

ENVIRONMENTAL & ENERGY ECONOMICS AND POLICY

BEPP/OIDD 2630

Spring Semester 2024, Tu/Th 12:00-1:30pm, JMHH 340

Note: This syllabus will be continuously updated. Please check Canvas for the latest version. Readings will be added/updated throughout the semester and as policy developments occur.

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Course overview. Over the last several decades, energy markets have become some of the most dynamic markets of the world economy. Traditional fossil fuel and electricity markets have seen a partial shift from heavy regulation to market-driven incentives, while rising environmental concerns have led to a wide array of new regulations and “environmental markets”. The growth of renewable energy is another source of rapid change, but brings with it a whole new set of technological and policy challenges. This changing energy landscape requires quick adaptation from energy companies, but also offers opportunities to turn regulations into new business. The objective of this course is to provide the economist’s perspective on a broad range of topics that professionals in the energy industry will encounter. Topics include the effect of competition, market power and scarcity on energy prices, extraction and pricing of oil and gas, geopolitical uncertainty and risk in hydrocarbon investments, the environmental policies related to the energy sector and their effectiveness, cap-and-trade markets, and transportation policies. There is special emphasis on the economics and finance of renewable energy, including an introduction to energy storage.

Readings. A mix of newspaper articles, academic papers, reports, plus the following textbook: Nathaniel Keohane and Sheila Olmstead (KO), *Markets and the Environment*, Washington, D.C.: Island Press, second edition, 2016. Starred (*) readings are required. Many starred readings are short. Non-starred readings are optional but I will discuss them in class, and you are highly encouraged to read them if you want further background on a specific topic. The best way to use the readings is as a supplement to the lectures, which overlap partially (but certainly not perfectly!) with the readings. You will be responsible for required readings not covered in class.

Prerequisites. An introductory microeconomics course (ECON1, or another course approved by the instructor) will be sufficient in most cases; BEPP 2500 or an equivalent intermediate microeconomics course is recommended.

Attendance. Attendance is mandatory. Please complete a [Course Action Notice](#) if you cannot attend a particular session.

Format. For most lectures, I will post prep questions on Canvas. Some lectures have pre-recorded videos. I will build on the video content in the lecture, so it is really important that you watch the assigned video beforehand. When a video is on the longer side, I may start the class later, so you have the option to watch it within the allocated 90-minute lecture slot. Feel free to email me (cc: Benji) any questions that arise as you watch the videos.

Electricity strategy game. Students will participate in a simulation of an electricity market. Student teams manage a portfolio of generation units (coal, natural gas, nuclear and renewables) and bid into an electricity market.

Guest lectures. The course has five guest lectures by various energy experts. This year's emphasis will be on renewable energy finance, renewable energy policy, energy storage, virtual power plants, and climate policy and the media. Two guest lectures will be joint with the MBA course *Climate and Financial Markets* (ACCT/BEPP 7640) and will take place on Tu/Th from 10:15-11:45am or 1:45-3:15pm. These lectures will be recorded. Attendance is mandatory unless you have a conflict with another class (please email me if you do) and the content of the guest lectures is fair game for questions on assignments and exams.

Assignments and grading. Four assignments (20%; full credit for timely submissions and scores of 60% or higher; partial credit below that), two in-class exams (50%), the Electricity Strategy Game (20%) and class participation (10%). Your class participation grade will be based on the quality of your comments during class and Canvas prep-questions (full credit for timely and “good-faith effort” completion only).

AI policy. You may use generative AI programs (e.g., tools like ChatGPT) to help generate ideas and brainstorm. However, you should note that the material generated by these programs may be inaccurate, incomplete, or otherwise problematic. Beware that use may also stifle your own independent thinking and creativity. You may not submit any work generated by an AI program as your own. If you include material generated by an AI program, it should be cited like any other reference material (with due consideration for the quality of the reference, which may be poor). Any plagiarism or other form of cheating will be dealt with severely under relevant Penn policies.

Study tips. To master the quantitative parts of this course, the best way to study is to rework through the examples from class and the lecture notes with pen and paper, and to attempt to solve all assignment problems on your own. I also highly recommend working in groups. The assignments are take-home and meant as practice for the tests. You may discuss assignments with other students but you need to formulate and submit answers with at most two other classmates. An extensive set of practice questions and solutions will be posted early in the semester. You can discuss them with the TA or with me during office hours if needed.

Exams. You should plan to attend both exams. Contact Beth Moskat in BEPP (emoskat@wharton.upenn.edu) if you have a medical issue or an emergency. No other

exceptions. Please do not email me about alternative exam dates for other reasons as I have no flexibility to accommodate such requests in all fairness to other students.

Cheating policy. It should not be necessary to say this – but for completeness: all students are expected to comply with the University of Pennsylvania’s Code of Academic Integrity. It is the policy of the department, and this course, to immediately fail any student for the course who is in violation of the University’s Code of Academic Integrity. Additional sanctions may be imposed of the Office of Student Conduct. The Code of Academic Integrity can be reviewed [here](#).

Electronics. Taking notes on tablets is permitted. Phones are permitted for responding to polls, but should otherwise not be a distraction to you or your classmates. No laptops as the sound of typing has proven to bother other students.

Other details. The course is included in Wharton undergraduate concentration in Business, Energy, Environment and Sustainability, the Environmental Studies majors from the Earth & Environmental Science department, and in the university-wide minors in Environmental Studies and Sustainability and Environmental Management. Non-Wharton students are welcome and encouraged to contact the professor in advance to discuss prerequisites.

ELECTRICITY MARKETS

Lecture 1 (Jan 18): Course Introduction & Energy Overview

International Energy Agency, 2023. *World Energy Outlook*, Executive Summary ([link](#)).

Lecture 2 (Jan 23): Market Efficiency and Scarcity Pricing

Topics: market efficiency; scarcity pricing; electricity markets; refined products markets.

(*) Pre-recorded video: Market Efficiency

Pre-recorded video: Scarcity Pricing (I will cover this in class too.)

(*) KO Chapter 4: “The Efficiency of Markets”.

(*) J. Mouawad, “A Fast-Growing Independent Strikes Gold in Oil Refining”, *New York Times*, 5/18/05 ([link](#)).

(*) J. Mouawad, “Oil Refiners See Profits Sink as Consumption Falls”, *New York Times*, 5/14/08 ([link](#)).

(*) C. Krauss, “Oil Refining’s Fortunes Rise”, *New York Times*, 10/24/12 ([link](#)).

(* L. Cook and B. Olson, “Hurricanes Stir up Profits for Refiners”, *Wall Street Journal*, 9/17/17 ([link](#)).

D. Winning and R. Elliott, “Pandemic Pushes Fuel Makers in Richer Countries to the Brink”, *Wall Street Journal*, 12/6/20 ([link](#)).

J. Lee, “America’s Refiners Are Running on Premium”, *Wall Street Journal*, 11/1/22 ([link](#)).

Lecture 3 (Jan 25): **Market Power in Electricity Markets (Start Lecture: 12:40pm)**

Topics: market power; deregulation.

(* Pre-recorded video: Market Power

(* S. Borenstein, 2000. “Understanding Competitive Pricing and Market Power in Wholesale Electricity Markets”, *The Electricity Journal* 13(6): pp. 49-57 ([link](#)).

(* M. Slezak, “Energy Companies Withholding Supply to Blame for July Price Spike, Report Finds”, *The Guardian*, 8/17/16 ([link](#)).

Lecture 4 (Jan 30): **Electricity Market Design**

Topics: California electricity crisis; Texas electricity crisis; electricity retail pricing.

Pre-recorded video: Electricity Retail Pricing

(* S. Borenstein, 2018. “The Electricity Price Isn’t Right.” Energy Institute Blog, UC Berkeley ([link](#)).

(* J. Bushnell, 2023. “(More) Breaking News! California Electricity Prices are Still High!” Energy Institute Blog, UC Berkeley ([link](#)).

(* C. Krauss, M. Fernandez, I. Penn and R. Rojas, “How Texas’ Drive for Energy Independence Set It Up for Disaster”, *New York Times*, 2/21/21 ([link](#)).

G. McDonnell Nieto del Rio, N. Bogel-Burroughs and I. Penn, “His Lights Stayed on During Texas’ Storm. Now He Owes \$16,752”, *New York Times*, 2/20/21 ([link](#)).

S. Borenstein, 2002. “The Trouble with Electricity Markets: Understanding California's Restructuring Disaster”, *Journal of Economic Perspectives* 16(1): pp. 191-211 ([link](#)).

ENERGY AND ENVIRONMENTAL POLICY

Lecture 5 (Feb 1): **Global Climate Change**

Topics: climate change impacts; the climate change debate; discounting; risk and uncertainty; social cost of carbon.

(*) Pre-recorded video: Climate Change Discounting.

(*) Lecture notes on climate change mitigation and discount rates (on Canvas).

(*) N. Farah and L. Clark, “EPA Floats Sharply Increased Social Cost of Carbon”, *E&E News*, 11/21/22 ([link](#)).

K. Rennert and B. Prest, “The US Environmental Protection Agency Introduces a New Social Cost of Carbon for Public Comment”, *Resources*, 11/15/22 ([link](#)).

B. Litterman, 2013. “What Is the Right Price for Carbon Emissions?”, *Regulation* 36(2): pp. 38-43 ([link](#)).

United Nations Environment Programme, 2022. *Emissions Gap Report*, Executive Summary ([link](#)).

Lecture 6 (Feb 6): **Externalities and Policy Instruments**

Topics: environmental externalities; tragedy of the commons; Coase Theorem; property rights; taxes vs. subsidies vs. standards; effect of regulations on business; double dividend.

(*) Pre-recorded video: Externalities and Policy Instruments.

(*) KO Chapter 5: “Market Failures in the Environmental Realm”.

(*) KO Chapter 8: “Principles of Market-Based Environmental Policy”, pp. 139-162.

(*) G. Ip, “Carbon Tax Sidelined in Biden’s Push on Climate, Taxes”, *Wall Street Journal*, 3/24/21 ([link](#)).

Lecture 7 (Feb 8): **Cap-and-Trade (End Lecture: 1:00pm)**

Topics: basics of cap-and-trade; cost-effectiveness; introduction to market design issues.

(*) Pre-recorded video: Cap-and-Trade.

(*) Lecture notes on the economics of cap-and-trade (on Canvas).

(* KO Chapter 9: “The Case for Market-Based Instruments in the Real World”, pp. 168-184.

Lecture 8 (Feb 13): **Designing Real-World Environmental Markets**

Topics: market design issues in cap-and-trade markets; EU Emissions Trading Scheme; RECLAIM; acid rain trading program.

(* KO Chapter 9: “The Case for Market-Based Instruments in the Real World”, pp. 190-198.

(* KO Chapter 10: “Market-Based Instruments in Practice”, pp. 199-207, 208-210 and 217-220.

Lecture 9 (Feb 15): **U.S. and Global Policy Developments**

Topics: global carbon trading developments; U.S. climate change policy.

(* J. Wolman, “Carbon Markets Are Heating Up”, *Politico*, 3/9/23 ([link](#)).

(* S. Twidale, K. Abnett and N. Chestney, “EU Carbon Hits 100 Euros Taking Cost of Polluting to Record High”, *Reuters*, 2/21/23 ([link](#)).

(* McKinsey & Company, “The Inflation Reduction Act: Here’s What’s In It”, 10/24/22 ([link](#)).

(* “Q&A: What is China's Carbon Trading Scheme?”, *Phys.org*, 2/7/21 ([link](#)).

“China Will Crack Down on Data Fraud to Bolster Its Ailing Carbon Trading Market”, *Bloomberg*, 3/4/23 ([link](#)).

Lecture 10 (Feb 20): **Climate Policy and the Media**

Guest speaker: Juliet Eilperin, Energy and Environment Reporter, The Washington Post

Topics: recent environmental policy developments; public opinion and energy policy; the role of the media in the debate about energy and climate change.

(* J. Eilperin and B. Dennis, “As Biden Vows Monumental Action on Climate Change, a Fight with the Fossil Fuel Industry Has Only Begun”, *The Washington Post*, 1/27/21 ([link](#)).

(* J. Eilperin, B. Dennis and J. Muyskens, “Tracking Biden’s Environmental Actions”, *The Washington Post*, 2/10/20 (regularly updated) ([link](#)).

J. Eilperin, B. Dennis and J. Muyskens, “Trump Rolled Back More Than 125 Environmental Safeguards. Here’s How.”, *The Washington Post*, 10/30/20 ([link](#)).

OIL AND GAS MARKETS

Lecture 11 (Feb 22): Oil and Natural Gas Extraction and Pricing (1)

Topics: trends in oil and gas reserves; optimal extraction; Hotelling model.

(*) Pre-recorded video: Hotelling Model

(*) Pre-recorded video: Hotelling Model Extensions

(*) KO Chapter 6: “Managing Stocks: Natural Resources as Capital Assets”.

(*) Lecture notes on the Hotelling model for optimal resource extraction (on Canvas).

B. Faucon and S. Said, "Russia’s Oil Ban Accelerates Shift in Global Energy Flows", *Wall Street Journal*, 12/30/22 ([link](#)).

Lecture 12 (Feb 27): Oil and Natural Gas Extraction and Pricing (2)

Topics: oil and gas price volatility; forecasting; futures.

(*) Video: Khan Academy, Forward and Futures Contracts, Lessons 1-5 ([link](#)). Lessons 6-12 are optional, but please watch if you need further explanation after the lecture.

(*) M. Mandavia, “Liquefied Natural Gas Will Have a Less Frenzied 2023”, *Wall Street Journal*, 1/19/23 ([link](#)).

(*) J. Jacobs, 2023. “US Stockpiles Natural Gas as Warm Winter Temperatures Cut Demand”, *Financial Times*, 1/15/23 ([link](#)).

(*) R. Dezember, “U.S. Oil Costs Less Than Zero After a Sharp Monday Selloff”, *Wall Street Journal*, 4/21/20 ([link](#)).

R. Dezember, “U.S. Glut in Natural-Gas Supply Goes Global”, *Wall Street Journal*, 8/27/19 ([link](#)).

J. Hamilton, 2009. “Understanding Crude Oil Prices.” *The Energy Journal* 30(2): pp. 179-188 (see Readings folder on Canvas). (*Note: this reading is old but still relevant!*)

Lecture 13 (Feb 29): **Exam I**

Note: the exam will be held during the regular class time in two different rooms (see below).

--- SPRING BREAK ---

THE ECONOMICS AND FINANCE OF RENEWABLE ENERGY

Lecture 14 (Mar 12): **The Economics of Renewable Energy & Introduction to the Electricity Strategy Game**

Topics: levelized cost of electricity; environmental benefits of renewables.

(*) Pre-recorded video: Electricity Strategy Game.

(*) Lecture notes on renewable energy finance and policy, pp. 1-4 (on Canvas).

Lazard, “Levelized Cost of Energy and Levelized Cost of Storage – 2021”, 10/28/21 ([link](#)).

Lecture 15 (Mar 14): **Renewable Energy Finance (1)**

Topics: intermittency; the variable value of renewable energy; intro to renewable energy finance; tax credits; accelerated depreciation; solar leases and PPAs.

(*) Lecture notes on renewable energy finance and policy, pp. 4-7 (on Canvas).

(*) K. Treece, “How Does a Solar Lease Work?”, *Consumer Affairs*, 3/2/23 ([link](#)).

(*) B. Church, “Solar Lease vs. Solar PPA”, *Consumer Affairs*, 3/10/23 ([link](#)).

Department of Energy, 2023. “Federal Solar Tax Credits for Businesses” ([link](#)).

Lecture 16 (Mar 19): **Renewable Energy Finance (2) & Electricity Strategy Game Auction**

Topics: energy storage basics; tax equity; securitization.

(*) Pre-recorded video: Energy Storage Basics.

(*) Lecture notes on renewable energy finance and policy, pp. 11-13 and 19 (on Canvas).

Video: Tax Equity Structure in US Renewable Energy Sector ([link](#)).

Lecture 17 (Mar 21): **Renewable Energy Project Finance**

Guest speaker: Gianluca Signorelli, VP, Head of Project Finance and M&A Execution, U.S. SB Energy (SoftBank)

Topics: renewable energy project finance, tax equity, capital structure, PPAs, hedging.

Note: this lecture will be held outside the regular class time in our usual classroom (10:15-11:45am or 1:45-3:15pm; location JMHH 340).

(*) Norton Rose Fulbright, “Project Finance NewsWire”, 3/23 ([link](#)). Please read pages 1-13, 14-18, and 23-20.

Lecture 18 (Mar 26): **Renewable Energy Finance (3) (Pre-Recorded Video Lecture)**

Topics: renewable portfolio standards; (S)RECs.

(*) Pre-recorded video: Renewable Energy Finance

(*) Lecture notes on renewable energy finance and policy, pp. 8-11, 13-18 (on Canvas).

Lecture 19 (Mar 28): **Financing Wind Energy Investments**

Guest speaker: Udit Goyal, Head of Project Finance, Offshore North America, Ørsted

Topics: investing in wind energy, wind energy finance, wind energy contracts.

Note: this lecture will be held outside the regular class time in a different location (1:45-3:15pm; JMHH F85).

(*) Center for American Progress, “The Road to 30 Gigawatts: Key Actions to Scale an Offshore Wind Industry in the United States”, 3/14/22 ([link](#)).

(*) U.S. Department of the Interior, “Biden-Harris Administration Sets Offshore Energy Records with \$4.37 Billion in Winning Bids for Wind Sale”, 2/15/23 ([link](#)).

K. Martin, “Cost of Capital: 2023 Outlook”, Norton Rose Fulbright, 3/6/23 ([link](#)).

E. Pogue et al., “US Offshore Wind Challenges”, *Project Finance International*, 4/20/22 ([link](#)).

Lecture 20 (Apr 2): **Renewable Energy Policy**

Topics: net metering; PACE; feed-in tariffs; tenders; import tariffs; green subsidy vs. carbon tax; waterbed effect.

(* S. Borenstein, “Can Net Metering Reform Fix the Rooftop Solar Cost Shift?”, *UC Berkeley Energy Institute Blog*, 1/25/21 ([link](#)).

(* S. Evans, “Record-Low Price for UK Offshore Wind Is Nine Times Cheaper Than Gas”, *CarbonBrief*, 7/8/22 ([link](#)).

J. Deign, “When Will European Offshore Wind See Negative Bids?”, *Greentech Media*, 11/18/19 ([link](#)).

Lecture 21 (Apr 4): **Climate Risks in Energy Markets**

“Ørsted’s Renewable-Energy Transformation”, McKinsey & Company, 7/10/20 ([link](#)).

“Sustainable Business Transformation - The Ørsted Case”, The Conference Board, 6/17/20 ([link](#)). (This is a podcast.)

Lecture 22 (Apr 9): **Electricity Strategy Game Debriefing**

Lecture 23 (Apr 11): **Demand Response and Virtual Power Plants**

Guest speaker: Elta Kolo, Vice President, Huck Capital

Topics: demand response; virtual power plants; home batteries; buildings as power plants.

(* Rocky Mountain Institute, “Virtual Power Plants, Real Benefits”, January 2023 ([link](#)).

(* J. St. John, “Inside the Software Running Sunrun’s Home Solar-Battery Fleets”, *Canary Media*, 2/21/23 ([link](#)).

(* K. Balaraman, “The Power Grid Faced Heat Waves, Record Demand and Tight Conditions in 2022. What Happens Next?”, *UtilityDive*, 11/22/22 ([link](#)).

(* Climate Tech VC, “Buildings as Power Plants”, 12/2/22 ([link](#)).

Lecture 24 (Apr 16): **Fuel-Economy Policy (1)**

Topics: policy developments in the car industry; fuel-economy standards; gasoline tax; unintended consequences from fuel-economy standards; cost-benefit analysis; electric vehicle policy.

(*) A. Hawkins, “US Unveils Stricter Tailpipe Emissions Standards for New Vehicles”, *The Verge*, 4/1/22 ([link](#)).

(*) H. Tabuchi and B. Plumer, “How Green Are Electric Vehicles?”, *New York Times*, 3/2/21 ([link](#)).

Lecture 25 (Apr 18): **Fuel-Economy Policy (2)**

Lecture 26 (Apr 23): **Energy Storage**

Guest speaker: Charlotte Beard, Chief Financial Officer, Form Energy

Topics: the economics and finance of energy storage; the various technologies; the connection between storage and large-scale renewables deployment.

(*) I. Ragazzi and S. Burger, “Solving the Clean Energy and Climate Justice Puzzle”, *Form Energy White Paper*, 7/20 ([link](#)).

(*) S. Burger, M. Ferrara, R. Go and A. Olson, “To Build a Zero-Carbon Grid, We First Need to Model It Accurately”, *Utility Dive*, 12/23/20 ([link](#)).

Optional: Form Energy’s *Insights* page has several other interesting articles ([link](#)).

Lecture 27 (Apr 25): **Unintended Policy Consequences & Course Wrap Up**

Topics: congestion policies; enforcement; cheating; emissions leakage; course summary.

Lecture 28 (Apr 30): **Exam II**

Note: the exam will be held during the regular class time in two different rooms (see below).

DUE DATES

Assignment dates

Assignment 1: posted on January 25, due by February 6
Assignment 2: posted on February 13, due by February 22
Assignment 3: posted on Mar 14, due by March 26
Assignment 4: posted on April 11, due by April 25

Electricity Strategy Game

March 12	Introduction to the Electricity Strategy Game in class
March 15	Bids due for the ESG test run
March 19	First ESG divestiture auction, in class
March 21	ESG strategies due by 10pm for year 1, day 1
March 25	ESG strategies due by 10pm for year 1, day 2
March 27	ESG strategies due by 10pm for year 1, day 3
March 28	Sealed portfolio bids for year 2 due by 10pm
April 1	ESG strategies due by 10pm for year 2, day 1
April 2	ESG strategies due by 10pm for year 2, day 2
April 3	ESG strategies due by 10pm for year 2, day 3
April 9	ESG strategy memo due before class
April 9	ESG debriefing in class

Exams

Thursday February 29 and Tuesday April 30, during regular class hours, location to be announced