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
Consider Generator Investment Response in Transmission Planning \cite{Awad2010}

**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. Resource (supply/DSM) substitution
   - Simulate gen operations & investment response to changed prices
   - Account for savings in all resource costs

---

**Transmission Economic Assessment Methodology (TEAM)**

- Continuous investment & output
- Regional correlations of wind/load (100-700 h/yr)
- Hydro pre-dispatch

- 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”**

- Transmission
- Generation

**“Wait & See”**

- $ Fuels
- $ Technology
- Policies
- Imports

---

UK Analysis (Radial-DC Model: MILP)

*(van der Weijde & Hobbs, 2012)*

Various new/upgrades

- £353M
- Subsea HVDC
  - £805M
- Onshore HVDC
  - £593M

Various new/upgrades

- £286M

2020

7 scenarios, 3 stages, 700 hrs $\rightarrow$ 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

$\Rightarrow 200,000$ variables + $300,000$ constraints

Generator Response 2021
- conventional
- wind
- Geothermal
- solar
Stochastic vs. Deterministic

Deterministic Scenario Analysis

<table>
<thead>
<tr>
<th>Stochastic</th>
<th>Status Quo</th>
<th>Techno</th>
<th>Electrification</th>
</tr>
</thead>
</table>

Can we make a recommendation based on deterministic solutions?

- "Robust" Solutions?

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
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

- 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)
**Conclusions**

We can:
- Co-optimize gen & transmission
  - For regional policy analysis
- Model DR
- Do least-regret planning:
  - Transmission as insurance

... *And it matters!*
- Examples: WECC, UK, EU
References


Appendix: WECC Model Formulation

\[
\min \mathcal{I}^{2011} + \sum_s p_s (\mathcal{I}^{2021}_s + \mathcal{O}^{2021}_s + \mathcal{O}^{2031}_s)
\]

1. **Reserve Margins**
\[
\sum_{u \in U, b \in B} (\sum_{k \in H} y^u_{b,k,s} + \sum_{k \in H} CC_k y^u_{b,k,s}) \geq (1 + RM) \sum_{b \in B} d^b_{s,s}
\]

2. **Resources**
\[
\sum_{t \in T_i} y^t_{b,k,s} \leq \overline{y}^t_{b,k,s}
\]

3. **Max Generation**
\[
g^t_{b,k,h,s} \leq \Delta_{b,k,h} \sum_{u \in U_i} y^u_{b,k,s}
\]

4. **RPS**
\[
\sum_{k \in H} \sum_{b \in B} \sum_{k \in H} \sum_{h \in H} g^t_{b,k,h,s} \geq \text{RPS} \sum_{k \in H} \sum_{b \in B} \sum_{k \in H} g^t_{b,k,h,s}
\]

5. **KCL**
\[
\sum_{u \in U_i, j \in J_k} f^{u,j}_{b,k,s} + \sum_{b \in B, h \in H} \left( \sum_{k \in H} g^t_{b,k,h,s} + d^b_{s,s} \right) = d^t_{b,k,s}
\]

6. **KVL**
\[
f^{u,j}_{b,k,s} - f^t_{b,k,s} (\theta^t_{b,k,s} - \theta^0_{b,k,s}) = 0
\]
\[
\left| f^{u,j}_{b,k,s} - f^t_{b,k,s} (\theta^t_{b,k,s} - \theta^0_{b,k,s}) \right| \leq M (1 - x^i_{b,k,s})
\]

7. **Thermal Limits**
\[
\left| f^{u,j}_{b,k,s} \right| \leq \tilde{f}^u_{b,k,s} \left| f^{u,j}_{b,k,s} \right| \leq \tilde{f} f^u_{b,k,s}
\]