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How to deal with uncertainty for Pan-European electricity system planning and operation modelling

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plan4res

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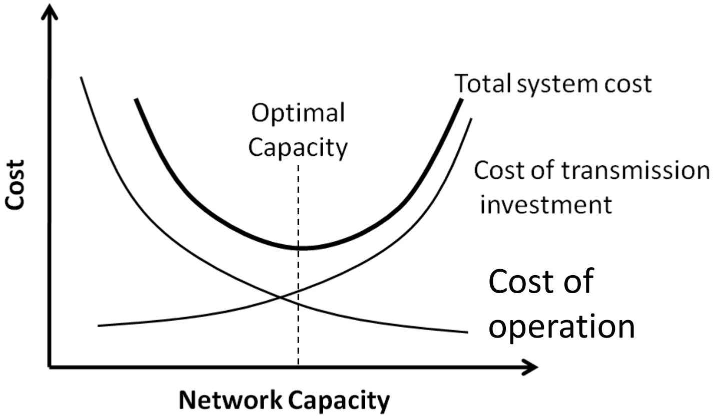
Planning in power systems

- Question: **where, when and how much capacity to build**?
- In thermal-dominated systems, transmission planning is driven by the need to meet peak demand with sufficient reliability.
- In systems with intermittent energy sources, transmission planning is driven by cost-benefit considerations

max{social welfare} = min{total cost}

- The system evolution is affected by significant uncertainty:
  - **Short-term Uncertainties** (operational timescale)
  - **Long-Term Uncertainties** (investment timescale)
    - Location, size and technology of new generation plants
    - Investment costs of novel technologies (e.g. storage)
    - Long-term demand growth due to electrification of transport and heat
    - Long-term price trends (e.g. coal, gas, CO2)



Why bother?

- Capital decisions in power systems are largely **irreversible**.
This creates the risk of inefficient investment (**stranded assets**).
- There is **learning** regarding future developments (inter-temporal resolution of uncertainty).
- The planner can exert **managerial flexibility** in his decision making; ‘Fit-and-forget’ vs. ‘Wait-and-see’.

Planning-under-uncertainty optimisation frameworks *are fundamental for identifying* ***openings for strategic action***

Decision criteria

Deterministic → Consideration of a single (e.g. worst case) scenario

+ Straightforward

− No consideration of strategic actions and alternative realisations

Stochastic → Minimisation of expected system cost

+ Consideration of strategic actions

− Definition of probabilities problematic

− No risk hedging

Risk-Constrained → Utilization of a spectral risk measure (e.g. CVaR)

+ User-defined risk profile → exploration of the ‘efficient frontier’

+ Linear mathematical formulation

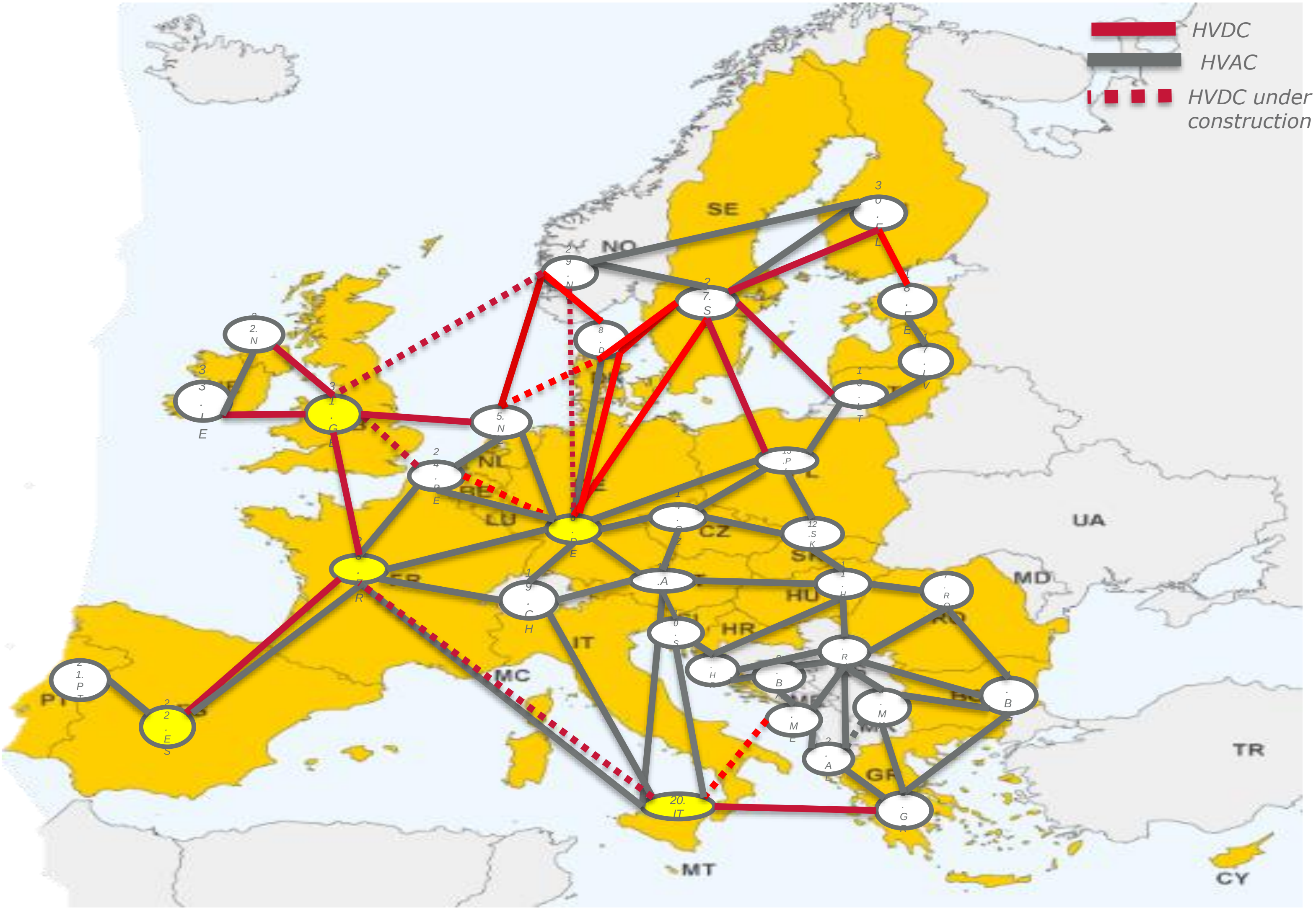
− Definition of probabilities problematic

Robust → Maximisation of a robustness metric (e.g. min{max{regret}})

+ Probability-independent

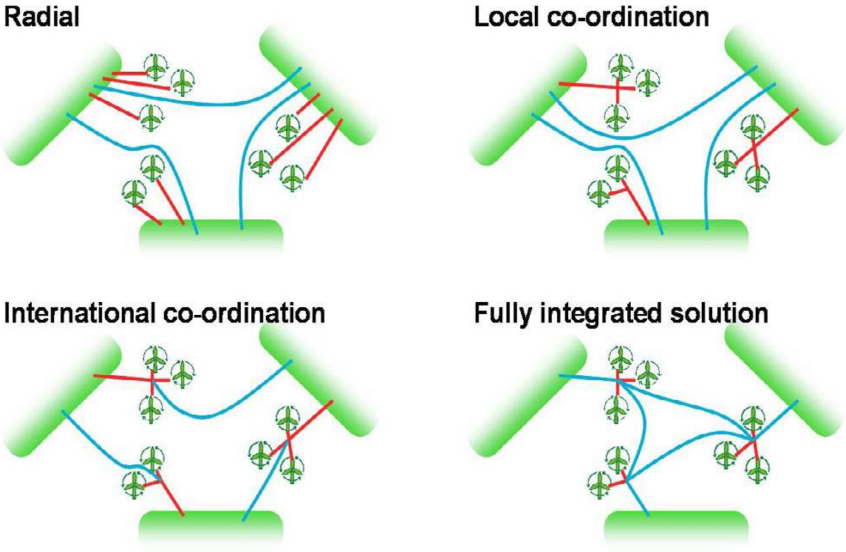
− Can be too conservative

EU Grid model



North Sea - Context

1. Today’s installed capacity levels of about **5GW** of offshore wind generation may reach **150GW** by 2030, with **half** of this capacity expected to be located in the North Seas ….. but there is significant ***uncertainty***
2. There may be a significant opportunity to **integrate offshore wind** generation **and interconnectors** projects in the North Europe in order to take advantage of potentially significant **economies of scales**



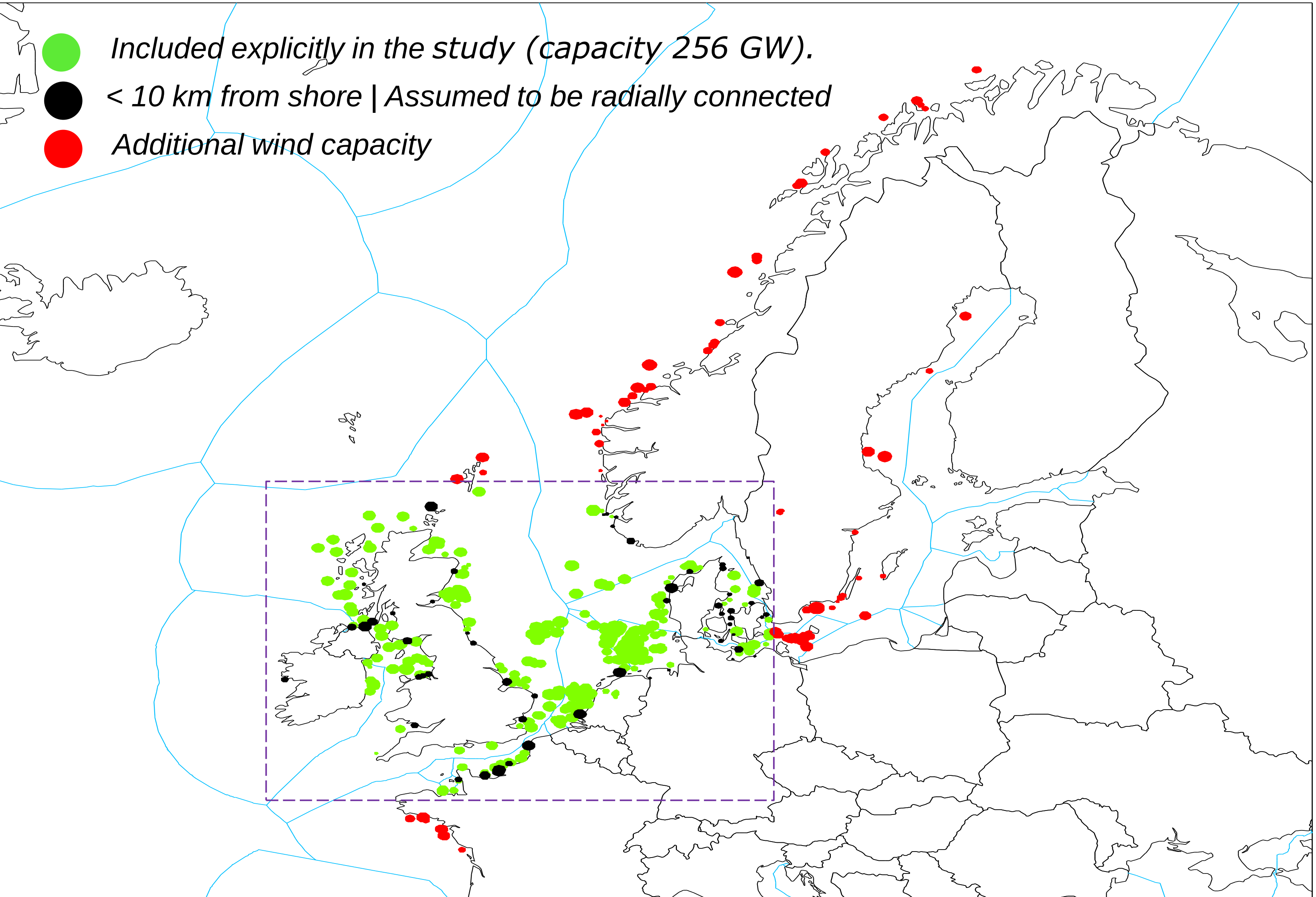
Radial

Local co-ordination

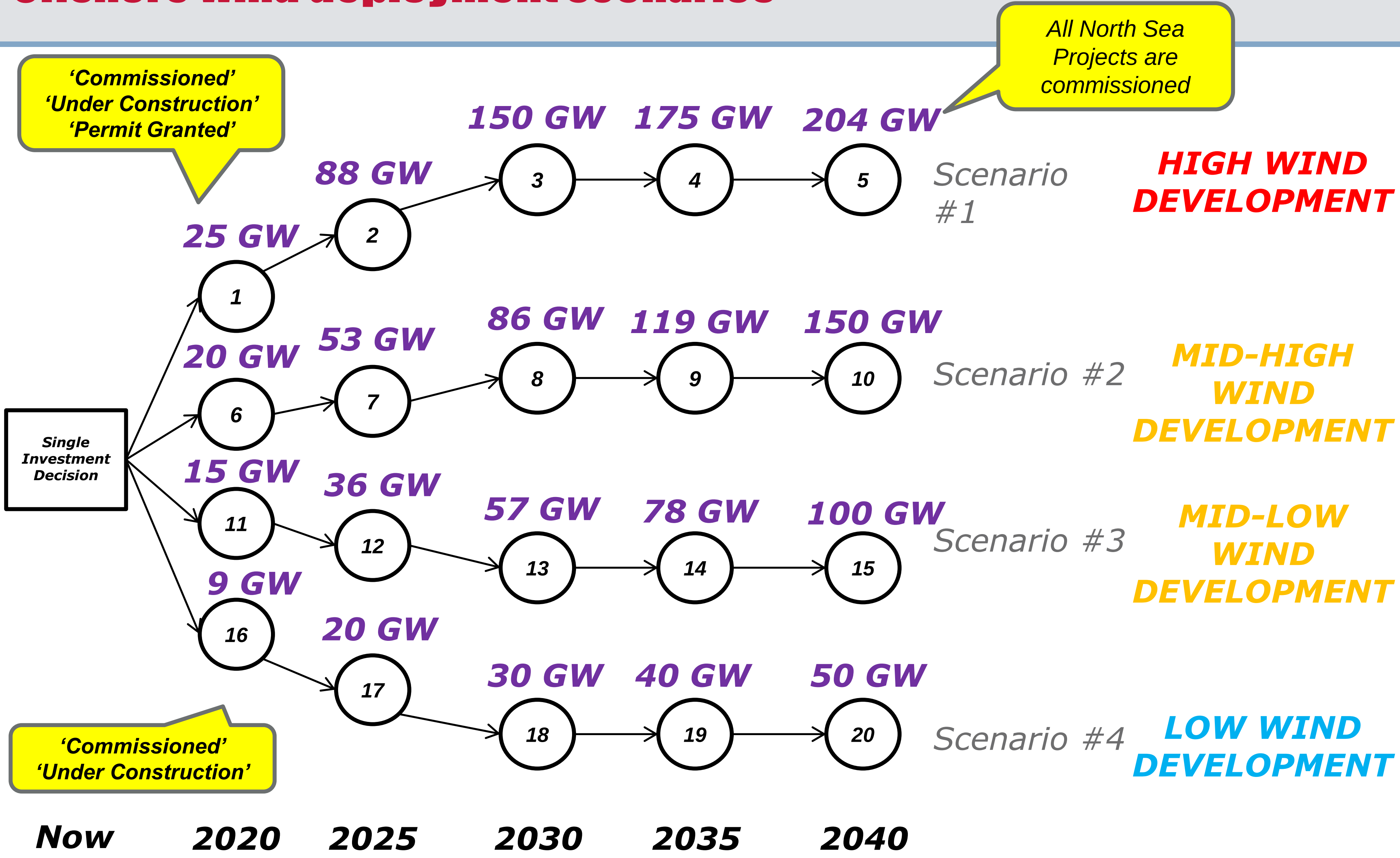
International co-ordination

Fully integrated solution

Offshore Wind Projects Database



Offshore wind deployment scenarios



'Commissioned'
'Under Construction'
'Permit Granted'

All North Sea
Projects are
commissioned

Single Investment Decision

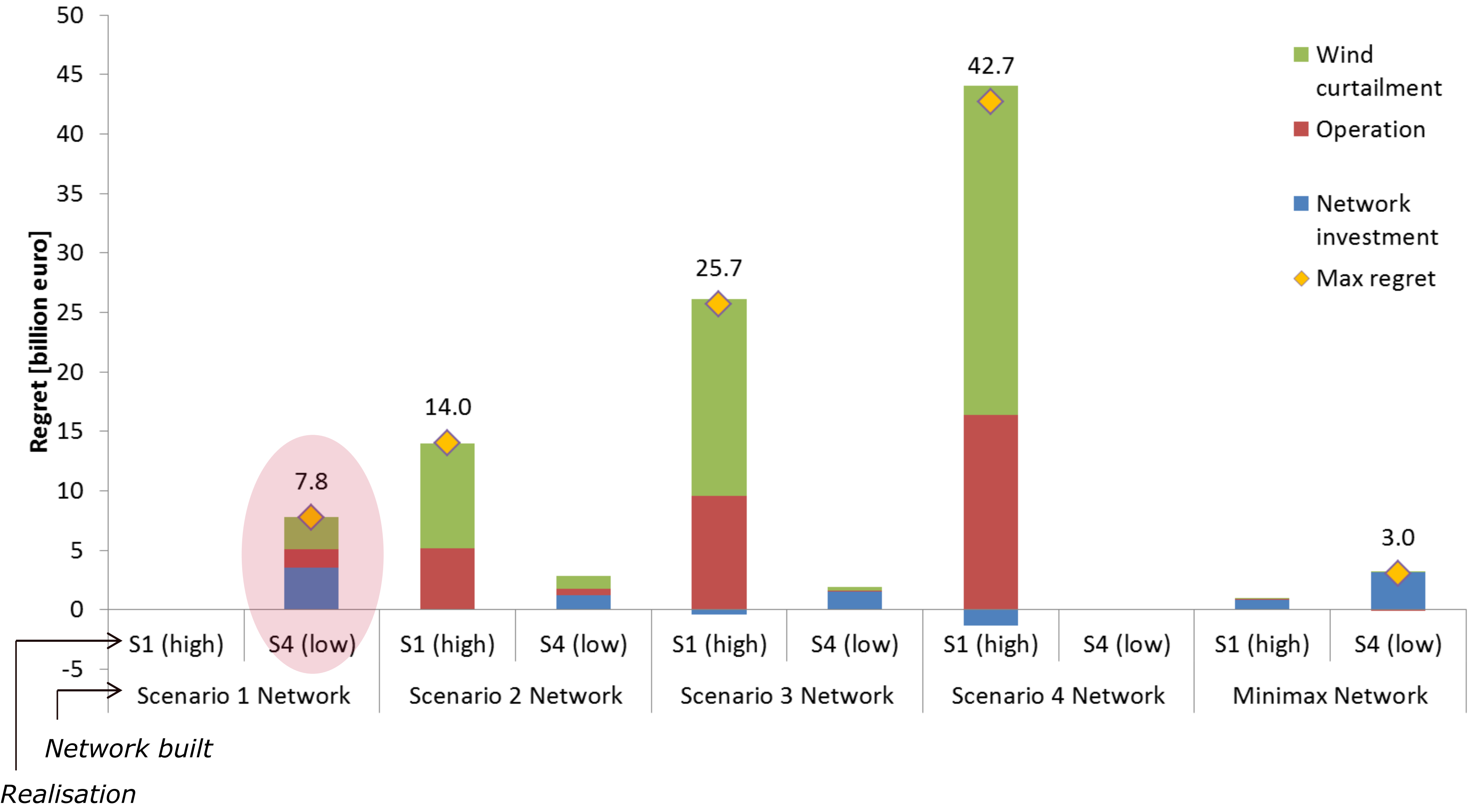
Now	2020	2025	2030	2035	2040		
Single Investment Decision	1 25 GW	2 88 GW	3 150 GW	4 175 GW	5 204 GW	Scenario #1	**HIGH WIND DEVELOPMENT**
	6 20 GW	7 53 GW	8 86 GW	9 119 GW	10 150 GW	Scenario #2	**MID-HIGH WIND DEVELOPMENT**
	11 15 GW	12 36 GW	13 57 GW	14 78 GW	15 100 GW	Scenario #3	**MID-LOW WIND DEVELOPMENT**
	16 9 GW	17 20 GW	18 30 GW	19 40 GW	20 50 GW	Scenario #4	**LOW WIND DEVELOPMENT**

'Commissioned'
'Under Construction'

Modelling approaches:

1. Existing work:
    1. Work led by North Seas Countries' Offshore Grid Initiative
    2. Offshore-Grid: Offshore Electricity Infrastructure in Europe
2. Areas for further enhancement:
    1. Optimising grid topology, including full quantification of the benefits of integrated design - considering operation and network investment (benefits from economies of scale)
    2. Concurrent optimisation of offshore grid and cross-border interconnectors
    3. Dealing with uncertainty in time, location and amount of wind generation deployment, demand growth and storage investment cost
    4. Understanding benefits of strategic/proactive network planning

Regret of different network solution



Problem Formulation

min{ $\mathcal{R}$(investment Cost + Operation Cost + Lost Load) }

subject to:

Investment constraints **(MILP)**

Operational constraints **(LP)**

- Power Flow equations
- Transmission constraints
- Generation constraints
- Storage Constraints

- *Multi-Stage problem*
- *Investment variables couple the stages*
- *Stochastic formulation – Uncertainty described by scenario trees:*
  - **+** *Consideration of strategic actions*
  - **–** *Definition of probabilities problematic*
- $\mathcal{R} \Rightarrow$ *Coherent Risk Measure (e.g. E[ ], CVaR)*

Modelling Challenges in Stochastic optimisation

Severe challenges related to the **problem size:**

- Consideration of large scenario trees with numerous multivariate nodes
  - **Multiple sources of uncertainty** expand tree size exponentially
  - Build times increase importance of **time resolution**
- Novel technologies introduce **more coupling** in the problem structure
  - Storage Elements/Demand-side response → time coupling
  - Corrective control automatons (e.g. FACTS) → pre/post-fault coupling

Decomposition & Reformulation

- **Numerous new technologies** in addition to traditional assets → binary variables

Convexification

- Renewables and new demand patterns **expand the operational state-space**

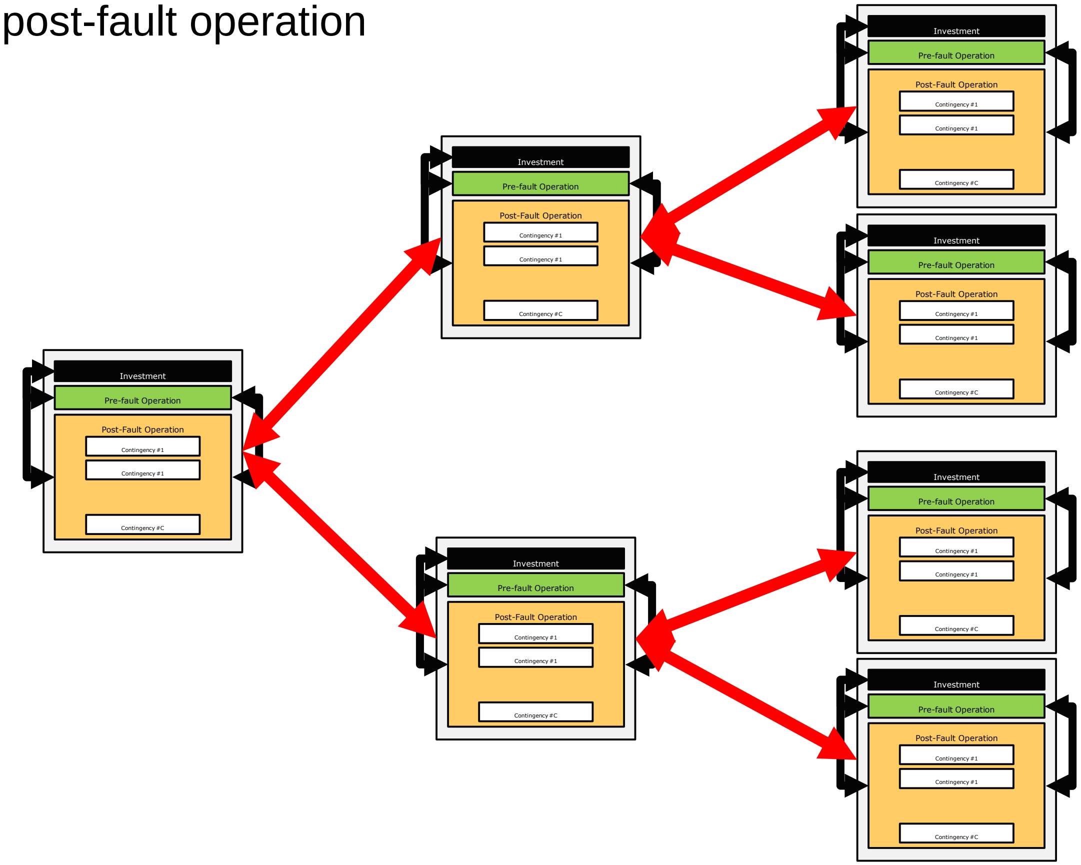
Optimal choice of representative points

(scenario selection)

*Traditional optimisation methods are reaching their **computational limits***

Modelling Opportunities

- Problem structure suitable for parallelization an decomposition:
  - Between investment and operation
  - Between operation of successive periods
  - Between pre-fault and post-fault operation
  - Per stage
  - Per scenario



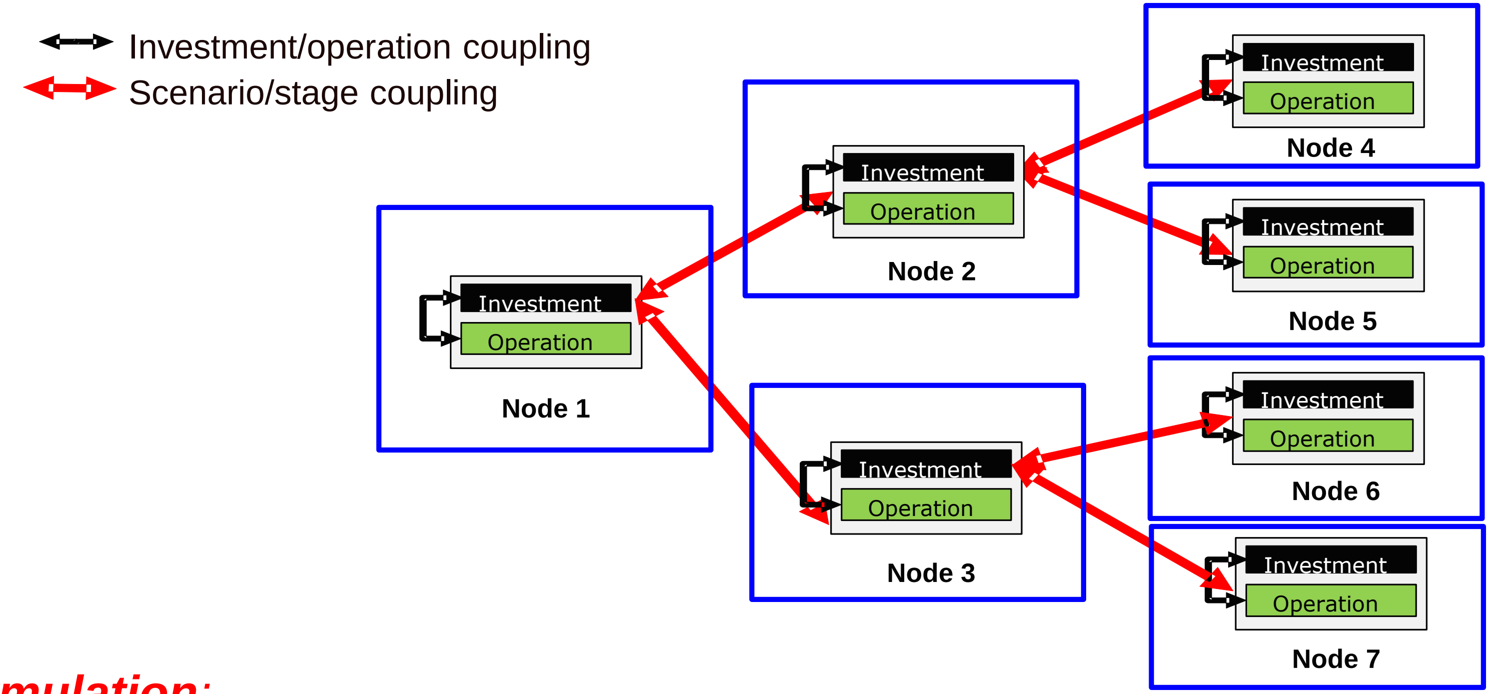
Large scale planning under uncertainty

Cost-effective European power system planning under high-dimensional uncertainty is **computationally extremely demanding,** making the case for decomposition.

3 methods for large – scale investment planning have been developed so as to reduce the computational burden of the original problem.

Nested Benders decomposition	*Forward and backward passes of the formulation increase the accuracy in the selection of Lagrange multipliers.*
Multicut Benders decomposition	*Numerous cut constraints are appended per iteration at the master, thereby increasing the speed of convergence.*
Hierarchical Benders decomposition	*A combination of the classic Benders approach with the nested decomposition aiming for greater computational performance.*

Nested Bender Decomposition



Node Formulation:

Forward pass: Identify interesting points (trials) in decision state-space.

Backward pass: Compute Lagrangian multipliers to approximate future cost function in each node.

Computational performance

Nodes	No. of Iterations	CPU Time	Cost lower bound (£m)	Cost upper bound (£m)	Gap
Benders Decomposition					
15	12	55s	6436.3	6346.3	0%
31	15	5m 52s	6917.1	6917.1	0%
63	11	3d 19h 39m	7309.5	7328.5	0.26%
127	6	15d 14h 35m	7559.8	7642.9	1.08%
255	7	21d 7h	7585.3	7674.4	1.17%
Nested Benders Decomposition					
15	13	1m 58s	6301.3	6348.8	0.74%
31	14	4m 28s	6840.8	6922.8	1.18%
63	16	10m 39s	7219.7	7316.9	1.32%
127	12	16m 13s	7449.2	7612.3	2.12%
255	12	28m 28s	7464.9	7637.4	2.26%

simple = better

better upper bound

45X

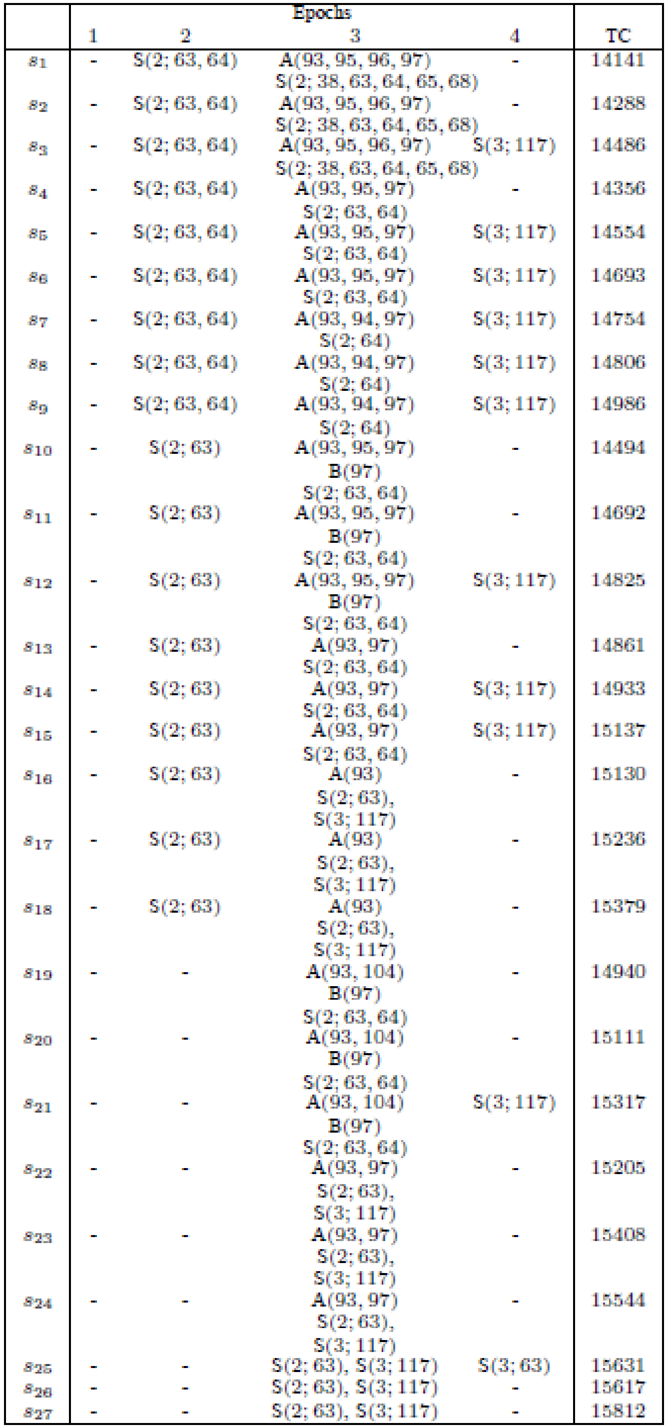
Decision under uncertainty

No. of Iterations	CPU Time	Cost lower bound (£m)	Cost upper bound (£ m)	Gap
Benders Decomposition				
5	>21d	14,468	15,139	4.4%
Nested Benders Decomposition				
314	2d 3h 10m	14,637	14,803	1.1%

Nested Benders is clearly superior for large planning problems

Large variability in decisions across scenarios

Inclusion of Energy storage assets leads to a 15% reduction of investment cost



	Epochs				TC
	1	2	3	4	
s_1	-	S(2; 63, 64)	A(93, 95, 96, 97) S(2; 38, 63, 64, 65, 68)	-	14141
s_2	-	S(2; 63, 64)	A(93, 95, 96, 97) S(2; 38, 63, 64, 65, 68)	-	14288
s_3	-	S(2; 63, 64)	A(93, 95, 96, 97) S(2; 38, 63, 64, 65, 68)	S(3; 117)	14486
s_4	-	S(2; 63, 64)	A(93, 95, 97) S(2; 63, 64)	-	14356
s_5	-	S(2; 63, 64)	A(93, 95, 97) S(2; 63, 64)	S(3; 117)	14554
s_6	-	S(2; 63, 64)	A(93, 95, 97) S(2; 63, 64)	S(3; 117)	14693
s_7	-	S(2; 63, 64)	A(93, 94, 97) S(2; 64)	S(3; 117)	14754
s_8	-	S(2; 63, 64)	A(93, 94, 97) S(2; 64)	S(3; 117)	14806
s_9	-	S(2; 63, 64)	A(93, 94, 97) S(2; 64)	S(3; 117)	14986
s_{10}	-	S(2; 63)	A(93, 95, 97) B(97) S(2; 63, 64)	-	14494
s_{11}	-	S(2; 63)	A(93, 95, 97) B(97) S(2; 63, 64)	-	14692
s_{12}	-	S(2; 63)	A(93, 95, 97) B(97) S(2; 63, 64)	S(3; 117)	14825
s_{13}	-	S(2; 63)	A(93, 97) S(2; 63, 64)	-	14861
s_{14}	-	S(2; 63)	A(93, 97) S(2; 63, 64)	S(3; 117)	14933
s_{15}	-	S(2; 63)	A(93, 97) S(2; 63, 64)	S(3; 117)	15137
s_{16}	-	S(2; 63)	A(93) S(2; 63), S(3; 117)	-	15130
s_{17}	-	S(2; 63)	A(93) S(2; 63), S(3; 117)	-	15236
s_{18}	-	S(2; 63)	A(93) S(2; 63), S(3; 117)	-	15379
s_{19}	-	-	A(93, 104) B(97) S(2; 63, 64)	-	14940
s_{20}	-	-	A(93, 104) B(97) S(2; 63, 64)	-	15111
s_{21}	-	-	A(93, 104) B(97) S(2; 63, 64)	S(3; 117)	15317
s_{22}	-	-	A(93, 97) S(2; 63), S(3; 117)	-	15205
s_{23}	-	-	A(93, 97) S(2; 63), S(3; 117)	-	15408
s_{24}	-	-	A(93, 97) S(2; 63), S(3; 117)	-	15544
s_{25}	-	-	S(2; 63), S(3; 117)	S(3; 63)	15631
s_{26}	-	-	S(2; 63), S(3; 117)	-	15617
s_{27}	-	-	S(2; 63), S(3; 117)	-	15812

Key observations

In high offshore wind deployment scenarios significant benefits from integrated, strategic approach to developing European grid

Reduction in the achieved operation cost and network investment cost

Flexible investment effective in dealing with large **uncertainty**

Evaluation of trades off requires detailed spatio-temporal integrated models

The computational advantages and effectiveness of decomposition schemes need to be further investigated on the Pan-European case

Thank you!