15-884/15-484 – Introduction

J. Zico Kolter

August 27, 2013
• Why sustainable energy and the smart grid?

• Why computation?

• What we will cover in this class
“Sustainable energy”

“Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs.”

– UN Report “Our Common Future”, 1987
U.S. energy consumption

Data: U.S. Energy Information Administration
U.S. petroleum production

Data: U.S. Energy Information Administration
Atmospheric carbon dioxide

Data: NOAA and Eteridge et al., 1998
Atmospheric carbon dioxide

Data: Barnola et al., 2003, Siegenthaler et al., 2005
Climate change

• Climate sensitivity

\[ \Delta T_{2x} \equiv \text{“Temperature increase from doubling CO}_2\text{”} \]

• “Climate sensitivity is likely to be in the range of 2 to 4.5°C with a best estimate of about 3°C and is very unlikely to be less than 1.5°C” — IPCC 2007 Synthesis Report

• \[ \Delta T_{2x} \left\{ \begin{array}{l} 33\text{-}50\% \text{ from CO}_2 \\ 50\text{-}66\% \text{ from feedbacks (largely water vapor)} \end{array} \right. \]
World population

Data: U.S. Census Office, 2010
Estimated U.S. Energy Use in 2010: ~98.0 Quads

Source: LLNL 2011. Data is based on DOE/EIA-0384(2010), October 2011. If this information or a reproduction of it is used, credit must be given to the Lawrence Livermore National Laboratory and the Department of Energy, under whose auspices the work was performed. Distributed electricity represents only retail electricity sales and does not include self-generation. EIA reports flows for hydro, wind, solar and geothermal in BTU-equivalent values by assuming a typical fossil fuel plant “heat rate.” (see EIA report for explanation of change to geothermal in 2010). The efficiency of electricity production is calculated as the total retail electricity delivered divided by the primary energy input into electricity generation. End use efficiency is estimated as 80% for the residential, commercial and industrial sectors, and as 25% for the transportation sector. Totals may not equal sum of components due to independent rounding. LLNL-MI-410527
For additional discussion...

http://www.withouthotair.com
The “smart grid”

“‘Smart grid’ generally refers to a class of technology people are using to bring utility electricity delivery systems into the 21st century, using computer-based remote control and automation. ... They offer many benefits to utilities and consumers – mostly seen in big improvements in energy efficiency on the electricity grid and in the energy users homes and offices.”

– U.S. Department of Energy
The “smart grid”

You: need to supply power to the country

The “smart grid”

You: need to supply power to the country

5,500 power plants (925 GW capacity)

The “smart grid”

83m residential and 5m commercial/industrial buildings (768 GW peak demand)

5,500 power plants (925 GW capacity)

You: need to supply power to the country

The “smart grid”

83m residential and 5m commercial/industrial buildings (768 GW peak demand)

172k miles of transmission lines

5,500 power plants (925 GW capacity)

You: need to supply power to the country

The “smart grid”

You: need to supply power to the country
5,500 power plants (925 GW capacity)
83m residential and 5m commercial/industrial buildings (768 GW peak demand)
172k miles of transmission lines
49 GW of installed wind/solar capacity

The “smart grid”

- 83m residential and 5m commercial/industrial buildings (768 GW peak demand)
- 172k miles of transmission lines
- 30m installed smart meters
- 5,500 power plants (925 GW capacity)
- 49 GW of installed wind/solar capacity

You: need to supply power to the country

Example: The emergence of power markets

- 1935 – Public Utility Holding Company Act (PUHCA)
- 1992/2005 – PUHCA repealed, (ideally) opens competition in power generation
Typical Market

<table>
<thead>
<tr>
<th>Producer 1</th>
<th>Producer 2</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1.png" alt="Graph" /></td>
<td><img src="image2.png" alt="Graph" /></td>
</tr>
</tbody>
</table>

Consumer: wants 1000 units

Power Market

- No time to wait for bidding system
- No way to store significant energy (yet?)
- Constraints of transmission grid
Schweppe et al., 1988
PJM (Pennsylvania’s regional transmission operator) website

Solving large non-convex optimization problems once every five minutes to determine energy production/distribution
Overview of course topics

Modeling / prediction

Unknown / hard to model elements:
- Machine learning

Physically well-understood elements:
- Electric power systems

Control
• Applications
  – electrical demand prediction, renewable resource availability, building energy consumption, power flow, power markets and economics, distributed storage and control, ...

• Algorithms
  – linear and non-linear regression and classification, convex optimization, time series prediction, Newton’s method, model predictive control, mixed-integer programming, ...

• Algorithms applied to real-world data in these domains, and a focus on implementation
An example final course assignment

• For a real-world electrical grid, forecast likely upcoming demand and renewable generation (using machine learning)

• Determine how power will be distributed over the grid given different possible generation scheduling (using power systems modeling)

• Optimally schedule generation in a manner that minimizes carbon emissions (using optimal control algorithms)

• Most of these techniques are broadly applicable in domains beyond sustainability and the smart grid
Class prerequisites

• Some programming experience, ideally in MATLAB

\[ P = \begin{bmatrix} 0 & 0; 0.5 & 1; 1 & 0 \end{bmatrix}; \]
\[ X = \text{zeros}(50000,2); \]
\[
\text{for } i=1:\text{size}(X,1)-1, \\
\quad X(i+1,:) = 0.5*X(i,:) + 0.5*P(\text{ceil}(3*\text{rand}),:); \\
\text{end} \\
\text{plot}(X(:,1), X(:,2), 'b.'); \]

• Basic knowledge of linear algebra

\[ Ax - b + x = c, \]
\[ x, b, c \in \mathbb{R}^n, \ A \in \mathbb{R}^{n \times n} \]

• Review notes for both of these posted to course web site
Class organization

• 4 problem sets
  – ~2 programming assignments per problem set

  – ~2 extensions / challenge problems

• Final project
  – Written report (max 5 pages) or programming assignment on topic in computational approach to energy or the smart grid

  – May be done in groups of 2

  – For 15-884, must be original research project, for 15-484/18-473, may be survey or advanced programming assignment

  – Come to office hours (soon!) to discuss possible topics
Class organization

• 4 problem sets
  – ~2 programming assignments per problem set
  – ~1 extension / challenge problem

• Final project
  – Written report (max 5 pages) or programming assignment on
    topic in computational approach to energy or the smart grid
  – May be done in groups of 2
  – For 15-884, must be original research project, for 15-484/18-473,
    may be survey or advanced programming assignment
  – Come to office hours (soon!) to discuss possible topics
Class policies

• Homework is due at the beginning of class on the due date

• You have a total of 5 late days you may use over the span of the course

• You may (and are encouraged to) collaborate in discussing homework problems, but the solutions (written problems and code) you write up must be done independently

• You are allowed to consult outside sources (anything except homework solutions from previous years), but please cite all sources