Offshore Power and Hydrogen Networks for Europe's North Sea

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Agenda

Technische Universität Berlin

1 Introduction and Motivation

Agenda

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2 Methodology

3 Study Case

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3 Study Case

4 Results

Introduction and Motivation

- Governments of North Sea committed to install at least 300 GW by 2050[1]

Hanz D Niemeyer et. al

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2) P. Hevia-Koch and H. Klinge Jacobsen, “Comparing offshore and onshore wind development considering acceptance costs,” ,2019

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- Onshore wind faces acceptance problems[2]

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1 Introduction and Motivation

- Governments of North Sea committed to install at least 300 GW by 2050[1]
- Onshore wind faces acceptance problems[2]
- Research questions:
  - Integration (radial, hybrid connections)
  - Offshore hydrogen production
  - Cost effective potential

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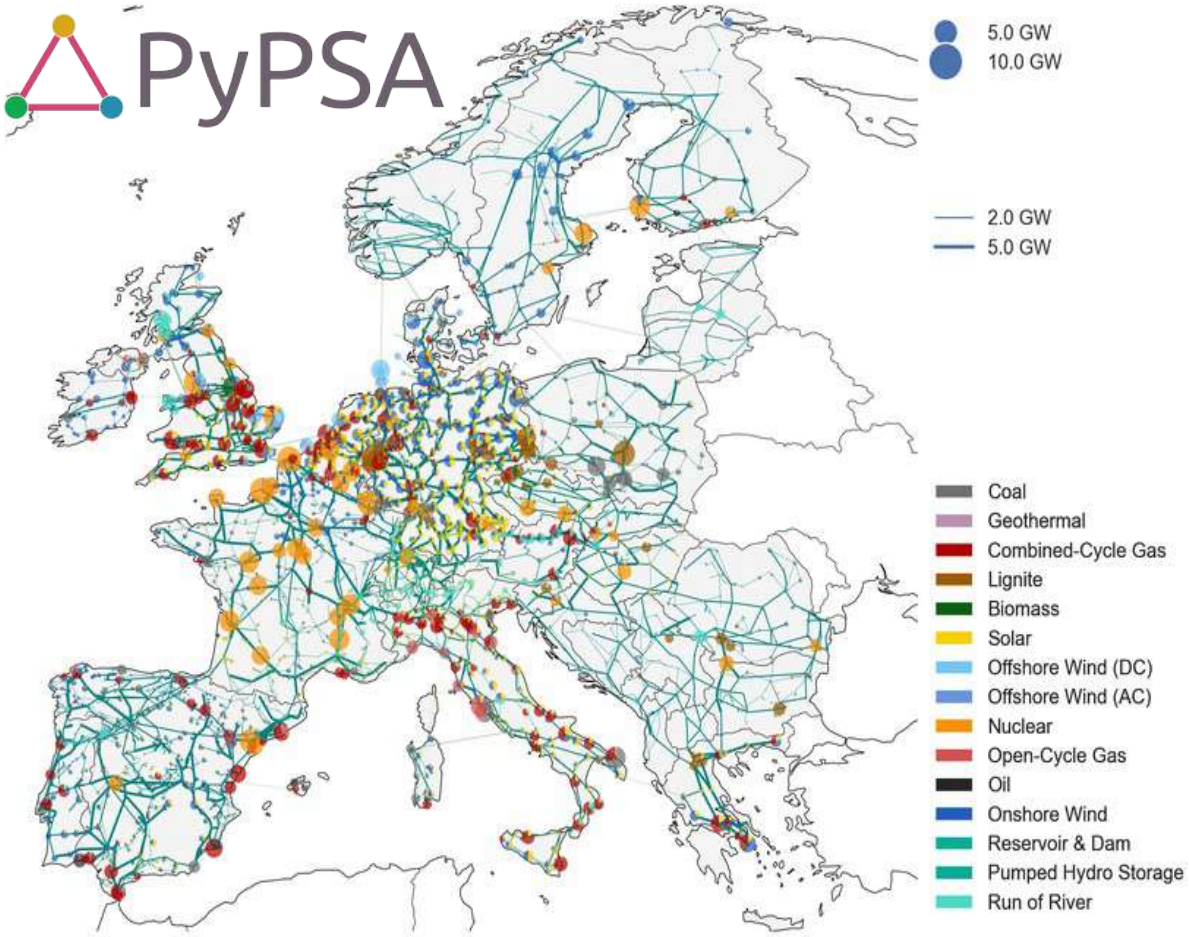
Methodology

- Sector-coupled model PyPSA-Eur to optimise operation and investment



Graphics from pypsa.org

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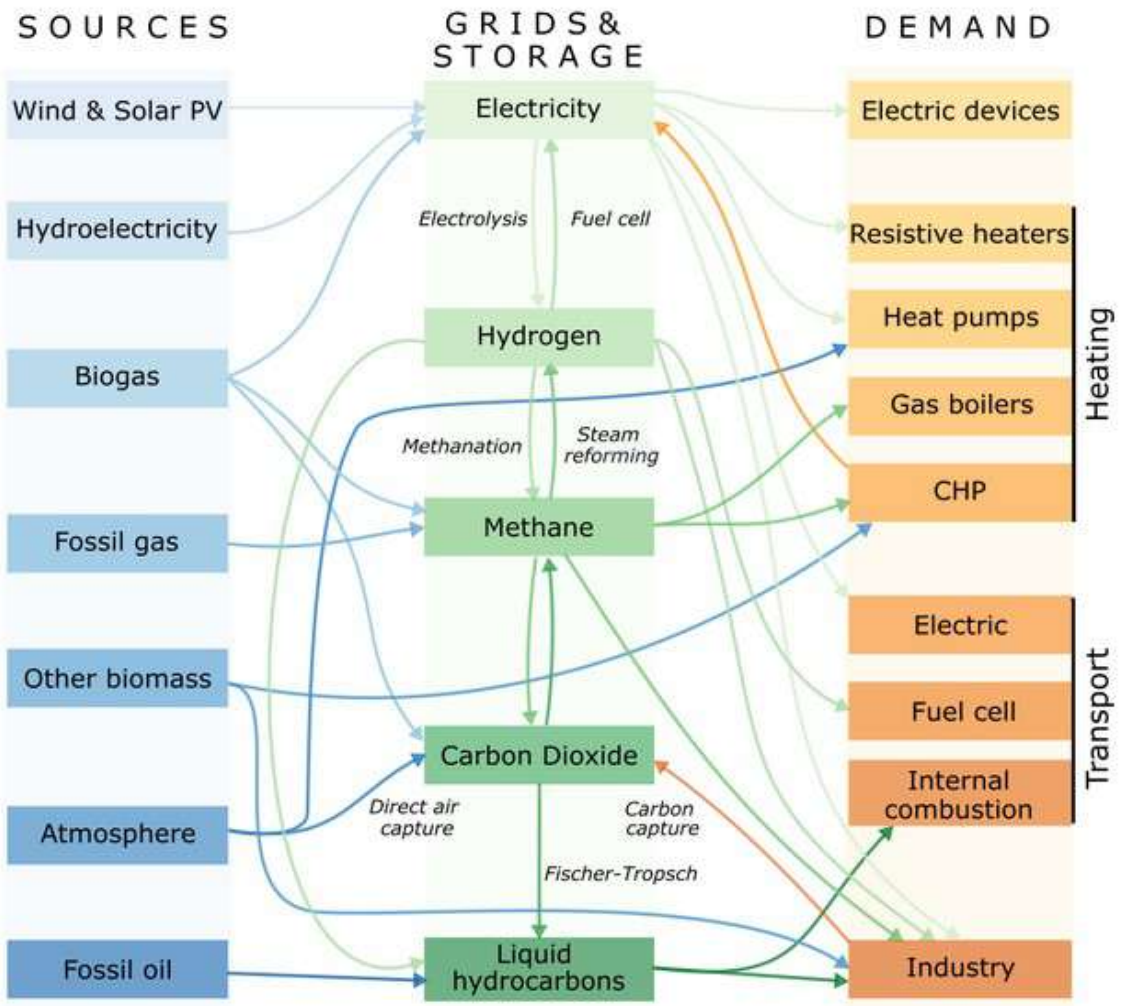

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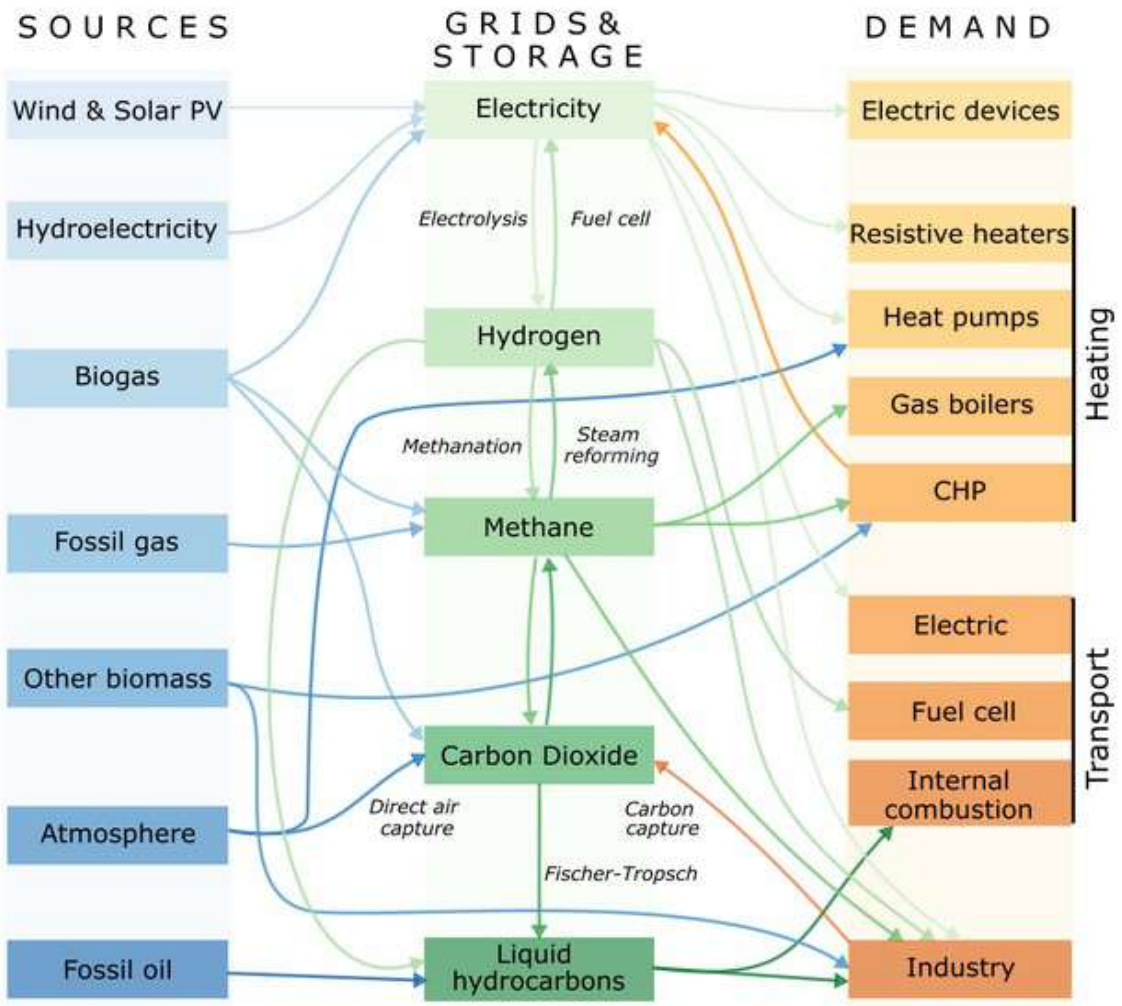
Methodology

- Sector-coupled model PyPSA-Eur to optimise operation and investment
- Improved features
  - Wind turbine cost model
  - Floating wind
  - Wake effect modelling
  - Offshore regions in higher resolution
  - Offshore network options



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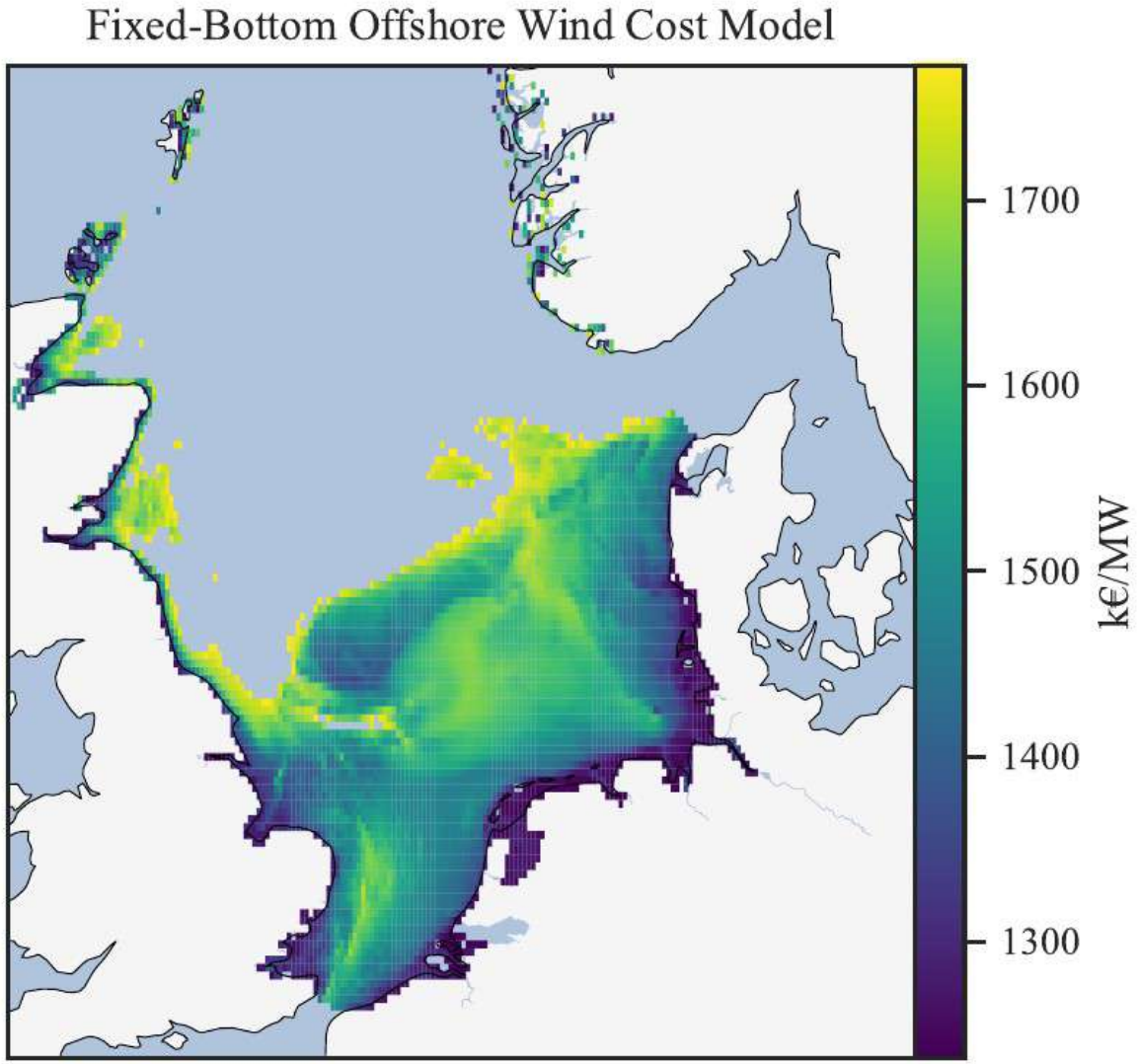
Turbine cost model from Danish Energy Agency[1] depending on:

- Water depth, rotor diameter, capacity, hub height



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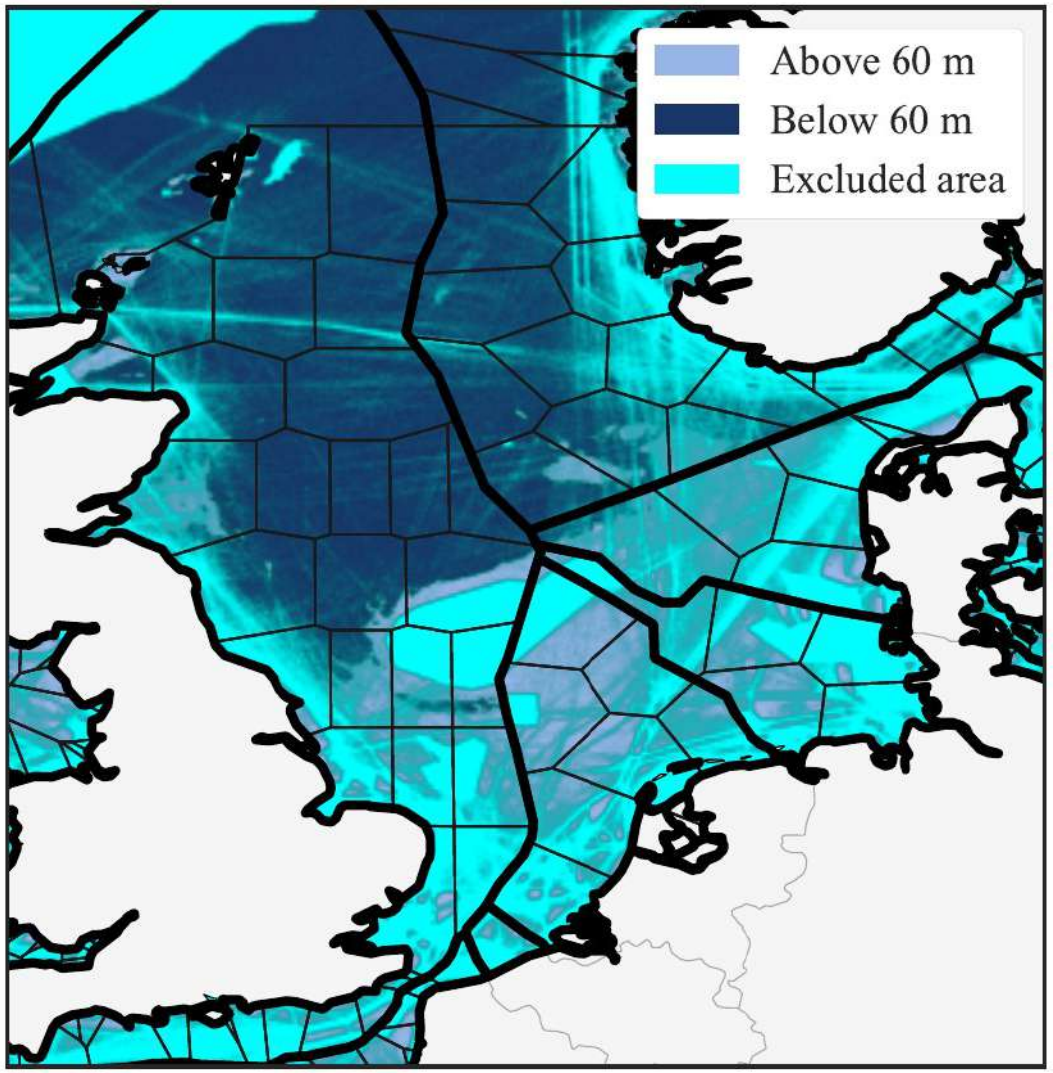
Floating wind turbines:

- Waters deeper than 60m
- Uniform cost of 2300 €/kW [2]



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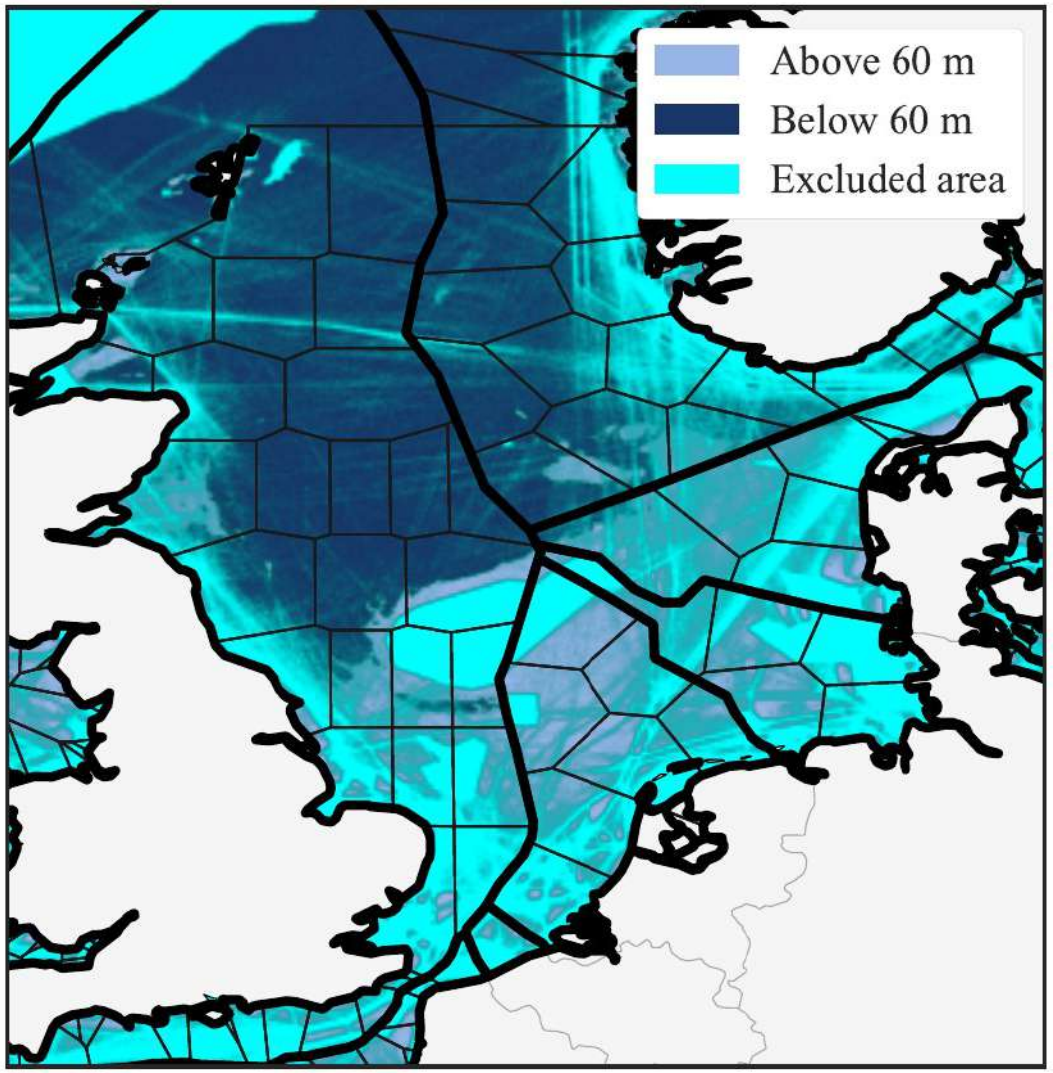
Consider wake effects for offshore wind turbines



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Offshore regions modelled in higher resolution

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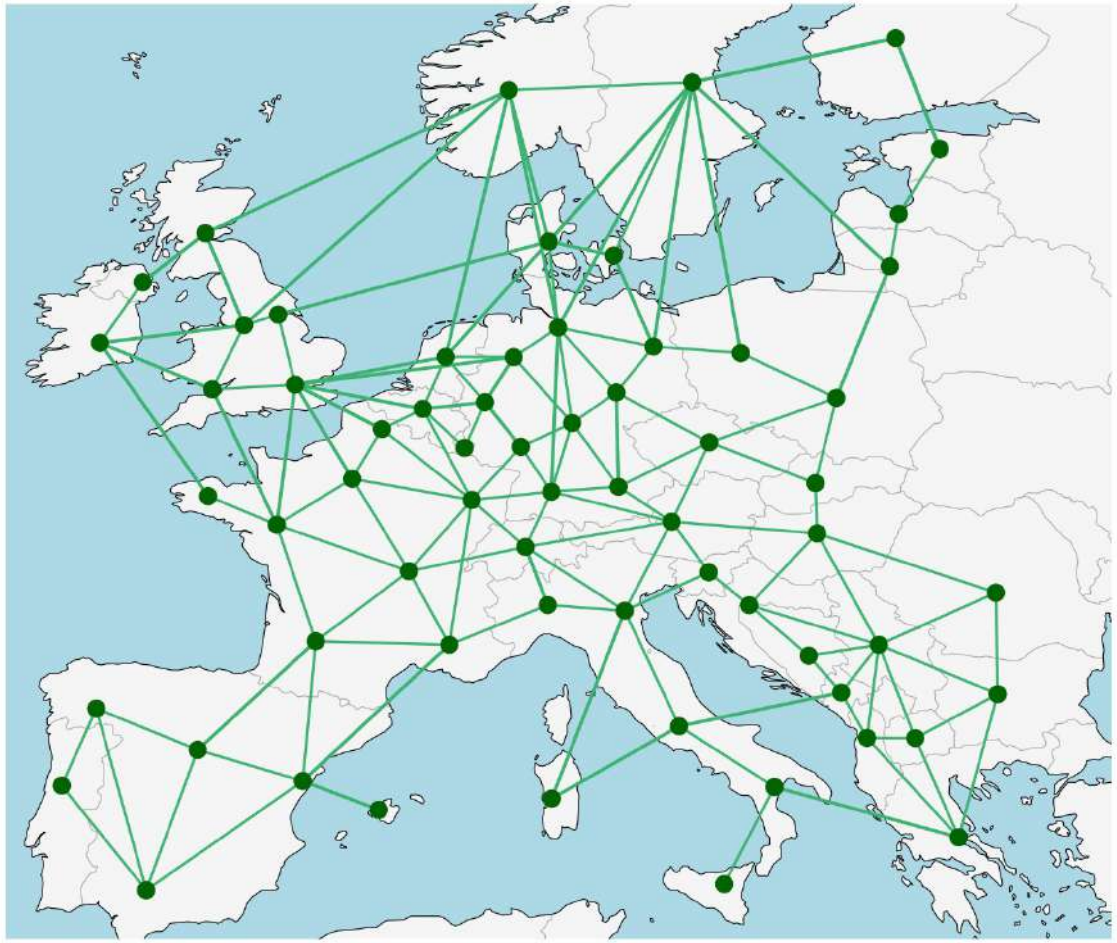
Offshore network candidates

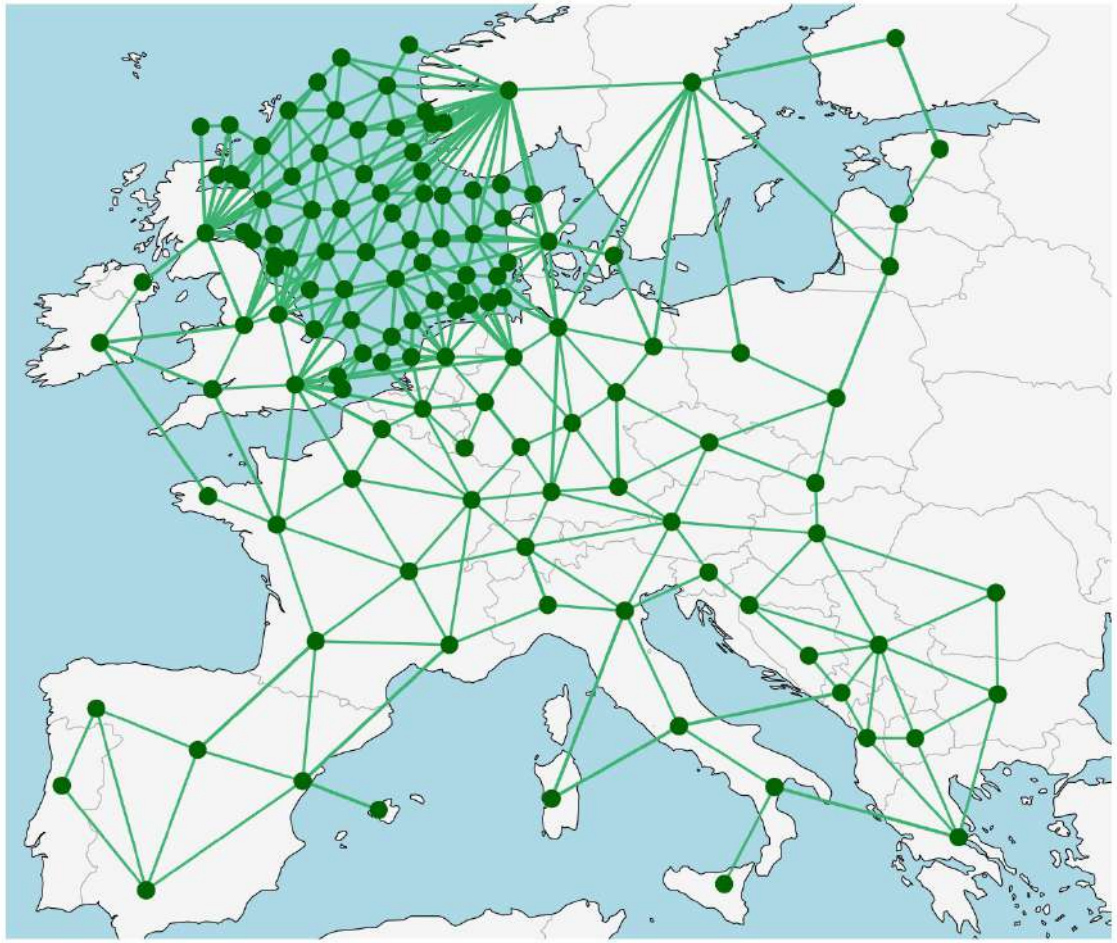
- Every offshore regions has own offshore connection point



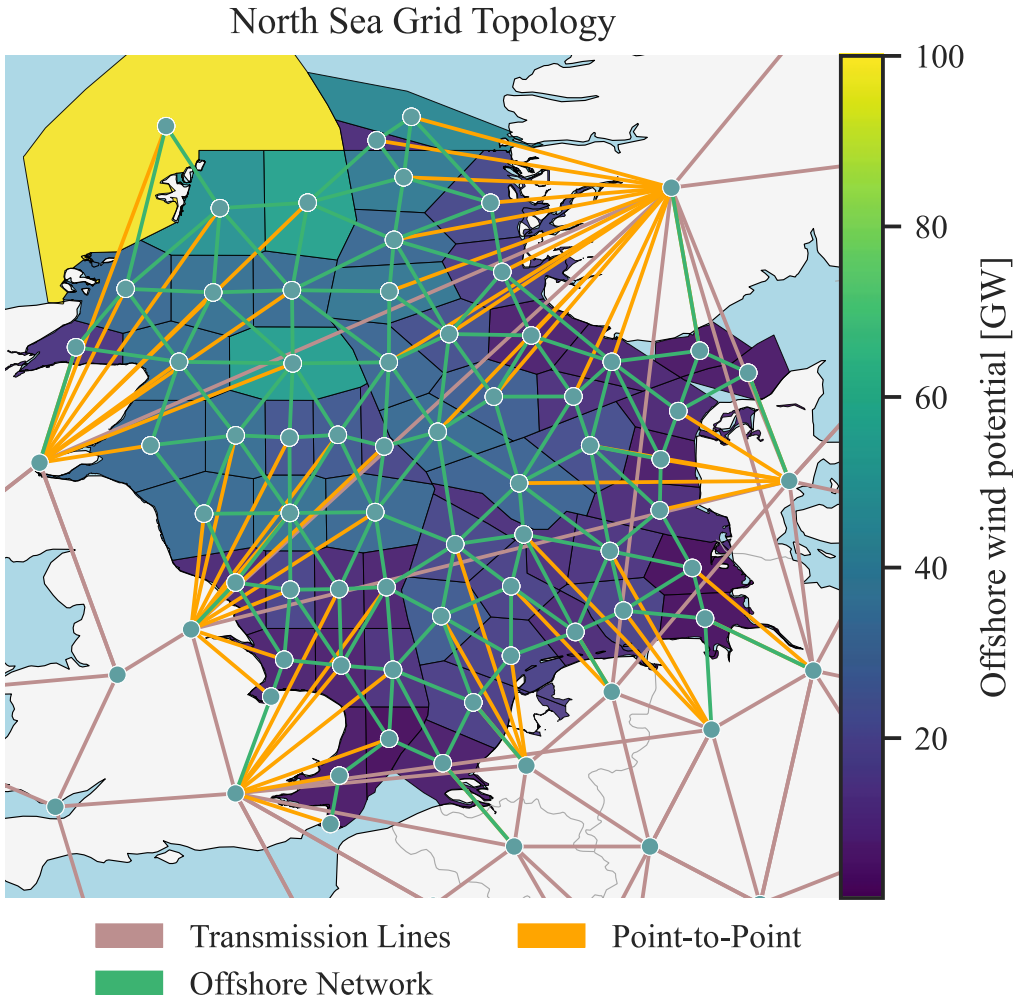
Offshore regions modelled in higher resolution

Offshore network candidates

- Every offshore regions has own offshore connection point
- Possible to interconnect as **meshed** network, or just connect to shore by **point-to-point** connection



Study Case



- European energy system

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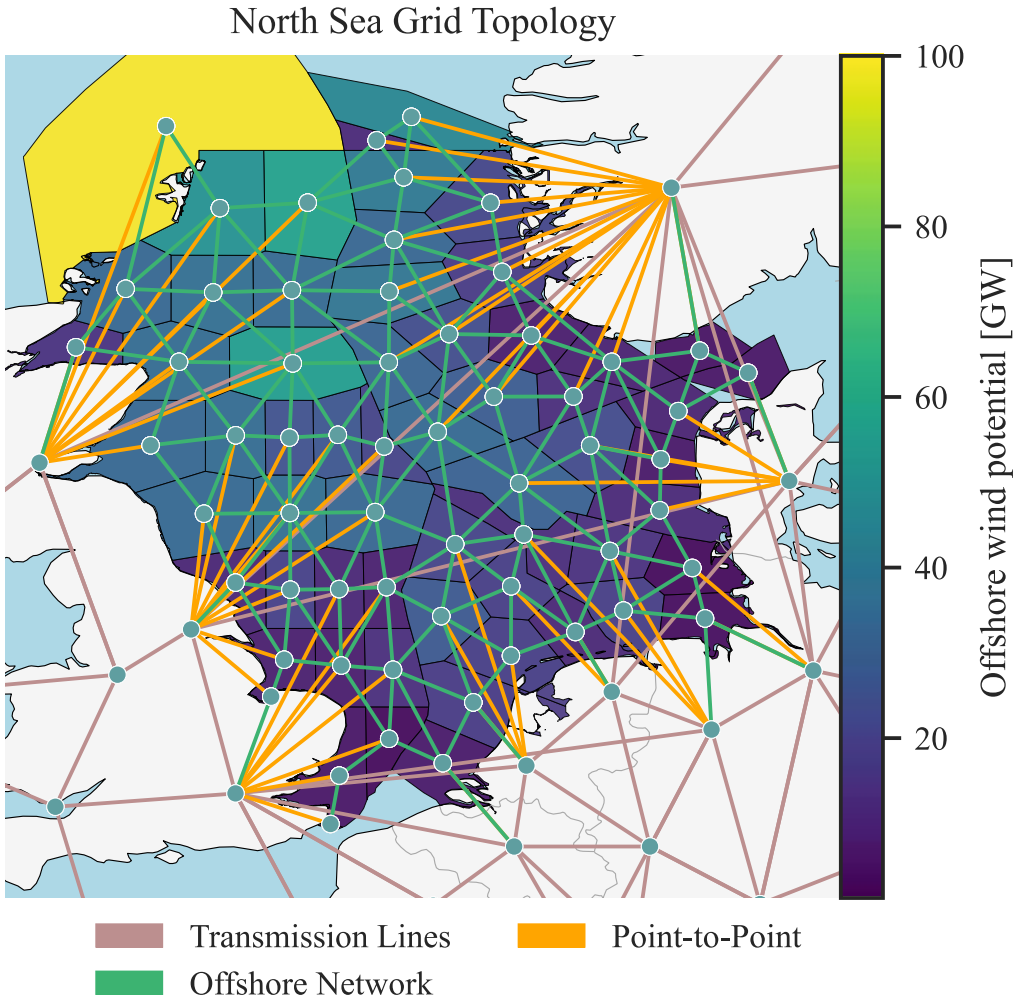

- European energy system
- Sector-coupled (residential, transport, industry, agriculture)

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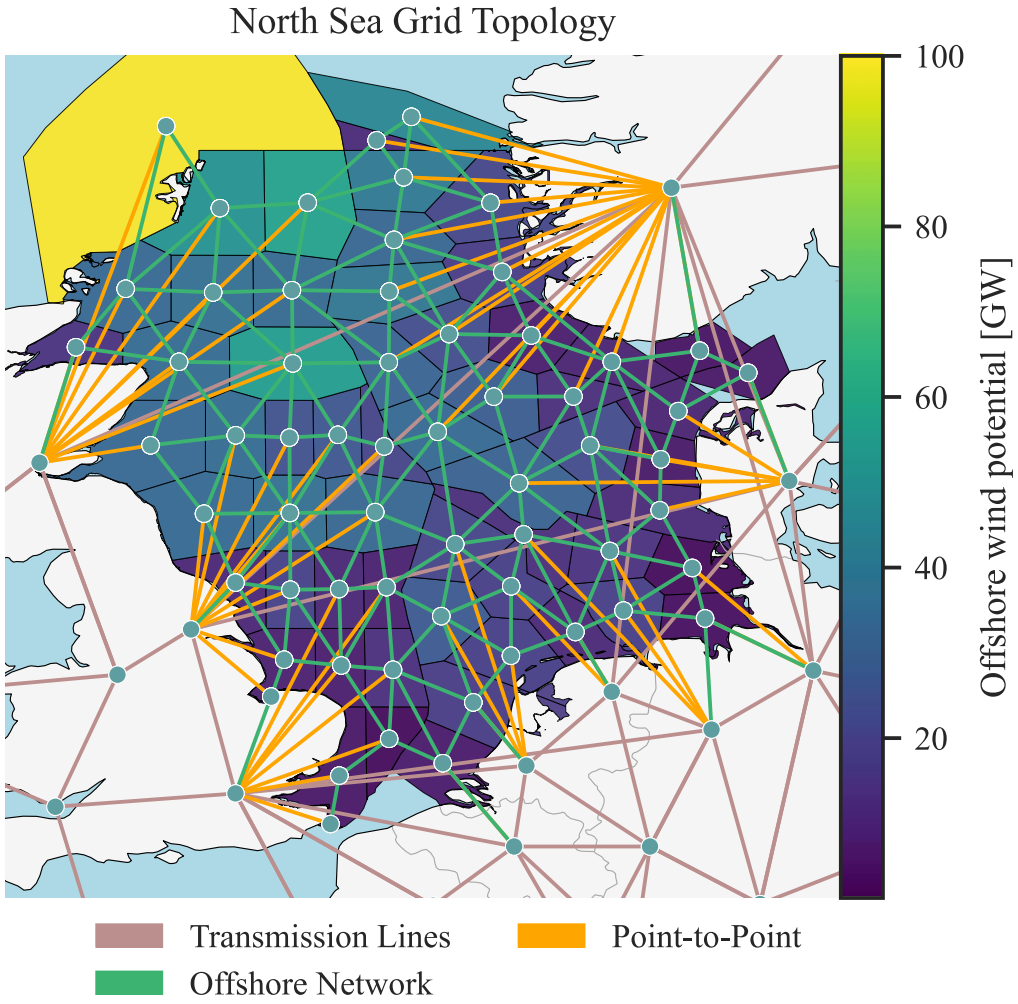

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- Sector-coupled (residential, transport, industry, agriculture)
- Carbon-neutral setting

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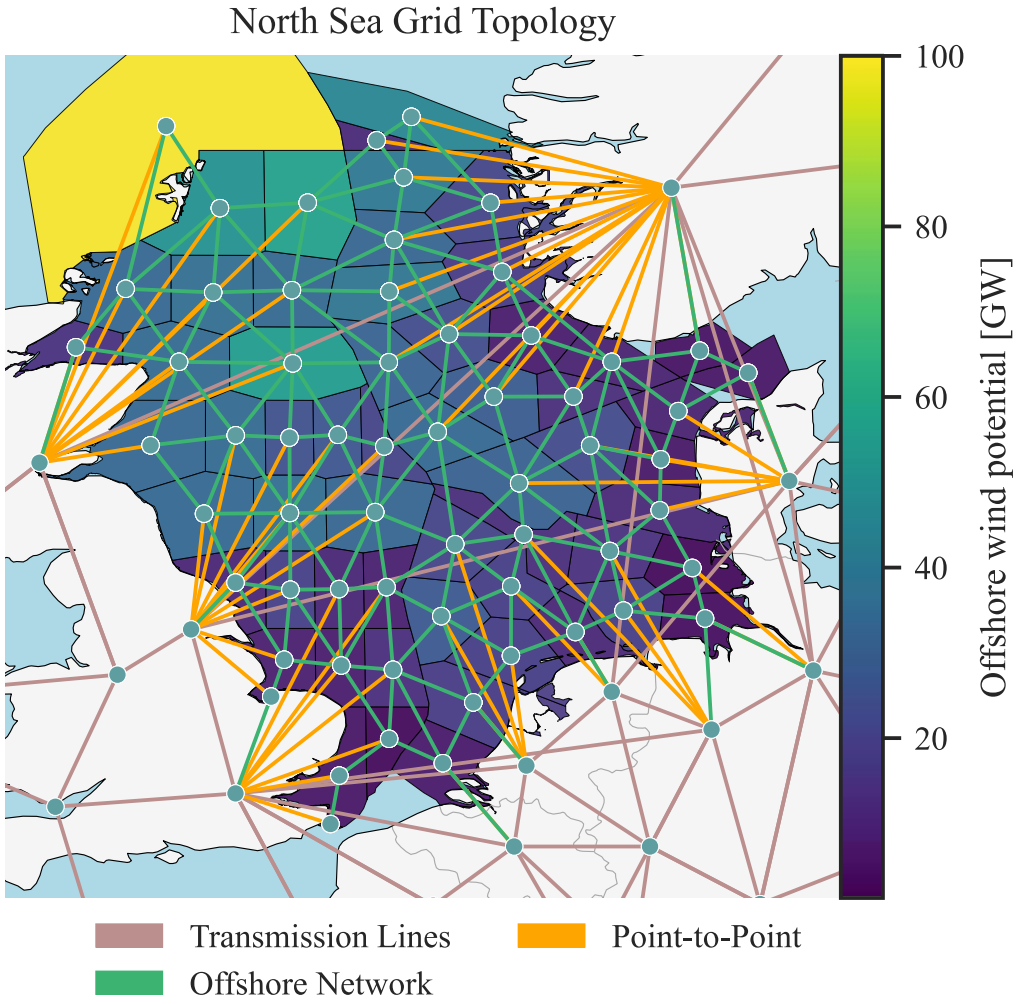

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- 64 onshore for 33 countries and 66 offshore nodes in North Sea

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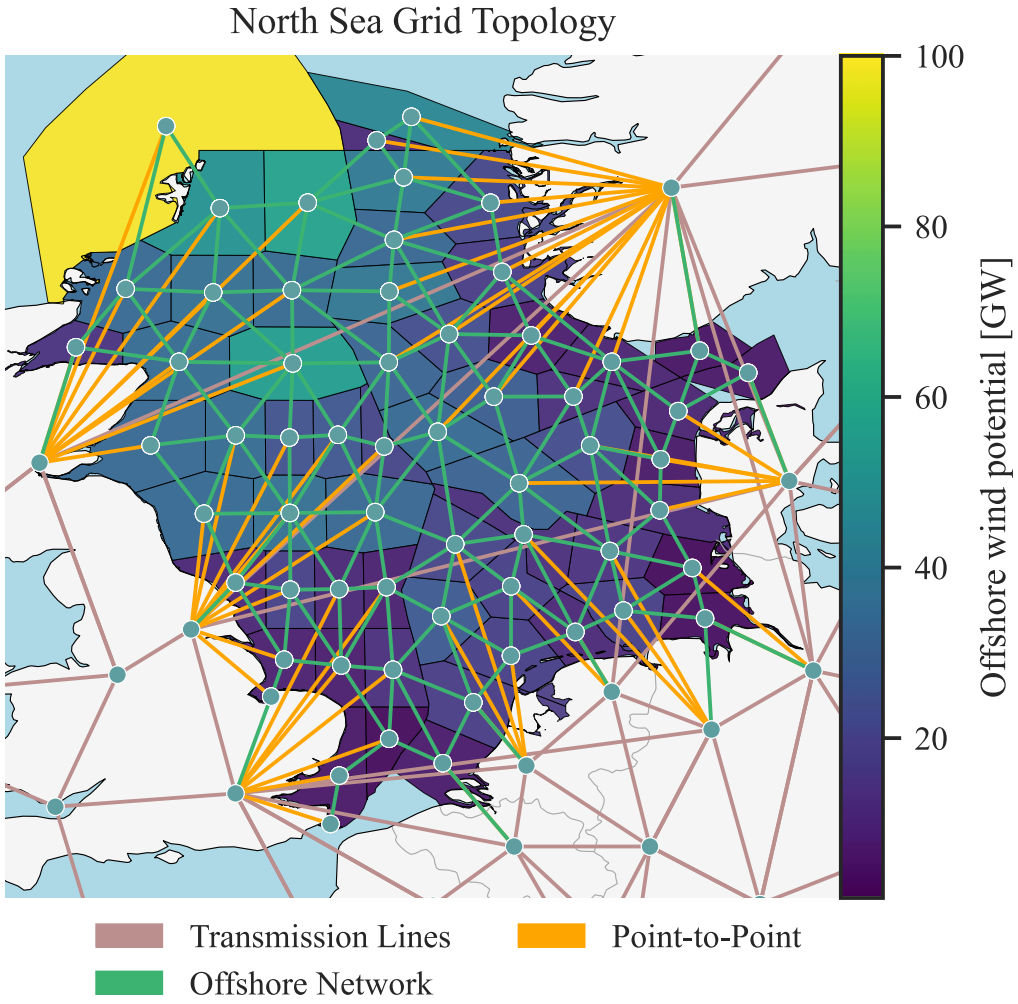

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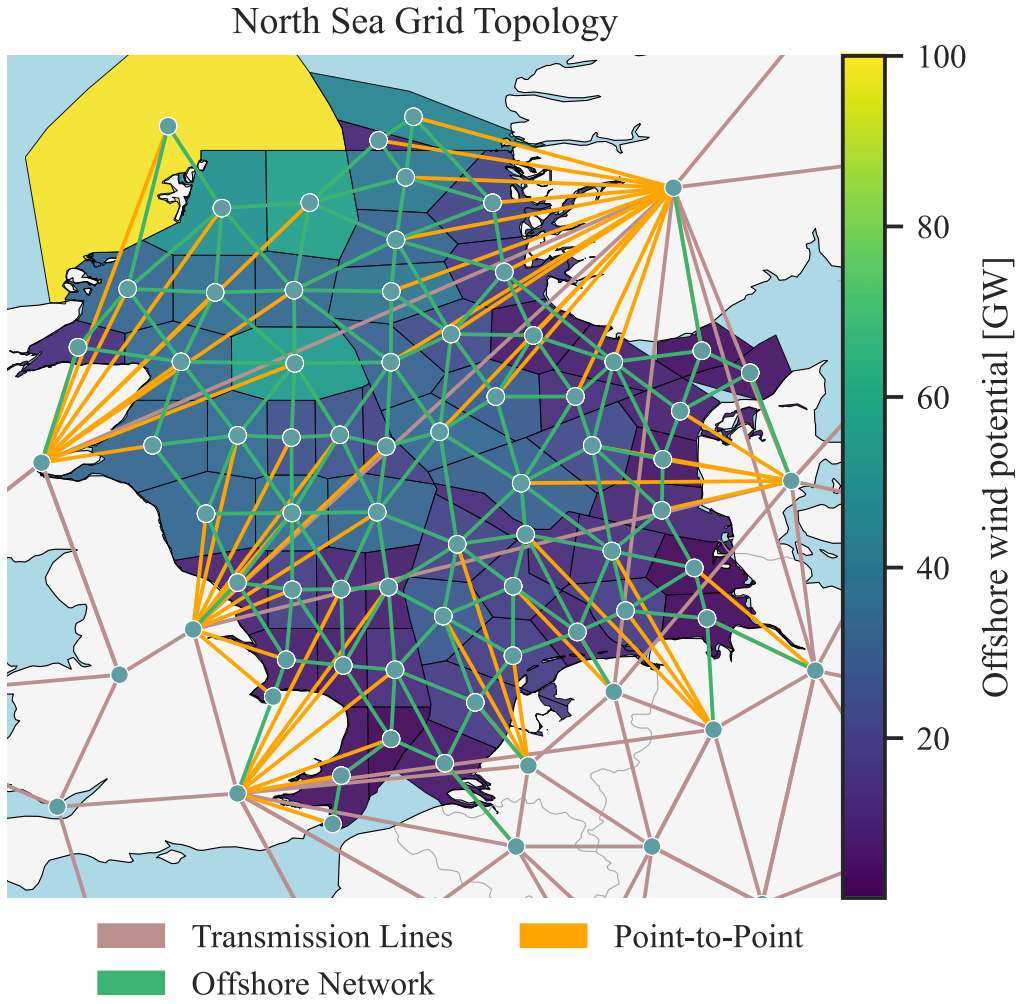

- European energy system
- Sector-coupled (residential, transport, industry, agriculture)
- Carbon-neutral setting
- 64 onshore for 33 countries and 66 offshore nodes in North Sea
- 3-hourly resolution for one year
- Green field expansion (except existing transmission grid and hydropower)

Study Case

48 models by varying 4 parameters:

- Offshore network

Offshore network
Meshed
Point-to-point (P2P)

Study Case

48 models by varying 4 parameters:

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- Offshore hydrogen production

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Offshore hydrogen
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Not available

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Transmission capacity
100 %
110 %
130 %
optimal

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Onshore wind potential
2.2 TW (25 %)
4.4 TW (50 %)
8.8 TW (100 %)

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48 combinations

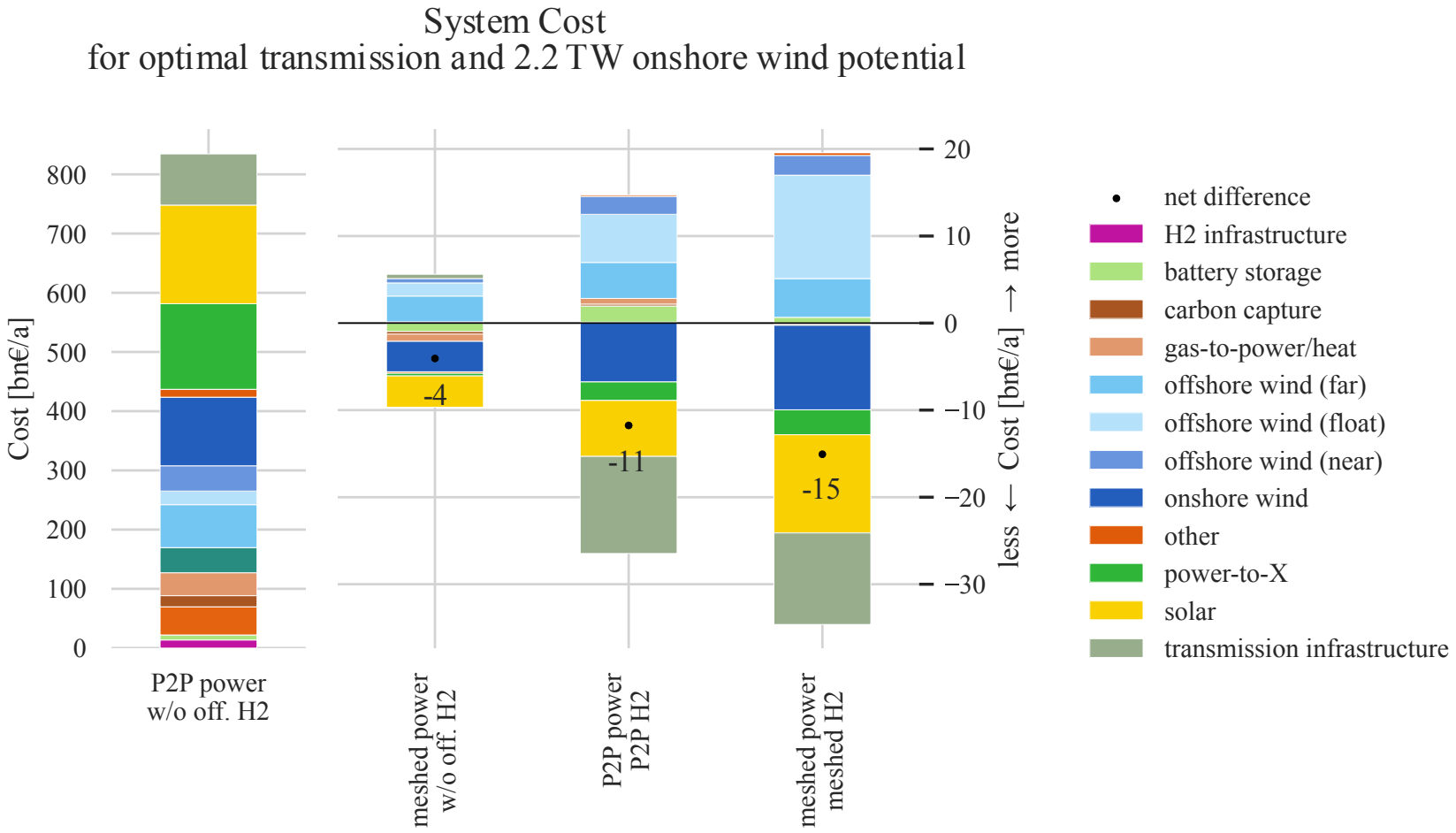
Study Case

We choose 4 main scenarios:

Offshore network	Offshore hydrogen	Transmission capacity	Onshore wind potential
Point-to-point (P2P)	Not available	optimal	2.2 TW (25 %)
Point-to-point (P2P)	Available		
Meshed	Not available		
Meshed	Available		

Results

- Total cost with P2P power network is 800 bn €/a



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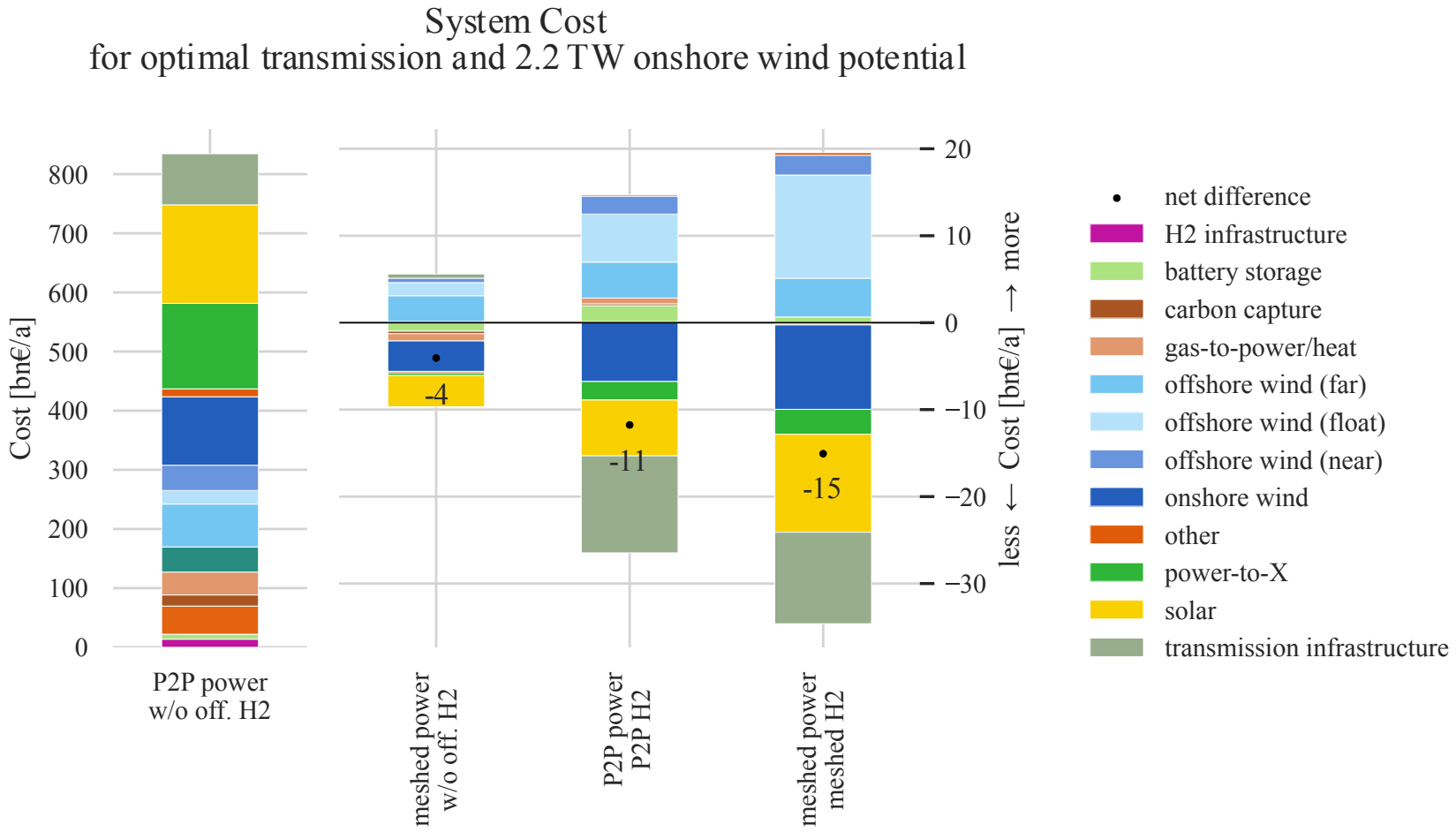
- Benefit of meshed power network of 4 bn €



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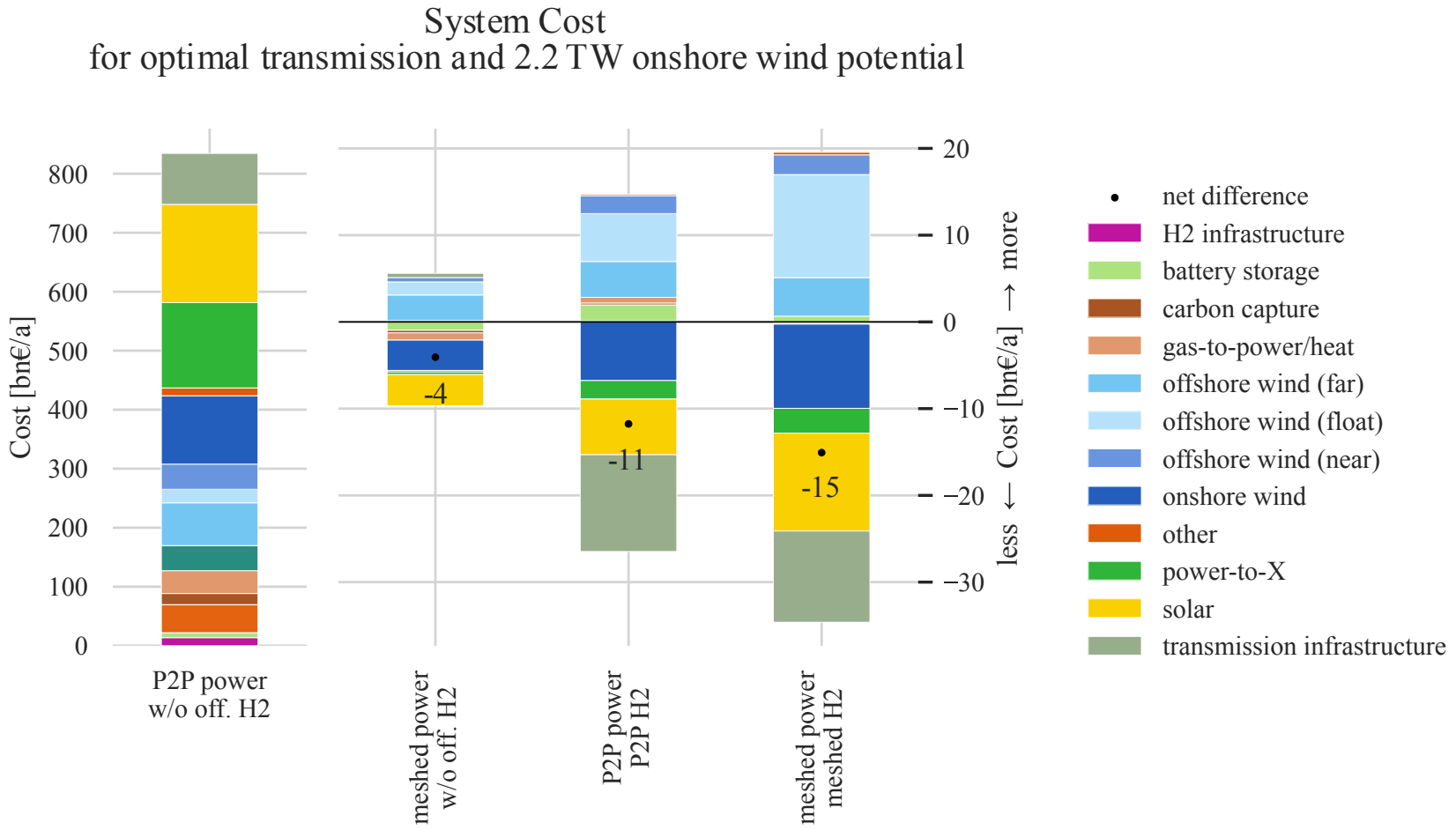
- Benefit of meshed power network of 4 bn €
- Introducing offshore hydrogen provides an additional benefit of 11 bn €



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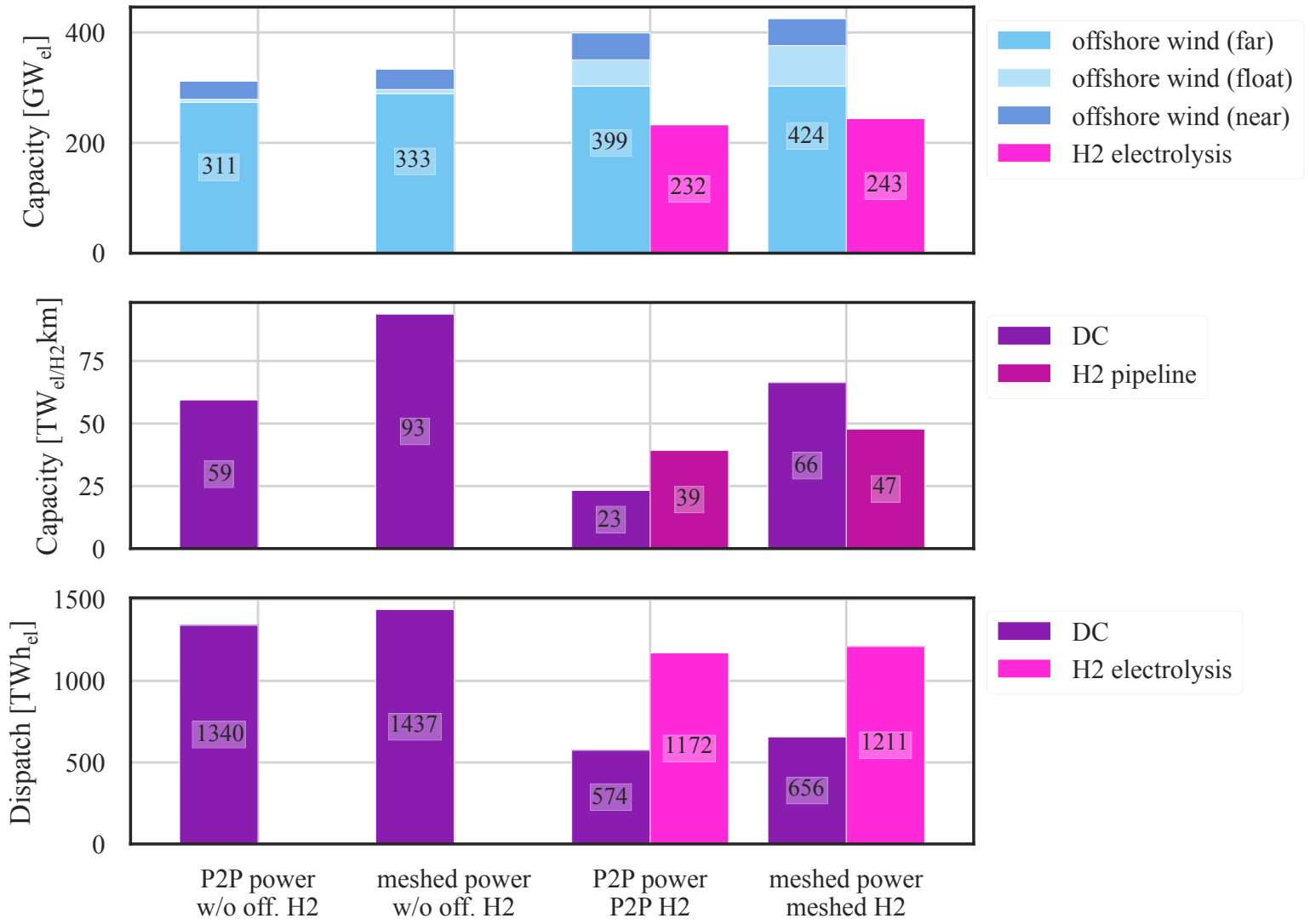
- Offshore wind capacities in North Sea from 311-424 GW



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- Offshore wind capacities in North Sea from 311-424 GW
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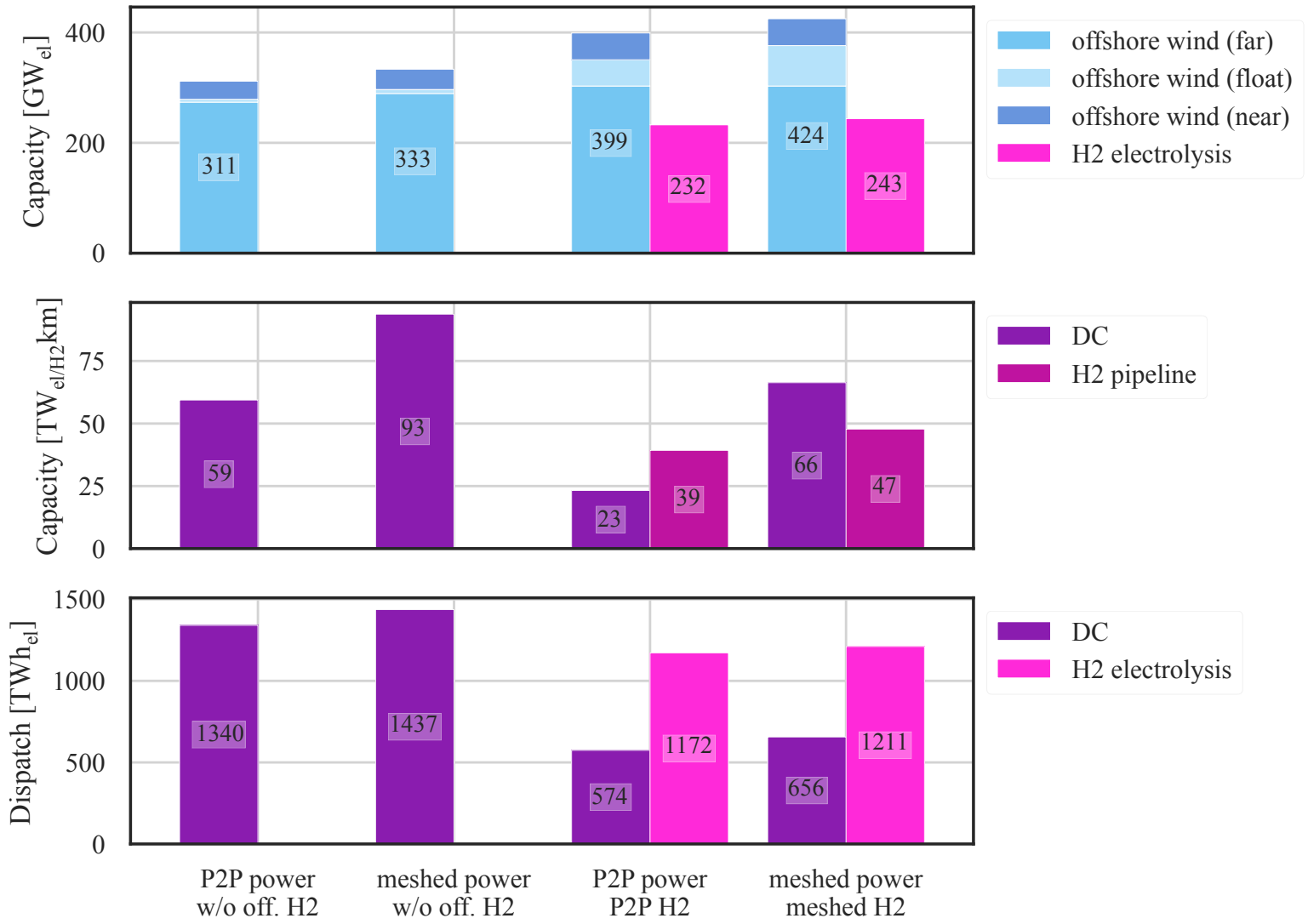

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- Offshore wind capacities in North Sea from 311-424 GW
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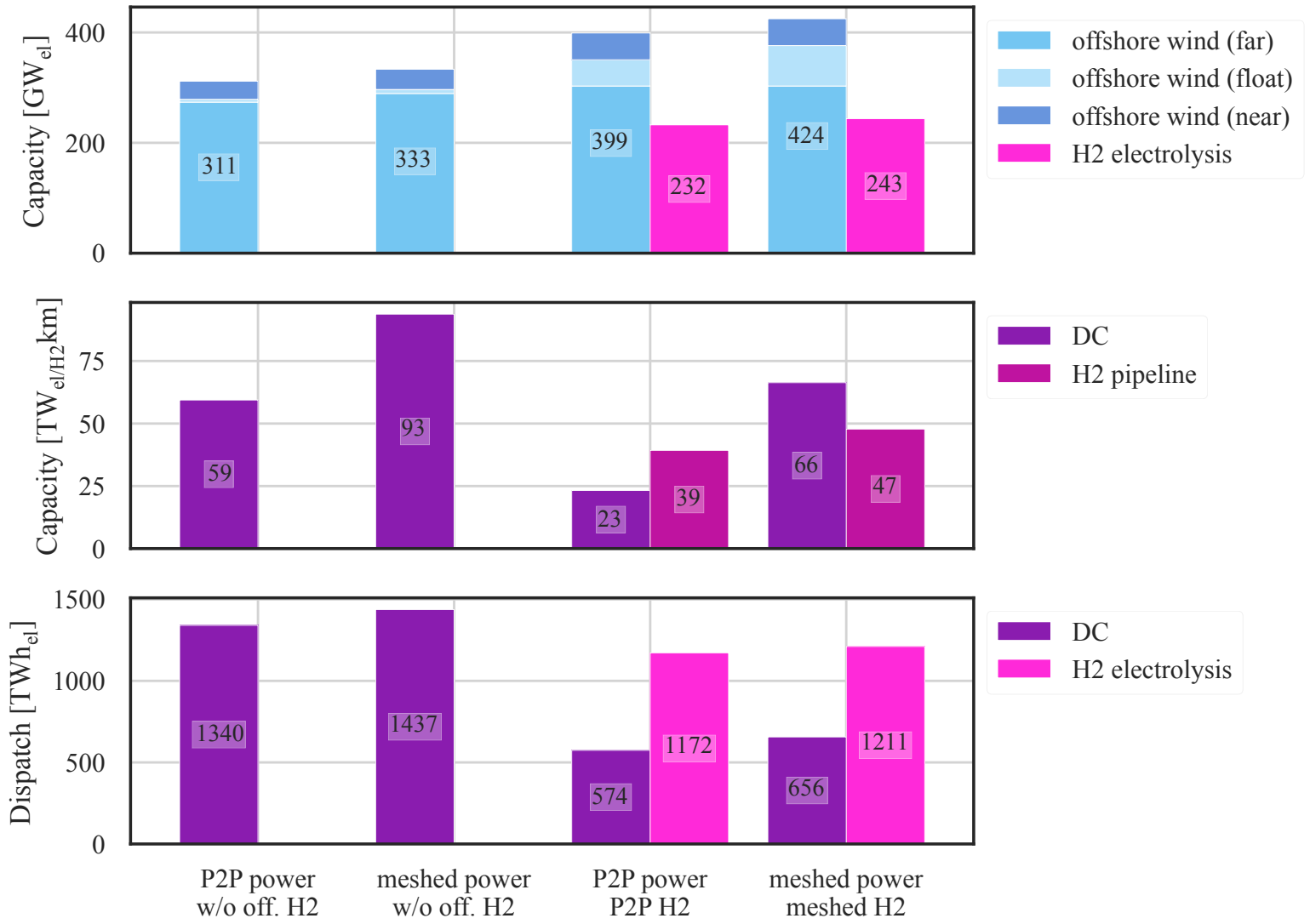

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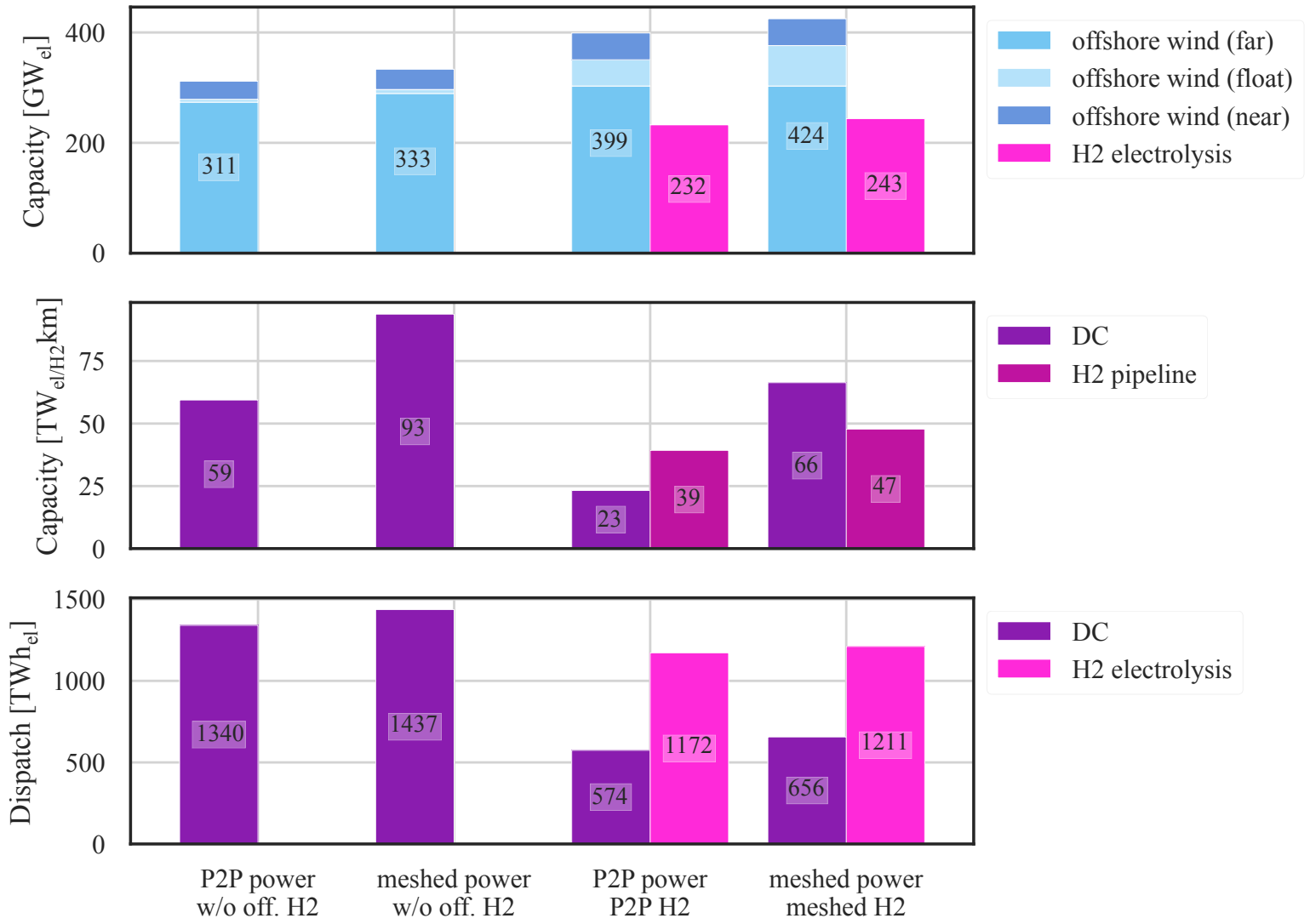

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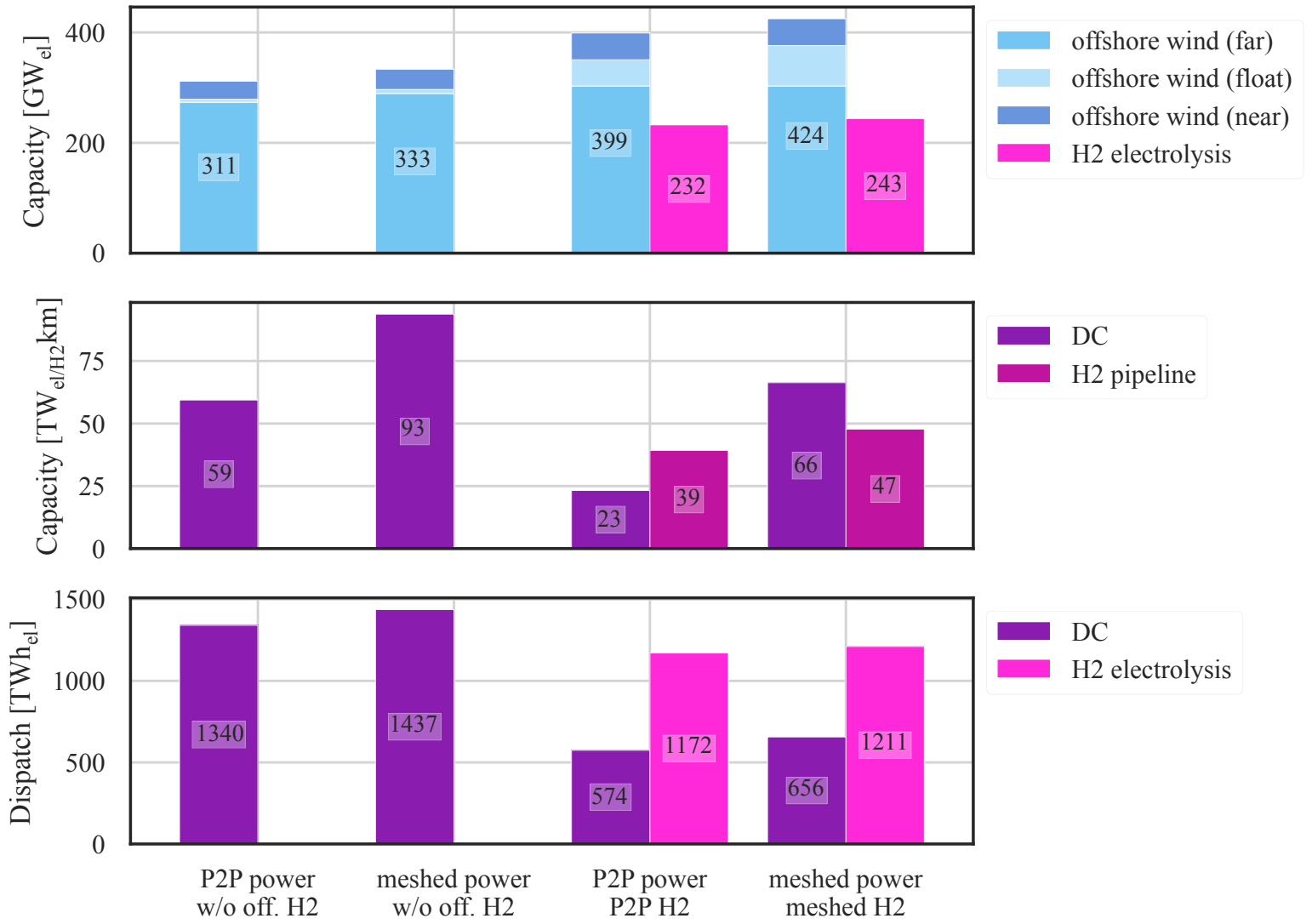
- 2/3 wind energy converted to H_2



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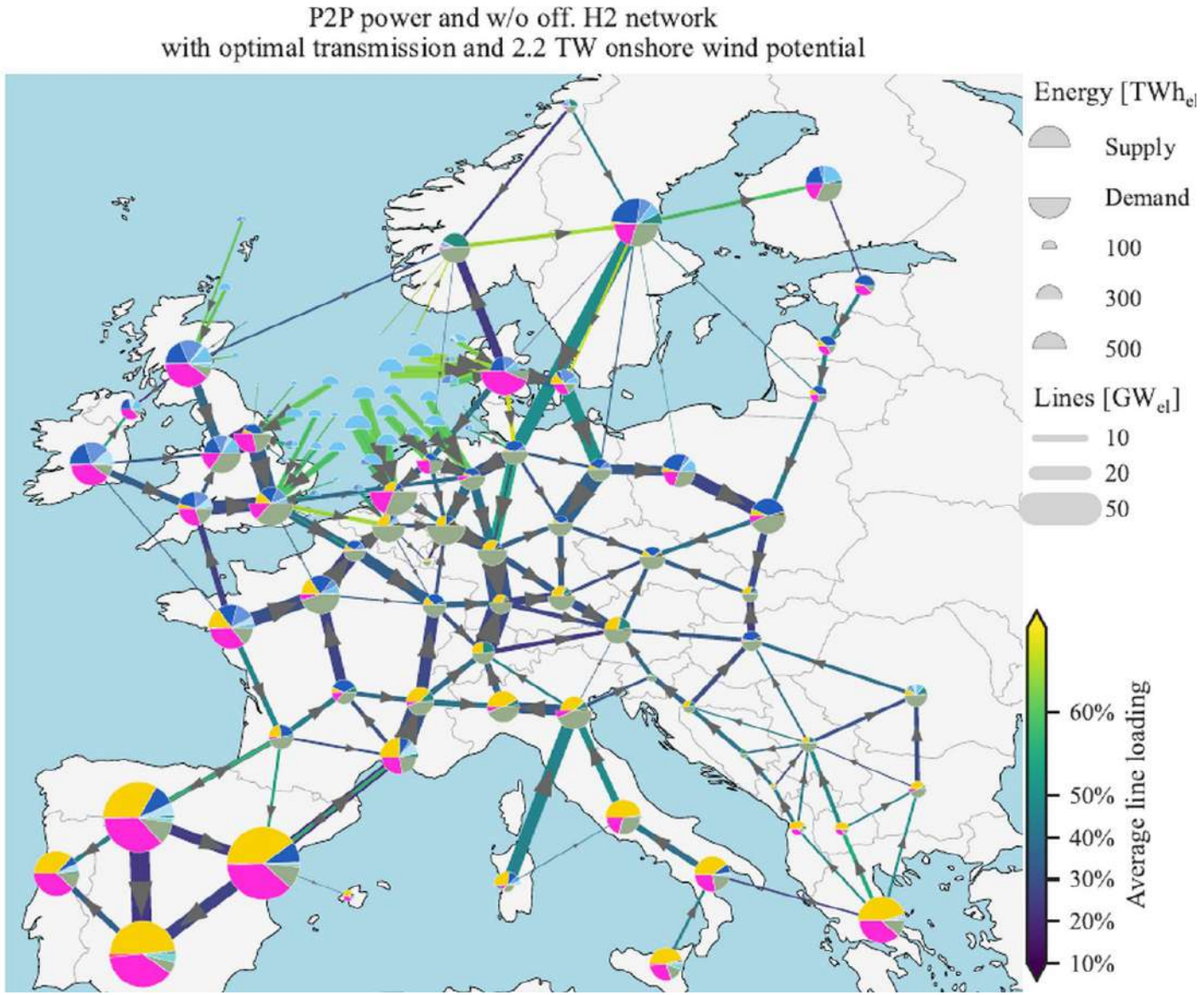

CHP
DAC
H2 electrolysis
H2 pipeline
battery storage
electricity demand
hydroelectricity
methanolisation
offshore wind (far)
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offshore wind (near)
onshore wind
solar PV

- P2P power lines have uniform utilization rates

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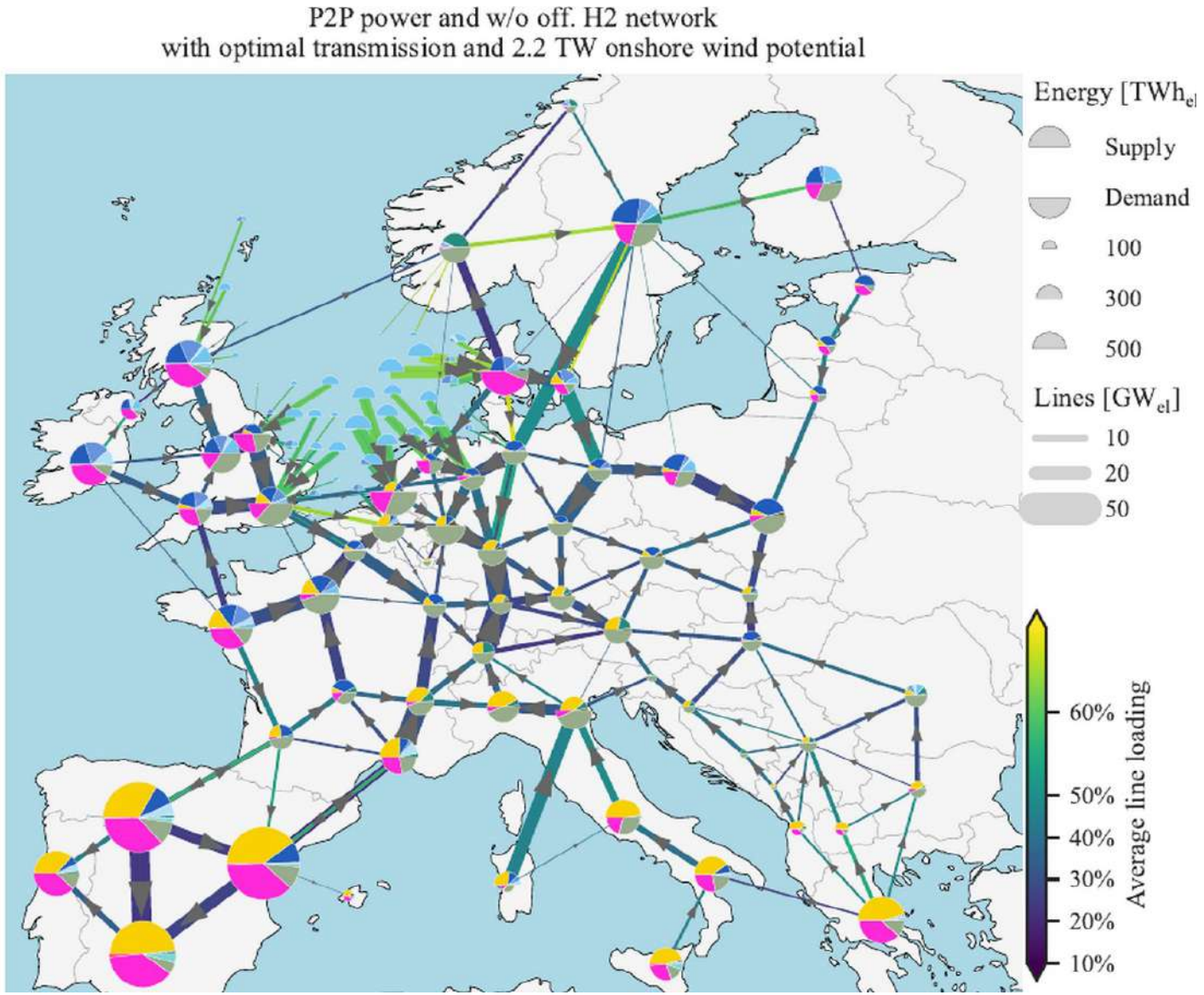

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- Plenty of power production in North Sea (20 % of total)

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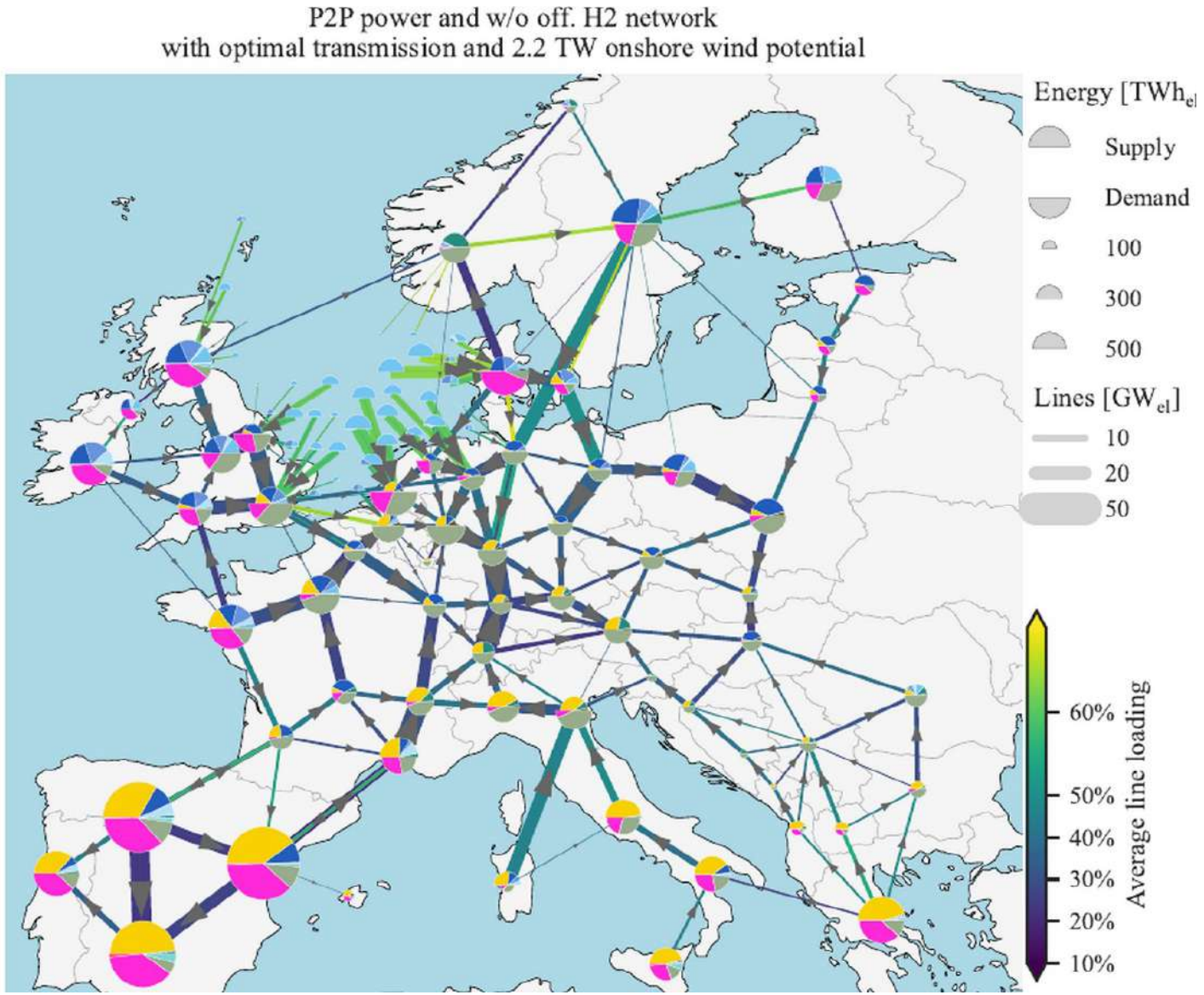

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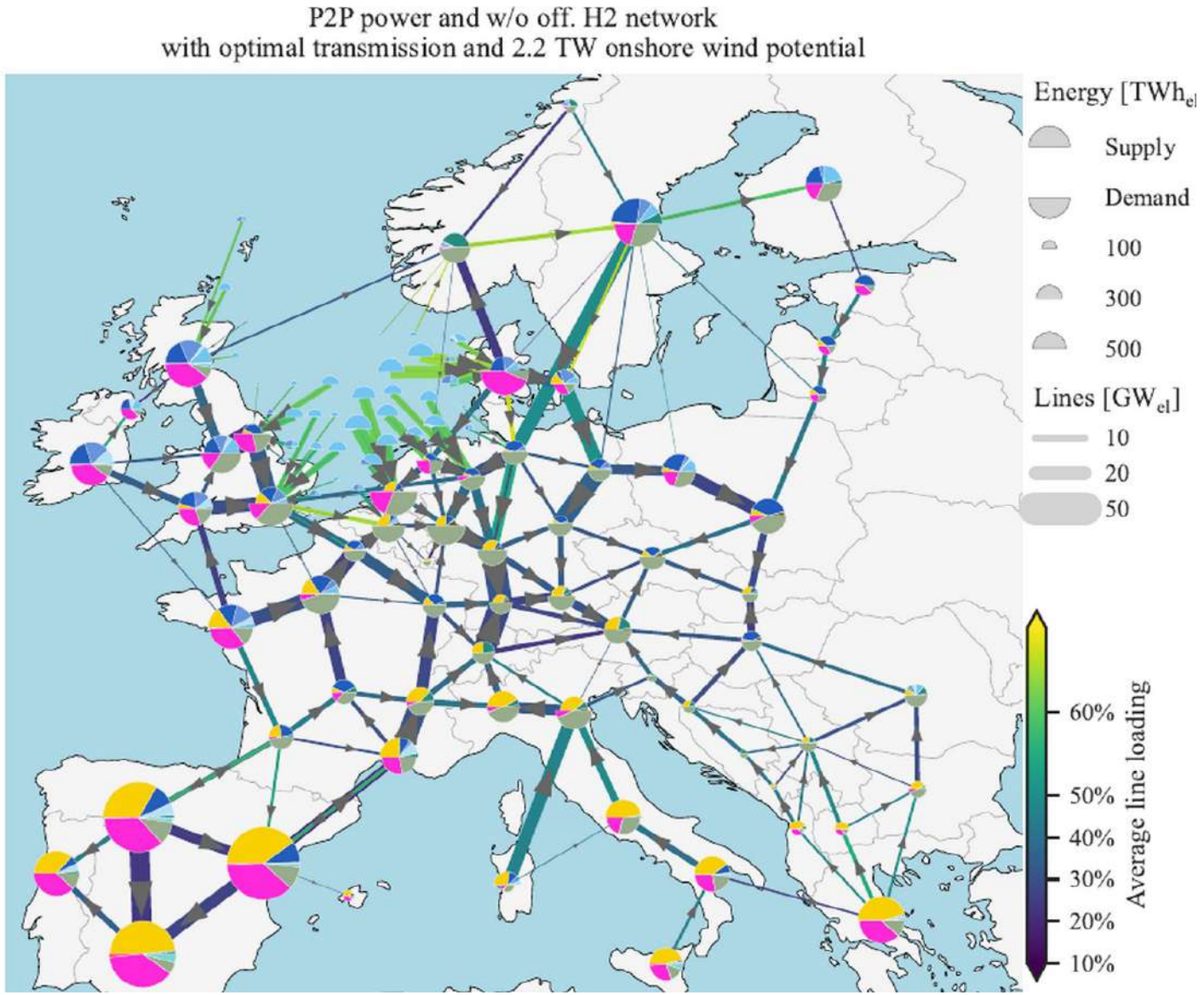

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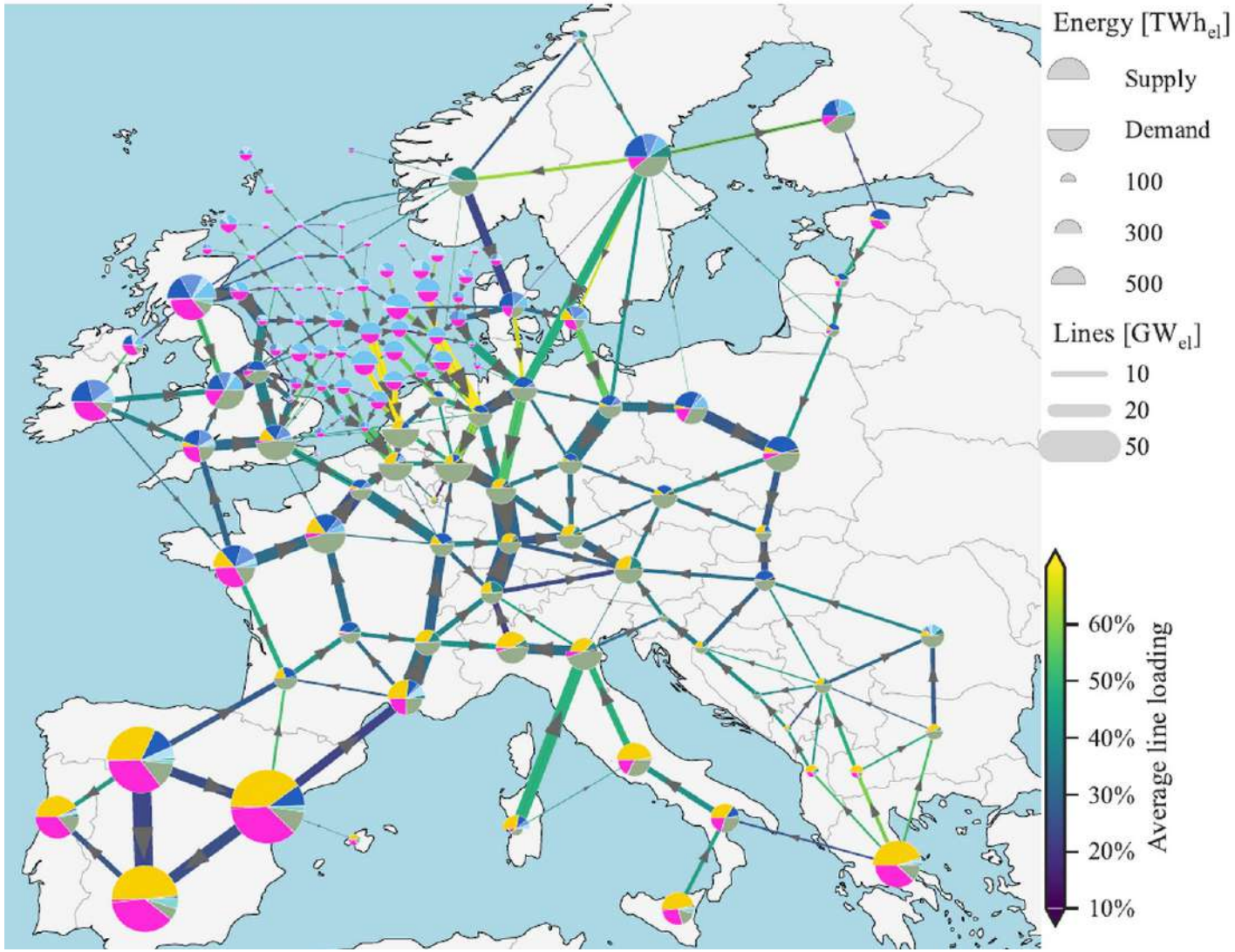
- System build TYNDP project “NorthConnect”

Results

Meshed power and meshed H2 network
with optimal transmission and 2.2 TW onshore wind potential



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- Main transmission corridors from UK to BE, NL and DE

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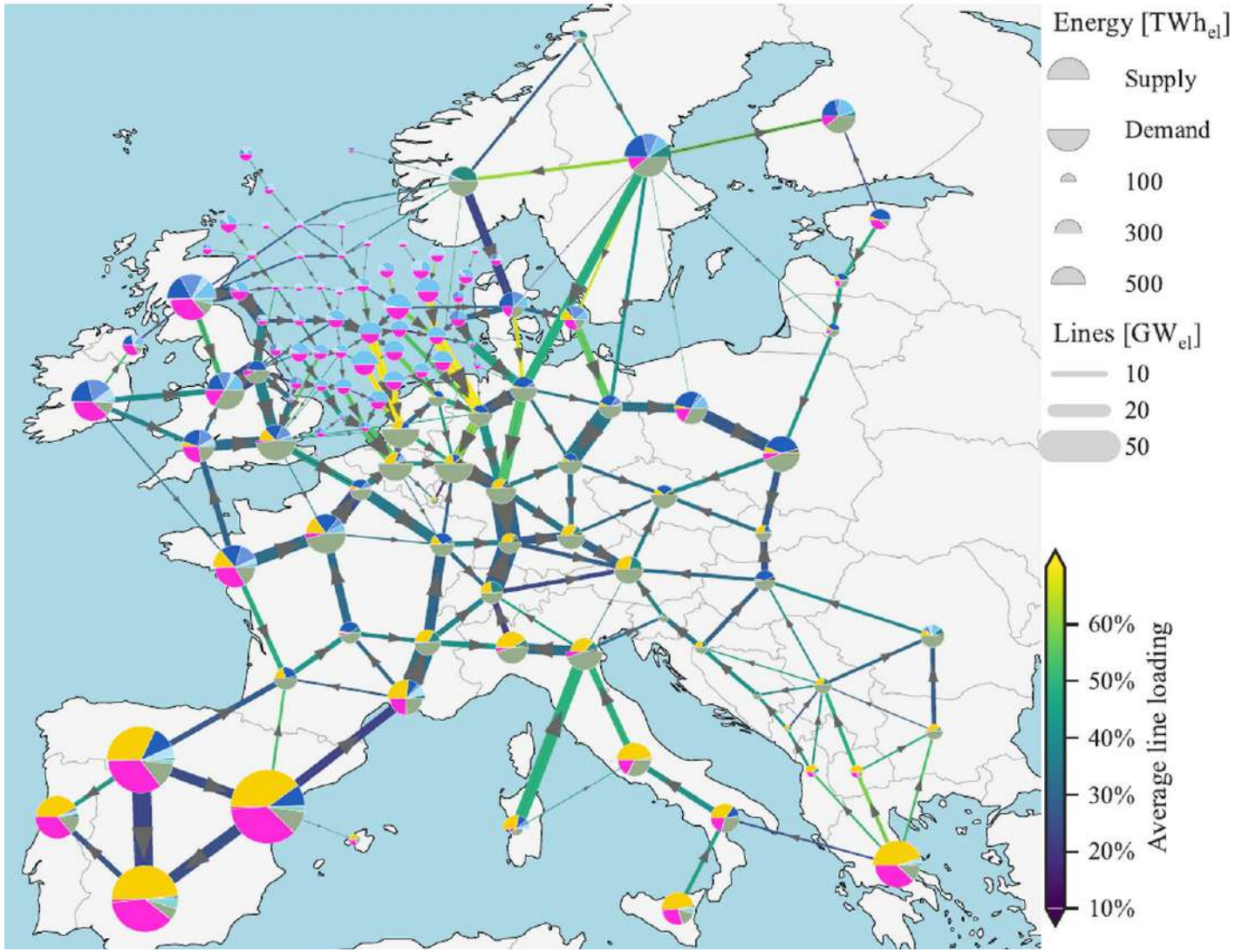

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- More offshore wind integration in remote areas

Results

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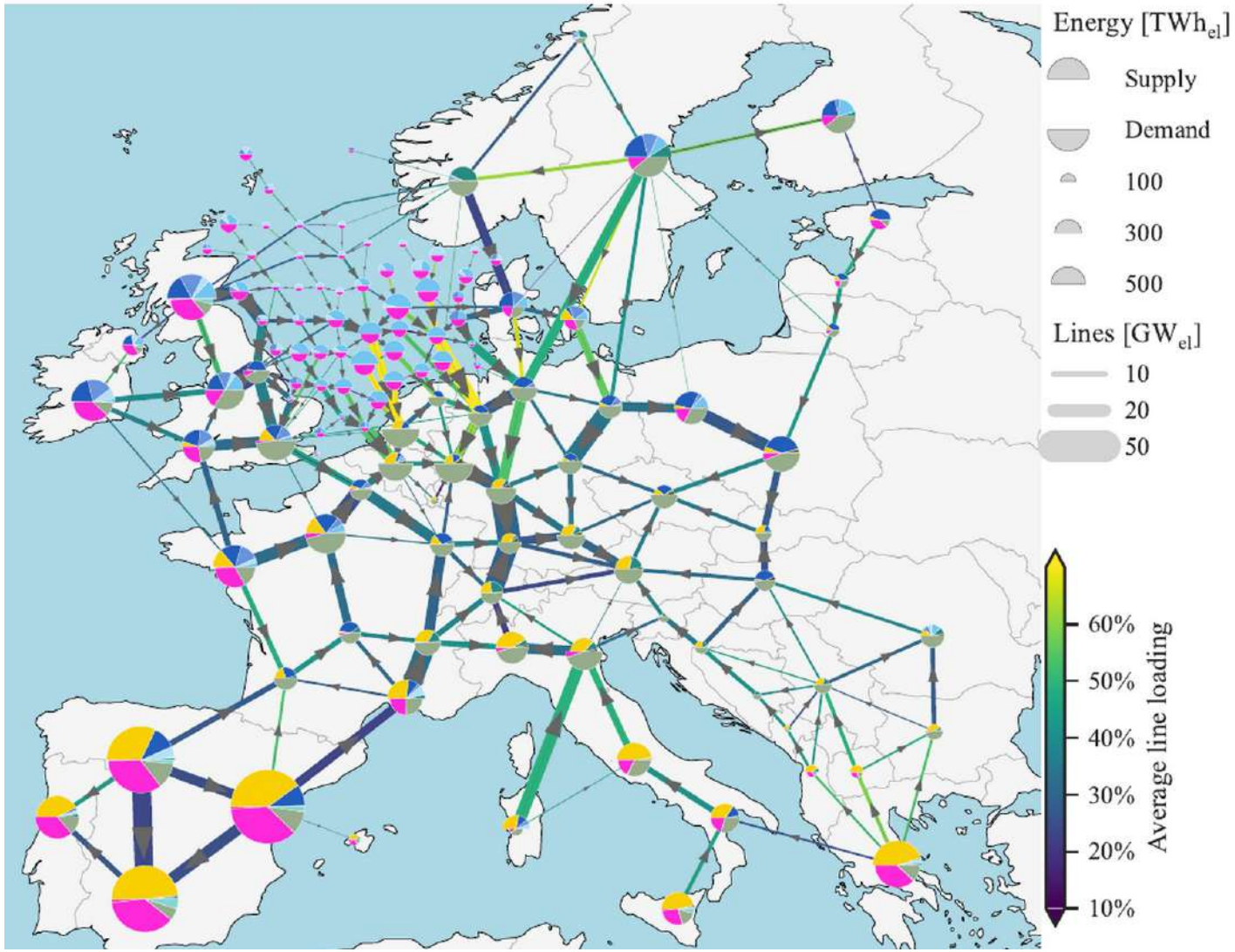

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- Onshore landing connections have higher utilization rates

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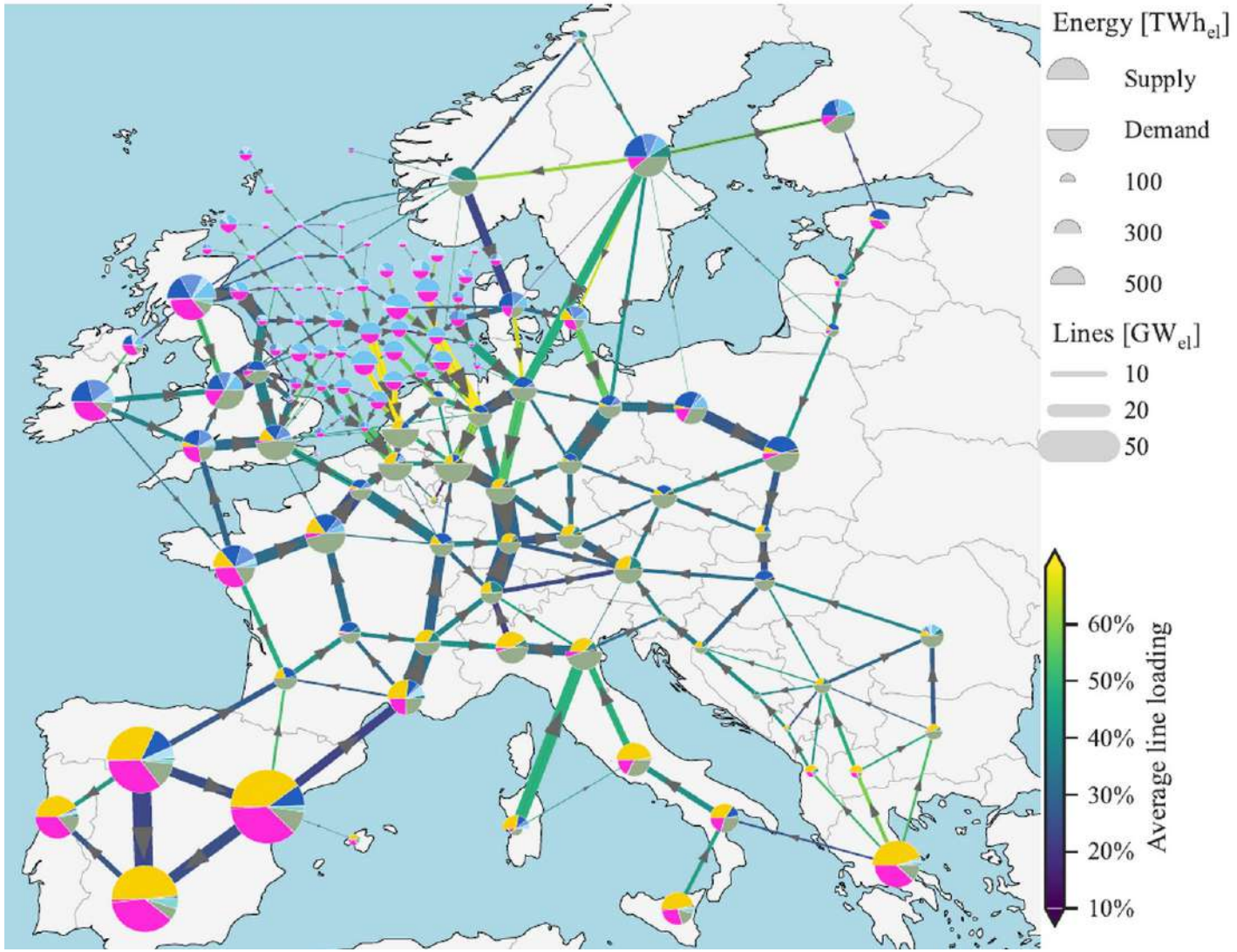

- Main transmission corridors from UK to BE, NL and DE
- More offshore wind integration in remote areas
- Onshore landing connections have higher utilization rates
- Offshore grid replaces “NorthConnect”

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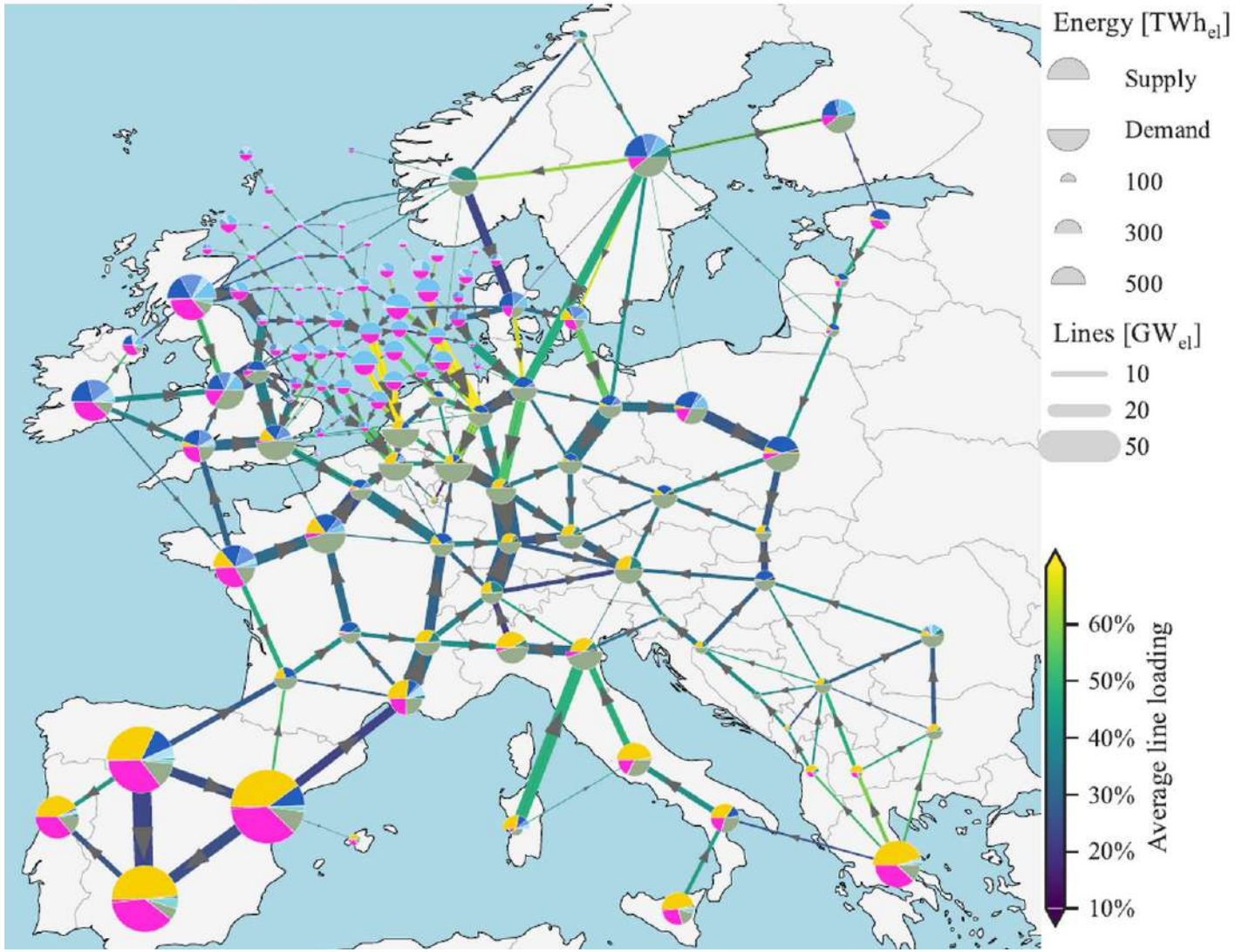
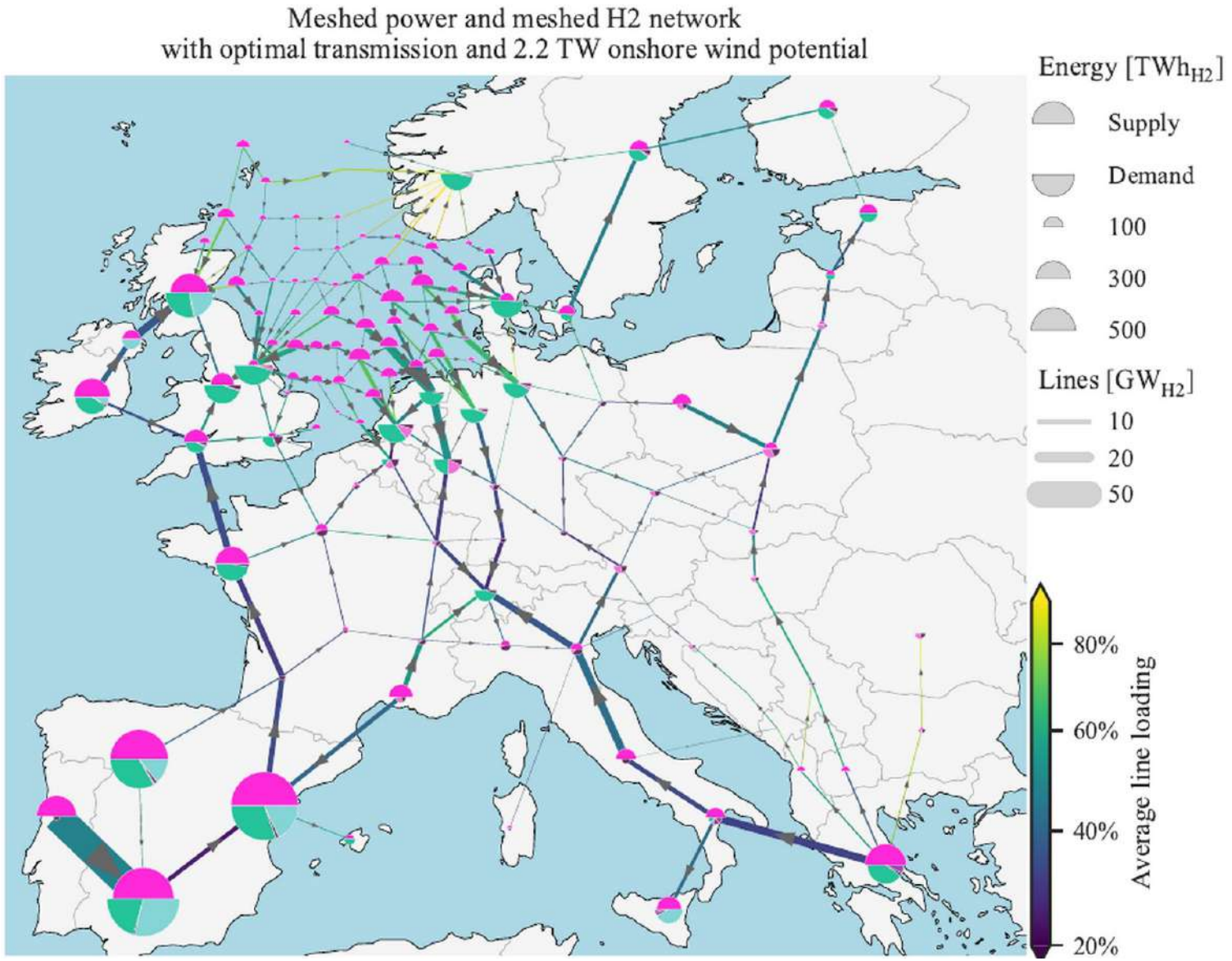


- Main transmission corridors from UK to BE, NL and DE
- More offshore wind integration in remote areas
- Onshore landing connections have higher utilization rates
- Offshore grid replaces “NorthConnect”
- Total demand: 9800 TWh$_{el}$

Results



- No onshore electrolysis from North Sea's power

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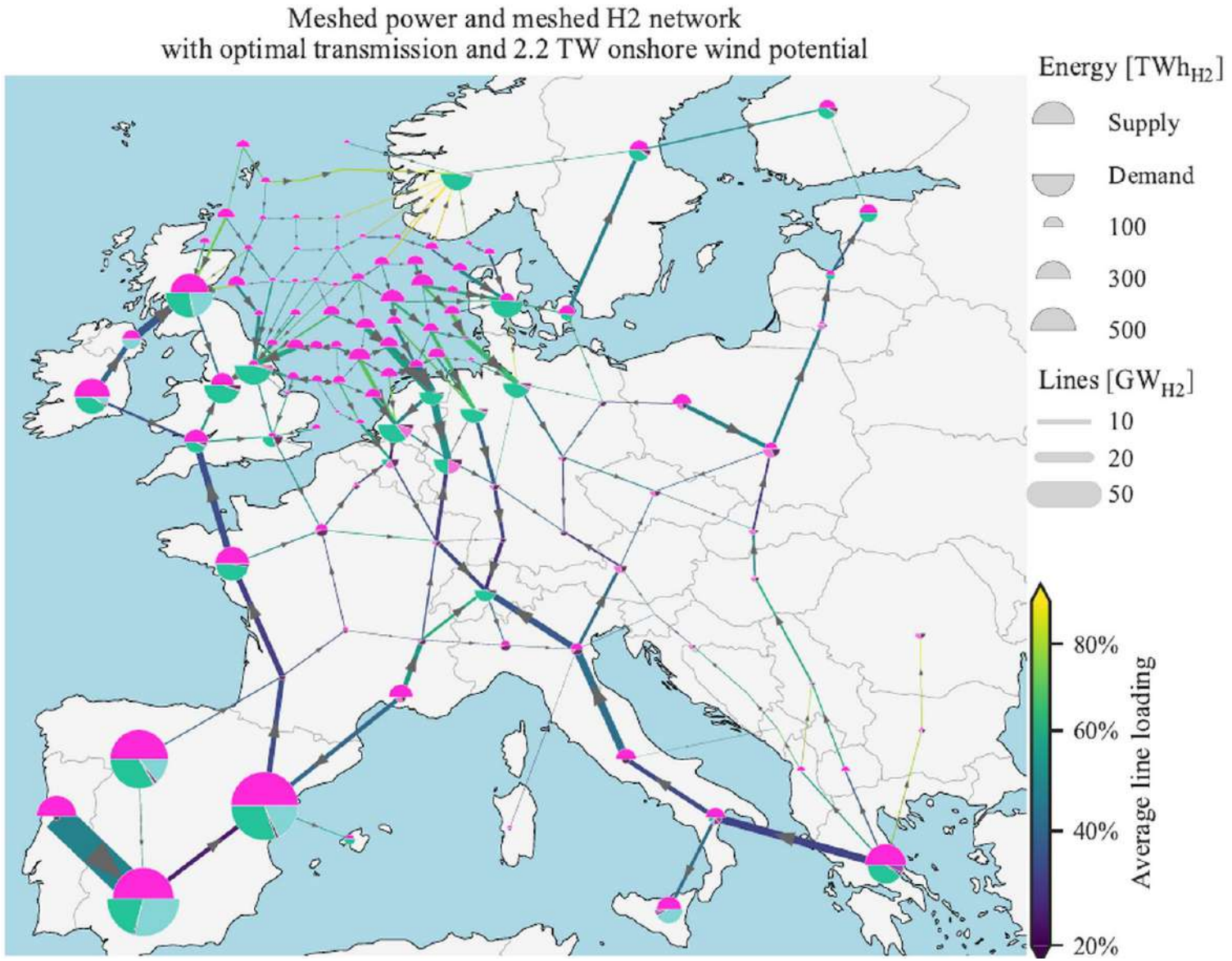

- No onshore electrolysis from North Sea's power
- Total H_2 demand 2900 TWH_{H2}

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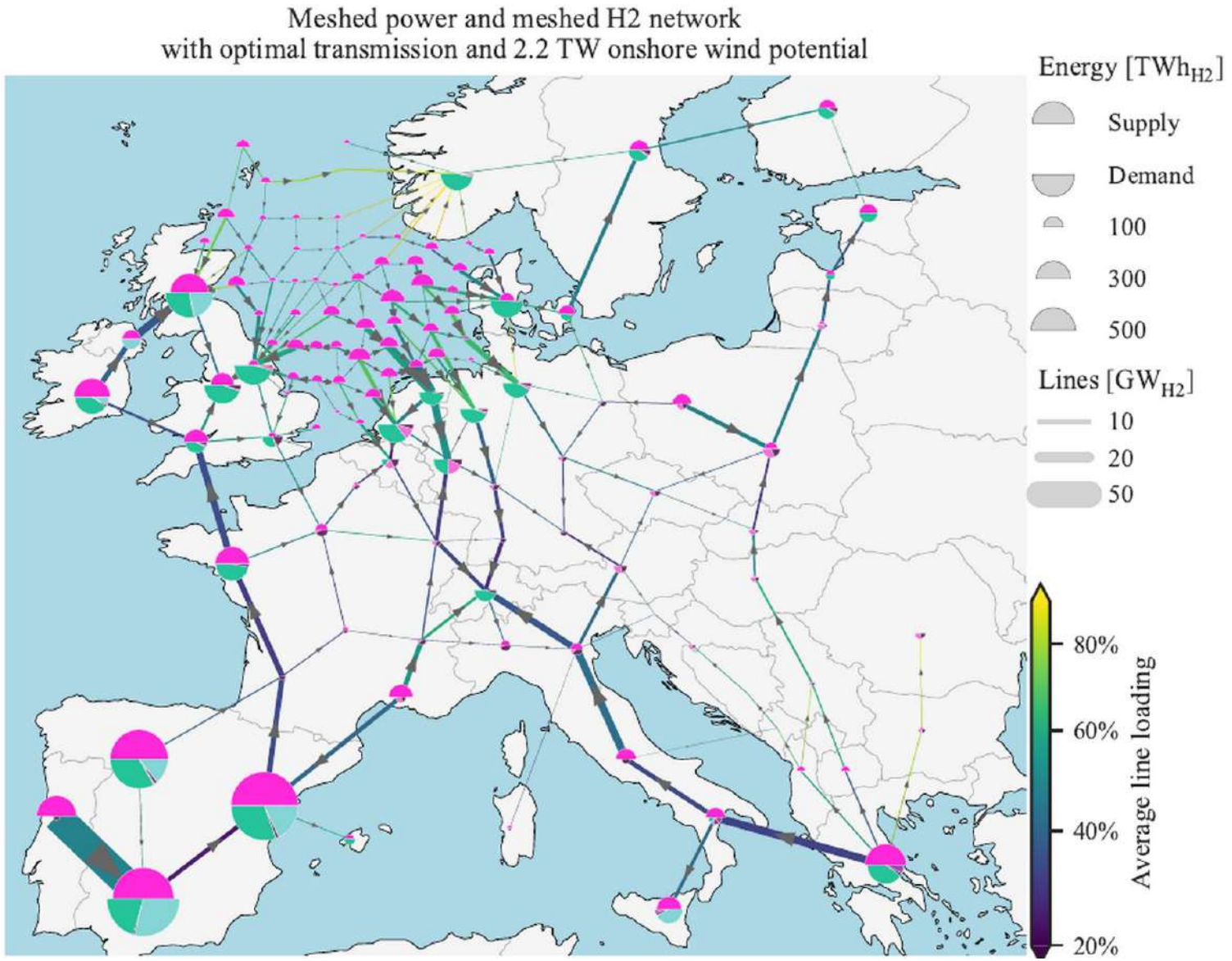
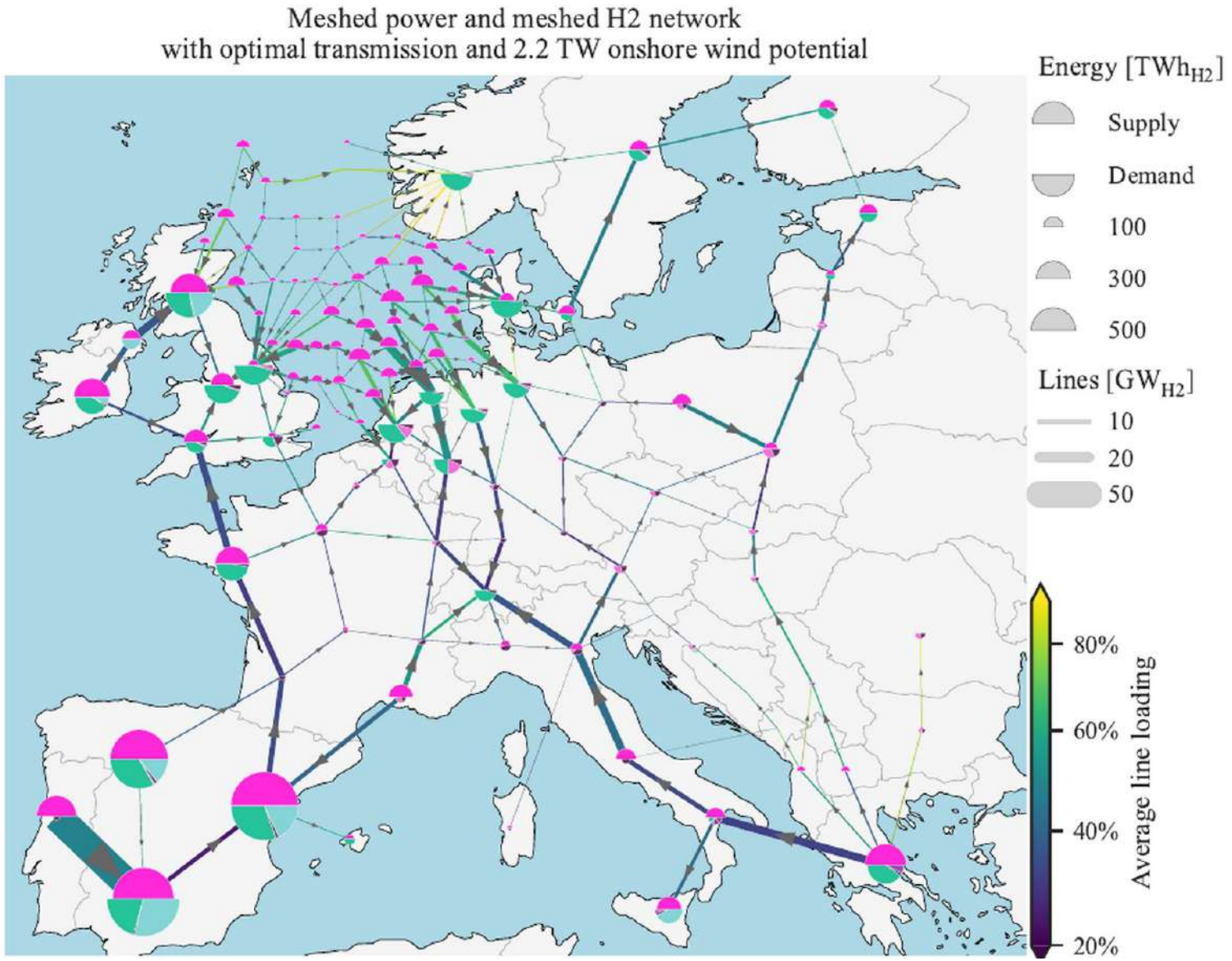


- No onshore electrolysis from North Sea's power
- Total H_2 demand 2900 TWH_{H2}
  - 930 TWH_{H2} in Spain

Results



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  - 830 TWH_{H2} North Sea

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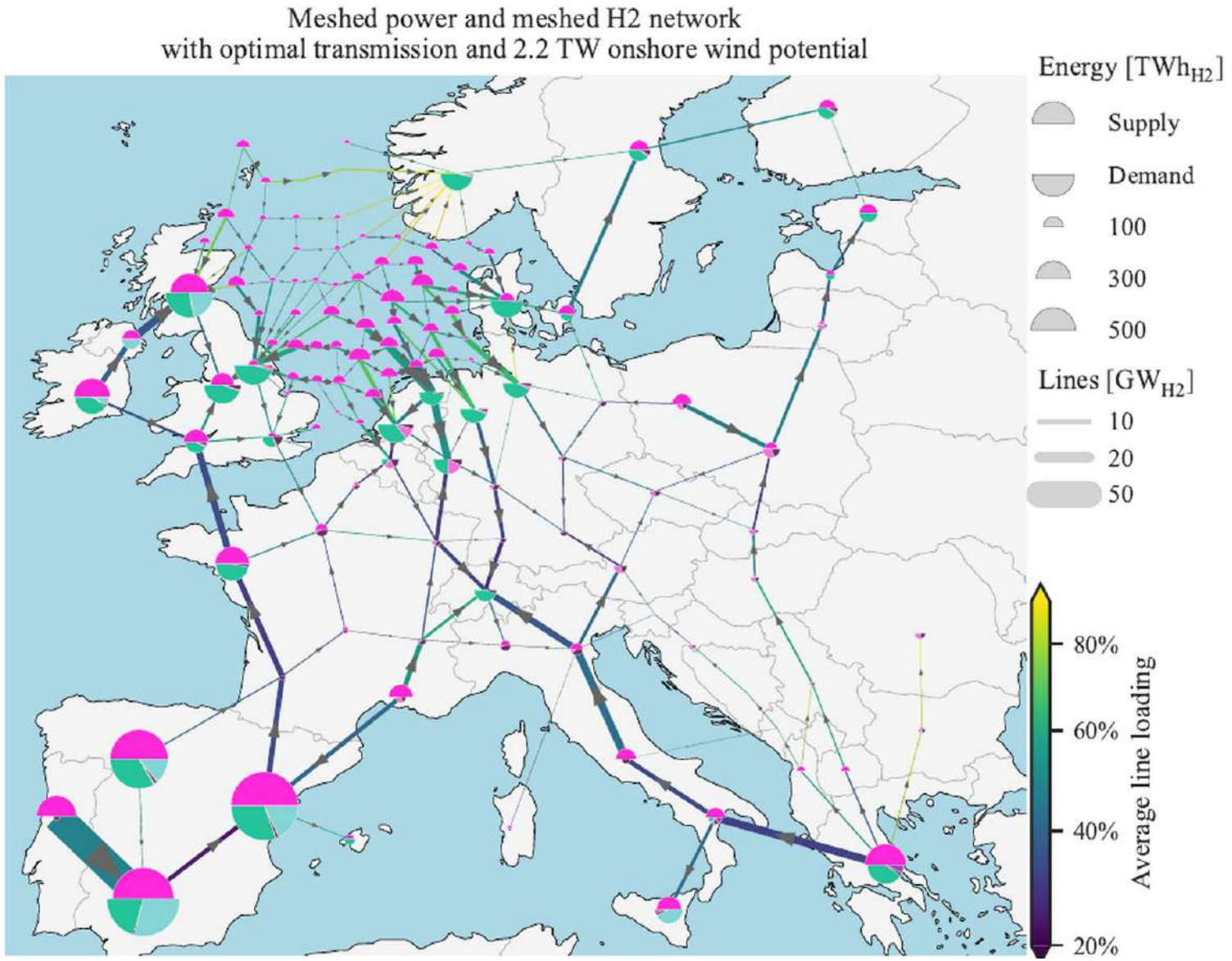
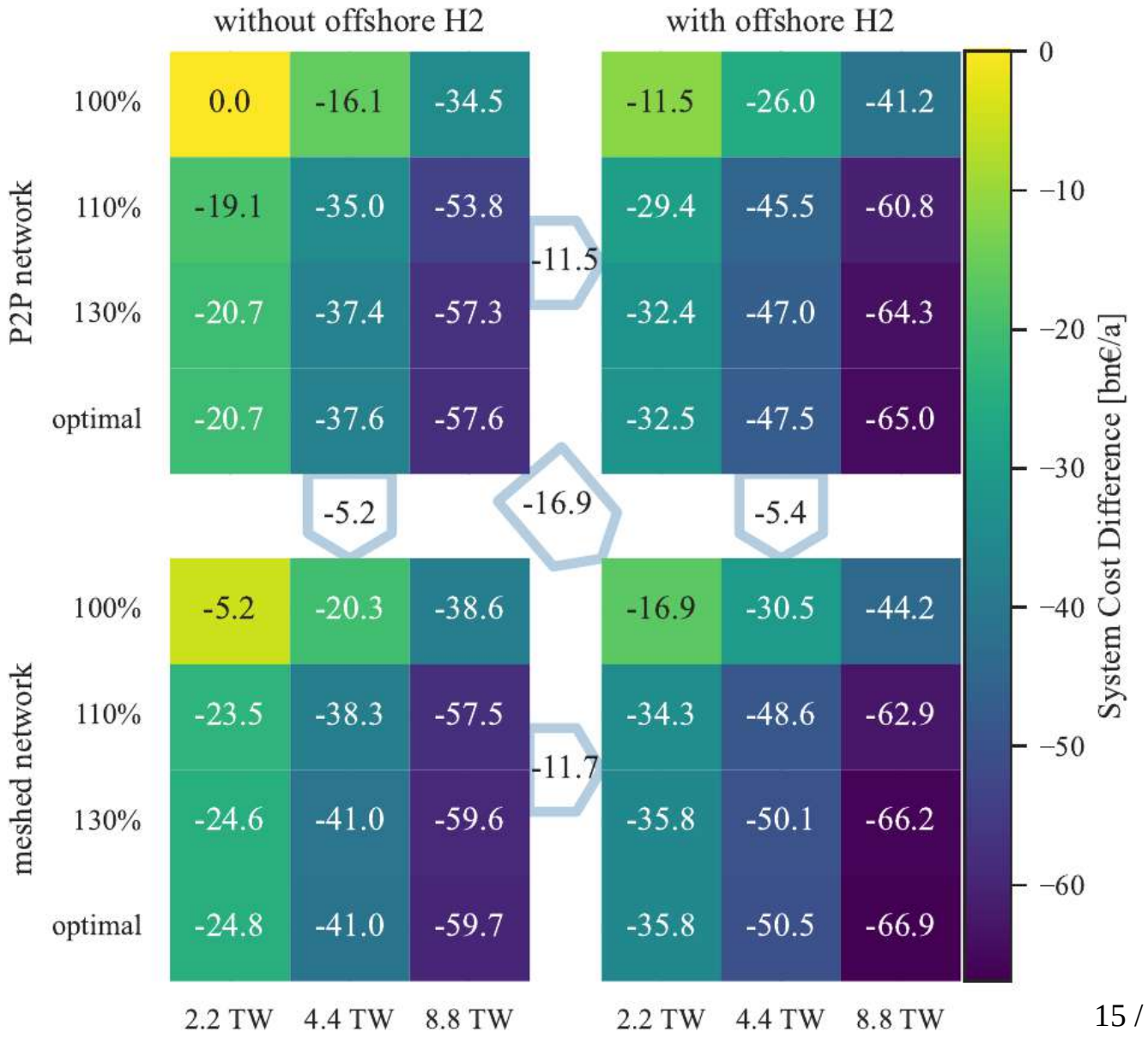


- No onshore electrolysis from North Sea's power
- Total H_2 demand 2900 TWH_{H2}
  - 930 TWH_{H2} in Spain
  - 830 TWH_{H2} North Sea
- Biggest pipelines capacities towards DE and NL

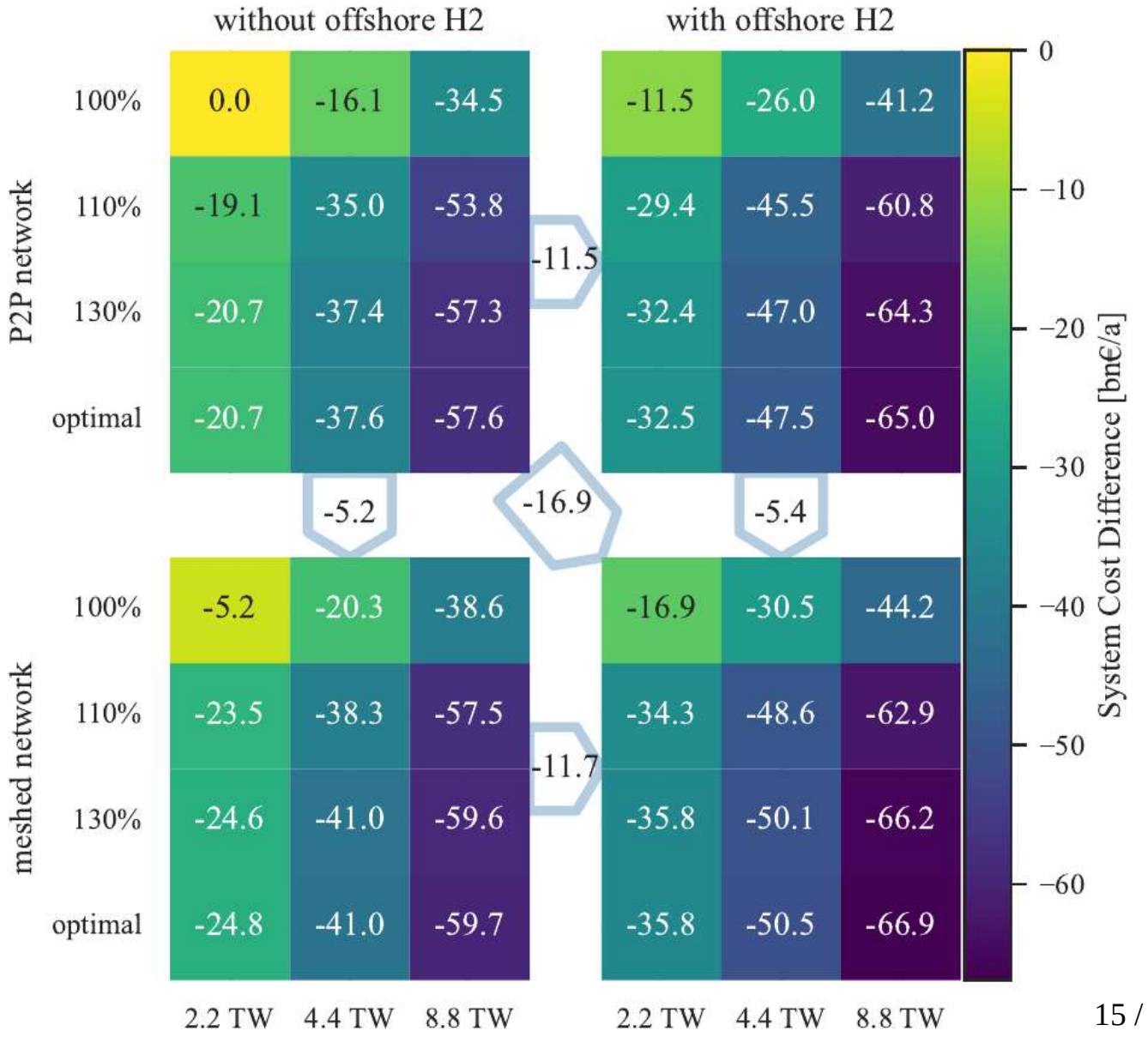
Results

- Decreasing benefits with higher transmission capacity and onshore wind potential

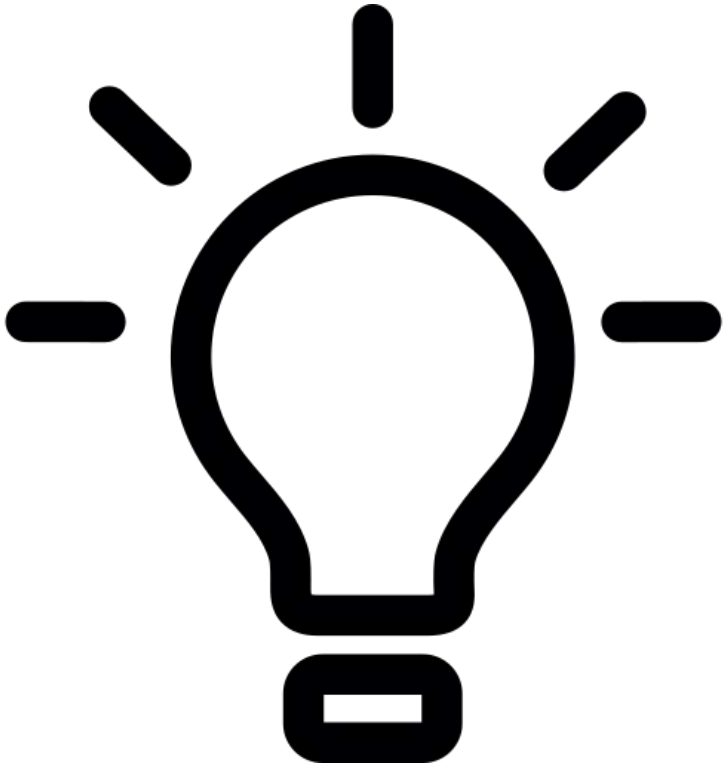


Results

- Decreasing benefits with higher transmission capacity and onshore wind potential
- Onshore potential has a greater impact on system cost

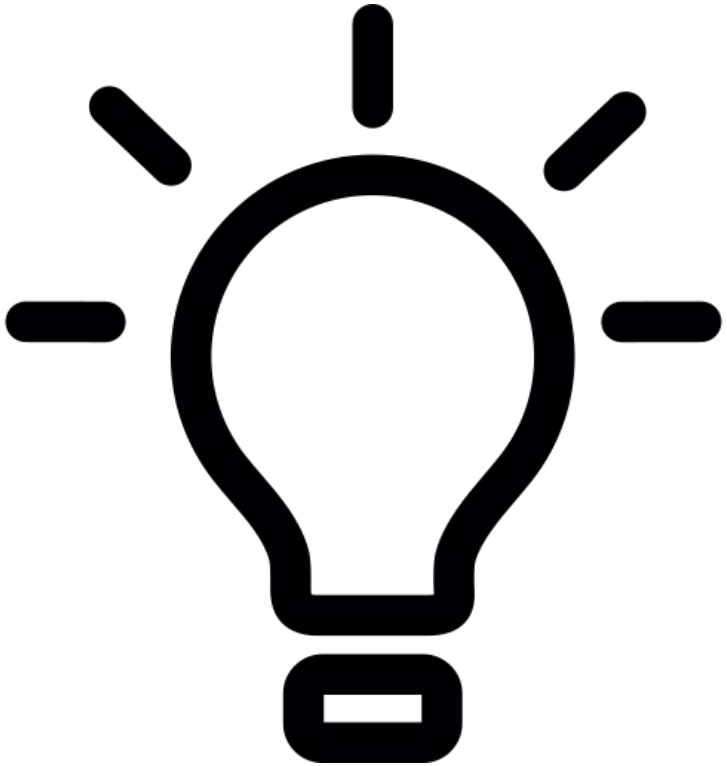


Key Takeaways



- Model opts for a mix of meshed power and H_2 network (15 bn€/a system benefits)

Key Takeaways



- Model opts for a mix of meshed power and H_2 network (15 bn€/a system benefits)
- Availability of offshore hydrogen more important than only meshed power network due to high power system cost (4 vs. 11 bn€/a system benefits)

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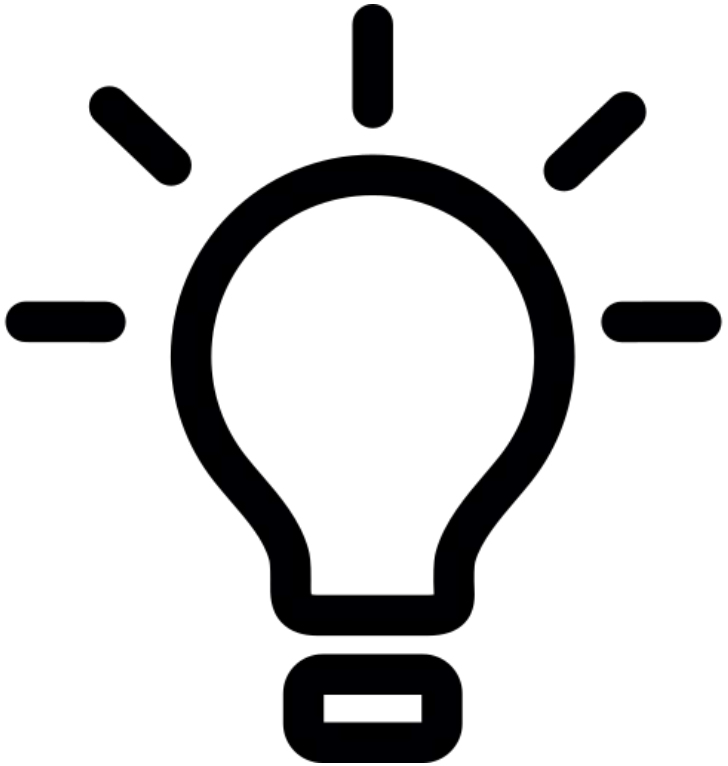

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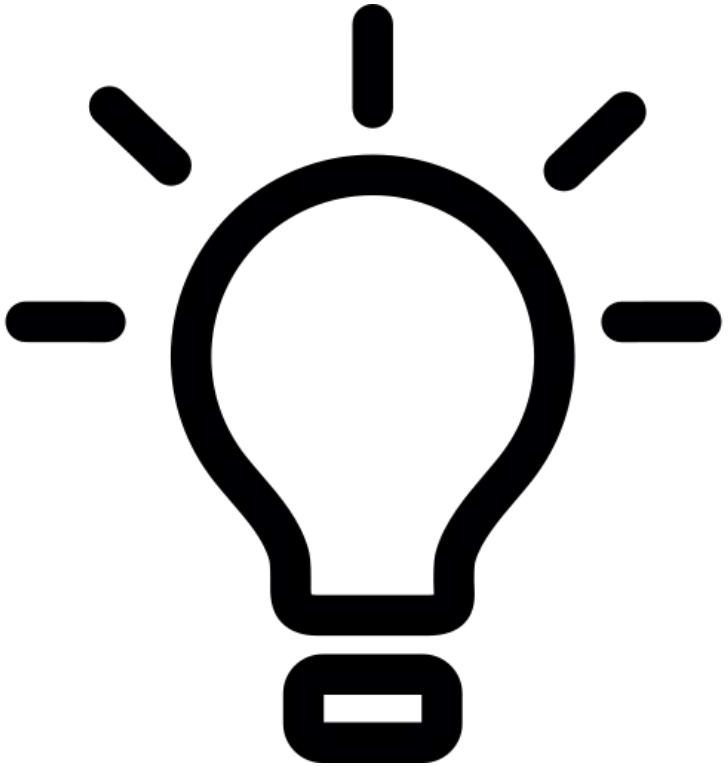

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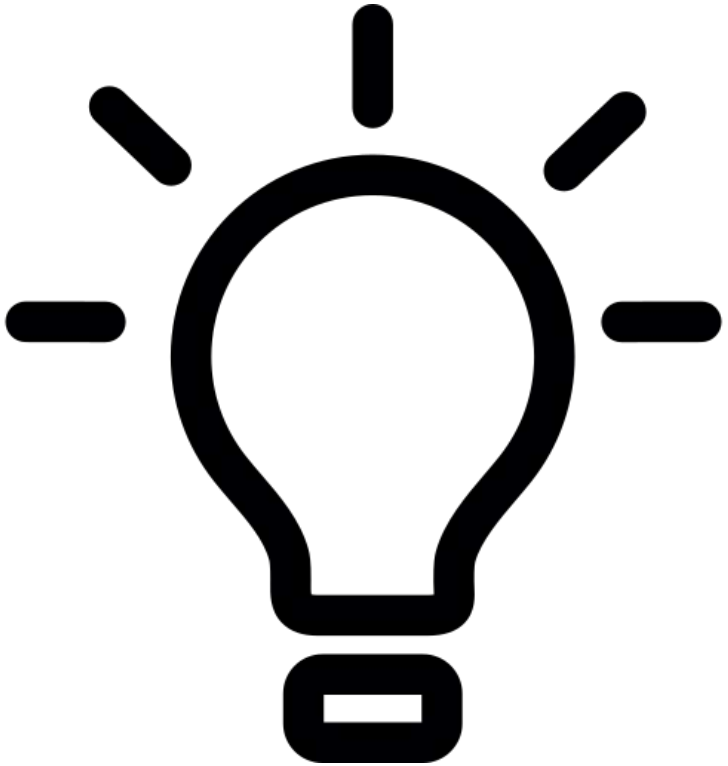

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- Up to 400 GW cost effective wind potential
- Limited onshore wind potential has a stronger impact than onshore transmission capacity
- North Sea has sufficient potential (370 GW fixed-bottom and 1000 GW floating) to replace large amounts of onshore wind generation

THANK YOU!

Questions?

Pre-Print:

Limitations

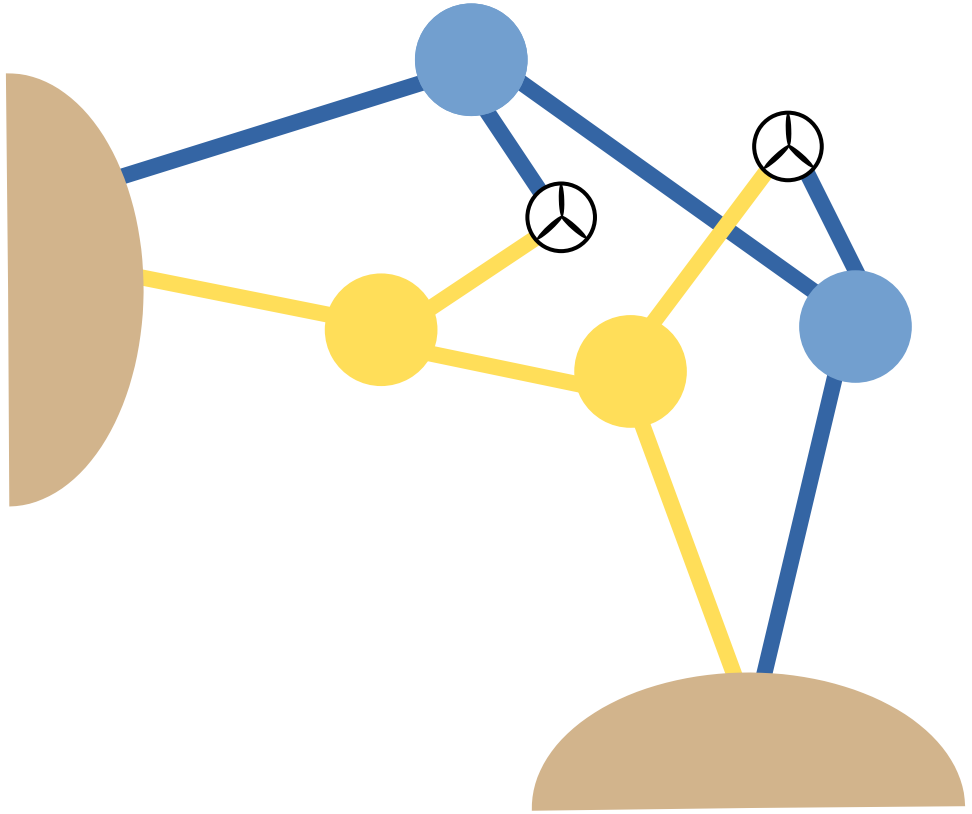
- Only DC system for North Sea
- Since model is linear, we cannot model discrete decisions which may lead to unrealistic investment decisions
- Non-linear power flows are simplified
- Did not consider ecological constraints or other obstacles for offshore infrastructure

Cost Assumptions

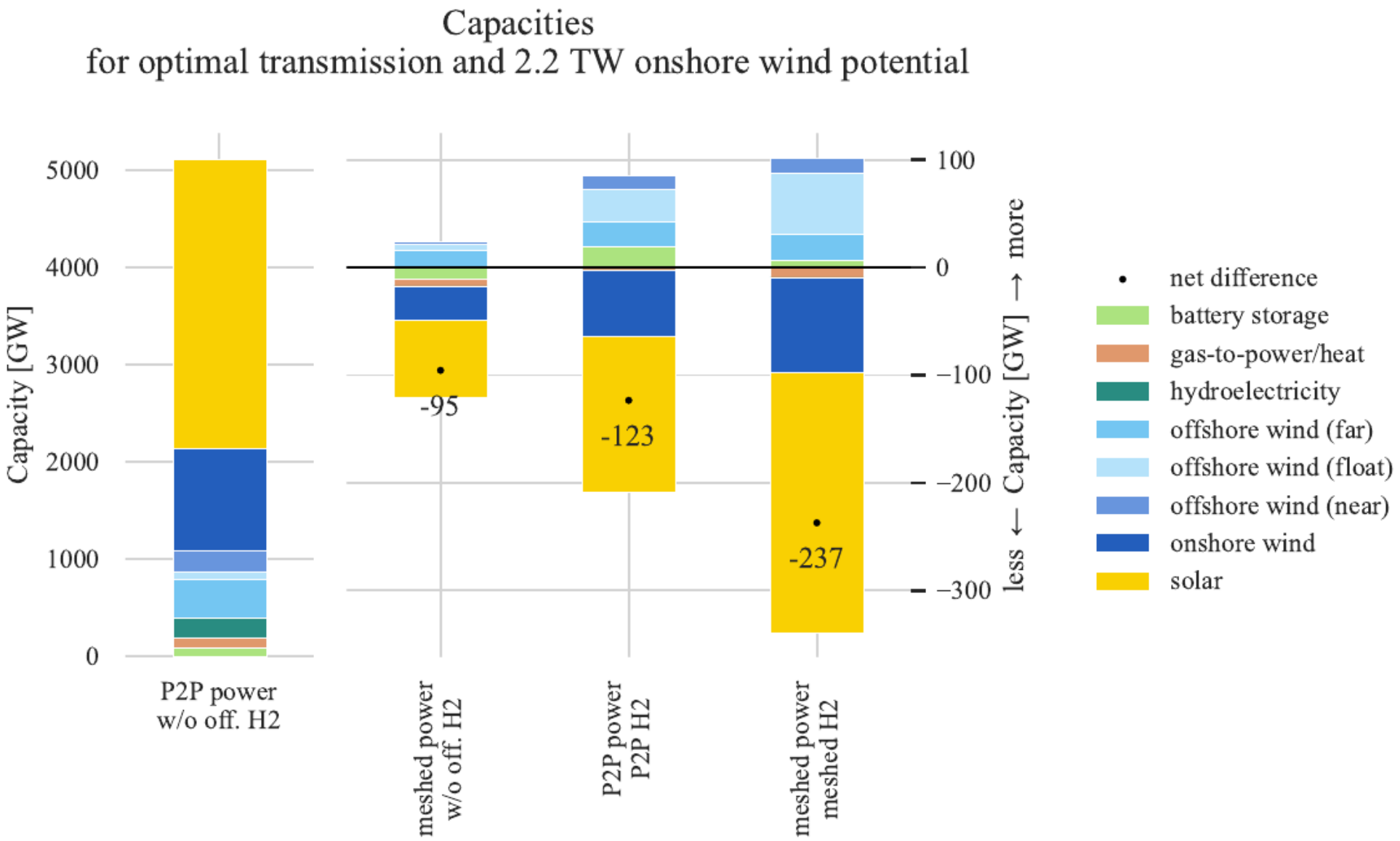
Technology	Value	Unit
HVDC overhead cable	430	€/MW/km
HVDC submarine cable	960	€/MW/km
Offshore HVDC platform	600	€/kW
Hydrogen pipeline	226	€/MW/km
Hydrogen submarine pipeline	329	€/MW/km
Electrolysis onshore	400	€/kW
Electrolysis offshore	440	€/kW
Floating offshore wind	2100	€/kW
Nearshore offshore wind (constant)	1250	€/kW
Far offshore wind (constant)	1600	€/kW

Offshore Topology Modeling

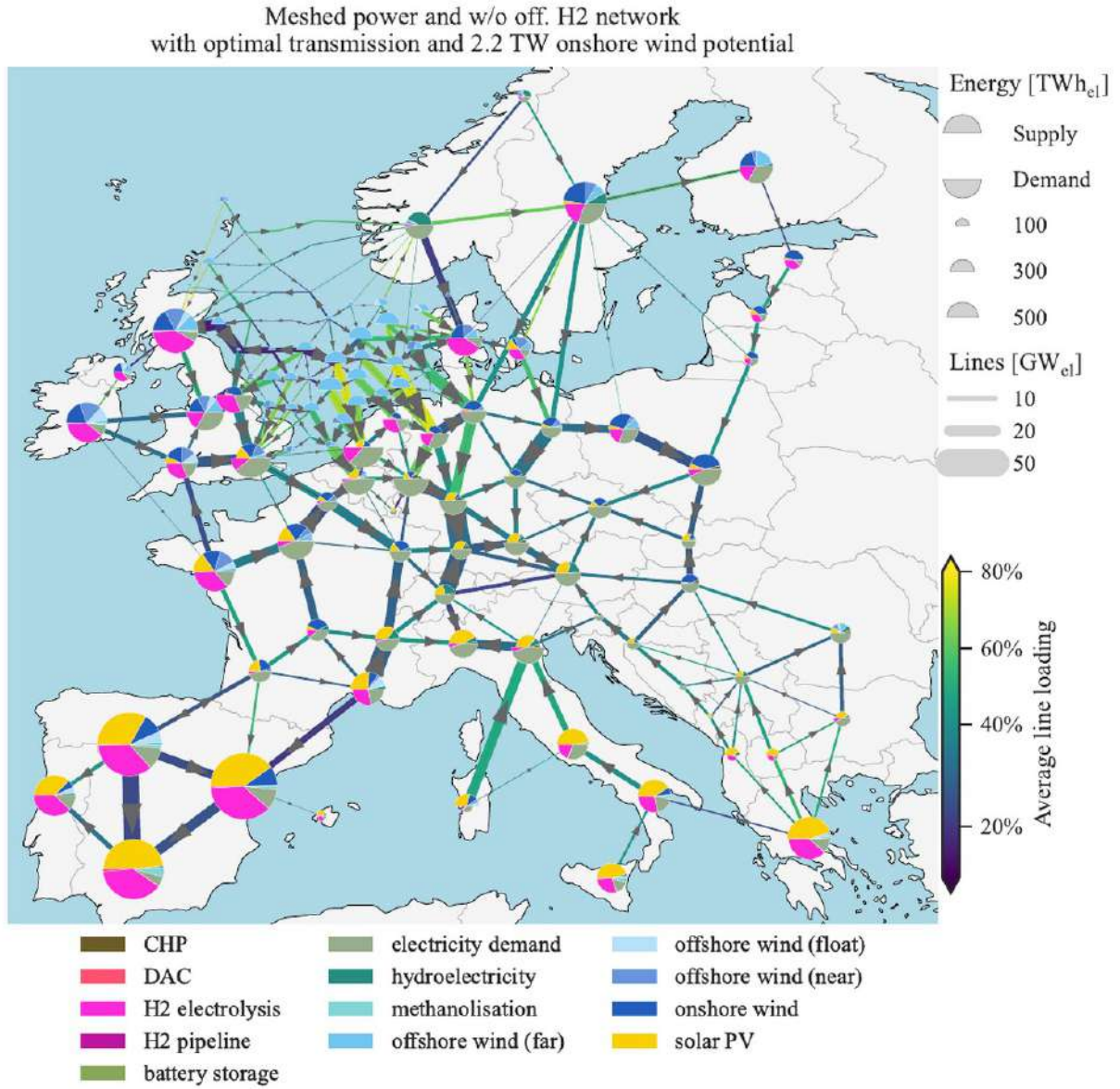
- Hydrogen platform with electrolysis and desalination
- DC platform with substation



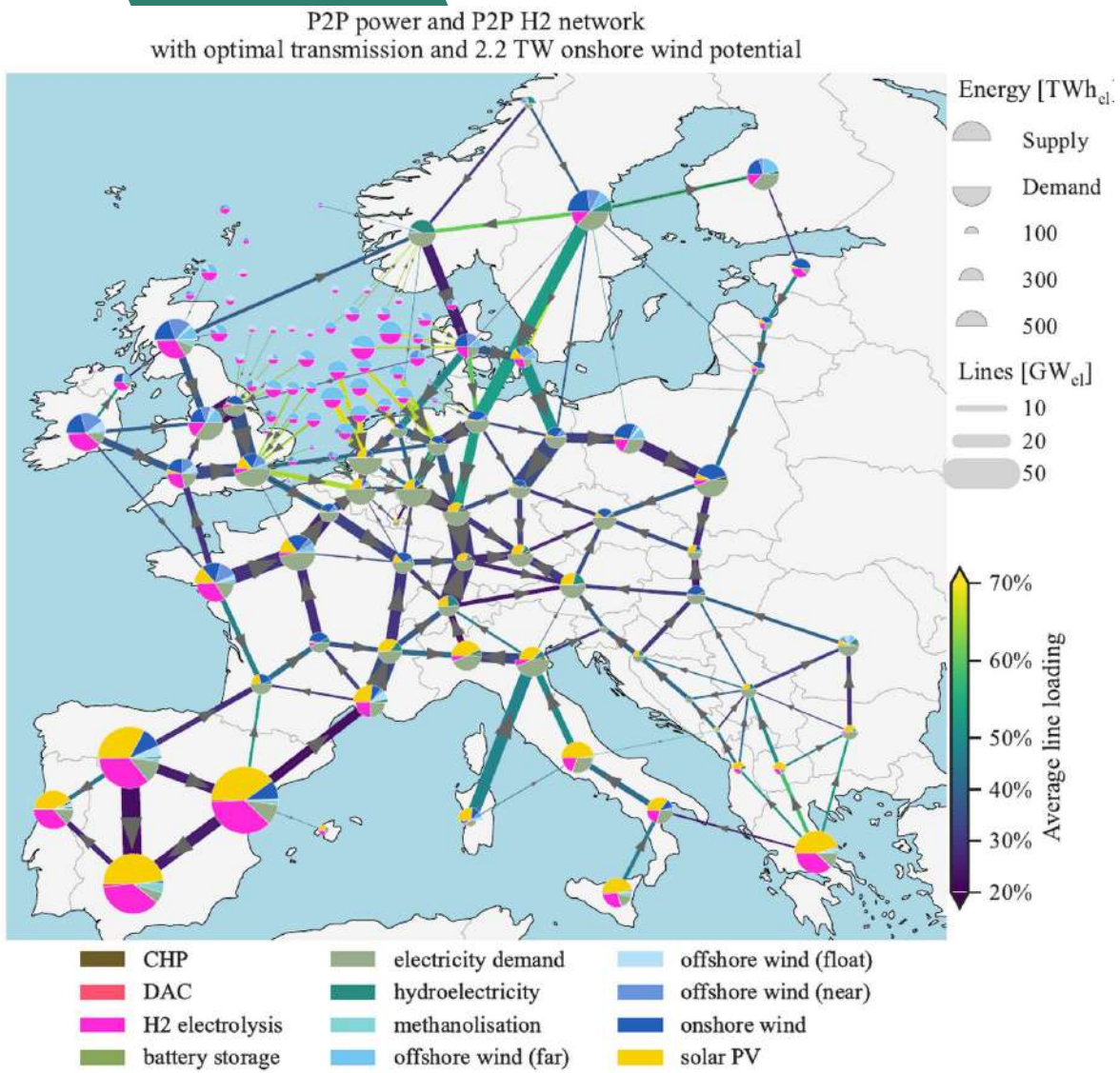
Optimal Generation Capacities

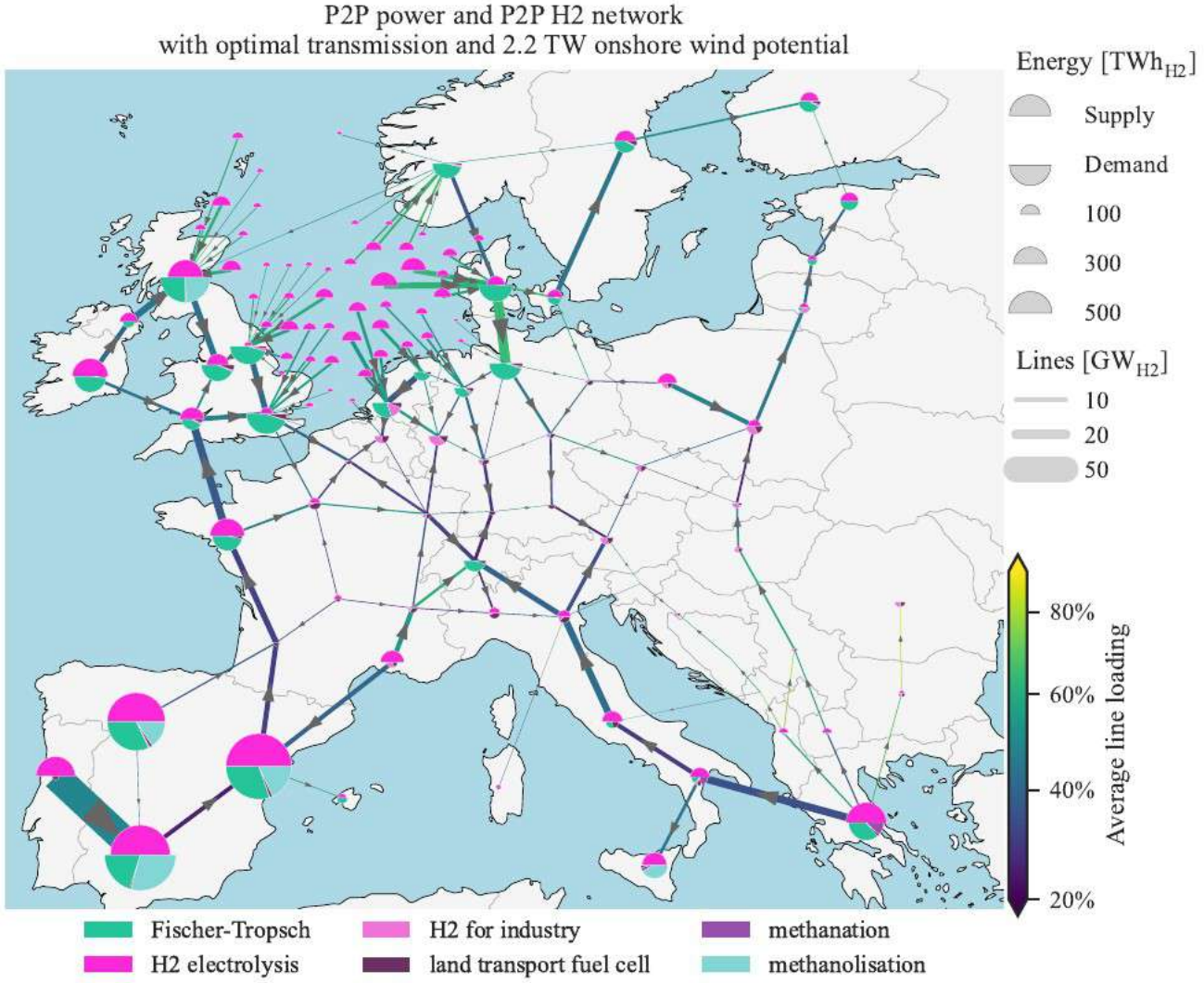


Meshed Power Network

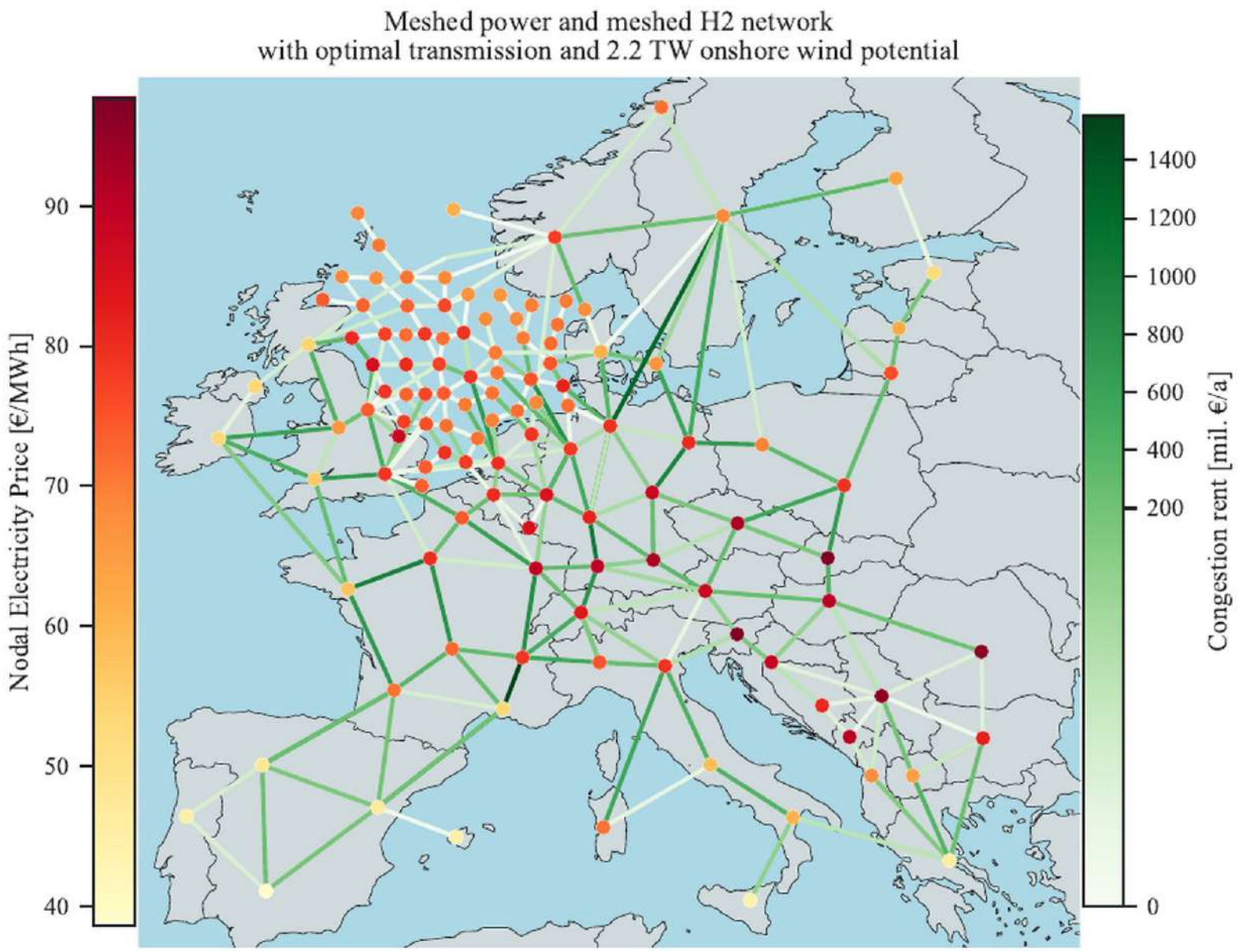


P2P Power and Hydrogen Networks

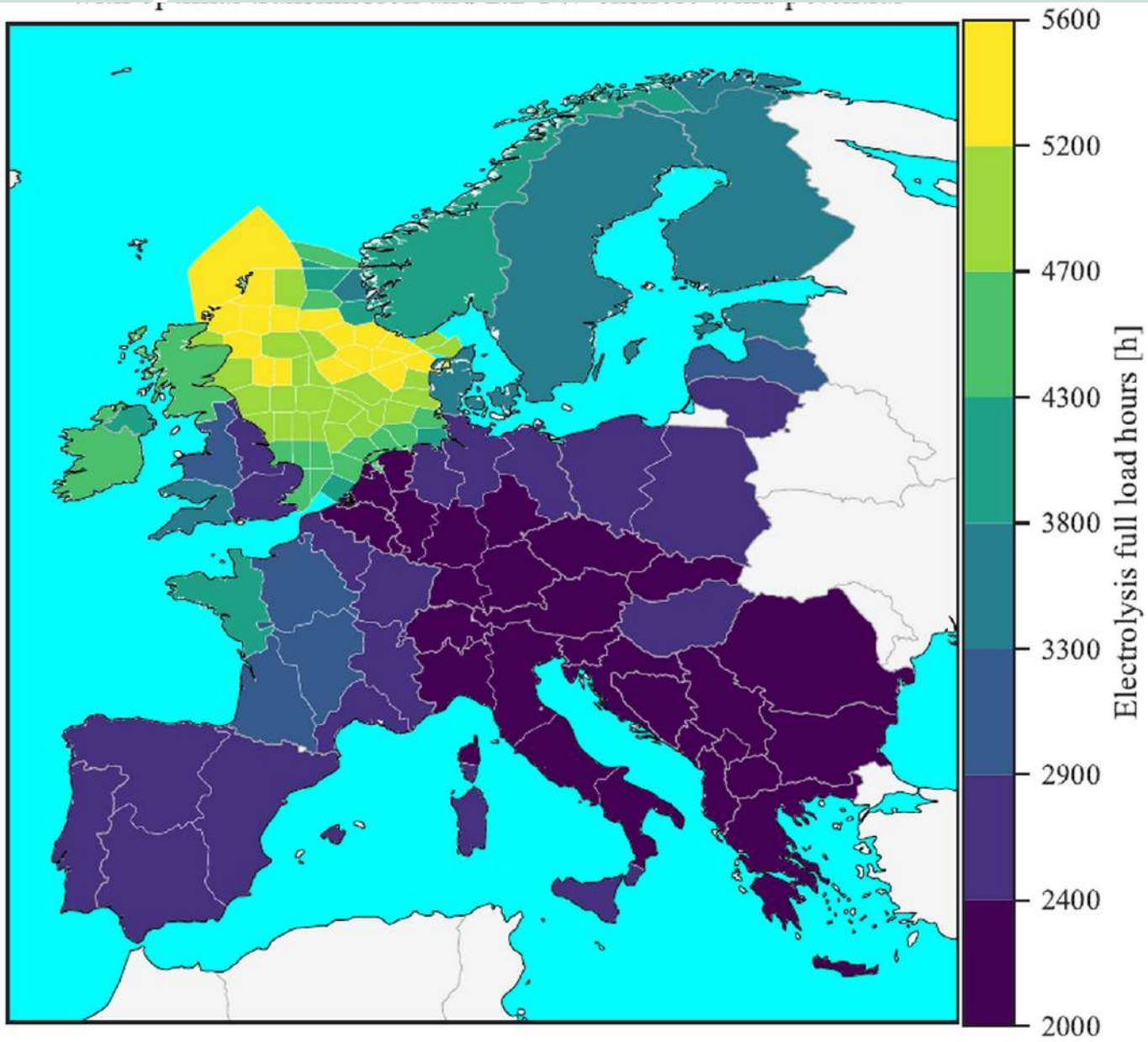




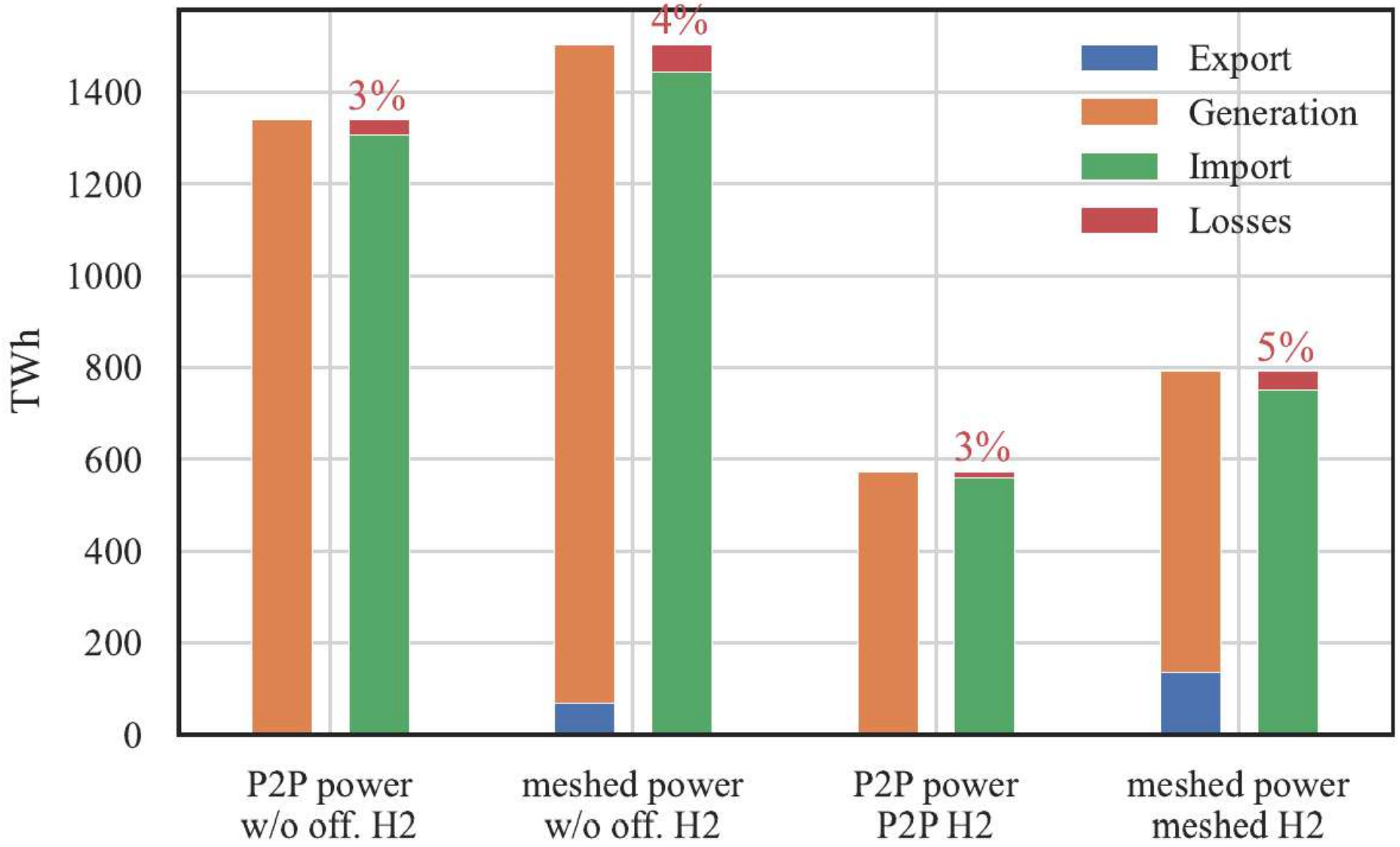
Electricity Prices



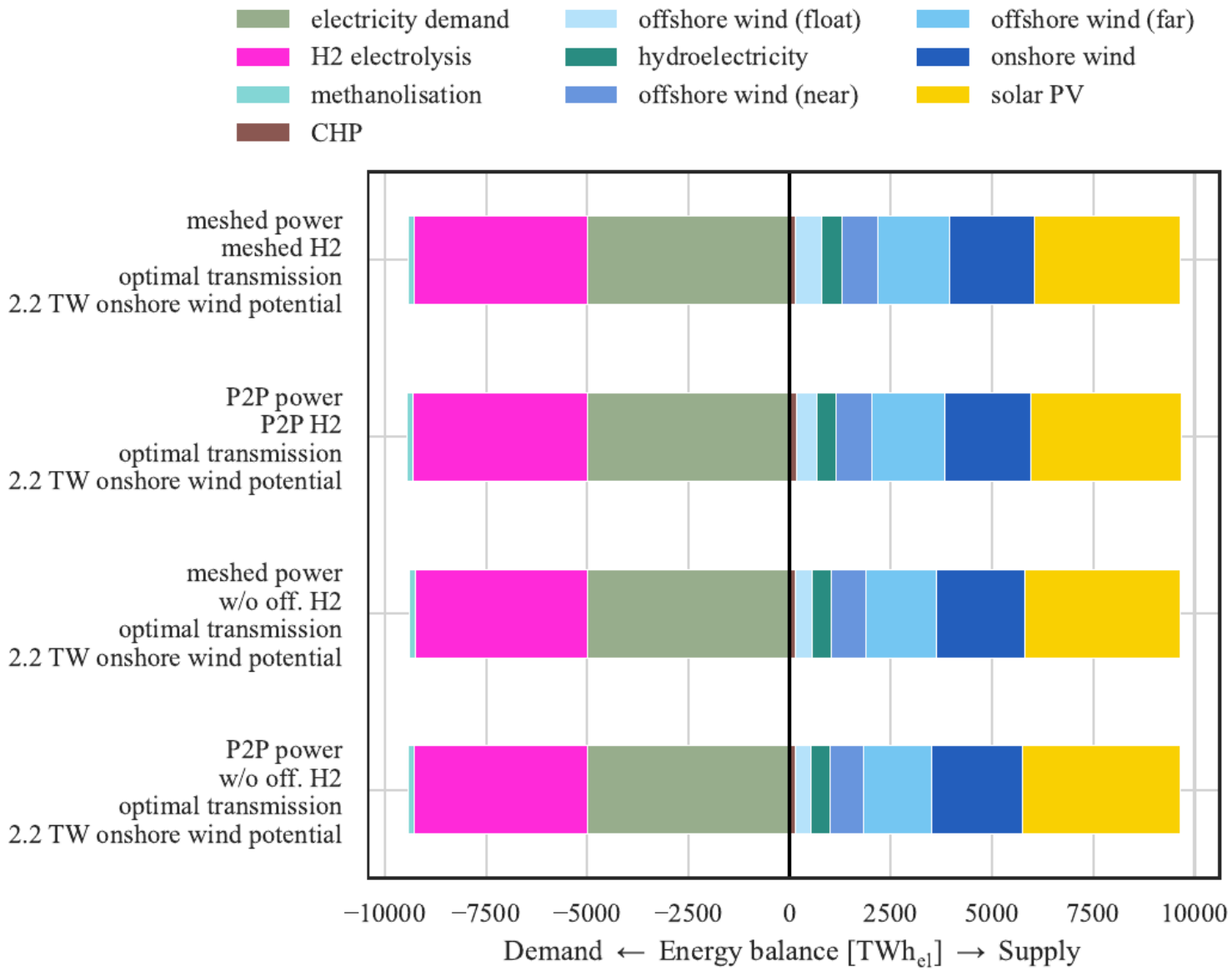
Electrolysis Full Load Hours



Offshore Network Utilization



Electricity Balance



Hydrogen Balance