OIDD 525: Thinking with Models: Business analytics for energy and sustainability
Syllabus, Fall 2020
Canvas:
https://canvas.upenn.edu/courses/1526584

Steven O. Kimbrough

August 9, 2020

The course will proceed very much as described in this syllabus, which is nevertheless subject to change. We are in especially unusual circumstances this fall on at least two grounds.

First, because of the Covid-19 pandemic the course will be held online unless and until the pandemic safely abates, which we have to assume is very unlikely before the beginning of 2021.

Second, this is the first time I have offered the course and so it is impossible for me to know with any precision beforehand what the interests and capabilities of the enrolled students will be. In consequence,

A. Please understand that I am absolutely committed to working with every enrolled student interested in modeling and/or energy and sustainability, regardless of their level of preparation, especially with regard to computer programming. There will be ample opportunity to do lots of programming, and to learn new tools. On the other hand, students wishing to avoid these "technical" subjects are welcome and will be accommodated without prejudice. Above all, if you are interested in learning, I will do my best to be a good teacher. This is not about evaluating you; it is about the joy and value of learning about modeling, energy, and sustainability.

B. The course deliverables will focus on student projects, for which I will serve as mentor and consultant to help you do them. My fond aim is that many of the student projects can result in short reports of broader interest, say to future employers or graduate schools. I will arrange to post successful projects online as a way, in part, of publicly validating your work.

The course will meet online and have interactive discussion during the class hour. Provision will be made for students living in distant time zones. Contact the instructor.

Contents

1 Course Title

“Thinking with Models: Business Analytics for Energy and Sustainability”

2 Short Description

The world is engaged in a transition to clean and sustainable energy. The ensuing disruption creates opportunities for innovation on many fronts, including new social arrangements, new business models, and entrepreneurial activities of many kinds. OIDD 525 is a business analytics class that will focus on these aspects of the energy transition.

The class will be taught online unless the coronavirus epidemic abates to a comfortable level of safety. The work of the class will divide roughly into two categories.

The first consists of lectures, briefings really, on what business analysts need to know about the energy transition. This includes technical and institutional knowledge, such as what the difference between power and energy is, why huge investments in green hydrogen are being tee’d up, and what a virtual power plant is.

The second consists of internship-like project work, guided and mentored by the instructor, in which the students actually do business analytics. The work products of these projects will be presented in voice annotated PowerPoint and shared with the class. Many students will also find it useful to share their project work products with prospective employers and graduate schools. The instructor will supplement classes with expanded office hours to help students do their projects.

To give a sense of the class, here are links to three recent journalistic articles pertaining to business analytics and the energy transition. They are simply a convenience sample. There are lots more of them out there.

`https://www.greentechmedia.com/articles/read/the-most-complete-climate-policy`

`https://oilprice.com/Alternative-Energy/Fuel-Cells/Is-Commercial-Hydrogen-Pos`
`html`

`https://www.greentechmedia.com/articles/read/bloom-energy-stock-price-soars-a`

`https://www.vox.com/energy-and-environment/2020/7/16/21324662/climate-change-`

In addition, there are excellent podcasts available. I especially like The Energy Gang, and The Interchange, both from GreentechMedia (www.greentechmedia.com).

It is a remarkable fact of our times that such sophisticated journalism, and business analytics, regularly appears in trade press discussions associated with the energy transition. The goals of the course may be stated in this regard as (i) To provide knowledge sufficient to being able to comprehend in depth this sort of journalism and to produce the sort of business analytics it is reporting on, and (ii) To mentor and guide the students to learn how to produce this sort of business analytics.

In terms of prerequisites, familiarity with scripting languages, Excel modeling, and that ilk will be useful, but not necessary. I'll work with the class from where it is. The same goes for knowledge of optimization and other forms of management science modeling.

3 Teaching Philosophy

This course, "Thinking with Models," and the subject it names (thinking with models) is about building and interpreting models, for both scientific purposes and to support decision making. Thinking with models is practiced pervasively outside the academy. It is an important and much relied upon, even essential, skill in the modern world, whether in the public, private, or third sector of the economy.

Our main goal in the course is for students to become proficient in this practice. In consequence, we emphasize above all "learning by doing" and undertaking projects as fundamental to the educational goals of the course. A portion of the time and effort in the course will follow the more traditional mode of instructors presenting information on the subject matter. The majority of the time and effort, however, will be spent in apprenticeship (or internship) mode, in which students learn by working on projects, calling on the instructors for guidance and special knowledge as needed.

Completed projects will be evaluated, of course. Project development in apprenticeship mode, however, is inherently cooperative and supportive, rather than evaluative. We emphasize throughout that the class constitutes a community of learners with shared interests in learning how to think with models.

4 Relation to OIDD 325

This course is an upper-level successor to OIDD 325, "Thinking with Models," focusing on more advanced techniques and concepts, and on models pertaining to energy and sustainability. Like OIDD 325, it emphasizes interpreting models and extracting information from models using computational methods.

5 Course Description

Models are lenses. They are instruments with which we view, interpret, and give meaning to data. In this course, students will be exposed to and do work in all phases of the modeling life-cycle, including model design and specification, model construction (including data gathering and testing), extraction of information from models during post-solution analysis, and creation of studies that use modeling results to support conclusions for scientific or decision making purposes. In addition, the course will cover critical assessments of fielded models and studies using them.

The course will focus broadly on models pertaining to energy and sustainability. This is not only an inherently interesting and important area, but it is very much a public one. In consequence, models, data, and studies using them are publicly and profusely available, as is excellent journalism, which facilitates introductions to specific topics. The course covers selected topics in energy and sustainability. Essential background will be presented as needed, but the course is *not* a comprehensive overview of energy and sustainability. Further, while we shall often discuss policy implications of findings from models and studies using them, this is not a course about policy making or policy analysis.

Modeling in the area of energy and sustainability analytics is rife with uncertainty, and yet decisions must be made. Uncertainty, and how to deal with it in model-based decision making, is an overarching theme of the course. We will focus on energy and sustainability, but that area is hardly unique in being beset with deep and vexing uncertainties. The lessons we learn will generalize.

The overall aim of the course is to teach facility with modeling and to use real-world data, models, and studies in doing so. In addition, students with interests in investment or policy analysis in the energy sphere will find the course's subject area focus useful.

6 Prerequisites

OIDD 325, "Thinking with Models," or equivalent, exposure to computer programming, or consent of instructor. Exercises and assignments will involve programming in NetLogo, and at times with R, using the NetLogo-R API, as well as other languages, such as Python and MATLAB, as called for. Key principles will be covered in class or in bootcamp sessions outside of class. Students with knowledge of NetLogo and/or serious exposure to another programming language can expect to be adequately prepared in this regard.

7 Required Texts

There is nothing necessary to purchase.

Our main text will be Randolph and Masters (2018), *Energy for Sustainability: Foundations for Technology, Planning, and Policy, 2nd ed.* This will be available as an ebook, through the library and Canvas.

We will (likely) do some readings from Kimbrough and Lau (2016), "Business Analytics for Decision Making." This will be available as an ebook, through the library and Canvas.

Other readings and handouts will be freely available on Canvas.

8 Course modules

I. Foundations

II. Electricity provision, optimization and design, and decision modeling focused on policy making

III. Agent-based models and simulation pertaining to energy and sustainability analytics

IV. Optimization and policy strategies

9 Class schedule

Begin module I: Foundations.

9.1 Begin module I: Introduction

In preparation for class:

- GTM podcast, The Energy Gang, "The State of Off-Grid Energy Access: This week on The Energy Gang: the cutting-edge business of bringing power to the last billion people on earth without it.," February 17, 2020 (Also February 14 on podcast sites such as iTunes). `https://www.greentechmedia.com/articles/read/the-state-of-off-grid-energy-access.` The is just pre-COVID-19, but still very relevant. It features lots of topics: politics, policy, technology, business models and investment, developing world, gender equality, and so on. Listen and come to class with questions. A main goal of the class is for students to become literate in these sorts of discussions.

- "How to drive fossil fuels out of the US economy, quickly: The US has everything it needs to decarbonize by 2035" by David Roberts at Vox.com Aug 6, 2020. `https://www.vox.com/energy-and-environment/21349200/climate-change-fossil-fuels-rewiring-am` A good opening on many of the topics that will concern us.

Introduction and overview of the course. A word or two on climate science and why it makes the energy transition imperative. Discussion of the preparation materials.

9.2 Energy Basics, 1

In preparation for class:

- (Randolph and Masters, 2018, chapter 4, pages 95–113), "Fundamentals of Energy Science." Read quickly for general understanding. More in depth next time.

9.3 Energy Basics, 2

Focus: variability of electricity supply and demand and the fact that electrical energy cannot be stored. This is a theme that will be with us throughout.

In preparation for class:

- (Randolph and Masters, 2018, chapter 4, pages 113–131), "Fundamentals of Energy Science." Read quickly for general understanding.
- (Kimbrough and McElfresh, 2018) at `http://knowledge.wharton.upenn.edu/article/is-a-more-rapid-transition-to-renewable-energy-on-the-verge-of-bein`

9.4 Energy Analytics, 1

In preparation for class:

- (Randolph and Masters, 2018, chapter 5, pages 133–148), "Energy Analysis and Life-Cycle Assessment." Read quickly for general understanding.

9.5 Energy Analytics, 2

In preparation for class:

- (Randolph and Masters, 2018, chapter 5, pages 148–167), "Energy Analysis and Life-Cycle Assessment." Read quickly for general understanding.

9.6 Data sources

First line data sources: EIA `https://www.eia.gov/`, PJM, Data Miner 2 `https://pjm.com/markets-and-operations/etools/data-miner-2.aspx` MISO?? BP, *Statistical Review of World Energy 2020* `https://www.bp.com/content/dam/bp/business-sites/en/global/corporate/pdfs/energy-economics/statistical-review/bp-stats-review-20` `pdf` IEA `https://www.iea.org`, IRENA `https://irena.org/`, Lazard `https://www.lazard.com/perspective/lcoe2019/`

First line sources for reports and studies: UNFCCC `https://unfccc.int/`, UN IPCC `https://www.ipcc.ch/`, Carbon Tracker `https://carbontracker.org` (note risk disclosure),RMI `https://rmi.org/`, American Council for an Energy Efficient Economy `https://www.aceee.org/`, Project Drawdown `https://drawdown.org`

In preparation for class: Redefining Energy podcast (`https://redefining-energy.com`), episode 29, July 20, 2020, "Electrifying Europe: Mobility, Heating, Digitisation (interview with Eurelectric)".

9.7 Decision modeling, 1: MAUT

In preparation for class:

- (Kimbrough and Lau, 2016, chapter 16), "Multiattribute Utility Modeling." Read quickly for general understanding.

In preparation for class:

- "How Cleantech Venture Capital Is Faring in a Pandemic: This week on The Interchange, we discuss how insulated cleantech and climatetech are from the economic tumult" The Interchange podcast, July 30, 2020, `https://www.greentechmedia.com/articles/read/how-cleantech-venture-capital-is-faring-in-a-pandemic`
- Recommended: Columbia Energy Exchange, "United We Are Unstoppable" August 3, 2020. `https://www.energypolicy.columbia.edu/podcast/columbia-energy-exchange` Able journalism that collects youth voices on climate change. Good to hear, if not absolutely central to this course.

End of module I: Foundations. Project assignment handed out and discussed, due in two weeks.

Begin module II: Electricity provision, optimization and design, and decision modeling focused on policy making

9.8 Begin module II: Electricity Provision, 1

In preparation for class:

- (Randolph and Masters, 2018, chapter 9), "Centralized Electric Power Systems." Read quickly for general understanding.

9.9 Electricity Provision, 2

In preparation for class:

- (Randolph and Masters, 2018, chapter 10), "Distributed Energy Resources." Read quickly for general understanding.

9.10 Decision modeling, 2: Risk and uncertainty, 1

In preparation for this class and the next:

Risk versus uncertainty. Decision analysis: decision making under risk. Decision making under uncertainty. Probability of exceedance. Value at risk. Deep uncertainty and related concepts.

Readings: (Bolinger, 2017); (Boholm et al., 2015).

Recommended background readings for the risk module: "A General, Analytic Method for Generating Robust Strategies and Narrative Scenarios" (Lempert et al., 2006); "We are almost

certainly underestimating the economic risks of climate change” https://www.vox.com/energy-and-environment/2018/6/8/17437104/climate-change-global-warming-models-r
Catastrophe Modeling: A New Approach to Manage Risk, (Grossi and Kunreuther, 2005) is a good source for practical application of probability of exceedance concepts. “Risk” (Hansson, 2018).

9.11 Decision modeling, 2: Risk and uncertainty, 2

- Robust Decision Making (RDM)
- Info-Gap theory
- DMDU: Decision Making under Deep Uncertainty
- The Resilience Dividend Valuation Model (RDVM)
- Measuring and pricing risk
- The Stern Report and controversies about the discount rate

Readings: (Lempert and Trujillo, 2018) and other readings from http://www.deepuncertainty.org/; (Kimbrough and Shafer, 2018).

Recommended readings: “Comparing Robust Decision-Making and Dynamic Adaptive Policy Pathways for model-based decision support under deep uncertainty” (Kwakkel et al., 2016). “The Exploratory Modeling Workbench: An open source toolkit for exploratory modeling, scenario discovery, and (multi-objective) robust decision making (Kwakkel, 2017). “Adapt or Perish: A Review of Planning Approaches for Adaptation under Deep Uncertainty” (Walker et al., 2013). “Dynamic adaptive policy pathways: A method for crafting robust decisions for a deeply uncertain world” (Haasnoot et al., 2013). “An uncertain future, deep uncertainty, scenarios, robustness and adaptation: How do they fit together?” (Maier et al., 2016). “Robust Climate Policies Under Uncertainty: A Comparison of Robust Decision Making and Info-Gap Methods” (Hall et al., 2012). On RDVM, see citations in §**??**.

9.12 Electricity Provision, 3: Capacity expansion models and power-to-gas.

In preparation for class:

- Instructor handout (capacity expansion and PtG)

9.13 Electricity provision analytics, 1

Topics from:

- (Randolph and Masters, 2018, chapter 11), “Photovoltaic Systems.” Read quickly for general understanding.

9.14 Electricity provision analytics, 2

Topics from:

- (Randolph and Masters, 2018, chapter 12), "Large-Scale Renewables." Read quickly for general understanding.

9.15 Electricity Provision, 4: Market and product innovations, 1

The "transaction grid."

In preparation for class:

- Instructor handout

End of module II: Electricity provision, optimization, and decision modeling focused on policy making. Project assignment handed out and discussed, due in two weeks.

Begin module III: Agent-based models and simulation pertaining to energy and sustainability analytics.

9.16 Module III: MCDM, MCMDM, sausage-making

In preparation for class:

- Instructor handout

9.17 ABM and simulation, 1

In preparation for class:

- Instructor handout: overview
- Read lightly: (Muaafa et al., 2017).

9.18 ABM and simulation, 2

In preparation for class:

- Instructor handout

9.19 ABM and simulation, 3

In preparation for class:

- Instructor handout

9.20 ABM and simulation, 4

In preparation for class:

- Instructor handout

9.21 Electricity Provision, 4: Market and product innovations, 2

The "transaction grid." Simulation of markets.

In preparation for class:

- Instructor handout
- Background only: (Kimbrough and Murphy, 2013).

End of module III: Agent-based models and simulation pertaining to energy and sustainability analytics.

9.22 Post-solution analysis; simulation optimization

In preparation for class:

- (Kimbrough and Lau, 2016, chapter 1), "Introduction."

9.23 Robustness analysis

In preparation for class:

- (Kimbrough and Lau, 2016, chapter 1), "Introduction."

End of module III: Agent-based models and simulation pertaining to energy and sustainability analytics. Project assignment handed out and discussed, due in two weeks.

Begin module IV: Optimization and policy strategies.

9.24 Module IV: Electricity Provision, 3: Capacity expansion models and power-to-gas.

In preparation for class:

- Instructor handout (capacity expansion and PtG paper)

9.25 Overview of optimization, exact and heuristic

In preparation for class:

- (Kimbrough and Lau, 2016, chapter 2), "Constrained Optimization Models: Introduction and Concepts." Read quickly for general understanding. Read later chapters in the book for special focus and for information on heuristic optimization.

9.26 Zone design

In preparation for class:

- Instructor handout

9.27 Capacity planning models

In preparation for class:

- Instructor handout

9.28 Energy and society; IAMs

Topics from:

- (Randolph and Masters, 2018, chapters 16–8).

10 Assignments and Grading

Three instructor-chosen small group projects, 20% each. Fourth student-chosen project, 20%. Class participation and small assignments, 20%.

References

Boholm, M., Möller, N., and Hansson, S. O. (2015). The Concepts of Risk, Safety, and Security: Applications in Everyday Language. *Risk Analysis*, 36(2):320–338.

Bolinger, M. (2017). Using probability of exceedance to compare the resource risk of renewable and gas-fired generation. Technical report. LBNL-1007269, Lawrence Berkeley National Laboratory. `https://emp.lbl.gov/publications/using-probability-exceedance-compare/`.

Grossi, P. and Kunreuther, H., editors (2005). *Catastrophe Modeling: A New Approach to Manage Risk*. Springer, New York, NY.

Haasnoot, M., Kwakkel, J. H., Walker, W. E., and ter Maat, J. (2013). Dynamic adaptive policy pathways: A method for crafting robust decisions for a deeply uncertain world. *Global Environmental Change*, 23(2):485–498.

Hall, J. W., Lempert, R. J., Keller, K., Hackbarth, A., Mijere, C., and McInerney, D. J. (2012). Robust Climate Policies Under Uncertainty: A Comparison of Robust Decision Making and Info-Gap Methods. *Risk Analysis*, 32(10):1657–1672.

Hansson, S. O. (2018). Risk. *The Stanford Encyclopedia of Philosophy*. https://plato.stanford.edu/archives/fall2018/entries/risk/.

Kimbrough, S. and McElfresh, M. (2018). Is a transition to renewable energy on the verge of being unstoppable? Knowledge at Wharton, online http://knowledge.wharton.upenn.edu/article/is-a-more-rapid-transition-to-renewable-energy-on-the-verge-of-being-unstoppa

Kimbrough, S. and Shafer, T. (2018). Synthetic baseload and intermediate decarbonization. In Cunningham, M. and Cunningham, P., editors, *Proceedings of IEEE ISTAS 2018 (IEEE International Symposium on Technology and Society)*, Washington, D.C. IEEE. ISBN: 978-1-5386-9479-4. http://sites.ieee.org/istas-2018/.

Kimbrough, S. O. and Lau, H. C. (2016). *Business Analytics for Decision Making*. CRC Press, Boca Ratan, FL.

Kimbrough, S. O. and Murphy, F. H. (2013). Strategic bidding of offer curves: An agent-based approach to exploring supply curve equilibria. *European Journal of Operational Research*, 229(1):165–178. http://dx.doi.org/10.1016/j.ejor.2013.02.006.

Kwakkel, J. H. (2017). The Exploratory Modeling Workbench: An open source toolkit for exploratory modeling, scenario discovery, and (multi-objective) robust decision making. *Environmental Modelling and Software*, 96:239–250.

Kwakkel, J. H., Haasnoot, M., and Walker, W. E. (2016). Comparing Robust Decision-Making and Dynamic Adaptive Policy Pathways for model-based decision support under deep uncertainty. *Environmental Modelling and Software*, 86(C):168–183.

Lempert, R. J., Groves, D. G., Popper, S. W., and Bankes, S. C. (2006). A General, Analytic Method for Generating Robust Strategies and Narrative Scenarios. *Management Science*, 52(4):514–528.

Lempert, R. J. and Trujillo, H. R. (2018). Deep Decarbonization as a Risk Management Challenge.

Maier, H. R., Guillaume, J. H. A., van Delden, H., Riddell, G. A., Haasnoot, M., and Kwakkel, J. H. (2016). An uncertain future, deep uncertainty, scenarios, robustness and adaptation: How do they fit together? *Environmental Modelling and Software*, 81(C):154–164.

Muaafa, M., Adjali, I., Bean, P., Fuentes, R., Kimbrough, S. O., and Murphy, F. H. (2017). Can adoption of rooftop solar panels trigger a utility death spiral? A tale of two U.S. cities. *Energy Research & Social Science*, 34:154–162. https://authors.elsevier.com/a/1VNlA7tZ6ZfVfm.

Randolph, J. and Masters, G. M. (2018). *Energy for Sustainability: Foundations for Technology, Planning, and Policy*. Island Press, Washington, D.C., 2nd edition.

Walker, W., Haasnoot, M., and Kwakkel, J. (2013). Adapt or Perish: A Review of Planning Approaches for Adaptation under Deep Uncertainty. *Sustainability*, 5(3):955–979.

File: Syllabus-TwM525-fall2020.tex