.gov/data/Documents/Metadata/harvest/MarineCadastre/NOAAChartedSubmarineCables.xml&f=html

- Mapping All Fifty U.S. States
- r - Relocating Alaska and Hawaii on thematic map of the USA with ggplot2 - Stack Overflow
- ohiprep/model_create_regions.py at 66bcf4e39b63b154437dda55aec6ed825ac47f05 · OHI-Science/ohiprep

2.3 Depth

The bathymetric depth comes from the GEBCO 30 arc-second grid. Here's there requested attribution:

GEBCO_2014 Grid, version 20150318, www.gebco.net

2.4 Renewable Energy

NREL.

2.5 Avoidance Zones for Siting New Facilities

"ICPC Recommendation 13 No. 2, which establishes a methodology for determining site-specific proximity limits between submarine cables and offshore wind facilities and a default separation distance in shallower waters of 500 meters on either side of an in-service submarine cable — a separation standard the principles of which also apply to other offshore renewable energy projects."

"Subsea Cables UK Guideline No. 6 (endorsed by NASCA), which establishes principles for determining safe proximity distances and negotiating proximity agreements between offshore wind farms and submarine cables and reflects extensive experience in the United Kingdom with managing spatial conflicts between offshore wind farms and submarine cables."

"endorse a default separation distance of 500 meters in water depths of less than 75 meters and the greater of 500 meters or two times the depth of water in greater water depths."

1. **Default separation distance** by depth:
   - `<= 250 m`: 500 m
   - `> 250 m`: 2 x depth

Psudocode:

```
# buffer based on depth
cables_buffers = list()
for (x in unique(cable_cells$depth)){

  cables_buffers[str(x)] = cable_cells %>%
    subset(depth == x) %>%
    buffer(x)

}
cable_buf = merge(cables_buffers)

# smooth out jagged edges between cells
cable_buf = simplify(cable_buf)
```

2.6 Separation Zones for Routing New Cables

"ICPC Recommendation 2 No. 10: parallel submarine cables maintain a separation distance of the lesser of 3 times depth of water or (where not achievable) 2 times the depth of water following consultation and

agreement between affected parties — a separation standard the principles of which also apply to spacing of submarine cables and other marine infrastructure"

At least 2 separation zones based on depth:

1. **Minimum**: 2 times the depth of water

2. **Recommended**: 3 times depth of water

Psudocode:

```
# convert depth (GEBCO 30 sec resolution) to polygons of cells
depth_cells = as.polygon(depth_raster)

# intersect cables with depth cells
cable_cells = intersect(cables_lines, depth_cells)

# buffer based on depth
cables_buffers = list()
for (x in unique(cable_cells$depth)){

  cables_buffers[str(x)] = cable_cells %>%
    subset(depth == x) %>%
    buffer(x)

}
cable_buf = merge(cables_buffers)

# smooth out jagged edges between cells
cable_buf = simplify(cable_buf)
```

2.7   Depth-Varying Buffer

A depth-varying buffer to the offshore cables, 2 * depth for "minimum" and 3 * depth for "recommended" separation zones for routing new cables, by first intersecting depth with cables, then iterating over each depth to apply the appropriate buffers before finally dissolving all buffers. In order to apply the buffer, I needed to project from geographic coordinates to a projection that minimizes area distortion, so chose Albers Equal Area and applied the "one-sixth rule" based on the extent of the cable features to minimize distortion.

3   Results

Generated by:

- create_cable-buffer.R
- extract_cable-energy.R

Google Earth files (*.kml):

- buf_2xdepth-incr100m.kml
- buf_3xdepth-incr100m.kml
- lns_d1x.kml

3.1 Overlap with Renewable Energy

Extract average and area of overlap between zones and renewable energy potential areas, possibly at various depth bins.

3.1.1 Wind

units: wind speed (m/s) at 90m hub height

TODO: - Visualise sf objects — ggsf • ggplot2

Constraints of cable (minimum - recommended) categories of wind speed (m/s) at 90m hub height.

Territory	Wind Speed (m/s)	Area (km2)	Min. Cable (2x)		Rec. Cable (3x)	
			Area (km2)	(%)	Area (km2)	(%)
East	7=>	8,006	50	0.6%	70	0.9%
East	7-8	48,890	240	0.5%	352	0.7%
East	8-9	124,946	2,991	2.4%	4,213	3.4%
East	9-10	75,695	3,235	4.3%	4,735	6.3%
East	10-11	41	0	0.0%	0	0.0%
Gulf of Mexico	7=>	6,083	12	0.2%	18	0.3%
Gulf of Mexico	7-8	90,254	1,079	1.2%	1,620	1.8%
Gulf of Mexico	8-9	28,855	0	0.0%	0	0.0%
Hawaii	7=>	38,998	5,871	15.1%	7,664	19.7%
Hawaii	7-8	59,131	20,335	34.4%	24,876	42.1%
Hawaii	8-9	45,787	13,400	29.3%	17,091	37.3%
Hawaii	9-10	14,099	488	3.5%	866	6.1%

3.1.2 Wave

units: wave energy flux (kW/m)

Constraints of cable (minimum - recommended) categories of wave energy (m/s) at 90m hub height.

Territory	Wave Energy (kW/m)	Area (km2)	Min. Cable (2x)		Rec. Cable (3x)	
			Area (km2)	(%)	Area (km2)	(%)
Alaska	0-500	165,671	1,459	88.1%	2,111	127.4%
Alaska	500-1000	737	26	351.8%	37	507.9%
Alaska	1000-1500	173	5	273.1%	7	405.8%
Alaska	1500<	114	2	190.4%	3	271.4%
East	0-500	83,474	1,797	215.3%	2,490	298.3%
East	500-1000	412	4	95.3%	7	162.5%
East	1000-1500	130	1	88.5%	2	123.8%
East	1500<	90	0	0.0%	0	0.0%
Gulf of Mexico	0-500	67,752	236	34.8%	345	51.0%
Gulf of Mexico	500-1000	38	0	0.0%	0	0.0%
Gulf of Mexico	1000-1500	8	0	0.0%	0	0.0%
Gulf of Mexico	1500<	3	0	0.0%	0	0.0%

- plotly - stacked bar chart
- plotly - horizontal bar chart
- plotly - percentages bar chart

3.1.3 Tidal

units: mean power (W/m^2)

TODO: seperate tif into east and west for display in leaflet

Constraints of cable (minimum - recommended) categories of tidal energy (W/m2) at 90m hub height.

Territory	Tidal Power (W/m2)	Area (km2)	Min. Cable (2x)		Rec. Cable (3x)	
			Area (km2)	(%)	Area (km2)	(%)
Alaska	0-500	165,671	1,459	88.1%	2,111	127.4%
Alaska	500-1000	737	26	351.8%	37	507.9%
Alaska	1000-1500	173	5	273.1%	7	405.8%
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Gulf of Mexico	500-1000	38	0	0.0%	0	0.0%
Gulf of Mexico	1000-1500	8	0	0.0%	0	0.0%
Gulf of Mexico	1500<	3	0	0.0%	0	0.0%

3.2 Next Steps

- stacked histogram by cbl2/(cbl3-cbl2)/other; hist(wind$Speed_90)
- simplify as native geojson

Musial et al (2016):

- wind speed (m/s) – Table A-3 (p. 48): <7, 7-8, 8-9, 9-10, 10-11, total
- depth classes (m) – Table B-1 (p. 49): <30, 30-60, 60-700, 700-1000, >1000, total
- distance to shore (nm) – Table B-2 (p. 50): <3, 3-12, 12-50, 50-200, total
- by states

4 Conclusions

4.1 Communication with Stakeholders

Products will be online and readily digestable by stakeholders.

References

Amante, C., Kilcher, L., Roberts, B., & Draxl, C. (2016). *Offshore Cable Analysis: Pilot Study.*

Communications Security, Reliability and Interoperability Council IV. (2014). *Protection of Submarine Cables Through Spatial Separation.*

Communications Security, Reliability and Interoperability Council IV. (2016). *Clustering of Cables and Cable Landings.*