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Large-Scale Stochastic Programming to Cooptimize Networks and Generation in the Face of Long-Run Uncertainties: *What Lines Should We Build Now?*

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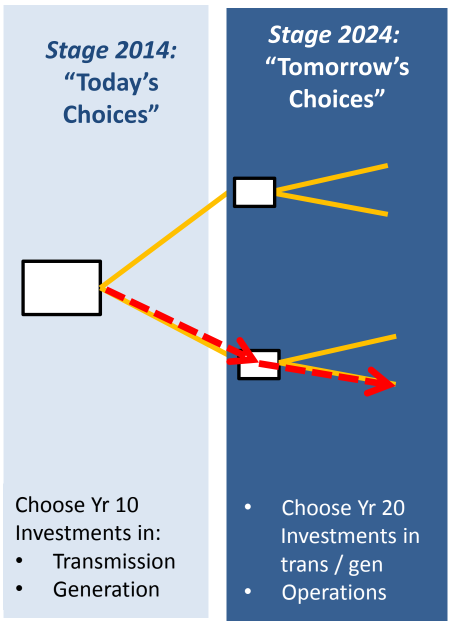
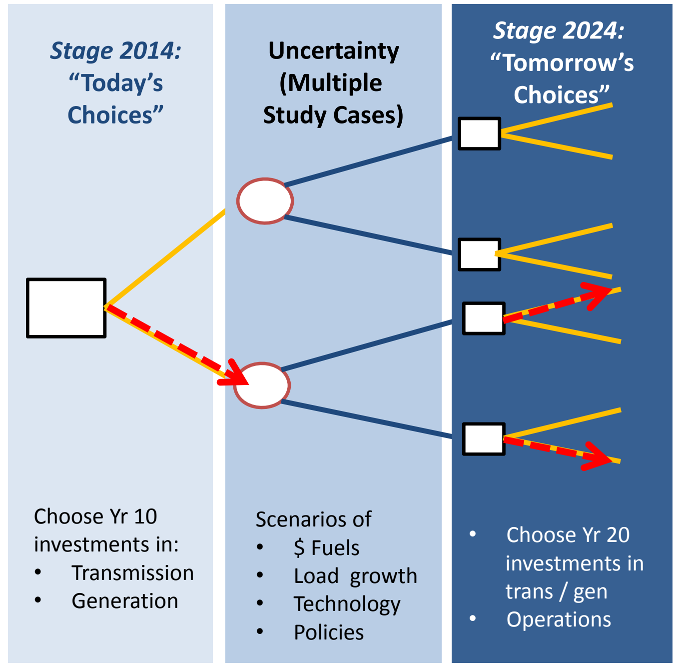
Overview

1. Introduction
2. Method Overview
3. Four Questions
   - Q1: What is the value of stochastic planning?
   - Q2: Is it practical?
   - Q3: What approximations affect the solutions?
   - Q4: What is the value of transmission-generation cooptimization?

Method: JHSMINE (Johns Hopkins Stochastic Multi-stage Integrated Network Expansion)



Deterministic Approach: One model for each study case



JHSMINE: Solve all cases at once in one model

JHSMINE Structure: Mixed Integer linear program

Optimize the objective:

Minimize (probability-weighted, present worth) of cost over 40 yrs

By choosing values of decision variables:

- Transmission investment (0-1)
  - 10 yr "portal" (optional) lines (in addition to Common Case lines)
  - 20 yr lines
  - Gen investment *(co-optimized)*
- Gen dispatch

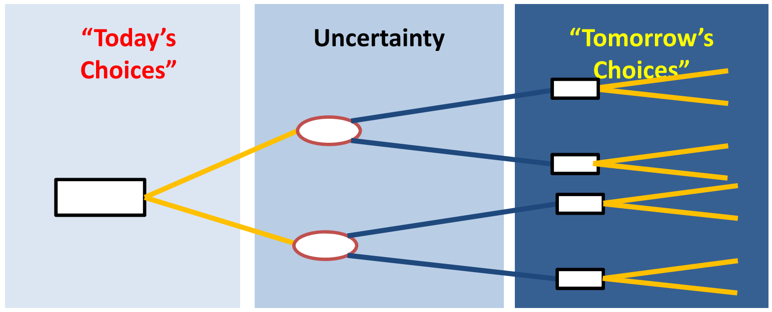
Respecting constraints:

- Kirchhoff's laws (linear OPF)
  - Load by hour
- Generator operating constraints
  - Variable renewable availability by hour
- RPS
- Siting restrictions

Accounting for uncertainties:

- load/renewable conditions (hourly variability)
- *IN STOCHASTIC MODEL:* long-run study cases

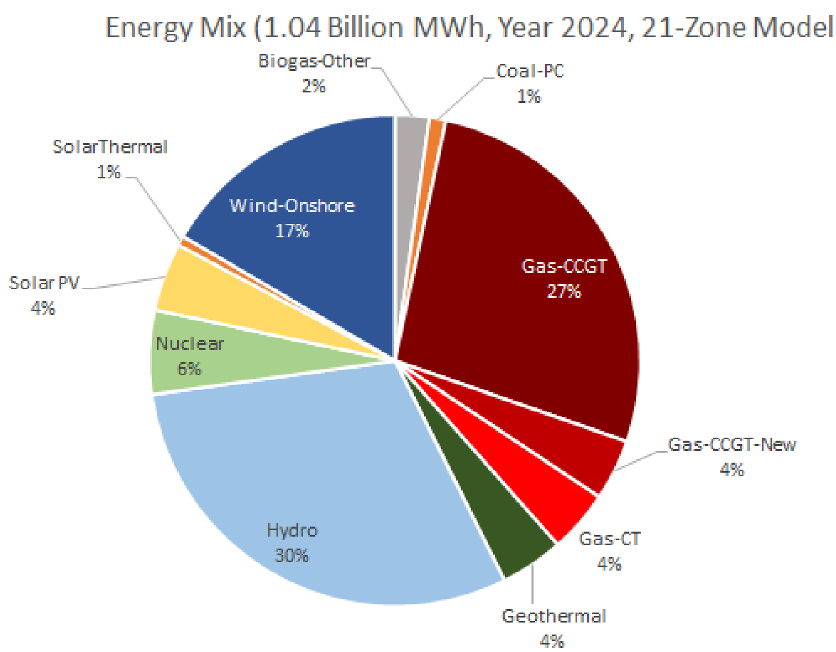
Mathematical structure



$$\text{MIN} \quad C_1 X_1 + \Sigma_{\text{scenarios } S} P_S * C_2 X_{2,S}$$
$$A_{1,1} X_1 \leq B_1$$
$$\{A_{2,1,S} X_1 + A_{2,2,S} X_{2,S} \leq B_{2,S}\}, \forall S$$

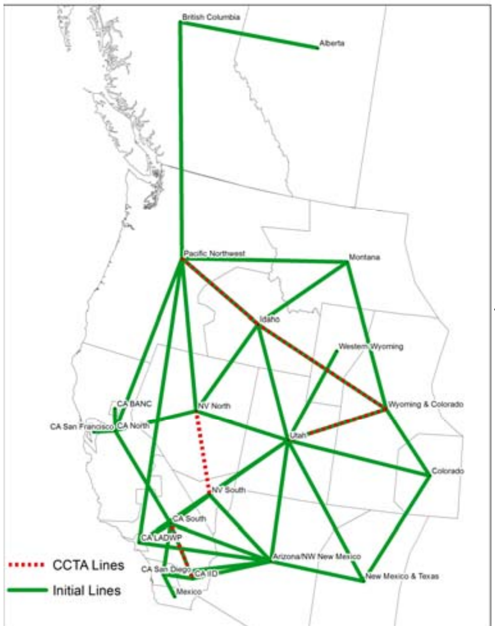
JHSMINE cooptimizes transmission and generation

- "Anticipative" transmission planning:
  - Where will generation build in response to line additions?
  - How will it operate?

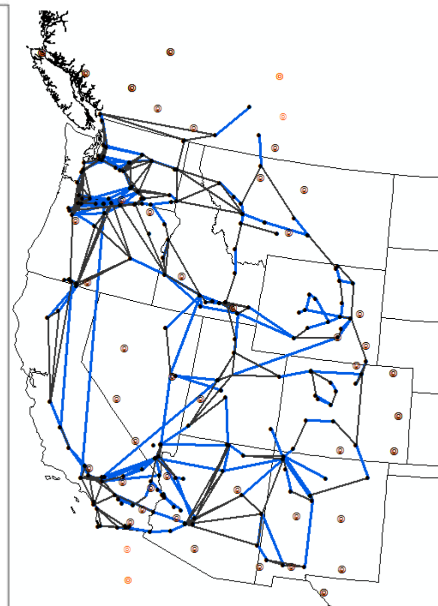


Two versions of JHSMINE-WECC

21 TEPPC Zone "Pipes-&-Bubbles"



300 bus network: Both Linearized DC OPF & "Pipes-&-Bubbles" versions



- Preserve WECC paths between regions
- 244 preserved monitored lines
- 282 equivalenced unmonitored lines
- 26 hubs for new thermal plants
- WREZs for renewable development

Question 1: ***What can we learn from stochastic transmission planning ?***

Q1.1 What transmission expansion best balances:

<u>value</u> of tomorrow's flexibility

vs.

today's investment <u>costs</u>?

…. Recognizing how generation siting, operations react ("anticipative planning"/"cooptimization")

Q1.2 Are those plans different, and cheaper on average, than traditional deterministic plans?

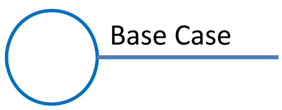
Q1.3 Are any high-value lines identified by stochastic programming that are missed by deterministic planning?

- Which add flexibility, optionality to system

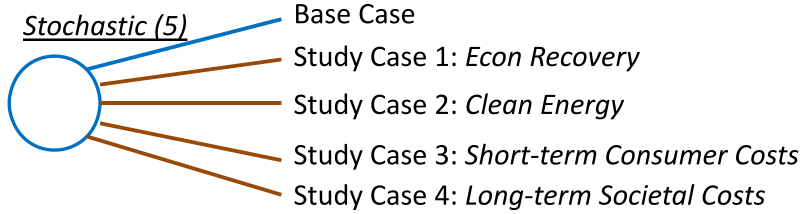
Q1.4 Are stochastic plans more robust against scenarios <u>not</u> considered?

Alternative Study Case/Scenario Sets: *1, 5, and 20*

Deterministic

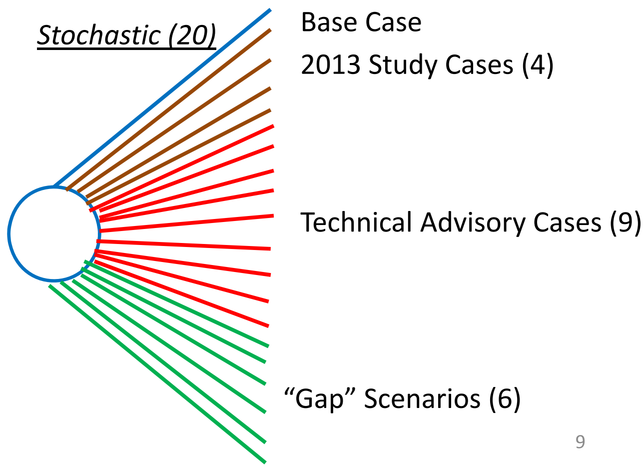


Stochastic (5)



- Three groups of uncertain parameters (24 parameters):
  - *P-Carbon, P-Gas, Energy growth*
  - *RPS, Renewable capital cost*
  - *Peak growth, storage*

Stochastic (20)

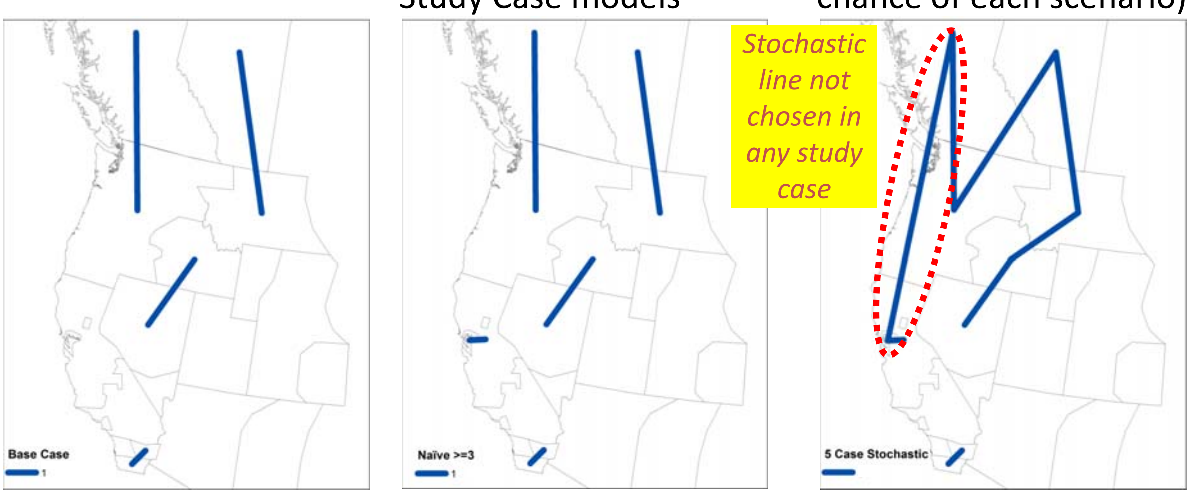


Example: Optimal "Portal" 10 yr Transmission (21 Zone model)

Optimal under just Base Case (100% probability)

Heuristically combine deterministic results: Optimal in ≥3 of 5 2013 Study Case models

Stochastic Optimum under 5 (and also 20) study cases (equal chance of each scenario)

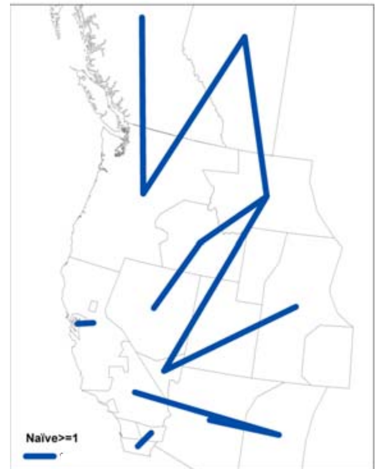


Expected PW cost under 20% chance of each of 5 study cases:

$681.4B $680.3B $678.5B (optimal)

Example: Optimal "Portal" 10 yr Trans (21 Zone) for Heuristics that Combine Deterministic Study Case Results

Optimal in all 5 2013 Study Case models	Optimal in ≥3 of 5 2013 Study Case models	Optimal in ≥1 of 5 2013 Study Case models

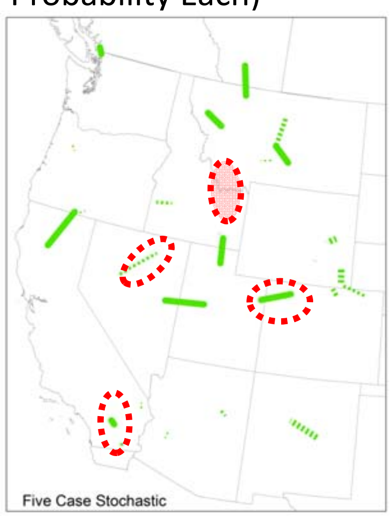


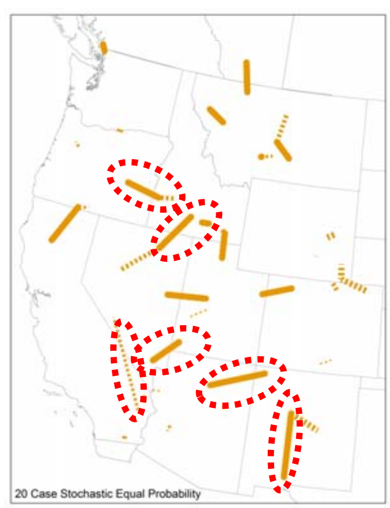
Expected PW cost penalty under 20% chance of each of study cases:

$5.2B | $1.9B | $3.2B

Comparison of Yr 10 Lines Under Alternative Scenario Sets (300 bus case)

Optimal under Base Case	Optimal under 5 Scenarios (20% Probability Each)	Optimal under 20 Scenario Case (5% Probability each)

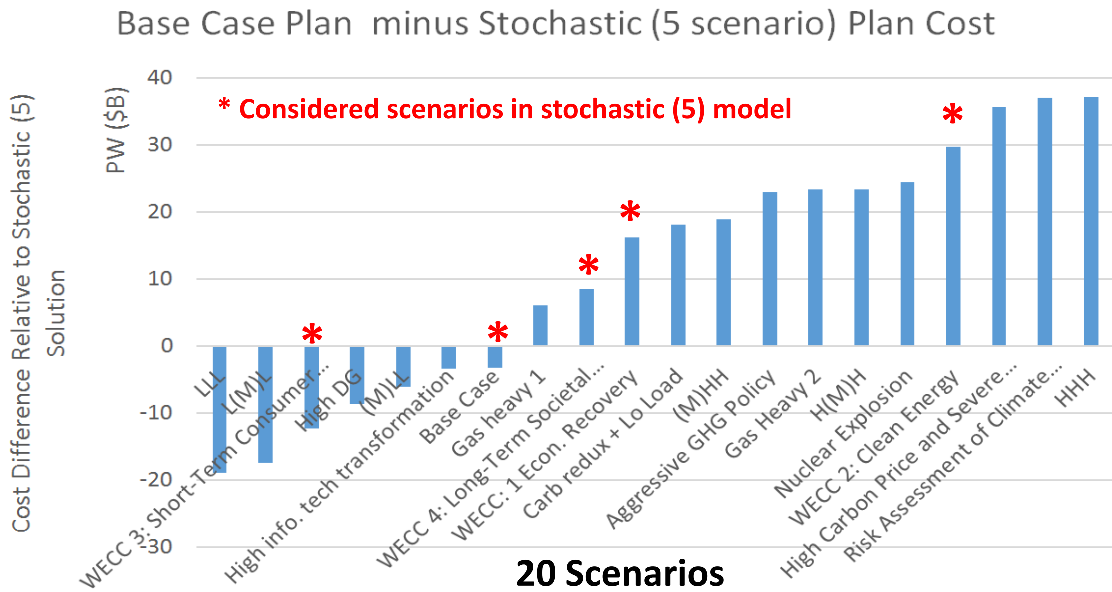




Expected suboptimality cost penalty under 5% chance of each of 20 scenarios:

$14.2B | $2.0B | $0B Optimal

Does a stochastic solution based on the "wrong" scenarios do better against other scenarios?



- The stochastic (5) plan does better in 10/15 of the unconsidered scenarios
- Not necessarily the case; but stochastic plans tend to build more in more places

Question 2: *Practical to Optimize Economic Planning of Regional Transmission?*

– *Yes:* Can rapidly screen, define, and assess performance of alternative plans

– After initial model set-up, ~0.5-2 hours to optimize a single stochastic WECC plan for a particular set of assumptions (single server)

→ If multiple servers, can quickly generate & evaluate many plans under various:

- study cases (climate, regulations, technology...)
- objectives (least-cost, least-emissions, least land use,...)

– Far faster than manual assembly & evaluation of plans

– You should always subject plans to detailed production costing!

What problem sizes are practical to solve?

- If Kirchhoff's voltage law enforced (DC OPF), 1 hr solution time on a workstation with a 0.5% optimality gap →

  ~100 candidate lines

  ~100,000 combinations of:

  Generation types

  X Buses/zones

  X Sample hours (load/renewable output)

  X Decision stages (in-service dates)

  X Long run regulatory/economic/technology study cases

  →Tradeoffs! (more detail on one aspect → less on another)

- Pipes-&-bubbles model

  ~100 candidate lines

  ~2,000,000 combinations

Problem size examples solved here

- Pipes-&-bubbles:

  8 Generation types

  X 21 TEPPC zones

  X 20 Sample hours (load/renewable output)

  X 2 Decision stages (2024, 2034)

  X 20 Long run regulatory/econ/tech scenarios

- KVL (DC OPF):

  10 Generation types

  X 300 Buses

  X 6 Sample hours (load/renewable output)

  X 2 Decision stages (2024, 2034)

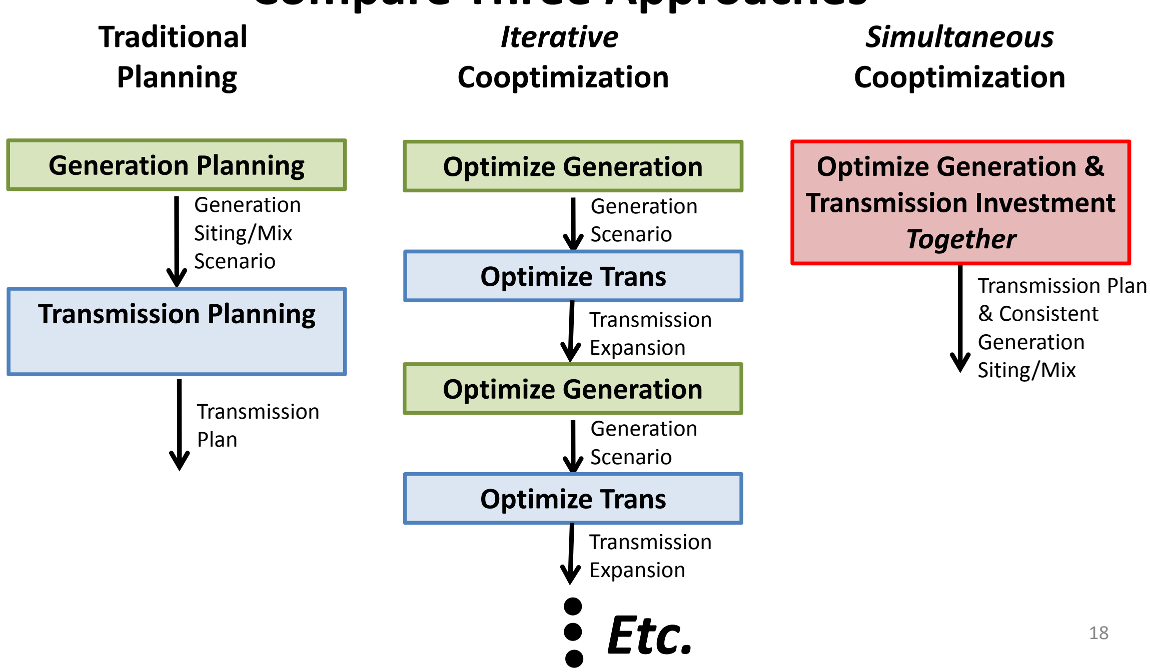
  X 3 Long run regulatory/econ/tech scenarios

Question 3: *What affects transmission decisions?*

- **What *strongly* matters?**
  - More lines recommended if:
    - Consider several study cases/scenarios at once (cf. 1 study case at a time)
    - Consider KVL (parallel flows)
  - Considering a range of load/renewable operating conditions
  - Considering KVL (parallel flows) → more lines
  - Unit commitment, *if* significant coal generation (low C cost)
- **What matters *less*?**
  - Going from 5 to 20 study cases/scenarios
    - No difference in 21 zone case, differences in 300
  - Precise probabilities of study cases/scenarios
  - Unit commitment, *if* low coal penetration
  - Consideration of "failure to launch" for planned lines—few additional lines are justified in Yr 10 as "insurance"

Question 4: *What is the value of cooptimization? ("Anticipatory Planning")*

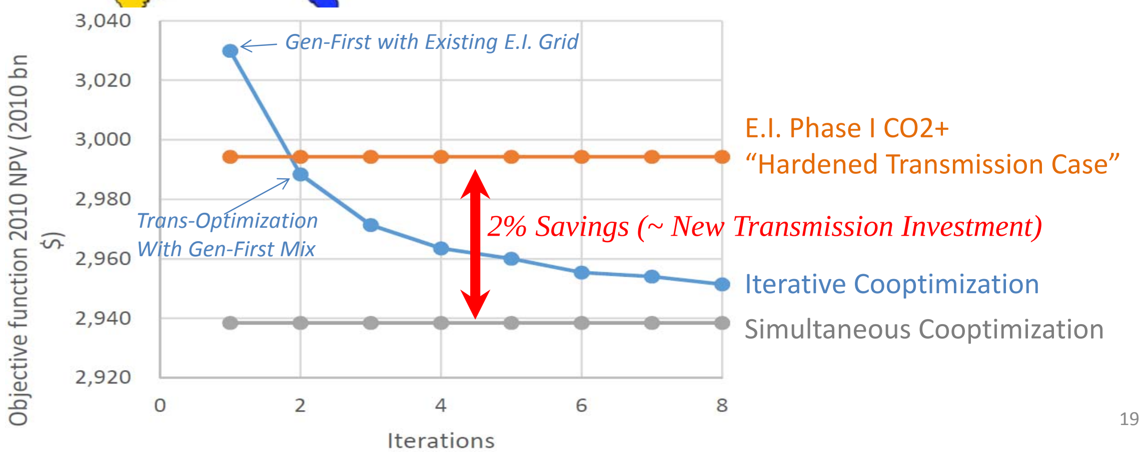
Compare Three Approaches



Eastern Interconnection Case Study: Comparison of Three Approaches (Johnson et al. 2015)

JHU Model (M.I.L.P.): *JHSMINE*

- *27 EI regions*
- *Pipes & Bubbles*
- *20 years of annual transmission & generation investment*



US-Wide Hypothetical Example (Liu et al., 2013)

JHSMINE Model:

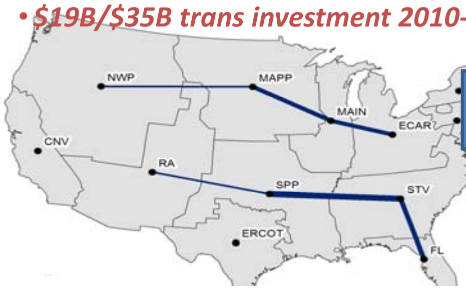
- *13 US regions*
- *Build & dispatch gen; build transmission*

Results:

1. Gen-Only (with existing grid): $1846B PW

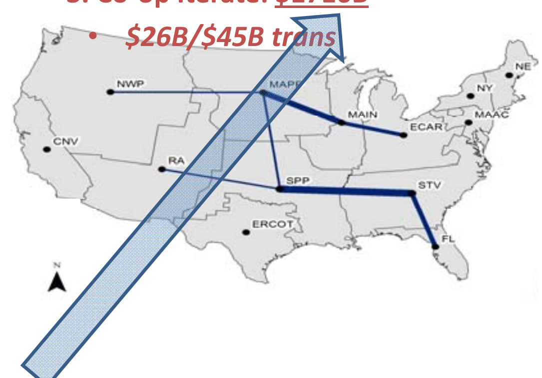
2. Trans-Only (with Gen-Only generation): $1766B

- ***$19B/$35B trans investment 2010-20/20-30***



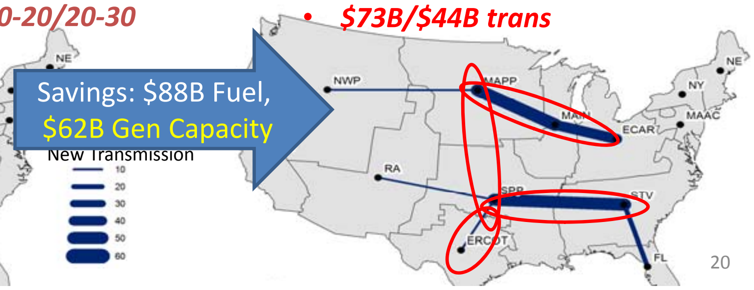
3. Co-op Iterate: $1716B

- ***$26B/$45B trans***



4. Co-op Simultaneous: $1679B

- ***$73B/$44B trans***



Conclusions

Q1: Stochastic plans are different & likely better

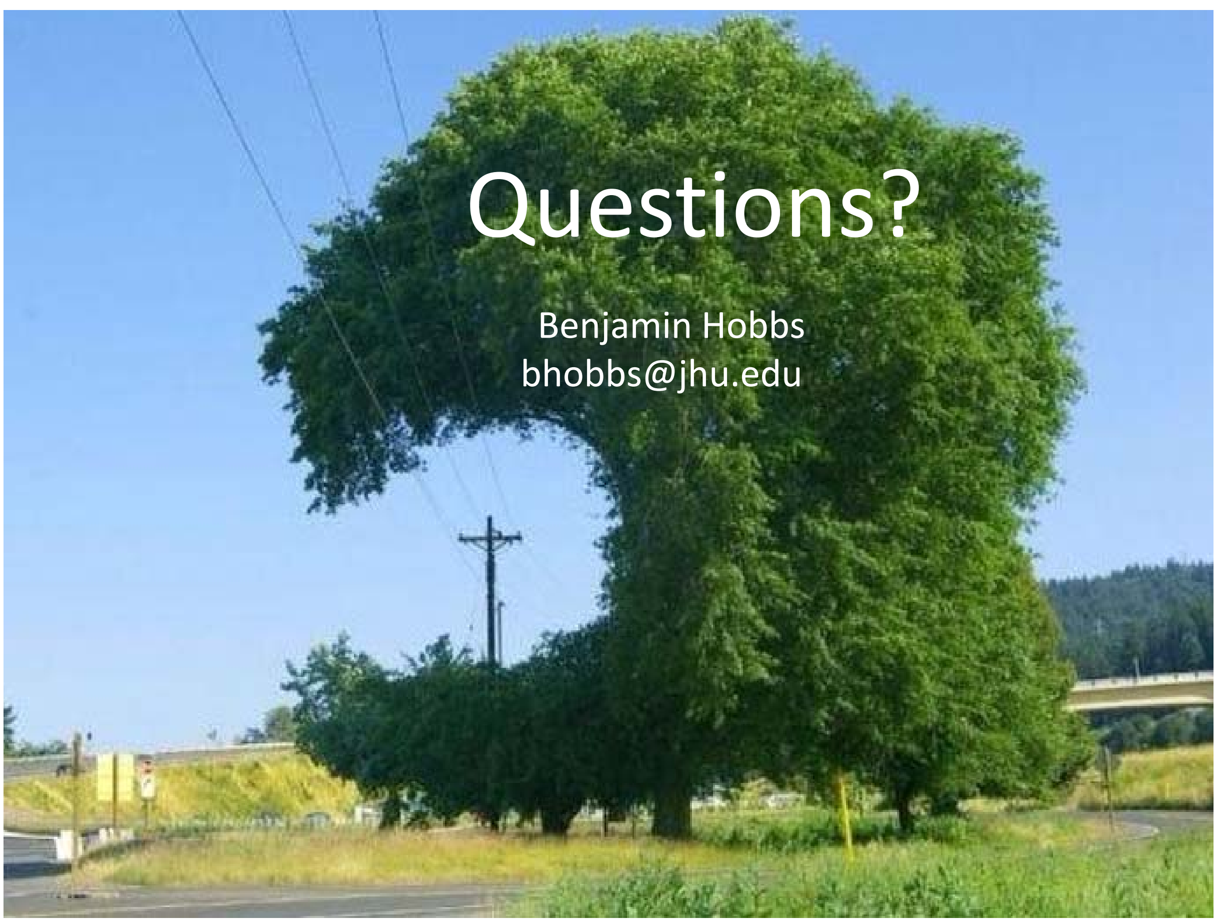
Q2: Stochastic planning is practical

Q3: Other approximations can be important as assuming certainty

Q4: "Anticipatory planning" (cooptimization) captures not only fuel cost savings, but generation capital cost savings

Next:

- detailed regional study for BPA
- Improved decompostion methods for solving huge problems



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