Planning *Towards* a 100 percent renewable electricity system

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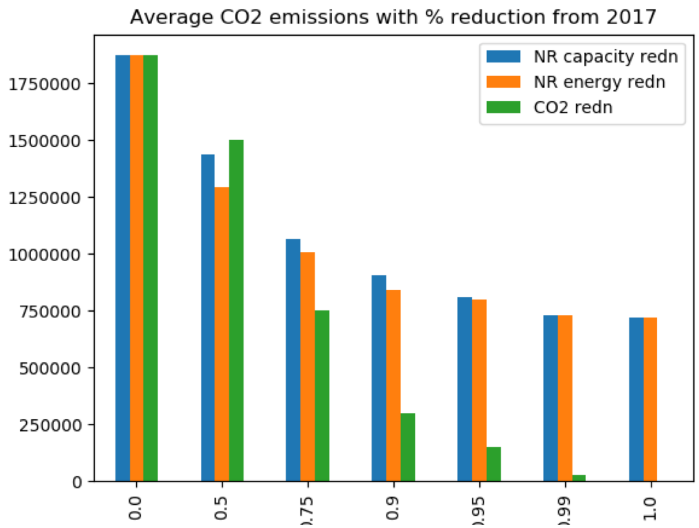
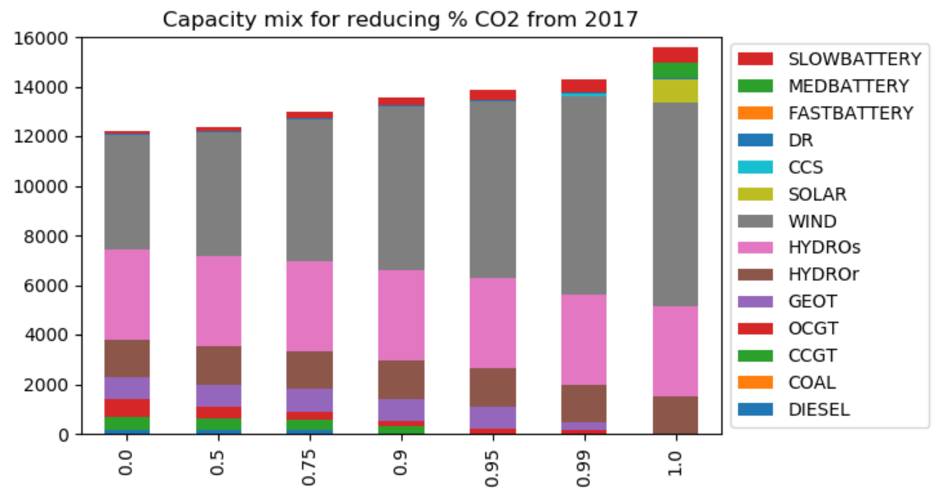
Joint work with Josh Arnold, Adam Christensen and Andy Philpott

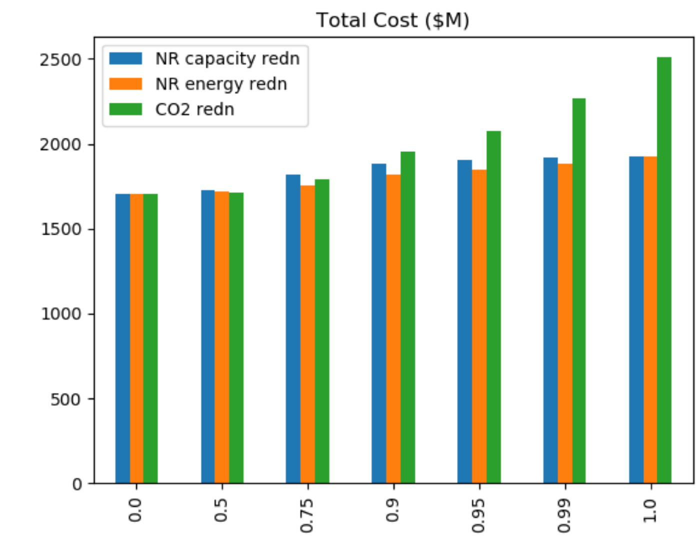
Jacinda's 2017 election deal

- Introduce a Zero Carbon Act and establish an independent Climate Commission.
- Request the Climate Commission to plan the transition to 100% renewable electricity by 2035 (which includes geothermal) in a normal hydrological year.
- Stimulate up to $1 billion of new investment in low carbon industries by 2020, kick-started by a Government-backed Green Investment fund of $100M.
- (Confidence and Supply Agreement between the New Zealand Labour Party and the Green Party of Aoteoroa)
  Built model GEMSTONE that was used by New Zealand Climate Commission to help inform this policy

New Zealand (Net Zero)

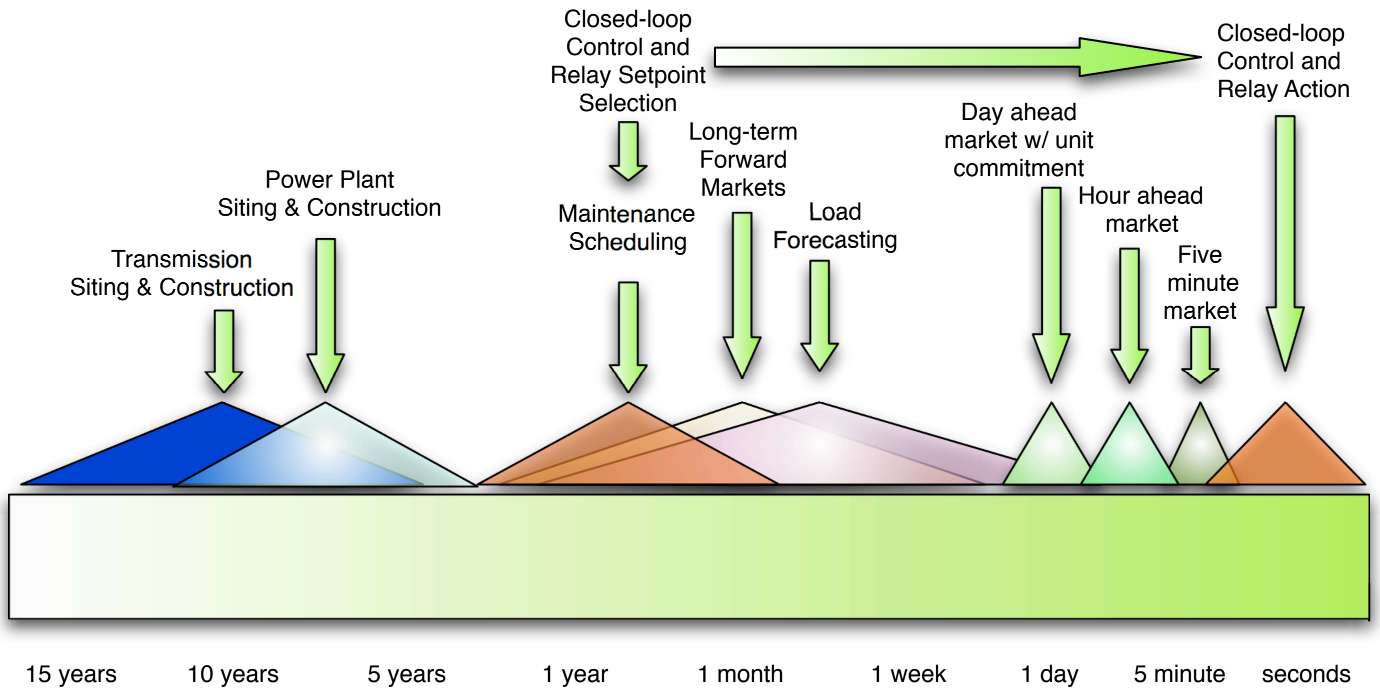






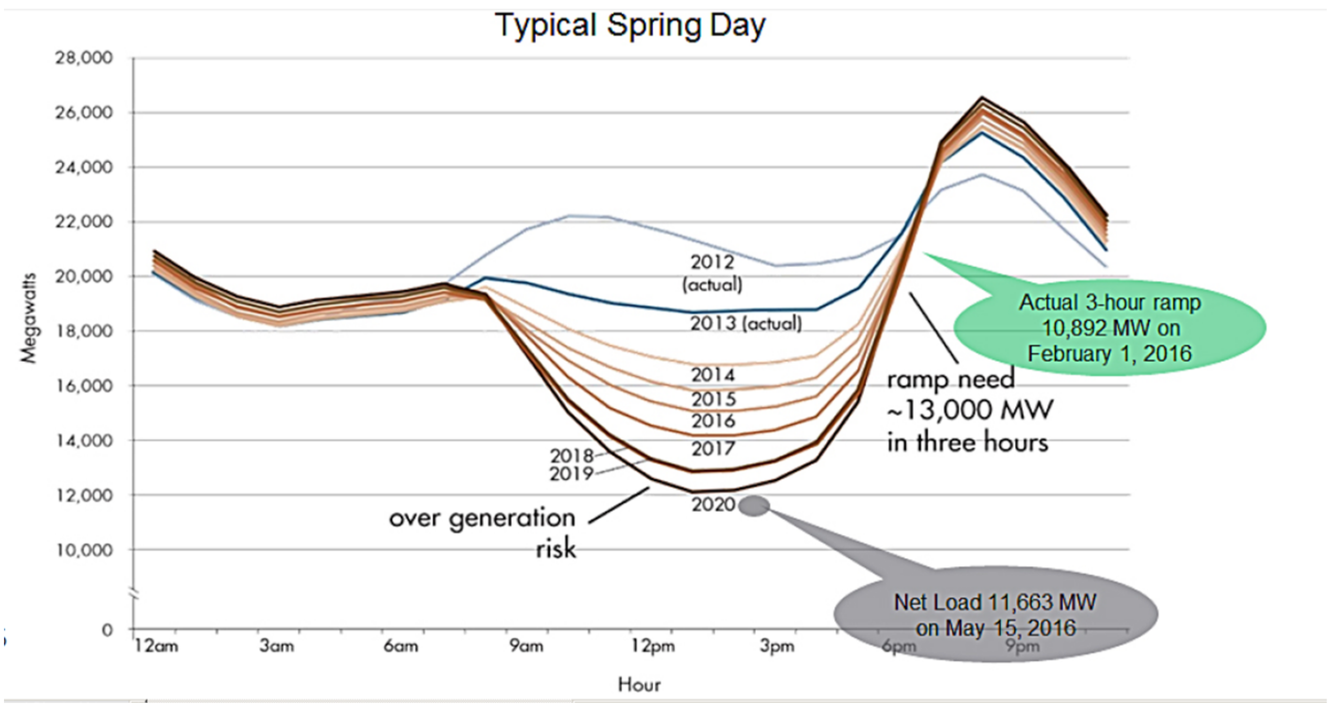
- Policies matter: affects reduction amounts and cost
- Portfolio of required technologies becomes complex as reduction increases
- Uncertainties and incentives key
- November 2019 climate act provides framework

Werewolf (Wisconsin Expansion of Renewable Electricity with Optimization under Long-term Forecasts)



- Design/policy decisions affecting operations/reliability and vice-versa
- Goal: to help policy and decision makers
  - to distinguish between objectives and actions;
  - to understand effects of uncertainty;
  - to understand effects of incentives;
  - to explore larger design space.

Renewable electricity is intermittent and random



[Source: http://www.caiso.com]

- Duck curve shows increasing need for ramping plant in evening.
- Electricity systems also need backup capacity to ensure supply with random renewable generation (e.g. wind).
- Very large literature on these topics using stochastic optimization models of various sorts.

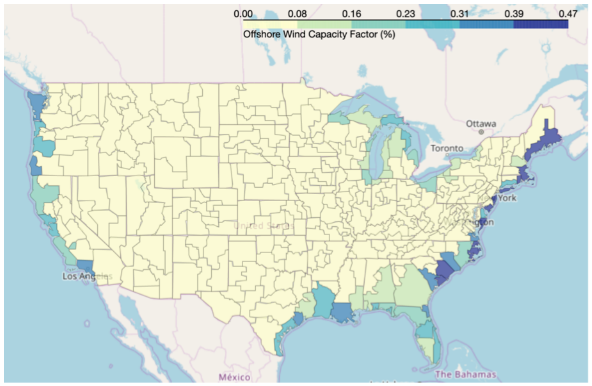
Simplified two-stage stochastic optimization model

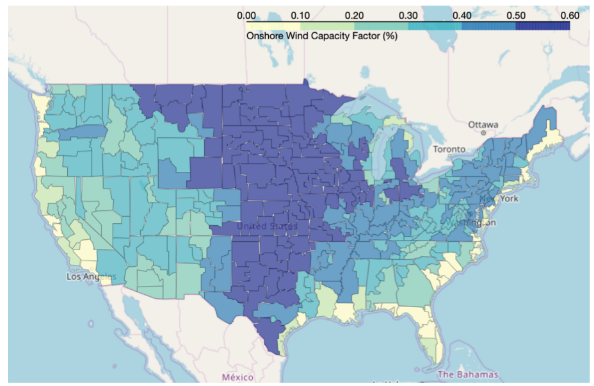
- Capacity decisions are z at cost K(z)
- Operating decisions: generation y at cost C(y), loadshedding q at cost Vq
- Scenarios (futures) ω, demand (load curve) is $d(\omega)$
- Minimize capital cost plus expected operating cost:

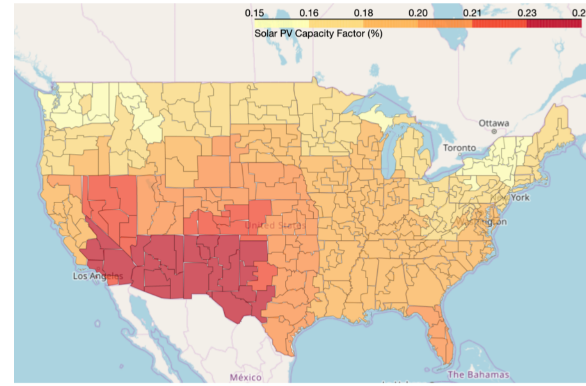
$$\begin{array}{ll} \min & K(z) + E_{\omega}[C(y(\omega)) + Vq(\omega)] \\ \text{s.t.} & y(\omega) \leq z \\ & y(\omega) + q(\omega) \geq d(\omega) \\ & (z,y,q) \in X \end{array}$$

- WEREWOLF populated using data from Wisconsin: develop the model for MISO and look at Wisconsin policies in particular
- Data and structure facilitate any US regional model

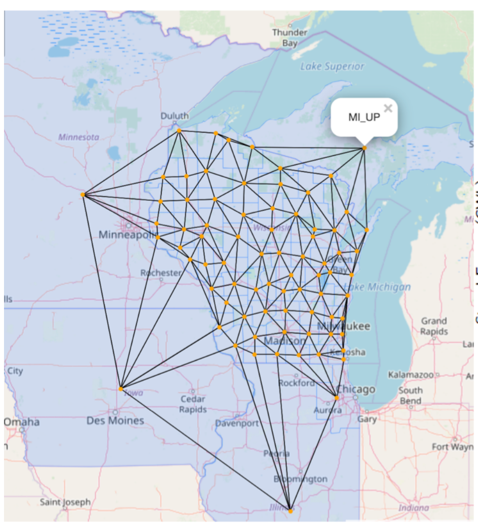
WEREWOLF data: (EPA NEEDS/Integrated Planning Model, NREL ReEDS data, NREL Annual Technology Baseline)

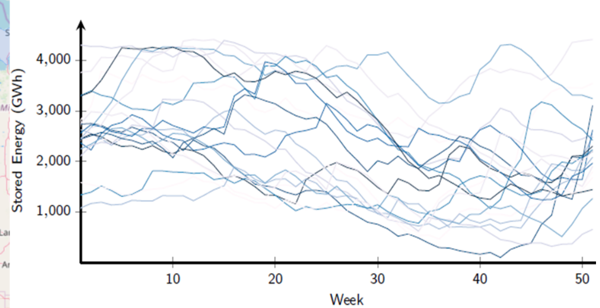


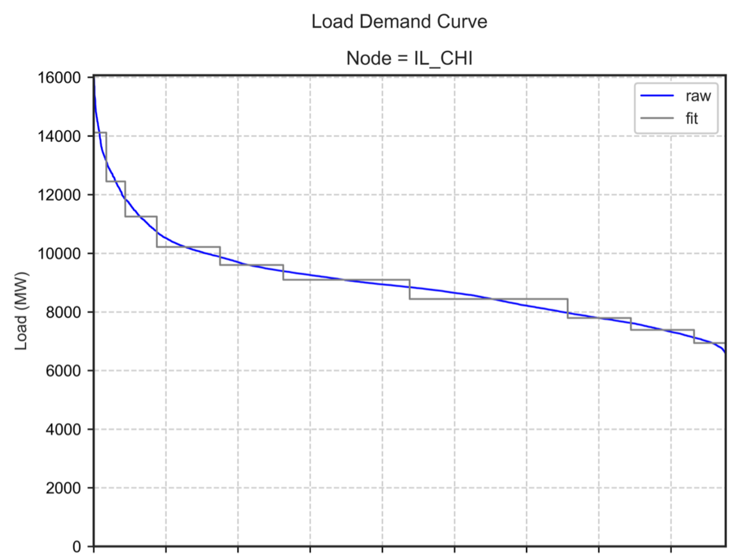




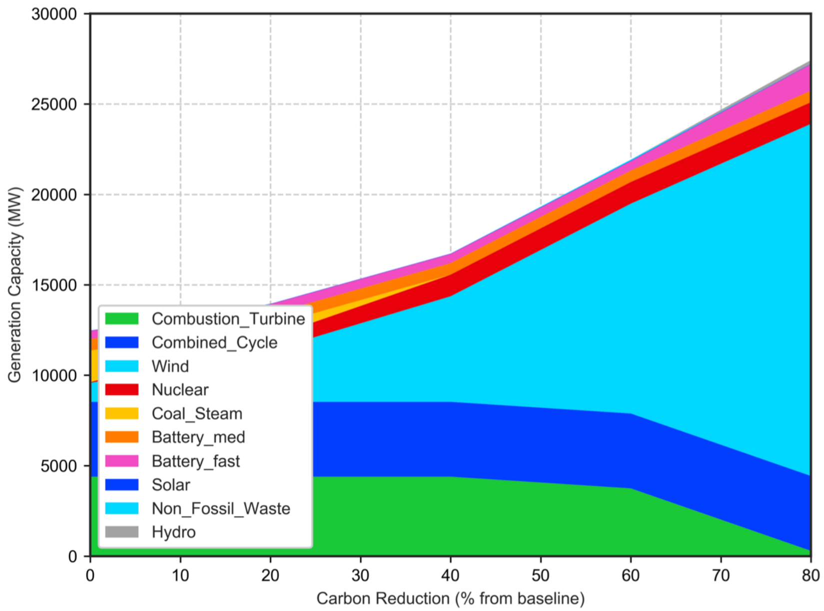
- Data is downscaled to county level - user can customize regions as aggregations of these counties
- Spatial impacts are captured in visualizations

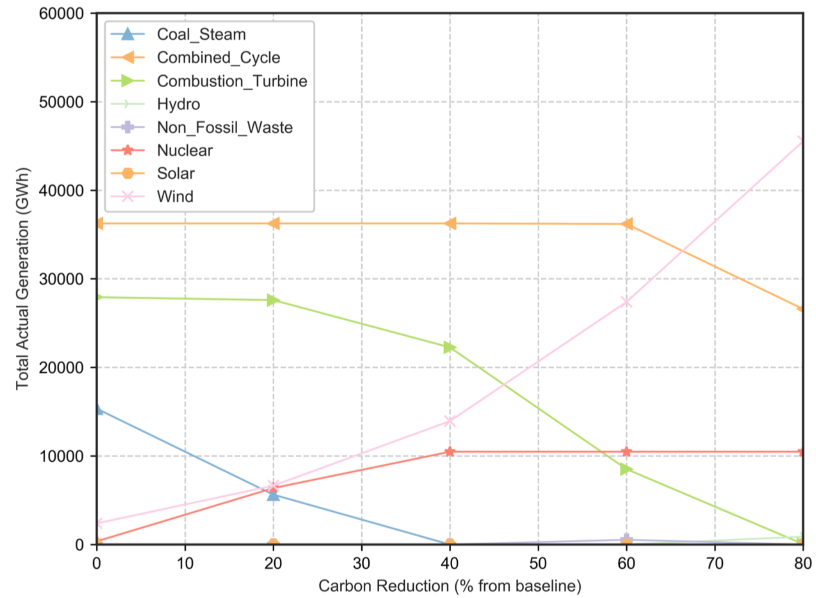


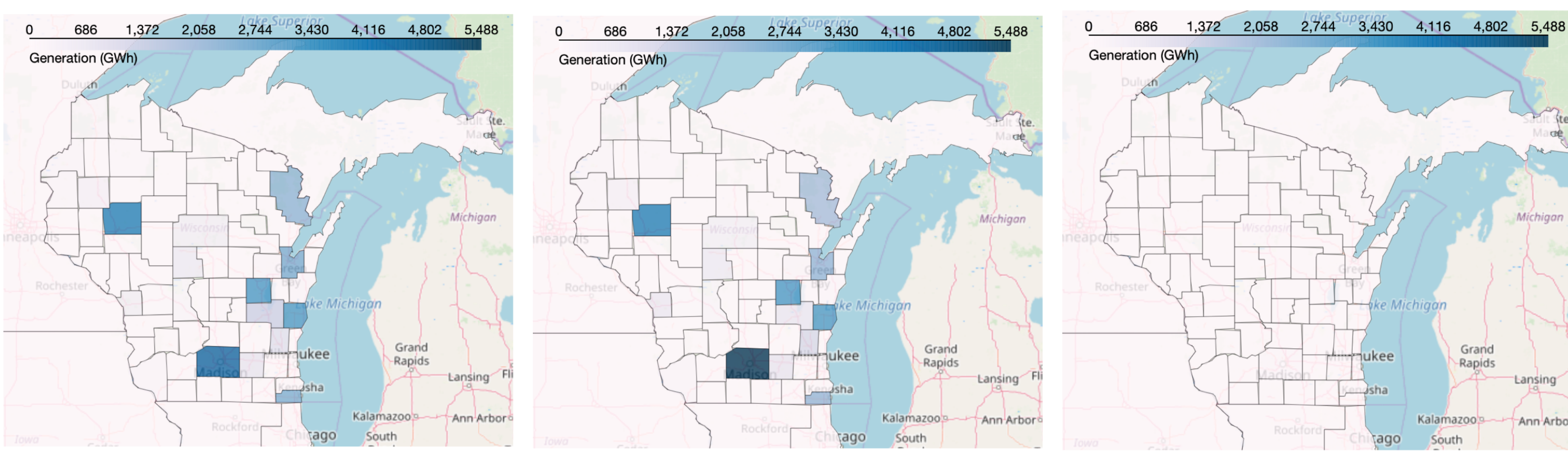




Carbon reductions, shutdowns allowed

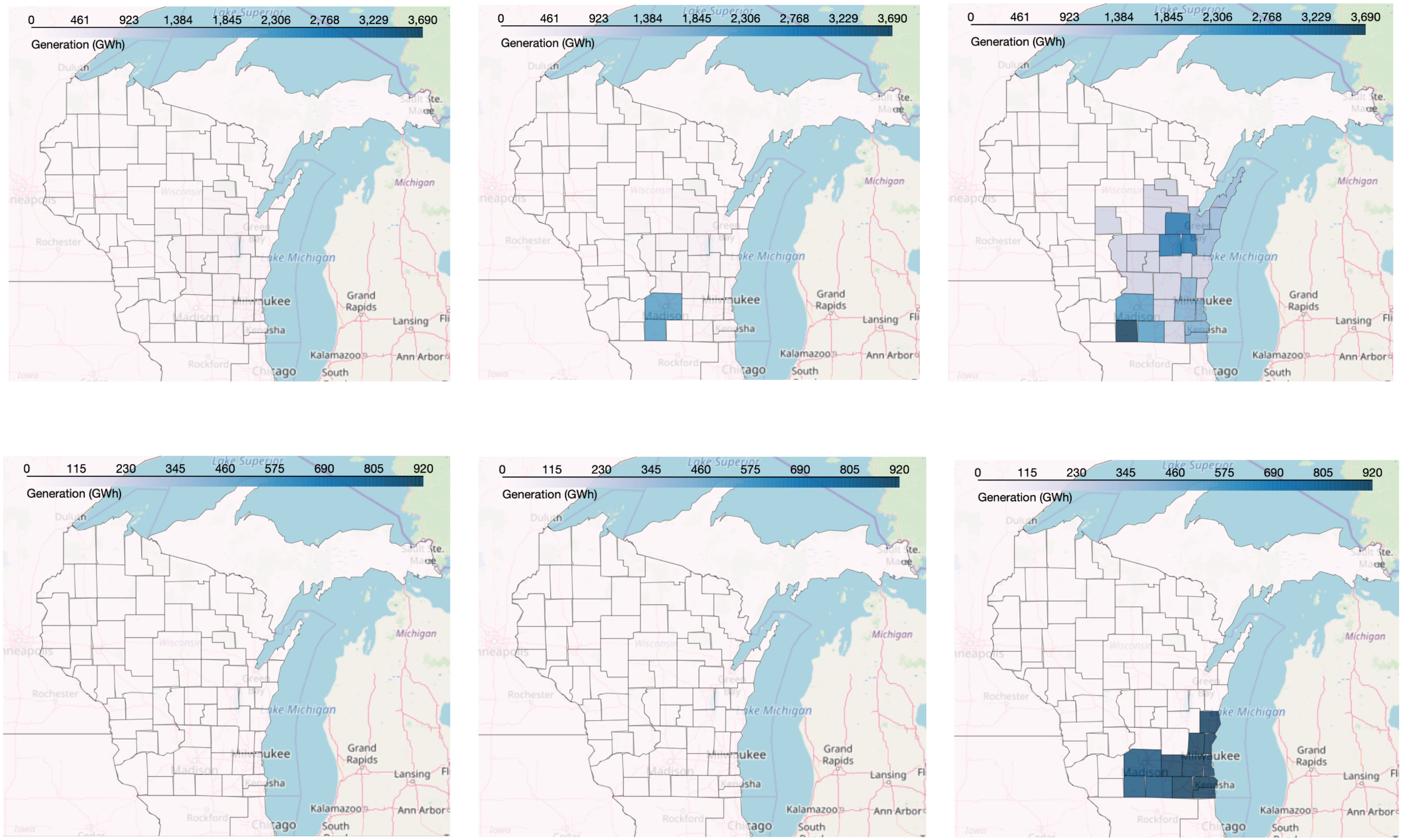






Combustion Turbine (natgas) ramps down (0, 40%, 80%)

Renewable increases (wind and solar) for 0, 40%, 80% carbon reduction



How can we help, some challenges

- Models can inform policy
- Models can show effects and costs of constraints
- Investment is coupled to reliability
- The model is currently being refined, and we are interested to get feedback from utility and policy experts about how this model would be useful in your utility and regulatory planning efforts
- Solving competitive equilibrium problems with incomplete risk markets is generally difficult
- Risk aversion complicates competitive capacity choices