An Optimization and Monte Carlo Planning Approach for High Penetrations of Intermittent Renewables

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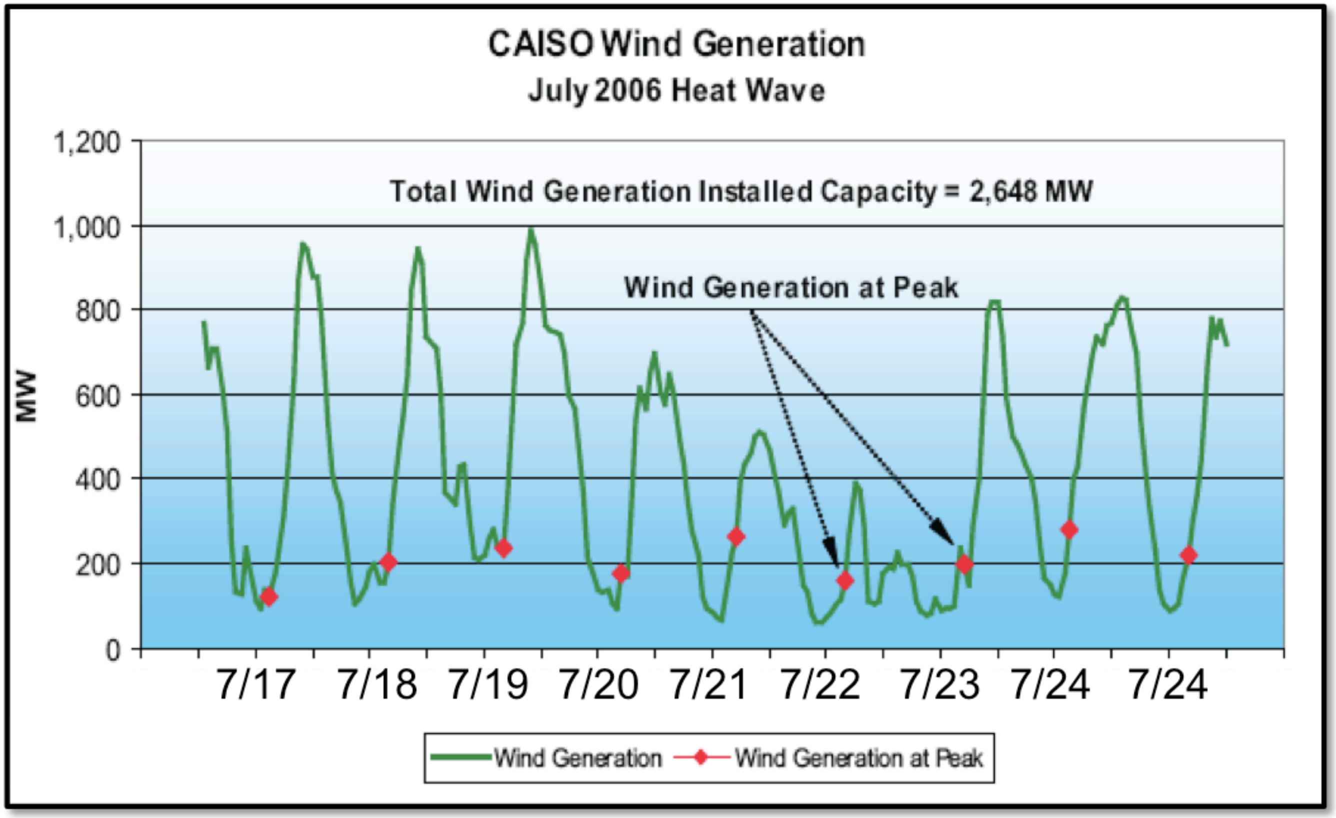
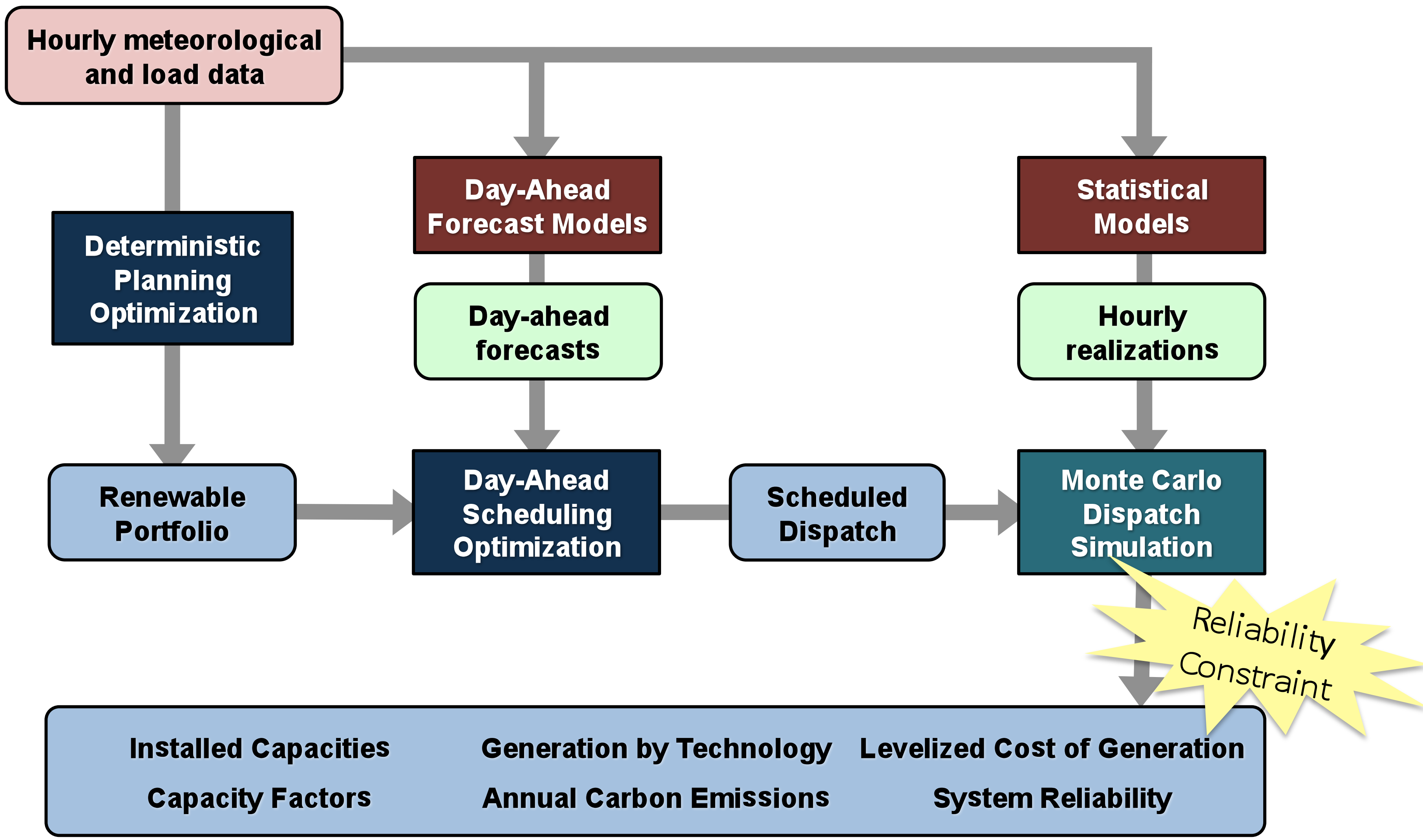
The Challenge



CAISO, 2007: "Integration of Renewable Resources," California ISO, November 2007.

How can the grid accommodate the intermittency of wind and solar to ***significantly*** reduce carbon emissions?

Low Carbon Portfolio Planning Model

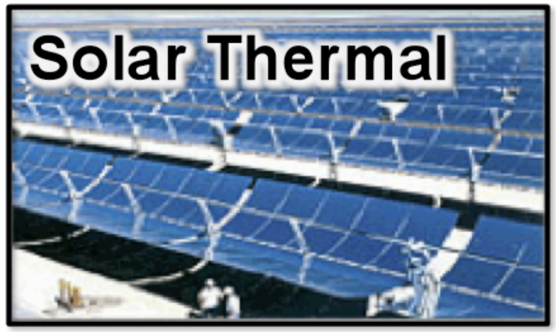


Problem Formulations

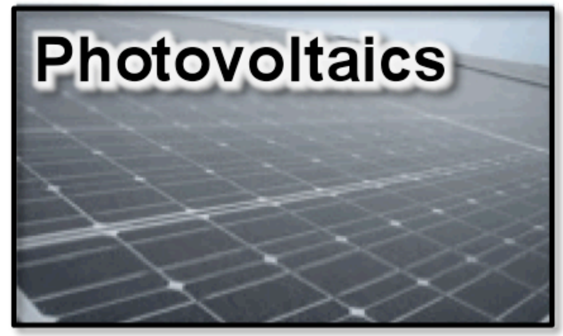
- Objective Functions
  - Cost (including annualized capital, fixed and variable O&M, fuel, and cost of carbon (in 2050 scenario)
  - Approximate Emissions – linear function of natural gas generation and spinning capacity
- Linear Constraints
  - System-wide power balance
  - Generator governing equations (affine w.r.t. capacity, fuel)
  - Thermal plant ramp rates
  - Energy (integrated power) constraints

Generator Technology Models

Intermittent Generators



(Image: NREL 2008)

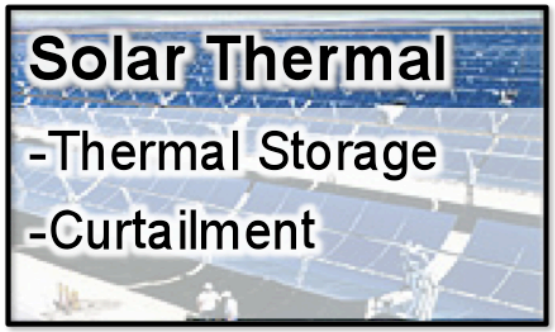


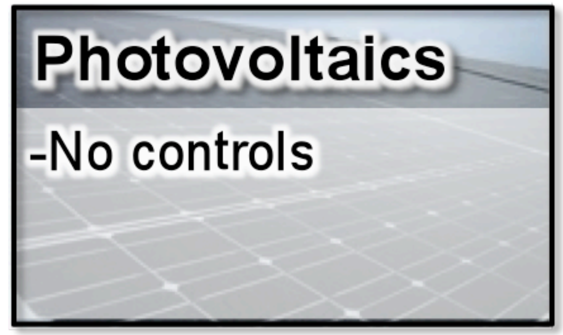
Conventional Generators

(Image: CEC 2009a)

Generator Technology Models

Intermittent Generators





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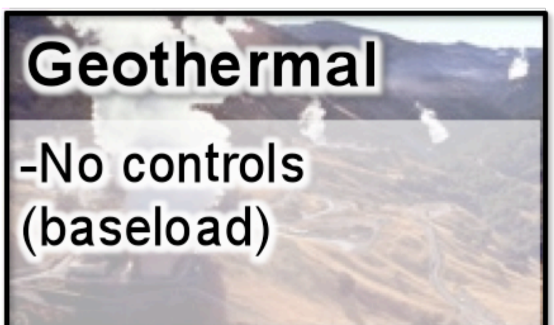
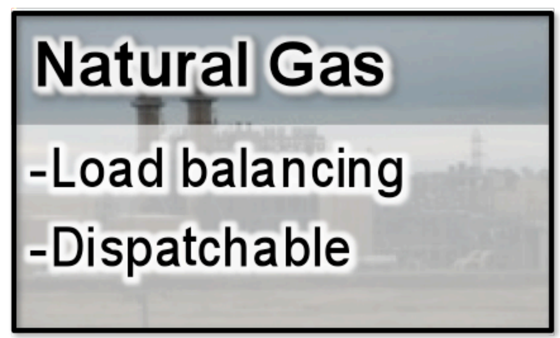
Conventional Generators





(Image: CEC 2009a)

Realization Models

- System Load, Irradiance (GHI => DNI, DHI), Wind Speed
- Linear statistical models of the form:

$$f(t) = A(t)\vec{x} + \tilde{b}$$

where $A(t) = \begin{bmatrix} a_1(t) & a_2(t) & \ldots \end{bmatrix}$ is comprised of functions like:

$a_i(t) = \hat{f}(t)$	(a forecast)
$a_i(t) = \hat{f}(t-1) - f(t-1)$	(prior forecast error)
$a_i(t) = \gamma(t)$	(diurnal or seasonal bias)
$a_i(t) = 1$	(constant bias)

Use linear regression to find $\vec{x}$ and characterize $\tilde{b}$ distribution

Realization Production

$$f(t) = A(t)\vec{x} + \tilde{b}$$

and $\tilde{b} \sim \mathcal{N}\left(0, \sigma_{model}\right)$ is a random variable

To create each realization, at each time step:

-Apply linear model

-Sample the model error distribution

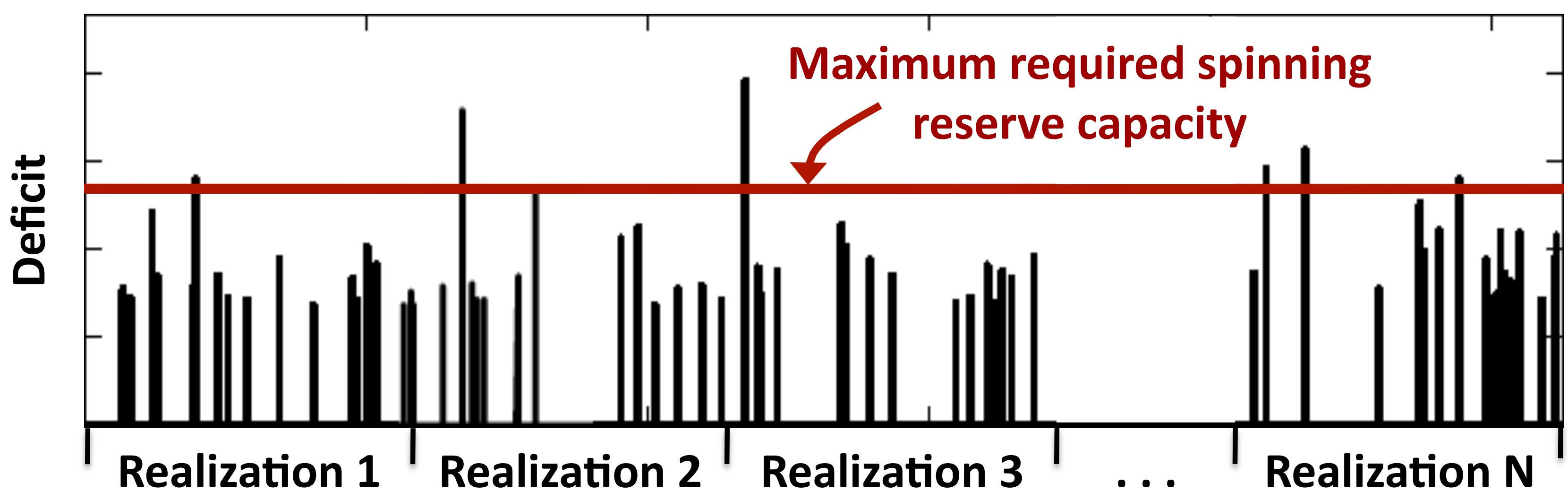
  -Impose site-site correlations where appropriate

-Apply additional models where necessary

  -eg. GHI => DNI => DHI

Ensuring System Reliability

- Dispatch optimization includes expensive deficit in case of extreme forecast error.
- Deficit signal is used with LOLE to determine necessary spinning reserve capacity and schedule



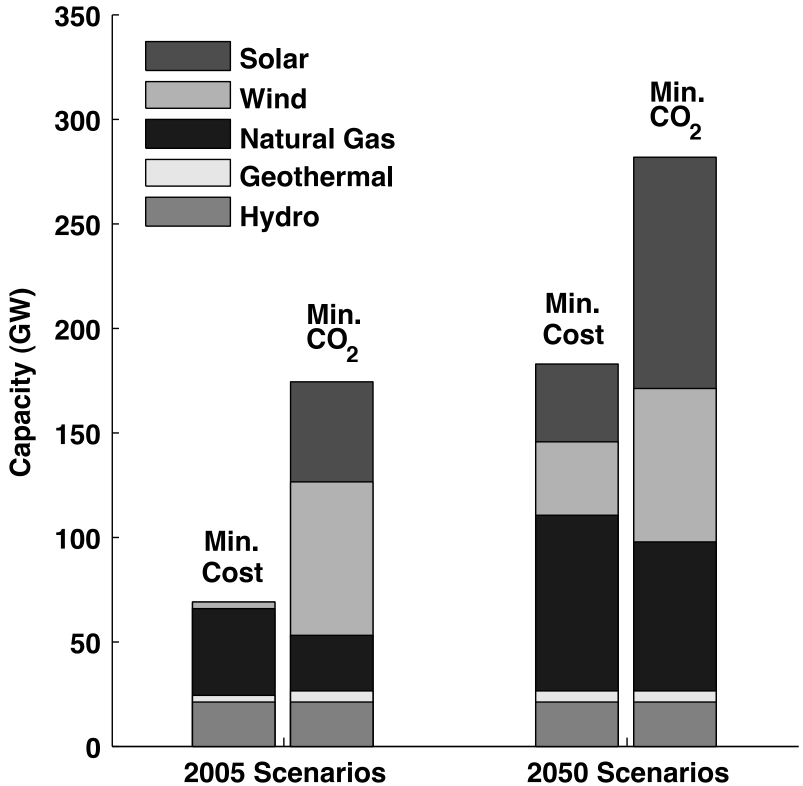
Case Studies

- Load scenarios:
  - 2005-2006 load data, 2050-2051 load projection
- Renewable Portfolios produced by minimizing:
  - Cost, Emissions
- Data:
  - Wind: Western Wind Integration Datasets (NREL, 3TIER)
  - Irradiance: NSRDB (NREL)
  - Load: California ISO OASIS Database
- Solve using CVX (Grant and Boyd, 2010)

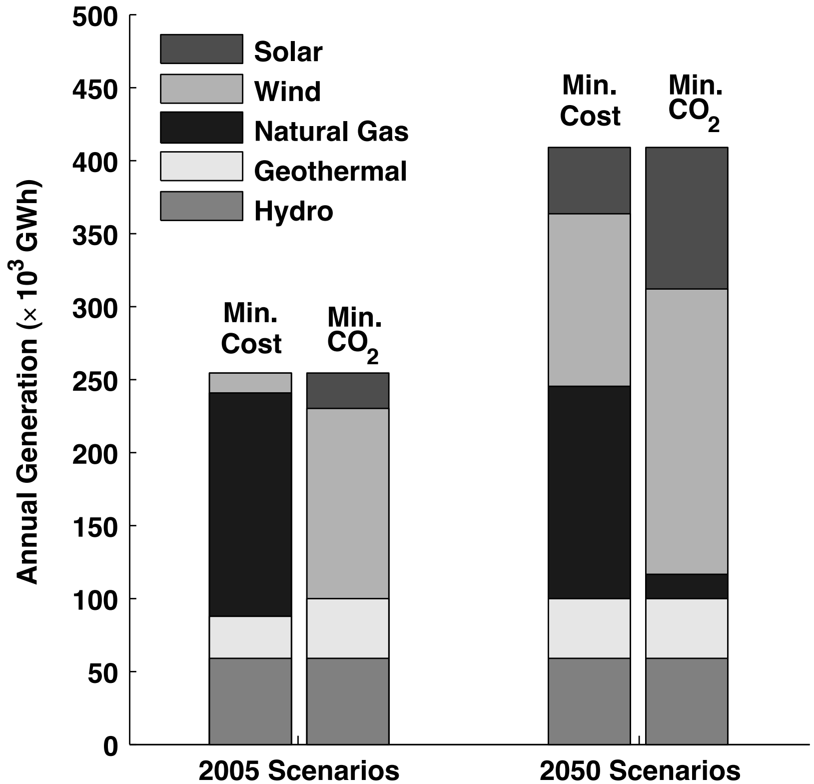
[17,520 time steps with 20 realizations each]

Solved Generator Portfolios

Capacity

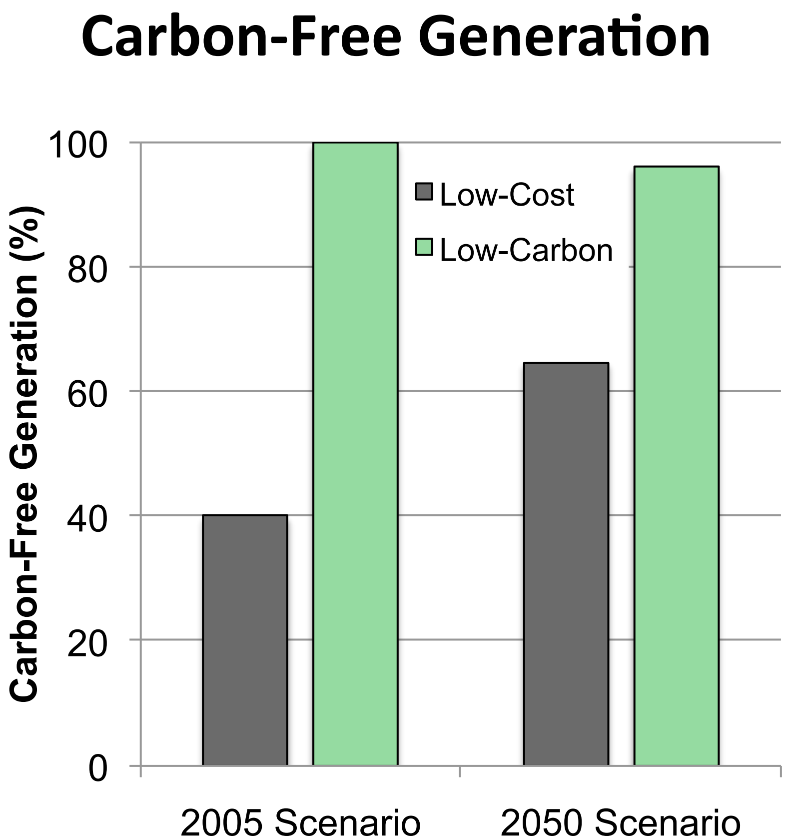


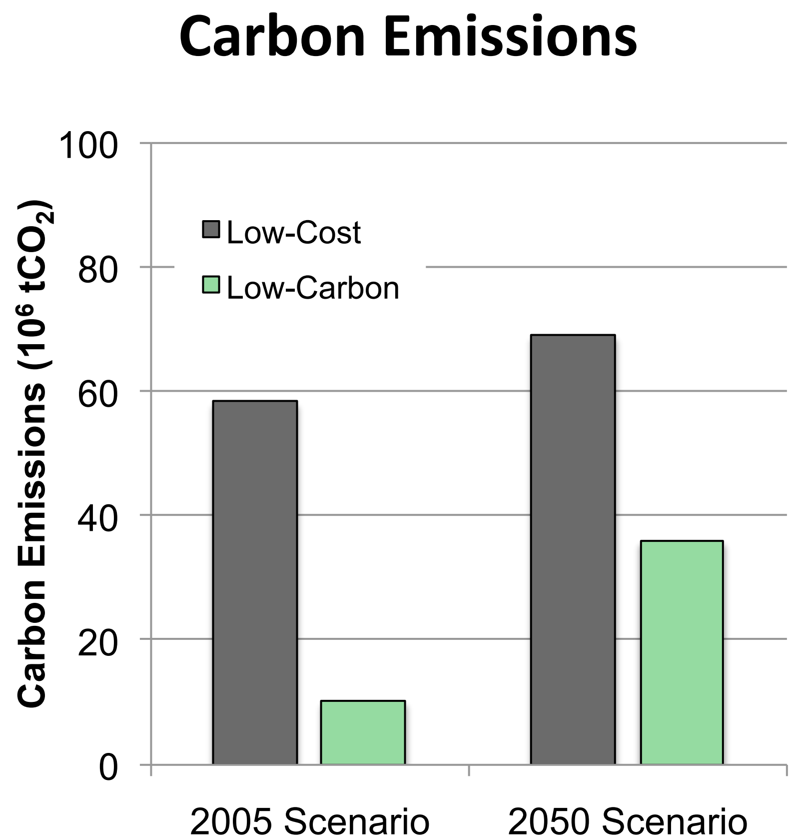
Generation



Hart and Jacobson, 2011. [In Review]

Carbon Emissions Characteristics





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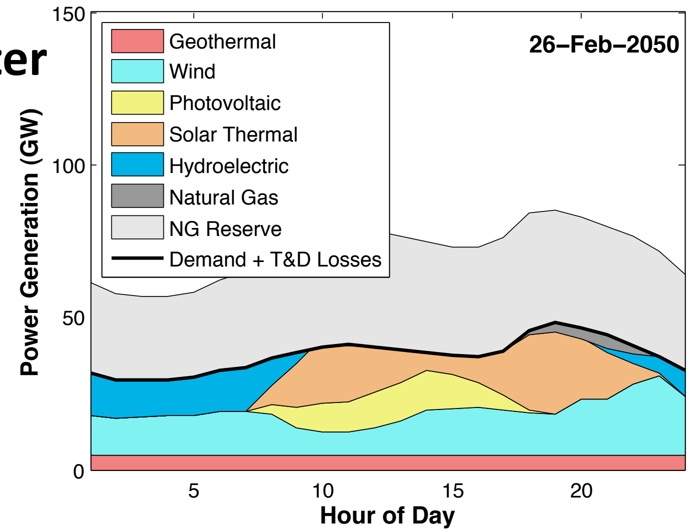
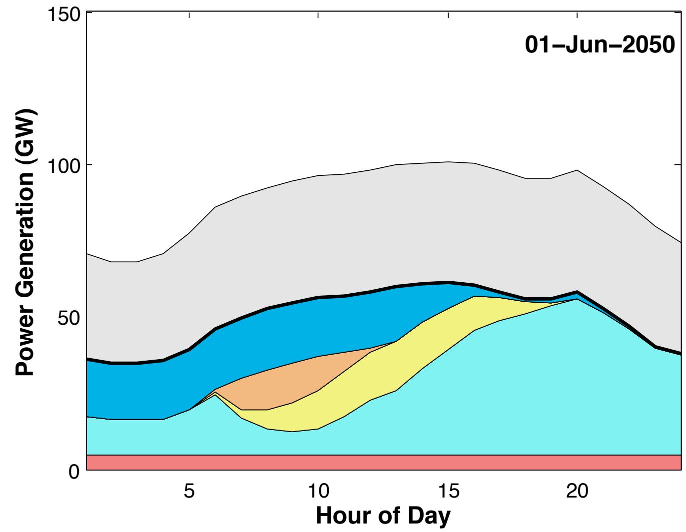
Example Realizations (2050 Low-CO_2)

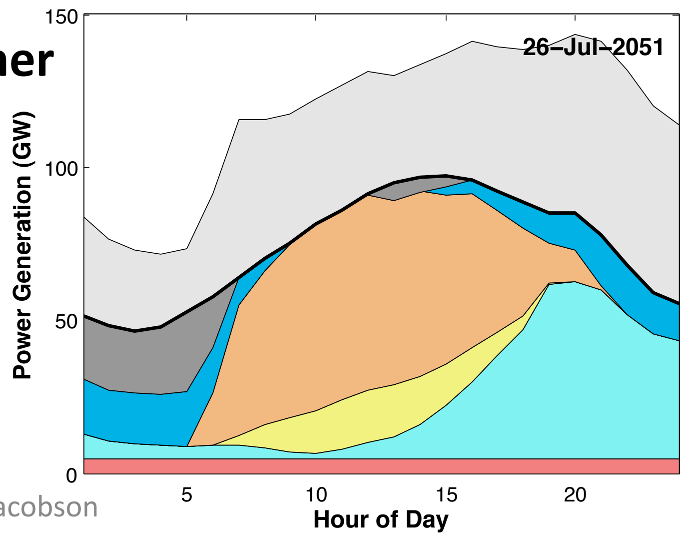
Winter



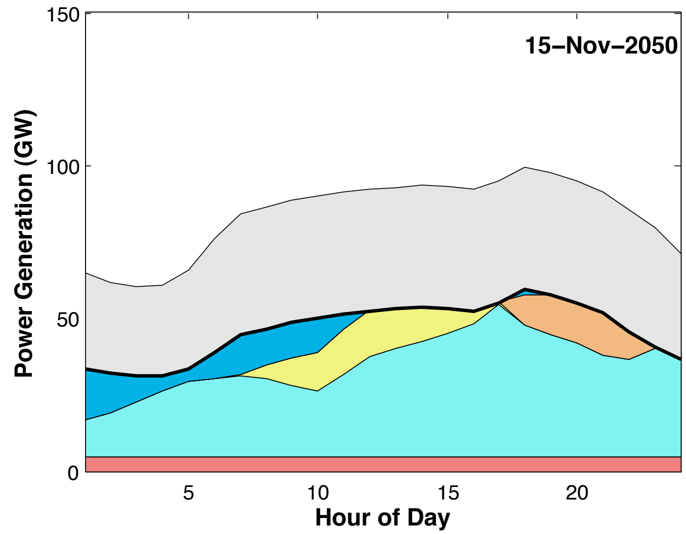
Spring



Summer



Autumn



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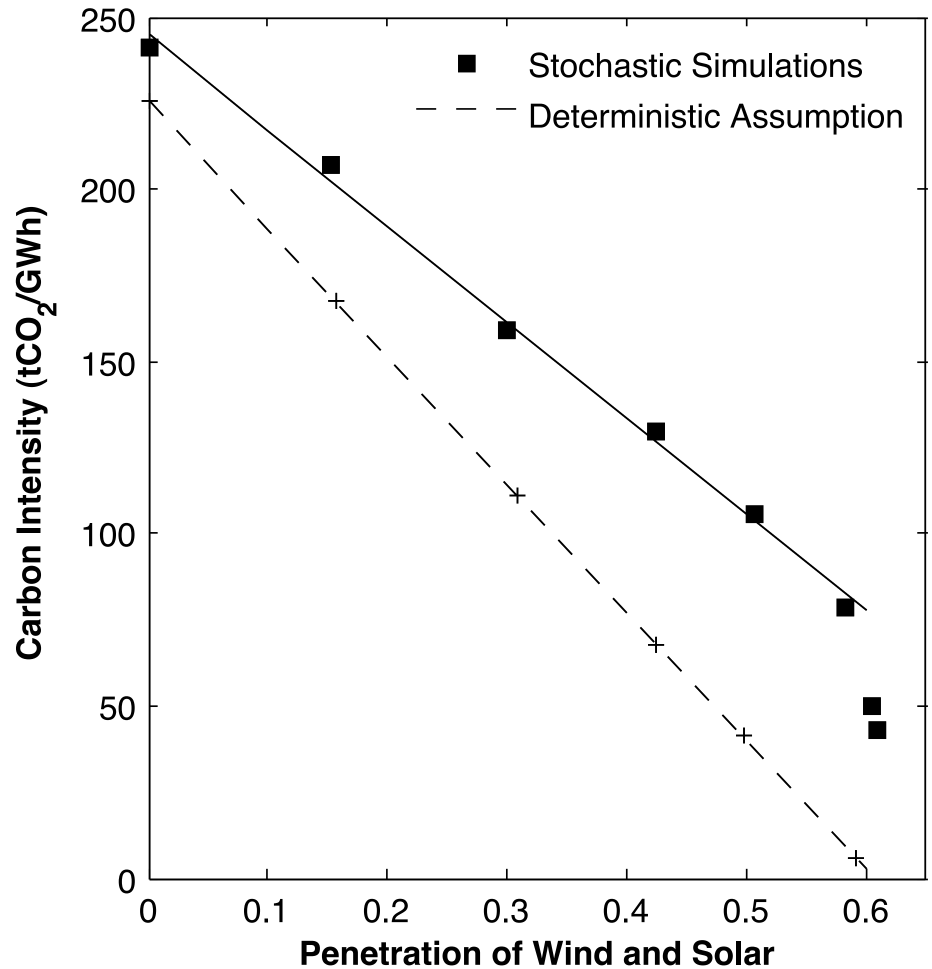
Stochastic vs. Deterministic

Portfolios produced by scaling 2005 low-carbon capacities uniformly

Stochastic simulations: Monte Carlo simulation with forecast error

Deterministic assumption: Simulate single realization where forecast = actual data



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Conclusions

- We can provide >99% of generation from non-carbon based generators while meeting an LOLE requirement of 1 day in 10 years
- With conservative assumptions regarding thermal plant operation, can still achieve significant reductions in carbon emissions from base case levels
- Stochastic analyses are needed in system planning
- Low capacity factors will require enhanced capacity markets for thermal plants

Next Steps

- Include hour-ahead forecasts
- Improve forecast error characterization
  - Include phase errors
- Improve flexibility of hydroelectric generators
- Build participating load and storage models
  - EV's, Batteries, Fuel Cells, CAES

Questions?

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- Bethany Corcoran, Mike Dvorak, Graeme Hoste, Eric Stoutenburg, John Ten Hoeve

For more information

(and a copy of this presentation):

www.stanford.edu/~ehart/