15-830 – Computational Methods in Sustainable Energy: Introduction

J. Zico Kolter

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• Why sustainable energy?

• Why computation?

• What we will cover in this class
“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. energy consumption

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
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\(^\circ\)C with a best estimate of about 3\(^\circ\)C and is very unlikely to be less than 1.5\(^\circ\)C” — IPCC 2007 Synthesis Report

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

Data: U.S. Census Office, 2010
### Sustainable Energy - Without the Hot Air

**David JC MacKay**

For additional discussion...

<table>
<thead>
<tr>
<th>Source</th>
<th>Energy per Day</th>
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<tbody>
<tr>
<td>Wind:</td>
<td>20 kWh/d</td>
</tr>
<tr>
<td>PV, 10 m²/p:</td>
<td>5 kWh/d</td>
</tr>
<tr>
<td>PV farm (200 m²/p):</td>
<td>50 kWh/d</td>
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<tr>
<td>Biomass: food, biofuel, wood, waste inciner, landfill gas:</td>
<td>24 kWh/d</td>
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<tr>
<td>Hydro:</td>
<td>1.5 kWh/d</td>
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<tr>
<td>Shallow offshore wind:</td>
<td>16 kWh/d</td>
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<td>Deep offshore wind:</td>
<td>32 kWh/d</td>
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<tr>
<td>Wave:</td>
<td>4 kWh/d</td>
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<tr>
<td>Tide:</td>
<td>11 kWh/d</td>
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<tr>
<td>Light:</td>
<td>1 kWh/d</td>
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<tr>
<td>Heating, cooling:</td>
<td>37 kWh/d</td>
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<tr>
<td>Jet flights:</td>
<td>30 kWh/d</td>
</tr>
<tr>
<td>Car:</td>
<td>40 kWh/d</td>
</tr>
<tr>
<td>Transporting stuff:</td>
<td>12 kWh/d</td>
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<tr>
<td>Stuff:</td>
<td>48+ kWh/d</td>
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<tr>
<td>“Defence”:</td>
<td>4 kWh/d</td>
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http://www.withouthotair.com
Why computation?

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

172k miles of transmission lines

5,500 power plants (925 GW capacity)

30m installed smart meters

49 GW of installed wind/solar capacity

You: need to supply power to the country

The rise of wind power

Data: U.S. Energy Information Administration
Heron’s Windwheel, 1st century AD
Smock Mill, 1802; Photo: L. Chatfield
Smith-Putnam 1.25 MW Turbine, 1941-1945
UMass WF-1 Turbine, 1975

- Optimal blade shape
- Variable speed operation
- Power control via pitch
- Computer controlled
Wilson and Lissaman, 1974

“The advent of the digital computer makes the task of preparing general performance plots of wind machines easy.”
GE 100-2.5 Turbine

Collier, 2010

Sebastian and Lackner, 2010
The emergence of power markets

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

Producer 1

Producer 2

Cost

0

1000

2000

Quantity

0

500

1000

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
Class prerequisites

• Some programming experience, ideally in MATLAB

```matlab
P = [0 0; 0.5 1; 1 0];
X = zeros(50000,2);
for i=1:size(X,1)-1,
    X(i+1,:) = 0.5*X(i,:) + 0.5*P(ceil(3*rand),:);
end
plot(X(:,1), X(:,2), 'b.');
```

• Basic knowledge of linear algebra

\[
Ax - b + x = c,
\]

\[x, b, c \in \mathbb{R}^n, \quad A \in \mathbb{R}^{n \times n}\]

• 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) on topic in computational approach to energy
  - Done in groups of 2-3
  - For 830, must be original research project, for 630 can be survey
  - Come to office hours (soon!) to discuss possible topics