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Uncertainty for Pan-European electricity system planning and operation modelling

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plan4res

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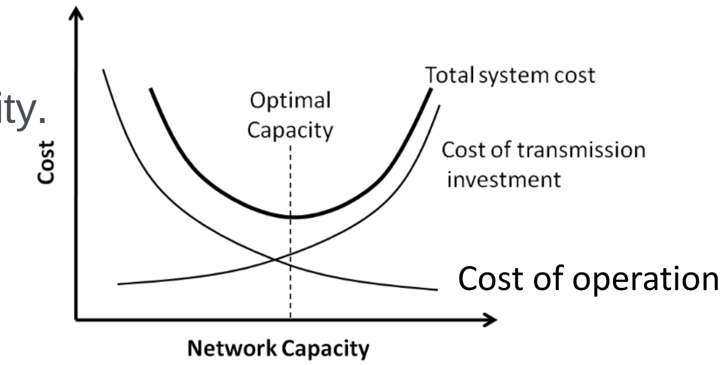
Planning in power systems

Where, when and how much capacity to build?

Transmission planning is driven by

- the need to meet peak demand with sufficient reliability.
- cost-benefit considerations



- **Significant uncertainty:**
  - **Short-term Uncertainties** (operational timescale)
  - **Long-Term Uncertainties** (investment timescale)

Why consider uncertainty?

- 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***

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)*

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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
- **Numerous new technologies** in addition to traditional assets → binary variables
- Renewables and new demand patterns **expand the operational state-space**

Decomposition & Reformulation

Convexification

Optimal choice of representative points
(scenario selection)

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

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Large scale planning under uncertainty

Cost-efficient 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.*

P. Falugi, I. Konstantelos, G. Strbac G, "Planning with Multiple Transmission and Storage Investment Options under Uncertainty: A Nested Decomposition Approach", IEEE Transactions on Power Systems, 2017

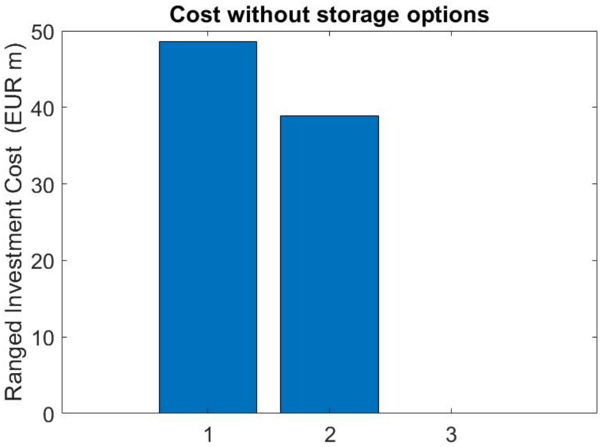
Decision under uncertainty

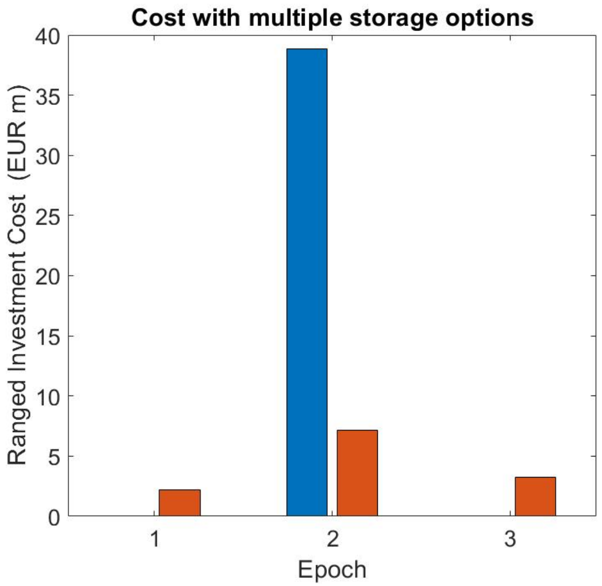
No. of Iterations	CPU Time	Cost lower bound (€ m)	Cost upper bound (€ m)	Gap
Benders Decomposition				
5	>21d	14,468	15,139	4.4%
Nested Benders Decomposition				
314	2d 3h 10m	14,637	14,803	1.1%

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

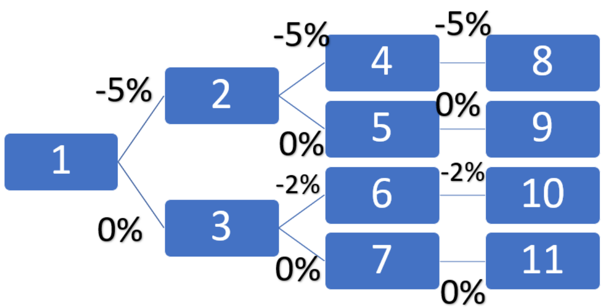




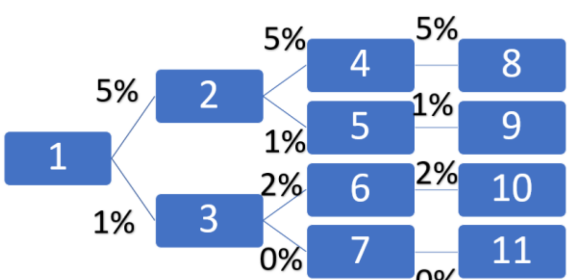
EU Grid model

Complex challenges in planning Pan European system due to significant uncertainty

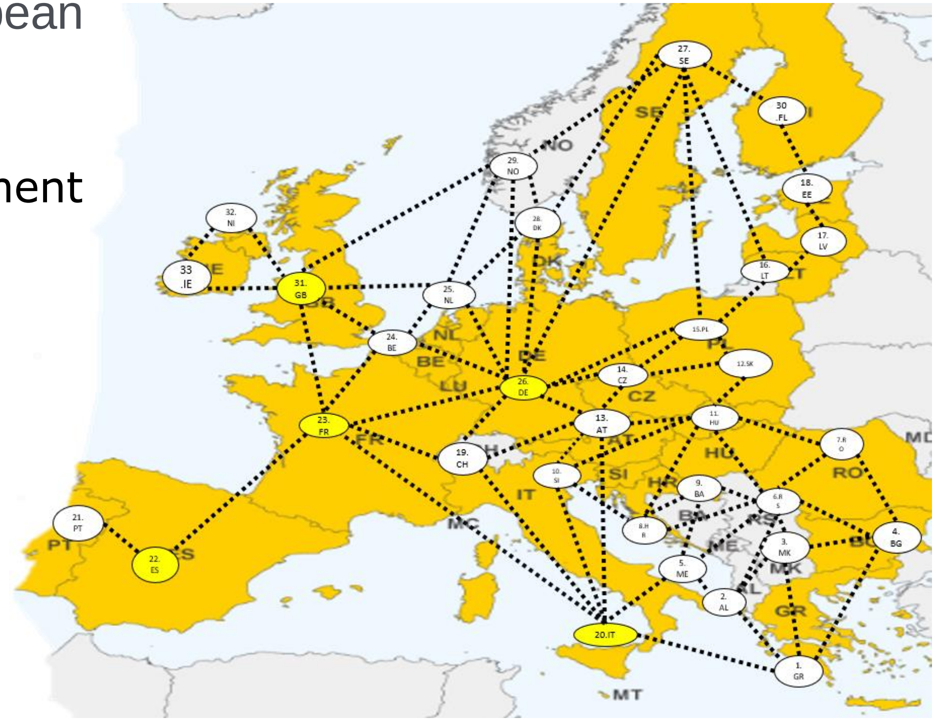
- Uncertainty in **wind and solar** deployment
- Uncertainty in storage **cost**



- Uncertainty in **demand** growth



Years: 2020 – 2060



- **Objective**:
  Develop numerical approaches to solve transmission planning under uncertainty problems considering option value of different technologies such as storage

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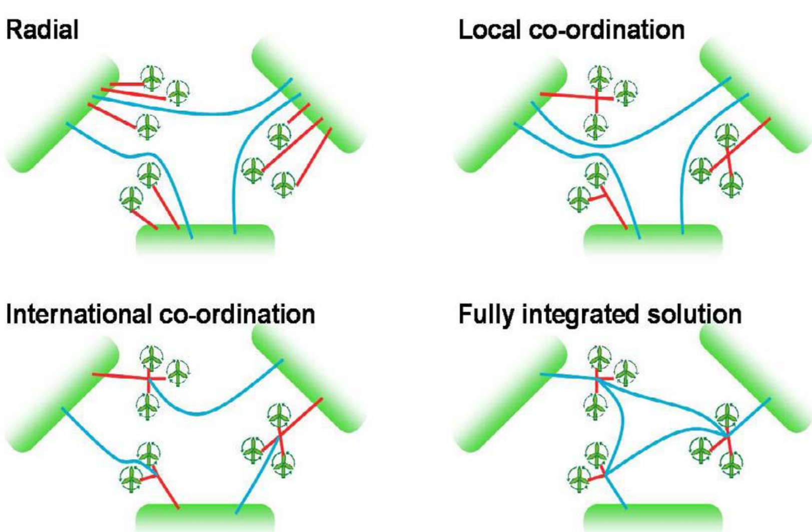
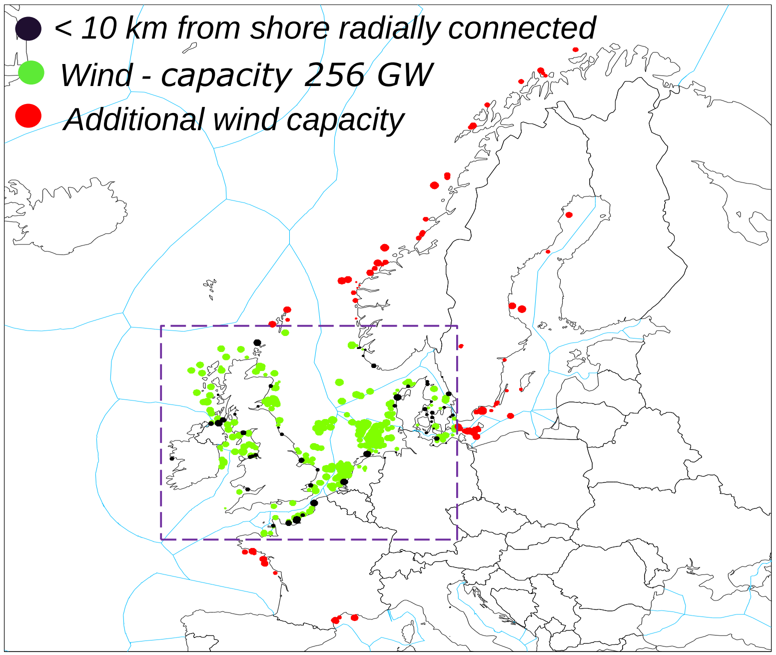
North Sea - Context

- 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***
- 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**



Offshore Wind Projects Database



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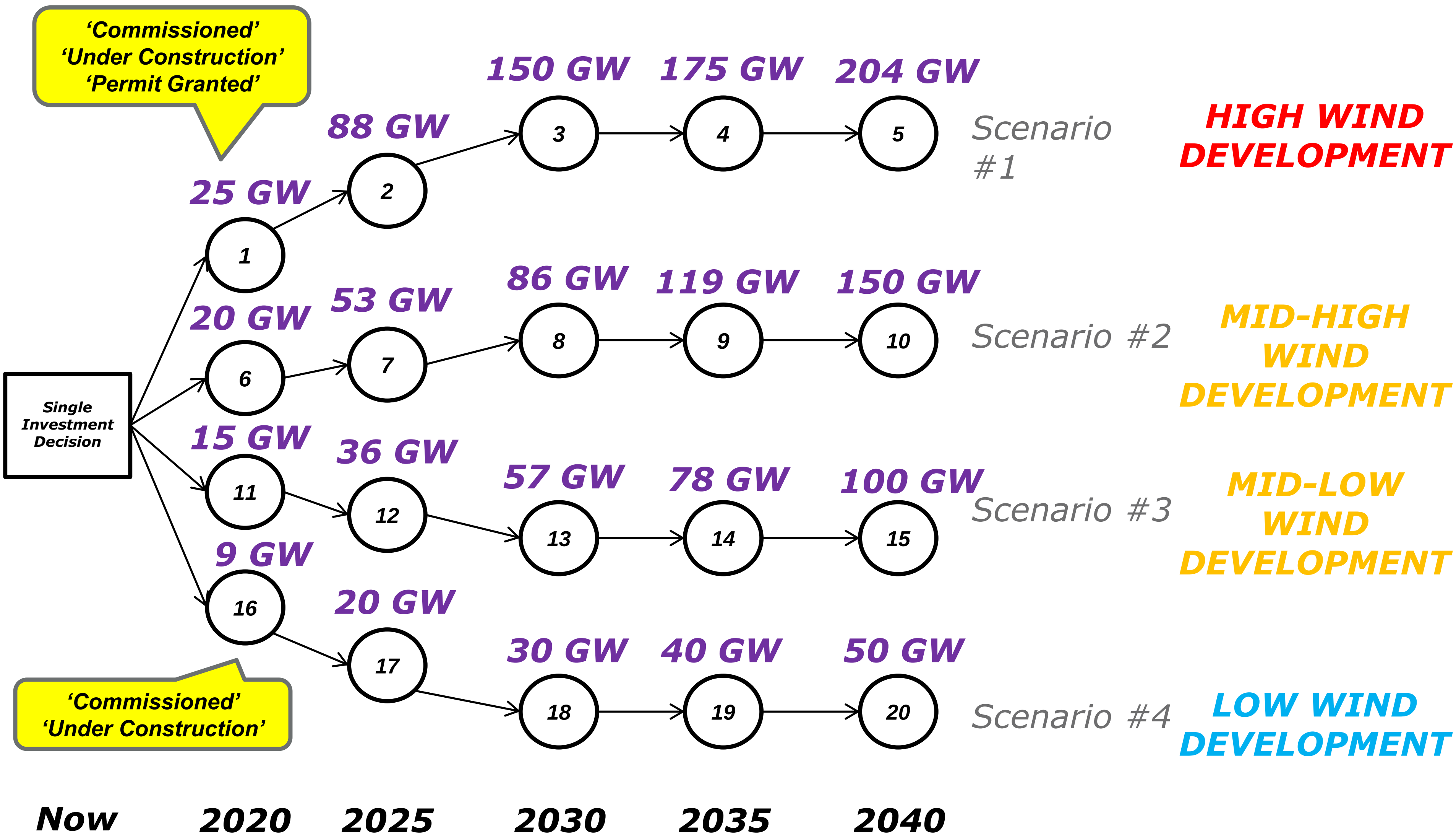
Offshore wind deployment scenarios



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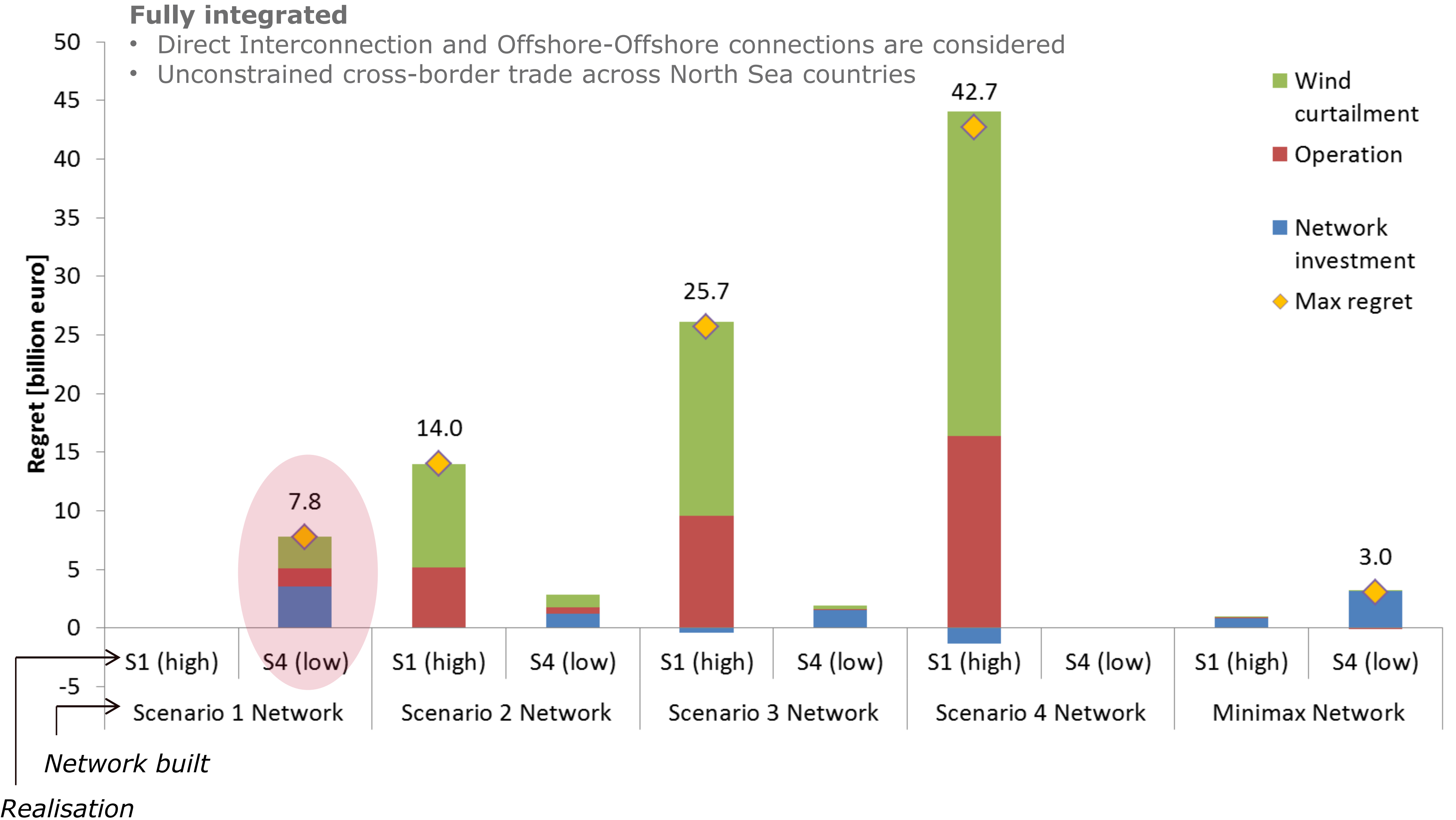
Regret of different network solution



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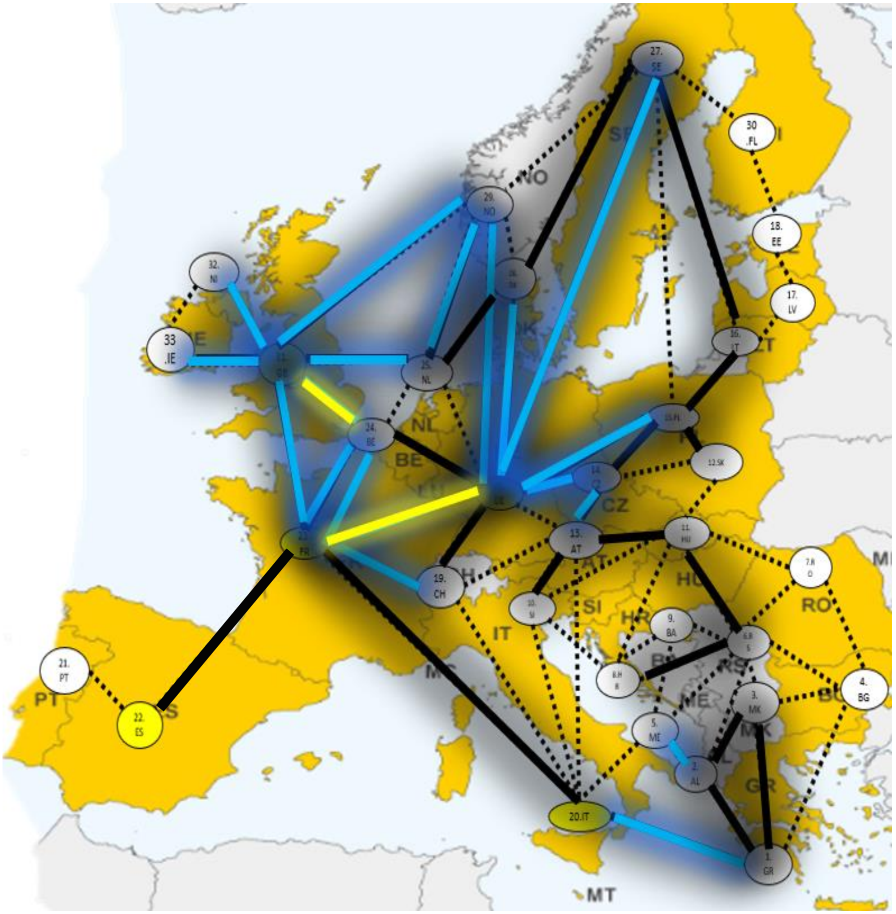
Key messages

- Consideration of uncertainty leads to more efficient investment decisions and better management of the investment risk

  → 'Reduction in operation and network investment cost'.

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

- **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



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

\- Thank you -