Practical Methods for Cooptimizing Transmission-Generation on a Regional Scale

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Outline

I. The problem
  - CAISO TEAM method

II. Cooptimize gen & discrete lines: *MILP*
  - 7 zone UK
  - 17 zone WECC
  - 240 bus WECC

III. Cooptimize gen & continuous line capacity: *Successive LP*
  - EU 26 model: COMPETES
  - Demand response

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Consider Generator Investment Response in Transmission Planning (Awad et al., 2010)

CALIFORNIA ISO

Transmission Economic Assessment Methodology (TEAM)

California Independent System Operator
June 2004

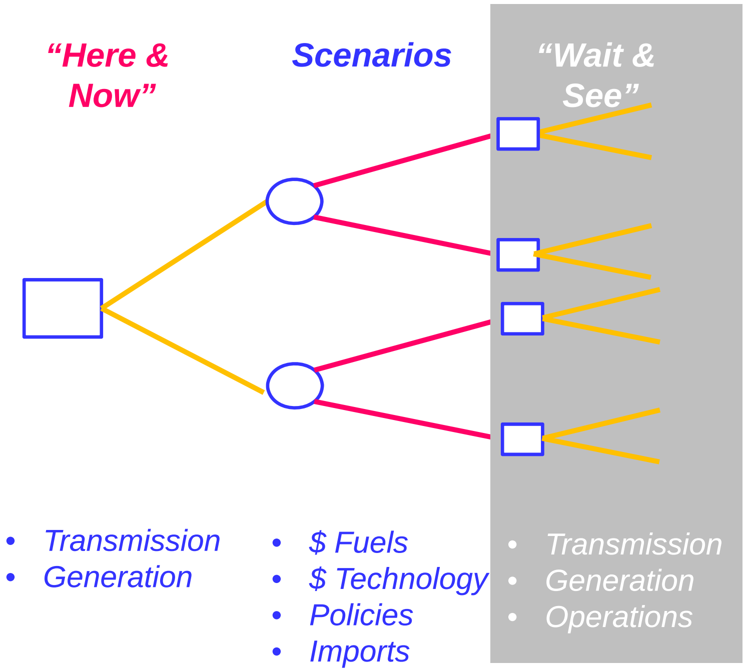
Integrated economic benefits method:

1. Benefits framework: Many perspectives
2. Full network (linearized dc)
3. Market-based pricing
   - *Recognize how upgrade mitigates market power*
4. Recognize uncertainty
   - *Transmission insures against extreme events*
5. <u>Resource (supply/DSM) substitution</u>
   - *Simulate gen operations & investment response to changed prices*
   - *Account for savings in all resource costs*

Cooptimize with Discrete Lines

- Generation representation
  - *Continuous investment & output*
  - *Regional correlations of wind/load (100-700 h/yr)*
  - *Hydro pre-dispatch*
- Transmission representation
  - *Discrete circuits*
  - *Linearized dc load flow*
- Uncertainty
  - *Here-and-now decisions (e.g., 2010)*
  - *Wait-and-see scenarios (decisions e.g., 2020,30)*
- MIP solved with AIMMS/CPLEX

Two-stage Stochastic Approach



"Here & Now"

Scenarios

"Wait & See"

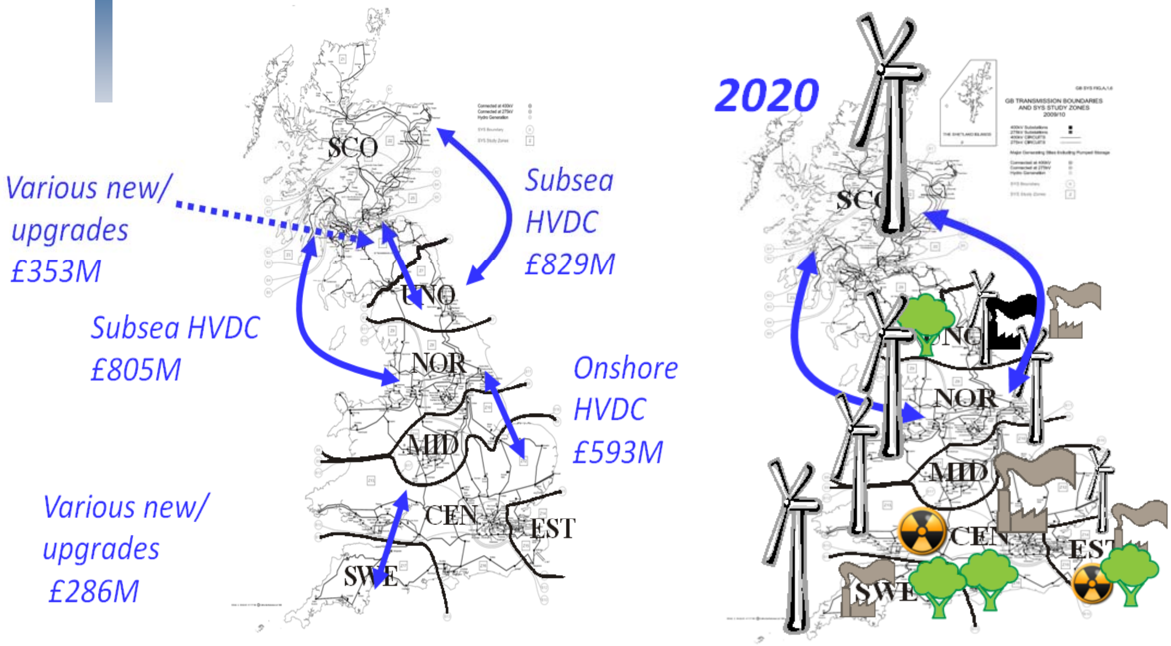
- *Transmission*
- *Generation*

- *$ Fuels*
- *$ Technology*
- *Policies*
- *Imports*

- *Transmission*
- *Generation*
- *Operations*

UK Analysis (Radial-DC Model: MILP)

(van der Weijde & Hobbs, 2012)



7 scenarios, 3 stages, 700 hrs → 500,000 variables

CAISO 17 Zone Test Case

(Munoz, Hobbs, Kasina 2012)

CAISO 17

Generator data from WECC 225-bus system
(Price et al. 2011)
24 corridors
5 Import buses

Time Series

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

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

→ *200,000 variables + 300,000 constraints*

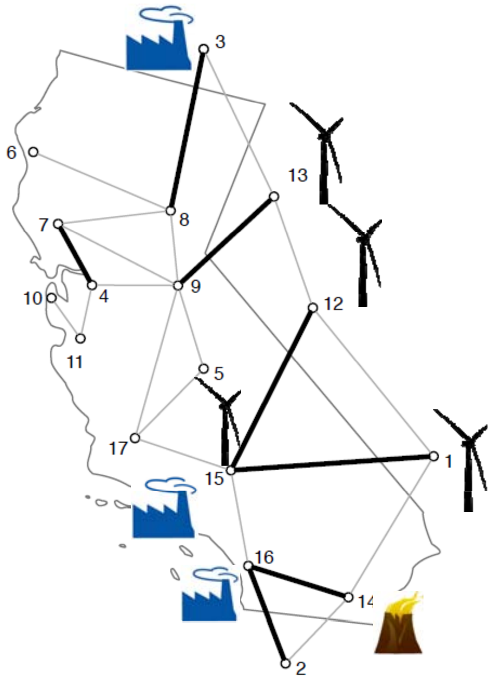
Generator Response 2021

conventional

wind

Geothermal

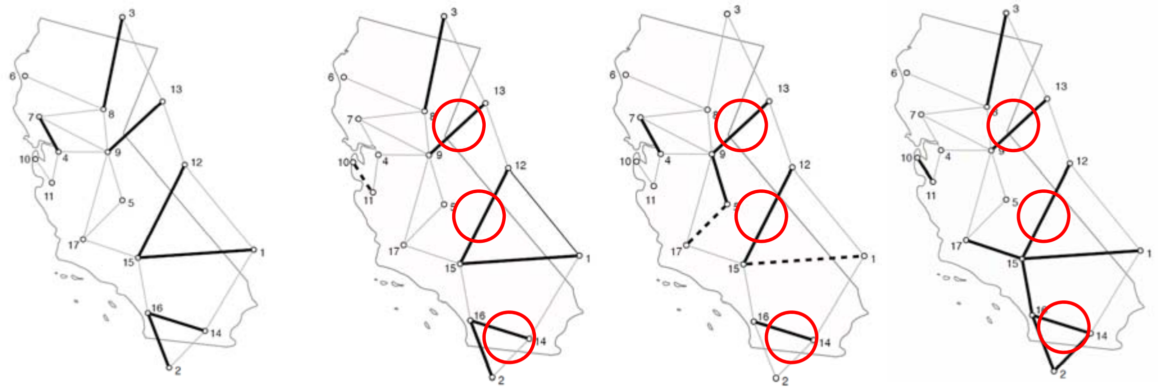
solar



Stochastic vs. Deterministic

Deterministic Scenario Analysis

Stochastic	***Status Quo***	***Techno***	***Electrification***



Stochastic Solution better by ~$300M

Can we make a recommendation based on deterministic solutions?

○ ***"Robust" Solutions?***

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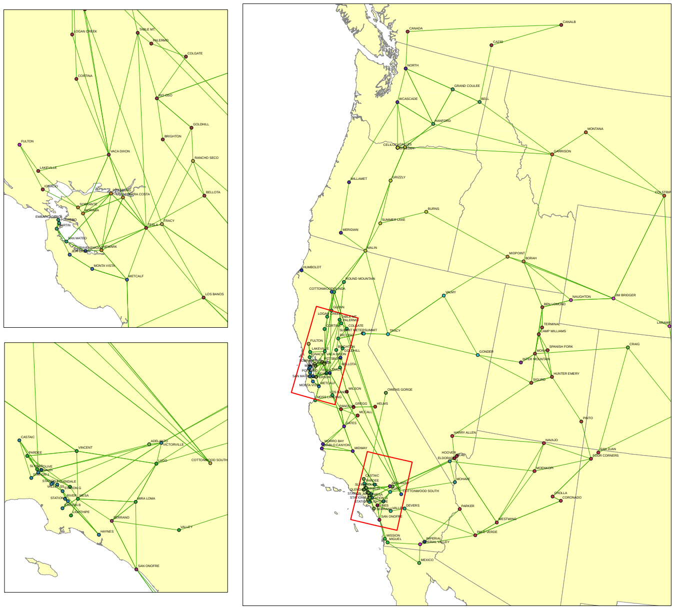
Next: WECC 240-bus test system

(Based on Price and Goodin, 2011)



- **Multiple circuits; bubble constraints; ramp limits**
- **Single scenario: 500 hr/yr, 4M vars**
- **Total Gen: 223,690 MW**
    - **579 generators in California, 418 rest of WECC**

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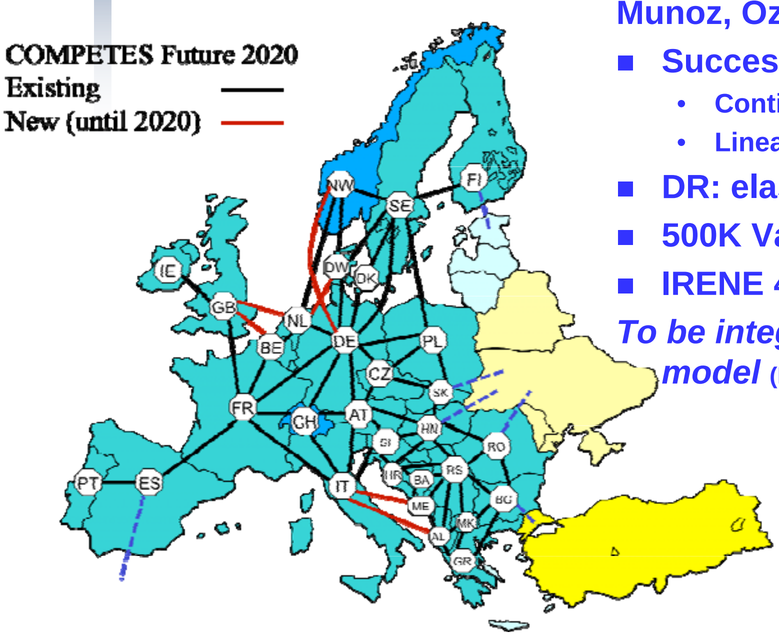
Cooptimizing Transmission, Gen & DR: COMPETES Market Model

(Hobbs et al. 2004; Lise, Hobbs, Hers, 2008)

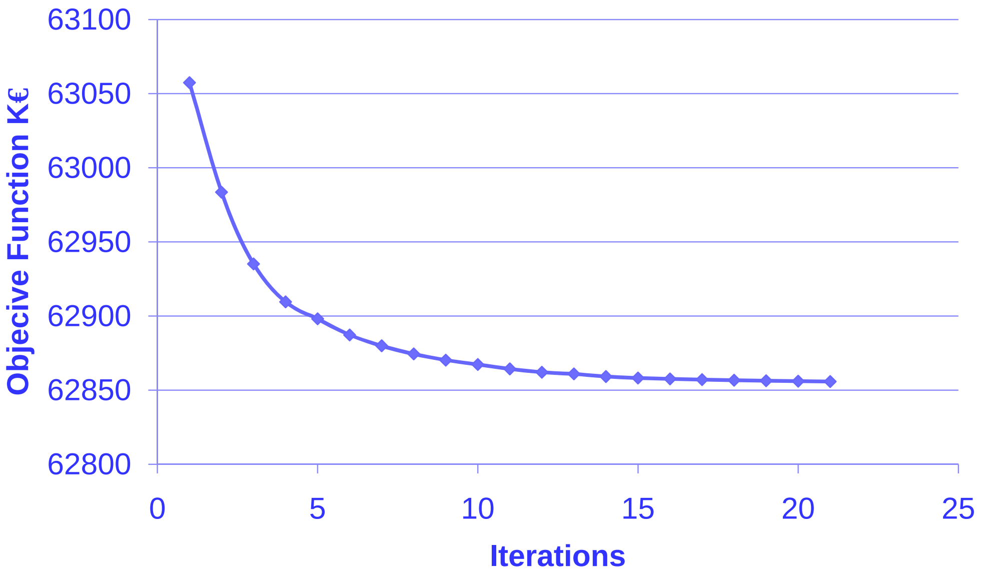


Munoz, Ozdemir, Hobbs (in progress):

- Successive LP
  - Continuous transmission capacity
  - Linearized dc
- DR: elastic demand
- 500K Variables
- IRENE 40 project

To be integrated with GASTALE gas model (Lise & Hobbs, 2010)

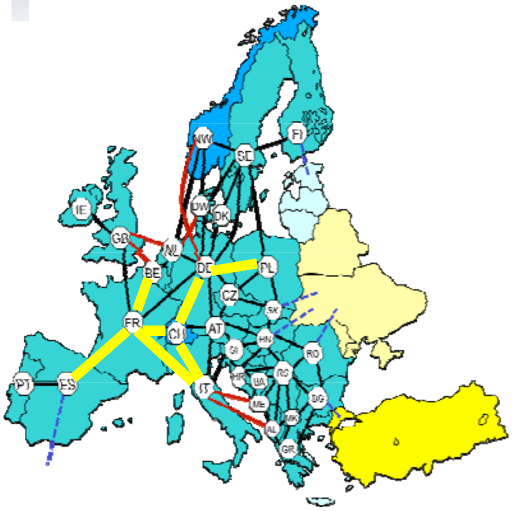
COMPETES Transmission Convergence

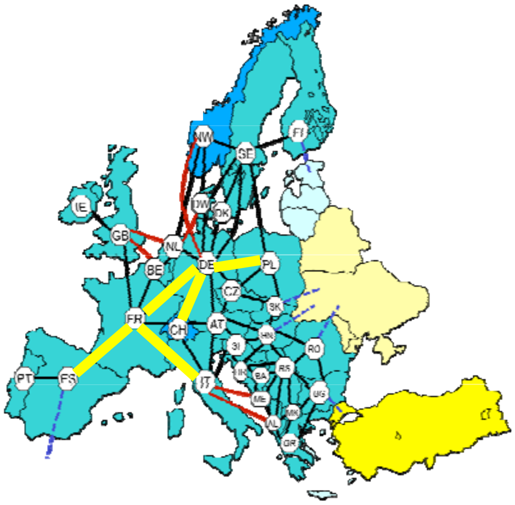


8 minutes per iteration

Effect of Kirchhoff's Voltage Law

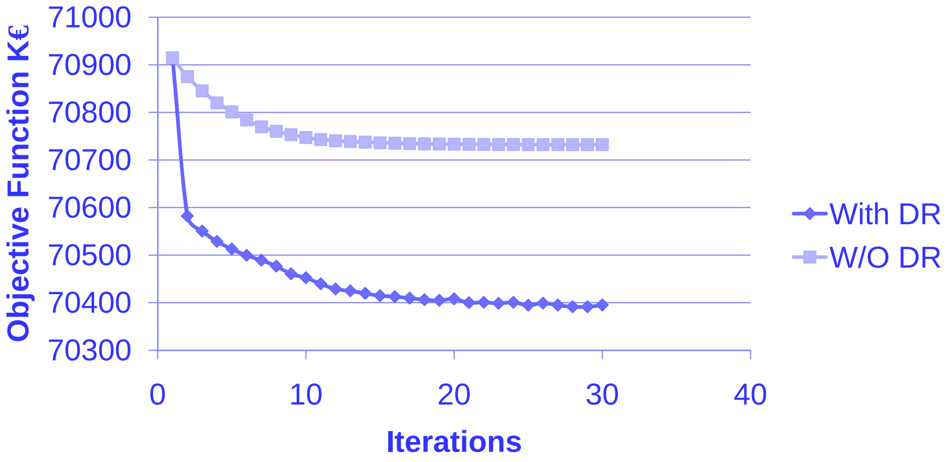
Linearized DC *vs.* Pipeline/Transport





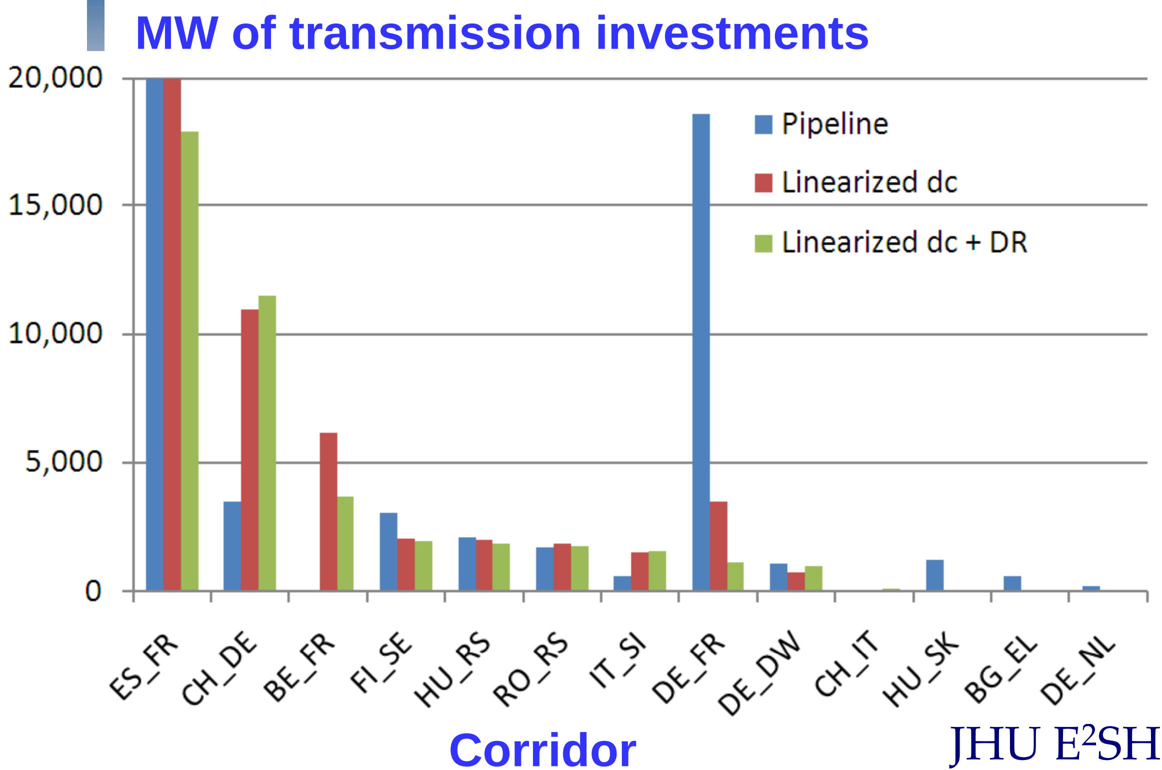
Demand Response

- Use Gauss-Seidel iteration
  - Update load with prices from last iteration (demand curves)
- 100 hr test case 2050 (100k variables), 10 sec/iteration



→ *Can make a large difference in gen mix* *(deJonghe, Hobbs, Bellman 2012)*

Comparison (100 h/yr case)



Conclusions

We can:

- **Cooptimize gen & transmission**
  - **For regional policy analysis**
- **Model DR**
- **Do least-regret planning:**
  - **Transmission as insurance**

… *And it matters!*

- **Examples: WECC, UK, EU**

References

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Appendix: WECC Model Formulation

$$\min \; I^{2011} + \sum_s p_s \left(I_s^{2021} + O_s^{2021} + O_s^{2031}\right)$$

1. *Reserve Margins* $$\sum_{u\in U_t}\sum_{b\in B}\Big(\sum_{k\in NI} y^u_{b,k,s} + \sum_{k\in I} CC_k y^u_{b,k,s}\Big) \geq (1+RM)\sum_{b\in B} d^t_{b,h*,s}$$
2. *Resources* $$\sum_{t\in U_t} y^t_{b,k,s} \leq \overline{y}^t_{b,k,s}$$
3. *Max Generation* $$g^t_{b,k,h,s} \leq \Delta_{b,k,s}\sum_{u\in U_t} y^s_{b,k,s}$$
4. *RPS* $$\sum_{k\in R}\sum_{h\in H}\sum_{b\in B} g^t_{b,k,h,s} \geq RPS^t_s \sum_{k\in K}\sum_{h\in H}\sum_{b\in B} g^t_{b,k,h,s}$$
5. *KCL* $$\sum_{u\in U_t}\sum_{l\in L_b} f^{u,t}_{l,h,s} + \sum_{b\in B}\Big(\sum_{k\in K} g^t_{b,k,h,s} + r^t_{b,h,s}\Big) = d^s_{b,h,s}$$
6. *KVL* $$f^{1,t}_{l,h,s} - \gamma^1_l\left(\theta^t_{b,h,s} - \theta^t_{p,h,s}\right) = 0 \qquad \boxed{\left|f^{u,t}_{l,h,s} - \gamma_l\left(\theta^t_{b,h,s} - \theta^t_{p,h,s}\right)\right| \leq M\left(1 - x^t_{l,s}\right)}$$
7. *Thermal Limits* $$\left|f^{1,t}_{l,h,s}\right| \leq \overline{f^1_l} \qquad \left|f^{u,t}_{l,h,s}\right| \leq \overline{f_l}\, x^t_{l,s}$$