

EAS615: Renewable Electricity & the Grid Syllabus

Term: Winter 2021

Course Time: Tuesday/Thursday, 10:00 am – 11:20 am

Location: Zoom (<https://umich.zoom.us/j/99294890887>)

Syllabus Last Updated: March 23, 2021

Professor: Michael Craig, mtcraig@umich.edu

Professor Office Hours: Thursdays 11:30 AM – 12:30 PM (or by appointment)

Location: Zoom. Please refer to Canvas for meeting link.

Graduate Student Instructor: Carlotta Pham, phamcc@umich.edu

GSI Office Hours: Tuesdays 3:30-4:30 PM, Wednesdays 4:30-5:30 PM (or by appointment)

Location: Zoom. Please refer to Canvas for meeting link.

Land Acknowledgement

I acknowledge the university's origins through an 1817 land transfer from the Anishinaabek, the Three Fires People: the Odawa, Ojibwe, and Bodewadami as well as Meskwahkiasahina (Fox), Peoria and Wyandot. I further acknowledge that our university stands, like almost all property in the United States, on lands obtained, generally in unconscionable ways, from indigenous peoples. Research on environmental science and sustainability has benefited and continues to benefit from access to land originally gained through the exploitation of others. Knowing where we live and work does not change the past, but understanding and acknowledging the history, culture, and impacts of colonial practices is an important step towards the creation of an equitable and sustainable future. This Land Acknowledgement serves as a starting point in my commitment to holding myself and our university more accountable to the recognition and sovereignty of indigenous people. I will work throughout this semester and beyond to decolonize this course.

Welcome

Welcome to EAS615! Renewables are near and dear to my heart and my research, so I'm thrilled to be teaching this course. Throughout my education, research, and work experience at the U.S. National Renewable Energy Laboratory, I have picked up a bunch of knowledge, skills, tools, and datasets that I will be sharing with you in this course. I think this material will benefit you in any career related to renewable energy. I strive to maintain an inviting and inclusive classroom environment, and I welcome students from all backgrounds and perspectives. If there's anything I can do throughout the semester to improve your classroom experience, please let me know.

Course Description:

Due to technological advancement and supportive policies, renewable energy technologies like wind and solar power are rapidly growing in the United States and globally. Integrating renewable energy technologies into power systems requires an understanding of generation technologies, the resources they depend on, power system planning and operations, and economics and policy. This course will introduce students to and give them experience working on each of these issues. Projects, problem sets, and readings will reflect various stakeholders' viewpoints and introduce skills and concepts that renewable energy professionals employ. Lectures and coursework will draw on materials from around the world, but the majority of material will be from the United States. This course will specifically cover the following topics:

- Renewable generation technologies
- Renewable resource characteristics
- Incorporating renewable energy into power system planning and operations
- Renewable energy markets, economics, policies, and regulations
- Complementary technologies for renewable energy technologies
- Challenges of high wind and solar penetrations

Student Course Learning Objectives

Upon completion of this course, students will have the skills and knowledge necessary to critically evaluate renewable energy technologies, deployment strategies, and policies. A successful student will be able to characterize the renewable resources in several locations; convert those resources to generation given different technologies; conduct simple cost and revenue requirement calculations for those technologies; model how electricity generated from those technologies would be integrated into the larger power system; and understand the challenges of deploying those technologies given the broader planning context of the power system. We will also discuss equity and justice issues related to renewable energy. Ultimately, this course aims to equip students to succeed in renewable energy-related jobs in utilities, research, government and nongovernmental organizations, and other organizations.

Enrollment Qualifications

Graduate students are eligible for this course, with enrollment preference given to SEAS master's and doctoral students. EAS574 (Sustainable Energy Systems) is a pre-requisite for this course. Other graduate-level energy courses or industry experience might be suitable alternatives for the pre-requisite. All students must know how power and energy differ and be comfortable with quantitative and computational analysis.

Classes

I will live stream classes during our regular intervals and post recorded classes to Canvas. Having an effective classroom experience will require everyone's help. **Please make sure your microphone is muted when not asking a question** during lecture portions of class. **Please ask questions during lectures** by using the Zoom raise hand feature or entering your question into the chat window. Carlotta and I will monitor the chat window and answer questions as they come in. If we do not answer your question satisfactorily or if you have a follow-up, we will ask you to unmute your microphone at that time. Please remember to mute your microphone after the exchange is over.

Office Hours

Office hours are a platform for you to share your experiences and interests with me and Carlotta, connect with other students, obtain support with problem sets, gain clarification on content discussed in lecture, receive feedback and support with the group project, and discuss career opportunities. We look forward to engaging with you in this context.

For office hours, please indicate your arrival to the Zoom meeting by posting in the chat window. I will move through questions in the order that people join the meeting. As in class, **please ensure your microphone is muted if you are waiting in line.**

Grading

Problem sets	55% (<i>lowest grade dropped, see "Stuff Happens" policy</i>)
Project	35%
Class participation	10%

Grading Challenges

Challenges to grades must occur within one week of the return of the assignment. Challenges must include a written explanation of why you are requesting a regrade, including justification for why you think your answer is right. A challenge will result in a complete regrading of the assignment, so your score may increase or decrease.

Problem Sets

For problem sets, we encourage you to discuss questions and solution methods with your peers. However, you must solve each problem individually. If you discuss any part of a problem set with your peers, you must list their names at the end of your solutions. Problem sets are due by the beginning of class, meaning **before** 10:00 a.m. on the due date. **This rule will be STRICTLY enforced.** Late problem sets will be accepted up to 24 hours later at a penalty of 25%. After 24 hours past the initial deadline, problem sets will not be accepted. Please also see the "Stuff Happens" policy below.

Project

Students will complete a group project due at the end of the semester. Groups will select between one of two topics: building a 100% renewable energy system from scratch or advising a utility in its transition from fossil fuel to renewable assets. A part of each assignment throughout the semester will yield data or models that students can use in their projects. I will release project details later in the semester.

Class Participation, Attendance, and Zoom Etiquette Electronics Policy

Attendance Given differing time zones and commitments imposed by the pandemic, attendance is optional. However, we *strongly* encourage synchronous participation in order to work with your peers and ask questions.

Class Participation I do not have a requirement for daily participation, but I encourage all students to participate in class. Your class participation grade will be driven by your participation in weekly current events (15%), discussion days (50%), and participating on Piazza or Slack (35%). To receive a full grade in each of these activities, you must comply with the participation ground rules (below) and contribute meaningfully to the discussion. Please see discussions and current events below for requirements for asynchronous participation.

Whenever participating in class (via Zoom, Piazza, Slack, or otherwise), please follow these ground rules:

- Speak from the “I” perspective
- Listen to understand, not to respond
- Give room for others to participate
- Express disagreement without attacking, shaming, or blaming
- Practice both/and thinking (often multiple answers are correct)

Zoom Etiquette Please ensure your microphone is muted when you are not speaking. I encourage students to turn their video on when they are comfortable doing so, particularly in breakout discussions. I will not require everyone to have videos on during lecture. I also recommend exploring the “Hide Self View” and “Speaker View” options to reduce the visual noise on Zoom.

Piazza

This course will use Piazza, a discussion board integrated with Canvas. **All questions related to problem sets, lecture materials, and other assignments must first be posted to Piazza before emailing them to us.** I highly encourage students to respond to other students’ questions on the discussion board. These responses will count towards your participation grade. We (Michael and Carlotta) will regularly check Piazza and post responses to any questions asked. Piazza has a number of excellent functionalities, such as instructor-endorsed answers, stickied posts, tagging posts, and searching previous posts that I will demonstrate in the first class. Before asking a question on Piazza, please make sure you search for whether it has been before. Also, please keep in mind that we (Michael and Carlotta) have lives outside of our instructor roles so might not be checking Piazza frequently the night before an assignment is due. Questions asked prior to the night before a due date are much more likely to get a response than those asked the night before.

Slack

We have set up a [Slack workspace](#) that is *optional* for students to join. The Slack workplace will serve as a forum to post materials you find relevant to the course, connect with students to work on problem sets, and connect with students to form teams for the group project. We recognize that the remote nature of this term creates challenges for connecting among classmates and will experiment with the use of Slack to promote connection. Please maintain appropriate and respectful interactions on Slack.

Weekly Current Event

Most Tuesdays we will spend 5 minutes at the beginning of the class in breakout rooms of 4-5 group members to discuss current events. Each student will be responsible for being a current event “presenter” for their group two times during the semester (once during the first half of the semester and once during the second half of the semester). Current events can be sourced from articles, podcasts, videos, and journal articles from the last week. Prior to the class session that you will present in, you will need to submit to Canvas reference information about the current event and a 2-3 sentence summary of the current event. Submission of the current event summary on

Canvas will count towards your participation. The purpose of this activity is to get in the habit of staying up to date on energy-related news, to practice facilitating discussion among peers, to link what you learn in class to the real-world, and to learn from your peers.

For asynchronous class participants, we will use Slack to facilitate discussion. We will form permanent groups of 4-5 for those that cannot attend class in person. The presenter must follow the guidelines established above, and other group members must engage in Slack (asynchronously) to discuss the article. Please email Carlotta if you need to join one of these groups; we will match people and create a private Slack channel for each group.

The following are potential sources (among many) that you may refer to for current events:

- Utility Dive (<https://www.utilitydive.com/>)
- E&E News Family (<https://www.eenews.net/>) – EnergyWire (<https://www.eenews.net/ew>), GreenWire (<https://www.eenews.net/gw>) – can view articles through VPN
- Vox Energy & Environment (<https://www.vox.com/energy-and-environment>)
- New York Times (<https://www.nytimes.com/>) – can view articles through UM Library
- Washington Post (<https://www.washingtonpost.com/>) – can view articles through UM Library
- Wall Street Journal (<https://www.wsj.com/>) – visit <https://www.csg.umich.edu/wsj> for access
- Volts (<https://www.volts.wtf/>)
- Green Tech Media (<https://www.greentechmedia.com/>)
- MIT Energy Initiative Podcast (<http://energy.mit.edu/podcast/>)
- The Energy Gang Podcast (<https://www.greentechmedia.com/podcast/the-energy-gang>)
- Axios Generate newsletter (<https://www.axios.com/newsletters/axios-generate>)

Paper Discussion Assignments and Classes

In several classes, we will spend the entire class in small group discussions. Each breakout group will discuss the reading internally, then each group will briefly report on their discussion to the class. Finally, if groups discuss separate readings, the class as a whole will discuss similarities, differences, and interactions between the papers. Student preparedness for and engagement in group discussions will factor into their class participation grade.

If you cannot attend class synchronously during one of these days (April 1, April 6, and April 13), you must email Carlotta. We will create groups, and each group must meet synchronously at a time that works for each member.

Stuff Happens

As stated above, problem set deadlines are strictly enforced and class attendance is required. However, I know for various reasons you might need to miss class or a problem set deadline. I will allow each student to drop one problem set and miss three classes over the course of the semester without penalty. Students who complete all assignments will receive extra credit for the problem set with the lowest grade. The extra credit will be added to your final grade and equal 3% times the percentage score of your lowest assignment. For instance, if a student receives 1 70% and otherwise 90% on their problem sets, the 90% grades will be used to calculate their total problem set grade, while the 70% will yield 2.1% extra credit added to their final grade ($3\% * 70\% = 2.1\%$).

Email Policy

For questions related to problem sets or other assignments, please use Piazza (see Piazza section above). For all other questions, I strongly prefer questions during office hours rather than by email. If you must email a question, please email Carlotta while CC'ing me (Michael) with a subject beginning [EAS615]. If you have a question you are not comfortable asking the GSI, please feel free to email me directly using a subject beginning [EAS615].

Academic Misconduct (or Cheating and Plagiarism)

Plagiarism or cheating on any exam or assignment is forbidden and will result in a failing grade on the exam or assignment and possibly in the course. Additionally, all cases of academic misconduct will be referred to the Office of the Assistant Dean for Undergraduate Education. You are responsible for knowing what constitutes academic misconduct (see <http://www.lsa.umich.edu/academicintegrity/examples.html>), although I will be glad to answer your questions. Academic misconduct includes (but is not limited to): cutting and pasting from a website;

lying about illnesses or other details related to missed work or classes; having someone complete a quiz or exam on your behalf; and submitting an assignment based on work from another student or course. You are encouraged to study for exams, share lecture notes, and discuss assignments with your classmates, but all assignments must be completed independently as described in the Problem Set section above.

Mental Health

Being a student can be extremely stressful and can lead to feelings of anxiety, depression, difficulty eating or sleeping, and drug and alcohol problems. If you have any of these feelings, you are not alone. Throughout my schooling, I (Michael) often experienced some of these feelings, and I guarantee you many of your classmates and friends have wrestled with these feelings as well at some point. In addition to these feelings, students can also be the victim of interpersonal or sexual violence, loss or grief, and other challenges. These feelings and experiences can take a significant toll on our lives, not to mention our academic performance. Moreover, we are currently living through extraordinary challenges – the ongoing COVID-19 pandemic, a transition of presidential leadership, recognizing and fighting racial injustice, actions against immigrants and international students and the ongoing climate crisis, to name a few. These events create and exacerbate the stresses in our lives.

In order to support you during such challenging times, the University of Michigan provides a number of confidential resources to all enrolled students, including Counseling and Psychological Services (CAPS) (734-764-8312), Sexual Assault Prevention and Awareness Center (SAPAC) (24-Hour Crisis Line: 734-936-3333), Psychiatric Emergency Services (734-996-4747), Spectrum Center (734-763-4186) and Services for Students with Disabilities (734-763-3000; 734-615-4461 [TDD]; 734-619-6661 [VP]). CAPS has a staff member dedicated to SEAS and PitE students. Dr. Andrea Sieg graduated from Loyola University Chicago in 2009 with her Masters in Social Work and became fully licensed in 2015. In Chicago, she worked with immigrants and refugees, among others. She has been with UM since 2016. She sees students between 10-6 on Tuesdays and 1-5 on Thursdays. Students can email her directly to schedule appointments with them: andsieg@umich.edu. In addition to these services, if you are feeling overwhelmed please feel free to reach out to me (Michael) to figure out what can be done at least through this course to bring more happiness and stability to your life.

Sexual Misconduct

Title IX prohibits discrimination on the basis of sex, which includes sexual misconduct in the forms of harassment, domestic and dating violence, sexual assault, and stalking. Sexual violence can undermine students' quality of life and academic success, so I encourage anyone dealing with sexual misconduct to talk to someone about their experience and get the support they need. Confidential support and academic advocacy can be found with the Sexual Assault Prevention and Awareness Center (SAPAC) on their 24-hour crisis line, (734) 936-3333 and at sapac.umich.edu. Alleged violations can be non-confidentially reported to the Office for Institutional Equity (OIE) at institutional.equity@umich.edu.

Religious Observances and Special Circumstances

I realize students may have religious obligations during the term. If you are aware of a conflict with a course expectation and your observance of a religious holiday, please contact me as soon as possible. I will do my best to make the necessary accommodations. The following link is to the University policies and guidelines specific to holiday observances: <https://lsa.umich.edu/lsa/academics/dates-and-deadlines/religious-holidays>.

Accommodations and Accessibility

If students think they may need an accommodation for a disability, they should let me (Michael) know at the beginning of the term. They should then contact the Services for Students with Disabilities (SSD) office. Once their eligibility for an accommodation has been determined, they will be issued a Verified Individual Services Accommodation (VISA) form and I will arrange for their accommodation. Any information students provide is private and confidential and will be treated as such. If students already have a VISA form from SSD, they should present this form to me at the beginning of the term, but no later than at least two weeks prior to the need for the accommodation so that there is enough time for the appropriate arrangements to be made.

Students with Children

I understand many of you may be juggling child care with coursework and other commitments. If this is the case and you must miss lectures or parts of lectures semi-regularly, please let me (Michael) know so we can find an accommodating solution.

Student Feedback

I am extremely interested in student feedback. There will be several defined opportunities for feedback but I welcome it at any point. Periodically I will distribute an anonymous survey for students to fill out. Among other topics, the survey will ask about the what is going well, what could be going better, difficulty and quantity of materials, whether you prefer class versus smaller discussion groups, and the classroom environment.

Writing Resources

The Sweetland Center for Writing offers free one-to-one writing support to all undergraduate and graduate students at the University of Michigan, regardless of background or discipline. Sweetland faculty and peer writing consultants meet with student writers to help with any stage of the writing process, from initial brainstorming to final revisions. Learn more about Sweetland's writing support, locations, and online writing consultations at <https://www.lsa.umich.edu/sweetland>.

Course Readings

We will use materials from journal articles, textbooks, and reports that will be freely available on Canvas or online through the library. No textbook is required. Except for paper discussion days, I strongly recommend you read the readings listed prior to “Skim:” before each class, as they will significantly help you understand lecture material. Readings listed after “Skim:” will further help prepare you for lecture.

Course Outline

Class #	Date	Topics	Readings	In-Class Participation Activity	Deadline
0	Jan 19 (Tues)	Course Introduction	None	Introductions	
I. Renewable Generation Resources and Technologies					
<i>This section will cover renewable resource assessment and technologies.</i>					
1	Jan 21 (Thurs)	Wind Resource Assessment <ul style="list-style-type: none"> • Collect, validate, and characterize wind resource • Convert wind speed to wind power density 	Brower, <i>Wind Resource Assessment</i> (Chapters 10, 11, and 12)	In-class exercise	
2	Jan 26 (Tues)	From Wind Resource to Electricity Generation <ul style="list-style-type: none"> • Turbine selection • Losses and curtailment • Costs and offtake • Levelized cost metrics 	Masters, <i>Renewable and Efficient Electric Power Systems</i> , Second Edition (Chapter 7) Wiser and Bolinger, “2018 Wind Technologies Market Report” (identify graphs and ideas that are of interest to you so that we can “crowd source” reading through breakout discussions)	Weekly current event Breakout discussion of “2018 Wind Technologies Market Report”	
3	Jan 28 (Thurs)	Solar Resource Assessment <ul style="list-style-type: none"> • Characterize components of solar resource • Clear sky insolation • Impact of panel orientation • Typical meteorological year 	Masters, <i>Renewable and Efficient Electric Power Systems</i> , Second Edition (Sections 4.10-4.13)	In-class exercise	
4	Feb 2 (Tues)	From Solar Resource to Electricity Generation <ul style="list-style-type: none"> • Principles of solar generation • PV I-V curves • Photovoltaic system design: cells, modules, arrays, inverters • Derating and costs 	Masters, <i>Renewable and Efficient Electric Power Systems</i> , Second Edition (Sections 6.1-6.4) Skim: Masters, <i>Renewable and Efficient Electric Power Systems</i> , Second Edition (Sections 5.4-5.9)	Weekly current event	
5	Feb 4 (Thurs)	From Solar Resource to Electricity Generation	Same as above		Problem Set #1 due

		<ul style="list-style-type: none"> Principles of solar generation PV I-V curves Photovoltaic system design: cells, modules, arrays, inverters Derating and costs 			
6	Feb 9 (Tues)	Discussion and Wrap Up: Wind and Solar Resource and Generation <ul style="list-style-type: none"> Variability versus uncertainty Forecasting (wind and solar) 	Bolinger and Seel, “Utility-Scale Solar”, 2019 Edition (identify graphs and ideas that are of interest to you so that we can “crowd source” reading through breakout discussions) Skim: Lew et al., “The Western Wind and Solar Integration Study Phase 2” (Chapter 4)	Weekly current event	Breakout discussion of “Utility-Scale Solar”
7	Feb 11 (Thurs)	Solar Thermal, Biopower, Geothermal and Hydropower <ul style="list-style-type: none"> Technologies, resources, and processes 	Masters, <i>Renewable and Efficient Electric Power Systems</i> , Second Edition (Sections 8.2, 8.7, and 8.8) Masters, <i>Renewable and Efficient Electric Power Systems</i> , Second Edition (Sections 8.5 and 8.6) NREL biomass maps and data Roberts, “Geothermal energy is poised for a big breakout” Skim: U.S. Environmental Protection Agency, “Municipal Solid Waste in the United States” (Executive Summary)	In-class exercise	Problem Set #2 due
II. Renewable Policies, Incentives, and Regulations <i>This section will cover policies, incentives, and regulations that encourage or govern renewable energy deployment.</i>					
8	Feb 16 (Tues)	Renewable Mandates and Incentives <ul style="list-style-type: none"> Renewable Portfolio Standards Compliance and voluntary Renewable Energy Credit markets PTC and ITC 	Skim: O’Shaughnessy et al., “Status and Trends in the U.S. Voluntary Green Power Market (2017 Data)” (Executive Summary) Merchant, “Corporate Renewables Procurement Accounted for Nearly a Quarter of All Deals in 2018” , <i>Greentech Media</i>	Weekly current event	

		<ul style="list-style-type: none"> Corporate targets 	<p>Wiser et al., “A Retrospective Analysis of the Benefits and Impacts of U.S. Renewable Portfolio Standards” (Executive Summary)</p> <p>www.dsireusa.org</p> <p>Bolinger, “An Analysis of the Cost, Benefits, and Implications of Different Approaches to Capturing the Value of Renewable Energy Tax Incentives” (Executive Summary)</p>		
9	Feb 18 (Thurs)	<p>Other Renewable-Relevant Policies and Regulations</p> <ul style="list-style-type: none"> Climate and local air quality PURPA 	None	None	Problem Set #3 due
10	Feb 23 (Tues)	<p>Equity and Renewable Energy</p> <ul style="list-style-type: none"> Environmental justice Socioeconomic dimensions of renewable energy Household energy burdens Distribution of renewable benefits and adoption Renewable energy and US indigenous tribes 	TBD	Weekly current event	
11	Feb 25 (Thurs)	<p>Discussion: U.S. Climate Policy</p>	<p>Biden Administration, “The Biden plan to build a modern, sustainable infrastructure and an equitable clean energy future”</p> <p>U.S. Congress, Ocasio-Cortez, “H.Res.109 – Recognizing the duty of the Federal Government to create a Green New Deal”</p>	Breakout discussions	
12	Mar 2 (Tues)	<p>Distributed Solar Policies and Regulations</p> <ul style="list-style-type: none"> Net energy metering Utility death spiral Feed-in tariffs Smart grid 	<p>Burger et al., “Why Distributed? A Critical Review of the Tradeoffs between Centralized and Decentralized Resources”</p> <p>Skim:</p> <p>Seel et al., “An Analysis of Residential PV System Price Differences between the United States and Germany”</p> <p>Hansen et al., “A Review of Solar PV Benefit and Cost Studies”</p> <p>Satchwell et al., “Financial Impacts of Net-Metered PV on Utilities and Ratepayers: A Scoping Study of Two Prototypical U.S. Utilities” (Section 5)</p>	Weekly current event	Problem Set #4 due

III. Renewables in Power System Planning and Operations					
<i>This section will first describe the basic features of power system planning and operations, then examine the benefits and challenges of including renewables in planning and operations.</i>					
13	Mar 4 (Thurs)	Power System Infrastructure <ul style="list-style-type: none"> • System structure • Transmission systems • Distribution systems • Basic power flow • Load 	MIT, “The Future of the Electric Grid” (Appendix B, Sections B.1-B.3) Skim: Masters, <i>Renewable and Efficient Electric Power Systems</i> , Second Edition (Chapter 1)	None	
14	Mar 9 (Tues)	Power System Operations <ul style="list-style-type: none"> • Types of power system operators and markets • Economic dispatch • Unit commitment • LMPs 	MIT, “The Future of the Electric Grid” (Appendix B, Sections B.4-B.5) Wood et al., <i>Power Generation, Operation, and Control</i> , Third Edition (Chapter 3, Sections 3.1-3.3 and 3.9-3.10; Chapter 4, Section 4.1)	Weekly current event	
15	Mar 11 (Thurs)	Power System Operations (cont.) <ul style="list-style-type: none"> • Typical generation operational profiles (baseload to peaker) • Conventional versus renewable generators • Ancillary services • Contingencies 	Zhou et al., “Survey of U.S. Ancillary Services Markets” (Summary and Overview)	In-class exercise	
16	Mar 16 (Tues)	Power System Operations (cont.) <ul style="list-style-type: none"> • Typical generation operational profiles (baseload to peaker) • Conventional versus renewable generators • Ancillary services • Contingencies 	Zhou et al., “Survey of U.S. Ancillary Services Markets” (Summary and Overview)	In-class exercise	
17	Mar 18 (Thurs)	Renewables in Power System Operations <ul style="list-style-type: none"> • Ancillary services for high renewable penetrations 	MIT, “The Future of the Electric Grid” (Chapter 3) California ISO, “What the Duck Curve Tells Us about Managing a Green Grid”	Weekly current event	Problem Set #5 due

		<ul style="list-style-type: none"> Operational flexibility for variability and uncertainty Duck curve Costs and revenue adequacy 	<p>Skim: Ela et al., “Wholesale Electricity Market Design with Increasing Levels of Renewable Generation: Incentivizing Flexibility in System Operations”</p> <p>Lew et al., “The Western Wind and Solar Integration Study Phase 2” (Chapters 5 and 6)</p> <p>Ela et al., “Effective Ancillary Services Market Designs on High Wind Power Penetration Systems”</p>		
March 23 (Tues) – NO CLASS, Well Being Break					
18	Mar 25 (Thurs)	<p>Power System Planning</p> <ul style="list-style-type: none"> Generation and transmission expansion planning Power system reliability Revenue adequacy 	<p>Wilson and Biewald, “Best Practices in Electric Utility Integrated Resource Planning”</p> <p>North American Electric Reliability Corporation, “Probabilistic Adequacy and Measures” (pages iv-17)</p>	In class exercise	
19	Mar 30 (Tues)	<p>Renewables in Power System Planning</p> <ul style="list-style-type: none"> Current approaches to incorporating renewables in planning Effective load carrying capability Transmission expansion for renewables Renewable energy zones Market design challenges 	<p>Milligan et al., “Capacity Value Assessments of Wind Power”</p> <p>MIT, “The Future of the Electric Grid” (Chapter 4)</p> <p>Skim: Milligan et al., “Wholesale Electricity Market Design with Increasing Levels of Renewable Generation: Revenue Sufficiency and Long-term Reliability”</p>	In class exercise with https://model.energy/	
20	Apr 1 (Thurs)	<p>Energy Storage and Demand Response</p> <ul style="list-style-type: none"> Technologies Applications Daily versus seasonal shifting needs Markets and business models 	<p>Center for Sustainable Systems, “U.S. Grid Energy Storage”</p> <p>Skim: Martín et al., “Energy Storage Technologies for Electric Applications”</p> <p>Arbabzadeh et al., “Twelve Principles for Green Energy Storage in Grid Applications”</p>	Weekly current event	Problem Set #6 due
21	Apr 6 (Tues)	<p>Guest Lecture: Michael Skelly, Clean Line Energy Partners</p>	<p>Gold, “Building the Wind Turbines Was Easy. The Hard Part Was Plugging Them In.”</p>	Current event	

22	Apr 8 (Thurs)	Guest Lecture: Renewables in Developing Countries (Amy Rose, NREL)	<p>Rose Mutiso’s Ted Talk “The Energy Africa Needs to Develop – And Fight Climate Change”. https://www.energyforgrowth.org/rose-mutiso-on-ted-the-energy-africa-needs-to-develop-and-fight-climate-change/ (Feel free to check out other insightful analysis and resources at the Energy For Growth Hub)</p> <p>“Faster Than You Think: Renewable Energy and Developing Countries” https://www.annualreviews.org/doi/full/10.1146/annurev-resource-100518-093759</p> <p>“Ten Principles for Power Sector Transformation in Emerging Economies” https://www.nrel.gov/docs/fy19osti/73931.pdf</p>	None	
23	Apr 13 (Tues)	Paper Discussion: Renewables in an International Context	<p>Choose one: Rose et al., “Prospects for Grid-Connected Solar PV in Kenya: A Systems Approach”</p> <p>Williams et al., “An Investment Risk Assessment of Microgrid Utilities for Rural Electrification Using the Stochastic Techno-Economic Microgrid Model: A Case Study in Rwanda”</p> <p>Mentis et al., “Lighting the World: The First Application of an Open Source, Spatial Electrification Tool (OnSSET) on Sub-Saharan Africa”</p> <p>Faria and Jaramillo, “The Future of Power Generation in Brazil: An Analysis of Alternatives to Amazonian Hydropower Development”</p> <p>Kammen et al., “A Clean Energy Vision for East Africa”</p>	Breakout discussions	
24	Apr 15 (Thurs)	Project Presentations	None	Presentations	Project due
25	Apr 20 (Tues)	Project Presentations	None	Presentations	