Offshore Wind Power: Science, engineering, and policy

MAST 428/628, Spring 2019

Tuesday, Thursday – 12:30-1:45, Robinson Hall 206
Instructors:

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Readings on Canvas
UD Capture
UD Center for Research in Wind, www.crew.udel.edu
Lewes Turbine real-time: http://www.ceoe.udel.edu/lewesturbine

Revised 4 March 2019

Topic and overview of course

This course will cover the multiple disciplines required to understand, plan, regulate, and develop offshore wind resources for large-scale power production. Offshore wind power is quickly emerging as a critical technology for large reductions in CO_2 emissions, because the technology is available, proven, and cost-competitive, and the resource is huge—for many of the world's populated coastal states, the offshore wind resource is larger than all current CO_2-producing energy sources combined.

The course will integrate science, engineering and policy. We will draw on the three instructors and multiple guest lecturers to cover topics including:

• Geophysics of wind resources; understanding and assessing the offshore resource;
• Governing law for state, Federal and international waters; current policy for offshore development; policies to encourage and/or regulate the industry;
• Basic electrical and mechanical engineering aspects of wind turbines and power transmission;
• Connecting wind electricity to the electric grid; electric markets; relative electric costs; combining wind with other renewables; CO_2 displaced from large coal and gas generators;
• Storage of intermittent wind power--engineering and economics; the synergistic role of an emerging electric vehicle fleet;
• Geology and bathymetry of the continental shelf, as they constrain anchoring technology and thus the size of the accessible wind resource
• Environmental impact of large offshore wind developments; the EIS process;
• Public opposition to, and support for, wind power; communication strategies.

Students should be knowledgeable in at least one of the above policy, science or engineering areas, and expect to gain a working knowledge of the other areas.

Elective and Area Requirements Satisfied

This course can meet the Oceanography Program degree requirements for distribution, with the Oceanography Program Director's approval. It satisfies 3 hours of the Mechanical Engineering Technical Elective Requirement (12ch). It is one of the additional area courses in the College of Engineering minor "Sustainable Energy Technology", and a core course for the Wind Energy Certificate. (Believed accurate as of time this was written, check with your program or department for confirmation.)

Credit and assignments

Students are expected to do readings prior to class, attend lectures and participate in discussion, do occasional problem sets to apply what we are learning, attend a field trip and complete a **final project with a team**.

There may be a complete day field trip on May 10. **Please plan accordingly**

Course grades* will be calculated as follows:

- 30% Homework**
- 10% Class Participation
- 70% Project**
  - Group Formation 5 pt
  - Project Abstract 5 pt
  - Extended Outline with Refs 10 pt
  - Rough Draft 35 pt
  - Presentation 20 pt
  - Project Final Papers 35 pts

**please note that undergraduate students and graduate students will be evaluated separately on homework and class participation.*

**Depending on the number of homework assignments, it could be increased to 40% and Project decreased to 60%

Readings

Most readings will be either out of the Manwell book listed below, or on the class Canvass site. Some lectures will also be placed on Canvass.

+Manwell, McGowan and Rogers, 2009, Wind Energy Explained: Theory, Design and Application. West Sussex: Wiley. **Second Edition (Blue Cover).** *A comprehensive textbook. More readings drawn from this than any other text. Purchase recommended. (On reserve at Morris Library.)*

Outline of class topics

Readings are to be read in advance of the class. Some classes are divided into more than one topic.

1) Introduction; People, concepts, Deepwater case, projects

- Power Technology, Block Island Wind Farm (3 pages)
- Rocky Mountain Institute, From Diesel to Wind on Block Island (4 pages)

(2) Offshore Wind Policies

- Firestone, J., Archer, CA., Gardner, MP, Madsen, JA, Prasad, AK, Veron, DE, The time has come for offshore wind power in the US, *Proceedings of the National Academy of Sciences*, 112(39):11985-11988, doi: 10.1073/pnas.1515376112 (2015)
- Firestone, J., Regulating Climate Mitigation: Offshore Windpower in the United States

(3) Overview, Wind Technology Survey, Guest: Prof. Willett Kempton

- Manwell, McGowan and Rogers, Read all of Chapter 1; in Chapter 2, read Section 2.1 and 2.2, and look at Figure 2.25, Figure 2.30, Table 2.5, and Figure 2.36. (These two chapters are on Sakai)
- Skystream 3.7, http://www.windenergy.com/products/skystream/skystream-3.7 and Brochure on Canvas
- Siemens Gamesa Renewable Energy G90-2.0, On Canvas, and see https://www.siemensgamesa.com/en-int/-/media/siemensgamesa/downloads/en/products-and-services/onshore/brochures/legacy-gamesa/siemens-gamesa-onshore-wind-turbine-g90-en.pdf
- Siemens Gamesa Renewable Energy G114-2.1 https://www.siemensgamesa.com/en-int/-/media/siemensgamesa/downloads/en/products-and-services/onshore/brochures/siemens-gamesa-onshore-wind-turbine-sg-2-1-114-en.pdf
- GE Haliade-X 12MW https://www.ge.com/renewableenergy/wind-energy/turbines/haliade-x-offshore-turbine

(4) Siting, MSP Considerations

- Mid-Atlantic Ocean Action Plan, pp. 38-77
- Samoteskul, K., Firestone, J., Corbett, J., Callahan, J., Analysis of Vessel Rerouting Scenarios to Open Areas for Offshore Wind Power Development Reveals Significant Societal Benefits, *Journal of Environmental Management*, 141: 146-154 (2014)
- Bates, A., Accounting for Commercial Fishing Interests in Offshore Wind Power Planning (skim)

(5) Marine Construction, Guest: Prof. Willett Kempton

- Willett Kempton, Andrew Levitt, Richard Bowers, et al. Report, 2017, "Industrializing Offshore Wind Power with Serial Assembly and Lower-cost Deployment", Report, 99 pages,
    - Read more carefully" pp 6 – 12 & 24-43.

- Euan Barlow, Diclehan Tezcaner Öztürk, Matthew Revie, Evangelos Boulougouris, Alexander H. Day, Kerem Akartunali, Exploring the impact of innovative developments to the installation process for an offshore wind farm" Ocean Engineering 109 (2015) 623–634.

(6) Continental Shelf Geology, Site Engineering, Guest: Prof. John Madsen

- BOEM, 2015. Guidelines for Providing Geophysical, Geotechnical, and Geohazard Information
- BOEM, 2017. Guidelines for Providing Archaeological and Historic Property Information

(7) Wind & Atmosphere Basics

Required

- Kump, The Earth System, ch. 4
- Archer and Jacobson 2005

Suggested

- Manwell et al, Chapter 2

(8) Measuring the Wind

Required

- Manwell et al, Chapter 2
- Lars Landberg, Lisbeth Myllerup, Ole Rathmann, Erik Lundtang Petersen, Bo Hoffmann Jørgensen, Jake Badger, Niels Gylling Mortensen, Wind Resource Estimation—An Overview, *Wind Energy*, 6, 3, 261-271, 2003. DOI: 10.1002/we.94
- Lackner et al., A new method for improved hub height mean wind speed estimates using short-term hub height data, Renewable Energy, 35 (10), 2340-2347, doi:10.1016/j.renene.2010.03.031.

Suggested

- Elliott, D.L. ; Schwartz, M.N., Wind energy potential in the United States, 1993, PNL-SA--23109; CONF-9306204—3
- Dhanju, Amardeep, Phillip Whitaker, Willett Kempton (2008), Assessing offshore wind resources: An accessible methodology, *Renewable Energy* 33(1): 55- 64. doi:10.1016/j.renene.2007.03.006
- Bryan Roberts, David Shepard, Ken Caldeira, Elizabeth Cannon et al, 2007, "Harnessing High-Altitude Wind Power" IEEE Transactions on Energy Conversion 22 (1) March 2007, pp 136-144.

(9) From the Field: Guest Lecture by Professors Art Trembanis & Matt Oliver

- Carton, et al., Munitions and Explosives of Concern Survey Methodology and In-field Testing for Wind Energy Areas on the Atlantic Outer Continental Shelf, Close reading of Chapters 9-10, skim remainder, on Canvas and at https://www.boem.gov/Munitions-and-Explosives-of-Concern-Survey-Methodology-and-In-field-Testing-for-Wind-Energy-Areas-on-the-Atlantic-Outer-Continental-Shelf/
- Breece, et al., Satellite driven distribution models of endangered Atlantic sturgeon occurrence in the mid-Atlantic Bight, ICES Journal of Marine Science (2018), 75(2), 562–571. doi:10.1093/icesjms/fsx187

(10) Wind Predictability

Required

- Anna Hilden, 2008: "Predictability and the Value of Wind Energy", *WindTech International*, March 2008, p. 35-37.
- Lew et al., 2012: "The Value of Wind Power Forecasting"
- Breslow and sailor 2002

Suggested

- David W. Keith, Joseph F. DeCarolis, David C. Denkenberger, Donald H. Lenschow, Sergey L. Malyshev, Stephen Pacala, and Philip J. Rasch, 2004, "The influence of large-scale wind power on global climate," *Proceedings of the National Academy of Sciences*, November 16, 2004 vol. 101 no 46 16115-16120. (backup copy is on this site)

- David W. Keith, Joseph F. DeCarolis, David C. Denkenberger, Donald H. Lenschow, Sergey L. Malyshev, Stephen Pacala, and Philip J. Rasch, 2004, "The influence of large-scale wind power on global climate" Proceedings of the National Academy of Sciences, November 16, 2004 vol. 101 no. 46 16115 - 16120. (backup copy is on this site.)
- James Oswald, Mike Raine, Hezlin Ashraf-Ball, 2008: Will British weather provide reliable electricity?, *Energy Policy*, **36**, 3202-3215.
- Pryor and Barthelmie (2010)
- Hueging et al. (2013)
- Cradden et al. 2010
- de lucena et al. 2010
- Sailor et al. 2008
- Jacobson and archer 2012

(11) Community Aspects of Wind Siting, Guest: Bonnie Ram

- Slovic, Perceptions of Risk (1987)
- Deitz and Stern, Public Participation in Environmental Assessment and Decision-making (Read Exec. Summary, Chapter 1 and Box 9-1 on page 224)

(12) Fishers and Wind: Guest, Annie Hawkins, Director, Responsible Offshore Development Alliance

- Responsible Offshore Development Alliance (RODA) comments regarding the Draft Environmental Impact Statement (DEIS) and associated Construction and Operations Plan (COP) submitted by Vineyard Wind, LLC (2019)

(13) Social Dimensions of Offshore Wind Power

- Firestone, J., Bidwell, D., Gardner, M., Knapp, L. 2018. Wind in the Sails or Choppy Seas?: People-Place Relations, Aesthetics and Public Support for the United States' First Offshore Wind Project, *Energy Research and Social Science*, 40: 232-243.
- Firestone, J., Hoen, B., Rand, J., Elliot, D., Hubner, G., & Pohl, J. 2017. Reconsidering Barriers to Wind Power Projects: Community Engagement, Developer Transparency and Place *Journal of Environmental Policy & Planning*, 20(3): 370-386Bates, A. and
- Krueger, A., G. Parsons, and J. Firestone, Preferences for Offshore Wind Power Development: A Choice Experiment Approach, Land Economics, 87(2): 267-83 (2011).

(14) LCOE and Power Purchase Agreements

- *In re: Review of Proposed Town of New Shoreham Project*, No. 2010-273-M.P. (RI Sup. Court 2011), **Read 1-38 only; skim/examine other parts of interest**
- *Cape Wind PPA*; *In re Mass. Elec. Co & Nantucket Elec. Co*., Docket No. 10-54 (Mass. Board of Public Utilities) (Nov. 22, 2010), **Read Executive Summary only; skim parts of interest**

(15) Wind Resource Activity

(16) Environmental

- Block Island Wind Farm and Block Island Transmission System Environmental Report/Construction and Operations Plan, **Executive Summary, (required)** (remainder for background)
- Firestone, J. and J. Kehne, Wind Energy, Ch. 16, 361-390 in Michael Gerrard (ed.), The Law of Clean Energy: Efficiency and Renewables (2011**), (pp. 366-373 and 378-81 only**

(17) New Jersey Offshore Wind Resources, Guest, Dr. Joseph Brodie, Rutgers

Read

- New Jersey Governor Murphy's Executive Order 8, https://nj.gov/infobank/eo/056murphy/pdf/EO-8.pdf

Supplemental Reading (not required)

- Seroka, G, et al. Sea Breeze Sensitivity to Coastal Upwelling and Synoptic Flow Using Lagrangian Methods, JGR Atmospheres, https://doi.org/10.1029/2018JD028940

(18) Harvesting the Wind, Aerodynamics, Guest Prof. Ajay Prasad

- Manwell et al, Chapter 3 Aerodynamics (Full chapter, some previously read for drive train lecture)

(19) Distributed Wind Sites and High Penetration Wind, Guest: Prof. Willett Kempton

- **Read carefully the following:**
  i. Willett Kempton, Felipe M. Pimenta, Dana E. Veron, and Brian A. Colle, 2010, Electric power from offshore wind via synoptic-scale interconnection, *Proceedings of the National Academy of Sciences*. 7240–7245 (April 20, 2010) vol. 107, no. 16: 7240–7245. [Long transmission across met regimes to make wind output more constant, more "firm capacity."]
  ii. Budischak, Cory, DeAnna Sewell, Heather Thomson, Leon Mach, Dana E. Veron, and Willett Kempton, 2013, Cost-minimized combinations of wind power, solar power, and electrochemical storage, powering the grid up to 99.9% of the time, *Journal of Power Sources*, 225(2013), 60-74. Published doi: 10.1016/j.jpowsour.2012.09.054, open access. [Model of how to create steady power from variable generation, at lowest cost.]

- **Skim**
  i. Gibson, Peter B., Nicolas J. Cullen, 2014. Regional variability in New Zealand's wind resource linked to synoptic-scale circulation: implications for generation reliability, *Journal of Applied Meteorology and Climatology* vol 54, doi: 10.1175/JAMC-D-14-0273.1
  ii. Grams, C.M., et al., 2017. Balancing Europe's wind-power output through spatial deployment informed by weather regimes. *Nature Climate Change* 7, 557-562,

(20) TBD

(21) Transmission, Guest: Kevin Pearce, Siemens

- Root, "What is Electricity" [Very basic concepts: voltage, resistance, current, power. For students with no background at all in electricity.]
- Manwell, Section 9.5 through end of chapter, "Wind Turbines and Wind Farms in Electrical Grids." Pp 433 – 446. [Analysis and planning of wind generation in electrical grids. Read through and understand concepts, calculations not required.]

(22) Wakes/Turbulence, Guest: Prof. Cristina Archer

- Manwell, Chapter 9. Only pages 422-432, Section 9.4.2 (up to, not including 9.5)
- Hong, J., M. Toloui, L. P. Chamorro, M. Guala, K. Howard, S. Riley, J. Tucker, F. Sotiropoulos, 2014: Natural snowfall reveals large-scale flow structures in the wake of a 2.5-MW wind turbine, *Nature Communications* vol 5, doi: 10.1038/ncomms5216
- Xie, Shengbai and Cristina Archer, 2014: Self-similarity and turbulence characteristics of wind turbine wakes via large-eddy simulation, *Wind Energy*, doi: 10.1002/we.1792

(23) TBD

(24) Student Presentations

(25) Student Presentations

(26) Student Presentations/Wrap-up

May 10 – Possible Wind Power Project Field Trip

May 21 – Final Projects Due