Transmission Planning Under Uncertainty: A Stochastic Two-Stage Modelling Approach

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INFORMS Annual Meeting
Austin, Nov. 8, 2010

Overview

- The problem
- Existing studies
- Our model
  - How it works
  - Data it needs
  - Data sources + assumptions
- Some results
- Conclusions

The Problem: Hyperuncertainty! What's a Poor Transmission Planner to do?

Dramatic changes a-coming!

- Renewables
  - How much?
  - Where?
  - What type?
- Other generation
  - Centralized?
  - Distributed?
- Demand
  - New uses? (EVs)
  - Controllability?
- Policy

???

Do these uncertainties have implications for transmission investments *now*?

The problem, Cont.

- Transmission planning
  - Generators respond: multi-level
  - Decisions can be postponed: multi-stage
  - Uncertainties & variability: stochastic
- Important questions:
  - Optimal strategy under uncertainty?
  - Value of information? (EVPI)
  - Cost of ignoring uncertainty? (ECIU)
  - Option value of being able to postpone?
- Deterministic planning can't answer these!
  - Stochastic can!

Decision making under uncertainty

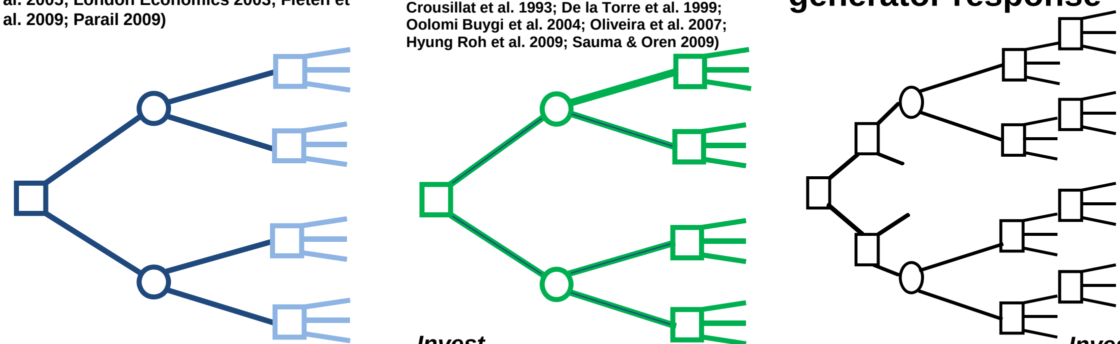
-----------Previous Work-----------

Real options analysis of single lines, usually based on exogenous price processes (Hedman et al. 2005; London Economics 2003; Fleten et al. 2009; Parail 2009)

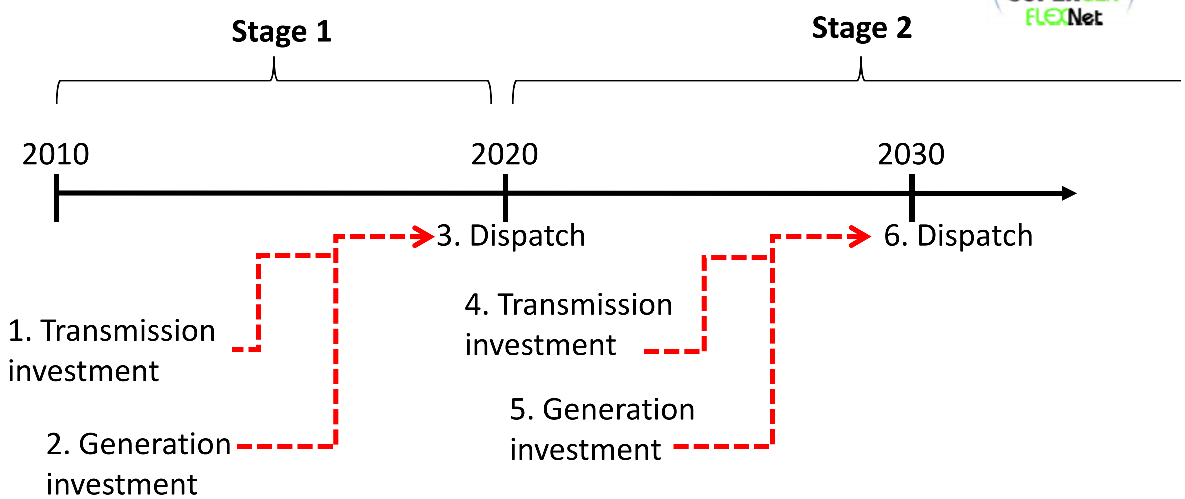
Single-stage trans-mission planning under uncertainty with generator response (Awad et al. 2009; Crousillat et al. 1993; De la Torre et al. 1999; Oolomi Buygi et al. 2004; Oliveira et al. 2007; Hyung Roh et al. 2009; Sauma & Oren 2009)

----------- Ours-----------

Two-stage trans-mission planning under uncertainty with generator response



Our model: timeline



Objective: min total costs (investment + generation) s.t. power flow constraints, wind availability, build limits, renewables targets

Structure of 2 Stage Programming

- Math programming with recourse
  - scenarios s=1,2,..,S, each with probability PR^s

- Simplest: Assume 2 decision stages:
  1. Choices made "here and now" before future is known
     - E.g., investments in 2010
     - These are x^1
  2. "Wait and see" choices, which are made after the future s is known.
     - E.g., dispatch/operations, investments in 2020
     - These are x^{2s} (one set defined for each scenario s)

- Model:

$$\text{MIN} \quad C^1(x^1) + \Sigma_s PR^s C^{2s}(x^{2s})$$
$$\text{s.t.} \quad A^1(x^1) = B^1$$
$$A^{2s}(x^1, x^{2s}) = B^{2s} \qquad \forall s$$

Some assumptions

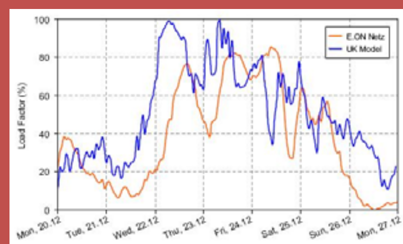
- Alignment of generation and transmission objectives
  - e.g., nodal pricing + perfect competition
- Generation
  - No unit commitment or dynamic constraints/costs
- Demand:
  - No short-term demand flexibility
- Renewables targets met in most efficient way

Data necessary

regions
+ transmission
constraints
+ losses

generator types + current capacities + maximum build limits + costs

wind output and demand time series (1 year)
+ interconnector flows



investment alternatives

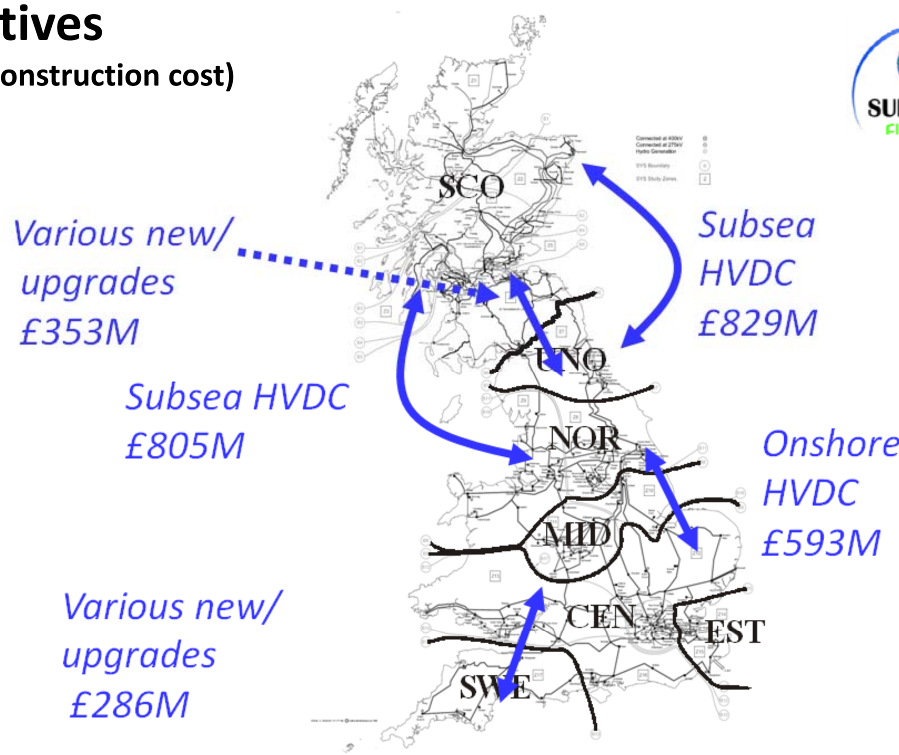
scenarios (2020, 2030) & probabilities: generation costs (incl. carbon price), transmission investment costs, demand, renewable targets, nuclear feasibility

Data sources

- Regional wind output: Neuhoff et al. (2007)
- Hydro output: Duncan (2010)
- Regional demand data: National Grid
- BritNed Flows: Parail (2010)
- Maximum build limits: Various
- Regions + trans. constraints: NG 7-year statement (2009)
- Transmission losses: own calculations
- Investment alternatives + costs: KEMA (2009)
- Generation costs: NEA and IEA (2005), US DOE, own calculations
- Scenarios: Various (Discovery, LENS, Redpoint, etc.)

Alternatives

(overnight construction cost)



Scenarios

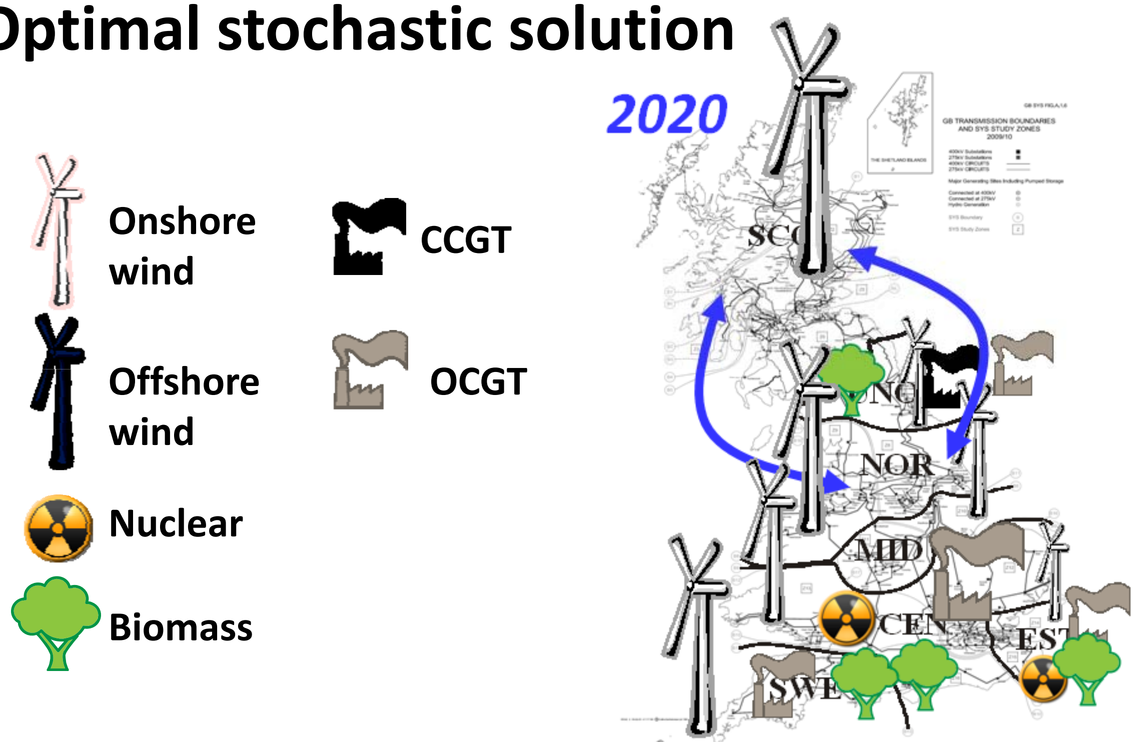
	Gen. investment cost	Gen. variable cost	Trans. investment cost	Demand	CO_2 price	Others
Status Quo		CCGT/OCGT/DG: +		+	+/-	No Renewable Target
Low cost DG	Distributed G: - -	CCGT/OCGT: - DG: - -		+	++	RT: + Nuclear replacement only
Low Cost Large Scale Green	Renewables : --	CCGT/OCGT/DG: ++		--	+++	RT: +++
Low Cost Conventional	Conventional: -	CCGT/OCGT/DG: -		++	+	No RT
Paralysis	All except offshore: +++	CCGT/OCGT/DG: +	Onshore: +++ Others +	++	++	RT: + Nuclear replacement only
Techno+	All : -	CCGT/OCGT/DG: +	-	++	++	RT: ++

Some results

Disclaimer: the following results are preliminary and based on restrictive assumptions.

They cannot be used to evaluate proposed transmission investments.

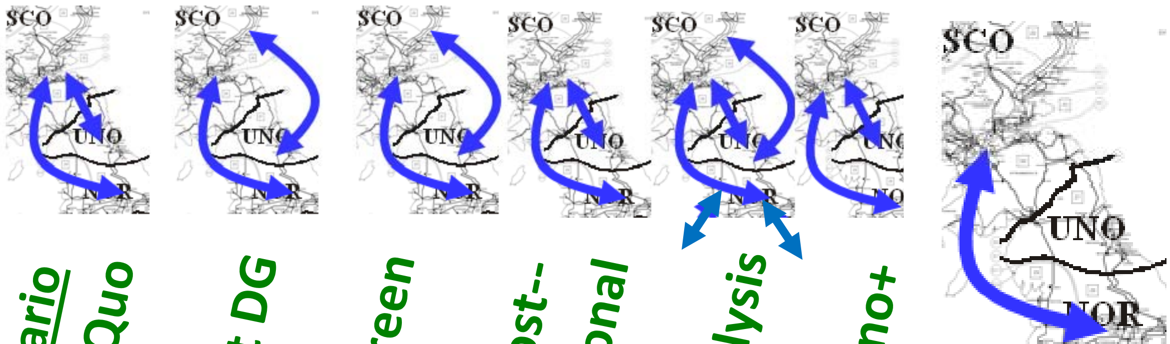
Optimal stochastic solution



Cf. Traditional robustness analysis

2020 Installations by Scenario

"Robust"



Scenario

- Status Quo
- Low Cost DG
- Low Cost Green
- Low Cost--Conventional
- Paralysis
- Techno+

Value of perfect information

- How much average savings if we knew which scenario would happen?
  1. Solve stochastic model
  2. Solve deterministic model for each scenario
  3. Calculate probability-weighted average of (2)

Δ= EVPI

- Results:
  - For gen & transmission: £3,729M (3%)
  - For trans alone: £101M (0.1%)

Cost of ignoring uncertainty

SUPERGEN FLEXNet

- How much would costs go up if we naively plan for one scenario but other scenarios can happen?
  1. Solve stochastic model
  2. Solve naïve (deterministic) model for each scenario
  3. Solve stochastic model, imposing first-stage transmission decisions from step 1

Δ= ECIU

Cost of ignoring uncertainty

SUPERGEN FLEXNet

Scenario planned for	ECIU (Transmission) *(Present worth)*
Status Quo	£432M
Low Cost DG	£0
Low Cost Large Scale Green	£29M
Low Cost Conventional	£196M
Paralysis	£221M
Techno+	£0
Average	£146M = 0.12% of expected costs (stochastic solution)

Value of flexibility

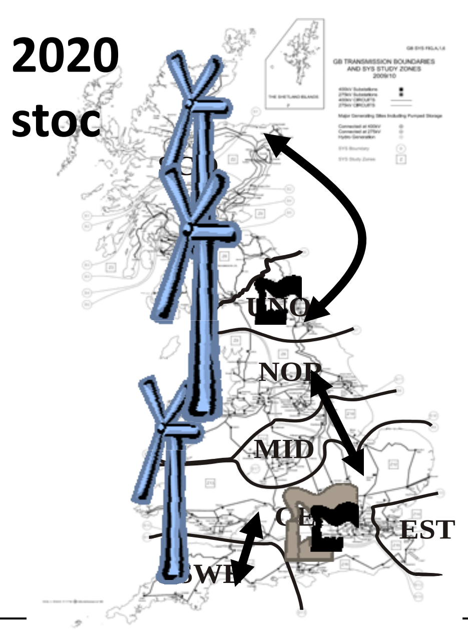
- How much would costs go up if we had to make all decisions now?

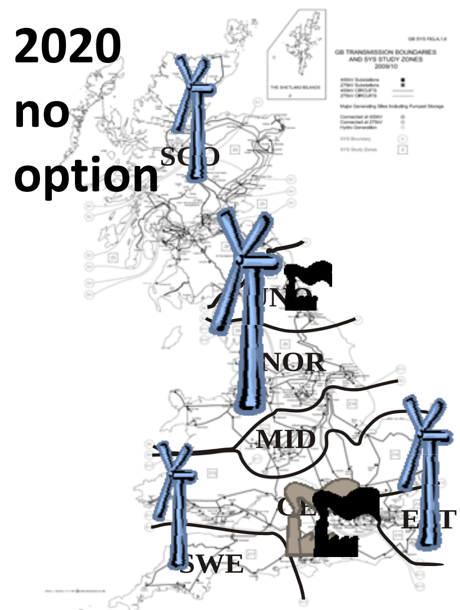
1. Solve stochastic model
2. Solve stochastic model, imposing same transmission expansion plan for all scenarios

Δ= Value of Flexibility

Option value of waiting

Example: Paralysis





Value of flexibility

- Option value (transmission only):

  = £102M present worth= 0.08% of total costs (stochastic)

Conclusions

- For transmission planning:
  - Ignoring risk has quantifiable economic consequences
  - Approach useful for policy/planning questions
- Future work
  - US Application
    - Integration with OPF via decomposition?
  - Demand response
  - Bi-level formulation

References

- E. O Crousillat, P. Dörfner, P. Alvarado, and H. M. Merrill, "Conflicting Objectives and Risk in Power System Planning," *IEEE Trans. Power Systems*, vol. 8, pp. 887-893, 1993.
- N. Duncan, Personal Communication,2010.
- S. -E. Fleten, A. M. Heggedal, and A. Siddiqui, "Transmission Investment under Uncertainty: The Case of Germany-Norway," presented at the 1st International Ruhr Energy Conference, Essen, Germany.
- K. W. Hedman, F. Gao, and G. B. Sheble, "Overview of Transmission Expansion Planning Using Real Options Analysis," in *Proc. IEEE North American Power Symposium*, 2005.
- J. Hyung Roh, M. Shahidehpour, and L. Wu, "Market-Based Generation and Transmission Planning With Uncertainties," *IEEE Trans. Power Systems* vol. 24, pp. 1587-1598, 2009.
- KEMA "Assessment of overall robustness of the transmission investment proposed for additional funding by the three GB Electricity Transmission Owners", 2009.
- London Economics, London, "Economic Evaluation of the Path 15 and Path 26 Transmission Expansion Projects in California".
- National Grid, "Seven-Year Statement", 2009.

References (cont'd)

- NEA and IEA, "Projected Costs of Generating Electricity – 2005 Update", Nuclear Energy Agency and International Agency, OECD, Paris, France, 2005.
- K. Neuhoff, J. Cust, L. Butler, K. Keats, H. Hoexter, A. Kreckzo, G. Sinden, and A. Ehrenmann, "Space and Time: Wind in an Investment Planning Model". *EPRG Working Papers 0603*, 2006.
- G. C. Oliveira, S. Binato, and M. W. Pereira, "Value-Based Transmission Expansion Planning of Hydrothermal Systems Under Uncertainty," *IEEE Trans. Power Systems*, vol. *22*, pp. 1429-1435, 2007.
- M. Oloomi Buygi, M. Shahidehpour, H. M. Shanechi, and G. Balzer, "Market Based Transmission Planning Under Uncertainties," *Proc. 2004 Int. Conf. on Probabilistic Methods Applied to Power Systems*, pp. 563-568.
- V. Parail, "Can Merchant Interconnectors Deliver Lower and More Stable Prices? The Case of NorNed," *EPRG Working Papers 0926*, Nov. 2009.
- V. Parail, "Properties of Electricity Prices and the Drivers of Interconnector Revenue", 2010.
- 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.