Mapping Operation & Maintenance Strategy for U.S. Offshore Wind Farms

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Overview of Collaboration

**Reference O&M Concepts for Near and Far Offshore Wind Farms**
- Understand impacts of meteorological ocean (metocean) conditions on operation and maintenance (O&M) costs
- O&M study of five offshore wind plants in the North Sea
- Tool: ECN O&M Calculator
- December 2016

**A Spatial-Economic Cost-Reduction Pathway Analysis for U.S. Offshore Wind Energy Development from 2015-2030**
- Quantify the impact of spatial characteristics of the U.S. offshore wind resource area on levelized cost of energy (LCOE)
- O&M specific tool: ECN O&M Tool
- September 2016

**Mapping O&M Strategy for U.S. Offshore Wind Farms**
- Collaboration between ECN and NREL
- O&M study of six offshore wind plants in the United States
- Tool: ECN O&M Calculator
- Anticipated joint publication 2017
NREL’s Spatial-Economic Analysis

The analysis considers:

- Four access strategies
  - Close to shore
  - Advanced close to shore
  - Medium distance
  - Far shore

- Three types of large maintenance strategies
  - In situ
  - Tow to port
  - Tow to assembly area

Key variables:
1. Metocean conditions
2. Distance from O&M port

CAPEX: Capital expenditures
OPEX: Operations and maintenance expenditures
Representative Metocean Conditions

Severe:
• Hs ~2.5 meters (m)

Moderate:
• Hs ~1.39 m

Mild:
• Hs ~0.88 m

Representative metocean conditions do not consider extreme weather events (e.g., hurricanes) or site-specific features (e.g., ice)
Distance from O&M Port and Access Strategies

**Crew Transfer Vessel (CTV)**

**Crew Transfer Vessel Advanced (CTV+)**

**Surface Effect Ship (SES)**

**Service Operations Vessel (SOV)**

Approximately 198 model runs to determine O&M costs for the various combinations of access strategies and large maintenance activities.
Total O&M Costs for Moderate Site with Turbine Supported by a Fixed-Bottom Substructure

Metocean conditions tend to drive the O&M cost compared to the distance from the O&M port.
Six U.S. Offshore Wind Sites
Wind Farm Capacity

- **600 MW (75 x 8 MW)**
  - Floating foundations

- **345 megawatts (MW) (100 x 3.45 MW)**
  - Monobucket (ice breaker) foundations

- **600 MW (100 x 6 MW)**
  - Fixed-bottom foundations

- **600 MW (100 x 6 MW)**
  - Fixed-bottom foundations

- **400 MW (50 x 8 MW)**
  - Floating foundations

- **600 MW (100 x 6 MW)**
  - Fixed-bottom foundations
Distance to Harbour

- Ashtabula: 30 kilometers (km)
- New York City: 70 km
- Kitty Hawk: 143 km
- Hueneme: 127 km
- Honolulu: 22 km
- Corpus Christi: 102 km
Water Depth Substructure

- 575 m Floating
- 700 m Floating
- 30 m Monobucket (ice breaker)
- 20–40 m Fixed bottom
- 30 m Fixed bottom
- 30 m Fixed bottom
Metocean Conditions

Avg. Wind Speed: 10.49 m/s
Avg. Wave Height: 2.01 m

Avg. Wind Speed: 8.30 m/s
Avg. Wave Height: 1.34 m

Avg. Wind Speed: 8.84 m/s
Avg. Wave Height: 1.08 m

Avg. Wind Speed: 8.32 m/s
Avg. Wave Height: 1.35 m

Avg. Wind Speed: 8.89 m/s
Avg. Wave Height: 1.27 m
Location Challenges

Deep water
>500 m deep

Hurricanes
June 1–Nov 30

Ice
11 weeks per year

Atlantic & Gulf of Mexico

Great Lakes

Pacific
Gemini (North Sea)

- 600 MW (150 x 4 MW)
- Eemshaven, 85 km
- ~30 m deep, fixed bottom
- $W_s$ & $W_h$: 9.49 m/s & 1.55 m
- Far-offshore wind farm site
Atlantic & Gulf of Mexico; Gemini (North Sea)

- **New York**
  - 600 MW (150 x 4 MW)
  - Eemshaven, 85 km
  - ~30 m deep, fixed bottom
  - $W_s$ & $W_h$: 9.49 m/s & 1.55 m
  - Far-offshore wind farm site

- **Kitty Hawk**
  - 600 MW (100 x 6 MW)
  - Between 70 km & 143 km
  - ~30 m deep, fixed bottom
  - $W_s$ & $W_h$: ~8.68 m/s, ~1.25 m

- **Gulf of Mexico**
O&M Strategies: Selection of the right mix of logistic solution.

**Primary Vessels**
- CTV
  - 12 m/s, 1.5 m
- CTV+
  - 15 m/s, 2.0 m
- SES
  - 17 m/s, 2.5 m

**Secondary Vessels**
- SOV
  - 20 m/s, 3.0 m

**Vessels for replacement**
- Daughter craft
  - 10 m/s, 1.0 m
- Helicopter (Heli)
  - 20 m/s, 4.0 m
- Jack-up barge
  - 10 m/s, 2.0 m

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**Vessels for replacement**
O&M Strategy: Selection of the logistic solution for Gemini

- **Primary access vessel**: SOV 20 m/s, 3.0 m
- **Secondary access vessel**: Helicopter 20 m/s, 4.0 m
- **Vessel for replacement**: Jack-up barge 10 m/s, 2.0 m
- **Daughter craft**: 10 m/s, 1.0 m
Gemini
(North Sea)

Validated with ECN O&M Calculator:
SOV & helicopter combined strategy

Availability (Time & Yield): 95-96%
Repair Costs (M$/year): 40
Atlantic & Gulf of Mexico; Gemini (North Sea)

New York
Kitty Hawk
Gulf of Mexico

Repair Costs (M$/yr)

~20% difference
Difference in O&M Costs: United States & Europe

Atlantic & Gulf of Mexico; Gemini (North Sea)

Repair Costs (M$/yr)

- New York: 21%
- Kitty Hawk: 20%
- Gulf of Mexico: 18%
How to Reduce the Difference in Repair Costs?

Optimisation and selection of the “most suitable O&M Strategy” with ECN O&M Calculator

- Criterion of min 95% availability (time and yield)
- Highest availability with a cost-effective solution
Outcomes

- SOV, SOV and Heli, and SES provide the best solutions in terms of availability (95%)
- SES is the most suitable O&M strategy
Outcomes

- SOV or SOV and Heli provide the highest availability
- SOV is the most cost-efficient strategy
Outcomes

- SOV, SOV and Heli, SES provide the best solutions in terms of availability
- SES is the most suitable strategy
Choice of the “most suitable” O&M Strategy

- New York: 13% (11% for Gemini)
- Kitty Hawk: 19% (10% for Gemini)
- Gulf of Mexico: 11.5% (6.5% for Gemini)

Atlantic & Gulf of Mexico; Gemini (North Sea)
How to Reduce the Difference in Repair Costs?

In-house manufacturing of vessels

- Alternative to current strategy of chartering vessels from Europe
- No additional support vessel requirement to comply with Jones Act
- Overall lower vessel price and less mobilization time
Repair Costs (M$/yr)

~19% difference
Mid-Atlantic; Gemini (North Sea)

Repair Costs (M$/yr)

Kitty Hawk

-8% 19%
U.S. Offshore Wind Challenges

Great Lakes

Pacific

Deep water

Atlantic & Gulf of Mexico

Hurricanes
Assumption: Hurricanes increase the failure rates of 20% of the most sensitive components.

Components mainly affected by hurricanes:
- **Wind Turbine:**
  - Rotor blade
  - Blade adjustment
  - Turbine structure (tower)
- **Balance of Plant:**
  - Foundations

Legend:
- Wind Farm Site
- EEZ Boundaries
- State Boundary Lines

Water Depth (m):
- -4000
- -3200
- -2400
- -1600
- -800
- 0
- 800

Gulf of Mexico
Gulf of Mexico; Gemini (North Sea)

Repair Costs (M$/yr)

11.5% 6.5% +4%
A challenge never experienced before:
Icing conditions at Lake Erie – 11 weeks per year

*Impact of the ice (in terms of availability)*
Without ice: ~ 95%
With ice: ~ 90%

Key:
Bureau of Ocean Energy Management (BOEM)
Primary access vessel accessibility only possible under 10% ice coverage

Logistic solutions:
- Ice Breaker limitation on ice coverage 50%
- Helicopter as secondary access vessel
Outcomes

- Ice breaking vessel availability: ~ +0%
- Helicopter availability: ~ +3.2%
- CTV and Heli is the most suitable strategy

Costs per kWh (c$/kWh)

- 4.27 c$/kWh
U.S. Offshore Wind Challenges

Atlantic & Gulf of Mexico

Great Lakes

Pacific

Deep water

Ice

Atlantic & Gulf of Mexico

Hurricanes
Extremely deep water conditions

North Pacific
Logistic Solution:

Large replacements by the towing vessel and 2 support barges

Outcomes:

• O&M strategy with only SES and SOV possible
• SES gives lower availability (~93%)
• SOV is the most suitable strategy

Costs per kWh (c$/kWh):

SES: 1.31 c$/kWh
SOV & Heli: 1.31 c$/kWh

North Pacific
Outcomes

- CTV+, SES, and SOV provide the highest availability
- CTV+ is the most suitable solution
“Each site needs a dedicated O&M strategy”
Leaders in O&M modeling for offshore wind
Thank You!!!

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