Thoughts on Modeling Renewable Energy

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Energy and Environmental Analysis Group
In Memory Of
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Topics

• Background
  – EPRI Team
  – US-REGEN Model

• How we Model Wind
  – Wind Economics 101 – 8760 hours/1 year
  – Choosing Hours in US-REGEN

• Technology Characterization
  – US Technology Competition?? Got to Beat Gas

• Concluding Thoughts
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*In March 2013. Geoff in Germany for 2 years, James to Stanford for PhD
US-REGEN Model Description

General Equilibrium Economy Model
- Aggregate Economic Representation
- Energy Markets for Oil, Natural Gas, Coal, & Bioenergy
- Foreign Exchange
- Landuse (Ag and Forest)

Energy Demand (Electric & Non-Electric)
- Energy Efficiency across Commercial, Industrial, & Residential Sectors
- Transportation: Detailed model of vehicle technologies and intermodal choices

Electric Sector Module
- CO₂ Mitigation Technologies
- Environmental Controls: Air, Water, Land
  - Transmission
US-REGEN Information

• Environmental Controls Analysis – Fall 2012
• CO2 Policy Analysis along with detailed model documentation and foundational studies – Fall 2013

• Next steps
  – Build out the demand side
    • Endogenous load shape, distributed generation, demand response, etc.
    • Examine business models
  – Improve analysis of plant cycling – fossil and nuclear
  – Build detailed natural gas supply and transport sector
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New AWS Truepower Data Set: Capturing the Variability of Wind

- **AWS Truepower wind data**
  - Based on actual 1997-2008 meteorology
  - Provides simulated hourly output for typical turbine (80m height, 1.5 MW)

- **Identified 5300+ “utility-scale” sites**
  - Exclusion areas
  - 100 MW site minimum
  - Distance to grid
  - Terrain/wake effects
Example Analysis of NW-Central Region Using New Wind Data

- State hourly load data for 2007 from Energy Velocity
- Hourly loads and wind output synchronized so driven by same 2007 meteorology
- Add 50 GW new installed wind capacity within region
- Rank sites by capacity factor, build best sites first
Anti-correlation of Wind with Load Creates Ramping Issues: 50 GW

The morning up-ramp

The evening down-ramp
Anti-correlation of Wind with Load Also Forces Diminishing Returns to Wind Additions: 100 GW

More wind than load produces local surplus that must be spilled or exported

NWC Time Series from 8/9/07 to 8/16/07 w 100 GW Added
Potential Supply Far Outstrips Region Load

Annual Generation Output and Uses by GW of Wind Additions

- Output and Load (TWh)
- Wind Additions (GW)

Graph showing the relationship between annual generation output (in TWh) and wind additions (in GW) with lines indicating NWC Wind TWh and NWC Load TWh.
Starting At 50 GW, Additions Show Diminishing Returns in Meeting Region Load

Annual Generation Output and Uses by GW of Wind Additions

Output and Load (TWh)

Wind Additions (GW)

NWC Wind TWh
NWC Load TWh
NWC Wind Used TWh
At 175 GW of Additions As Much Wind is Spilled as is Used to Serve Load

90% of load covered by wind generation
With Spills Incremental COE of Delivered Wind Generation Skyrockets
EPRI Wind Resource Assessment from Truepower Shows Vast Generation Potential

2007 Combined On- and Off-shore Wind Generation Supply

- **Cost** of Electricity ($/MWh)
- **Wind TWh** (million MWh)

- **2007 Gen by Coal**
- **Total U.S. Gen in 2007**
- **Cost to generate a MWh from wind (no tax credits)**

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Considerable Year-to-year Variation in National Wind Energy Supply

Combined On- and Off-shore Wind Generation Supply for Selected Years

- 2007 Generation Cost
- 1998 (worst)
- 12 Yr Avg
- 2008 (best)
National Wind Energy Potential Supply Curves*
(including delivery costs)

Cost of Electricity ($/MWh)

Delivered Cost with Existing Transmission
Delivered Cost with New Transmission
Transmission Line Miles
Generation Cost

Wind TWh (million MWh)

New Transmission Line Miles (thousands)

0 500 1,000 1,500 2,000 2,500 3,000 3,500 4,000 4,500 5,000

0 10 20 30 40 50 60 70 80

$0 $50 $100 $150 $200 $250 $300 $350 $400

*EPRI – AWS TruePower National Wind Energy Supply Curves
NW-Central Region-wide (7 states) Low Output Can Continue for Extended Periods – Capacity Value??

NWC Time Series from 5/5/07 to 5/12/07 w 50 GW Added

May 8, 2007, at 2pm (EST) had zero wind output

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Temporal Distribution

- 8760-profile developed by region for load, 8 classes of wind, 3 classes of solar PV, and solar CSP (sample below)
• Our non-trivial computational capacity cannot solve electric model QCP at 8760 resolution (Limit: ~200, practical limit <100)
Hour Choosing Algorithm

- Model solution – hours satisfying ‘bubble constraint’ in each of 15 regions:
  - For this set of data, algorithm chooses \(44\) hours (upper bound: \(8 \times 15\))
- Clustering algorithm provides 40 additional hours
- We additionally add the peak load hours of the eastern and western interconnects
- Weighting algorithm then applied
Some Sample Load Duration Curves

Load Duration Curve for NewYork

- 8760 hourly data
- 86 segment data (with additional hours from clustering)
Some Sample Resource Duration Curves

Variable Resource Duration Curve for slpv-n1 in California

- 8760 hourly data
- 86 segment data

Fraction of Maximum

Hours of Year
Some Sample Resource Duration Curves

Variable Resource Duration Curve for wind-n3 in NW-Central

Fraction of Maximum vs. Hours of Year

- 8760 hourly data
- 86 segment data
Alternative Gas Price Futures, Which Path are We On?

Henry Hub NG Price

AEO 2013ER

2012 High TRR

~$1 difference in 2020, $1.50 difference by 2030
U.S. Wellhead Price History Shows a 7¢ per year Upward Price Trend, and Lots of Noise

Wellhead Price $/MMBtu (2012$)

\[
y = 0.0002x - 2.588
\]

\[R^2 = 0.1741\]
Different Price Paths Lead to Distinct Futures at the National-Level

**Reference**

- Existing Coal
- New Coal w/CCS
- Nuclear (New)
- Geothermal
- Environmental Retrofit
- CCS Retrofit
- Nuclear (Existing)
- Hydro+
- Wind
- Gas
- Gas w/CCS
- Biomass
- Solar
- EE + Price Response
- Baseline

**Hi TRR Gas**

- New Coal
- Nuclear (Existing)
- Hydro+
- Wind
- Gas
- Gas w/CCS
- Biomass
- Solar
- EE + Price Response
- Baseline
Regional Reference
High TRR Gas

- Gas
- New Coal
- Environmental Retrofit
- Existing Coal
- Wind
- Hydro+
- Nuclear (New)
- Nuclear (Existing)
- Imports
- Total Energy for Load
- Solar
- Geothermal
- Biomass

Graphs showing energy trends in the East, West, Midwest, and South from 2010 to 2040 in TWh (trillion kilowatt-hours).
Concluding Thoughts

• US-REGEN can help us understand wind and solar deployment
  – Run intertemporal, 8760, and unit commitment versions to gain insights
• MERGE can be parameterized to mimic US-REGEN, but cannot replace it
  – Crosswalk is not straightforward, e.g., discount rates
• Analytical, financial and political battles over the “true cost” of renewables are just beginning and likely to persist
Together...Shaping the Future of Electricity

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