Syllabus, Spring 2023, for OIDD 5250: Thinking with Models: Business analytics for energy and sustainability (TwM)

3:30–5:00 p.m., Tuesdays and Thursdays. Room: TBA
Canvas:
`https://canvas.upenn.edu/courses/1689797`
GitHub: TBA

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

December 19, 2023

Masking in class is required until further notice, due to the ongoing community transmission of Covid, flu, RSV, strep A, polio, and who knows what else.

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 525X 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 most 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

4.1 Introduction

Main topics:

- Course overview
- The climate change imperative

  A quick overview of climate science and why it makes the energy transition imperative. Relying on the IPCC.

  Slide deck: 2021 Global Virtual Training PowerPoint English Short.zip, courtesy of The Climate Reality Project.
- Local policy making

  Slide deck: Opportunities in Municipal Climate Transitions.pdf

Assigned reading(s):

a. IPCC AR6 Working Group III report, *Climate Change 2022: Mitigation of Climate Change*. Read the "Summary for Policymakers" IPCC (2022).

4.2 Fundamentals of Energy Science, 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.

4.3 Fundamentals of Energy Science, 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)

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4.4 Electric Energy Systems, 1

Main topics:

- Overview of centralized electric power systems
- Electricity grids: design, components, configurations.

- Electricity: delivery of services, history, regulation, deregulation.

Assigned reading(s):

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

b. Readings from the *Lecture Notes*.

4.5 Electric Energy Systems, 2

Main topics:

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

Assigned reading(s):

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

4.6 Variability and intermittency

Main topics:

- The grand challenge of accommodating variable renewable energy (VRE).
- PJM production and load data
- Fuel price risk

Assigned reading(s):

a. Readings in the *Lecture Notes*.

Reference material:

a. Geocaris, M. (2022, September 12). On the Road to 100% Clean Electricity: Six Potential Strategies To Break Through Last Few Percent. `https://www.nrel.gov/news/program/2022/on-the-road-to-100-clean-electricity-six-potential-strategies-to-break-thro` `html` https://www.nrel.gov/news/program/2022/on-the-road-to-100-clean-electricity-six-potential-strategies-to-break-through-the-last-few-percent.html

4.7 Optimization

Main topics:

- Constrained optimization
- Exact solver methods
- Heuristic solver methods; metaheuristics

Assigned reading(s):

a. (Kimbrough and Lau, 2016, chapters 1–2)

4.8 Optimization and deep decarbonization

Main topics:

- Capacity planning models and deep decarbonization
- Other optimization models for energy and sustainability

Assigned reading(s):

a. (Kimbrough and Lau, 2016, chapter 3)

b. Yilmaz, H. Ü., Kimbrough, S. O., van Dinther, C., & Keles, D. (2022). Power-to-gas: Decarbonization of the European electricity system with synthetic methane. Applied Energy, 323, 119538. https://doi.org/10.1016/j.apenergy.2022.119538

Reference material:

a. Hobbs, B. F. (1995). Optimization methods for electric utility resource planning. European Journal of Operational Research, 83(1), 1–20. https://doi.org/10.1016/0377-2217(94)00190-N Hobbs (1995)

b. Hansen, K., Breyer, C., & Lund, H. (2019). Status and perspectives on 100% renewable energy systems. Energy, 175, 471–480. https://doi.org/10.1016/j.energy.2019.03.092 Hansen et al. (2019a)

4.9 Energy Analysis, 1

Main topics:

- Data resources
- Accounting models, in which we add things up. (Not financial accounting.)

- Energy Analysis
- EU green taxonomy
  - Protocol for measuring GHG emissions
  - Modeling tools and use

Assigned reading(s):

a. *Lecture Notes* Appendix A.

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

c. EU green taxonomy: Union (2022),

Reference material:

a. TEG (2022)

b. `https://ec.europa.eu/info/business-economy-euro/banking-and-finance/sustainable-finance/eu-taxonomy-sustainable-activities_en`

4.10 Energy Analysis, 2

Main topics:

- Energy Analysis and Life-Cycle Assessment
- Carbon footprinting
- The GHG Protocol

Assigned reading(s):

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 for general understanding.

b. Greenhouse Gas Protocol Protocol (2022)

c. "Value for the calorie? - Corporate social responsibility and benchmarking analysis of calorie efficiency in food retailing" Jensen et al. (2019)

4.11 Cost-Benefit Analysis (CBA) & its discontents

Main topics:

- Cost-benefit analysis: principles, pluses and minuses
- Cost-benefit analysis: examples

Assigned reading(s):

a. *Lecture Notes*

b. "Cost benefit analysis of composting and anaerobic digestion in a community: a review" Zulkepli N.E. et al. (2017)

Reference material:

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

b. DeMartino, G. F. (2022). The Tragic Science: How Economists Cause Harm (Even as They Aspire to Do Good). The University of Chicago Press.

4.12 Quiz #1

Quiz #1. In-class. Closed book but with one two-sided crib sheet.

Quiz #1. In-class.

4.13 ABM: Concepts and Philosophy

Main topics:

- Agent-based models (ABMs): Concepts, history, uses.
- Two kinds of decision contexts (and models); role of ABM
- Overview of ABM modeling in the green transition.

Assigned reading(s):

a. *Lecture Notes*

b. Gilbert, N., Ahrweiler, P., Barbrook-Johnson, P., Narasimhan, K. P., & Wilkinson, H. (2018). Computational Modelling of Public Policy: Reflections on Practice. Journal of Artificial Societies and Social Simulation, 21(1), 14. `https://www.jasss.org/21/1/14.html`

Reference material:

a. Hansen, P., Liu, X., & Morrison, G. M. (2019). Agent-based modelling and socio-technical energy transitions: A systematic literature review. Energy Research & Social Science, 49, 41–52. https://doi.org/10.1016/j.erss.2018.10.021 Hansen et al. (2019b)

b. *Growing Artificial Societies: Social Science from the Bottom Up* Epstein and Axtell (1996)

c. Ringler, P., Keles, D., & Fichtner, W. (2016). Agent-based modelling and simulation of smart electricity grids and markets – A literature review. Renewable and Sustainable Energy Reviews, 57, 205–215. https://doi.org/10.1016/j.rser.2015.12.169

d. Castro, J., Drews, S., Exadaktylos, F., Foramitti, J., Klein, F., Konc, T., Savin, I., & Bergh, J. van den. (2020). A review of agent-based modeling of climate-energy policy. WIREs Climate Change, n/a(n/a), e647. `https://doi.org/10.1002/wcc.647`

4.14 ABM, 1: Introduction & NetLogo

Main topics:

- Introduction to agent-based modeling
- Introduction to NetLogo and its programming

Assigned reading(s):

a. *NetLogo Users Manual,* tutorials #1, #2, and #3.

b. PNbook, Preface and chapters 1 & 2.

Reference material:

a. Wilensky, U., & Rand, W. (2015). An Introduction to Agent-Based Modeling. The MIT Press. Available on JSTOR as a series of PDFs: `http://www.jstor.org/stable/j.ctt17kk851`

b. 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) `https://www.santafe.edu/news-center/news/new-book-agent-based-modeling-archa`

4.15 ABM, 2: NetLogo

Main topics:

- Programming in NetLogo
- BehaviorSpace in NetLogo

Assigned reading(s):

a. PNbook, appendix G, "BehaviorSpace."

b. PNbook, chapters 2 & 3 (BehaviorSpace).

Reference material:

a. *NetLogo Users Manual*

b. Wilensky, U., & Rand, W. (2015). An Introduction to Agent-Based Modeling. The MIT Press. Available on JSTOR as a series of PDFs: `http://www.jstor.org/stable/j.ctt17kk851`

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 3 and 4) `https://www.santafe.edu/news-center/news/new-book-agent-based-modeling-archa` (Has free PDF at this location. File ABMA_color_version.pdf posted on Canvas.)

4.16 ABM, 3

Main topics:

- ABMs in energy and sustainability
- Rooftop solar models
- Food rescue model
- Braess Paradox.nlogo in the NetLogo Models Library
- Climate Change.nlogo in the NetLogo Models Library

Reference material:

a. Residential_Solar_PV_Adoption_1.0_6.nlogo

b. Muaafa, M., Adjali, I., Bean, P., Fuentes, R., Kimbrough, S. O., & 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.

c. cl_wsc_4.nlogo

d. Mittal, A., Gibson, N. O., & Krejci, C. C. (2019). An Agent-based Model of Surplus Food Rescue Using Crowd-shipping. 2019 Winter Simulation Conference (WSC), 854?865. https://doi.org/10.1109/WSC40007.20

4.17 ABM, 4

Main topics:

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

Reference material:

a. Hansen, P., Liu, X., & Morrison, G. M. (2019). Agent-based modelling and socio-technical energy transitions: A systematic literature review. Energy Research & Social Science, 49, 41–52. https://doi.org/10.1016/j.erss.2018.10.021 Hansen et al. (2019b)

b. Ringler, P., Keles, D., & Fichtner, W. (2016). Agent-based modelling and simulation of smart electricity grids and markets – A literature review. Renewable and Sustainable Energy Reviews, 57, 205–215. https://doi.org/10.1016/j.rser.2015.12.169

c. Castro, J., Drews, S., Exadaktylos, F., Foramitti, J., Klein, F., Konc, T., Savin, I., & Bergh, J. van den. (2020). A review of agent-based modeling of climate-energy policy. WIREs Climate Change, n/a(n/a), e647. `https://doi.org/10.1002/wcc.647`

4.18 Other (than ABM) Simulation

Main topics:

- Discrete event simulation
- IAMs (integrated assessment models)

Assigned reading(s):

a. Instructor handout

Reference material:

a. Mawson, V. J., & Hughes, B. R. (2019). The development of modelling tools to improve energy efficiency in manufacturing processes and systems. Journal of Manufacturing Systems, 51, 95–105. https://doi.org/10.1016/j.jmsy.2019.04.008

b. Hussain, J., Lee, C.-C., & Chen, Y. (2022). Optimal green technology investment and emission reduction in emissions generating companies under the support of green bond and subsidy. Technological Forecasting and Social Change, 183, 121952. https://doi.org/10.1016/j.techfore.2022.121952

c. Integrated Assessment Models (IAMs) and Energy-Environment-Economy (E3) models — UNFCCC. (n.d.). Retrieved December 18, 2022, from https://unfccc.int/topics/mitigation/workstreams/response-measures/modelling-tools-to-assess-the-impact-of-the-implementation-of-response-measures/integrated-assessment-models-iams-and-energy-environment-economy-e3-models

d. Integrated Assessment Models (IAMs) for Climate Change. (n.d.). Obo. Retrieved December 18, 2022, from `https://www.oxfordbibliographies.com/display/document/obo-9780199363445/obo-9780199363445-0043.xml`

e. Wikipedia `https://en.wikipedia.org/wiki/Integrated_assessment_modelling` "All numerical models have shortcomings. In 2021, the integrated assessment modeling community examined gaps in what was termed the 'possibility space' and how these might best be consolidated and addressed.[42] In an October 2021 working paper, Nicholas Stern argues that existing IAMs are inherently unable to capture the economic realities of the climate crisis under its current state of rapid progress."

4.19 Decision theory (DT), 1

Main topics:

- Utility and preference
- Risk
- Uncertainty

Assigned reading(s):

a. *Teaching Notes*

Reference material:

a. Hansson, S. O. (2005). Decision Theory: A Brief Introduction. `https://people.kth.se/~soh/decisiontheory.pdf`

4.20 Decision theory, 2: MCDM, MAUT

Main topics:

- Multiple criteria decision making
- MAUT and SMARTER
- Example applications

Assigned reading(s):

a. *Lecture Notes*

b. (Kimbrough and Lau, 2016, chapter 16), "Multiattribute Utility Modeling."

Reference material:

a. "SMARTS and SMARTER: Improved Simple Methods for Multiattribute Utility Measurement" Edwards and Barron (1994)

b. Read quickly for general understanding. Kimbrough (2019)

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

4.21 Decision theory, 3: MCDM, AHP

Main topics:

- AHP
- Examples, case studies

Assigned reading(s):

a. *Lecture Notes*

Reference material:

a. Teknomo, K. (n.d.-a). Analytic Hierarchy Process (AHP) Tutorial. `https://mathsci2.appstate.edu/~wmcb/Class/5340/ClassNotes141/AHP/AHP%20Tutorial%20Teknomo.pdf`

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

4.22 Decision theory, 4: MCDM, outranking methods

Main topics:

- ELECTRE
- PROMETHEE
- Examples

Assigned reading(s):

a. *Lecture Notes*

Reference material:

a. "Stakeholder-driven multi-attribute analysis for energy project selection under uncertainty" Read et al. (2017)

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

4.23 Quiz #2

Quiz #2. In-class. Closed book but with one two-sided crib sheet.

Quiz #2. In-class.

4.24 Risk and uncertainty, 1: Concepts

Main topics:

- Risk versus uncertainty
- Probability of exceedance
- Deep uncertainty and related concepts

Readings & background material:

a. (Bolinger, 2017)

b. (Boholm et al., 2015)

c. *Lecture Notes*

Reference material:

a. “A General, Analytic Method for Generating Robust Strategies and Narrative Scenarios” (Lempert and Trujillo, 2018)

b. “We are almost certainly underestimating the economic risks of climate change” Link

c. *Catastrophe Modeling: A New Approach to Manage Risk*, (Grossi and Kunreuther, 2005) is a good source for practical application of probability of exceedance concepts.

d. “Risk” (Hansson, 2018)

4.25 Risk and uncertainty, 2: Methods

Main topics:

- Robust Decision Making (RDM)
- Info-Gap theory
- DMDU: Decision Making under Deep Uncertainty
- The Resilience Dividend Valuation Model (RDVM)
- Measuring risk
- The World Bank’s decision tree framework

Reference material:

a. Ray, P. A., & Brown, C. M. (2015). Confronting climate uncertainty in water resources planning and project design: The decision tree framework. World Bank. `https://documents.worldbank.org/en/publication/documents-reports/documentdetail/516801467986326382/Confronting-climate-uncertainty-in-water-resources-planning-and-project-design-t`

b. "Comparing Robust Decision-Making and Dynamic Adaptive Policy Pathways for model-based decision support under deep uncertainty" (Kwakkel et al., 2016)

c. "The Exploratory Modeling Workbench: An open source toolkit for exploratory modeling, scenario discovery, and (multi-objective) robust decision making (Kwakkel, 2017).

d. "Adapt or Perish: A Review of Planning Approaches for Adaptation under Deep Uncertainty" (Walker et al., 2013)

e. "Dynamic adaptive policy pathways: A method for crafting robust decisions for a deeply uncertain world" (Haasnoot et al., 2013)

f. "An uncertain future, deep uncertainty, scenarios, robustness and adaptation: How do they fit together?" (Maier et al., 2016)

g. "Robust Climate Policies Under Uncertainty: A Comparison of Robust Decision Making and Info-Gap Methods" (Hall et al., 2012)

4.26 Risk and uncertainty, 3: Case studies

- Run-of-the-river generation.

  Chapter 4: Ray, P. A., & Brown, C. M. (2015). Confronting climate uncertainty in water resources planning and project design: The decision tree framework. World Bank. `https://documents.worldbank.org/en/publication/documents-reports/documentdetail/516801467986326382/Confronting-climate-uncertainty-in-water-resources-planning`

- Water management in the Colorado River Basin

  Chapter 7 in Marchau, V., Walker, W. E., Bloemen, P. J. T. M., & Popper, S. W. (Eds.). (2019). Decision Making Under Deep Uncertainty. Springer. `https://doi.org/10.1007/978-3-030-05252-2_1`, "Robust Decision Making (RDM): Application to Water Planning and Climate Policy" by David G. Groves et al.

  Discussion in DeMartino, G. F. (2022). The Tragic Science: How Economists Cause Harm (Even as They Aspire to Do Good). The University of Chicago Press.

- Robust investment strategies for the Green Climate Fund (GCF)

  Chapter 7 in Marchau, V., Walker, W. E., Bloemen, P. J. T. M., & Popper, S. W. (Eds.). (2019). Decision Making Under Deep Uncertainty. Springer. `https://doi.org/10.1007/978-3-030-05252-2_1`, "Robust Decision Making (RDM): Application to Water Planning and Climate Policy" by David G. Groves et al.

4.27 Energy and Society

Topics from

- (Randolph and Masters, 2018, chapters 16–18).
- *Informing Decisions on Climate Change* National Research Council (2009).
- Pichert, D., & Katsikopoulos, K. V. (2011). Green Defaults: Information Presentation and Pro-environmental Behaviour. In G. Gigerenzer, R. Hertwig, & T. Pachur (Eds.), Heuristics: The Foundations of Adaptive Behavior (pp. 712–724). Oxford University Press.

4.28 Last class

- Topics from (Randolph and Masters, 2018, chapters 16–18)RDVM
- Course summary

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.

40% Homework assignments. There will be 3–4 in all, including an end of term somewhat larger assignment. These will be done in self-formed groups of two.

36% Two quizzes. Noted in the margins in the "Class Schedule" section.

24% Class participation (including attendance, in-class exercises).

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, spring 2023

	0	1	2
0	—	T: 2023-02-14	T: 2023-03-28
1	R: 2023-01-12	R: 2023-02-16	R: 2023-03-30
2	T: 2023-01-17	T: 2023-02-21	T: 2023-04-04
3	R: 2023-01-19	R: 2023-02-23	R 2023-04-06
4	T: 2023-01-24	T: 2023-02-28	T: 2023-04-11
5	R: 2023-09-26	R: 2023-03-02	R 2023-04-13
6	T: 2023-01-31	T: 2023-03-14	T: 2023-04-18
7	R: 2023-02-02	R 2023-03-16	R: 2023-04-20
8	T: 2023-02-07	T: 2023-03-21	T: 2023-04-25
9	R: 2023-02-09	R: 2023-03-23	—

Table 1: Class number :: date correlation, for Tuesday (T) and Thursday (R) classes, spring 2023. Penn academic calendar `https://almanac.upenn.edu/penn-academic-calendar`

References

Boholm, M., Mller, 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 Lab. (LBNL), Berkeley, CA (United States).

Edwards, W. and Barron, F. H. (1994). SMARTS and SMARTER: Improved Simple Methods for Multiattribute Utility Measurement. *Organizational Behavior and Human Decision Processes*, 60(3):306–325.

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