North Sea Offshore Grid – Norwegian perspective and grid optimisation research

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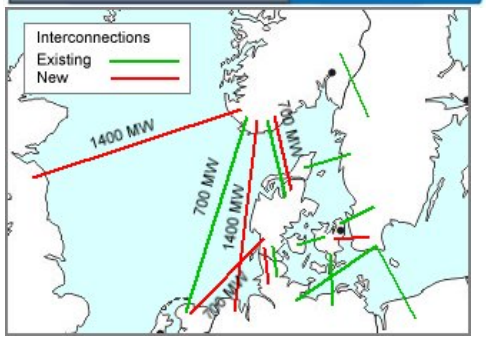
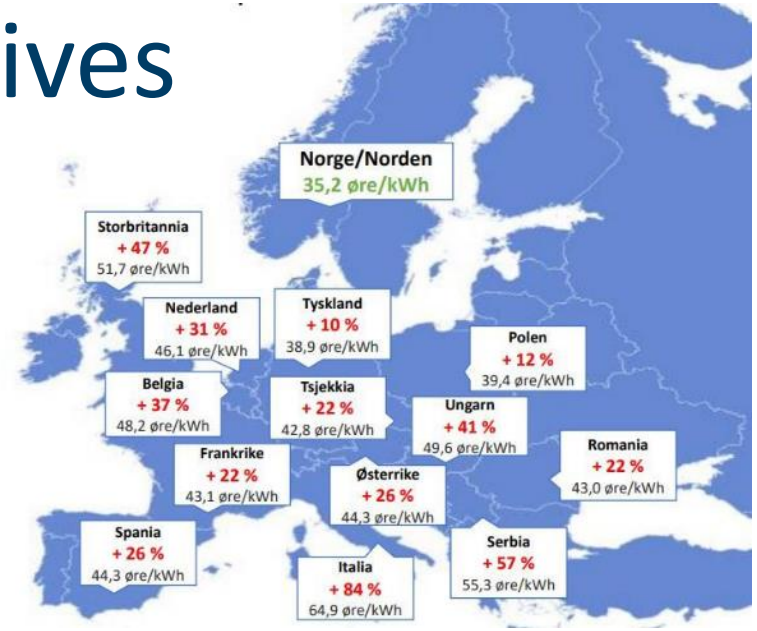


Norwegian perspectives



- Hydro power
- Hydro storage
- Interconnectors
- Oil and gas platforms
- Floating wind
- Cheap electricity
- Power **producers**: How to maximise the value of Norwegian resources? (surplus renewable energy and storage) — more grid!
- Power **consumers**: How to avoid importing (high) continental power prices? — no grid!

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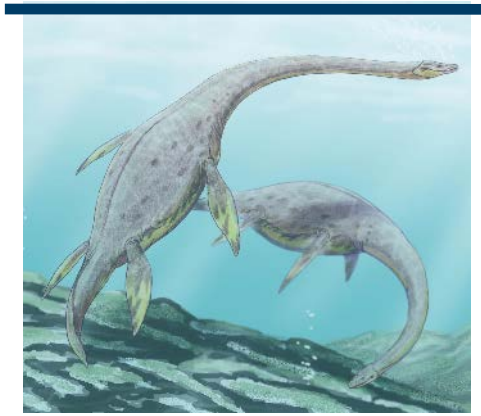
Norwegian NSON-activities

-200 M



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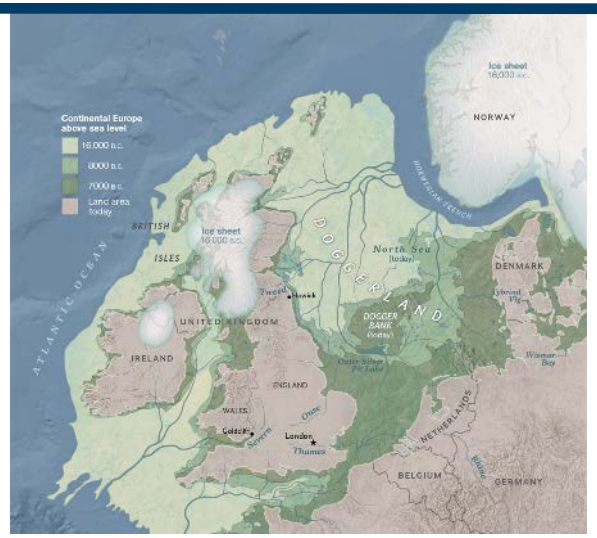

2008

2019

Deep Sea Wind project

NOWITECH

NSON

LowEmission

OffshoreGrid

IRPWind

TradeWind

EERA-DTOC

HVDCPro

BestPaths

NTNU offshore grid research

20 20 20 Twenties
Transmitting wind

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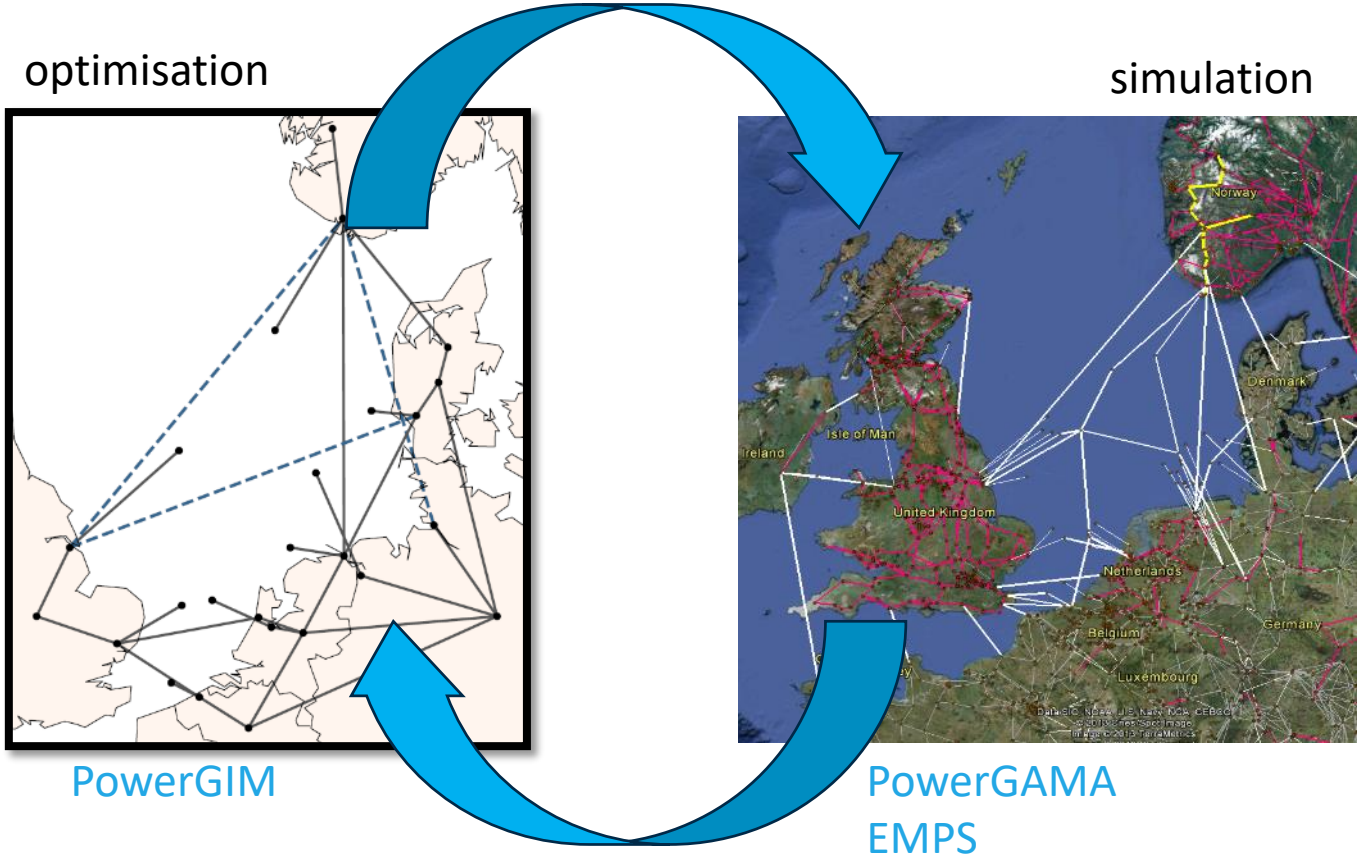
Grid optimisation / impact assessment



Optimisation: Explore a large number of alternatives, and find the best grid investments

Simulation: Detailed analysis of the impact of a given scenario

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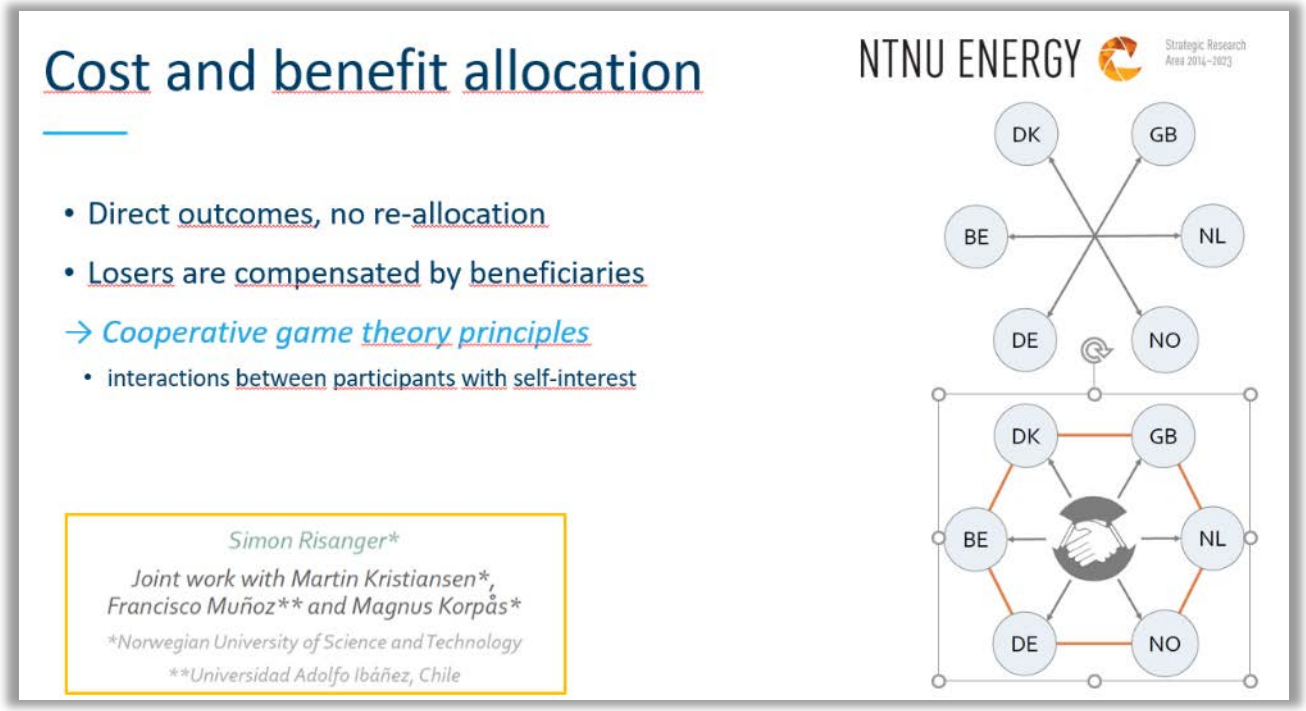
Methods for fair cost-benefit allocation



- How to reconcile what is good for Europe with what is good for each country

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Step-wise offshore grid optimisation

- Step-wise optimisation with uncertainty
- Example 1: Wind farm cluster
- Example 2: Electrification of North Sea oil/gas fields

Offshore wind energy and grid will be built step by step

What is the best way to do this? (cost-effective, avoid stranded assets...)

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Optimisation with uncertainties

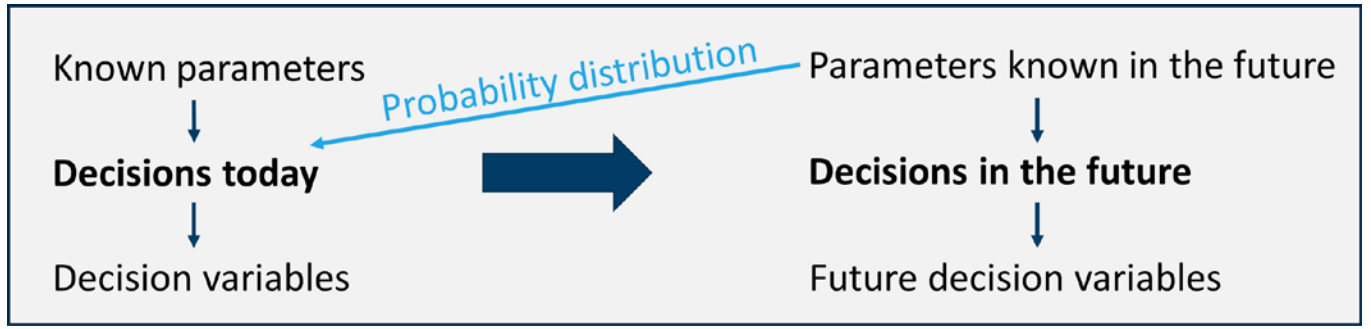
- Step-wise development
  - wind farms built at different times. Always uncertainties about what happens in the future
  - Some decisions are here-and-now, others can wait
- Multiple perspectives (our focus is the second)
  - **Wind farm/interconnector developers** – interested only in their own project, but should consider what others are doing since it affects them (the narrow picture) – maximise profit
  - **Policy makers (strategic developers)** – Need to know what we should aim for, in order to put in place the right incentives (the big picture) – minimise total system costs

Uncertain parameters

- Optimal solution is irrelevant if it is based on wrong assumptions
- Parameters are often unknown or uncertain

A better approach is to optimise for a range of (likely) parameter values

>> Stochastic programming



Approach

- Two-stage mixed-integer linear programming problem with uncertain parameters

Identify offshore grid that gives the lowest costs for the system as a whole

MIN {cost of investments + cost of generation throughout lifetime}
SUBJECT TO:
power balance in each node
power limited by capacity (generation and line flow)

- **Deterministic**: Disregard uncertainties
- **Stochastic**: Consider probability distribution (scenario tree)

Optimisation – overview

Main optimisation variables

- Which connections to build (grid layout) (integer)
- Cable capacities (continuous)

Considering

- A set of candidate investments
- Different operating conditions (variable generation and demand/power prices)
- Linear cost model (linear function of power rating)

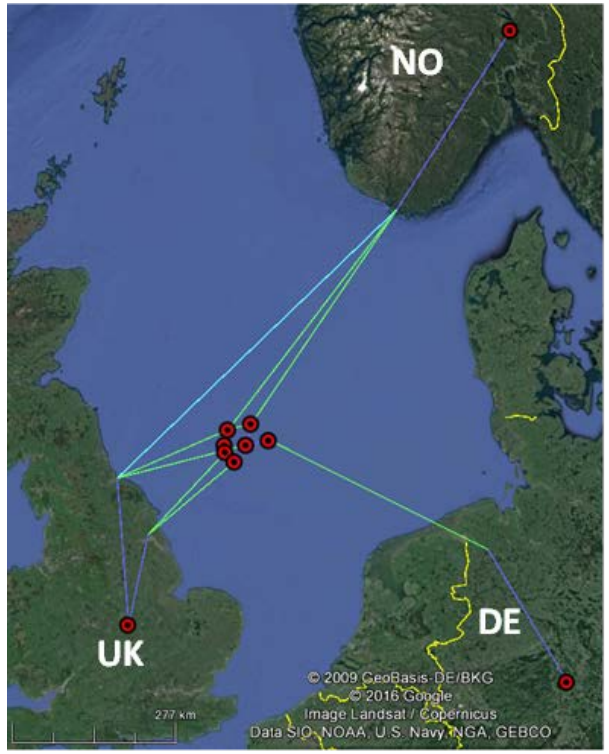
Implementation

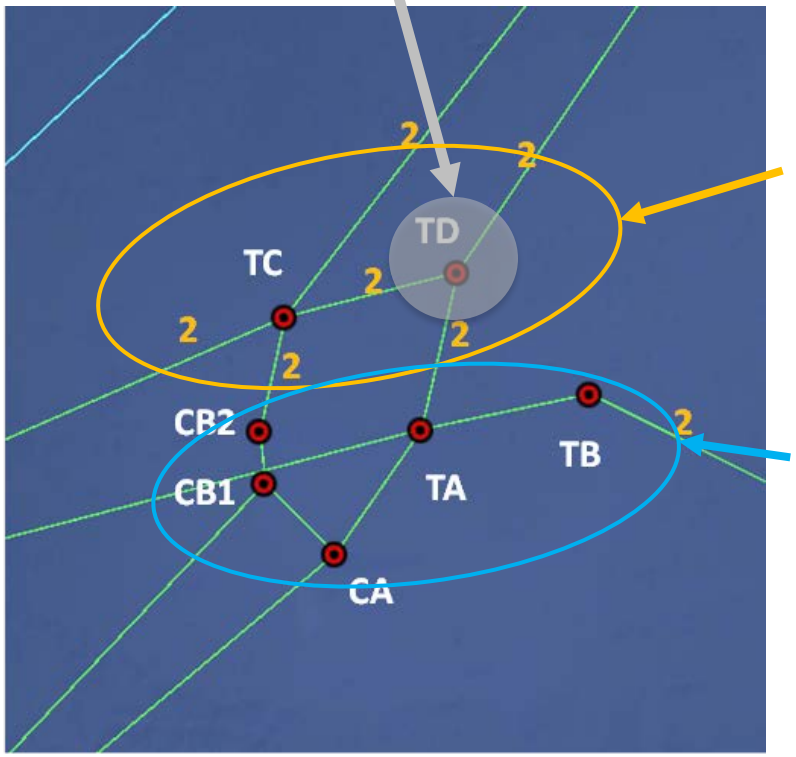
- Python package using Pyomo/PySP: PowerGAMA/PowerGIM

Example 1: Grid connection of offshore wind farm cluster

Example 1: North Sea wind farm cluster

2-stage development





Stage 2
TC, TD
(2 × 1.2 GW)
(year 1)

Stage 1
CA, CB, TA, TB
(4 × 1.2 GW)
(year 0)

wind farms and candidate connections

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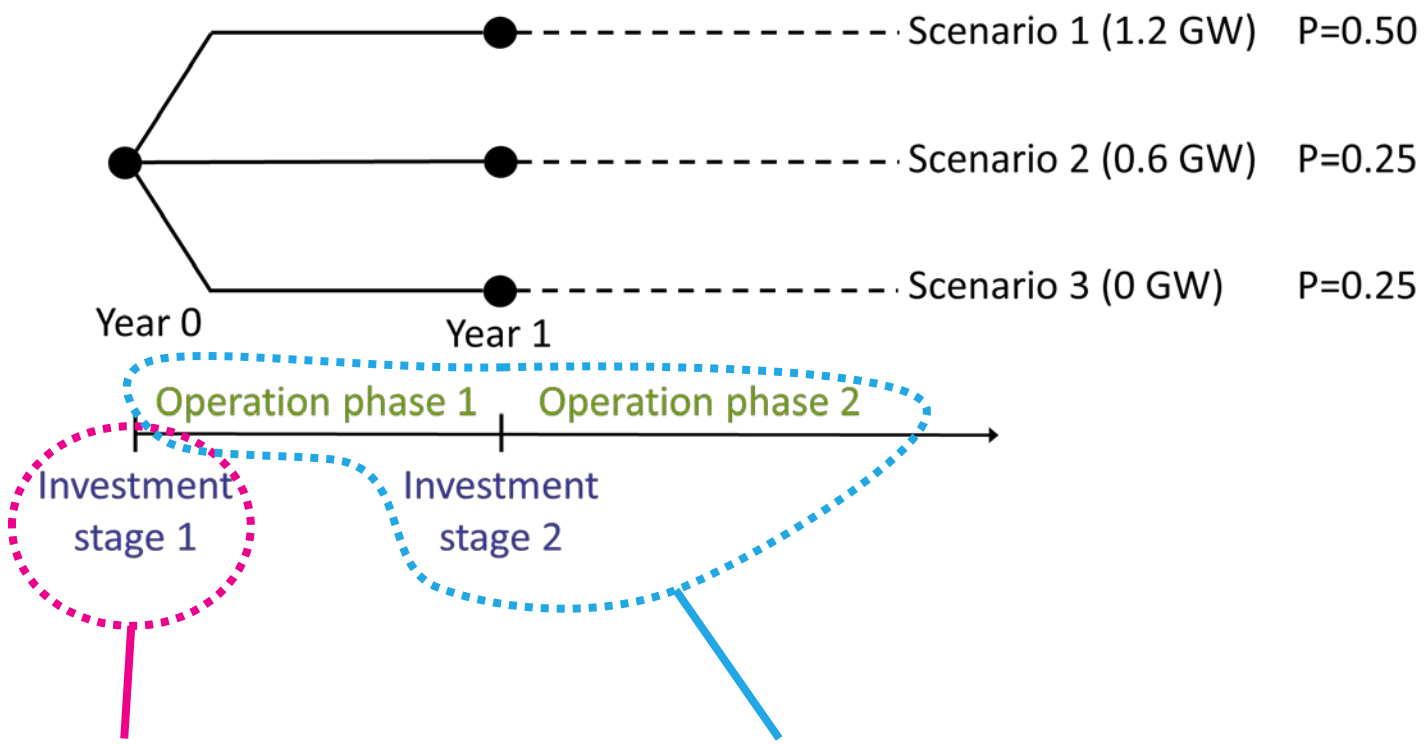
3 scenarios



stage 1 variables
(decisions now)

stage 2 variables
(future decisions)

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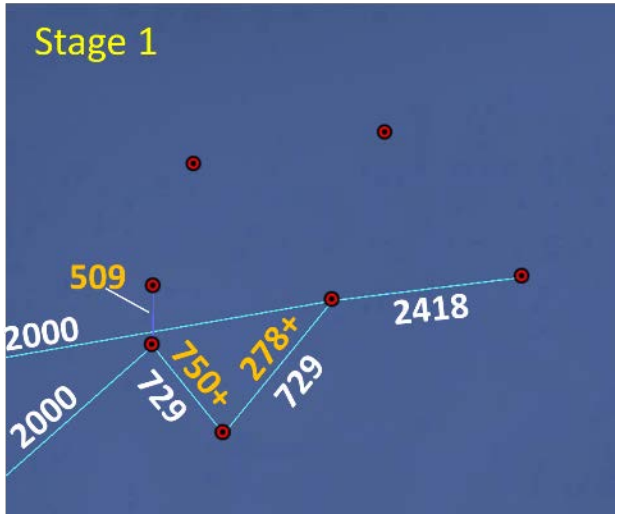
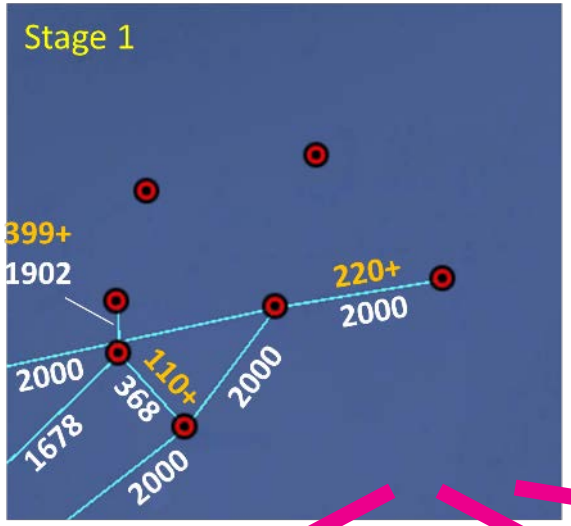
Without uncertainty
DET



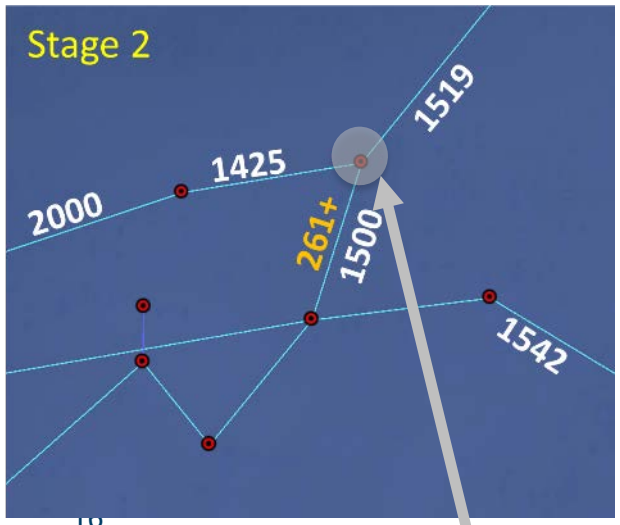
With uncertainty
STO



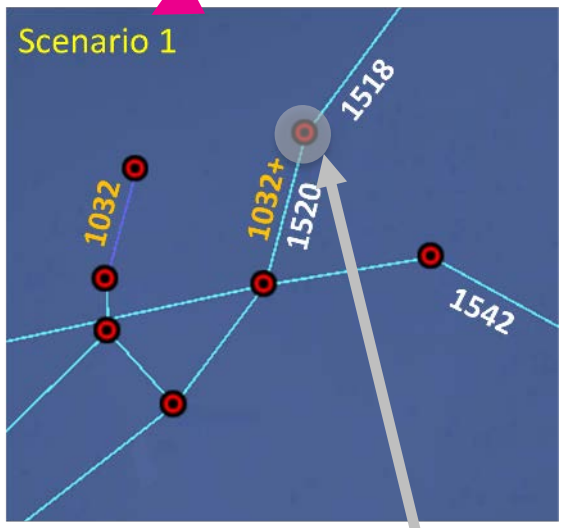
Stage 1 = here-and-now investments

numbers show capacities in MW

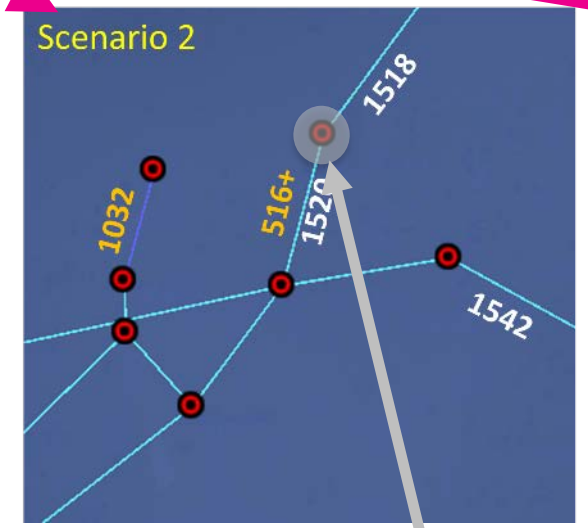
yellow = AC
white = DC



1.2 GW



1.2 GW



0.6 GW

0 GW

Stochastic approach gives better, more robust result

Absolute numbers (M€):

Scenario	Stage 1	Stage 2	Generation	Sum
1 DET	9242	2451	771454	783146

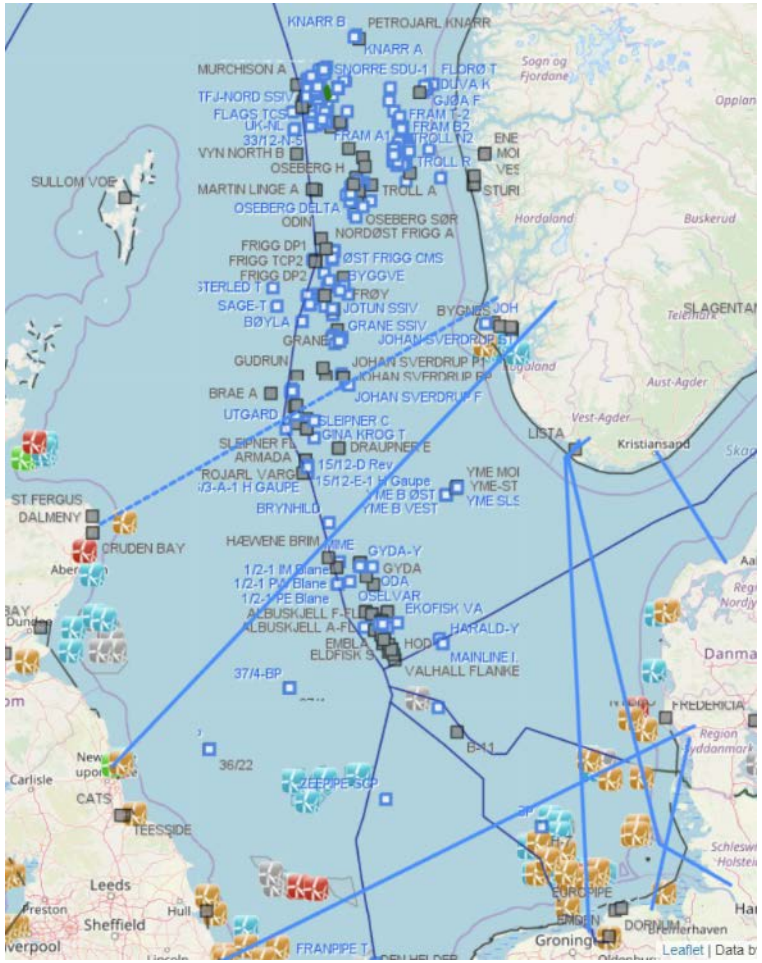
Values compared to base case (1 DET) (M€):

Scenario	Stage 1	Stage 2	Generation	Sum	Difference	
1 DET	0	0	0	0		
1 STO	44	-186	143	1	**1**	if scenario 1 is realised
2 DET	0	0	1173	1173		
2 STO	44	-257	1289	1076	**-97**	if scenario 2 is realised
3 DET	0	0	2359	2359		
3 STO	44	-373	2460	2131	**-228**	if scenario 3 is realised

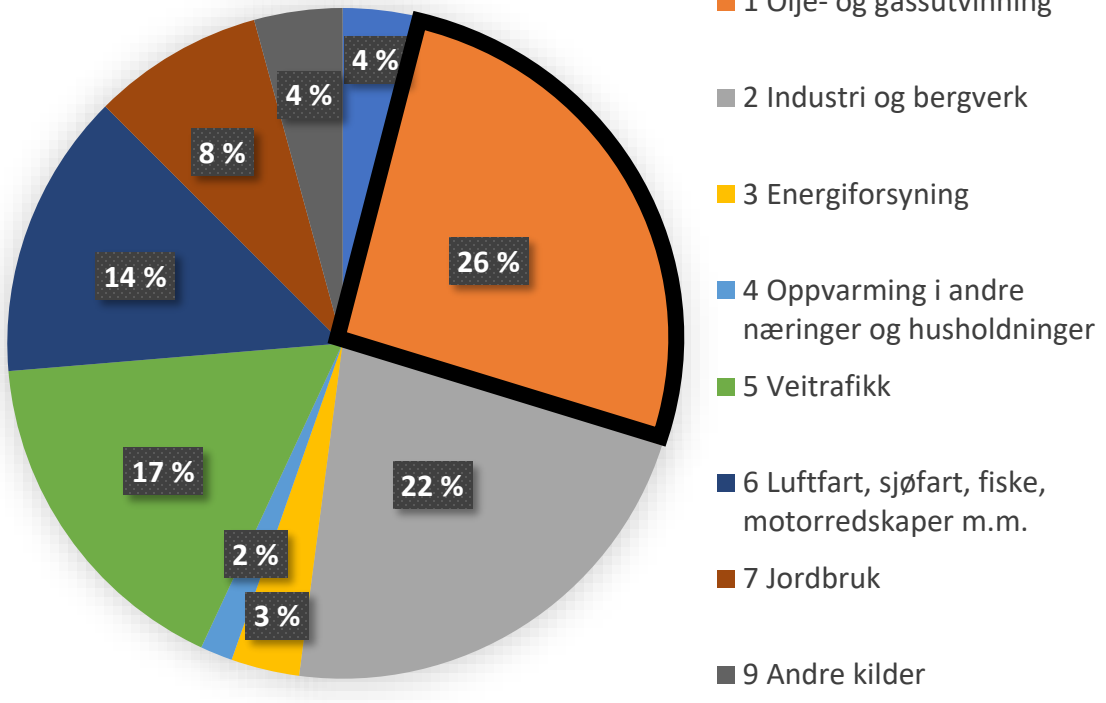
Expected total saving with stochastic approach = **-81 M€**

Example 2: Oil and gas field electrification

Norwegian oil and gas extraction activity



- 26% of national greenhouse gas emissions (2018)
- Mainly from offshore power supply using on-site gas turbines



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Low Emission Research Centre

- The Low Emission Research Centre will develop new technologies and concepts for offshore energy systems, energy efficiency and integration with renewable power production technologies for application on the Norwegian Continental Shelf (NCS)

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Oil/gas platform electrification and optimal offshore grid layout

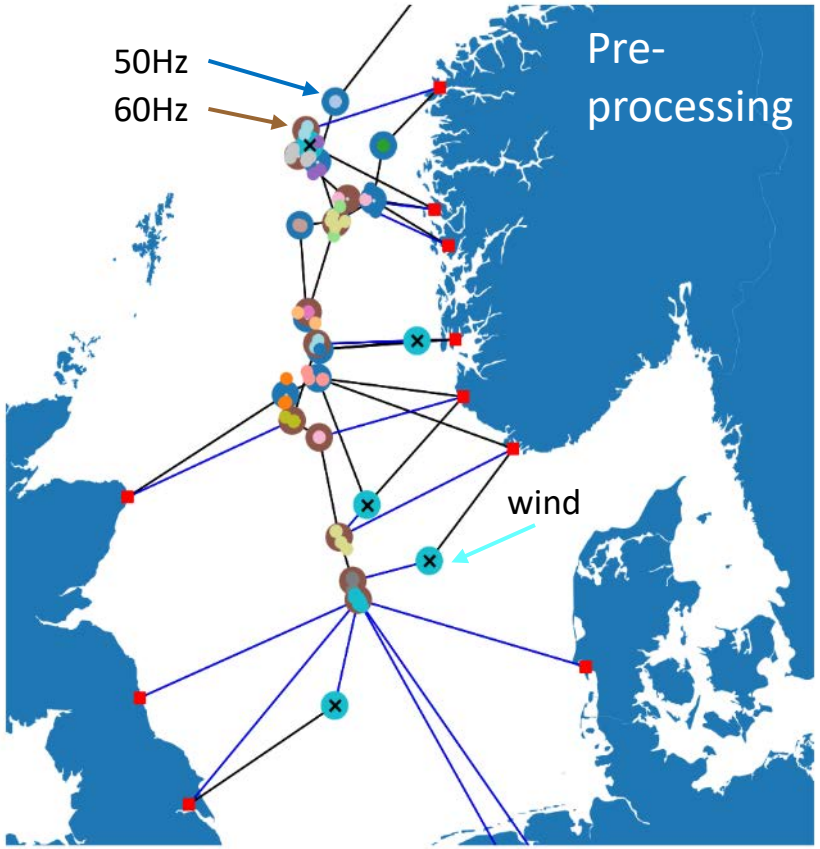
Finding the socio-economic optimal grid layout, considering

- cable system investment costs (more cables, more costs)
- present value of operating costs: cost of electric power generation (more cables allow better use of cheaper energy sources)
- variable operating conditions: wind availability, power prices (using time-series samples)
- both 50Hz and 60Hz systems, both AC and DC systems relevant
- linear constraints and objective function

- Two main steps:
  - pre-processing (clustering, time-series sampling, selection of candidate connections)
  - mixed integer linear programming optimisation

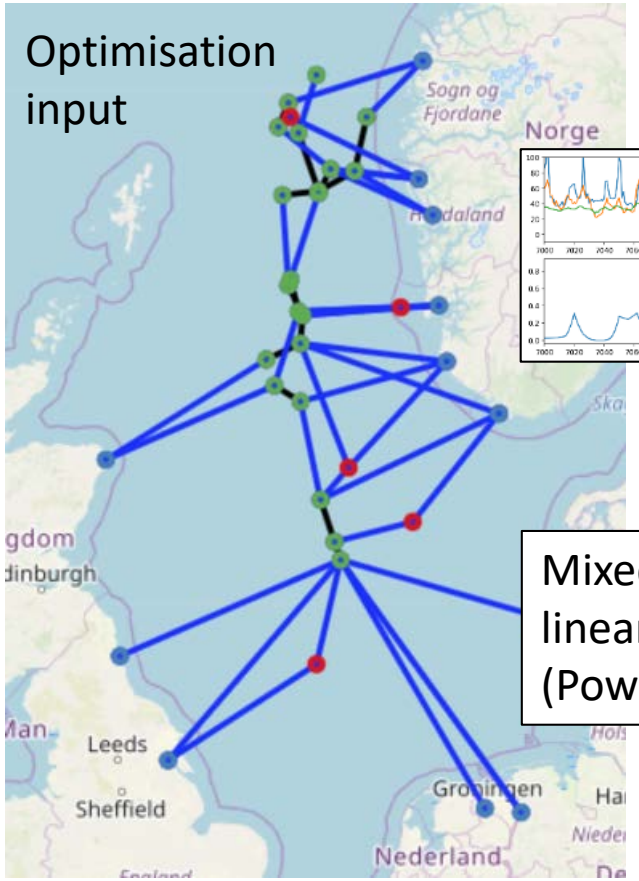
Full electrification of Norwegian oil and gas

Clustered oil and gas facilities, wind farms, candidate power cables

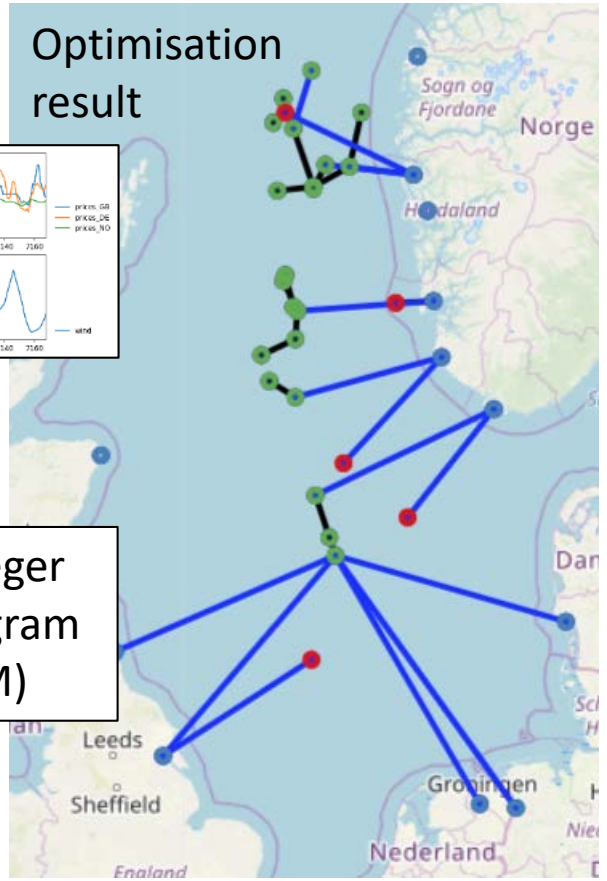


*50 Hz clusters are **blue**, 60 Hz clustes are **brown**, Wind farms are turqoise with a cross*

Candidate AC and DC connections



Optimal North Sea grid layout



Mixed-integer linear program (PowerGIM)

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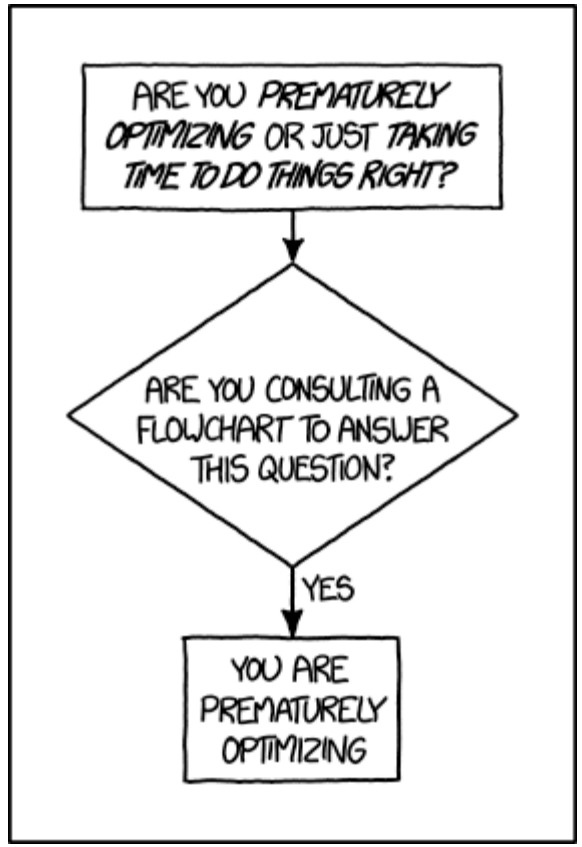
Concluding remarks

- High costs, long planning times and long lifetime makes multistage optimisation with uncertainties highly relevant
- Incorporating uncertainties in the optimisation has a demonstrable benefit
- Gives more robust decisions
- Caution: Need to have a good description of the system before optimisation makes sense



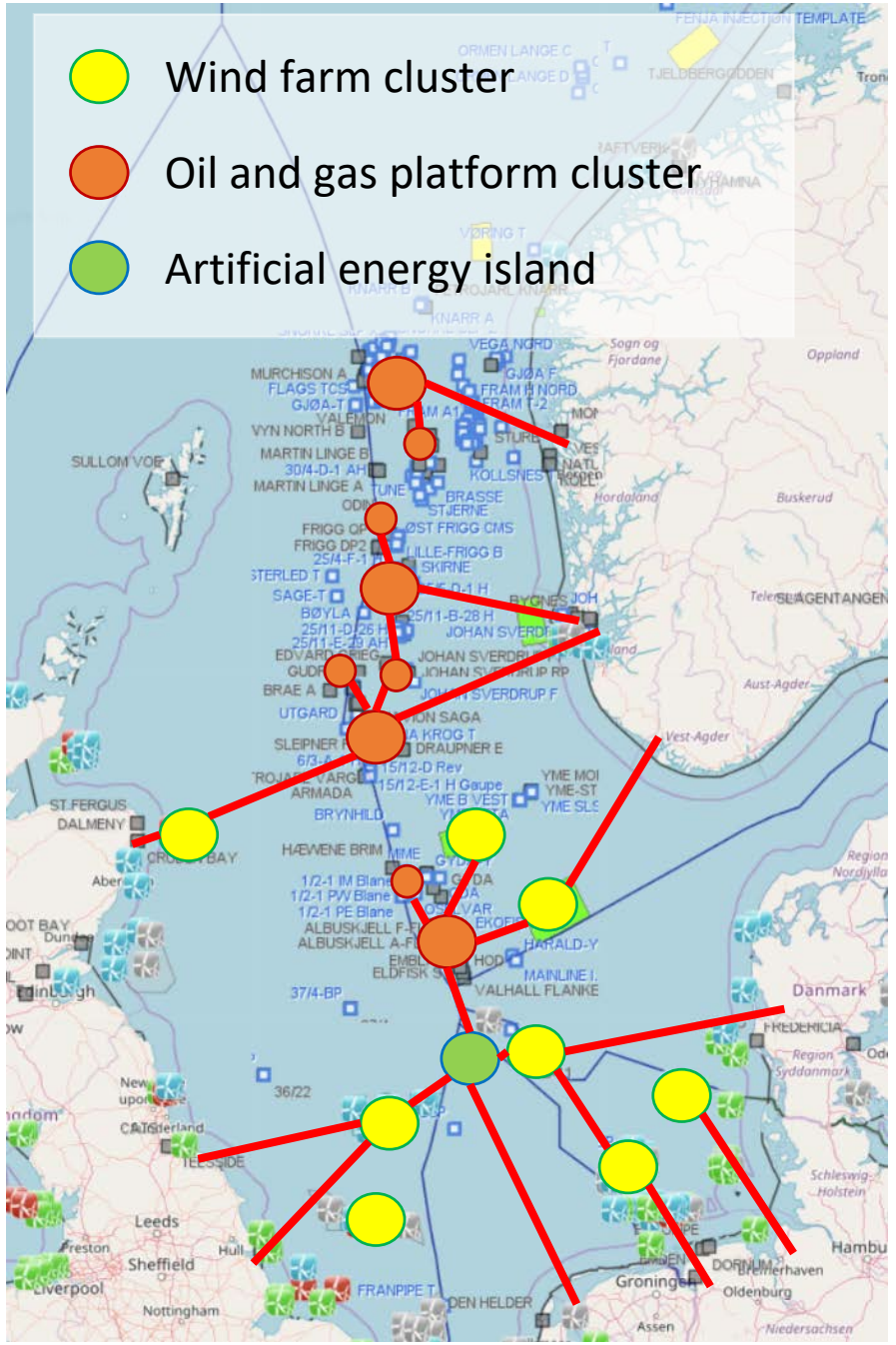
https://xkcd.com/1691/

Extra: Using oil platforms after the oil...

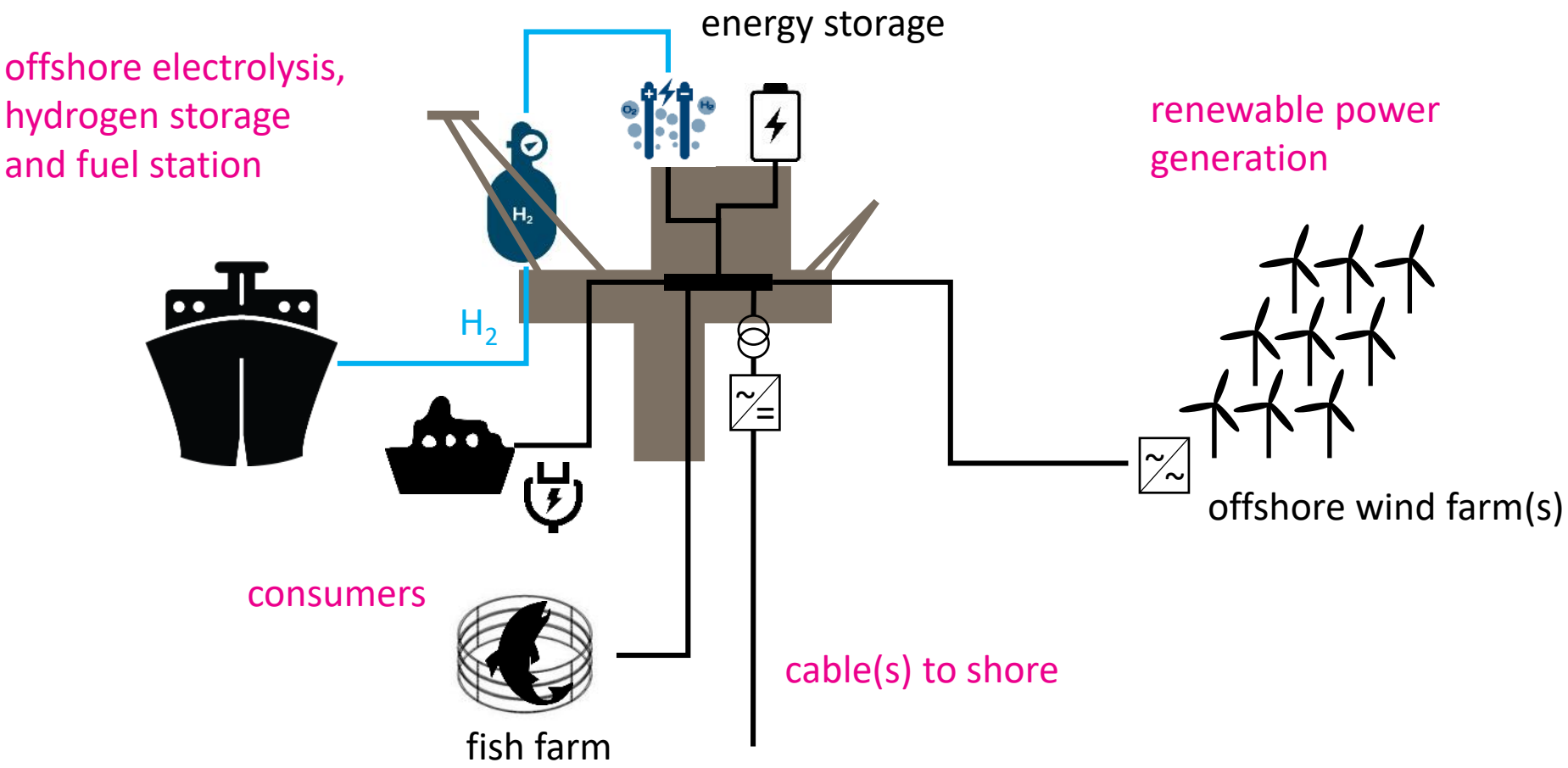
1: Decommissioned platforms as hubs in a North Sea grid?

Topics:

- step-wise development of north sea electricity grid
- optimise North Sea grid investments (and wind farm development) taking into account the possibility to reuse platforms and the timing/lifetime
- Lifetime platform vs electrical infrastructure
- Retrofitting old platform vs scrap and build new

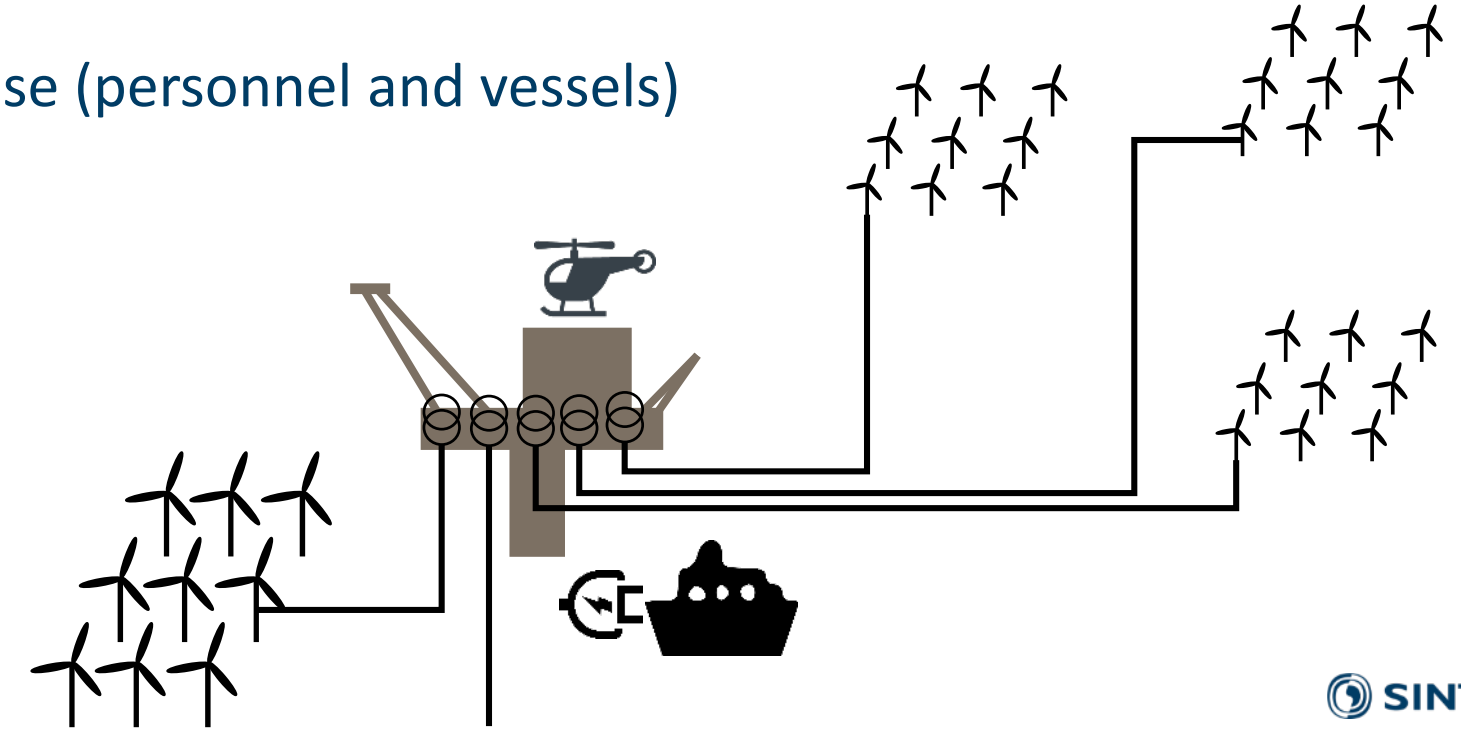


2: Offshore energy/charging station



3: Offshore wind cluster hub

- Platform for transformer, batteries, compensation, HVDC equipment serving a cluster of wind farms
- Offshore maintenance base (personnel and vessels)



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Technology for a better society