Modeling the Details of U.S. Renewable Energy Electricity

2010 GTSP Technical Workshop
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May 27, 2010
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- Hierarchy of models
- U.S. Electric Sector Capacity Expansion - ReEDS model
- Hourly modeling - GridView model
- From Global to Local – GCAM/ReEDS project
Complexities of Modeling Renewable Electric Technologies - Attributes

• Resource variability
  • Temporally
    • Diurnally, seasonally, annually, susceptibility to climate
    • Uncertainty – forecast errors
  • Spatially
    • Locally
    • Regionally /diversity
    • Non-portability of the resource – wind, solar, hydro
      • Transmission requirements

• High Capital, low operating costs
  • Nascent industries

• Modularity of the technology – costs, transportability

• Environmental impacts – visual, large land areas, etc.
Complexities of Modeling Renewable Electric Technologies - Impacts

- Resource variability
  - Temporal – the smaller the time step, the better
    - Capacity value, operating reserves, curtailments, transmission req’ts, storage requirements
  - Dynamic
- Spatial – the smaller the regions, the better
  - Inter-region transmission
  - Diversity difficult to capture, even with small regions

- High capital costs; low operating costs
  - Economic and financial parameter values have huge impacts
  - Nascent industry growth rates impact prices

- Modularity
  - Modularity of many renewables not recognized by most models
  - World markets for technologies – solar, wind

- Environmental impacts – visual, sound, local codes
Actual Models

- Limitations
  - Run time and memory requirements
  - Data inputs
  - Analyst time

- Existing model limitations
  - Very aggregated time slices (GCAM 4, NEMS 11, ReEDS 17)
  - Limited number of regions (GCAM 1 for U.S., NEMS 13, ReEDS 358)
  - Limited transfers between regions – no optimal power flow
  - Aggregated economic, financial, tax structure
  - Continuous plant sizes
  - World technology-supply markets largely ignored
  - Market structure largely ignored
Hierarchy of Models

• No one model can “do it all”
• Different model purposes call for different areas of focus
  • GCAM – integrated assessment modeling
  • NEMS – national forecast and policy analysis
  • ReEDS – potential of central renewable electric technologies
  • SolarDS – potential of photovoltaics on buildings
  • GridView – 8760 hours/year production cost with optimal power flow model (ABB product)
• A hierarchy of models allows one to come closer to “doing it all”
NREL’s Electricity Market Model Hierarchy

does it work hourly?

rooftop PV penetration

 GridView

SolarDS

ReEDS
PNNL/NREL Modeling Construct

GridView

rooftop PV penetration

does it work hourly?

SolarDS

National Renewable Energy Laboratory
Innovation for Our Energy Future
ReEDS Overview

• **Capacity expansion & dispatch** for the US electricity sector out to 2050 including transmission & all generator types – AP coal, IGCC coal w/wout CCS, Gas CTs, Gas CCs w/wout CCS, oil/gas steam, nuclear, hydro, PHS, major renewables

• **Minimize total system cost** in each 2-year investment period
  - All constraints (e.g. balance load, reserves, etc.) must be satisfied
  - Investment decision based on 20 year present value cost of each technology

• **Multi-regional**
  - 3 interconnections – separately synchronized
  - 13 NERC subregions – fuel price differences
  - 48 states – incentives, state RPSs, etc.
  - 134 power control areas (PCAs) – balance generation & load
  - 356 wind/csp regions – resource availability/quality, grid connection
  - Enables transmission capacity expansion
  - Enables treatment of the variability of wind/solar

• **Temporal Resolution**
  - 17 timeslices in each year
    - 4 typical days representing the 4 seasons
    - each typical day separated by 4 timeslices (morning, afternoon, evening, night)
    - 1 superpeak summer afternoon timeslice
  - Statistical treatment of variability of wind & non-dispatchable solar
Wind and PV Capacity Value

Wind Capacity Value/MW = DL/Wind Nameplate Capacity
Value of Diversity
Wind and PV Curtailments

Conventional and Load

Wind

Must Run - Load

Wind + Must Run - Load

Surplus
Wind and PV Induced Operating Reserve

Operating reserves driven by
- contingency and regulation reserves
- Load/wind following reserves

Load/wind following reserves
- Based on errors in load and wind forecasts

Operating reserves comprised of
- Spinning reserves
- Quick-start capability
- Interruptible load
20% Wind Energy by 2030
(Results from ReEDS/WinDS model)

Direct Electric System Cost

20% Wind Scenario Costs 2% More
20% Wind Energy by 2030

Wind (MW) on Transmission Lines

Existing  New
100 - 200
200 - 500
500 - 1000
> 1000

Wind (MW) Used Inside the BA
100 - 300
300 - 500
500 - 1000
1000 - 5000
> 5000

Total Between BA Transfer >= 100 MW (all power classes, land-based and offshore) in 2030. Arrows originate and terminate at the centroid of the BA for visualization purposes; they do not represent physical locations of transmission lines.

20% Wind 06-19-2007
Detailed Studies Following the 20% Wind Energy by 2030 Study
ReEDS Now Includes All Major RETs

- WIND
- CSP
- GEO
- BIO

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PNNL/NREL Modeling Construct

GCAM

GridView

ReEDS

SolarDS

does it work hourly?

rooftop PV penetration
GridView

Commercial production-cost (8760 hour simulation with unit commitment), optimal DC power flow model by ABB

Used by ISOs, utilities, and others for wide variety of purposes

- 11,000 generators
- 85,000 transmission lines
GridView Representation of ReEDS Results

- Buses/substations
- ReEDS region
- Transmission lines
GridView - 2050 U.S. Electricity Demand
RE Generation from the High RE Scenario

The chart illustrates the renewable energy (RE) generation from the high RE scenario. The x-axis represents the months from January to December, while the y-axis measures the generation in megawatts (MW) from 0 to 800,000 MW. The data shows significant variation throughout the year, with peaks and troughs indicating periods of high and low generation.
Thermal generation

[Graph showing thermal generation over the year with MW on the y-axis and months on the x-axis]
Actual renewable generation

![Graph showing actual renewable generation from Jan to Dec with MW on the y-axis and months on the x-axis.]
Curtailment (14% of renewable gen)
Curtailment by PCA (TWh)
GCAM/ReEDS Project Purpose

- Compare model results and identify reasons for differences
- Learn from each model and adopt improvements
- Develop a joint capability that allows analysis from global to local
### Brief Comparison of ReEDs and GCAM US Electric Sectors

<table>
<thead>
<tr>
<th></th>
<th>GCAM</th>
<th>ReEDS</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Regional Coverage</strong></td>
<td>Global model with 14 regions. U.S. is one region.</td>
<td>U.S. only; 358 subregions built from county data</td>
</tr>
<tr>
<td><strong>Sectoral Coverage</strong></td>
<td>Full agricultural and energy sector coverage</td>
<td>Electricity sector only</td>
</tr>
<tr>
<td><strong>Solution Mechanism</strong></td>
<td>Dynamic recursive, economic equilibrium</td>
<td>Linear Optimization sequentially through time with limited foresight</td>
</tr>
<tr>
<td><strong>Technology Choice</strong></td>
<td>Logit choice approach forces diversification</td>
<td>Optimization with regional variations in resource, prices</td>
</tr>
<tr>
<td><strong>Capacity Expansion</strong></td>
<td>New capacity is coupled with new generation</td>
<td>Explicit generation capacity expansion</td>
</tr>
<tr>
<td><strong>Reserves</strong></td>
<td>Not modeled.</td>
<td>Reserve margin and operating reserve requirements</td>
</tr>
<tr>
<td><strong>Dispatch</strong></td>
<td>Logit choice for investment, continued operation of capital stock vintages</td>
<td>Optimal dispatch in 17 timeslices</td>
</tr>
<tr>
<td><strong>Transmission</strong></td>
<td>Average transmission costs, no capacity constraints</td>
<td>Explicit transmission capacity expansion and transmission use</td>
</tr>
</tbody>
</table>
First Comparison Runs – Carbon Cap Case

![Graph showing energy sources and comparisons between GCAM and ReEDS](image-url)

- **GCAM**
  - Coal w/o CCS
  - Coal-CCS
  - Gas-CCS
  - Nuclear
  - Oil w/o CCS
  - Oil-CCS
  - Gas w/o CCS
  - Wind
  - CSP
  - Hydro
  - Central PV
  - Geothermal
  - Biopower
  - Distributed PV

- **ReEDS**
  - Coal w/o CCS
  - Coal-CCS
  - Gas-CCS
  - Nuclear
  - Oil w/o CCS
  - Oil-CCS
  - Gas w/o CCS
  - Wind
  - CSP
  - Hydro
  - Central PV
  - Geothermal
  - Biopower
  - Distributed PV
Harmonization Steps

Advanced Supply (allow nuclear and CCS construction)
1. Unharmonized (only load and carbon cap are synchronized)
2. Harmonized model inputs (tech and fuel costs, emissions rates)
3. Harmonized capital cost financing (use fixed charge rate)
4. Harmonized annual generation for biopower and distributed PV
5. **Harmonized annual generation for nuclear power**
6. Harmonized annual generation from all conventionals
7. Completely harmonized (renewables and conventional
Harmonized Runs - Carbon Cap Case

Tech costs, finance and taxes, emission rates, biopower, nuclear, PV

**GCAM**

**ReEDS**

![Graph showing energy production by year for GCAM and ReEDS](chart.png)
Continued collaboration will lead to improvements of both models and a joint capability

GCAM benefits from updated supply curves from ReEDS for renewable technologies.

GCAM also benefits from ReEDS temporal detail with addition of base, intermediate, and peak competition in the electric sector.

GCAM will benefit from ReEDS modeling of the grid integration of intermittent resources and reliability.

ReEDS benefits from GCAM experience with technologies that are not currently fully functional in ReEDS.
  – Rooftop PV.
  – Biogasification Combined Cycle with and without CCS.

ReEDS will benefit from information about other sectors from GCAM.
  – Biofuels influence on biopower.
  – Influence of heating demand on natural gas prices.
Conclusions

• Simulating renewable electric technologies requires extra-ordinary detail

• A hierarchy of models provides insights and checks on higher level models