UNIVERSITY OF CAMBRIDGE | Electricity Policy Research Group

SUPERGEN FLEXNet

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

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The Next Generation of Electricity Planning Models
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Overview

SUPERGEN FLEXNet

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

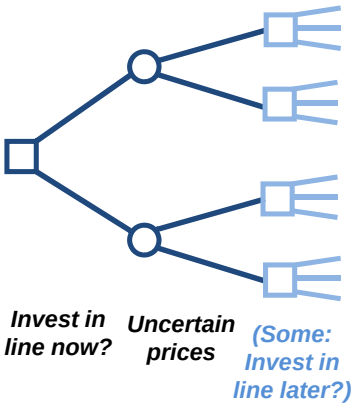
The problem, Cont.

- 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!

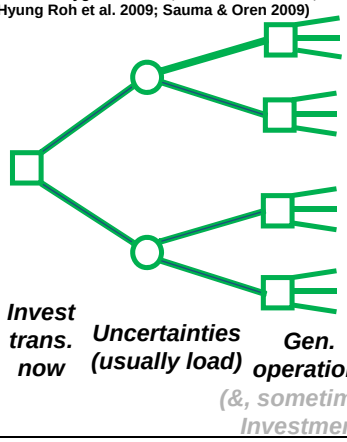
Decision making under uncertainty

----------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)

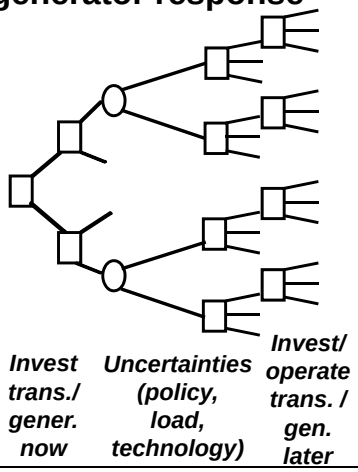


Single-stage trans-mission planning under uncertainty with generator response (Awad et al. 2009; Crousillat et al. 1993; De la Torre et al. 1999; Oolomi Buygi et al. 2004; Oliveira et al. 2007; Hyung Roh et al. 2009; Sauma & Oren 2009)

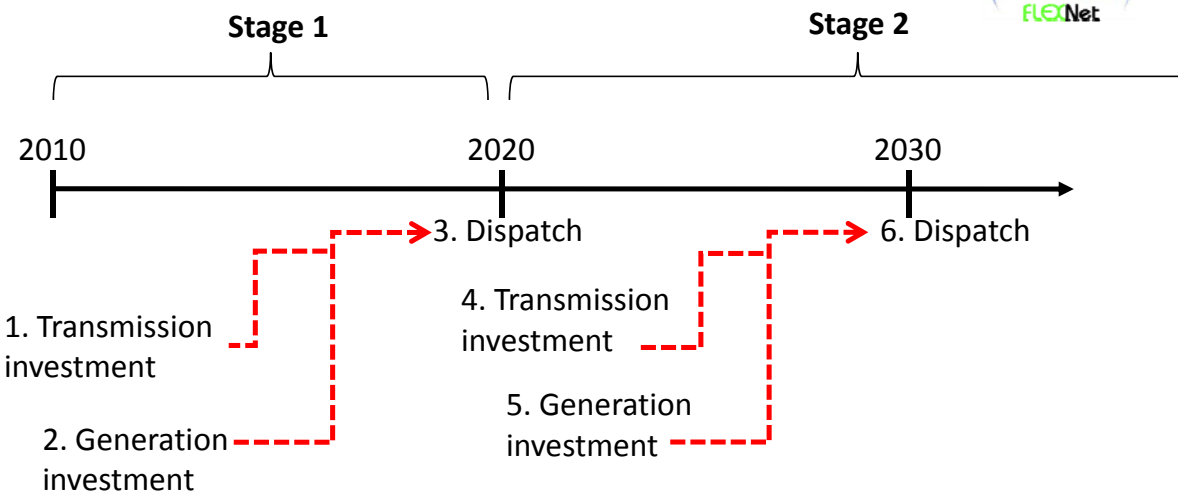


---------- Ours----------

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

Mathematical Schematic

- **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

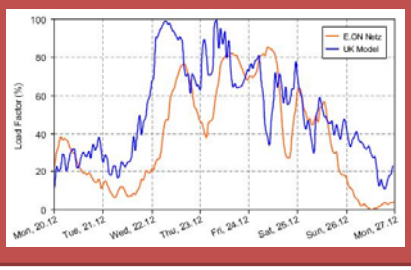
- Alignment of generation and transmission objectives
  - e.g., nodal pricing + perfect competition
- Generation
  - Constant variable costs
  - No start-up costs, min run levels, 'lumpy investment'
  - No ramping constraints
- Demand:
  - No short-term demand flexibility, demand-side management
- Renewables 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



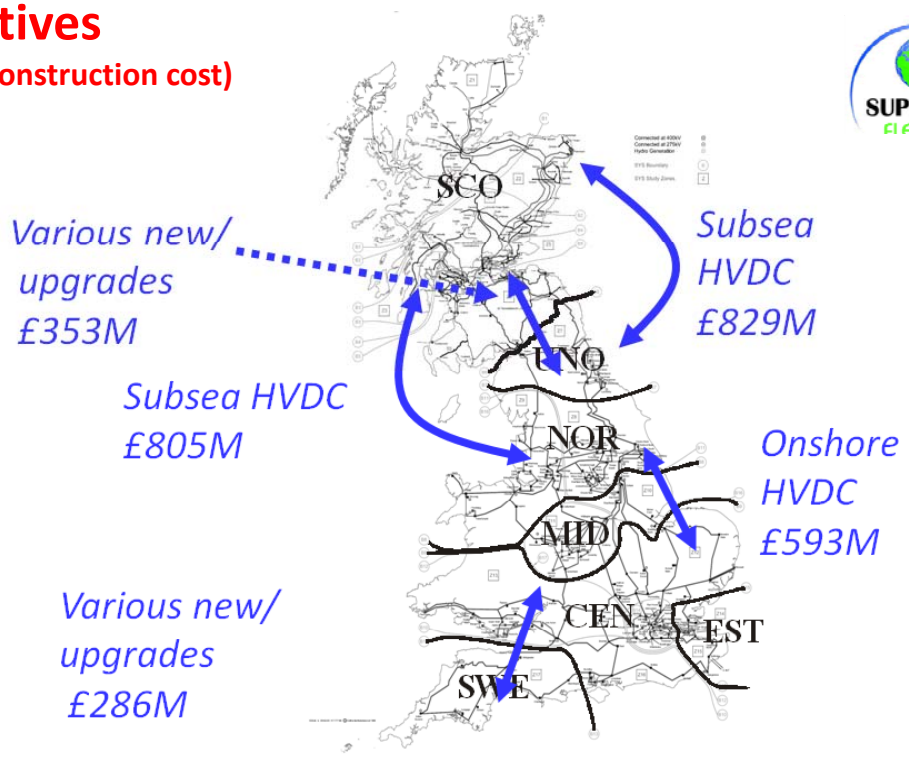
investment alternatives

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. inv. cost	Var. gen cost	Trans. inv. cost	Demand	CO_2 price	Others
Status Quo		CCGT/OCGT/DG: +		+	+/-	No RT
Low cost DG	DG: --	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

Onshore wind

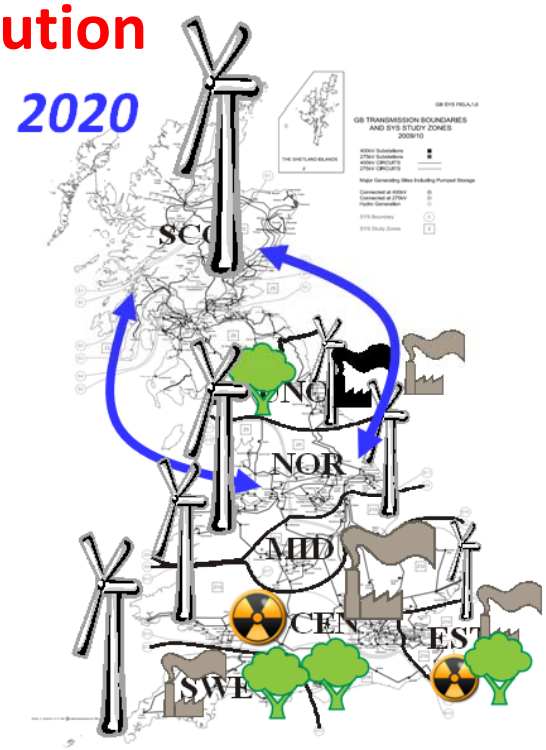
Offshore wind

Nuclear

Biomass

CCGT

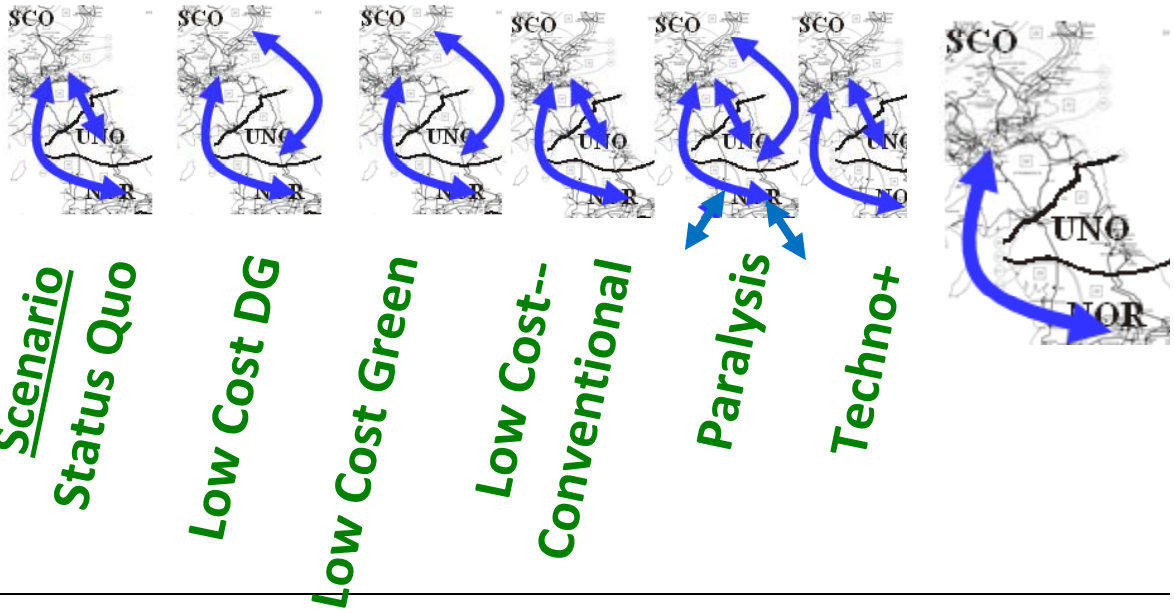
OCGT



Cf. Traditional robustness analysis

2020 Installations by Scenario

"Robust"



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. Compare objectives (1) and (2)

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

Cost of ignoring uncertainty

- 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
4. Compare objectives (1) and (3)

Cost of ignoring uncertainty

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)

Option value of waiting

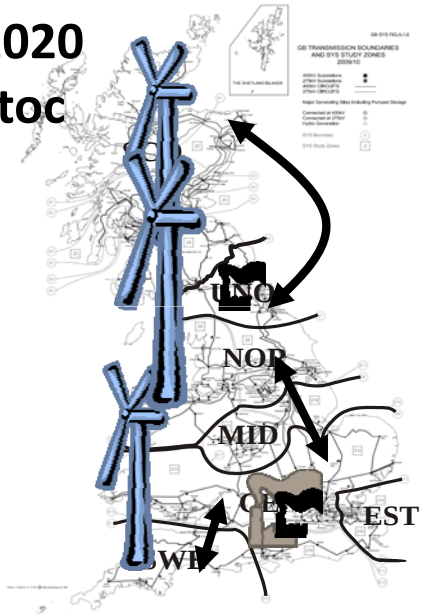
- How much would costs go up if we had to make all decisions now?

1. Solve stochastic model
2. Solve stochastic model, imposing same transmission expansion plan for all scenarios
3. Compare objectives (1) and (2)

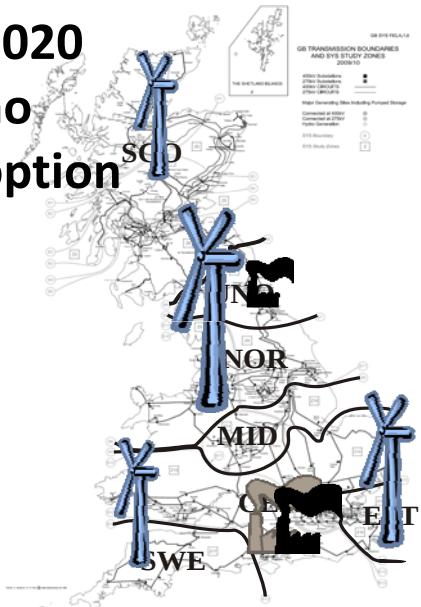
Option value of waiting

Example: Paralysis

2020 stoc



2020 no option



Option value of waiting

- Option value (transmission only):

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

Conclusions

- For transmission planning:
  - Ignoring risk has quantifiable economic consequences
  - Option values can be significant
  - Approach useful for policy/planning questions
- Future work
  - Demand response
  - Bi-level formulation

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