ENVIR 716K

Quantitative modeling for energy systems analysis

Fall 2018

Dates / course meeting time: TBD

Academic credit: 3 credits

Course format: lecture + lab

Instructor's information

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Dalia Patiño-Echeverri is associate professor at the Nicholas School of the Environment at Duke University, where she studies the economic and environmental impacts of power generation technologies, market rules, and policies affecting capital investment and operating decisions within the electricity industry. All of her research uses and develops optimization and computer simulation models like the ones taught in this class.

What is this course about?

This course is an introduction to the use of computer models and the methods of optimization and simulation for students interested in the analysis of energy systems. The course makes emphasis in the formulation of optimization problems and simulation models, and in the identification of the available methods to solve them.

Our goal is to enable students to formulate, implement, and use their own quantitative model to puzzle out problems related to private and public decision making in the context of energy systems and the environment. The applications and case studies presented, deal with problems of energy systems, their externalities, and the government policies that affect them.

What background knowledge do I need before taking this course?

Prerequisites

College-level calculus (including partial derivatives of functions of several variables), probability theory, and basic linear algebra (how to write -and solve- systems of linear equations in matrix form). Students should also be familiar with capital-sigma (∑) notation for compactly representing summation of similar terms, and know the basics of Excel.

What will I learn in this course?

In these course you will develop three different types of skills useful for the quantitative analysis of energy systems. At the end of the semester you will be able to:

1. Develop your own spreadsheet model and user friendly interface in VBA for excel useful to
2. Formulate and solve linear programming models
3. Conduct probability analysis and develop Montecarlo simulation models

These skills will be useful to approach several public policy questions such as:
-What is the levelized cost of electricity and cost of carbon abatement of different electricity generation technologies?
-What is the risk associated to develop a wind farm?
-What is the best way to develop the power generation capacity of a system, if there is uncertainty on climate change, fuel prices, technological advancement, and future regulations?

What will I do in this course?

Each lecture will be complemented with in-class exercises. In addition there will be 9 assignments (Assignment 8 has two parts). The assignments ask to apply concepts and tools learned in class:

Assignment #1 ***Posted on Sakai 8/31; Due 9/9***
Spreadsheet modeling

Assignment #2 ***Posted on Sakai 9/7; Due 9/16***
Analyzing large data sets in excel.

Assignment #3 ***Posted on Sakai 9/14; Due 9/23***
Simple macros and functions.

Assignment #4 ***Posted on Sakai 9/21; Due 9/30***
Formulation of mathematical programs, graphical and excel solution to lp programs

Assignment #5 ***Posted on Sakai 9/28; Due 10/7***
Formulation and solution of linear programs.

Assignment #6 ***Posted on Sakai 10/5; Due 10/16***
Multi-period problems. Networks. Logical constraints. Unit commitment problem

Assignment #7 ***Posted on Sakai 10/12; Due 10/21***
More on Networks

Assignment #8a ***Posted on Sakai 10/19; Due 10/28***
Review of probability theory

Assignment #8b ***Posted on Sakai 11/2; Due 11/11***
Probability analysis

Assignment #9 ***Posted on Sakai 11/16; Due 12/2***
MonteCarlo Simulation

Students are encouraged to work in study groups of up to three people on these problem sets and help each other learn. However, each student must submit his or her own copy of the assignment and it is a violation of the Nicholas School Honor Code to directly copy another student's work. An example of appropriate problem set collaboration would be for Student A to explain the procedure used in the problem to Student B. Then Student B goes off by himself and completes the problem again and writes up his own explanation. It would be inappropriate for Student B to directly copy the math or the explanation/interpretation from Student A. Study groups are most effective when everyone attempts to do the problem sets BEFORE meeting as a group. Only those who really try to solve the problem on their own will realize whether they understand the methods and their application.

How can I prepare for the class sessions to be successful?

Students are encouraged to read the suggested material before each lecture and to review the slides of previous lectures as needed.

What required texts, materials, and equipment will I need?

Readings, class announcements, schedule changes, grades, power point slides and working files (excel) will all be posted to the course Sakai site. Students are also encouraged to use Sakai's discussion boards to continue the discussion of course issues beyond the classroom. Anyone having trouble working with the Sakai site should seek help from their fellow students, or contact Information Technology (http://sakai.duke.edu/home.do). For this class students will be required to use software that can only be installed on a windows platform. Mac users may work in the computer clusters or make other arrangements.

Excel files with examples of quantitative analysis and macros will occasionally be posted on Sakai. These are all developed on a windows PC with MS Office 2016 (with solver add-in) and it is the students responsibility to solve all the compatibility issues that may arise. DKU IT can provide support if any help is needed.

Readings as indicated in class schedule below may be available on the internet or via Duke library, and others available via Sakai. Required readings begin with RR. Optional readings begin with OR.

What optional texts or resources might be helpful?

You may want to purchase a copy of the "Excel Bible" by John Walkenbach that corresponds to the version of Excel you will be using (i.e., Excel 2013 or Excel 2016). A number of optional readings recommended below come from this book and are not posted on Sakai. You may read online Duke's library digital copy, but there is a limit on the allowed number of concurrent viewers.

How will my grade be determined?

Each assignment will be evaluated using a numbered grade (0-100) and your overall numbered grade will be determined using the following weights:

Assignments (9):	90% (10% each)
*Quizzes:	10%
Total:	100%

Letter grades of A+, A, A-, B+, B, B-, C+, C, C-, or F will be assigned according to numbered grades in the following way:

Above 100:	A+
(95-100]	A
(90-95]	A-
(85-90]	B+
(80-85]	B
(75-80]	B-
(70-75]	C+
(65-70]	C
(60-65]	C-
60 or below	F

What are the course policies?

Class etiquette
1. Please make sure you do everything you can to make our classroom culture a comfortable learning environment for everyone. We will likely have people from many different backgrounds in this class and you should all feel comfortable and make each other comfortable while participating.
2. Please take responsibility for making the class successful. What you learn in the class will be largely dependent on your attitude and work. Ask yourself what you can do during each class to move the course forward in a positive way.
3. If you must enter the class late, please do so quietly. If for any reason the door is locked please knock. It is preferred to have a short disruption than a student missing an entire class.
4. Please try your best to focus in class and keep laptops and cellphones outside of the classroom. Take notes on a notebook, not on your laptop.

Quizzes. The first 5-20 minutes of each class may be devoted to complete a quiz on the material covered in previous classes and assignments. The instructor will solve the quiz immediately after students finish but there will not be graded feedback on the quizzes. At the end of the semester, the quizzes grade may be raised for those students who attended all labs and lectures and participated actively and constructively for their own benefit and the benefit of others. Students must remain in silence and looking only at their quiz until all students have finished and the instructor starts to discuss the solution. We will not have makeup quizzes for any reason (please do not ask) but we will not take into account your two worst quizzes.

Sakai Forum. Questions related to the assignments are to be posted in Sakai using the forum tool. In this way all students will benefit from the answers and help others get when asking questions.

Policy on late assignments. All assignments are due by 11:55PM on the posted due date. Assignments submitted after the due date will lose 0.5 points per minute. Please do not ask for exceptions. If you are ill or have a family emergency that prevents you from being able to complete the assignment on time, please submit the web-based short-term illness form prior to the due date. The short-term illness form can be found at: http://trinity.duke.edu/undergraduate/academic-policies/illness.
You are governed by the DKU Honor Code in completing this form (see below). An assignment that is not submitted because of illness or family emergency will be excluded from your grade calculation (so the 80% of assignments will be based on 7 instead of 8 assignments). If your illness or family situation prevents you from completing more than one assignment please communicate this in a timely fashion. We may

recommend that you drop or withdraw the class, or may require a test at the end to make up for the missed assignments.
An answer key for all assignments will be posted no later than 72 hours after the due date. Please take the time to review the answer key and identify any mistakes you may have in your assignment and any remaining questions you may have about the material.

Bonus points. There may be opportunities for getting bonus points by attending and writing short commentaries on seminars, lectures and extracurricular activities. Some of you might be unable to participate and that is ok. Because this class uses an absolute grading system (e.g. your grade is unaffected by the performance of your classmates) you should not feel it is unfair that others can get bonus points and you can't.

Grade disputes. Students will be informed of the grade received in each assignment no later than 12 days after the assignment has been submitted. Students who consider there has been a mistake in the grading process should upload to Sakai a written document, no later than 7 days after the grades have been released. Please do not talk to or send emails to the TAs, regarding your grades. There will be a separate grade dispute folder for each assignment under the "Assignments" tab in Sakai.
The grade dispute document should contain the following information
1. The type of problem you found
a) a factual error (like adding up the numbers wrong or referencing something that is not there)
b) an inconsistency error (standards were inconsistently applied between students)
c) an interpretation dispute (you think you should have gotten more points)
2. A short description of the issue.
2a.Possibly including why you should get more points.
3. References that explain where to find the supporting material (e.g. "I put the graded document in your mailbox," or "My excel model is in the digital Dropbox and it is named *.xls"...).

The interpretation disputes may require faculty input and may only be resolved at the end of the semester. Others disputes will be resolved no more than 3 weeks after being submitted.

Although the grade dispute document needs to be uploaded no later than 7 days after the graded assignments are returned, discrepancies occurring when there is an error in adding up points for an assignment, or when the wrong grade has been uploaded (i.e. points appearing in your 'Gradebook' on Sakai are different from points you actually received) have no expiration date. Let us know anytime (by e-mail/in person during office hours) if you see such errors.

Academic Integrity:

As a student, you should abide by the academic honesty standard of the Duke Kunshan University. Its Community Standard states: "Duke Kunshan University is a community comprised of individuals from diverse cultures and backgrounds. We are dedicated to scholarship, leadership, and service and to the principles of honesty, fairness, respect, and accountability. Members of this community commit to reflecting upon and upholding these principles in all academic and non-academic endeavors, and to protecting and promoting a culture of integrity and trust."

Academic Policy & Procedures:

You are responsible for knowing and adhering to academic policy and procedures as published in University Bulletin and Student Handbook. Please note, an incident of behavioral infraction or academic dishonesty (cheating on a test, plagiarizing, etc.) will result in immediate action from me, in consultation with university administration (e.g., Dean of Undergraduate Studies, Student Conduct, Academic Advising). Please visit the Undergraduate Studies website for additional guidance related to academic policy and procedures.

Academic Disruptive Behavior and Community Standard:

Please avoid all forms of disruptive behavior, including but not limited to: verbal or physical threats, repeated obscenities, unreasonable interference with class discussion, making/receiving personal phone calls, text messages or pages during class, excessive tardiness, leaving and entering class frequently without notice of illness or other extenuating circumstances, and persisting in disruptive personal conversations with other class members. Please turn off phones, pagers, etc. during class unless instructed otherwise. Please keep laptops away and used them only if required by the instructor. If you choose not to adhere to these standards, I will take action in consultation with university administration (e.g., Dean of Undergraduate Studies, Student Conduct, Academic Advising).

Academic Accommodations:
If you need to request accommodation for a disability, you need a signed accommodation plan from Campus Health Services, and you need to provide a copy of that plan to me. Visit the Office of Student Affairs website for additional information and instruction related to accommodations.

What campus resources can help me during this course?

Academic Advising and Student Support
Please consult with me about appropriate course preparation and readiness strategies, as needed. Consult your academic advisors on course performance (i.e., poor grades) and academic decisions (e.g., course changes, incompletes, withdrawals) to ensure you stay on track with degree and graduation requirements. In addition to advisors, staff in the Academic Resource Center can provide recommendations on academic success strategies (e.g., tutoring, coaching, student learning preferences). Please visit the Office of Undergraduate Advising website for additional information related to academic advising and student support services.

Language Learning Studio
If you want additional help with academic writing – and more generally with language learning – you are welcome to go to the Language Learning Studio (LLS), located in the Conference Center. You can find more information on the LLS website.

What is the expected course schedule?

Date	**Monday August 27**
Class topic/unit name	**Class Overview and introductions**
Pre-class work for students	OR1-Excel 2016 Bible: Chapters 1 through 4, review if needed
Planned in-class activities	Lecture on quantitative modeling for energy systems and introductions
Assignments due	

Date	**Wednesday August 29**
Class topic/unit name	**Spreadsheet modeling: A simple cost model for a power plant**
Pre-class work for students	• Please review basic energy terms and units • RR2-EIA Levelized Cost of Electricity and Levelized Avoided Cost of Electricity Methodology Supplement. • RR2- Rubin Ch 13 FinancialEng.pdf (Chapter on Economics and the Environment) • OR2-Excel 2016 Bible: Chapter 10
Planned in-class activities	Lecture on good modeling practices. Form Controls. In class exercises
Assignments due	

Date	**Monday September 3 and Wednesday September 5**
Class topic/unit name	**Spreadsheet modeling: Analysis of large data sets with Excel. eGrid database (contains information on characteristics and performance of all electric power plants in the U.S.).**
Pre-class work for students	• RR3- egrid_faq.pdf (eGRID FAQ: https://www.epa.gov/energy/emissions-generation-resource-integrated-database-egrid-questions-and-answers) • OR3-Excel 2016 Bible: Chapters 13, 14, 17, 33, 34, 42
Planned in-class activities	Review use of functions: if, count, countif, sum, sumif, indirect, tables, Pivot tables, Lookup, vlookup, data analysis (descriptive statistics, correlation, histograms)
Assignments due	

Date	**Monday September 10**
Class topic/unit name	**VBA Macros in Excel I (LCOE model for a NGCC power plant)**
Pre-class work for students	RR5- Excel and VBA class notes.docx (Notes on Excel and Visual Basic)
Planned in-class activities	VBA Excel Macros for Beginners: Using the absolute and relative macro recroding
Assignments due	

Date	**Wednesday September 12 (LCOE model for a NGCC power plant)**
Class topic/unit name	**VBA Macros in Excel II**
Pre-class work for students	
Planned in-class activities	Modifying macro recordings to get users inputs and develop user-friendly applications
Assignments due	

Date	**Monday September 17 (LCOE model for a NGCC power plant)**
Class topic/unit name	**VBA Macros in Excel III**
Pre-class work for students	OR7- Excel 2016 Bible: Chapter 44
Planned in-class activities	Introduction to the use of If Then statements, Loops, Functions and Sub routines for macro development
Assignments due	

Date	**Wednesday September 19**
Class topic/unit name	**Introduction to mathematical programming (and brief discussion of the history of energy modeling for policy analysis)**
Pre-class work for students	• RR8-Energy modeling for policy studies.pdf (Hogan, W.W. (2002). Energy Modeling for Policy Studies. Operations Research, (50) 1, 2002, pp.89-95.) • OR8-Using graphical methods-LP.pdf (Reeb,J. and Leavengood

	(1998). Using graphical methods to solve linear programs.) • RR9- Optimization_Technology_for_Energy_and_Power.pdf. (Bloom, J. 2008). Optimization Technology for Energy and Power. Power Point Slides, ILOG 2008. • RR9-AvoidingSolverMistakes.pdf (Evans, J, 2008) Teaching Note—Some Practical Issues with Excel Solver: Lessons for Students and Instructors. James R. Evans, (2008) INFORMS - Transactions on Education 8(2):89-95. http://dx.doi.org/10.1287/ited.1070.0006
Planned in-class activities	Lecture and in-class exercises to introduce the concepts of: Feasible region, feasible solution, objective function, decision variables, binding and non-binding constraints. Linear and non-linear programming. Assumptions of lp. Graphical method for lp problems with two decision variables
Assignments due	

Please note there will be no class on September 24 and 26 due to a previous commitment of the instructor with the Duke Immerse Program "The future of food". Also, there will not be class on October 1 and 3 to follow the DKU academic calendar.

Date	**Monday October 8**
Class topic/unit name	**Lp post-optimality (shadow prices and their meaning in energy systems)**
Pre-class work for students	• RR10-Vector and Matrix Algebra.pdf. pp1-10.(Excerpts from the books of Johnson &Wichern (Applied Multivariate Statistical Analysis) This will be used in the formulation of lp network problems discussed at the end of October. Make sure you understand how to add, subtract and multiply vectors and matrices and seek help if you need it.
Planned in-class activities	
Assignments due	

Date	**Wednesday October 10**
Class topic/unit name	**Formulation of lp programs**
Pre-class work for students	• RR11-Bazaraa Ch-1.pdf. (Bazaraa M.S.; Jarvis, J.J.; Sherali, H.D. (1990) Linear Programming and Network Flows. Second Edition. New York: John Wiley & sons. Chapter 1: Introduction. pp1-24.)

	• OR11-using simplex methods LP.pdf (Reeb,J. and Leavengood (1998). Using the Simplex Method to Solve Linear Programming Maximization Problems.)
Planned in-class activities	Lecture and in class exercises: Formulating LP problems in canonical and standard form. Lp formulation using sigma-capital notation and in matrix form. Assumptions of lp. Example: Gasoline blending problem.
Assignments due	

Date	**Monday October 15**
Class topic/unit name	**Multi-Period lp programs. Handling inventories (biofuels and natural gas)**
Pre-class work for students	• OR11-using simplex methods LP.pdf (Reeb,J. and Leavengood (1998). Using the Simplex Method to Solve Linear Programming Maximization Problems.)
Planned in-class activities	Formulation and excel soluton of multiperiod lp models.
Assignments due	

Date	**Wednesday October 17**
Class topic/unit name	**Network flow models problems. Transportation networks. (saving fuel)**
Pre-class work for students	• RR13-NetworkFlowModels_JensenBarnes.pdf (Jensen, P.A. & Barnes, J.W. (1980). Network Flow Programming. New York: John Wiley and Sons, Inc. Chapter 1: Network Flow Models. pp.1-50)
Planned in-class activities	Formulation and excel solution of transportation networks If time allows Quick review of **Basic Matrix Operations with Excel and Matlab:** Addition, Subtraction, Multiplication, Transposition, and Inversion, and Solving Systems of linear equations
Assignments due	

Date	**Monday October 22**
Class topic/unit name	**Networks: Trans-shipment**
Pre-class work for students	
Planned in-class activities	Formulation and excel solution of transshipment networks. Expressing formulation in terms of vectors and matrices.

Assignments due	

Date	**Wednesday October 24**
Class topic/unit name	**Networks: Shortest path**
Pre-class work for students	
Planned in-class activities	Formulation and excel solution of lp shortest path problems
Assignments due	

Date	**Monday October 29**
Class topic/unit name	**Networks: Maximum flow - Networks as an abstract representation of planning problems: Planning trucks replacement**
Pre-class work for students	
Planned in-class activities	• OR15- Applications of Network Problems.pdf. M.O. Ball et al., Eds., Handbooks in OR & MS, Vol. 7, Chapter 1 – *Applications of Network Optimization*. Ahuja, R.K. et al. 1995.
Assignments due	

Date	**Wednesday October 31**
Class topic/unit name	**MILP - Ontario Hydro optimal investment and operating strategy I**
Pre-class work for students	• RR16-power planning ontario.pdf (Muller, R.A.&Geroge, P.J.(1985). *Northern Hydroelectric Development in and Optima Expansion Program for Ontario Canada.* Canadian Public Policy-Analyse de Politiques, XI:3, pp.522-532)
Planned in-class activities	
Assignments due	

Date	**Monday November 5**
Class topic/unit name	**MILP - Ontario Hydro optimal investment and operating strategy II**
Pre-class work for students	

Planned in-class activities	Another example of an optimal investment problem: • OR17-Plugging ships in ports.pdf (Vaishnav, P et al. (2015). Shore Power for Vessels Calling at U.S. Ports: Benefits and Costs. Vaishnav, P, et al. Environmental Science and Technology 2015)
Assignments due	

Date	**Wednesday November 7**
Class topic/unit name	**Probability Analysis and Introduction to MonteCarlo simulation. Coping with uncertainties in energy systems: electricity demand, solar and wind power productions, fuel prices**
Pre-class work for students	• OR18- Morgan and Henrion Chapters.pdf (Chapter 5 and an excerpt from Chapter 8 of Morgan and Henrion's book Uncertainty. Chapter 5 reviews the material covered in RR15)
Planned in-class activities	
Assignments due	

Date	**Monday November 12**
Class topic/unit name	**MonteCarlo simulation: Fitting and generating random variables in Excel I (Electricity, coal, natural gas prices, demand, wind speeds and wind power production)**
Pre-class work for students	
Planned in-class activities	Lecture and in class exercises on how to fit probability distributions to data and then how to generate random draws of a given distribution in excel Distributions: Uniform, Poisson, exponential, Weibull, normal
Assignments due	

Date	**Wednesday November 14**
Class topic/unit name	**generating correlated random variables in Excel II (Wind speeds: time series vs i.i.d)**
Pre-class work for students	
Planned in-class activities	Lecture and in-class exercises on how to generate correlated random

	draws of known probability distribution functions
Assignments due	

Date	**Monday November 19**
Class topic/unit name	**Simulating wind power production and profits of a wind farm – Value at Risk I**
Pre-class work for students	
Planned in-class activities	Review of a cost and profits model and application to the economic analysis of a wind farm. Development of a Montecarlo simulation model. Introduction of the Value at Risk Concept
Assignments due	

Date	**Wednesday November 21**
Class topic/unit name	**Simulating wind power production and profits of a wind farm – Value at Risk I**
Pre-class work for students	
Planned in-class activities	Introduction to a Markov Chain Motencarlo model
Assignments due	

Date	**Monday December 3**
Class topic/unit name	**Fitting and generating random variables using @risk**
Pre-class work for students	Install free trial of the @risk software in your computer
Planned in-class activities	
Assignments due	

Date	**Wednesday December 5 and if possible Monday December 12**
Class topic/unit name	**Intro to optimization under uncertainty – stochastic programming. Planning natural gas inventories under weather uncertainty**

Pre-class work for students	• OR24-Reading meters for SOCAL (Wunderlinch, J.; Collette, M.; Levy, L.; Bodin, L. (1999) Scheduling Meter Readers for Southern California Gas Company. Interfaces pp.22-30.) • OR24-Implications of generator siting for CO_2 pipeline infrastructure.pdf (Newcomer, A. & Apt, J. (2008). Implications of generator siting for CO_2 pipeline infrastructure. Energy Policy 36, 1776–1787.) • OR25-Energy Planning Multistage stochastic optim.pdf (Li et. al (2010). Regional-scale electric power system planning under uncertainty - A multistage interval-stochastic integer linear programming approach. Energy Policy 38, 475–490)
Planned in-class activities	Lecture on how to formulate an lp when the parameters are uncertain.
Assignments due	