NREL
Transforming ENERGY

Assessing the Potential for Improved Lubricants to Reduce Wind O&M Costs

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Outline

1. Introduction: How can lubricants affect OpEx?
2. Methods: Analysis tools and scenario development
3. Results: OpEx and Time-Based Availability
4. Results: Spatial Analysis
5. Conclusions
6. Q&A

Background

- Operations and maintenance (O&M) costs make up between 17% and 34% of the lifetime cost of wind energy.
- Gearbox maintenance is a significant cost driver:
  - High repair cost
  - Relatively high failure rate.
- Opportunity for new lubricants to reduce costs associated with gearbox maintenance.

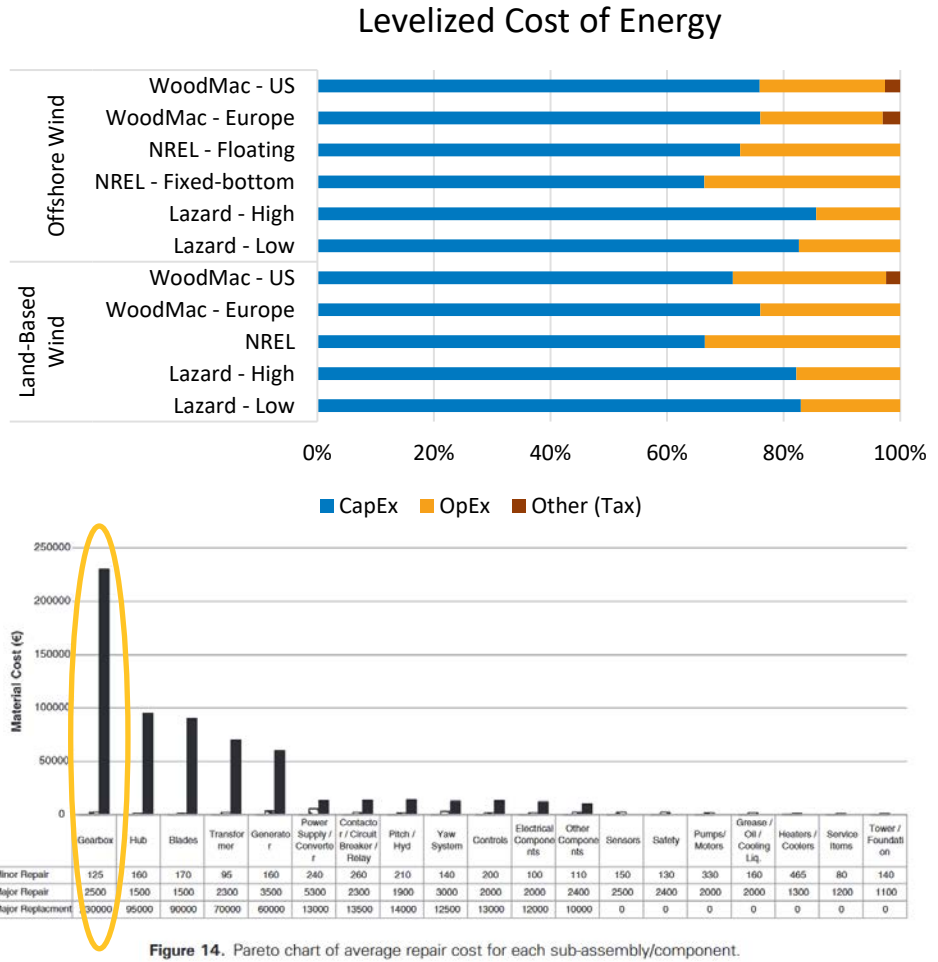


Figure 14. Pareto chart of average repair cost for each sub-assembly/component.

Figure sources: (Top) Data from Wood Mackenzie 2022 (“WoodMac”); Wood Mackenzie 2023; Stehly & Duffy 2022 (“NREL”); Lazard 2023. (Bottom) Figure from Carroll et al. 2016.

Lubricant Impacts

Opportunities to reduce O&M costs:

- Enable operation in colder weather
- Reduce frequency of oil changes
- Lower cost of oil replacement
- Improve gearbox efficiency
- Reduce gearbox failure rates by lowering friction and temperature.

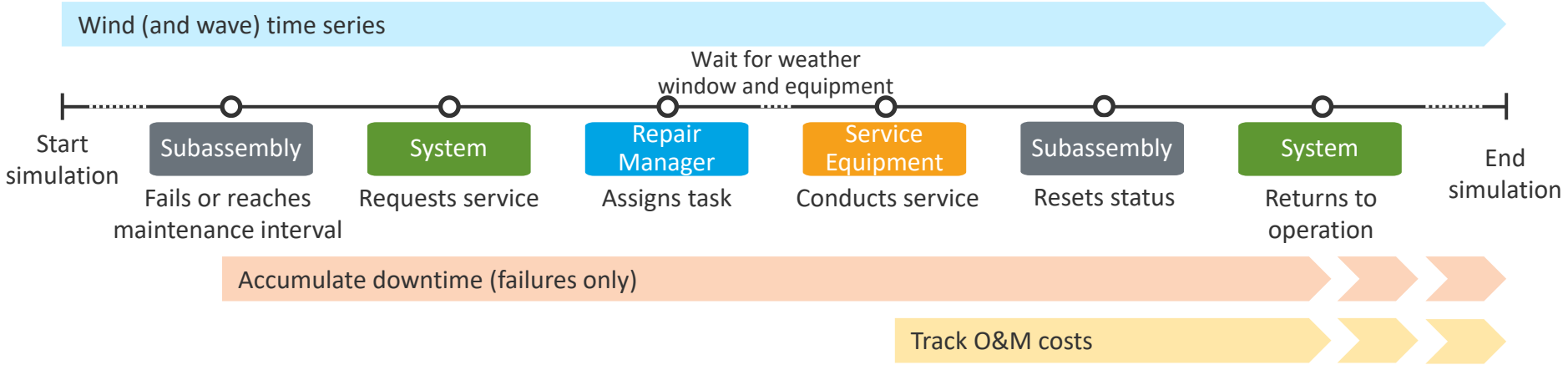
Photo by Jon Keller, NREL

Scenario Development

Improvement Mechanism	Scenario		
	Baseline	**Realistic**	**Stretch**
Oil change frequency	Every 5 years	Every 7 years (−29%)	Every 10 years (−50%)
Oil cost	$15/liter	$10/liter (−33%)	$5/liter (−67%)
Cold weather operation	21 hours of cold weather stoppage per year in Ice Class 2+	15 hours / year (−29%)	9 hours/year (−57%)
Gearbox efficiency	Unmodified reference power curve	+0.5% at <10% load +0.2% at 10–50% load +0.1% at >50% load	+1.0% at <10% load +0.4% at 10–50% load +0.2% at >50% load

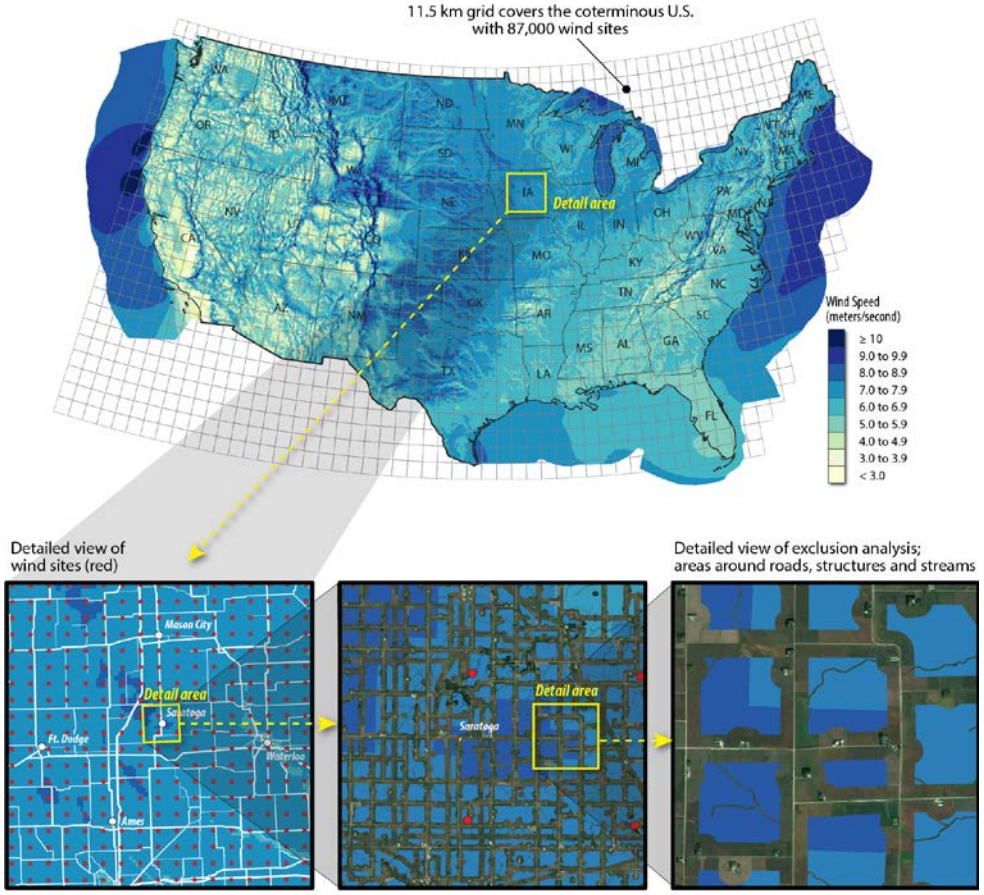
WOMBAT: Windfarm Operations and Maintenance cost-Benefit Analysis Tool

- https://github.com/WISDEM/WOMBAT
- WOMBAT evaluates O&M costs using discrete event simulation—a series of events in sequential order where no changes occur between events.
- Each subassembly has user-defined repair and maintenance tasks with their own timing.



The Renewable Energy Potential Model (reV)

A high-performance computing model for massive spatial-temporal data



reV is a geospatial platform for assessing system performance, available capacity, transmission siting, and total costs for potential wind and solar energy deployment (Maclaurin et al. 2019).

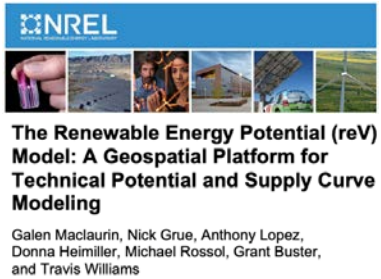
reV is used to contextualize and quantify the broader challenges facing wind (and solar) technology, as it is increasingly relied on at higher contributions in the electricity sector, through higher- and mixed-fidelity modeling at a national scale.

Multi-Resolution Spatial Hierarchy

- 90-m spatial constraints/characterizations
- 2-km wind resource
- 4-km solar resource
- 11.5-km wind/photovoltaics “sites” (~67,000)

Site Characteristics

- Hourly multi-year generation profiles (red dots)
- Installable capacity
- Site and spur-transmission costs
- Land characteristics (e.g., land-cover, species habitat, avian risk, radar LOS, and more)



Levelized Cost of Energy

$$LCOE = \frac{(FCR * CapEx) + OpEx}{AEP_{net}}$$

where:

LCOE = levelized cost of energy ($/MWh)
FCR = fixed charge rate (%/year)
CapEx = capital expenditures ($/kW)
OpEx = average annual operational expenditures ($/kW/year)
AEP_{net} = net average annual energy production (MWh/year)

LCOE is helpful to compare projects/technologies with different cash flow profiles and over time.
LCOE does not capture the locational and time value of the generated energy and other services.

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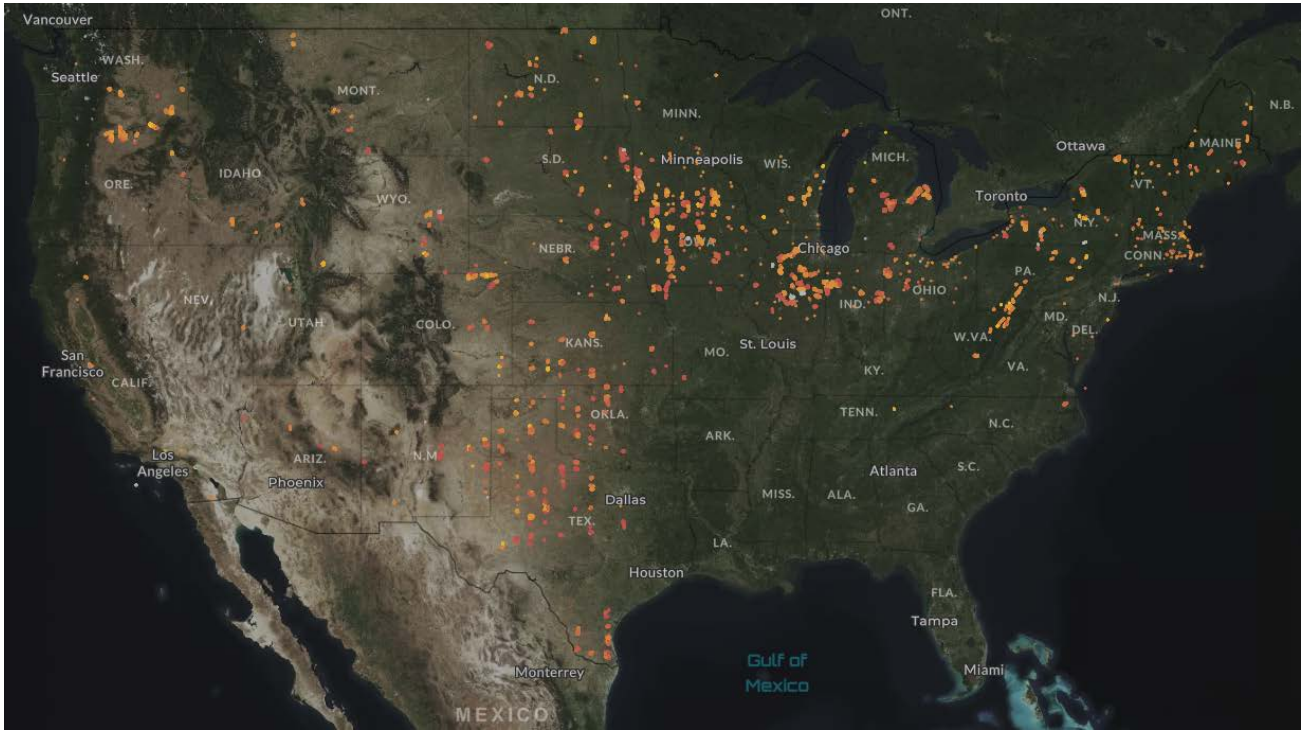
CapEx = capital expenditures ($/kW) NO CHANGE
OpEx = average annual operational expenditures ($/kW/year) WOMBAT (cost)
AEP_{net} = net average annual energy production (MWh/year)
WOMBAT (time-based availability)
reV (updates to power curves & spatial variation)

LCOE is helpful to compare projects/technologies with different cash flow profiles and over time.
LCOE does not capture the locational and time value of the generated energy and other services.

Current U.S. Wind Turbine Fleet

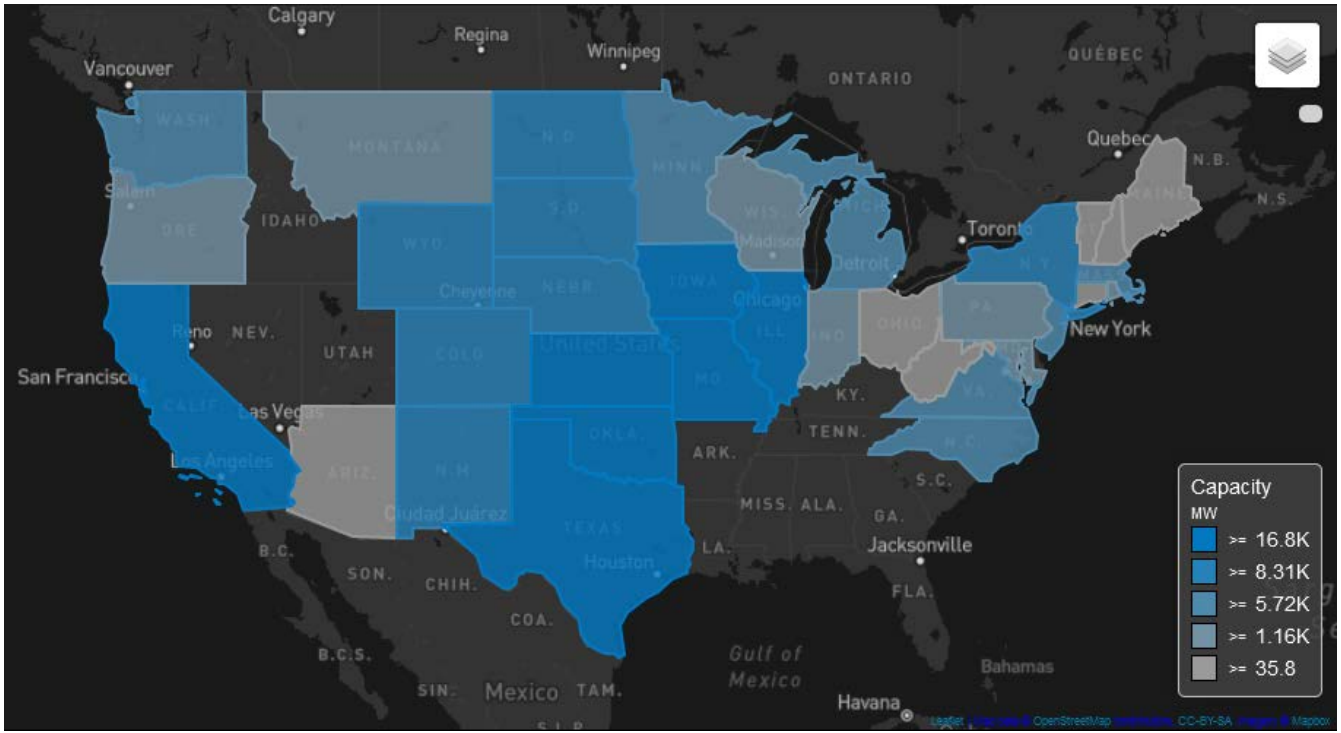
U.S. Wind Turbine Database (Hoen et al. 2023)



- ~142 GW
- ~73,000 wind turbines
- Represented in reV by 1.5-MW turbines at each location.

Future U.S. Wind Turbine Fleet

2050 Standard Scenario Mid-Case (Gagnon et al. 2022)



Land-Based Wind

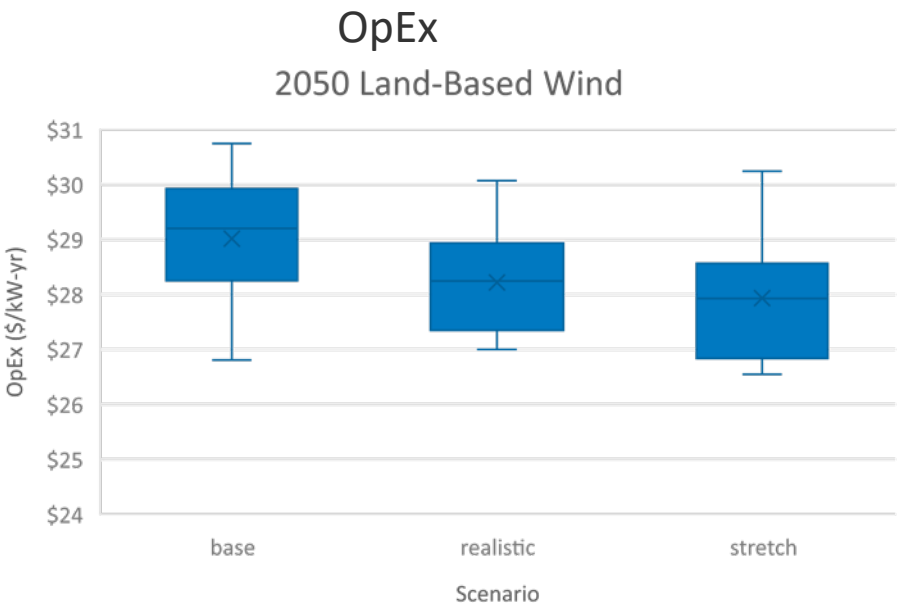
- 345 GW
- Represented in reV by 5.5-MW turbines.

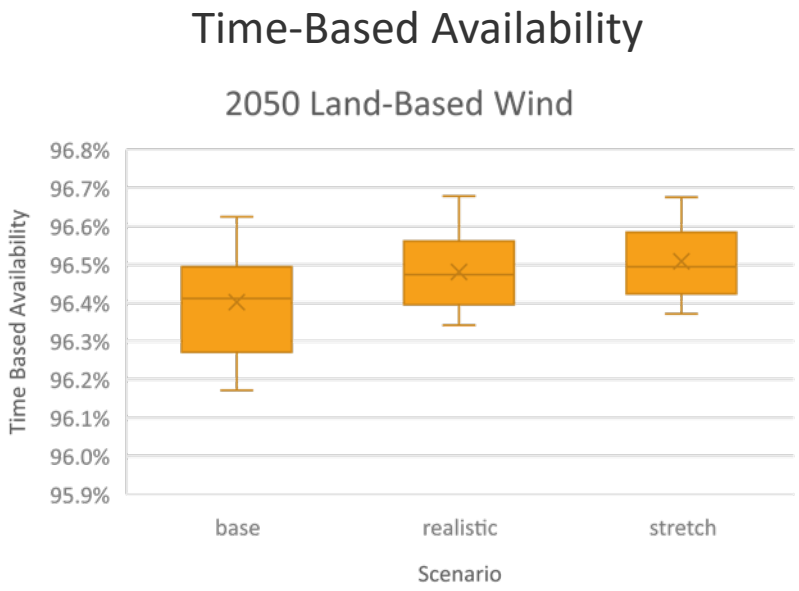
Offshore

- 61 GW, of which 30.5 GW geared
- 15-MW turbines.

Results

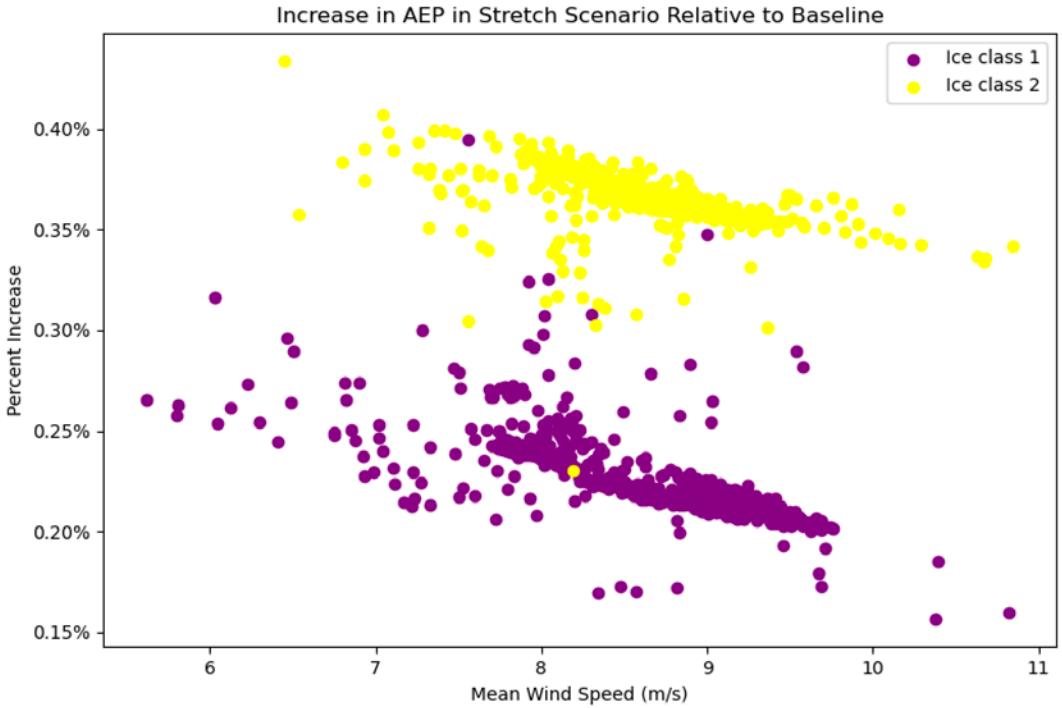
WOMBAT Results 5.5 MW





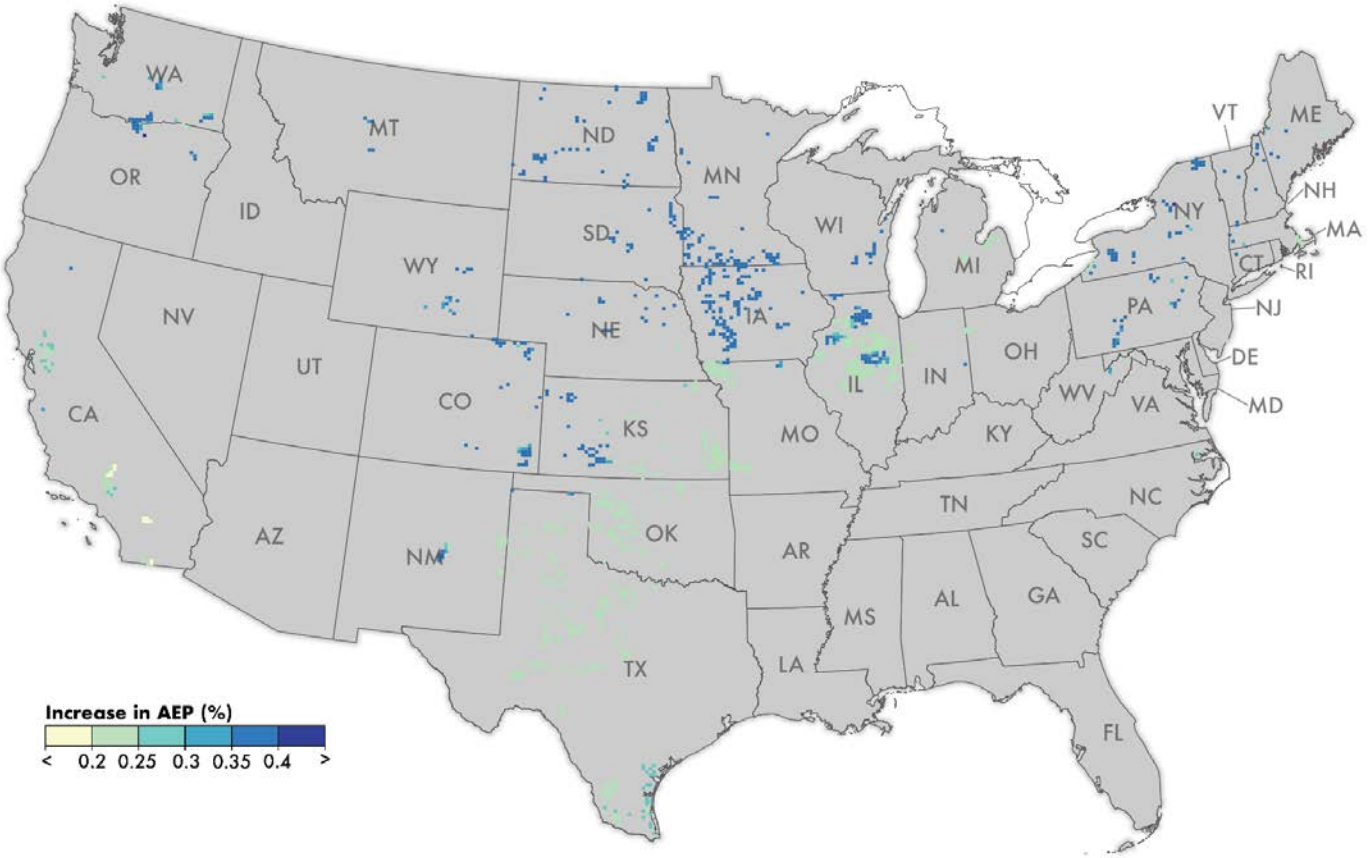
Results: 2050 Land-Based Wind Fleet (~333 GW)

- Spatial variation in costs comes from regional CapEx (no variation between scenarios) and AEP (varies between scenarios)
  - Site-based AEP improved by about 0.29% on average in stretch relative to baseline
  - Spatial variation in AEP improvements is 0.28%, largely due to cold region TBA improvements.
- Average site-based LCOE reduction of 1.91% in stretch relative to baseline
  - 0.56% spatial variation.



About 43% of plants in Ice Class 2+

Results: 2050 Land-Based Wind Fleet (~333 GW)



OpEx Sensitivities

- Land-based wind in 2050
- 5.5-MW Annual Technology Baseline turbine
- Varied cost and frequency of lubricant replacement
- All values relative to base case.

Scenarios		Lubricant Cost		
		$15/liter	$10/liter	$5/liter
Replacement Frequency	5 years	Base	1	4
	7 years	2	Realistic	
	10 years	3		Stretch

OpEx – Comparison With Base

$/kW-yr	$15/liter	$10/liter	$5/liter
5 years	$ -	−$0.26	−$0.36
7 years	−$0.14	−$0.35	
10 years	−$0.32		−$0.48

$2,650 per turbine per year

TBA – Comparison With Base

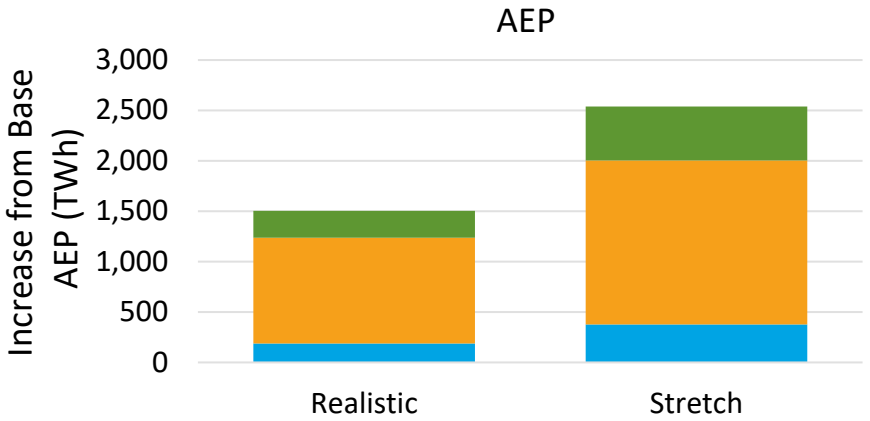
%	$15/liter	$10/liter	$5/liter
5 years	-	-	-
7 years	0.02%	0.02%	
10 years	0.04%		0.04%

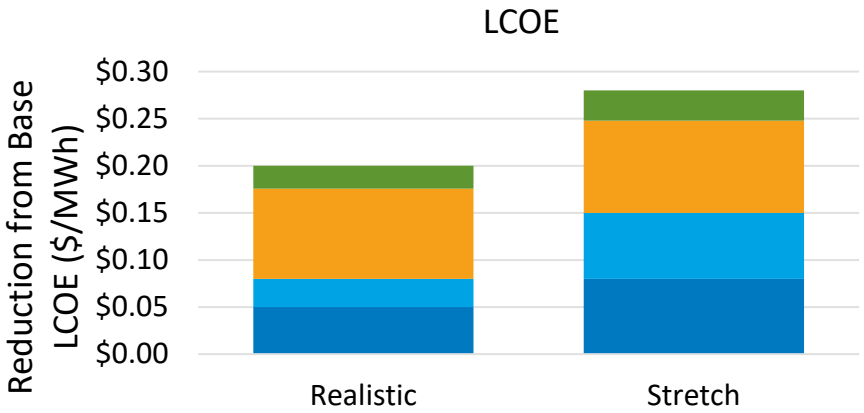
1.4 hours per year

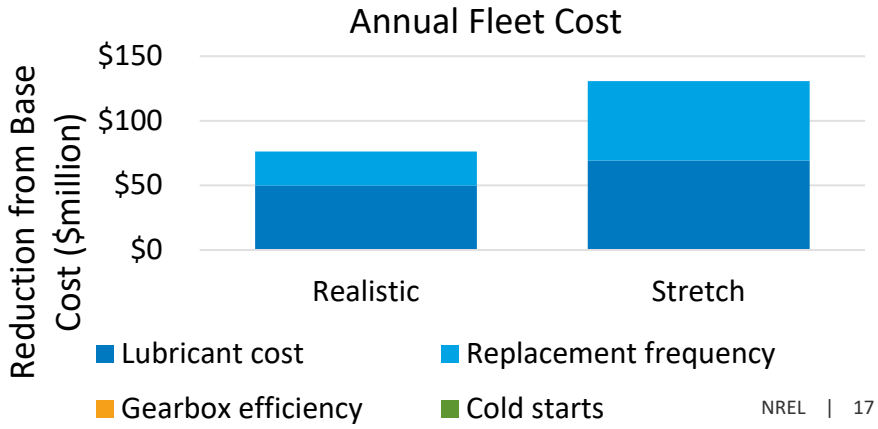
2 hours per year

Sensitivity Analysis

- AEP is affected by changes to replacement interval, gearbox efficiency, and cold-start reductions.
- Variations in annual fleet costs are only affected by lubricant cost and oil replacement frequency.
- Efficiency improvements have the largest effect on LCOE.







Conclusions

- Modeled improvements in lubricant reduce OpEx and increase time-based availability and annual energy production.
- Lubricant improvements in Stretch scenario reduce median levelized cost of energy by 0.8%–2.0%.
  - Gearbox efficiency improvements led to the largest LCOE reductions, followed by oil cost reductions.
- Efficiency improvements have the largest impact in low-wind-speed regions.

Photo by Werner Slocum, NREL

Thank you!

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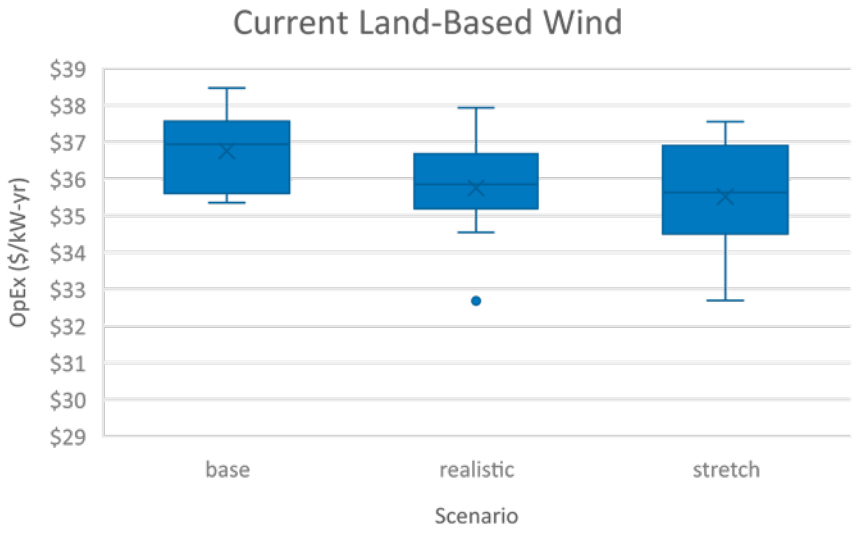
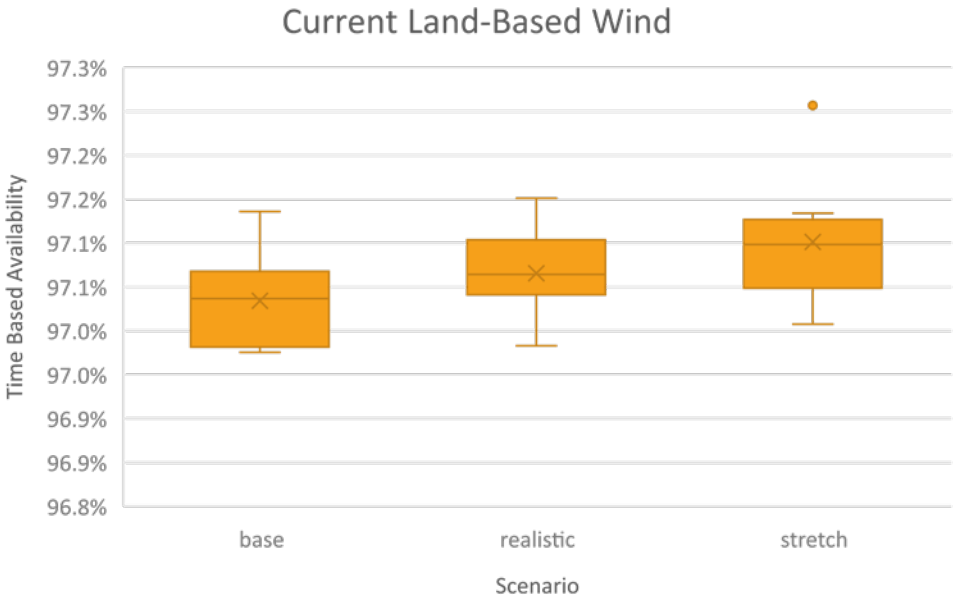
WOMBAT Results 1.5 MW

OpEx

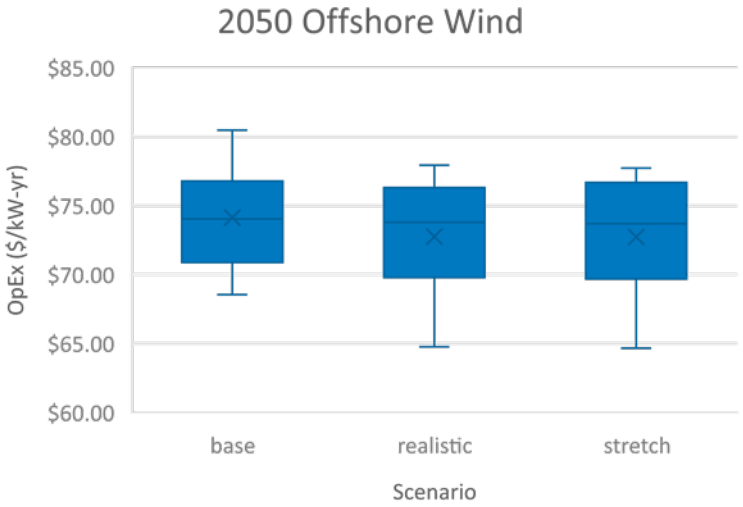


Time-Based Availability



WOMBAT Results 15 MW

OpEx



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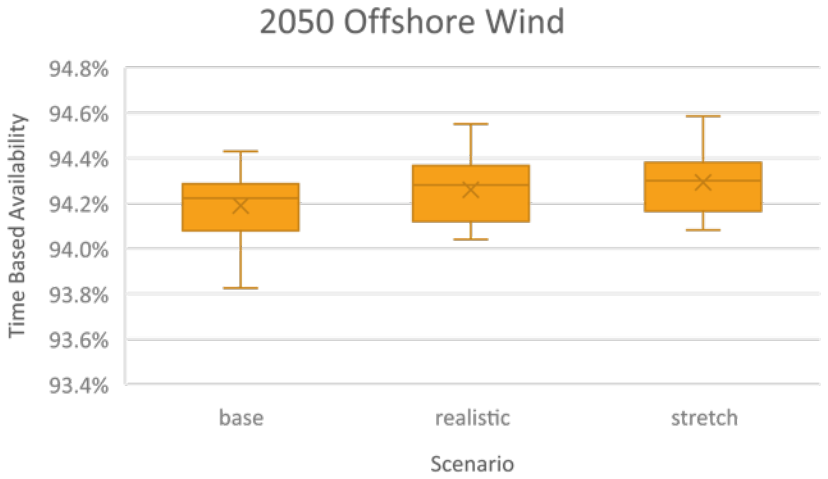
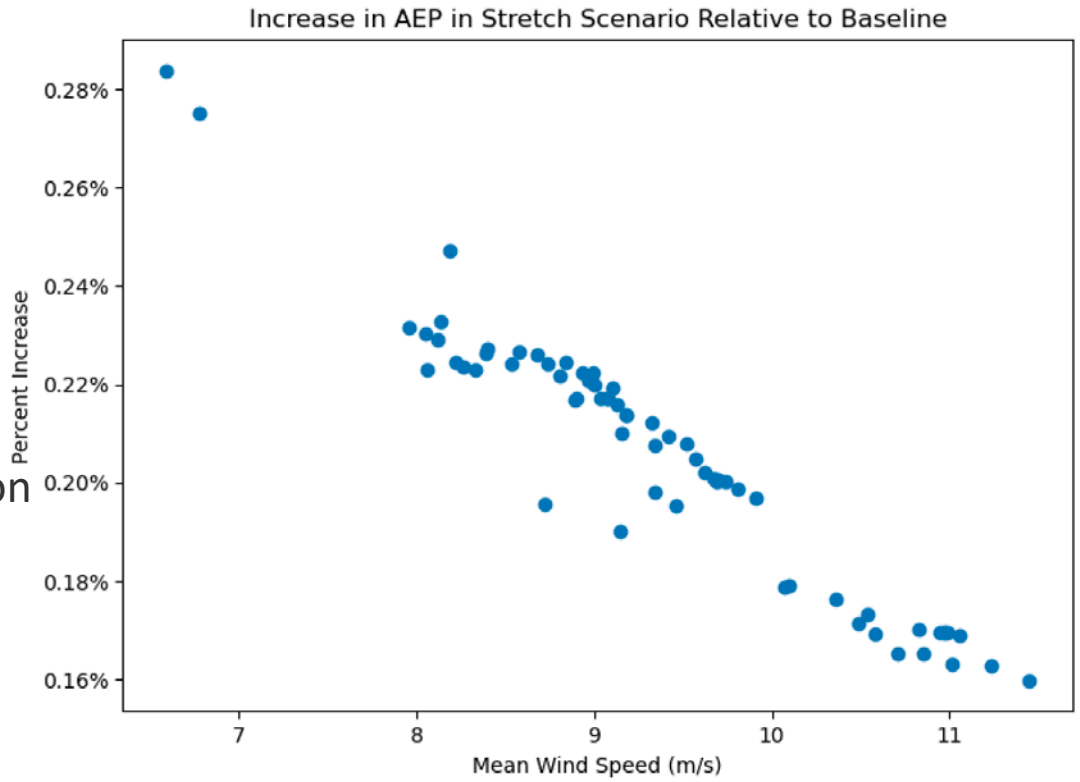


Results: 2050 Offshore Wind Fleet (~30.5 GW)

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