Syllabus, Fall 2022, for OIDD 5250:
Thinking with Models:
Business analytics for energy and sustainability (TwM)
3:30–5:00 p.m., Tuesdays and Thursdays. Room: TBA
GitHub: TBA

Instructor: Professor Steven O. Kimbrough
Office hours: T & R 10:00–11:30 and by appointment

August 16, 2022

Masking in class is required until further notice, due to the ongoing community transmission of Covid, monkey pox and polio.

Contents

1 Course Description

The world is engaged in a transition to clean and sustainable ("green") 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 5250 is a business analytics class that addresses these matters by surveying and introducing the main kinds of models and modeling techniques being used in the green transition. These include: (non-financial) accounting models (e.g., for calculating carbon footprints, for ESG investing, for life-cycle analysis), constrained optimization models (resource allocation using mathematical programming or AI methods in the form of metaheuristics), and system performance models (typically as simulations and often using AI methods such as agent-based modeling). There will be special emphasis on decision theoretic models and multi-criteria decision making (MCDM). These models are used to support decision making based on data and model outputs from multiple sources and domains. The problem of overcoming low data quality with proper use of modeling is a major theme in the course.

1. The Earth is experiencing global warming caused by greenhouse gas emissions.

2. "Greenhouse gas (GHG) emissions are externalities and represent the biggest market failure the world has seen."

   Stern, N. (2008). The Economics of Climate Change. American Economic Review, 98(2), 137. https://doi.org/10.1257/aer.98.2.1

   Hence intervention in markets is required. This very difficult and fraught with clash of interests as well as uncertainty. (Think: stranded assets.)

3. The extent and pace of global warming has created the present climate emergency. Vastly destructive consequences will ensue soon—during the lifetimes of those now living—and are already plainly in evidence. Things will only get much worse, absent necessary revisions in current practices (BAU, business as usual). Action needs to be taken proactively and with immediacy.

4. There is no credible prospect of eliminating GHG emissions without disruption of BAU. The social and economic consequences are immense, including conflict with entrenched economic interests.

5. The destructive levels of GHG emissions are due to combustion of fossil fuels (oil, gas, coal). Thus an *energy transition* is required.

6. At the same time, but with somewhat less urgency, we must undertake a sustainability transition. This is necessary even without global warming. Together—energy and sustainability—we call these the green transitions. The course will address both, with emphasis on energy.

7. The energy transition will be disruptive and transformative. Things will be different. There will be losers, but there will also be great opportunities for entrepreneurial innovation.

What are the grand challenges for business analytics and modeling for the green transitions? There are two main categories:

A. Choice of alternatives: Choosing alternatives and portfolios of alternatives from among the very large number alternatives available for making the transitions. Alternatives may be technologies, systems, policies, rules, . . . anything material for the green transitions. Which should be implemented? In what form? Under what timing? What mix of public, commercial and non-profit sector involvement? What mixes of technologies and where are they best? Etc. This is also a portfolio problem with immense complexities, all operating in the civil analog of the fog of war. Here the main modeling tools come from decision theory. The course will be particularly interested in multi-criteria decision making (MCDM) for exploring design tradeoffs. This class of models is practised widely, independent of the energy transition. Examples include: selection of a portfolio of R&D projects, selection of a collection of policies to meet a diverse set of goals.

B. Understanding system configuration and performance: Broadly speaking, these are design optimization problems, for which many different kinds of modeling techniques prove useful. Because of the extent of change needed, there is nearly unlimited need for system configuration and performance modeling. Example areas include: Capacity planning, transit oriented development (TOD), building design, urban design, services design.

The course will have particular focus on (and across) these topics:

i. Accommodating intermittency of variable sources of renewable energy (wind, solar, etc.). This is a special and important topic for system configuration and performance modeling as well as an important area of policy design and choice.

ii. Risk assessment related to intermittency, fuel prices, risk imposition, system performance, and much else.

iii. Modeling in the presence of uncertainty, making good decisions with imperfect data and models and in the face of great uncertainty. This is a theme that suffuses everything in the course.

iv. Services design and the green transitions, e.g., for new services, such as district geothermal, as well as existing services, such a food rescue programs and walkability design.

The overall aim of the course is to teach facility with modeling and to use real-world applications in doing so. As a means to this end, we will study key material elements of the green transition, including where greenhouse gas emissions (GHGs) originate, how electric power systems ("the grid") function and are organized, renewable energy systems (RES), and social design ideas (such as Transit Oriented Development and Complete Streets). Students with interests in entrepreneurial investment, policy analysis, activism, or administration in the energy sphere will find the course useful. The modeling problems and techniques that we study in the context of the green transition are entirely transferable to other domains.

2 Prerequisites

The essential prerequisite is interest in the subject. Students should comfortable with spreadsheet modeling and with using provided computational tools, executing them and configuring them to do analyses. The instructor will provide support as needed. Basic instruction in NetLogo will be given for the purpose of working with and understanding agent-based models (ABMs) as they apply to energy and sustainability. Students interested in implementing computational models will have opportunity and support for doing so, but this is not a requirement.

3 Required Texts

- 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 use it as a source for information on energy and sustainability.
- *Multi-criteria analysis: a manual* Great Britain and Department for Communities and Local Government (2009), available on Canvas.
- NetLogo. Software tool for agent-based modeling. Available for free at `https://ccl.northwestern.edu/netlogo/`.
- *Lecture Notes* for some classes will be posted on Canvas. These notes are required or suggested readings, as indicated.
- Other readings and handouts will be freely available on Canvas.

4 Class Schedule

1. Introduction
   - Course overview
   - IPCC A quick overview of climate science and why it makes the energy transition imperative.

   Assigned reading(s):

   a. IPCC AR6 Working Group III report, *Climate Change 2022: Mitigation of Climate Change* "Summary for Policymakers" (2022)
   https://www.ipcc.ch/report/sixth-assessment-report-working-group-3/

   Reference material:

   a. IPCC AR6 home page IPCC (2022b)

b. “Climate Change 2021: The Physical Science Basis: Summary for Policymakers” Link Working Group I, Assessment Report 6, IPCC.

c. *Climate Change 2022: Impacts, Adaptation and Vulnerability* IPCC (2022a).

d. “The Energy Gang: The IPCC Climate Report Uncovered on Apple Podcasts” Gang (2022)

2. Energy Basics, 1

   - Energy, power (not the same thing!)
   - Forms of energy, units, and conversions

   Assigned reading(s):

   a. *Energy for Sustainability: Foundations for Technology, Planning, and Policy* (Randolph and Masters, 2018, chapter 4, pages 95–113), “Fundamentals of Energy Science.” Read for general understanding. More in depth next time.

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.

   - Chemical energy
   - Solar energy
   - Nuclear energy

   Assigned reading(s):

   a. *Energy for Sustainability: Foundations for Technology, Planning, and Policy* (Randolph and Masters, 2018, chapter 4, pages 113–131), “Fundamentals of Energy Science.” Read for general understanding.

   b. “Is a Transition to Renewable Energy on the Verge of Being Unstoppable?” Kimbrough and McElfresh (2018)

4. Electricity Provision, 1

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

   Constrained optimization: capacity planning models.

   Readings from the *Lecture Notes*.

   - Overview of centralized electric power systems

- Overview of modeling and analysis for them, capacity planning models, etc.

In preparation for class:

- (Randolph and Masters, 2018, chapter 9), "Centralized Electric Power Systems." Read quickly for general understanding.
- "Status and perspectives on 100% renewable energy systems" Hansen et al. (2019a)

5. Electricity Provision, 2

   - Overview of DERs (distributed energy resources)
   - Overview of modeling and analysis of DERs

   Resources:

   - (Randolph and Masters, 2018, chapter 10), "Distributed Energy Resources." Read quickly for general understanding.
   - "Status and perspectives on 100% renewable energy systems" Hansen et al. (2019a)

6. Variability and intermittency

   Main topics:

   (a) The grand challenge of accommodating variable renewable energy (VRE)
   (b) Variability
   (c) Intermittency

   Slide deck: Instructor handouts.

   Assigned reading(s):

   a. "Synthetic Baseload and Intermediate Decarbonization" Kimbrough and Shafer (2018)

7. Optimization Primer

   Main topics:

   (a) The concept of constrained optimization. Types of models.
   (b) Mathematical programming and exact optimization
   (c) Heuristic optimization

   Slide deck: Instructor handout

   Assigned reading(s):

   a. *Business Analytics for Decision Making* (Kimbrough and Lau, 2016, Chapter 2)

Reference material:

a. *Business Analytics for Decision Making* (Kimbrough and Lau, 2016, Chapter 1)

8. Energy system optimization, 1

   Main topics:

   (a) Capacity planning
   (b) Optimal dispatch

   Slide deck: Instructor handout

   Reference material:

   a. "Optimization methods for electric utility resource planning" Hobbs (1995)
   b. "Power-to-gas: Decarbonization of the European electricity system with synthetic methane" Yilmaz et al. (2022)

9. Energy system optimization, 2

   Survey of applications. Instructor notes and handout.

10. Energy Analysis, 1

    Accounting models, in which we add things up. Not financial accounting.

    Key reference material:

    a. *Energy for Sustainability: Foundations for Technology, Planning, and Policy* (Randolph and Masters, 2018, chapter 5, pages 133–148), "Energy Analysis and Life-Cycle Assessment."

11. Demand response and energy management systems

    Class #11, on October 4, 2022, will not be held as scheduled. Instead, students are to view the following videos in lieu of the normal lecture. We will debrief during class #12 on October 11, 2022. Students are responsible for the material, e.g., on the quiz.

    (a) "The Basics of Demand Response" 3:00 minutes. `https://www.youtube.com/watch?v=4jTzExD-xQM`

        This is an infomercial, but well worth watching. No endorsement implied.

    (b) "Learning and Control of Residential Demand Response" 46:05 minutes. `https://www.youtube.com/watch?v=8SsD6NK9WOA`

(c) "Optimization in Energy Management Systems" 29:34 minutes `https://www.youtube.com/watch?v=7yiLBrReD08`
Energy management system is the accepted name for a widely used category of software product.
This is an infomercial, but well worth watching. No endorsement implied.

12. Energy Analysis, 2

    Key reference material:

    a. *Energy for Sustainability: Foundations for Technology, Planning, and Policy* (Randolph and Masters, 2018, chapter 5, pages 148–167), "Energy Analysis and Life-Cycle Assessment." Read quickly for general understanding.

    Assignment #1 released. Due in two weeks. Posted on Canvas.

13. Energy Analysis, 3: GHG Protocol and EU green taxonomy

    Businesses around it. Carbon footprint

    - Protocol for measuring GHG emissions
    - Modeling tools and use

    Key reference material:

    a. Greenhouse Gas Protocol Protocol (2022)
    b. "Value for the calorie? - Corporate social responsibility and benchmarking analysis of calorie efficiency in food retailing"
    c. EU green taxonomy: Union (2022),
    d. TEG (2022)
    e. `https://ec.europa.eu/info/business-economy-euro/banking-and-finance/sustainable-finance/eu-taxonomy-sustainable-activities_en` Jensen et al. (2019)

14. Quiz #1

    Forty-five minutes, then use the remaining time for special topics (and catch up).

    Quiz #1. In-class.

15. Community Energy, Land Use, Mobility

    Main topics:

    (a) Transportation policies
    (b) TOD: transit oriented development
    (c) Land use
    (d) Planning

Assigned reading(s):

a. *Energy for Sustainability* (Randolph and Masters, 2018, chapter 15)

16. Walkability

    Main topics:

    (a) Livable communities
    (b) Complete streets
    (c) Modeling for livability

    Reference material:

    a. Walk Score `https://www.walkscore.com/`

17. ABMs, 1

    - introduction to agent-based modeling
    - Agent-based models (ABMs): Concepts, history, uses.
    - Brief overview of ABM modeling in the green transition.

    Reference material:

    a. "Agent-based modelling and socio-technical energy transitions: A systematic literature review" Hansen et al. (2019b)
    b. *Growing Artificial Societies: Social Science from the Bottom Up* Epstein and Axtell (1996)

18. ABMs, 2

    After some basic instruction in programming NetLogo, students will be fully able to participate in the NetLogo exercises to come. Those students who wish to go further and develop models as part of class work will have an opportunity to do so.

    Main topics:

    (a) Introduction to NetLogo

    Assigned reading(s):

    a. Download and install NetLogo (it's free) NetLogo Home Page. Retrieve from `https://ccl.northwestern.edu/netlogo/`.
    b. From the *NetLogo User Manual* (which comes with the installation), the three tutorials in the "Learning NetLogo" section:
        - Tutorial #1: Models

- Tutorial #2: Commands
- Tutorial #3: Procedures

c. Romanowska, I., Wren, C. D., & Crabtree, S. A. (2021). Agent-Based Modeling for Archaeology: Simulating the Complexity of Societies. SFI Press. (Romanowska et al., 2021, chapters 1 and 2)
Link (Has free PDF at this location. File ABMA_color_version.pdf is posted on Canvas.)

19. ABMs, 2

    Main topics:

    (a) Programming in NetLogo

    Assigned reading(s):

    a. Romanowska, I., Wren, C. D., & Crabtree, S. A. (2021). Agent-Based Modeling for Archaeology: Simulating the Complexity of Societies. SFI Press. (Romanowska et al., 2021, chapters 3 and 4)
    Link (Has free PDF at this location. File ABMA_color_version.pdf posted on Canvas.)

    b. *NetLogo Tutorial Notes,* chapters 2, 3, and 4.

    Reference material:

    a. *NetLogo Users Manual*

20. ABMs, 3

    - Survey of the many applications reported in the energy and sustainability literature (continued).
    - Design of ABMs (and simulation models)

    Readings in the *Lecture Notes*.

21. Quiz #2 — Quiz #2. In-class.

    Forty-five minutes, then use the remaining time for special topics (and catch up).

22. Energy Policy

    Main topics:

    (a) International policy

    (b) Federal policy

    Assigned reading(s):

a. *Energy for Sustainability* (Randolph and Masters, 2018, chapter 17)

Reference material:

a. *Informing Decisions on Climate Change* National Research Council (2009)

23. State and community policy

    Main topics:

    (a) State energy policy
    (b) Community energy and sustainability policy and planning
    (c) More counting models.

    Assigned reading(s):

    a. *Energy for Sustainability* (Randolph and Masters, 2018, chapter 18)

24. MCDM, 1

    The many applications reported in the energy and sustainability literature.

    - Local policy initiatives
    - Introduction to MCDM
    - AHP

    Begin reading *Multi-criteria analysis: a manual* Great Britain and Department for Communities and Local Government (2009), available on Canvas.

25. MCDM, 2: MAUT, Outranking methods

    - Simple MAUT (multiattribute utility theory) modeling
    - (Kimbrough and Lau, 2016, chapter 16), "Multiattribute Utility Modeling." Read quickly for general understanding.
    - Kimbrough (2019)

    Continue reading *Multi-criteria analysis: a manual* Great Britain and Department for Communities and Local Government (2009), available on Canvas.

26. Survey of MCDM and energy and sustainability policy modeling, 1

27. Survey of MCDM and energy and sustainability policy modeling, 2

    Including portfolio decision making

28. Last class

    - Course summary and look ahead
      And Q&A on final assignments.

5 Grades and Conduct of Class

Attendance: Mandatory. Please email me in advance if you have a good reason not to attend a particular session.

Electronics: No phones, laptops, tablets or other electronics, unless specifically directed otherwise.

Grading will be based on several components, as follows.

30% Two quizzes. Noted in the margins in the "Class Schedule" section.

30% Class participation (including attendance, in-class exercises) and homework assignments.

40% Term project, due the last day of finals.

Grading: $x >$ 95%, A+; 91% $\leq$ 95%, A; 85% $< x \leq$ 91%, A-/B+, 75% $< x \leq$ 85%, B; 65% $< x \leq$ 75%, C; 55% $< x \leq$ 65%, D; $x \leq$ 55%, F. With the caveat that I can give lots of As if merited but it's very unlikely I can give lots of A+s.

Most of all, I want to see you engaged and involved in the class. I'll prepare lectures for the classes, but much prefer to conduct class with lots of interactive, give and take, and discussion.

Two further items/requirements:

- Every student should come chat with me at least once during (online) office hours. If my posted hours conflict with your schedule, let me know and we'll make arrangements. Also, you need not come alone. It's fine to come with a group of up to four.

- You will occasionally need your laptop in class. I'll let you know ahead of time. However, during lectures and similar periods when we are not actively using them, use of laptops, PDAs, etc. are forbidden.

6 Calendar, fall 2022

Last class is on Thursday, December 8, 2022.

	0	1	2
0	—	R: 2022-10-29	T: 2022-11-08
1	T: 2022-08-30	T: 2022-10-04	R: 2022-11-10
2	R: 2022-09-01	T: 2022-10-11	T: 2022-11-15
3	T: 2022-09-06	R: 2022-10-13	R 2022-11-17
4	R: 2022-09-08	T: 2022-10-18	T: 2022-11-22
5	T: 2022-09-13	R: 2022-10-20	T: 2022-11-29
6	R: 2022-09-15	T: 2022-10-25	R: 2022-12-01
7	T: 2022-09-20	TR 2022-10-27	T: 2022-12-06
8	R: 2022-09-22	T: 2022-11-01	R: 2022-12-08
9	T: 2022-09-27	R: 2022-11-03	—

Table 1: Class number :: date correlation, for Tuesday (T) and Thursday (R) classes, fall 2022. Penn academic calendar `https://almanac.upenn.edu/penn-academic-calendar`

References

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Union, E. (2022). EU taxonomy for sustainable activities. https://ec.europa.eu/info/business-economy-euro/banking-and-finance/sustainable-finance/eu-taxonomy-sustainable-activities_en.

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