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Consortium for Electric Reliability Technology Solutions

Transmission Investments Under Uncertainty & High Renewable Penetration:

Representing Market Response using a Multi-stage Stochastic Model Approach with Recourse

Benjamin F. Hobbs & Francisco Munoz

Geography & Environmental Engineering, Applied Math & Stat.
Environment, Energy, Sustainability & Health Institute
The Johns Hopkins University

Richard E. Schuler

Civil & Environmental Engineering, and Economics
Cornell University

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Overview

1. The problem
2. Our model
3. Example: 17-bus network
4. Future Work

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The Problem: Hyperuncertainty!

Fuel Prices

Technology Costs

Efficiency Measures

Carbon Tax

Transmission Planner

New RPS

Distributed Generation

Demand Response

Electric Vehicles

Transmission Planning Features

- Generators respond: Multi-level
- Decisions can be postponed: Multi-stage
- Uncertainties and variability: Stochastic
- Loop-flows!

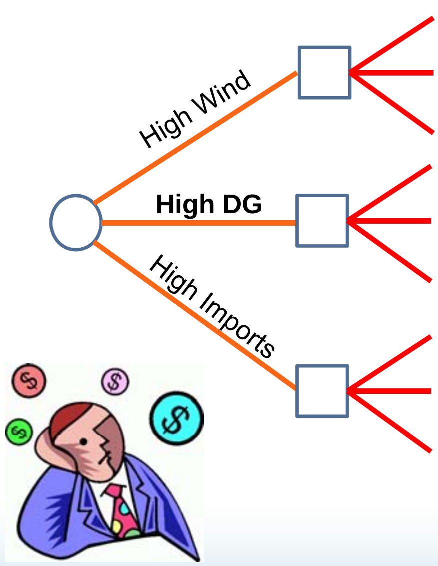
Important Questions

- Optimal strategy under uncertainty?
  - *Do future uncertainties have implications for investments today?*
  - *Are there 'no regrets' investments?*
- Value of information?
- Cost of ignoring uncertainty?
- Value of flexibility?

CERTS JHU-Cornell Project

- Build & test simple 2 & 3 stage models for transmission planning
- Decomposition approaches for coordinating investment & (Super) OPF operating models
- Impacts of wind penetration on transmission planning and value of rapid response

Scenario Analysis

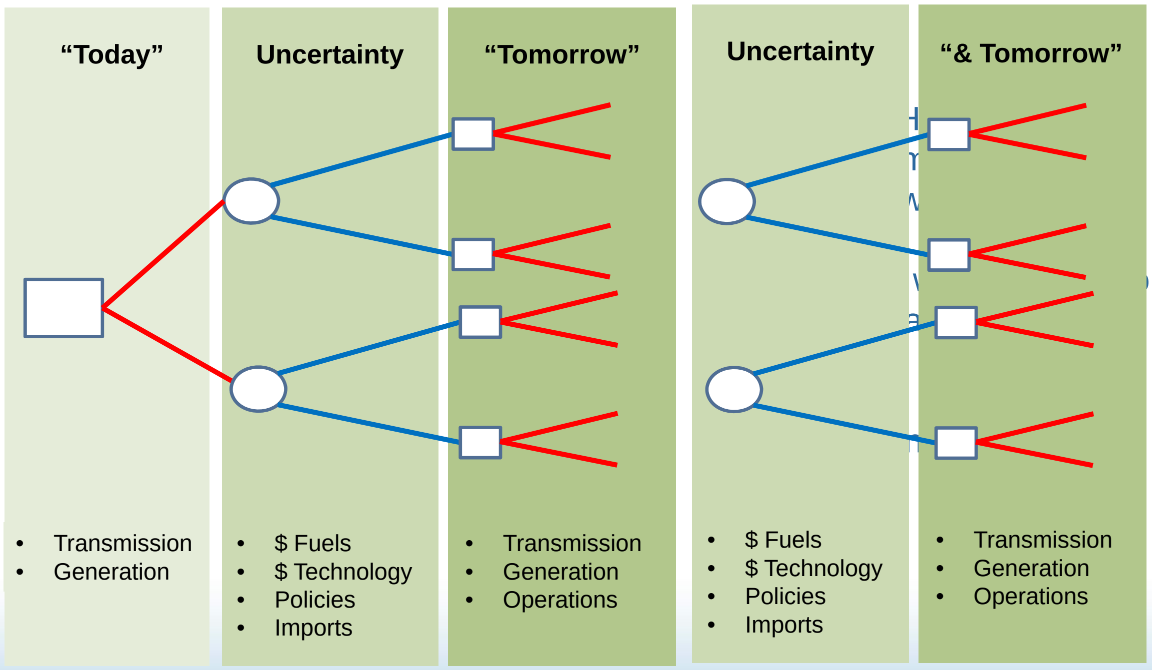


Optimal transmission plans for each scenario

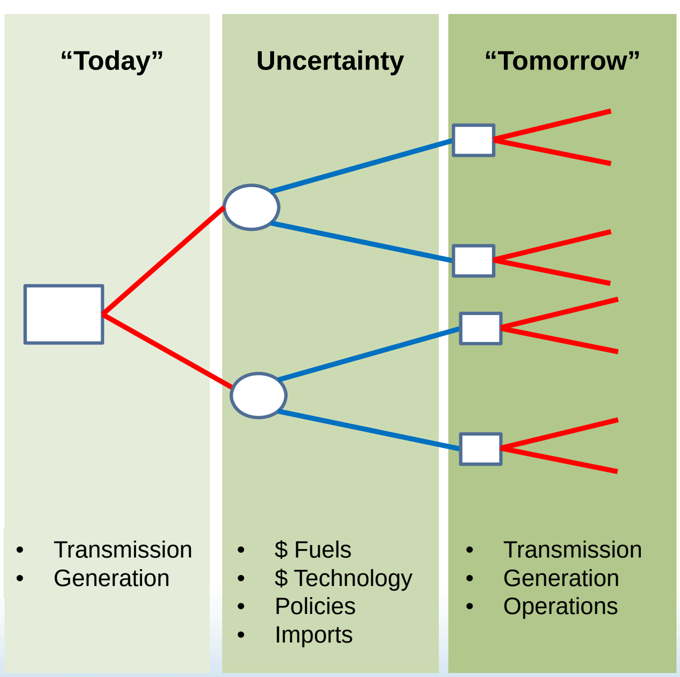
What if we plan for High Wind but High DG happens?

Scenario analysis is too optimistic!

Two-stage stochastic programming *& three*



Two-stage stochastic programming



Advantages:

- Realistic: Here-&-now decisions made before future known
- Recourse: we can adapt to each scenario with later wait-&-see decisions
- Timing of investments

Assumptions

- Alignment of generation and transmission objectives
  - Ex.: Nodal pricing + Perfect Competition
- Generation
  - No unit commitment or ramping constrains/costs
- Demand
  - No demand response
- Renewable targets met in most efficient way

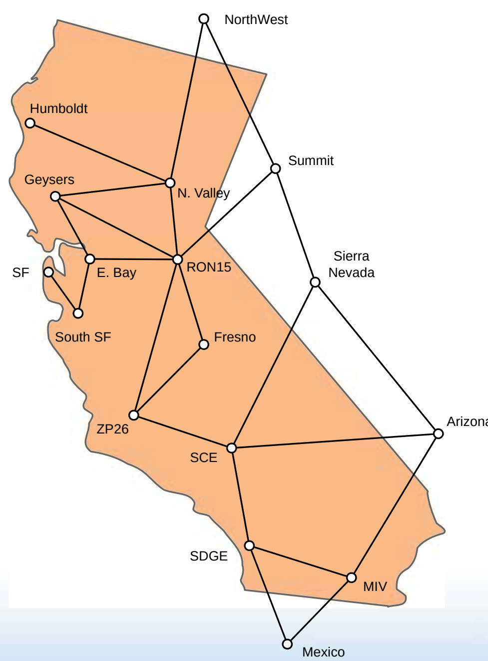
Example: 17-bus CAISO network

Warning: Results highly preliminary & illustrative

- Generator data from WECC 225-bus system (Price, Oren, et al.)
- 24 corridors
- 5 Import buses

Time Series:

- Demand (CAISO)
- Wind (NREL)
- Solar (NREL)
- Hydro (EIA)



Scenarios

Uncertainty: Scenario	Fuel Prices	Demand 2021 / 2031 [TWh]	Siting & Resources	RPS 2021 / 2031
Status Quo	-	309 / 378	Normal	33% / 33%
Eco	+30%	276 / 306	Hard in CA	33% / 40%
Electrification	-10%	370 ? 527	Easy	33% / 33%

Sample of 100 hrs/yr + 2 Stages + 3 Scenarios

=> 200,000 variables + 300,000 constraints

Optimal Stochastic Solution: First Stage

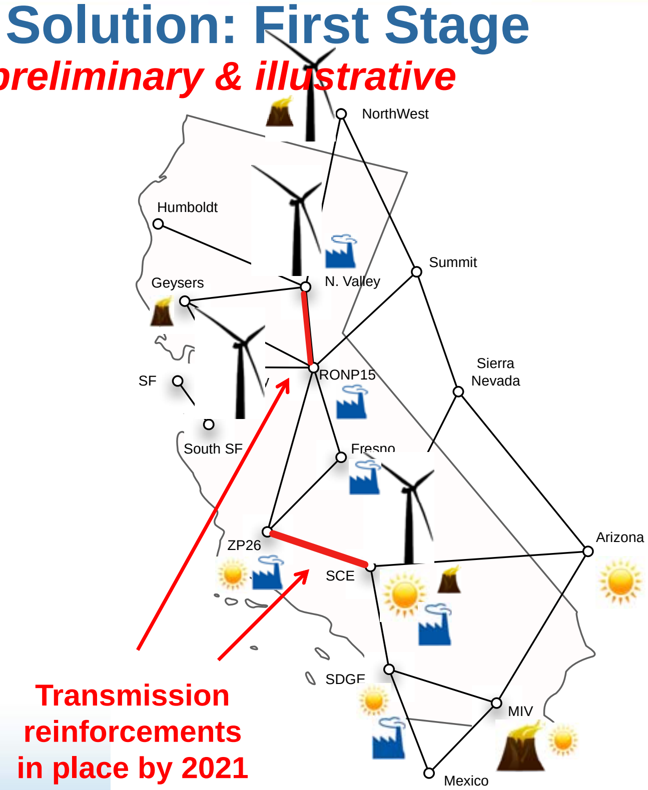
Warning: Results highly preliminary & illustrative

Wind

Geothermal

Solar

CCGT



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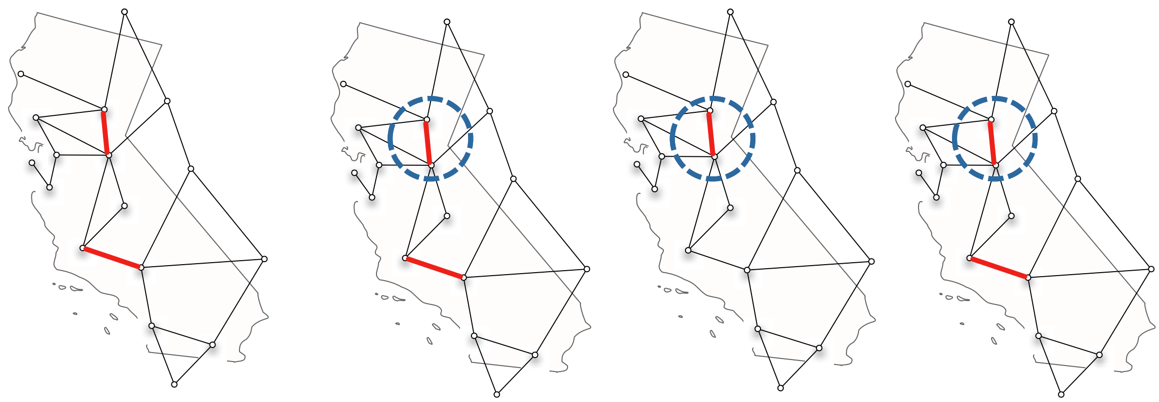
Stochastic vs Deterministic: First Stage

Warning: Results highly preliminary & illustrative

Stochastic 2021	**Deterministic 2021**		
	Status Quo	Eco	Electrification



"Robust"

Value of Perfect Information

Warning: Results highly preliminary & illustrative

How much could we save if we knew which scenario would happen?

1. Solve stochastic model (ECSS)
2. Solve deterministic (perfect foresight) model for each scenario
   - Then calculate probability-weighted average of (2) (ECPI)

EVPI = ECSS – ECPI = $17 billion (8%)

-- If both transmission planner and generators have perfect information
-- Upper Bound to value of imperfect forecasts

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Cost of Ignoring Uncertainty

Warning: Results highly preliminary & illustrative

What would be the costs of planning naively for one scenario but other scenarios can happen?

1. Solve stochastic model (ECSS)
2. Solve deterministic model for each scenario
   - Solve stochastic model imposing first-stage transmission decisions from (2)

ECIU (transmission only) = $69 billion! (32.5%)

Some topologies are infeasible for other scenarios

=> curtailments at 500 $/MWh!

More realistic recourse would lower cost

Value of Flexibility

Warning: Results highly preliminary & illustrative

How much would costs go up if we had to make all decisions now?

1. Solve stochastic model (ECSS)
2. Solve stochastic model imposing same transmission expansion plan for all scenarios

VF = $22.7 million (0.01%)

Case Study: Conclusions

For transmission planning:

- Ignoring risk has quantifiable economic consequences
- This tool could be useful for policy/planning questions

Future Work

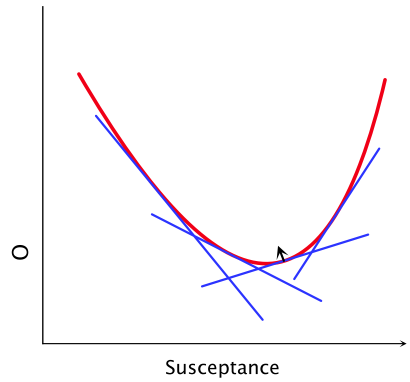
1. Benders Decomposition

   A framework for testing integration of SuperOPF

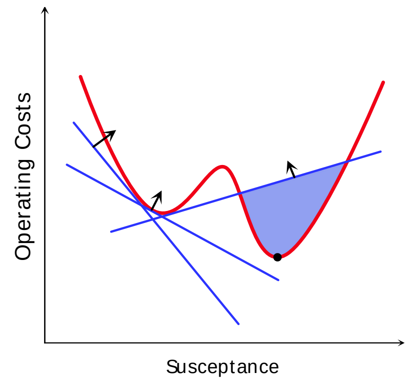
2. WECC 225-bus system

1- Benders Decomposition: *Separate Investment & Operations Problems*

Convex



Non-Convex



Continuous formulation

$$f_l = s_l(x)\cdot(\theta_i - \theta_j)$$

1- Benders Decomposition

Disjunctive formulation

$$-M\cdot(1-z) \le f_l - s_l\cdot(\theta_i - \theta_j) \le M\cdot(1-z)$$

Incorporate lumpiness of investments

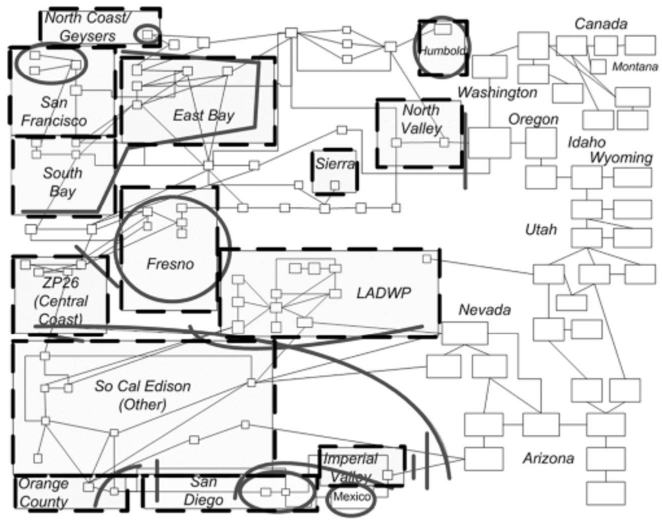
"Big Ms" induce numerical difficulties

Alternatives:

- Master Problem IP
Sub-problem LP
- Nested Benders + Lagrangian relaxation (*Cerisola and Ramos*)
- L-shaped method (*Laporte and Louveaux*)
- Logic-based Benders decomposition (*Hooker*)

2- WECC 225-bus System

- More realistic representation of California and neighboring states



- 223 transmission lines
- “Bubble” constraints

References

- H. van der Weijde and B.F. Hobbs, Planning electricity transmission to accommodate renewables: Using two-stage programming to evaluate flexibility and the cost of disregarding uncertainty. Cambridge Working Paper in Economics 113, 2011.
- Binato, S.; Pereira, M.V.F.; Granville, S.; , "A new Benders decomposition approach to solve power transmission network design problems," *Power Systems, IEEE Transactions on* , vol.16, no.2, pp.235-240, May 2001
- E. E. Sauma, and S. S. Oren, “Proactive Planning and Valuation of Transmission Investments in Restructured Electricity Markets,” Journal of Regulatory Economics 30, pp. 261-290, 2006.

Data

- CAISO Oasis
- EIA
- NREL

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