UNIVERSITY OF CAMBRIDGE | Electricity Policy Research Group

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

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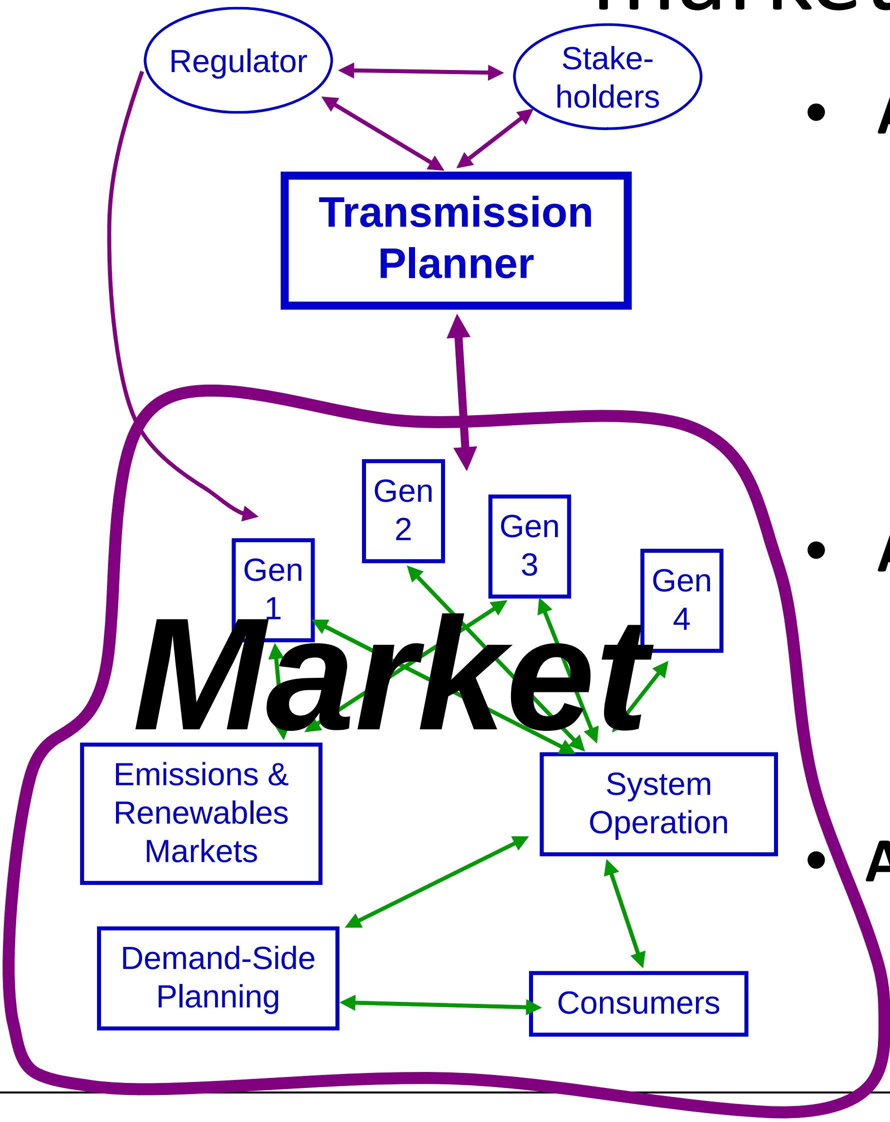
Outline

- Basic questions
- Modeling framework
- Assumptions
- Results
  - Robust plans
  - Value of information
  - Cost of naiveté
  - Option value

Plan transmission, but consider market response!



- A "multilevel" (Stackelberg) game:
  - *Upper level:* planners (& regulator, stakeholders), who anticipate reactions of …
  - *Lower level:* market response of consumers, generators
- Account for responses:
  - Price effects on gen type and siting decisions
  - Influence of policy on above
- Account for uncertainties:
  - Want robust plans that do well under a range of possible futures

Basic questions

- **Optimal strategy under multiple scenarios?**
  - **Solve stochastic two-stage model: "OPT"**
- **Value of perfect information (EVPI)?**
  - **Optimize separately for each scenario s: "PI_s"**
  - **Compare cost of PI_s *vs* OPT, averaged over scenarios**
- **Cost of ignoring uncertainty (ECIU)?**
  - **Solve naïve model (no uncertainty): "NAÏVE"**
  - **Compare cost of NAÏVE *vs* OPT averaged over scenarios**
- **Option value?**
  - **Solve model assuming no options later: "OPENLOOP"**
  - **Compare cost of OPENLOOP *vs* OPT**

Deterministic planning can't answer these!

Modelling framework

- Two-stage Stackelberg game:

1. TSOs decide on transmission investment
2. Generators decide on generation investment
3. Decisions are implemented; Market operation
4. Repeat 1-3

Modelling framework

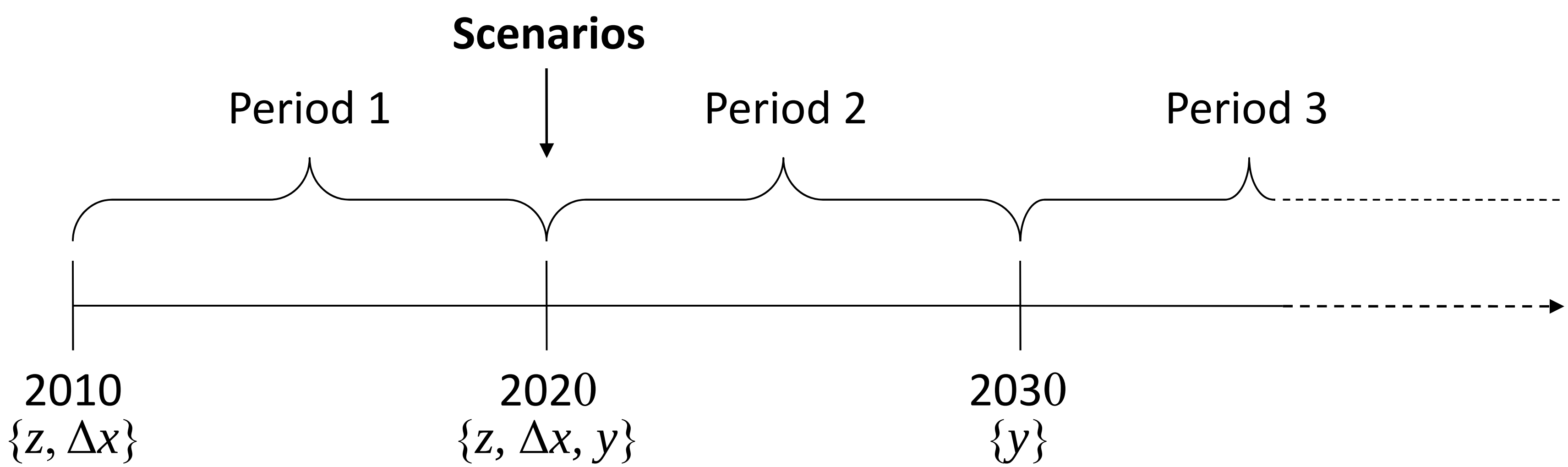
SUPERGEN FLEXNet

- If objectives are aligned:

1. Decisions on transmission+generation investment
2. Decisions are implemented; Market operation
3. Repeat 1-2

- Our approach:
  – two stage stochastic programming
  – Mixed integer program (0-1 transmission variables)

Modelling framework



z	transmission investment decisions
Δx	decisions to build new generation capacity
y	generation dispatch

Modelling framework: Two stage optimization

- Objective: $MIN\ InvestCost_{2010}$
  $+ \Sigma_s P_s (InvestCost_{2020,s} + O\&MCost_{2020+2030,s})$
- Subject to constraints:
  - Build limits for 2010 and each *s* in 2020:
    - Transmission
    - Regional gen capacity
  - Operating constraints for each *s* in 2020 & 2030:
    - Capacity constraints upon gen & flows
    - Kirchhoff's laws for power flow
    - Renewable target
- ~ 0.5M variables, constraints
  - Coefficients, constraints can vary by *s*

Assumptions I - Structural

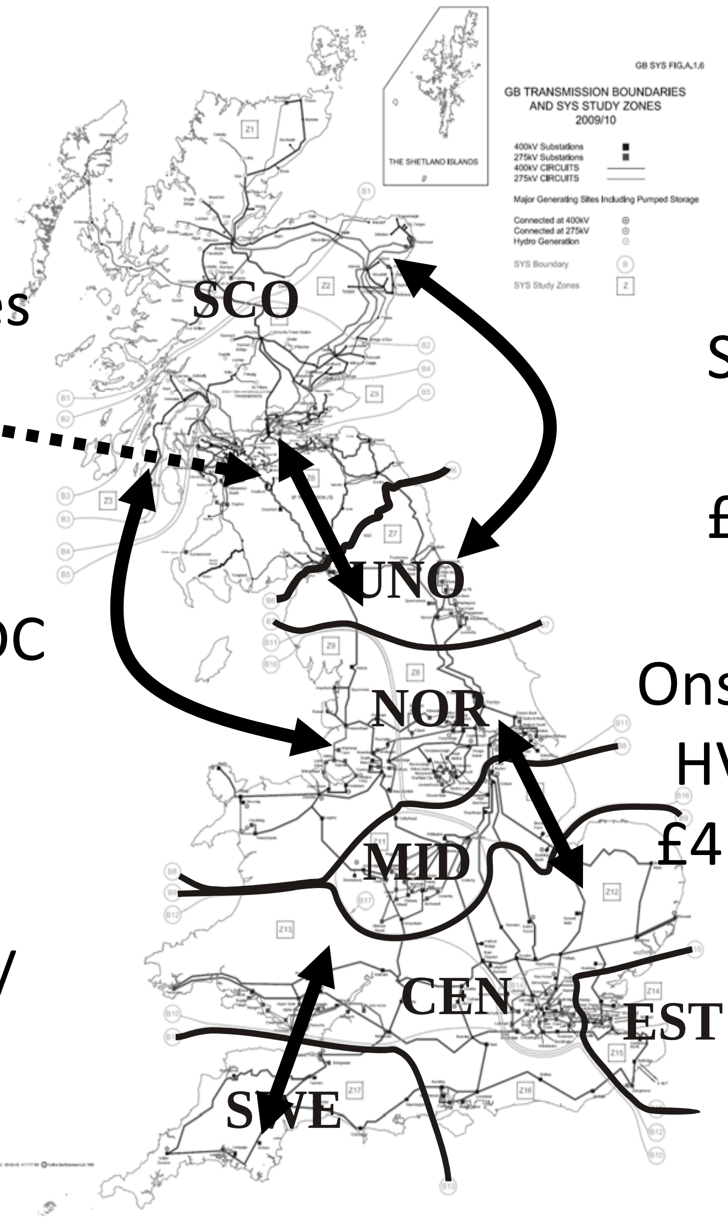
- Alignment of transmission & gen objectives
- Generation:
  - linear cost functions
  - no start-up costs, min run levels, 'lumpy' investment
- Transmission: constant flow limits
- Demand:
  - constant regional fractions
  - no demand response
- Renewables targets: met in most efficient way
- Storage

Assumptions II - Numerical

- Wind data from Neuhoff et al. (2006)
  – One year of wind output in each region
- Transmission constraints from National Grid
- Existing capacity and demand data from DECC
- Transmission investment alternatives from ENSG
- Sampling

Assumptions II - Numerical

Regions and
Transmission investment alternatives



Various new/ upgrades £260M

Subsea HVDC £575M

Subsea HVDC £575M

Onshore HVDC £410M

Various new/ upgrades £410M

Making networks fit for renewables …

Assumptions II – Numerical

Scenarios

	Investment cost	Fuel cost	Trans. Cost	Demand	CO_2 price	Other
Status Quo		CC/GT/DG: +30/+80%		+2.5%/ +5%	15/15	No Renewables target
Low cost DG	DG -50%	CC/GT -10/-20% DG: -50%		+2.5%/ +5%	30/50	RT: 10/20% No new nuclear
Low Cost Large Scale Green	Renewables -40%	CC/GT/DG +60/+160		-20%/ - 30%	50/80	RT: 20/30%

Assumptions II – Numerical

Scenarios

	Investment cost	Fuel cost	Trans. Cost	Demand	CO_2 price	Other
Low Cost Conven-tional	Conven-tional -30%	CC/GT/DG: -10/-20%		+20%/ +40%	20/25	No RT
Paralysis	All except offshore wind +100%	CC/GT/DG: +30/+80%	Onshore +100% Others +20%	+20%/ +40%	30/50	RT: 10/20%; No new nuclear
Techno+	All -30%	CC/GT/DG: +30/+80%	All -20%	+10%/ +20%	30/50	20/30%

Results

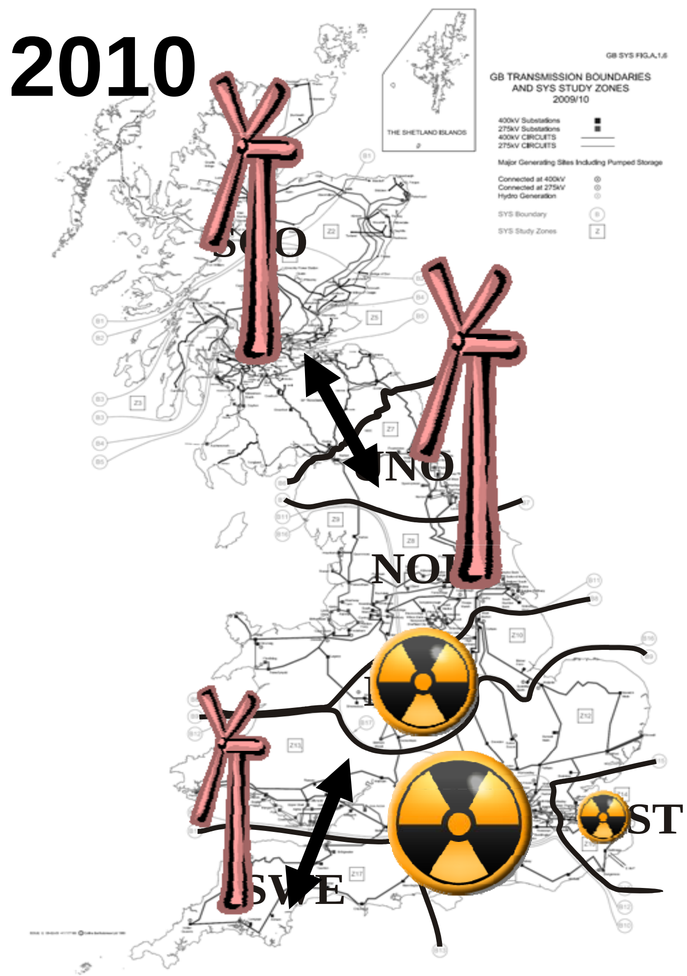
1. Optimal robust solution
   – Two-stage stochastic model
2. Value of Information (EVPI)
   – Deterministic model (best trans & gen solution for each scenario) → $EVPI_{T\&G}$
   – Deterministic model with generation decisions fixed → $EVPI_{Trans}$ (lower bound)
3. Cost of naïve decision (ECIU)
   – Stochastic model, imposing naïve 1st stage transmission decisions → $ECIU_{Trans}$
4. Option value of transmission
   – Stochastic with same transmission decision in every scenario → $\text{Option value}_{Trans}$

Disclaimer

The following results are (very) preliminary and used for method illustration purposes only. They cannot be used to evaluate proposed transmission investments.

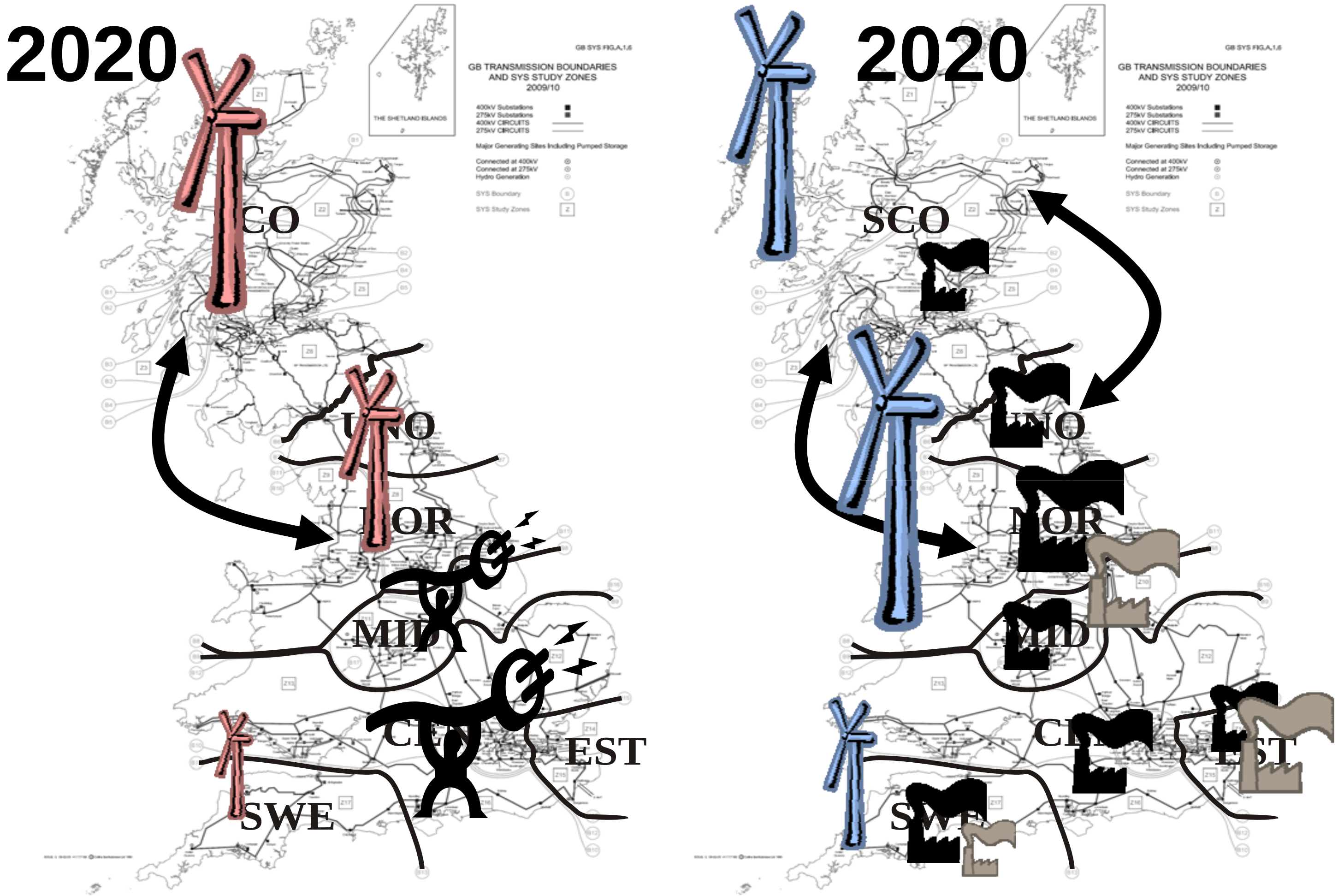
Stochastic model – stage 1

Onshore wind	CC
Offshore wind	GT
Nuclear	DG
Biomass	



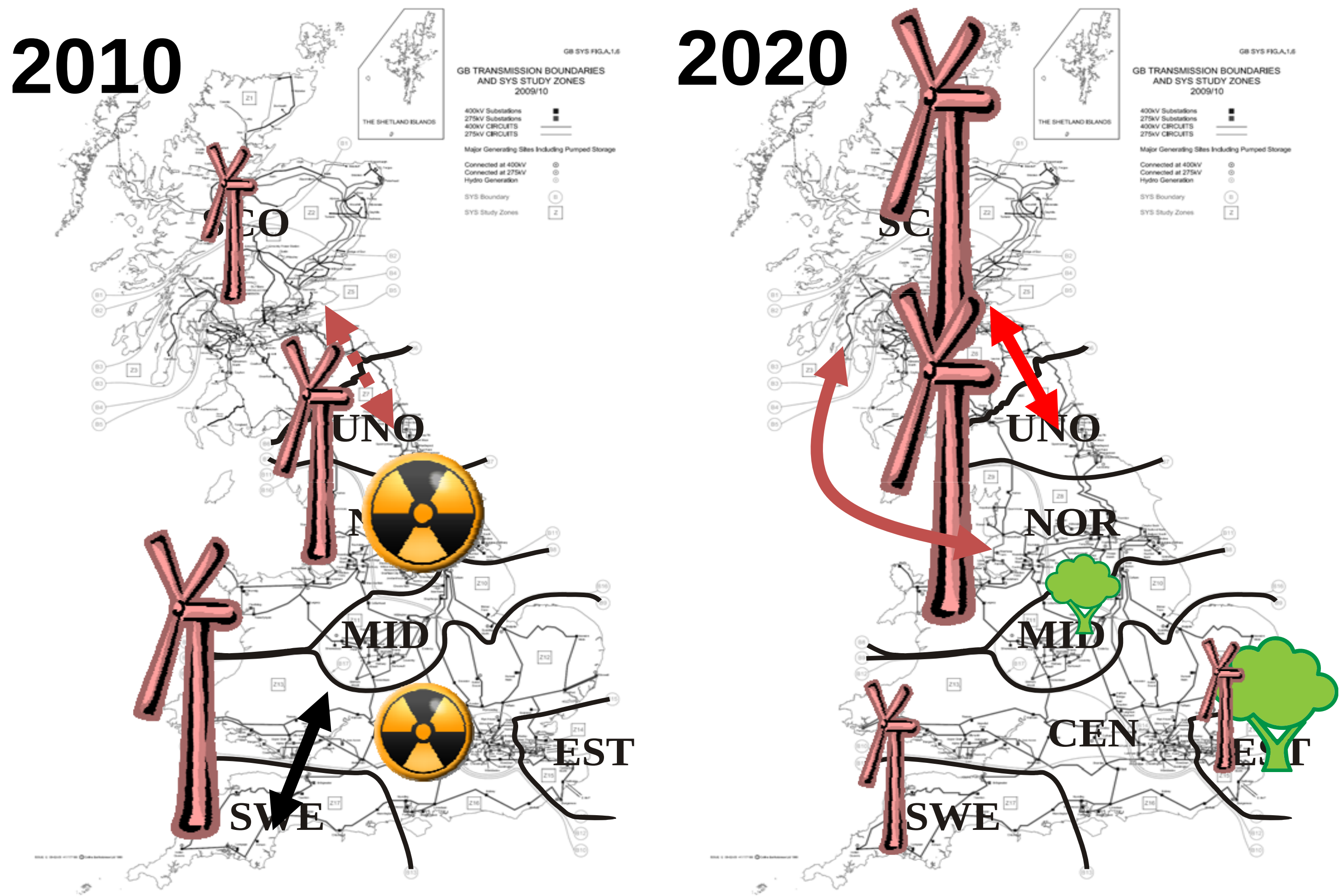
Stochastic model – stage 2

Scenarios: Low Cost DG; Paralysis



What if you had perfect foresight?

Low Cost Large Scale Green, stages 1 & 2



Value of Perfect Information

- Total EVPI = $TC_{stoch} - \sum_{s} \pi^{s} TC^{s}_{determ}$

  = £7,182M (7.37% of TC_{stoch})
- EVPI when generators do in the 1st stage what they did in the stochastic model

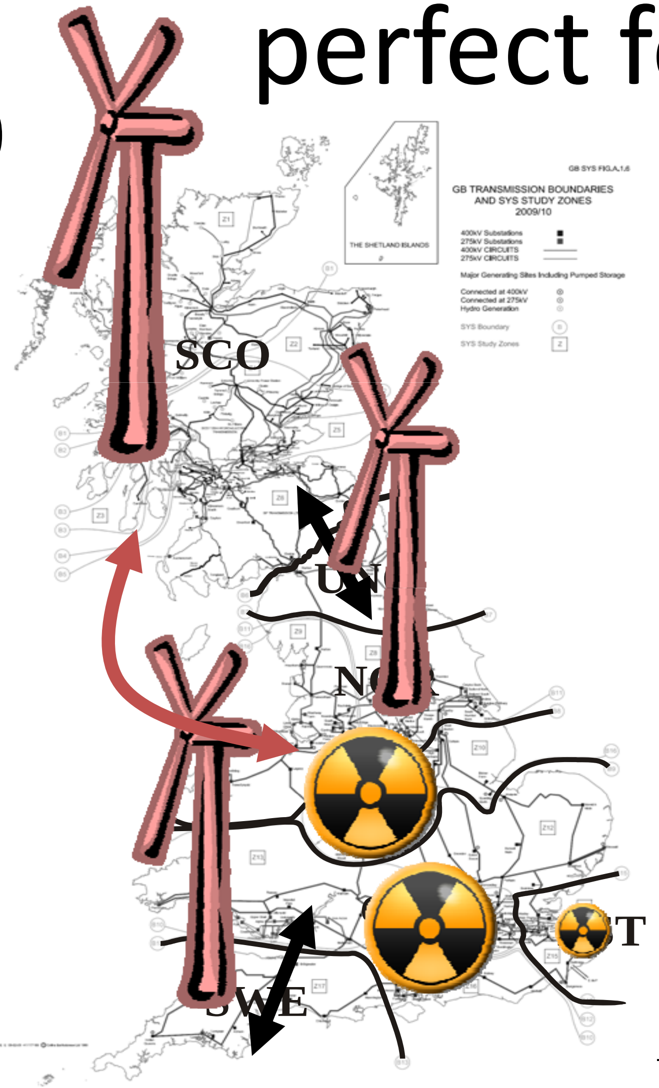
  = £10M (0.01%)

  = lower bound on $EVPI_{Trans}$

What if you think you have perfect foresight?

2010

E.g., Paralysis imposed stage 1



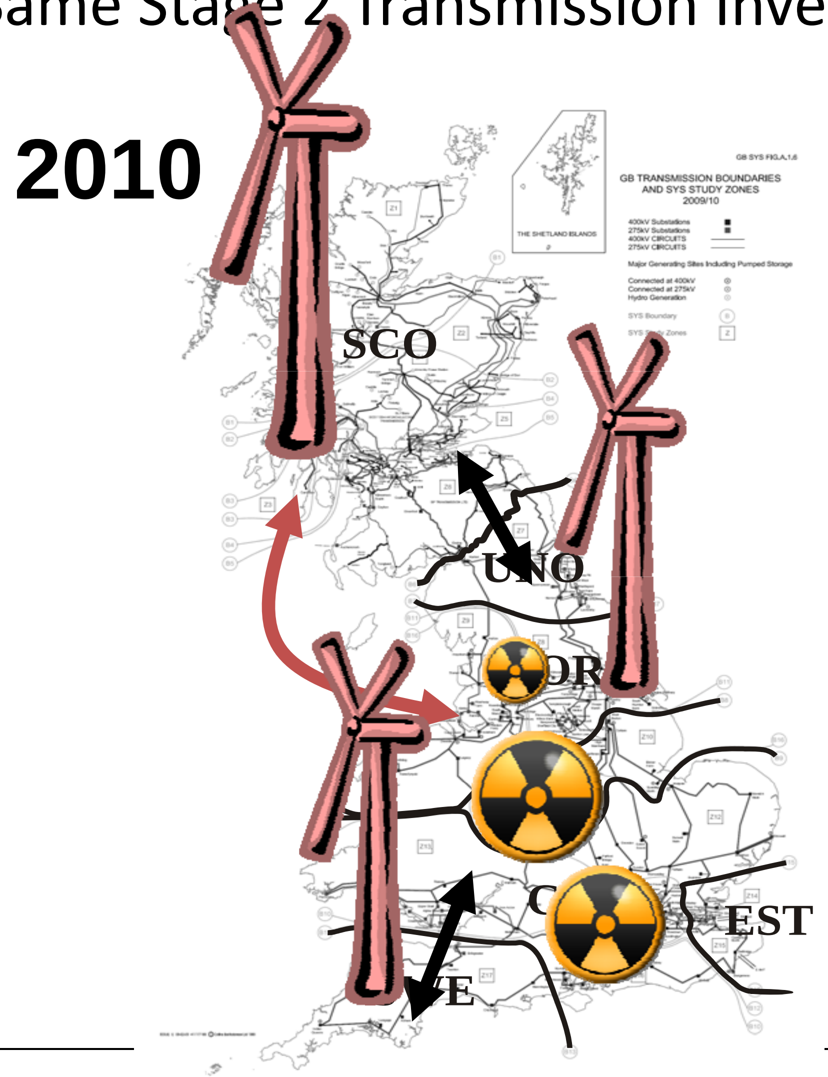
Cost of Naïve Decisions: $ECIU_{Trans}$

Impose Status Quo	£261M	0.27%
Impose Low Cost DG	£261M	0.27%
Impose Low Cost Large Scale Green	£ 79M	0.08%
Impose Low Cost Conventional	£261M	0.27%
Impose Paralysis	£ 36M	0.04%
Impose Techno+	£ 36M	0.04%
Average	£156M	0.16%

Comparable to 1st stage Transmission Investments

What if there is no optionality?

Same Stage 2 Transmission Investments in all scenarios



Making networks fit for renewables …

Option Value (Transmission)

= Increase in cost when eliminate optionality

= £117M (0.12%)

Conclusions

- Main insights
  - Ignoring risk has quantifiable economic consequences
  - Option values can be significant
  - Approach useful for policy/planning questions
- Future work
  - Revisit assumptions
  - Bi-level formulation