Weather-Informed Energy Systems
Utilizing the WIS:dom Optimization Model

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May 3, 2018
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WIS:dom Optimization Model

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Prepared For:
The Payne Institute, Colorado School of Mines
May 3rd, 2018

Disclaimer:

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Purpose of Vibrant Clean Energy, LLC:

- Reduce the cost of electricity and help evolve economies to near zero emissions;
- Co-optimize transmission, generation, storage, and distributed resources;
- Increase the understanding of how Variable Generation impacts and alters the electricity grid and model it more accurately;
- Agnostically determine the least-cost portfolio of generation that will remove emissions from the economy;
- Determine the optimal mix of VG and other resources for efficient energy sectors;
- Help direct the transition of heating and transportation to electrification;
- License WIS:dom optimization model and/or perform studies using the model;
- Ensure profits for energy companies with a modernized grid;
- Assist clients unlock and understand the potential of high VRE scenarios, as well as zero emission pathways.
The WIS:dom Optimization Model
WIS:dom is the only combined capacity expansion and production cost model. It combines:

- Continental-scale (globally capable), spatially-determined co-optimization of transmission, generation and storage expansion while simultaneously determining the dispatch of these sub systems at 13-km or 3-km, hourly or 5-minutely resolution;

- Dispatch includes:
  - Individual unit commitments, start-up, shutdown profiles, and ramp constraints;
  - Transmission power flow, planning reserves, and operating reserves;
  - Weather forecasting and physics of weather engines;
  - Detailed hydro modeling;
  - High granularity for weather-dependent generation;
  - Existing generator and transmission asset attributes such as heat rates, line losses, power factor, variable costs, fixed costs, capital costs, fuel costs, etc.;

- Large spatial and temporal horizons;
- Policy and regulatory drivers such as PTC, ITC, RPS, etc.;
- Detailed investment periods (2-, 5-, or 10- year) out past 2050;
- 100 - 10,000x increased resolution compared with nearest competitor for VRE, load, and conventional generator descriptions.
What Do Models Need To Consider?
Wind Resource at 3-km Resolution
Solar PV Resource at 3-km Resolution
Existing Generators (2017)
Existing Electricity Transmission (2017)
Landcover Inputs For Siting Constraints

Original Data Source: https://lpdaac.usgs.gov/dataset_discovery/modis/modis_products_table/mcd12c1
Optimal Hub Heights Mapped in WIS:dom
Rooftop Solar Potential Mapped in WIS:dom
Demand-side Inputs
<table>
<thead>
<tr>
<th>Constraint ID</th>
<th>Equation Name</th>
<th>Equation Purpose</th>
<th>Impact Estimation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Total System(s) Cost Objective</td>
<td>To define the objective that is being minimized</td>
<td>Critical</td>
</tr>
<tr>
<td>2</td>
<td>Reliable Dispatch Constraint</td>
<td>Enforce WIS:dom meets demand in each region each hour without fail</td>
<td>Critical</td>
</tr>
<tr>
<td>3</td>
<td>Market Clearing Price Adjustment</td>
<td>Allowing WIS:dom to estimate the dispatch stack &amp; attribute price vs cost</td>
<td>Critical</td>
</tr>
<tr>
<td>4</td>
<td>DSM Balancing Constraint</td>
<td>Ensures that DSM providers can balance their demand</td>
<td>High</td>
</tr>
<tr>
<td>5</td>
<td>Transmission Power Flow Constraint</td>
<td>Produces the optimal power flow matrix and associated losses</td>
<td>Critical</td>
</tr>
<tr>
<td>6</td>
<td>Transmission Capacity Constraint</td>
<td>Calculates the capacity of each transmission line</td>
<td>Critical</td>
</tr>
<tr>
<td>7</td>
<td>Planning Reserve Constraint</td>
<td>Ensure planning reserve margins are maintained</td>
<td>High</td>
</tr>
<tr>
<td>8</td>
<td>Coal, NGCC, NGCT, Nuclear, Hydro, Geo Capacity Constraints</td>
<td>Maintain the capacity of generators above their peak production</td>
<td>Without the constraints generations can be incredibly based on marginal costs alone</td>
</tr>
<tr>
<td>9</td>
<td>Storage Power &amp; Energy Capacity Constraints</td>
<td>Complex equations &amp; constraints to determine the utilization of storage</td>
<td>Storage correctly modeled can change all investment decisions and dispatch</td>
</tr>
<tr>
<td>10</td>
<td>Coal, NGCC, NGCT, Nuclear, &amp; Geo P_min Constraints</td>
<td>Constraints that force WIS:dom to adhere to P_min attributes for thermal generators</td>
<td>Medium</td>
</tr>
<tr>
<td>11</td>
<td>RPS &amp; Emission Constraints</td>
<td>To enable WIS:dom to understand policy, regulatory and societal limitations</td>
<td>Critical</td>
</tr>
<tr>
<td>12</td>
<td>Generator &amp; Transmission Capacity Expansion Constraints</td>
<td>To require WIS:dom to keep investments in new generation &amp; transmission to specific levels</td>
<td>Low-Medium</td>
</tr>
<tr>
<td>13</td>
<td>Coal, NGCC, NGCT, Nuclear, &amp; Geo Ramping Constraints</td>
<td>Describing the speed at which generators can alter their output for WIS:dom</td>
<td>Medium</td>
</tr>
<tr>
<td>14</td>
<td>DER Deployment &amp; Cost Constraints</td>
<td>Specifies to WIS:dom the amount of DERs to be constructed and/or cost to system of these assets</td>
<td>Low-Medium</td>
</tr>
<tr>
<td>15</td>
<td>CIL &amp; CEL Constraints</td>
<td>Describe the import &amp; export limits between markets, countries, states, and interconnections</td>
<td>Medium-High</td>
</tr>
<tr>
<td>16</td>
<td>Spatial Limitation Constraint</td>
<td>Allow WIS:dom to understand the space requirement for generators and competition for land use</td>
<td>Medium</td>
</tr>
<tr>
<td>17</td>
<td>Extraction Limits For VRE</td>
<td>Determines the limits to VRE extraction for nearby sites</td>
<td>Medium-High</td>
</tr>
<tr>
<td>18</td>
<td>Nuclear &amp; Hydro Dispatch Schedule</td>
<td>Informs WIS:dom that nuclear and hydro must conform to addition constraints regarding the water cycle, water temperature, and refuelling</td>
<td>Low-Medium</td>
</tr>
<tr>
<td>19</td>
<td>Relicense / Repower Decision</td>
<td>Facilitates WIS:dom apting to relicense or repower an existing nuclear or VRE site</td>
<td>Medium-High</td>
</tr>
<tr>
<td>20</td>
<td>Load / Weather Forecast Error Estimator</td>
<td>Enables WIS:dom to detect regions with poor weather and/or load forecasts for consideration during investment decisions</td>
<td>Low-Medium</td>
</tr>
</tbody>
</table>
**WIS:dom Consider Numerous Factors For The Optimization Of The Electricity Grid**

<table>
<thead>
<tr>
<th>Input ID</th>
<th>Input Name</th>
<th>Existing</th>
<th>New</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Heat Rate</td>
<td>All Current Thermal Data</td>
<td>NREL ATB 2017 Value</td>
</tr>
<tr>
<td>2</td>
<td>Minimum Load</td>
<td>All Current Thermal Data</td>
<td>Fleet Average</td>
</tr>
<tr>
<td>3</td>
<td>Power Factors</td>
<td>All Current Generator Data</td>
<td>Fleet Average</td>
</tr>
<tr>
<td>4</td>
<td>Fuel Costs</td>
<td>All Current Thermal Data For Multiplier</td>
<td>NREL ATB 2017 Value</td>
</tr>
<tr>
<td>5</td>
<td>Fixed O&amp;M Costs</td>
<td>All Current Generator Data</td>
<td>NREL ATB 2017 Value</td>
</tr>
<tr>
<td>6</td>
<td>Non-fuel Variable O&amp;M Costs</td>
<td>All Current Generator Data</td>
<td>NREL ATB 2017 Value</td>
</tr>
<tr>
<td>7</td>
<td>Capital Costs</td>
<td>All Current Generator Data</td>
<td>NREL ATB 2017 Value</td>
</tr>
<tr>
<td>8</td>
<td>Relicense / Repower Costs</td>
<td>All Existing Nuclear, Wind, and Solar Generators</td>
<td>45% For VRE, N/A For Nuclear</td>
</tr>
<tr>
<td>9</td>
<td>Discount Rates</td>
<td>Uses Same Rate as “New”</td>
<td>5.87% Real</td>
</tr>
<tr>
<td>10</td>
<td>Economic Lifetimes</td>
<td>All Current Generator Data</td>
<td>NREL ATB 2017 Value</td>
</tr>
<tr>
<td>11</td>
<td>Transmission Costs</td>
<td>Uses Same Cost As “New”</td>
<td>ABB / Blended Existing Costs</td>
</tr>
<tr>
<td>12</td>
<td>Transmission Topology</td>
<td>Current Above 69 kV Aggregated To Reduced Form</td>
<td>New Lines Allowed Within WIS:dom; constrained by user</td>
</tr>
<tr>
<td>13</td>
<td>Demand</td>
<td>Current Demand By Sector</td>
<td>Growth Estimates Provided By Sector By VCE</td>
</tr>
<tr>
<td>14</td>
<td>Weather / Power Data</td>
<td>N/A</td>
<td>One Year Of Hourly Power Data For Wind &amp; Solar Over EI</td>
</tr>
<tr>
<td>15</td>
<td>Policy &amp; Regulations</td>
<td>Apply All Existing Policies &amp; Regulations</td>
<td>Input As Constraints On Future Scenarios</td>
</tr>
<tr>
<td>16</td>
<td>Locational Multiplier</td>
<td>N/A</td>
<td>Black &amp; Veatch / NREL Public Data Combined By VCE</td>
</tr>
</tbody>
</table>
Eastern Interconnection Study: Economically-Driven
Installed Capacities

WIS:doM Installed Capacities For The Eastern Interconnection

Peak Original Demand

Peak Flexible Demand

Installed Capacity [Gw]

2017 2020 2025 2030 2035 2040 2045 2050

Coal CCGT CT Nuclear Geo Hydro Storage Wind Offshore Roof PV Solar PV

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Installed Capacities
Installed Capacities
Installed Capacities
Installed Transmission Capacities

Import To State

Export From State
Changes in Emissions & Pollutants

Change in Emissions and Pollutants From EI Electricity System

VCE

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Cost Changes Compared with 2017

Change in Retail Costs of Electricity in El Relative to 2017

- 2020: 2.9%
- 2025: -3.9%
- 2030: -8.2%
- 2035: -10.5%
- 2040: -12.7%
- 2045: -14.4%
- 2050: -16.1%

VCE

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Job Changes Compared with 2017

Change in Full Time Employment in EL Electricity Sector Relative to 2017

- 2020: 1.0%
- 2025: -0.9%
- 2030: 5.6%
- 2035: 23.9%
- 2040: 42.1%
- 2045: 56.4%
- 2050: 70.7%

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Economic Dispatch

Example El-wide Winter Economic Dispatch (2020)
Economic Dispatch
Economic Dispatch
Western Interconnection Study: Economically Driven
Installed Capacities
Installed Capacities
Installed Capacities

WIS:dom Installed Capacity By State (2030)

Installed Capacity (MW)

AZ  CA  CO  ID  MT  NM  NV  OR  UT  WA  WY

- Coal
- NGCC
- NGCT
- Storage
- Nuclear
- Hydro
- Wind
- Offshore
- Rooftop PV
- Utility PV
- CSP
- Geo

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Installed Capacities

[Bar chart showing the installed capacities by state in 2050, with different energy sources represented by colored bars.]

WIS:dom Installed Capacity By State (2050)

AZ, CA, CO, ID, MT, NM, NV, OR, UT, WA, WY

- Coal
- NGCC
- NGCT
- Storage
- Nuclear
- Hydro
- Wind
- Offshore
- Rooftop PV
- Utility PV
- CSP
- Geo

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Installed Capacities
Installed Capacities
Installed Capacities
Changes in Emissions & Pollutants

Change in Emissions and Pollutants From WECC Electricity System

- Change in Emissions Compared with 2017 Levels (%)
- CO2
- CO
- SO2
- NOx
- CH4
- N2O
- VOC
- PM2.5
- PM10

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Cost Changes Compared with 2017

Change in Retail Costs of Electricity in WECC Relative to 2017

- 2020: 3.5%
- 2025: -9.4%
- 2030: -13.2%
- 2035: -12.7%
- 2040: -12.2%
- 2045: -10.2%
- 2050: -8.3%
Economic Dispatch

Example WECC-wide Winter Economic Dispatch (2020)

- Coal
- Hydro
- Nuclear
- Geo
- Wind
- Offshore
- NGCT
- Storage
- NGCC
- Utility PV
- Rooftop PV
- Load
- Altered Load

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Economic Dispatch
Economic Dispatch
Thank You

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