The Future of Wind Energy: Work From The UMass IGERT

Presented by Erin Baker

Professor, *Industrial Engineering and Operations Research*

Director, *NSF IGERT: Offshore Wind Energy, Environmental Impacts, and Policy*

University of Massachusetts Amherst

EXPERT ELICITATION SURVEY ON FUTURE WIND ENERGY COSTS

Presented by Erin Baker
Professor, *Industrial Engineering and Operations Research*
Director, *NSF IGERT: Offshore Wind Energy, Environmental Impacts, and Policy*
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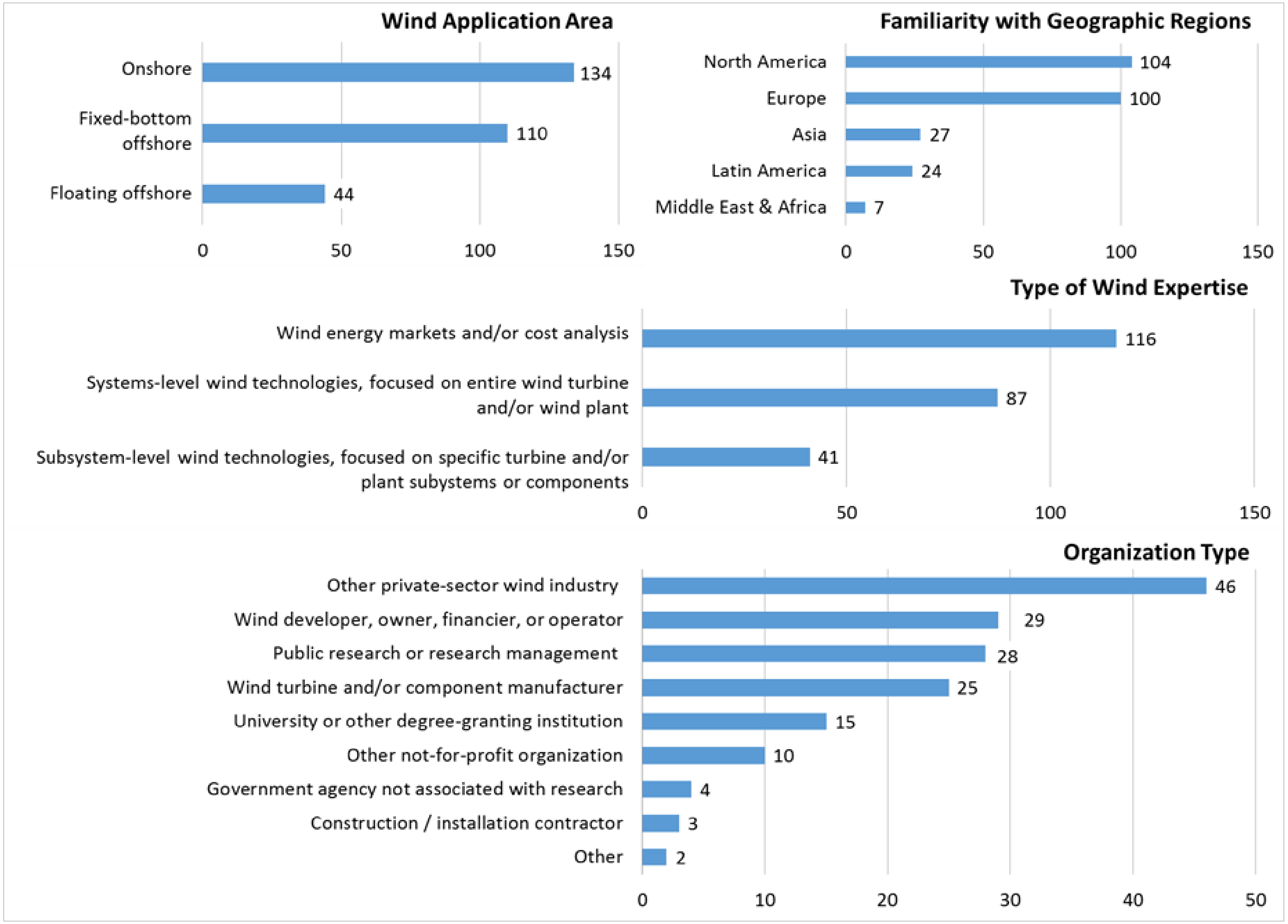
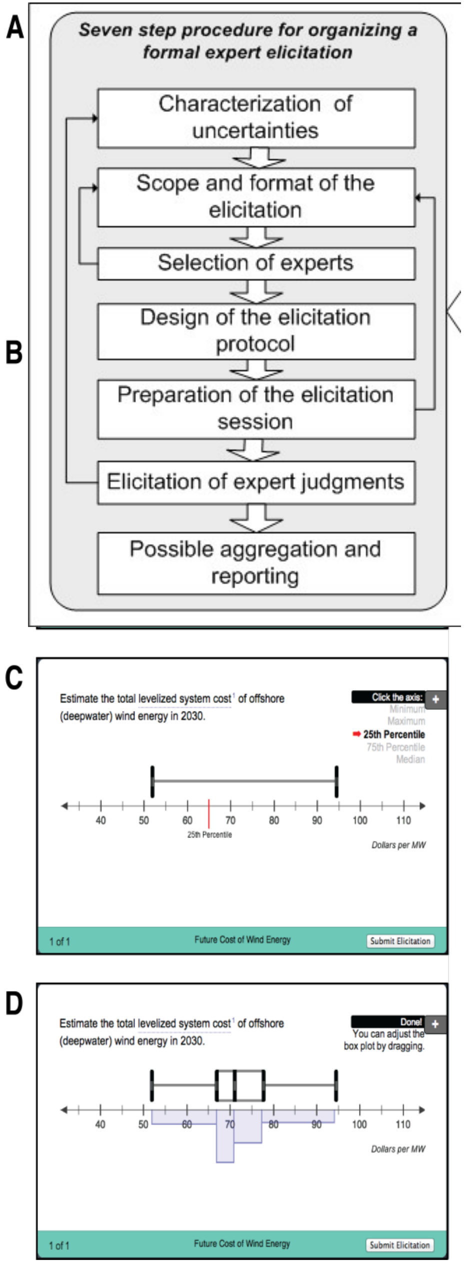
Based on: *Wiser, Jenni, Seel, Baker, Hand, Lantz, & Smith* (2016) ***Nature Energy*** *Vol 1 : 16135*

Expert Elicitation

A structured method for eliciting subjective probabilities from experts.





Seven step procedure for organizing a formal expert elicitation

- Characterization of uncertainties
- Scope and format of the elicitation
- Selection of experts
- Design of the elicitation protocol
- Preparation of the elicitation session
- Elicitation of expert judgments
- Possible aggregation and reporting

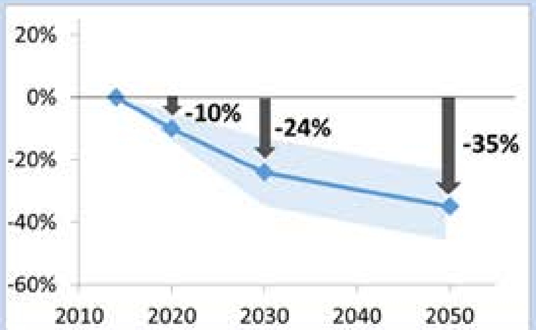
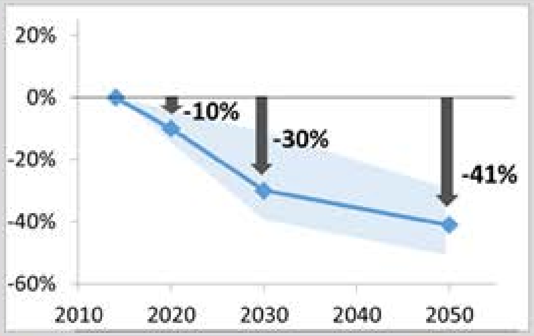
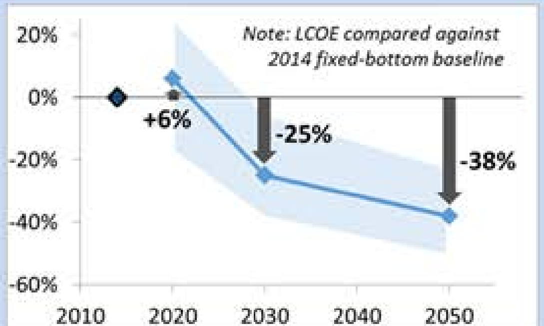
Estimate the total levelized system cost[1] of offshore (deepwater) wind energy in 2030.

Estimate the total levelized system cost[1] of offshore (deepwater) wind energy in 2030.

Done!

You can adjust the box plot by dragging.

Summary of key results

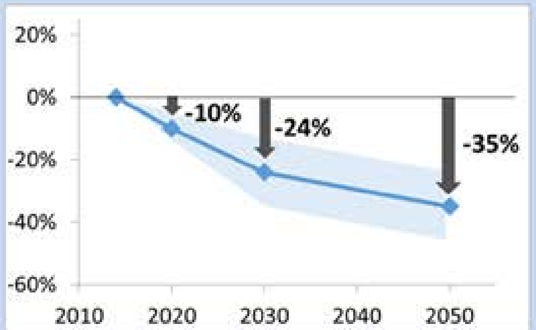
	ONSHORE (LAND-BASED)	FIXED-BOTTOM OFFSHORE	FLOATING OFFSHORE
a) LEVELIZED COST OF ENERGY			Note: LCOE compared against 2014 fixed-bottom baseline
b) DRIVERS FOR COST REDUCTION IN 2030	Capacity factor: +10% Project life: +10% CapEx: -12% OpEx: -9% WACC: no Δ	Capacity factor: +4% Project life: +15% CapEx: -14% OpEx: -9% WACC: -10%	Capacity factor: +9% Project life: +25% CapEx: -5% OpEx: -8% WACC: -5%
c) TURBINE SIZE IN 2030	3.25 MW 115 m hub height 135 m rotor diameter	11 MW 125 m hub height 190 m rotor diameter	9 MW 125 m hub height 190 m rotor diameter
d) TOP-FIVE IMPACT CATEGORIES	• Larger rotors, reduced specific power • Rotor design advancements • Taller towers • Reduced financing costs • Component durability / reliability	• Larger turbine capacity • Foundation / support structure design • Reduced financing costs • Economies of scale via project size • Component durability / reliability	• Foundation / support structure design • Installation process efficiencies • Foundation / support manufacturing • Economies of scale via project size • Installation / transport equipment

Summary of key results

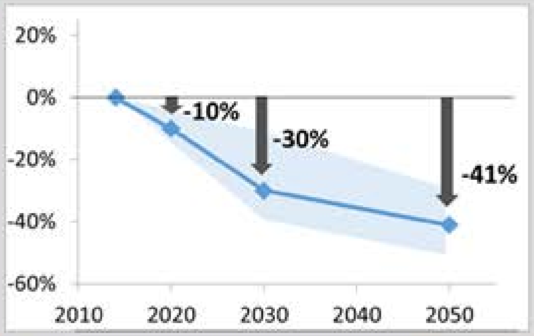
	ONSHORE (LAND-BASED)	FIXED-BOTTOM OFFSHORE	FLOATING OFFSHORE

a) LEVELIZED COST OF ENERGY

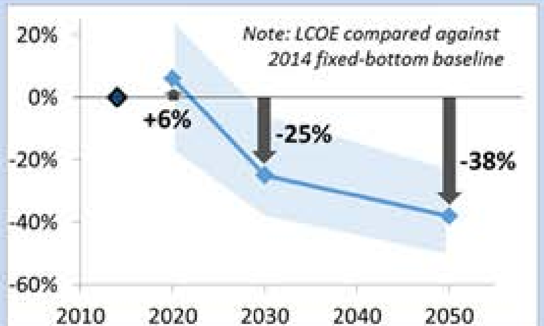
ONSHORE (LAND-BASED)



FIXED-BOTTOM OFFSHORE



FLOATING OFFSHORE



Note: LCOE compared against 2014 fixed-bottom baseline

b) DRIVERS FOR COST REDUCTION IN 2030

Capacity factor: +1
Project life: +10%

CapEx: -1
OpEx: -9
WACC: n

factor: +9%
fe: +25%

CapEx: -5%
OpEx: -8%
WACC: -5%

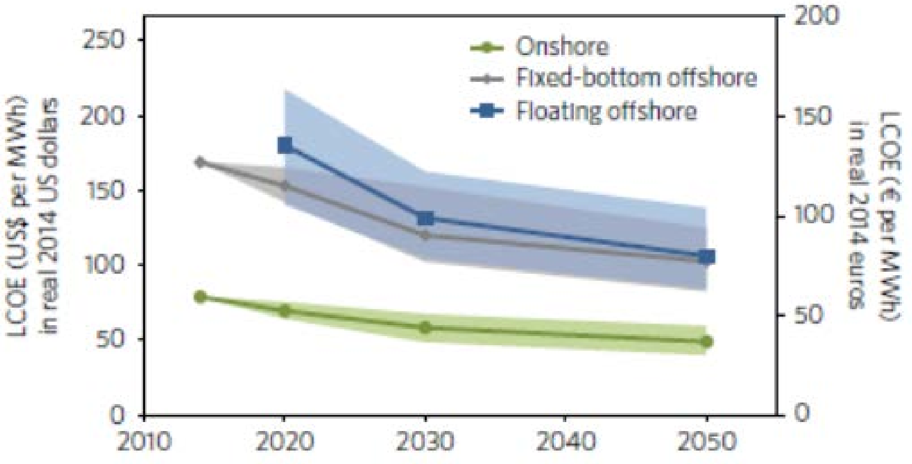


Figure 2 | Expert estimates of median-scenario LCOE. Lines/markers indicate the median-expert response for the median LCOE scenario. Shaded areas show the first to third quartiles of expert responses. A review of expert responses for the low and high LCOE scenarios is included in the Supplementary Discussion.

c) TURBINE SIZE IN 2030

3.25 MW
115 m hub
135 m rot

9 MW
125 m hub height
190 m rotor diameter

d) TOP-FIVE IMPACT CATEGORIES

- Larger rotors, reduced s
- Rotor design advanceme
- Taller towers
- Reduced financing costs
- Component durability / reliability

- Reduced financing costs
- Economies of scale via project size
- Component durability / reliability

- / support structure design
- process efficiencies
- Foundation / support manufacturing
- Economies of scale via project size
- Installation / transport equipment

Summary of key results

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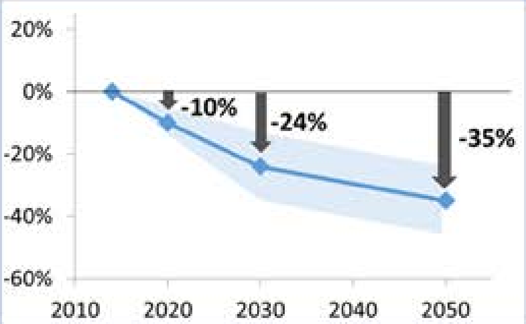
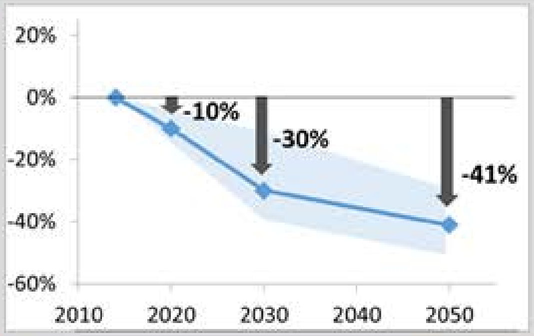
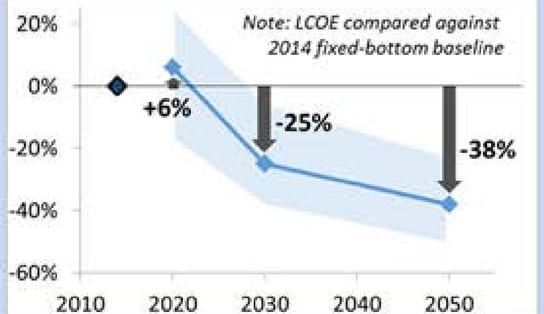
a) LEVELIZED COST OF ENERGY			
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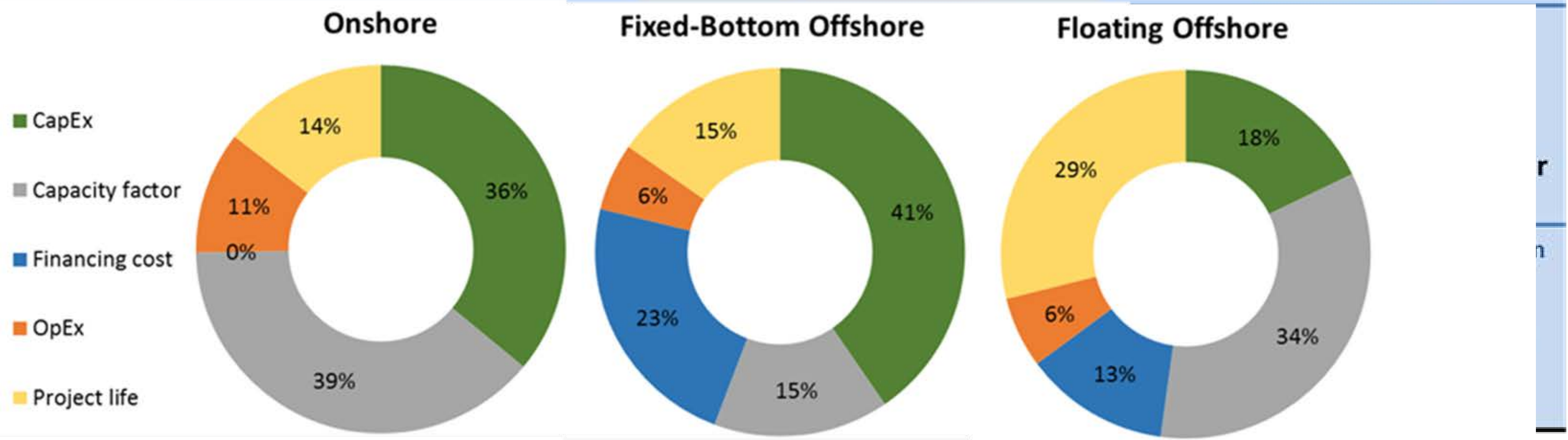
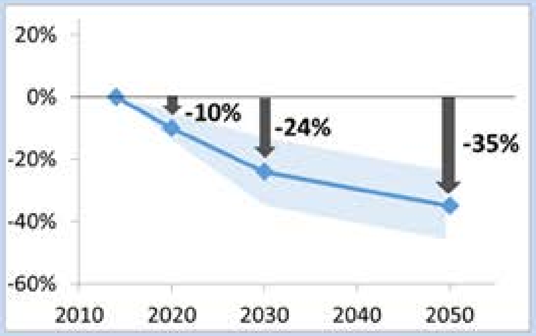
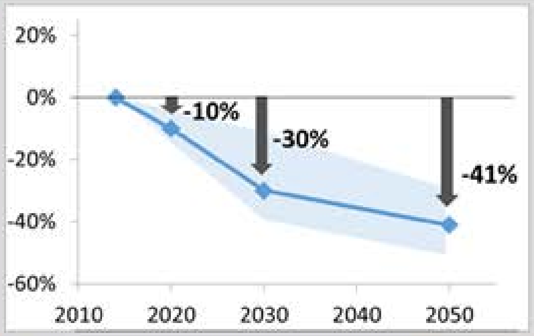
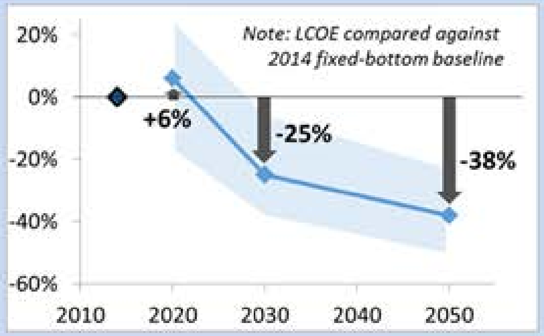
Note: LCOE compared against 2014 fixed-bottom baseline



Summary of key results

	ONSHORE (LAND-BASED)	FIXED-BOTTOM OFFSHORE	FLOATING OFFSHORE
a) LEVELIZED COST OF ENERGY			*Note: LCOE compared against 2014 fixed-bottom baseline*
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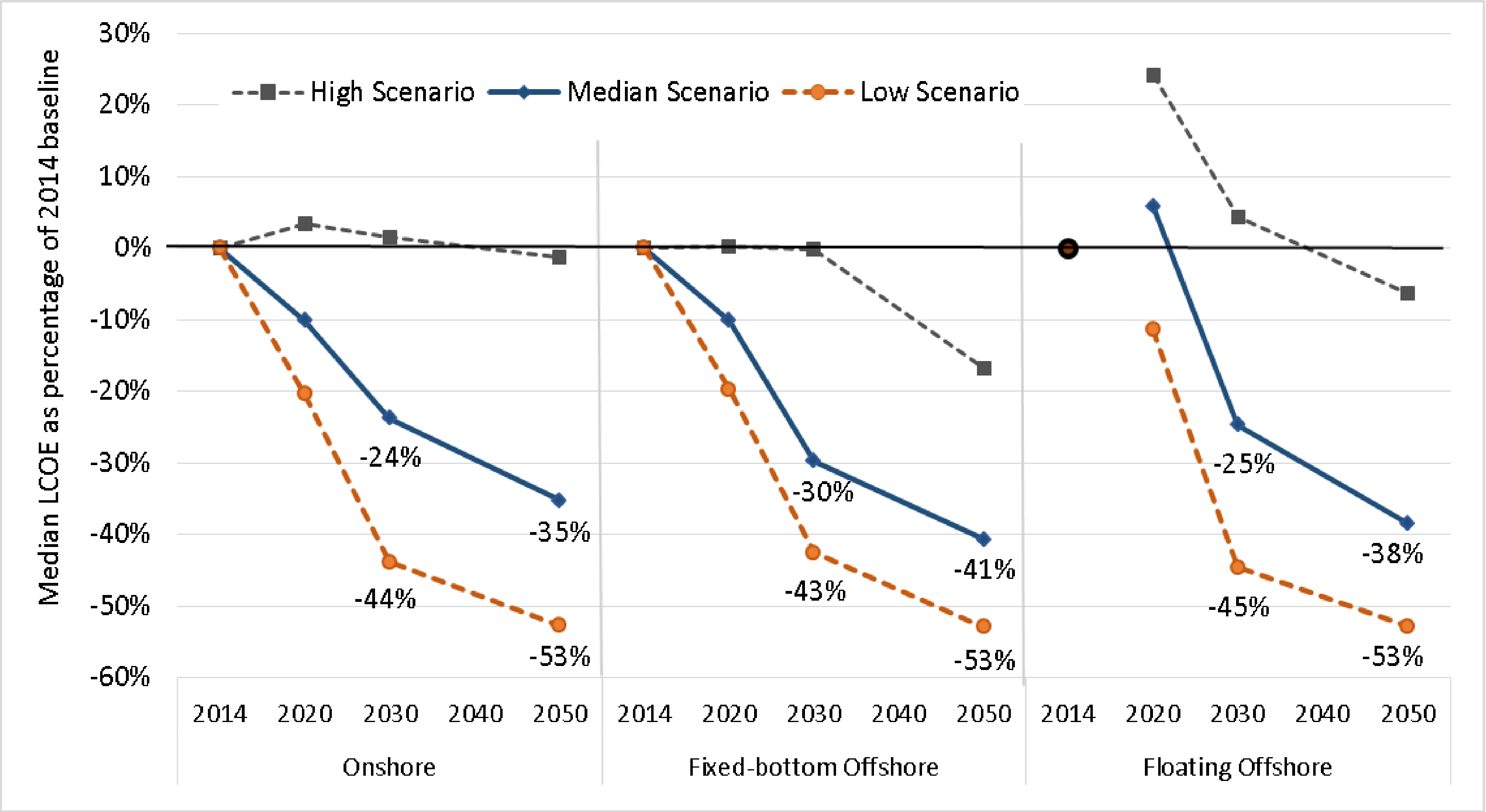
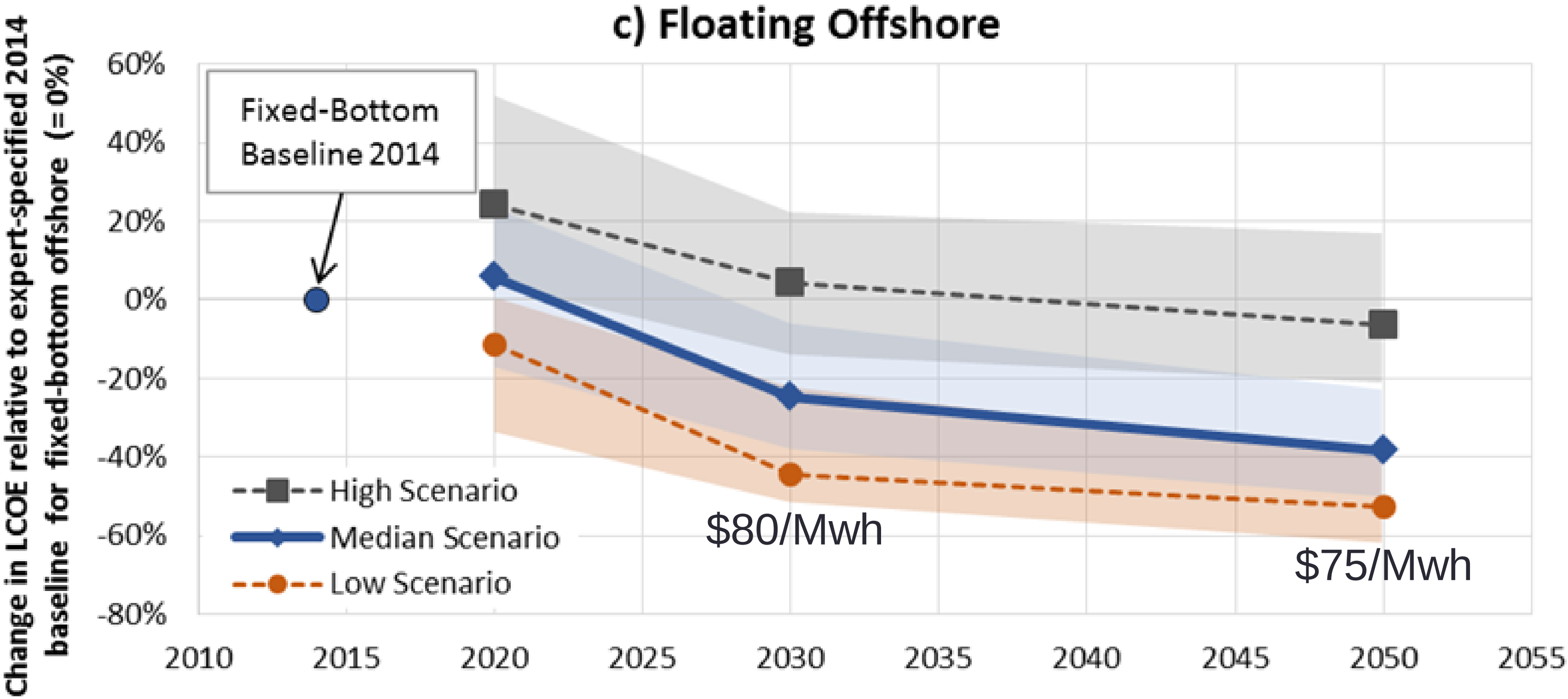
Estimated Change in LCOE over time



Estimated change in LCOE over time across all three scenarios. Depicts the median of expert responses for expected LCOE reductions in the median (50th percentile) scenario as well as the low scenario (10th percentile) and high scenario (90th percentile) in percentage terms relative to 2014 baseline values. Floating offshore wind is compared against the 2014 baseline for fixed-bottom offshore. See Supplementary Discussion for full results.

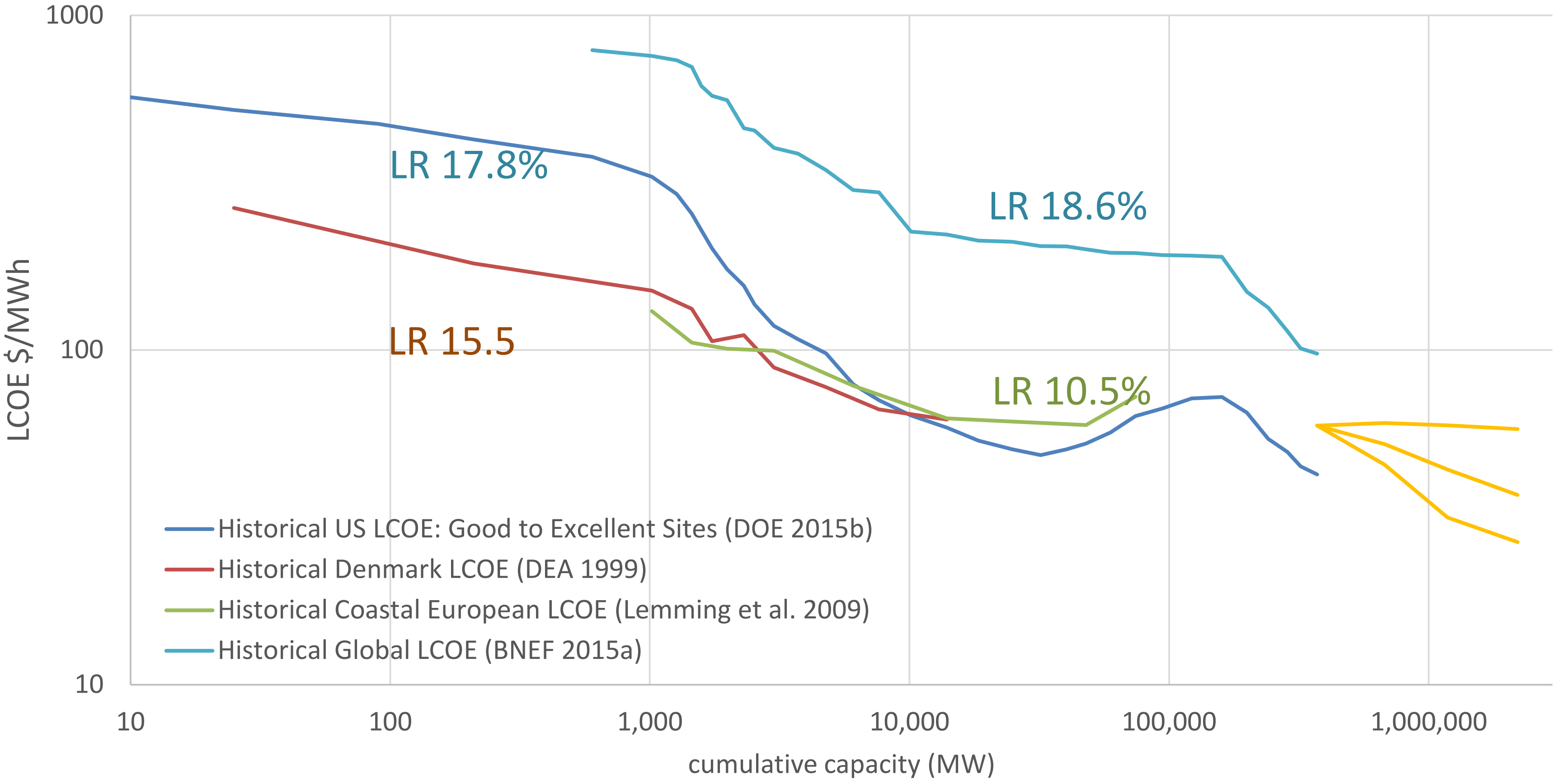
Significant uncertainty around cost reductions for floating offshore



Lines/markers indicate the **median** expert response
Shaded areas show the 1st-3rd quartile range of expert responses

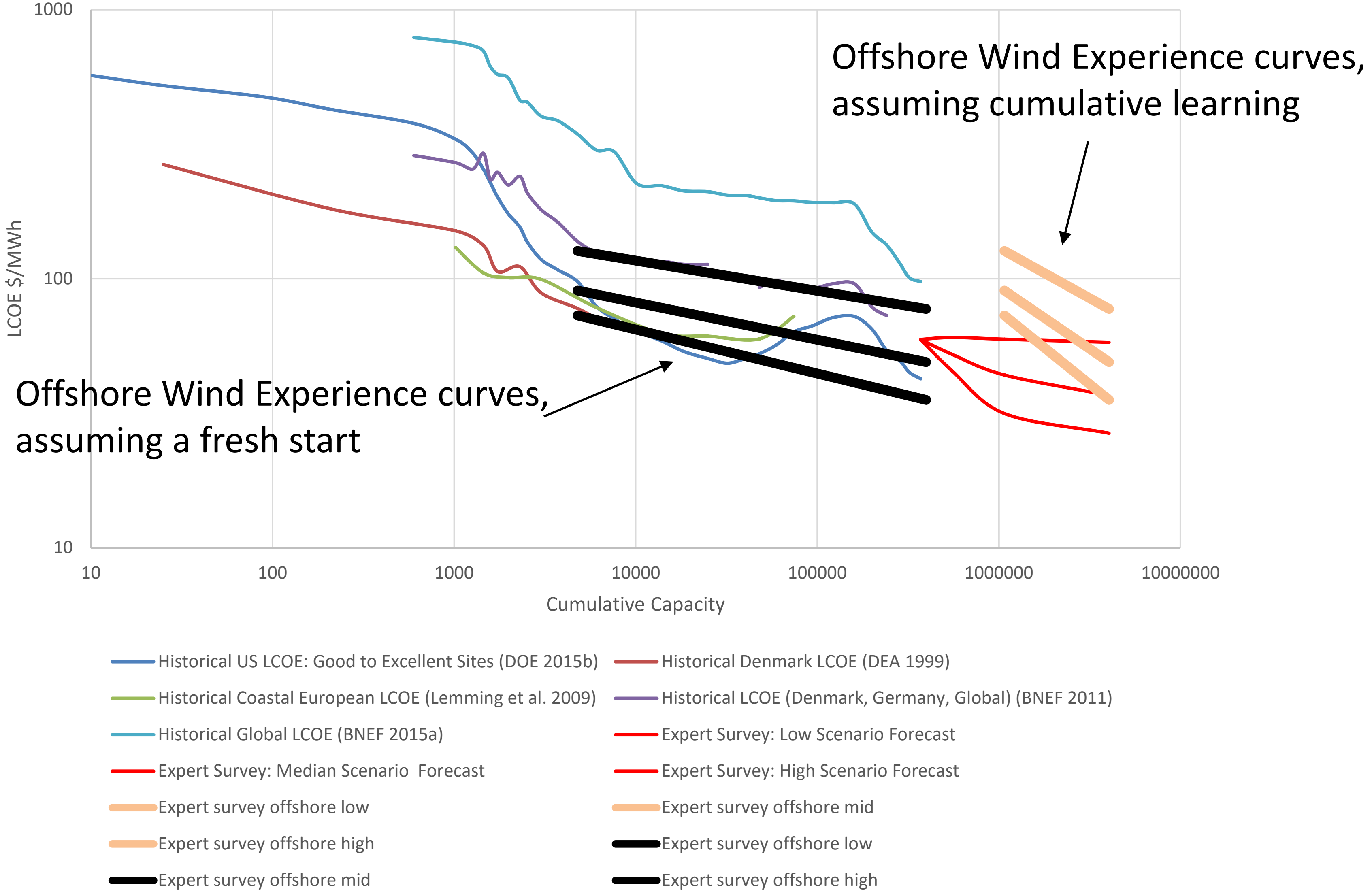
Note: Change is shown relative to baseline for fixed-bottom offshore as no 2014 baseline was established for floating offshore

Historical and forecast experience curves for onshore wind



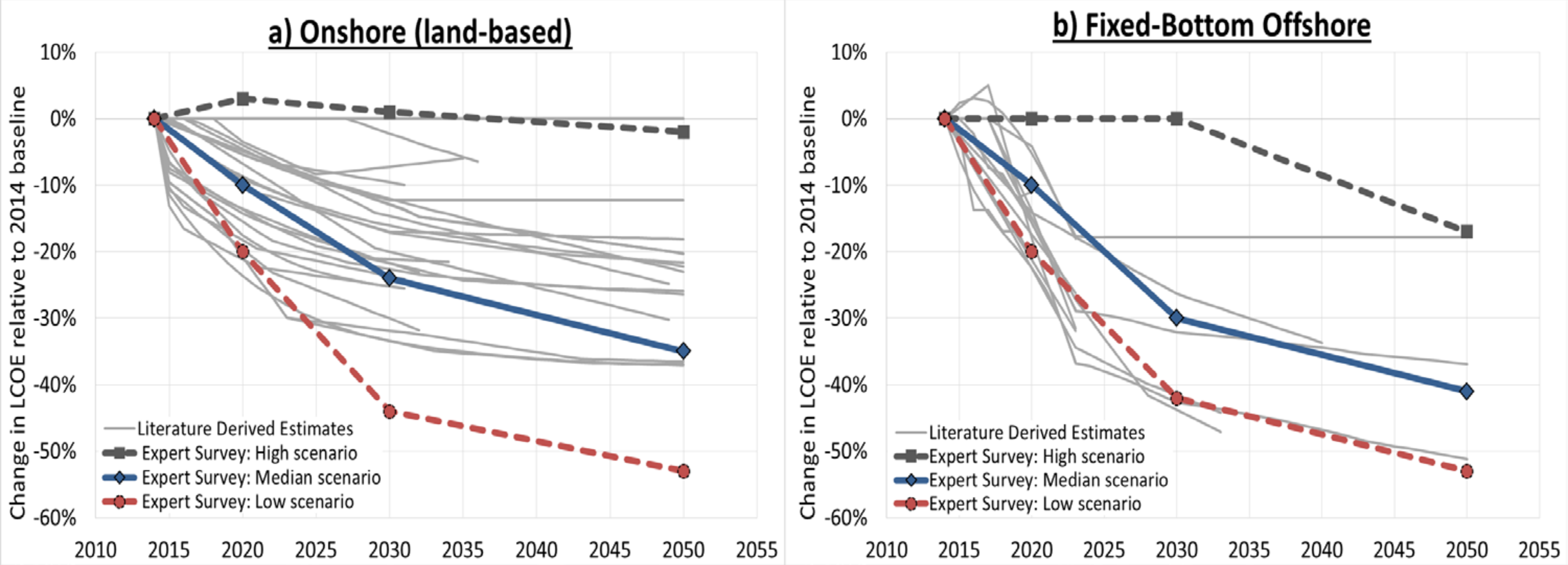
Historical LCOE estimates come from four sources (Global: BNEF 2015a; US: DOE 2015b; Denmark: DEA 1999; European Coastal: Lemming et al. 2009). Historical single-factor learning rates (LRs) are calculated based on cumulative global wind capacity. To estimate the implicit learning rate from the expert elicitation, we use median-scenario LCOE estimates and a range of projections for cumulative global wind capacity from IEA “New Policies” (IEA 2015), Bloomberg “Base Scenario” (BNEFb 2015), and GWEC “Moderate Scenario” (GWEC 2014).

Forecast experience curves for offshore wind



Offshore Wind Experience curves, assuming cumulative learning

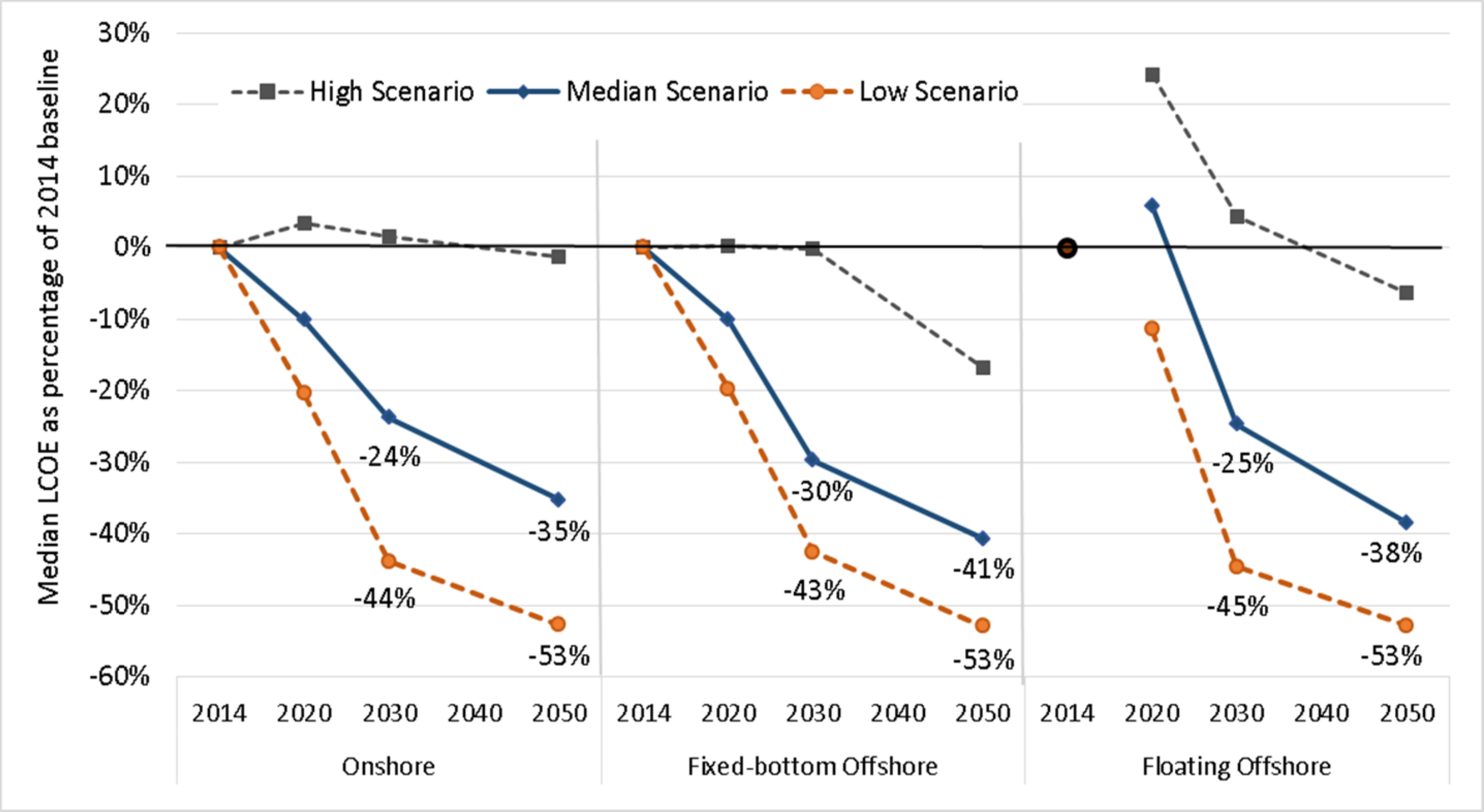
Offshore Wind Experience curves, assuming a fresh start



Estimated change in LCOE for (a) onshore and (b) fixed-bottom offshore: expert survey results vs. other forecasts. Depicts the median of expert responses for expected LCOE reductions in the median (50th percentile) scenario as well as the low scenario (10th percentile) and high scenario (90th percentile) in percentage terms relative to 2014 baseline values. Other forecasts are included for comparison, originally compiled and presented in a U.S. Department of Energy report (DOE 2015).

Conclusions

- Significant opportunity for cost reductions
- Option value in policies that increase future flexibility



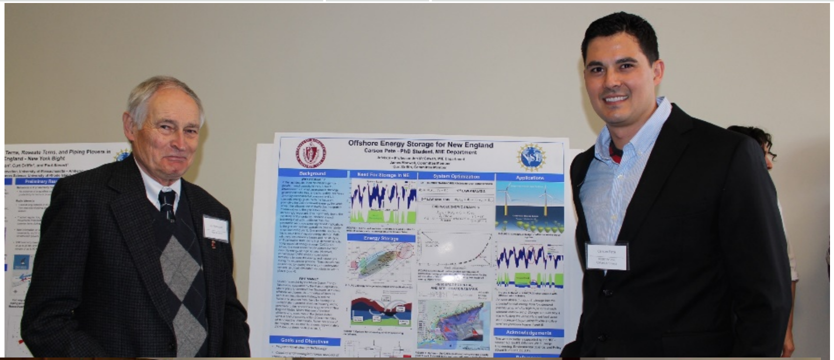
IGERT: Offshore Wind Energy Engineering, Environmental Impacts, and Policy

University of Massachusetts, Amherst

Erin Baker, Professor of Industrial Engineering and Operations Research,
Director of IGERT

A diverse group of PhD students interested in Wind Energy

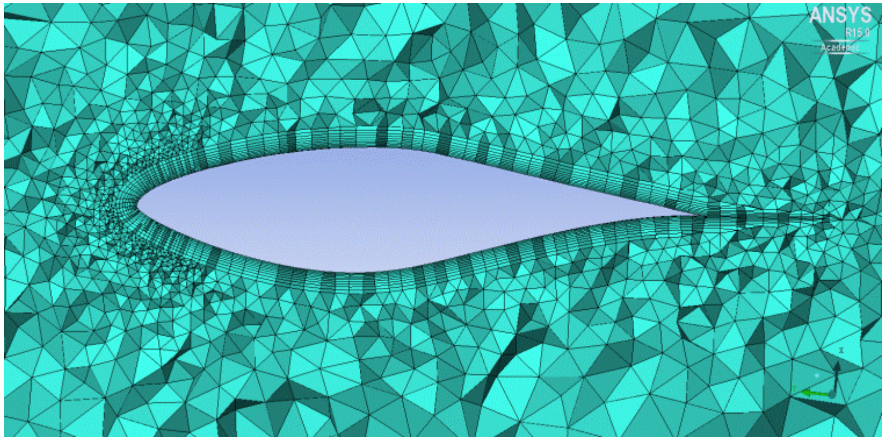
Area	#	Majors
Engineering	17	Mech, Indus, Civil
Environment	9	Wildlife ecology
Policy	4	Env. Conservation; Planning; Poli Sci

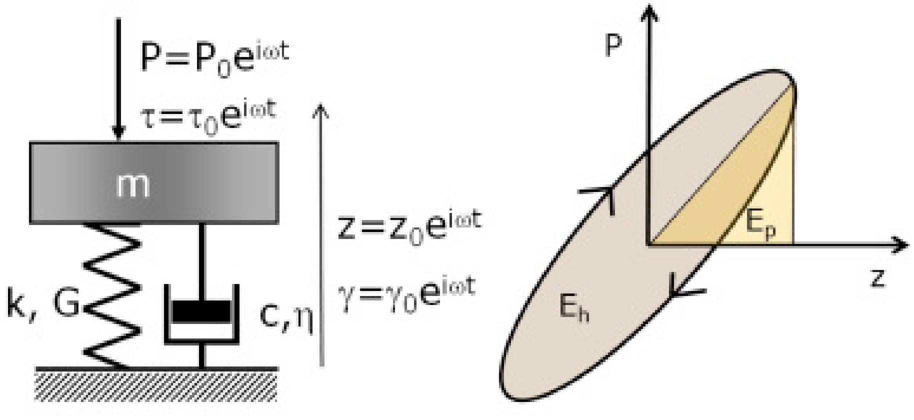


IGERT Fellows, Associates, and Alumni 2015-2016

Engineering Offshore Wind Energy Systems

- *17 fellows*
- *Departments of*
  Mechanical & Industrial Engineering
  Civil & Environmental Engineering
  Electrical & Computer Engineering





(A) (B)

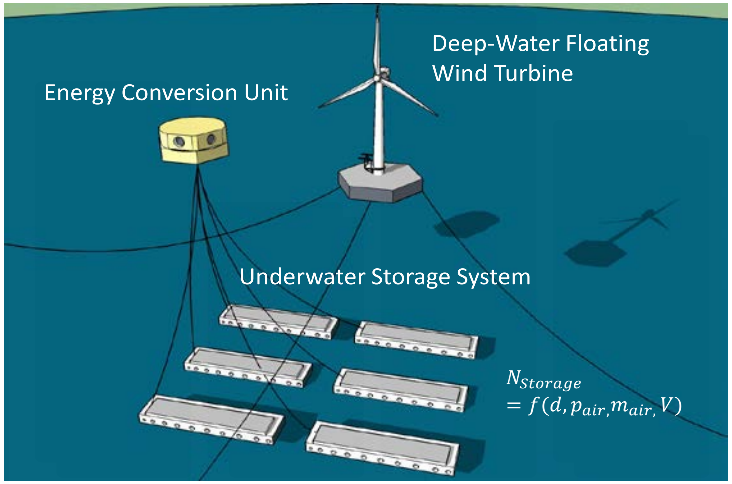
UMass IGERT
Engineering Offshore Wind Energy Systems

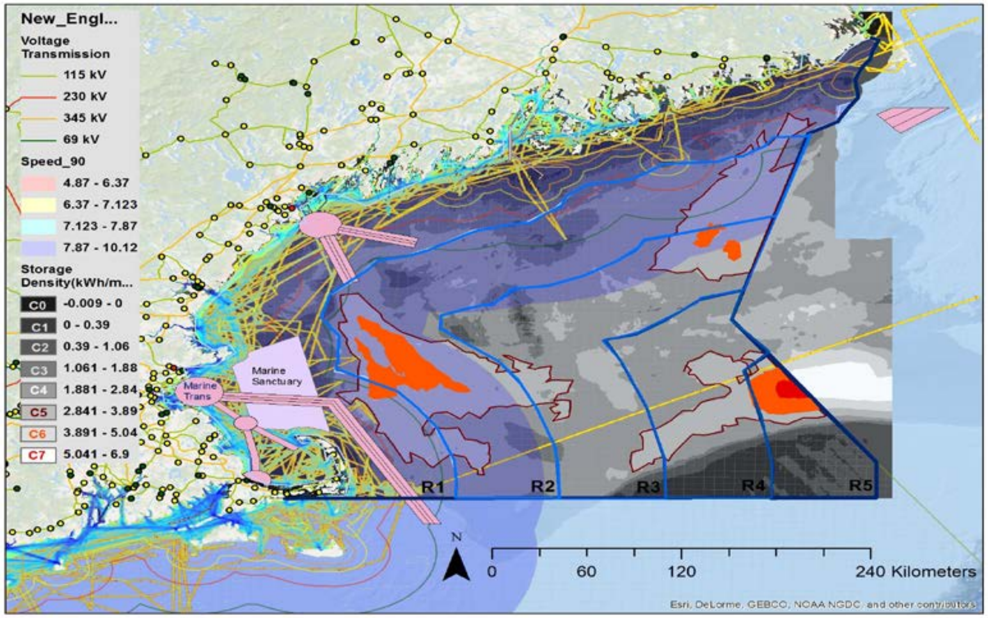
Carson Pete

Advisor: Jon McGowan

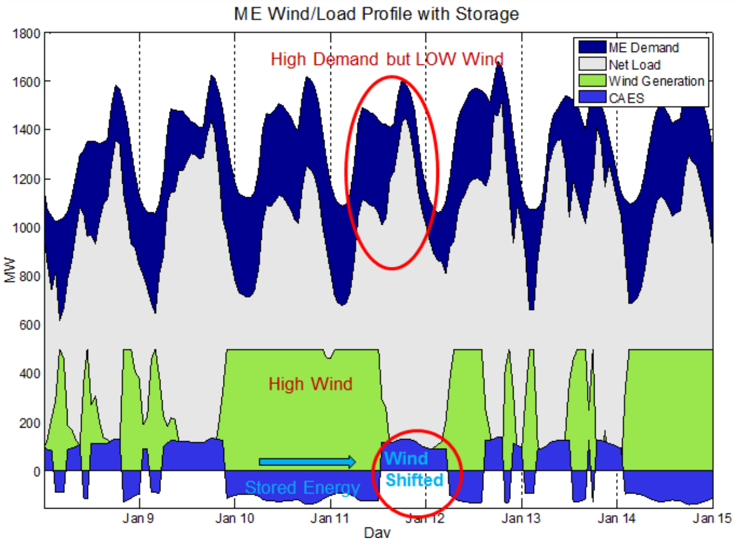
Understanding the impacts and benefits of offshore wind coupled with storage

- *Underwater CAES*
- *Environmental Implications*
- *Multi-objective Optimization*
- *Resource Assessment*





Esri, DeLorme, GEBCO, NOAA NGDC, and other contributors

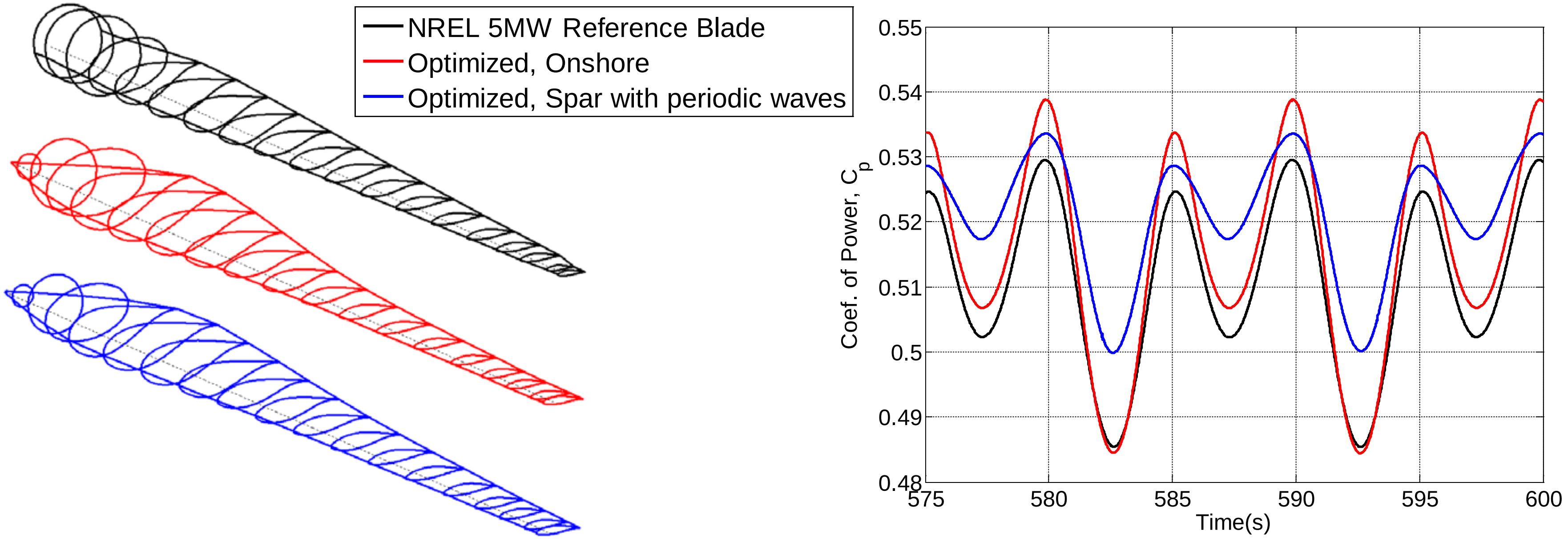

ME Wind/Load Profile with Storage

Evan Gaertner

Advisor: Matt Lackner

Design optimization of floating offshore wind turbine rotors

- *Explicitly account for aerodynamic and platform motion coupling in design load cases*
- *Reduce sensitivity to meta-ocean conditions*
- *Improve aerodynamic efficiency and reduce cyclical loading*

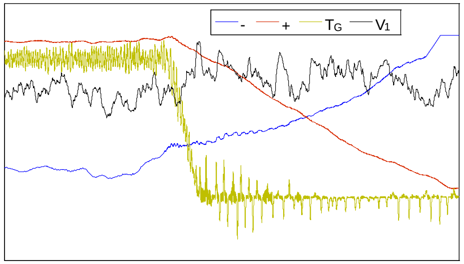


William La Cava

Advisor: Kourosh Danai

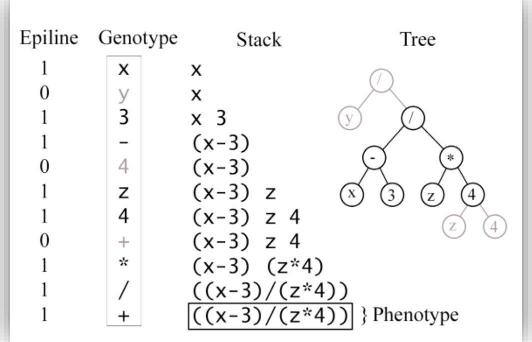
Automatic identification of closed-loop wind turbine dynamics

- *Control Design*
- *Evolutionary Optimization*

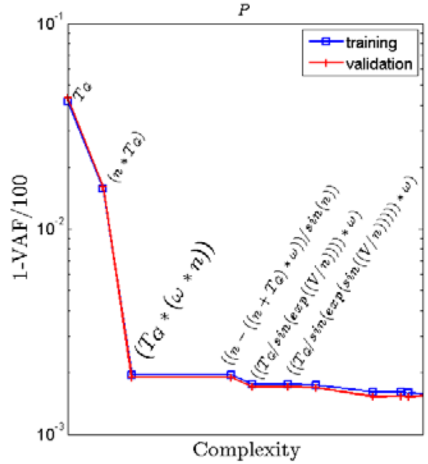


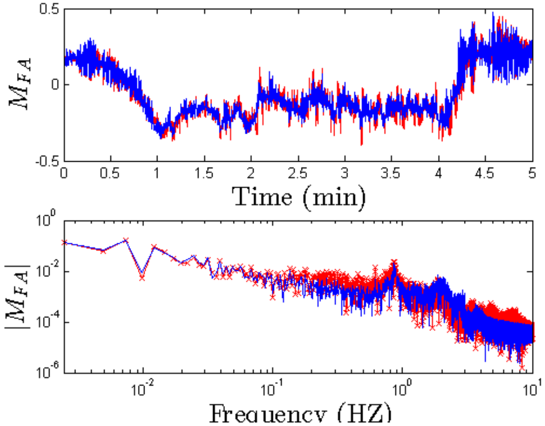
Data

Evolutionary Multi-objective Optimization

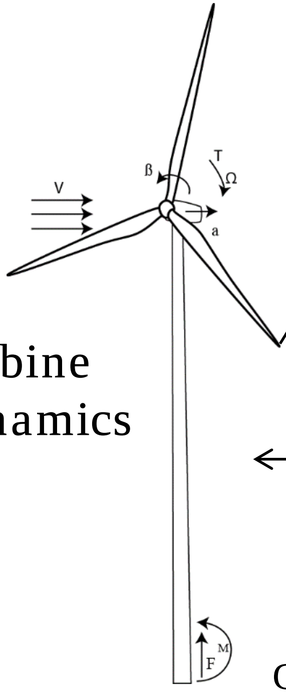


Epiline	Genotype	Stack
1	x	x
0	y	x
1	3	x 3
1	-	(x-3)
0	4	(x-3)
1	z	(x-3) z
1	4	(x-3) z 4
0	+	(x-3) z 4
1	*	(x-3) (z*4)
1	/	((x-3)/(z*4))
1	+	((x-3)/(z*4)) } Phenotype





Turbine Dynamics

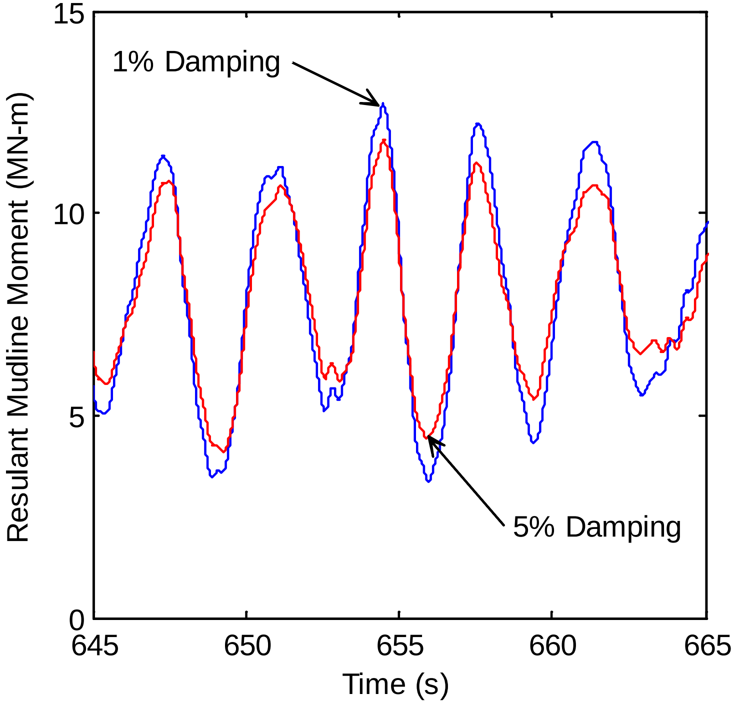


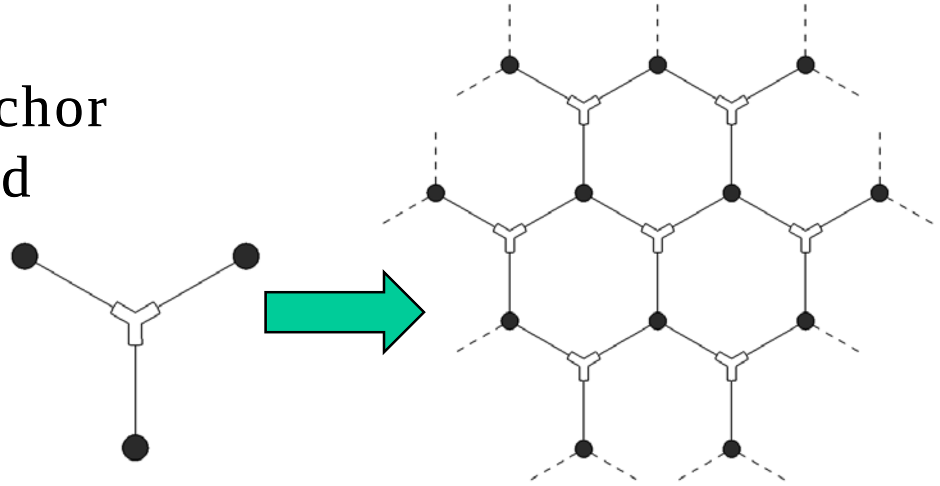
Control Design

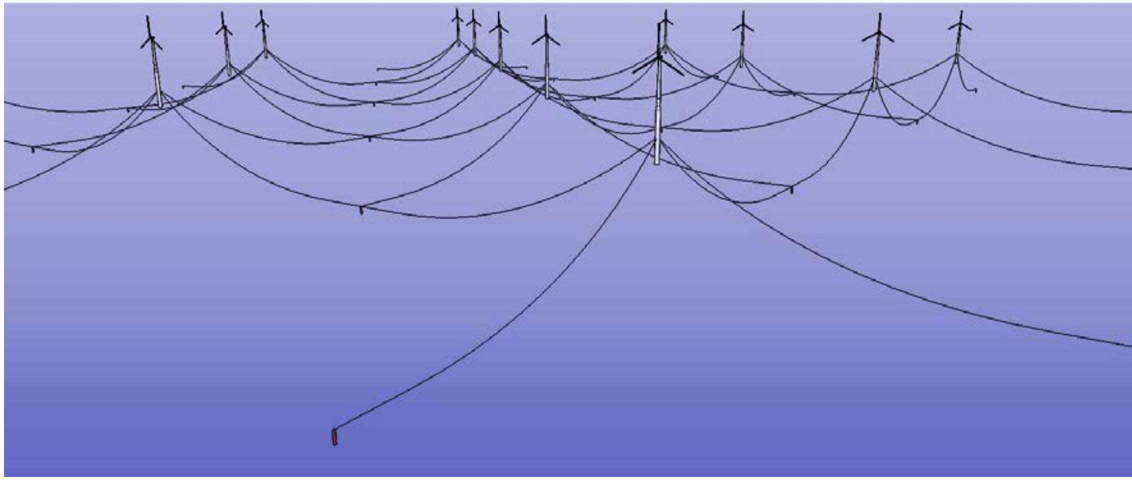
Casey Fontana

Advisors: Sanjay Arwade
Don DeGroot

- Quantifying role of foundation damping in the dynamics of monopile-supported offshore wind turbine
- Examining efficient multiline anchor systems for floating offshore wind turbines

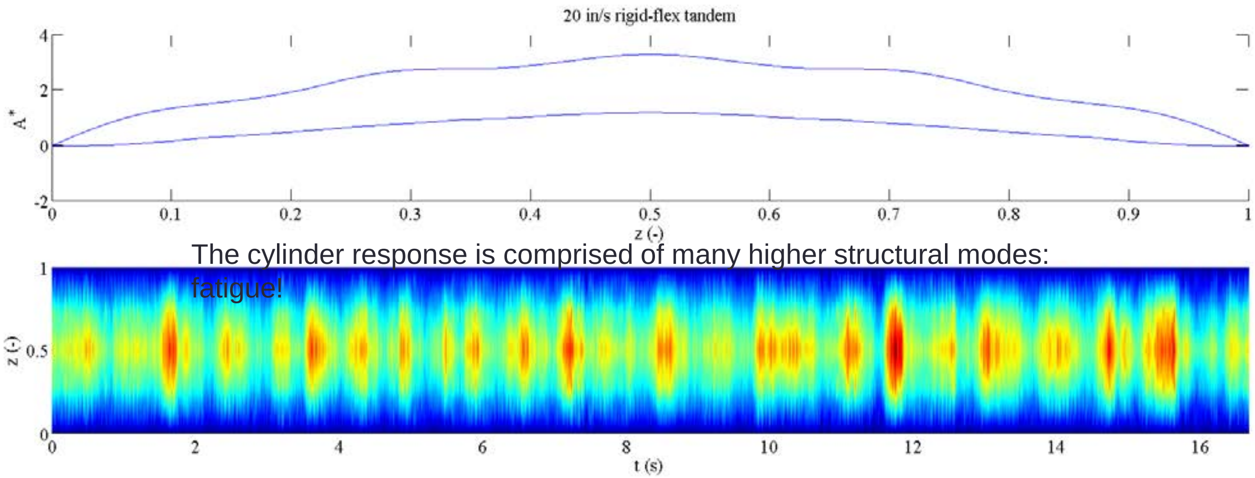






Wake-induced vibration of clustered cylinders for new mooring systems

Dan Carlson



The cylinder response is comprised of many higher structural modes: fatigue!

Rachel Koh

Advisors: Matt Lackner
Bob Hyers
Peggi Clouston

- Evaluating if renewable bio-based materials can be used for megawatt-scale wind turbine blades
- Investigating the mechanical properties of wood and flax laminates to see if they have potential for the wind turbine blade application

Evaluation of Generation Portfolios for the New England Power System

Destenie Nock and Erin Baker

Table 1: The Level of Capacity (MW) in each Generation Portfolio

	Portfolio 1	Portfolio 2	Portfolio 3
hydro	3000	3000	10000
onshore wind	5000	3000	10000
nuclear	4091	2000	2700
solar	5000	3000	10000
natural gas	10000	15000	5000
coal	6000	500	5000

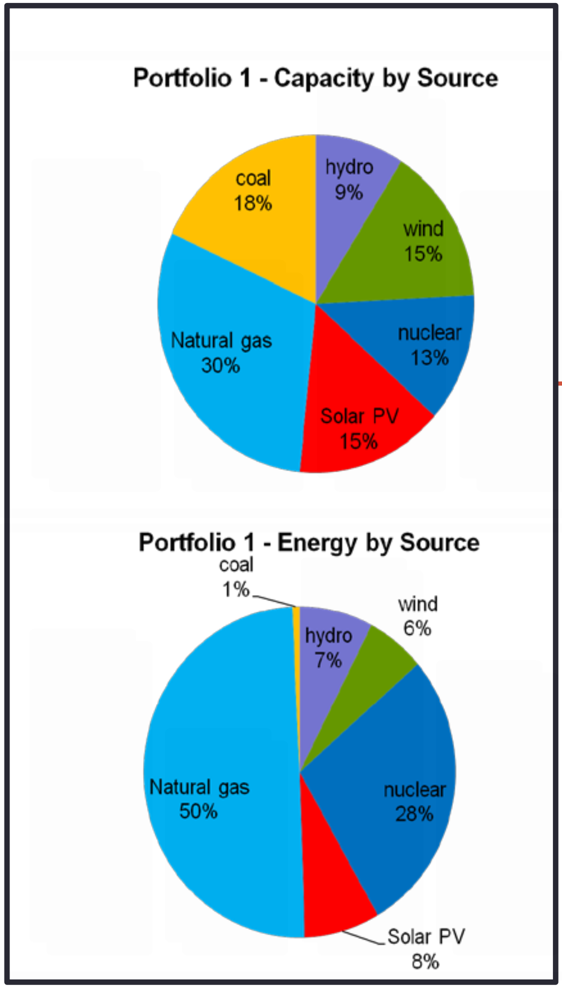
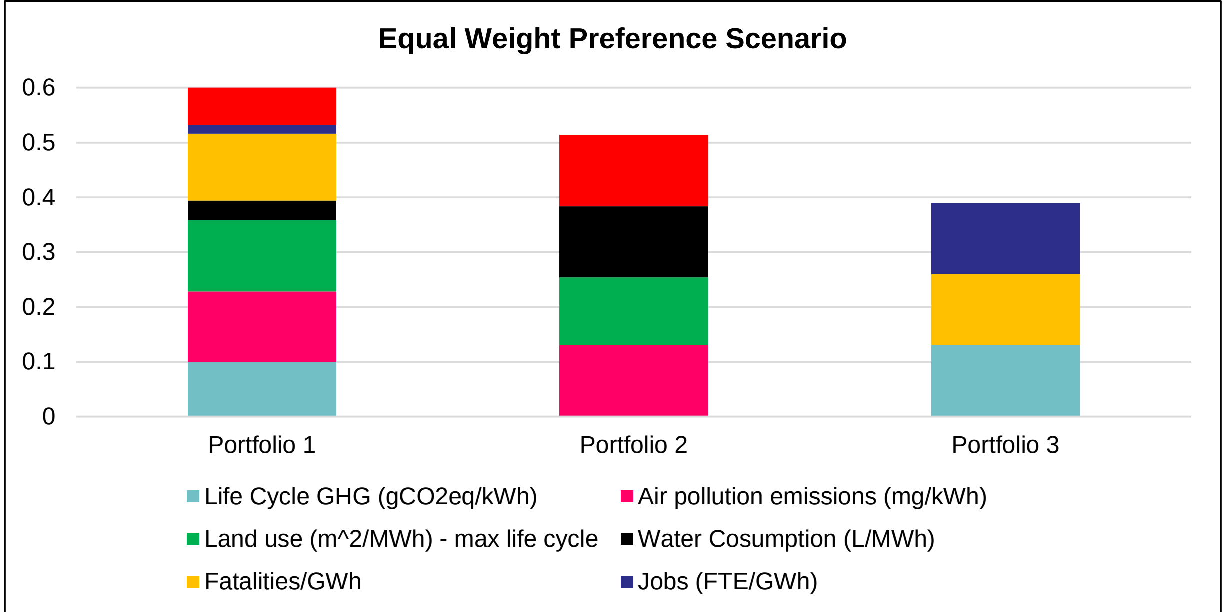
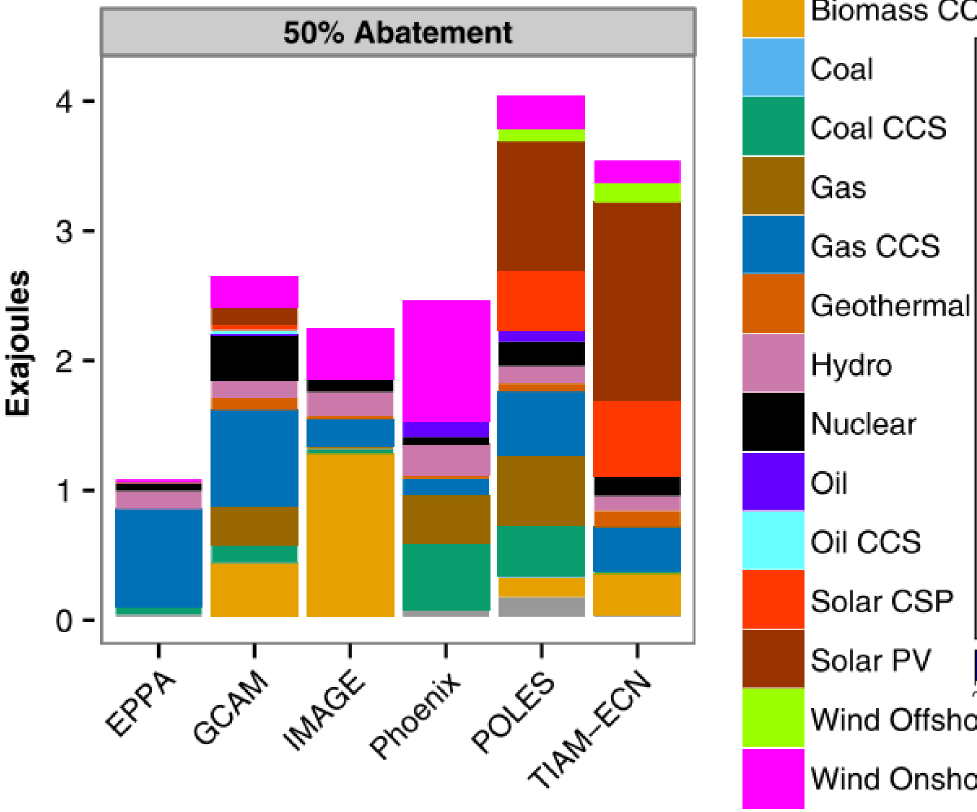


Figure 5: The level of Capacity and Energy for each technology

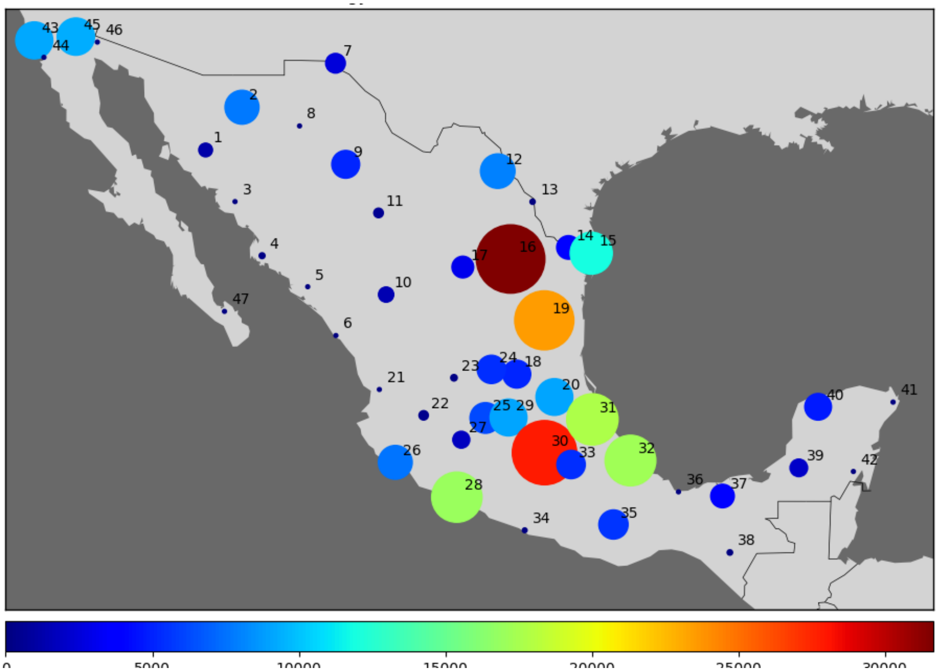


Development Pathways for Mexico's Electrical Grid

Electricity Generated in Mexico 2050



Electricity Generated in Mexico MWh 2050



Source: J. Veysey, C. Octaviano, “Pathways to Mexico’s climate change mitigation targets: A multi-model analysis,” *Energy Econ.*

Zana Cranmer

Advisor: Erin Baker

- Developing cohesive set of models to understand the interactions of economic and environmental value of offshore wind development
- Facilitating decision making across multiple objectives, scales, and stakeholders

Figure 1: Binary network model structure.

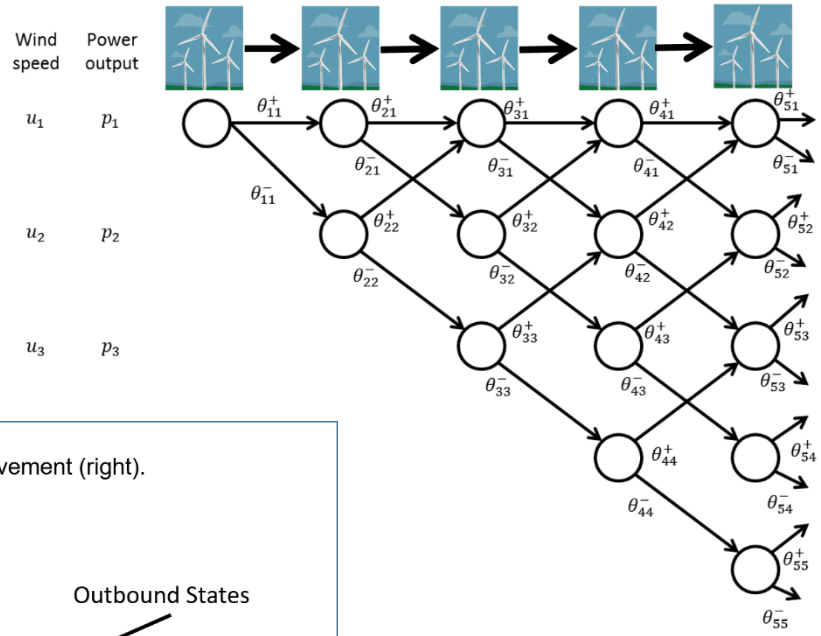
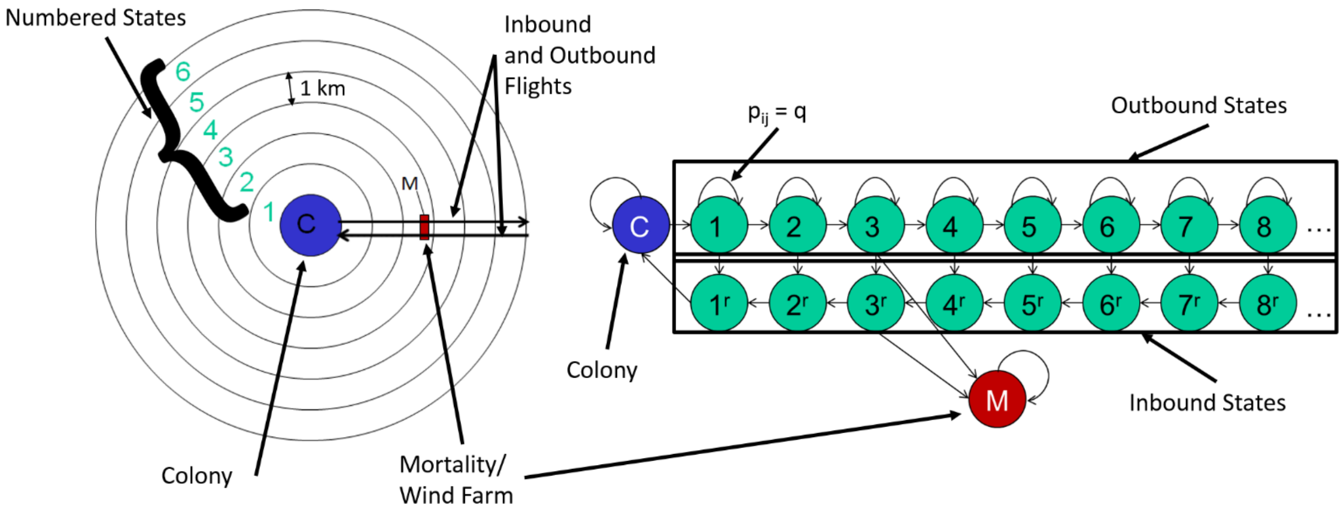


Figure 2: Conceptual model of bird movement (left) and Markov model of movement (right).



Repurposing models traditionally used in business applications for public benefit

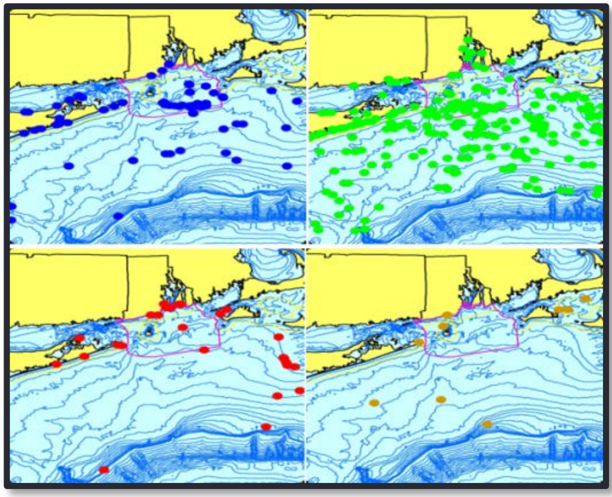
UMass IGERT

Environmental Issues of Offshore Wind Energy

- *9 fellows*
- *Department of Environmental Conservation*


© National Geographic


© birdnote.org

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UMass IGERT
Environmental Conservation

Kate McClellan Press

Advisor: Andy Danylchuk

Understanding how power transmission cables may effect electro-sensitive fishes (sharks, rays)

Analyzing behavioral responses of sharks and rays to electric fields in the lab and in their natural environment.

Jen Smetzer

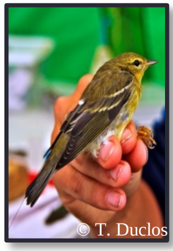
Advisor: David King

Understanding and minimizing effects of wind development on migratory songbirds and breeding marine birds

Flight behavior – hazard exposure

Migratory routes

Colony attendance – Spatial Planning Tool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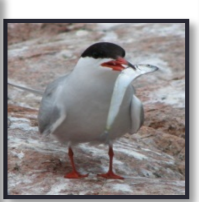


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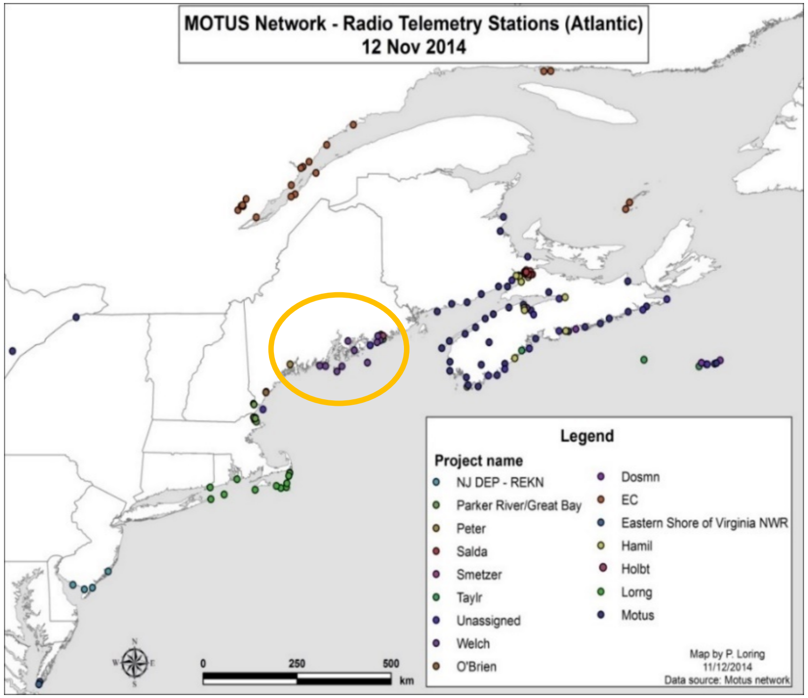
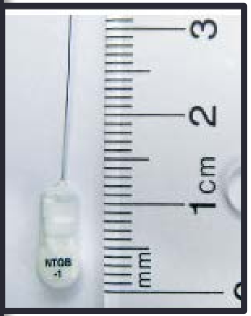
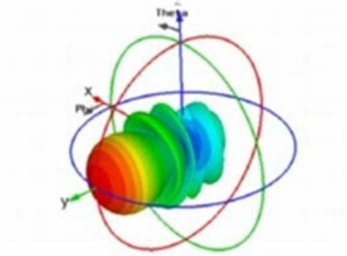
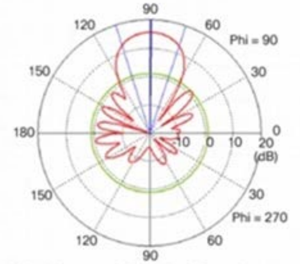

MOTUS Network - Radio Telemetry Stations (Atlantic)
12 Nov 2014

Map by P. Loring
11/12/2014
Data source: Motus network





(b) Yagi Antenna 3D Radiation Pattern



) Yagi Antenna Elevation Plane Pattern

Pam Loring

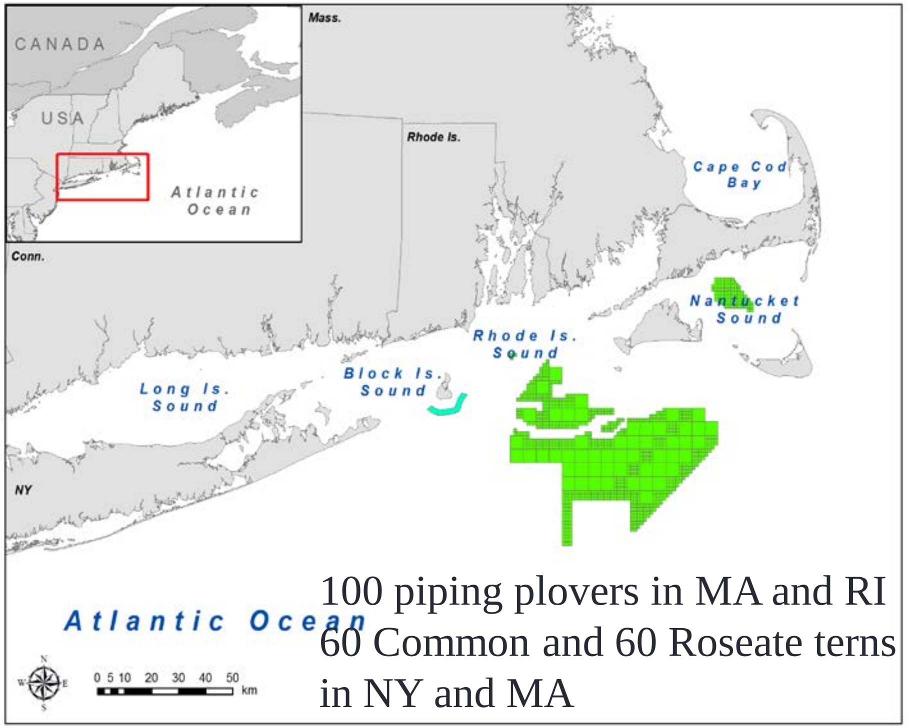
Advisors: Paul Sievert
Curtice Griffin

Modeling bird movements across southern New England

Quantifying exposure to Wind Energy Areas

Examining environmental drivers

Roseate Tern & Piping Plover Tracking



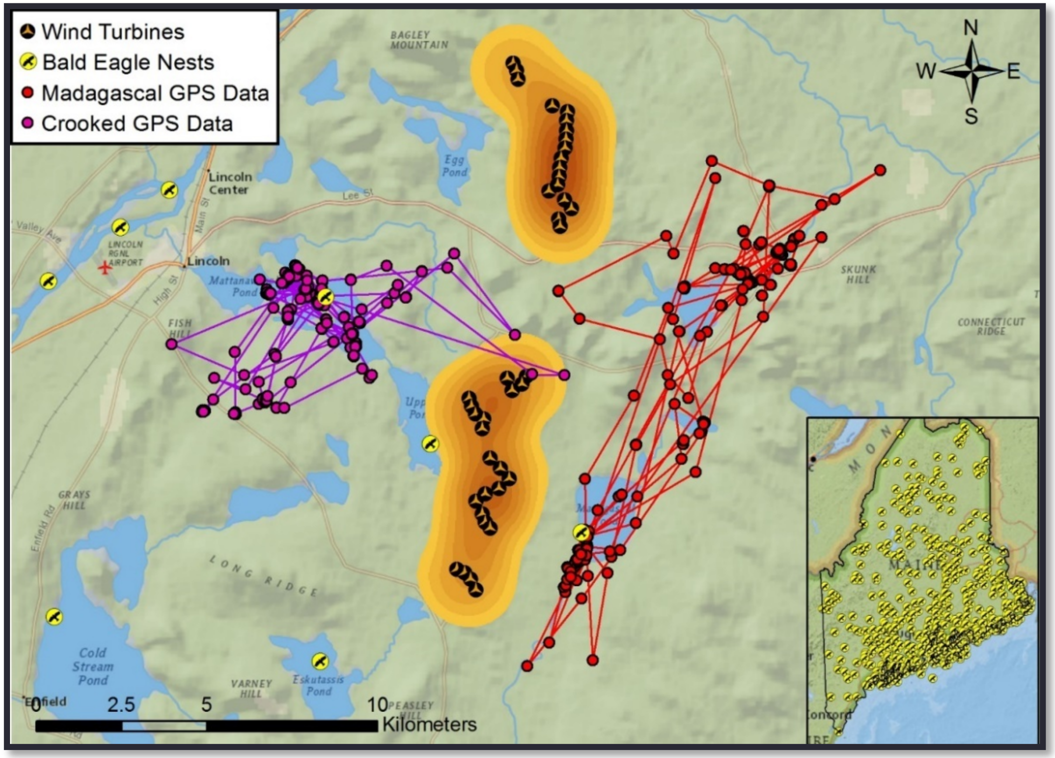
100 piping plovers in MA and RI
60 Common and 60 Roseate terns in NY and MA

UMass IGERT
Environmental Conservation

Blake Massey

Advisors: Curt Griffin
Kevin McGarigal

- Using GPS telemetry data and GIS data layers to analyze eagle habitat use and behavioral patterns
- Developing a spatially-explicit, individual-based movement model to simulate flight patterns and habitat utilization



Zara Dowling

Advisors: Paul Sievert
Betsy Dumont

Minimizing effects of wind development on migratory bats and rare WNS-affected bat species in the Northeast

Fall migration of hoary and eastern red bats
- *Greatest risk in Northeast*
- *Know very little about their migratory routes or habits*

Summer foraging and fall migration of northern long-eared bat
- *Federally threatened*

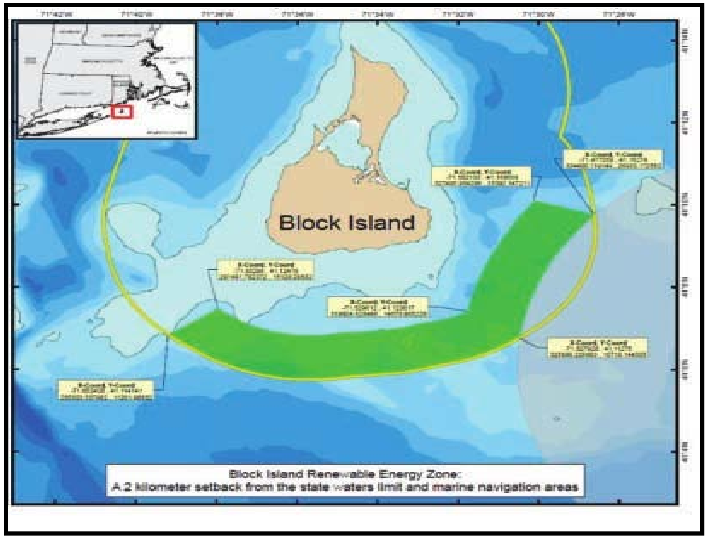
UMass IGERT
Environmental Conservation

Kendra Ryan

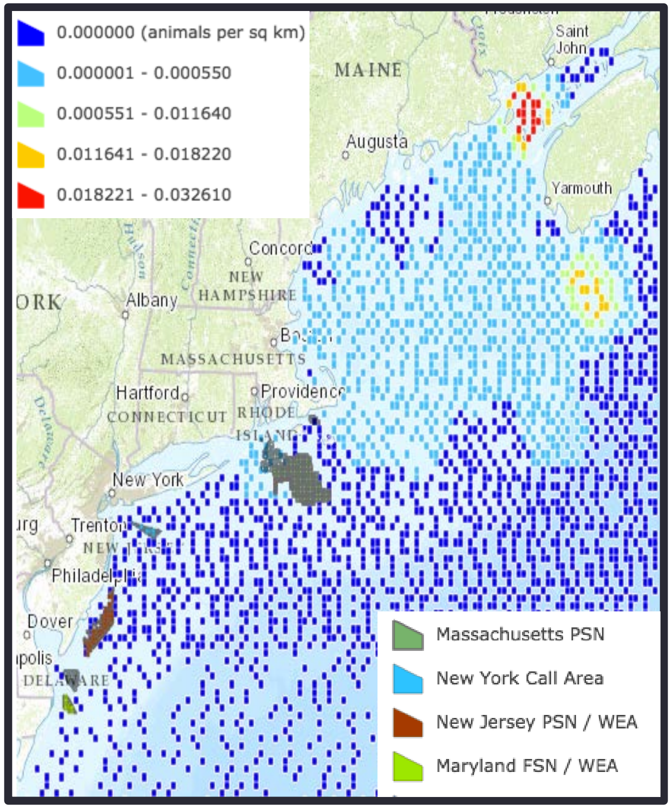
Advisor: Adrian Jordaan

Overcoming data deficiencies in environmental permitting of offshore wind energy in the United States

- *Marine Spatial Planning*
- *Habitat Modeling*
- *Regulatory Acceptance*



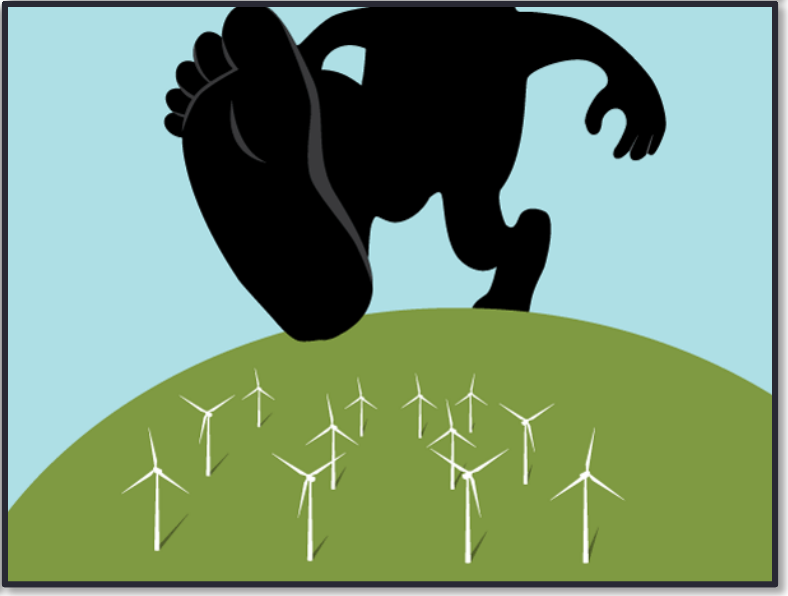
First US offshore wind energy project, located in state waters managed by one of the first marine spatial plans in the US.



Habitat model of North Atlantic right whale presence in proximity to wind energy areas.

Politics & Human Dimensions of Offshore Wind Energy

- *4 fellows*
- *4 departments*

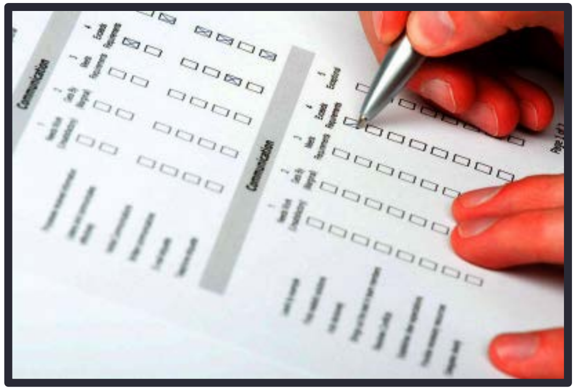


Rebecca Sokoloski

Advisor: Ezra Markowitz

Understanding how people conceptualize offshore wind projects

Studying how we can best communicate project information to communities



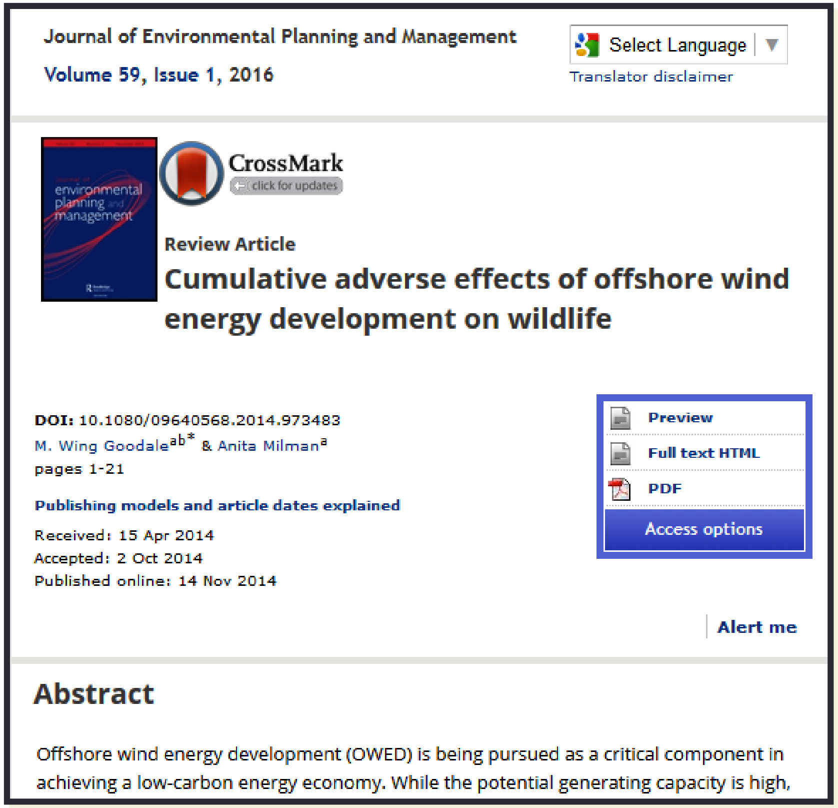
UMass IGERT
Policy

Wing Goodale

Advisor: Anita Milman

Developing public-private partnerships to address cumulative adverse effects

- *Environmental uncertainty*
- *Proprietary data*
- *Regulatory uncertainty*



Journal of Environmental Planning and Management

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Review Article

Cumulative adverse effects of offshore wind energy development on wildlife

DOI: 10.1080/09640568.2014.973483

M. Wing Goodale[ab]* & Anita Milman[a]

pages 1-21

Publishing models and article dates explained

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Published online: 14 Nov 2014

Abstract

Offshore wind energy development (OWED) is being pursued as a critical component in achieving a low-carbon energy economy. While the potential generating capacity is high,

Robert Darrow

Advisor: Jane Fountain

- Politics of energy transitions: does the adoption of renewable energy result in a more democratic energy regime?

- *Investigating how Denmark has transitioned from an electric system almost entirely reliant on fossil fuels to the world's leading renewable energy producer per capita in less than 40 years*

Collective-built Tvind turbine

Small household turbine on Samso island

Interdisciplinary Collaborations

Engineering **Policy** **Environmental Conservation**

Jen Smetzer & Zana Cranmer

Jen Smetzer & Acadia Engineer in Nova Scotia

Pam Loring & UMass Antenna Engineer

Zara Dowling & Dan Carlson

Blake Massey & Willian La Cava

Walt Jaslenek & Carson Pete

Zana Cranmer & School of Public Policy

IGERT: Offshore Wind Energy Engineering, Environmental Science, and Policy

Our goal is to create a community of researchers who understand the technological challenges, environmental implications, socioeconomic, and regulatory hurdles of offshore wind farms.

Thank you!