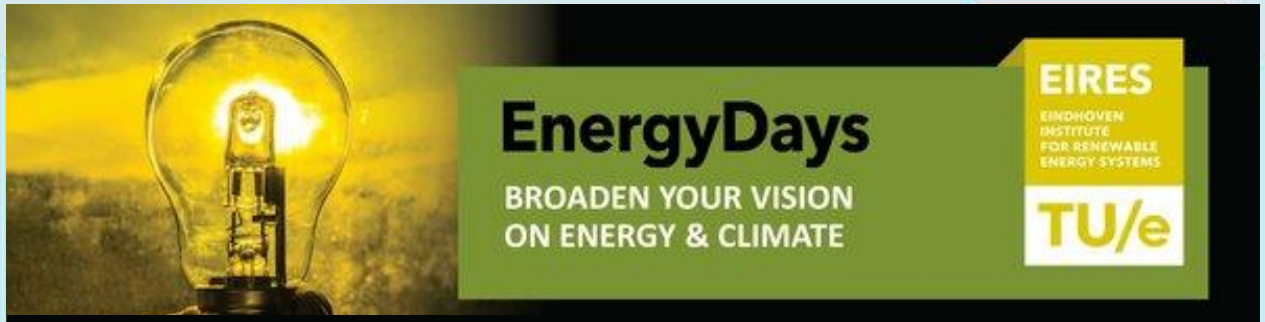

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Modeling of the electricity grid and the potential role of nuclear fusion

Emiel van Druten

About me

What does the future energy system look like?

How does the (costs) optimal future energy system look like?

Ervaring LinkedIn

Scenario Developper for Energy System Planning
TenneT TSO B.V. · Parttime
nov. 2023 - heden · 2 mnd
Arnhem, Gelderland, Nederland · Op locatie

Developing scenario for the future energy system contribution to studies like the Adequacy Outlook, Investment Plans and Integral Infrastructure Outlook 2030-2050.

PhD candidate 'Energy system optimisation & trade-offs'
Technische Universiteit Eindhoven · Parttime
feb. 2021 - heden · 2 jr 11 mnd
Eindhoven, Noord-Brabant, Nederland

In my PhD research use energy system optimization, to seek the balance between investments in generation, storage, conversion, and networks. I also investigate their substitution in case the pace of grid reinforcement is a constraint.

Integral transition models - NEON Research
Work package 10: Integral transition models

Witteveen+Bos
7 jaar 9 maanden

Energy Transition consultant
Parttime
mei 2016 - okt. 2023 · 7 jr 6 mnd
Deventer

Outline

1. **Energy system optimization**
2. **Potential role of cheap fusion**
3. **Challenges for fusion to become competitive on costs**

Energy system optimisation

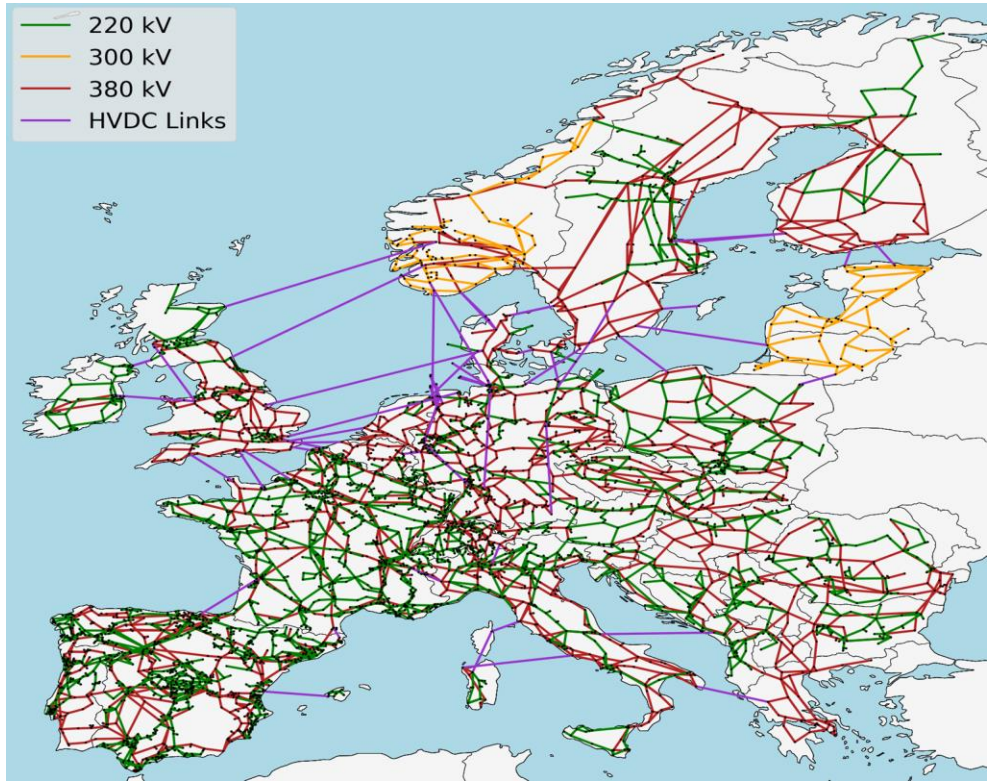
Using PyPSA

Energy system optimization using PyPSA

Python for Power System Analysis (PyPSA)

Technische Universität Berlin

- **Open source** tool for modelling energy systems at **high resolution**.
- Fills missing gap between **power flow software** (e.g. PowerFactory, MATPOWER) and **energy system simulation software** (e.g. PLEXOS, TIMES, OSeMOSYS).
- Good grid modelling is increasingly important, for integration of **renewables** and **electrification** of transport, heating and industry.



PyPSA is available on **GitHub**. It is **used worldwide** by researchers, consultants, TSOs and NGOs.

Time Series for **Variable Renewables** in PyPSA

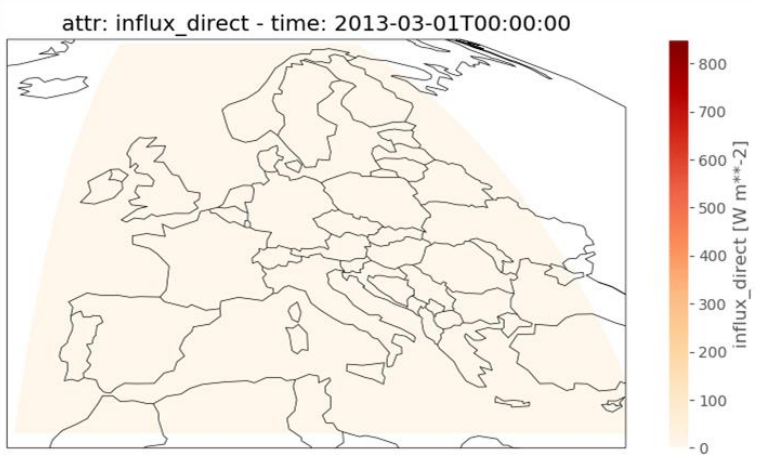
Karlsruher Institut für Technologie

Attend A.3 and A.4

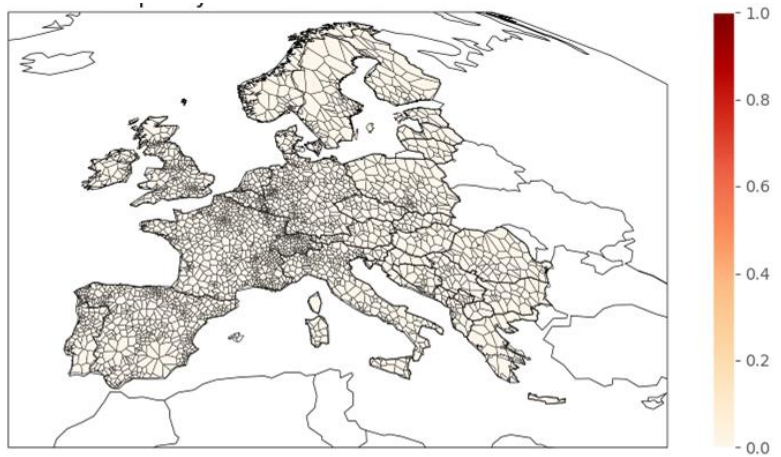
https://atlite.readthedocs.io/
https://github.com/PyPSA/atlite

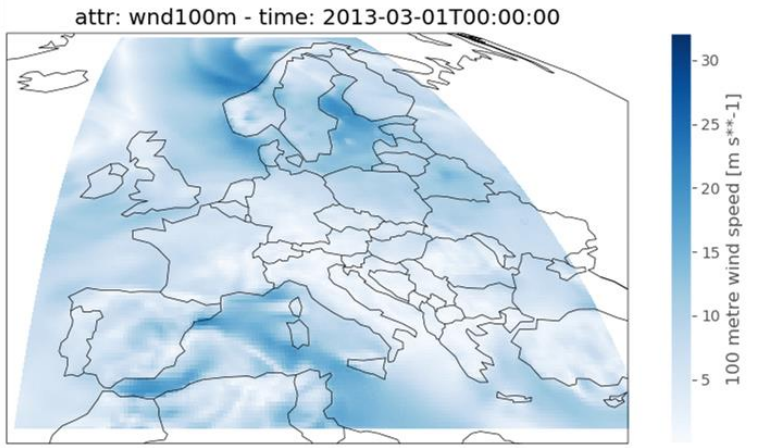
Atlite: Convert weather data to energy systems data

pypi v0.0.2 | conda-forge v0.0.2 | docs passing | license GPLv3

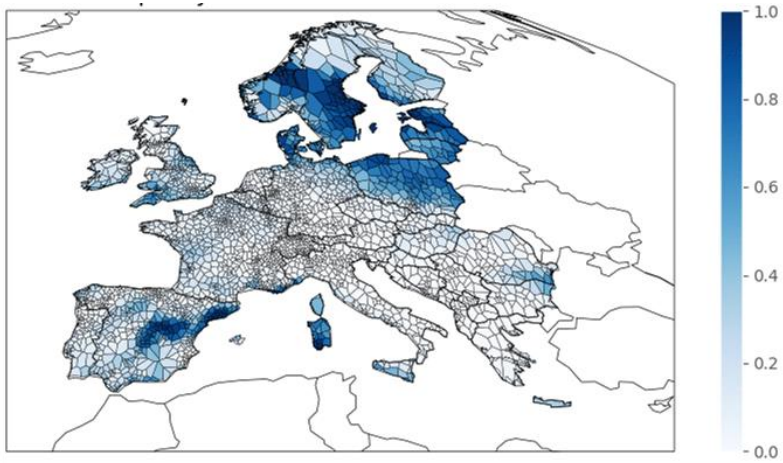


Solar panel models
- orientation
- material

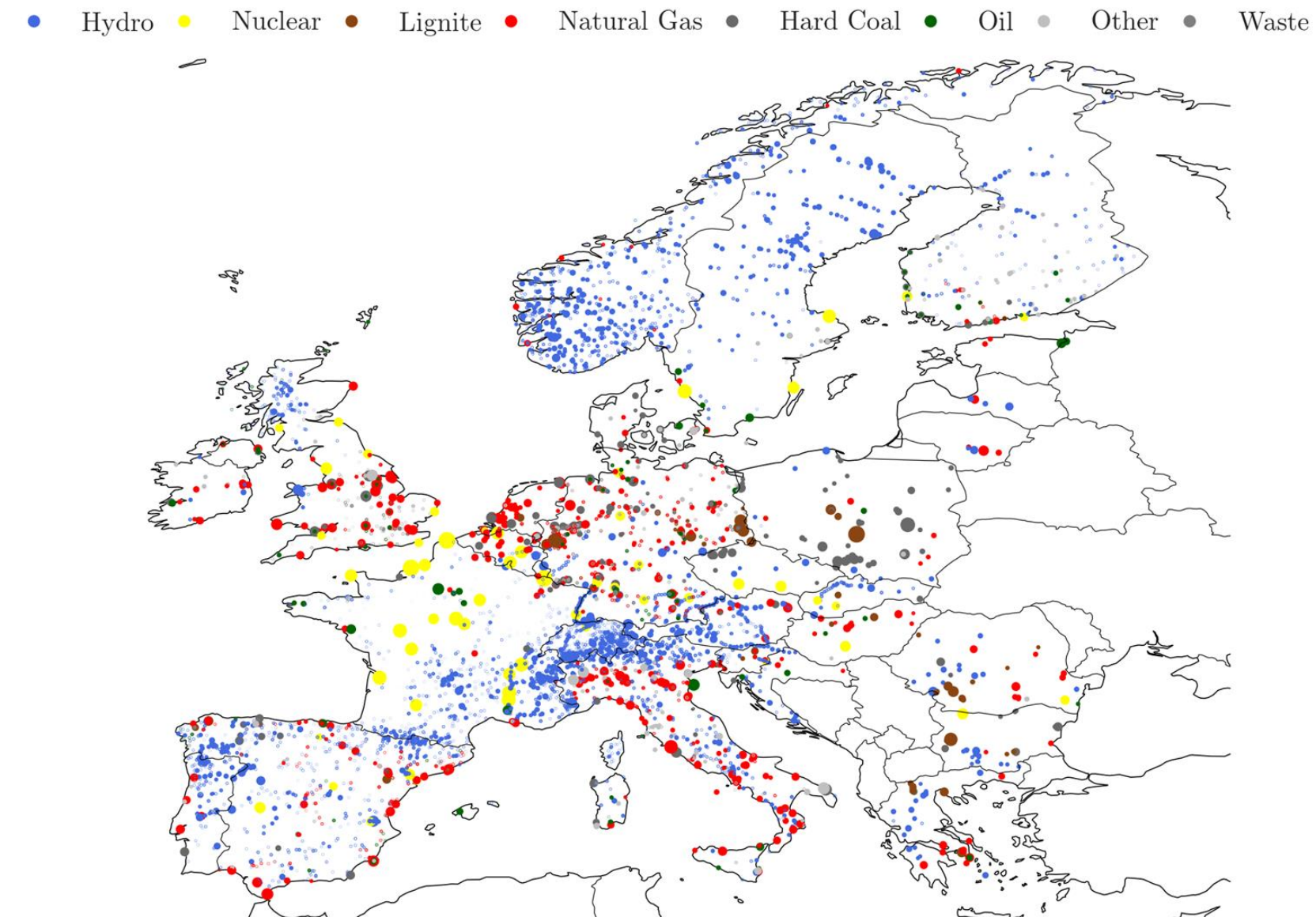




Wind turbine models
- power curve
- surface roughness



Includes database on **existing power plants**



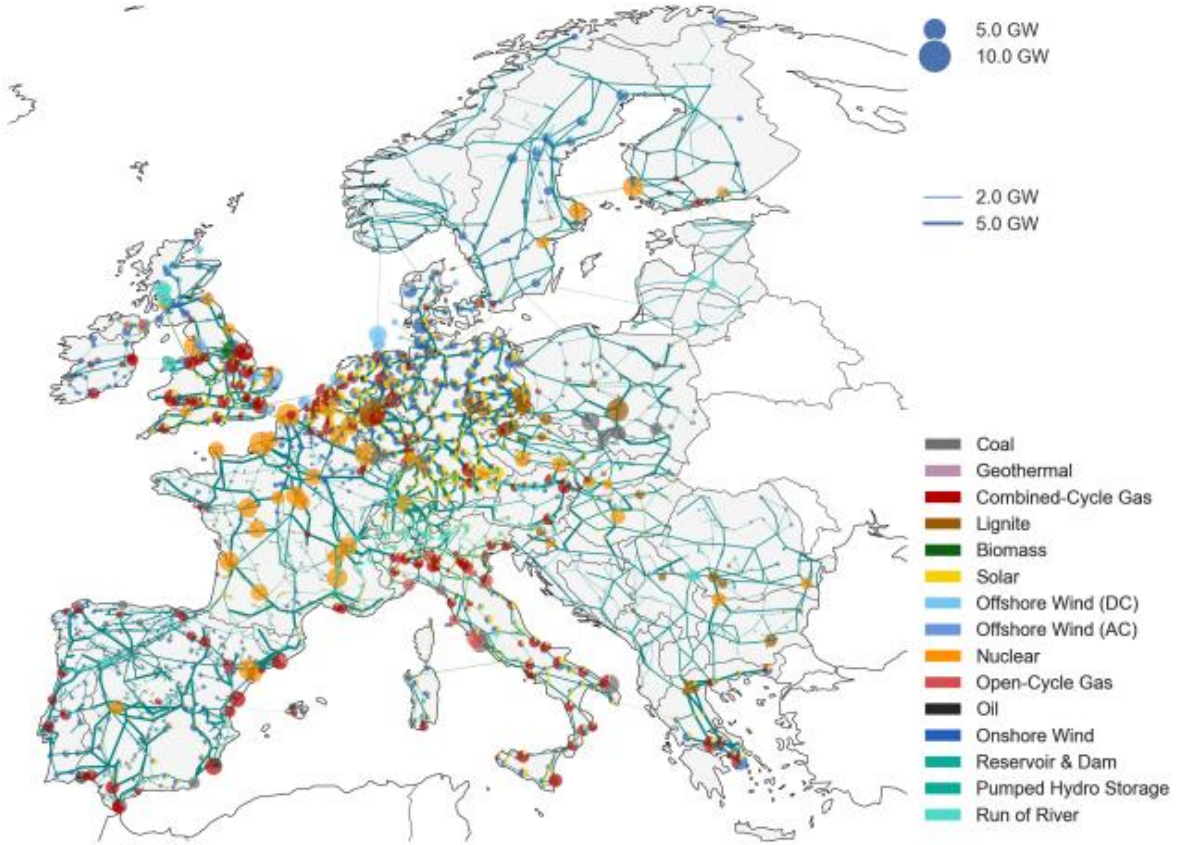
Solve the problem

Set the problem up:

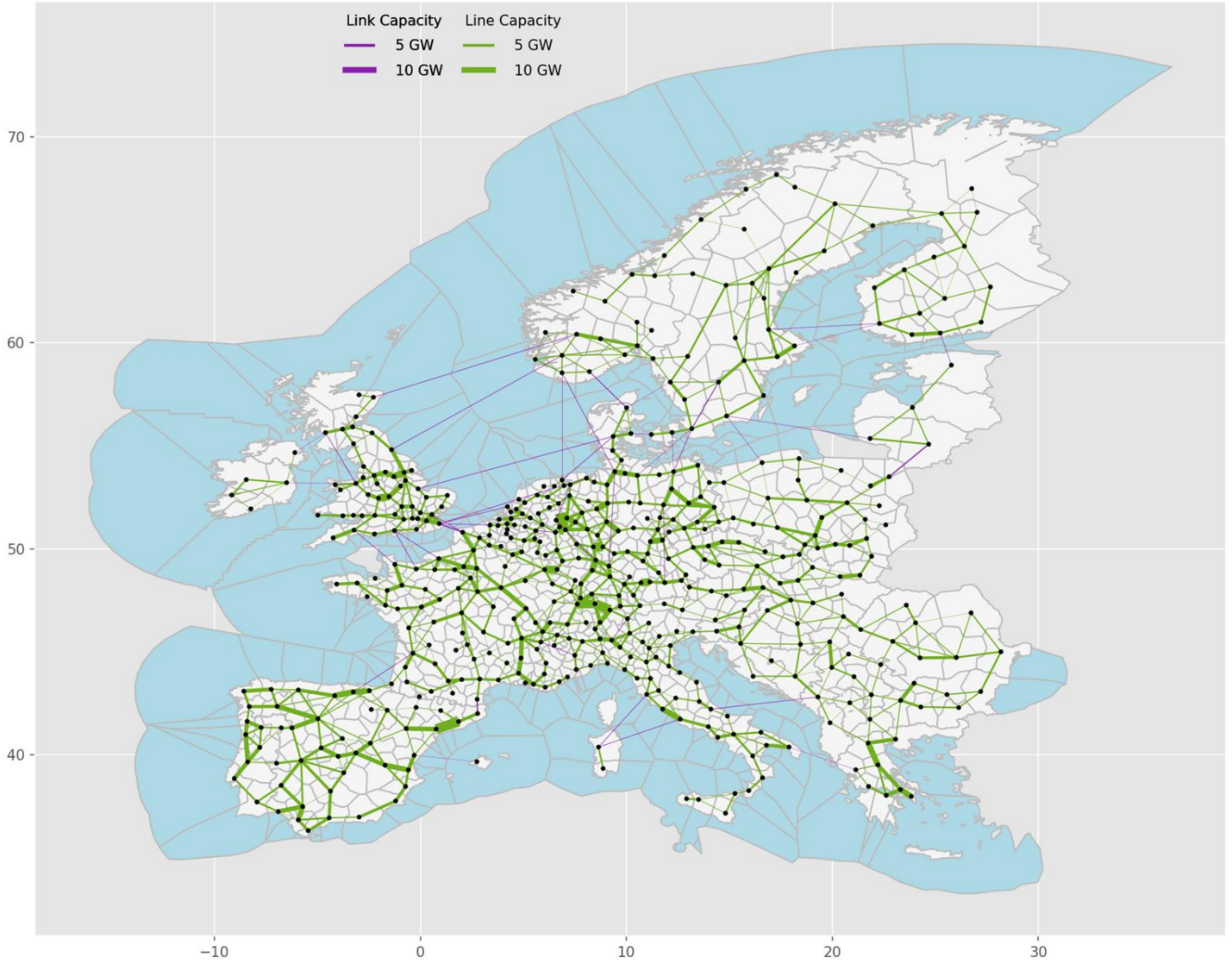
- CO2-reduction goal
- Future demand profile for each region

Co-optimizing for:

- Generation, storage, conversion and transmission!
- Electricity, heat and hydrogen (*system integration*)



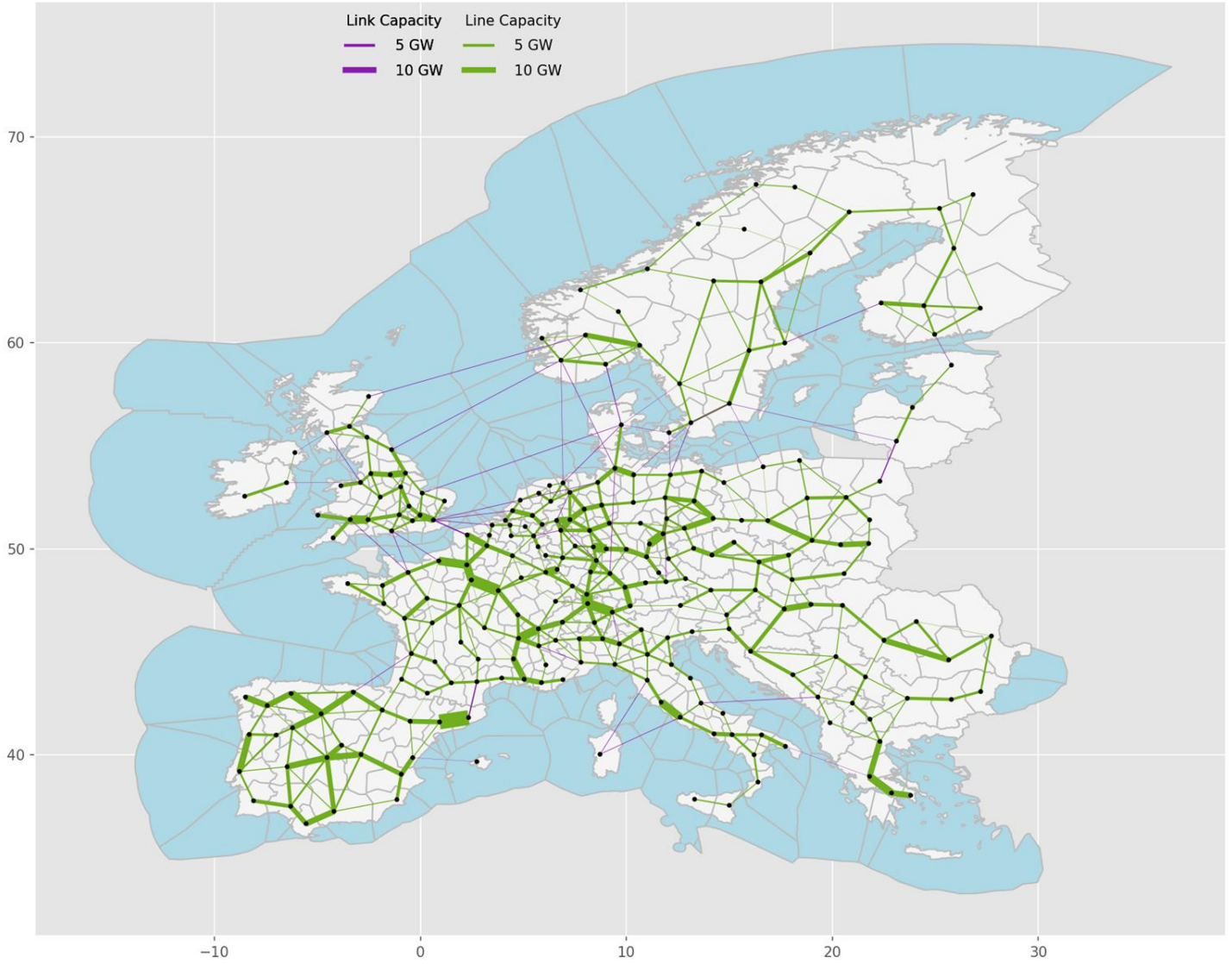
Reducing solving time: The `cluster_network` rule:



Clustered to **512 buses**

Transformed to **380 kV**

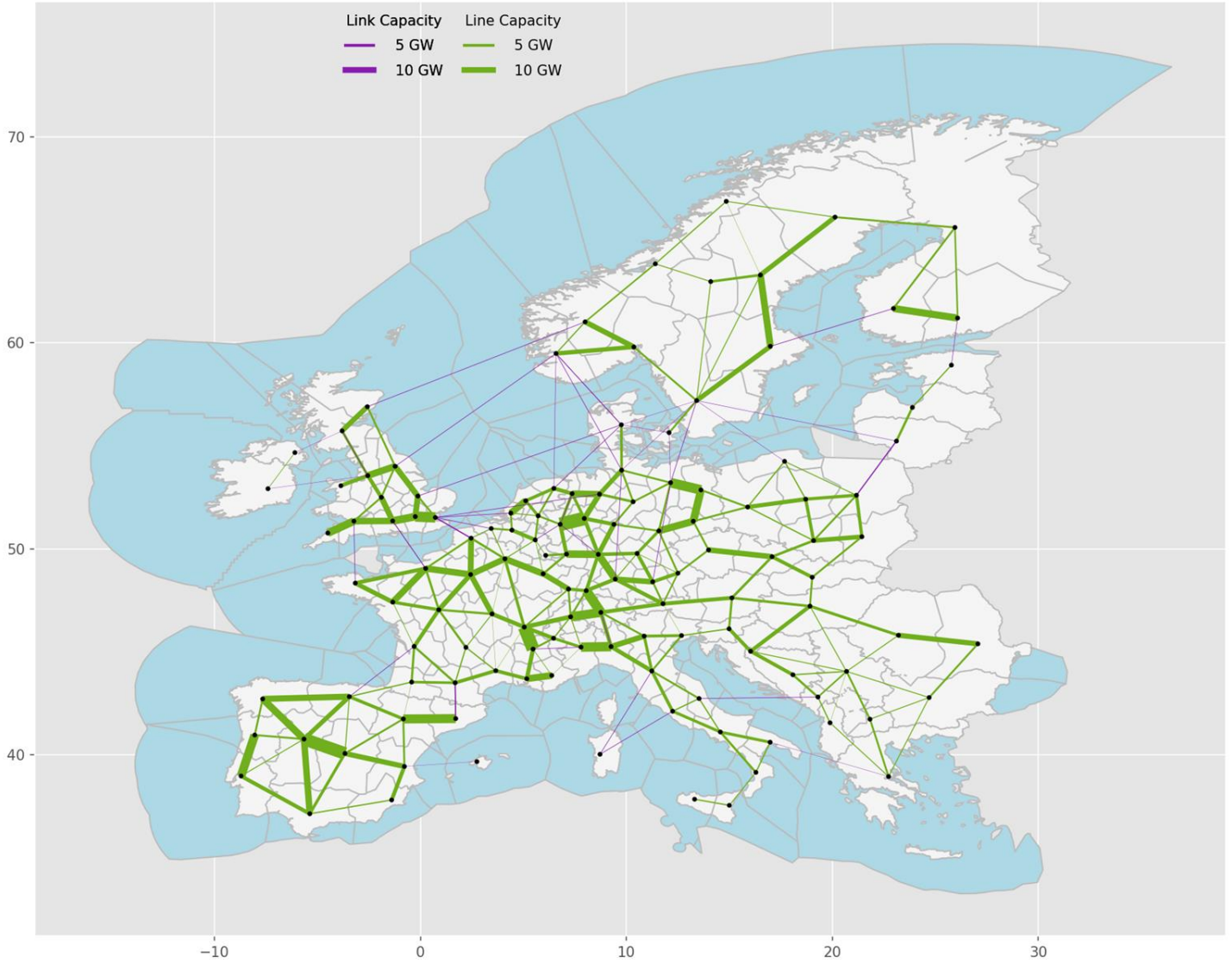
Reducing solving time: The `cluster_network` rule:



Clustered to **256 buses**

Transformed to **380 kV**

Reducing solving time: The `cluster_network` rule:



Clustered to **128 buses**

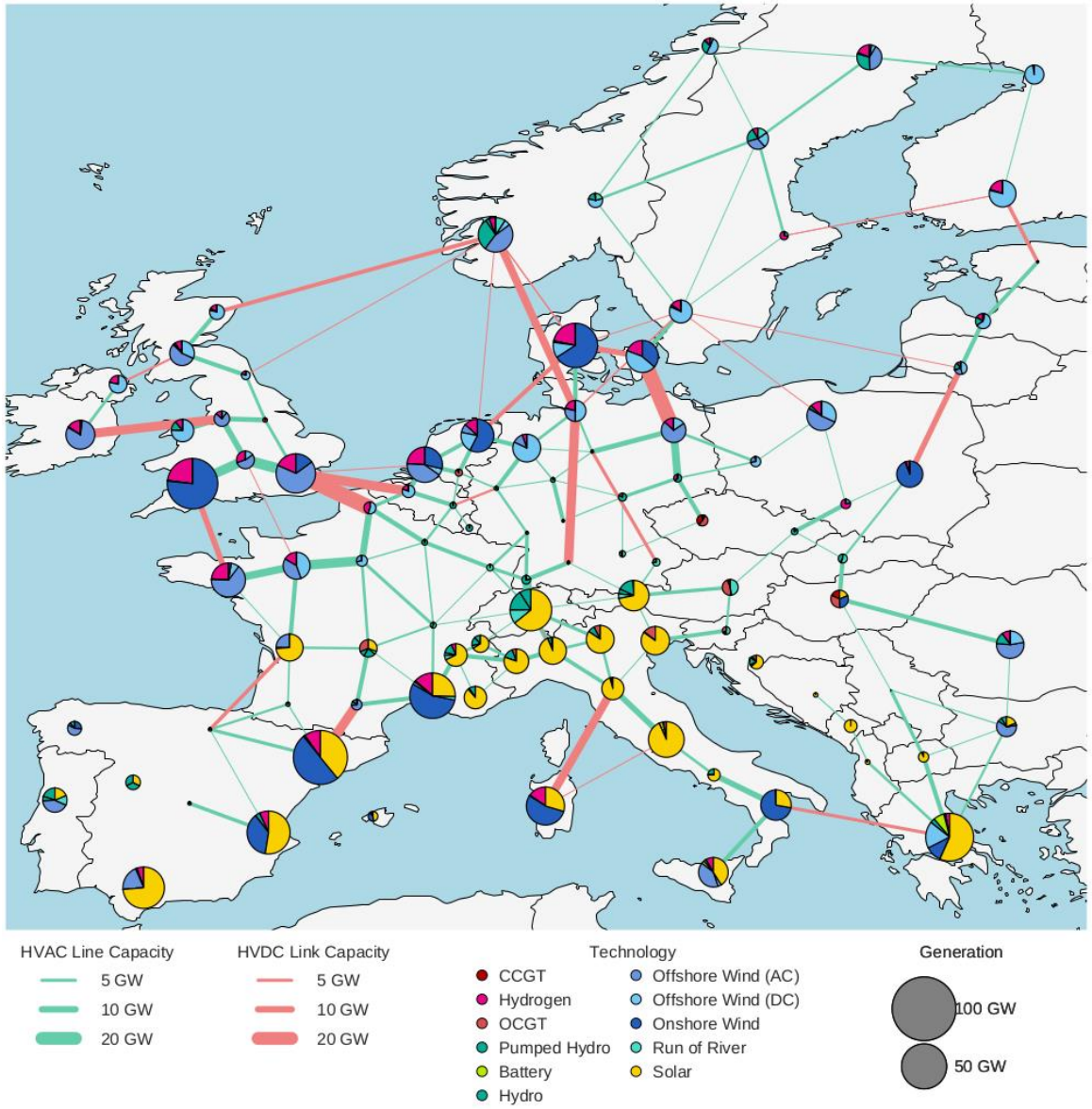
Transformed to **380 kV**

Solving time and summarizing networks

Performance (memory and solving time):

Nodes	Snapshots	Memory (RAM)	**Solving Time**
350	4,780 (2h)	70 GB	**14 h**
100	2,920 (3h)	21 GB	**1.5 h**

There are scripts to **plot and summarise** solved networks. (example to the right)



Potential role for fusion

Based on the scenario study nuclear (2022) for the Dutch government

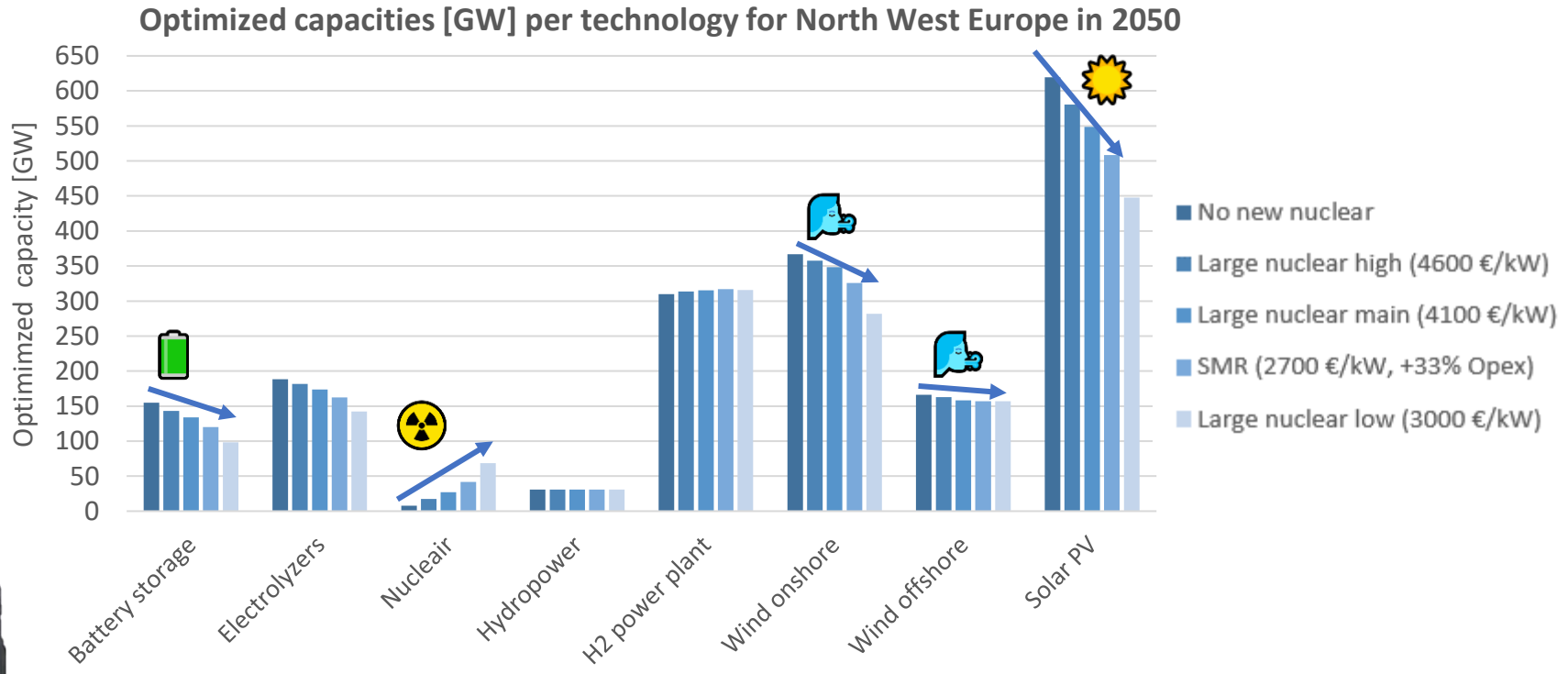
For energy modeling nuclear fission and fusion quite the same

- Generates heat to run a turbine
- High investment (Capex)
- Low fuel cost and maintenance (Opex)
- Long lifetime

Potential role for nuclear by 2050 (fission or fusion)?

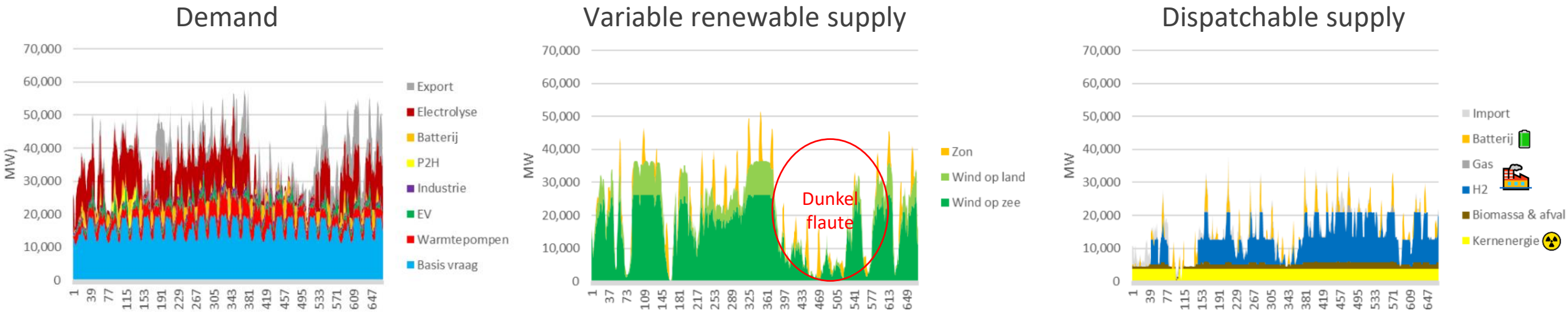
- If new nuclear can be cheap (≤ 4100 €/kW), it can play an optimal role
- Wind, solar and storage form the basis, with nuclear you need a bit less

Me in parliament answering questions from MPs about this study



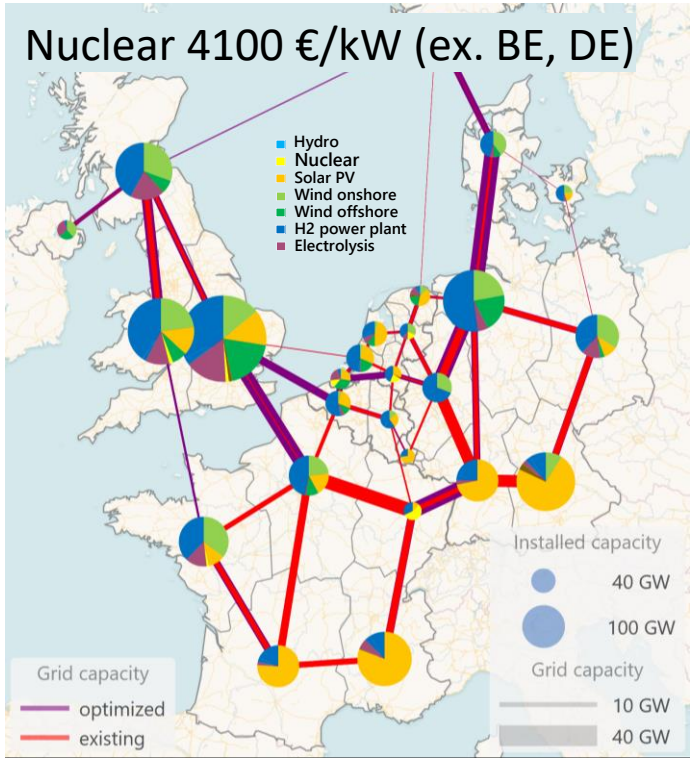
Is nuclear the solution for Dunkelflautes?

- No, but nuclear does help:
  - needing fewer H2 and methane gas power plants as back-up
  - charging batteries in off-peak hours so they can discharge in peak-hour
- The figure below shows the Netherlands with 2 new nuclear power plants for January of the weather year 1987



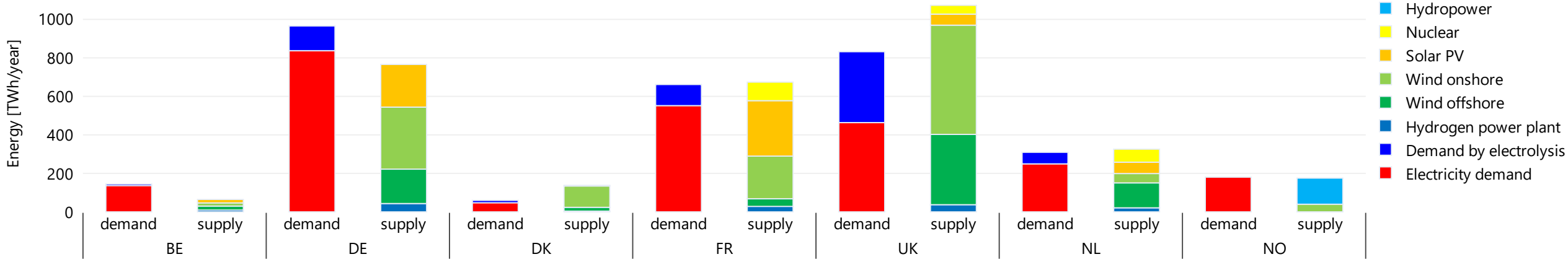
Where would cheap nuclear be optimal by 2050?

- Inland regions with local demand higher than renewable potential:
  - In the East of the Netherlands and North-East of France
  - Partly for export to Belgium and the German Ruhr area (which phased out nuclear)



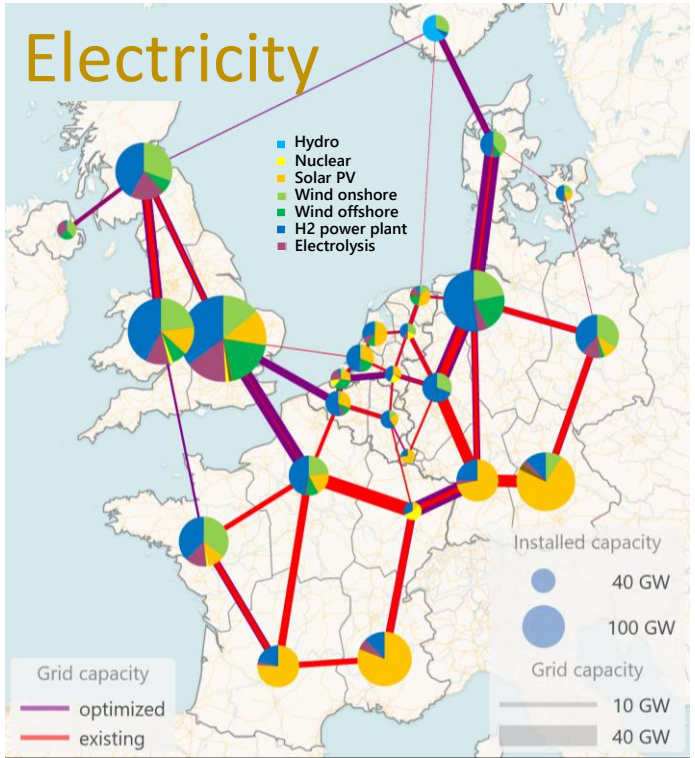
Supply and demand balance per country

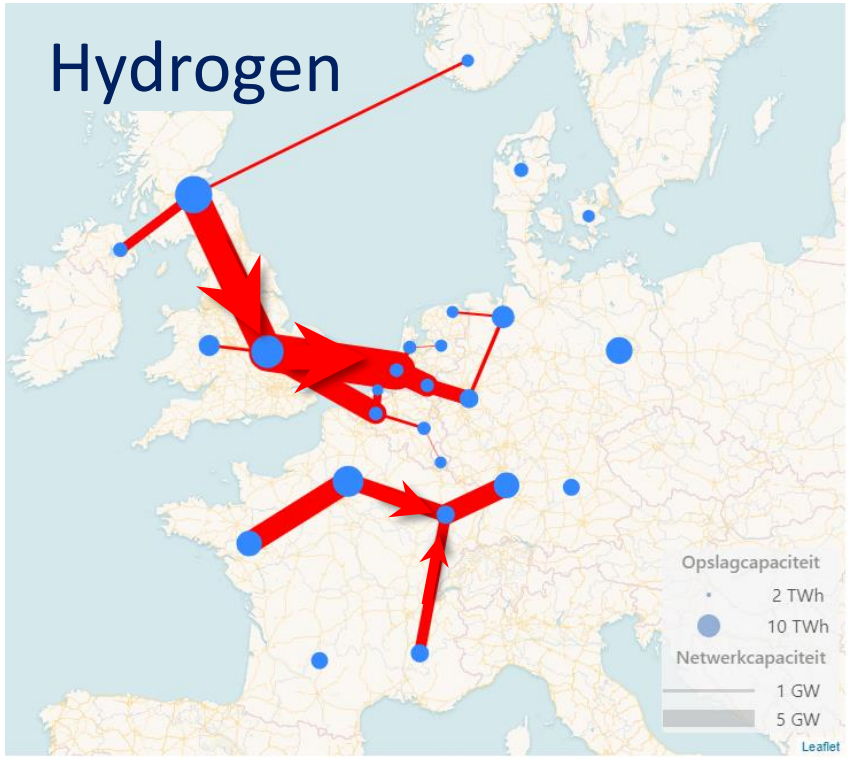
- Belgium and Germany net importers
- Denmark and UK net exporters
- France, Nederland, and Norway ≈ neutral on energy
  - Net export of electricity
  - Net import of hydrogen



Bulk transport of energy

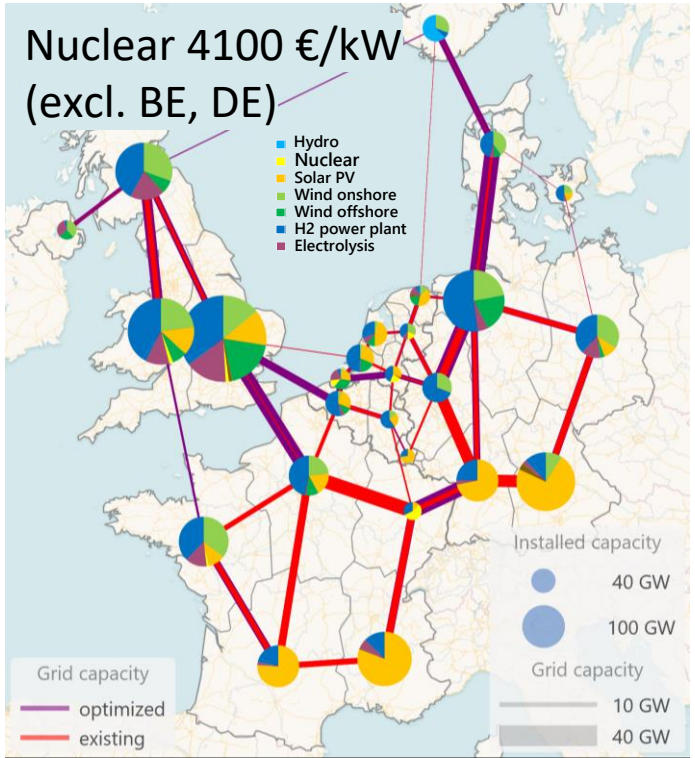
- Sharing wind as electricity via grid upgrades upto 500 km:
  - Netherlands → Germany & Denmark → Germany
- Conversion electricity into hydrogen and share it upto 1000 km via pipeline:
  - Scotland → England → Netherlands → German Ruhr area

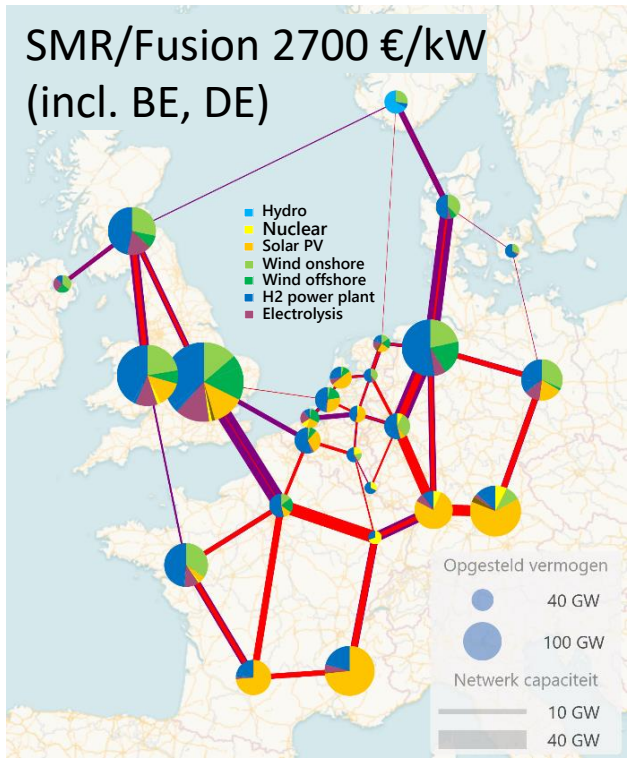




The promise of cheap SMR/fusion by 2050?

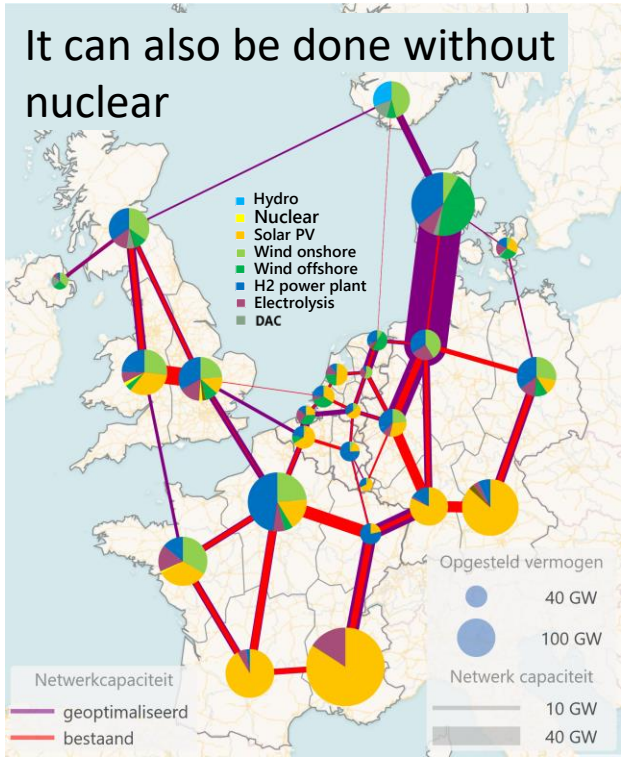
- If cheap and safe nuclear is available, they might again be accepted in Belgium and Germany and play a role there

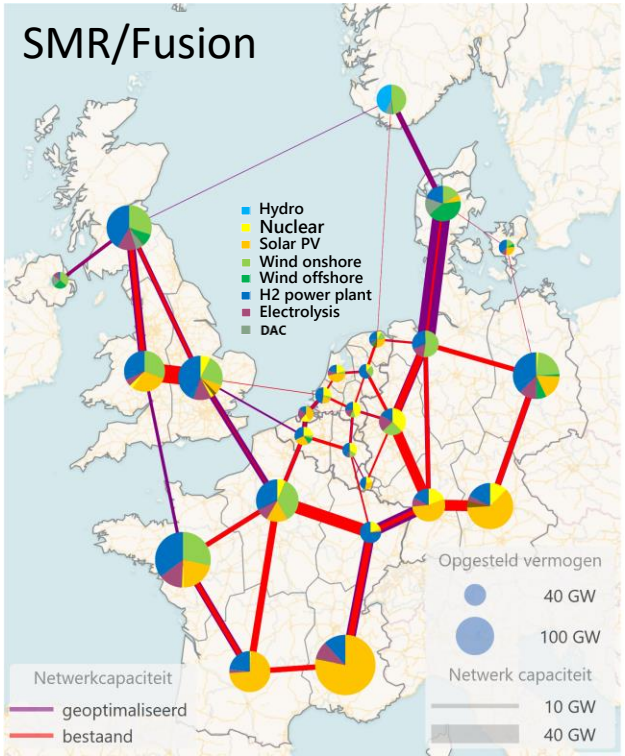


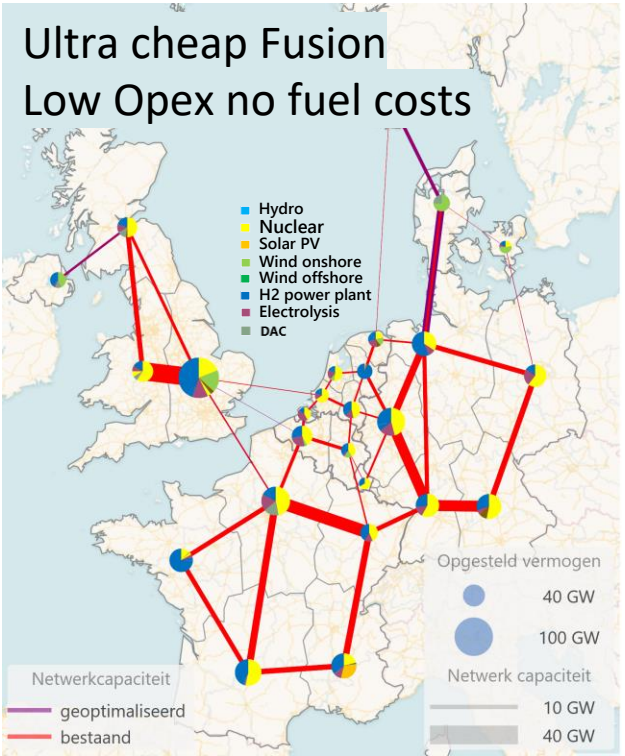


Potential growth of SMR/fusion toward **2070**?

- Assuming further demand growth toward 2070 and greenfield conditions
  - Further growth for the SMR/Fusion with the same cost assumptions
  - Ultra cheap fusion: dominant, except for onshore wind in DK and Northern Island







Challenges for fusion

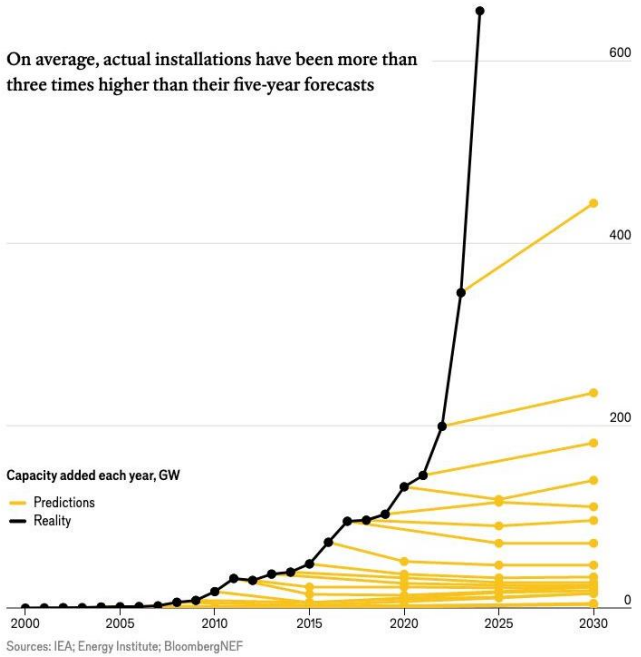
to become competitive on costs

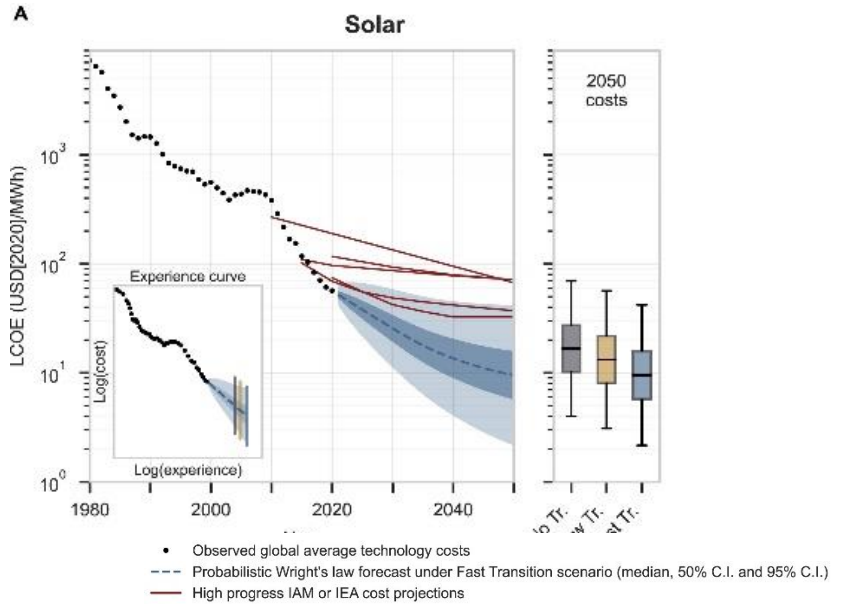
Challenges for fusion

- Can we make energy positive fusion work?
  - Sure, we are humans: with unlimited budget we can do everything.
- Can fusion be cost-competitive with wind, solar, and storage?
  - Some things I recently learned about nuclear fission make me skeptical about fusion, too…

Future cost estimates for PV and batteries

- IEA track record of underestimating solar deployment
- Wright law: PV learning rate ≈ 20% per doubling of deployment
- Underestimating deploying → underestimating cost reduction
- The 4100 €/kW threshold might be too high…



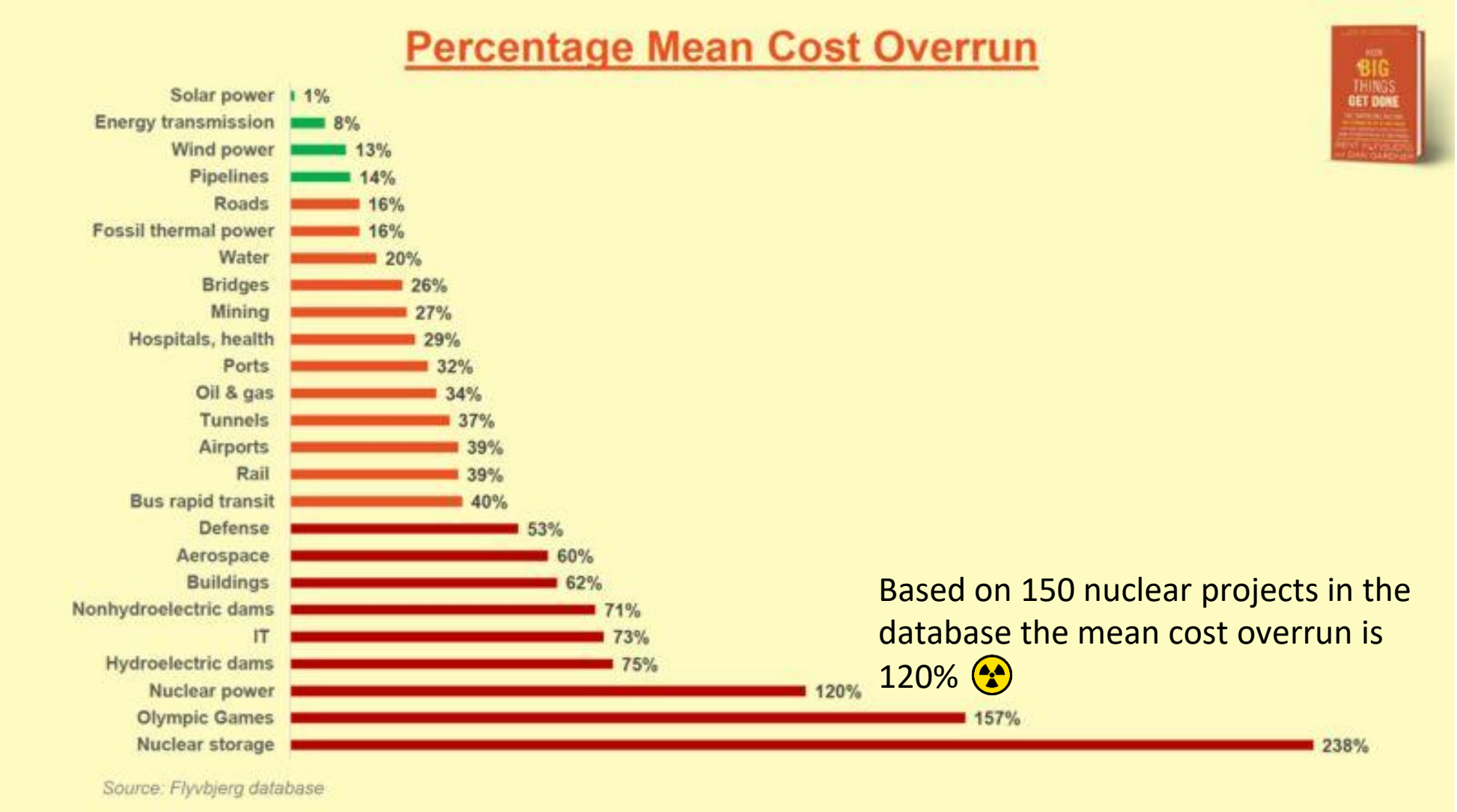


Source: Way et al. (2021) Empirically grounded technology forecasts and the energy transition

Cost of Korean reactors in Czech Republic

- 8 billion per 1 GW reactor = 8000 €/kW
- Nearly a factor 2 too expensive to be a cost-optimal addition to the energy system

How big things get done - Bent Flyvbjerg



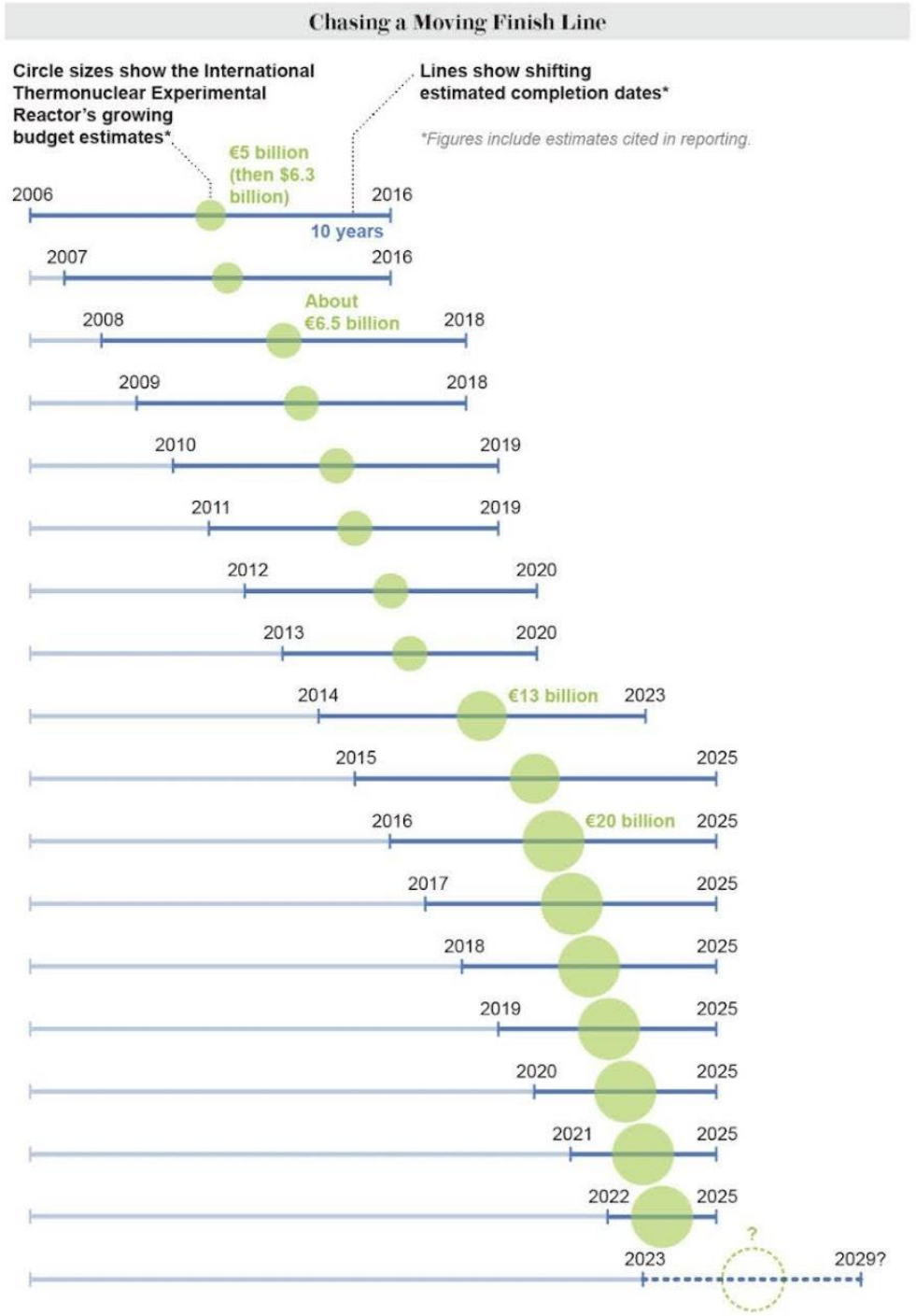
How big things get done - Bent Flyvbjerg

- **Conditions of success**: simple technology consisting of just a few modular Lego bricks that can be put up quickly
- **Indicators for trouble**: big complex project with many bespoke parts, that take a long time to build and include concrete and digging.

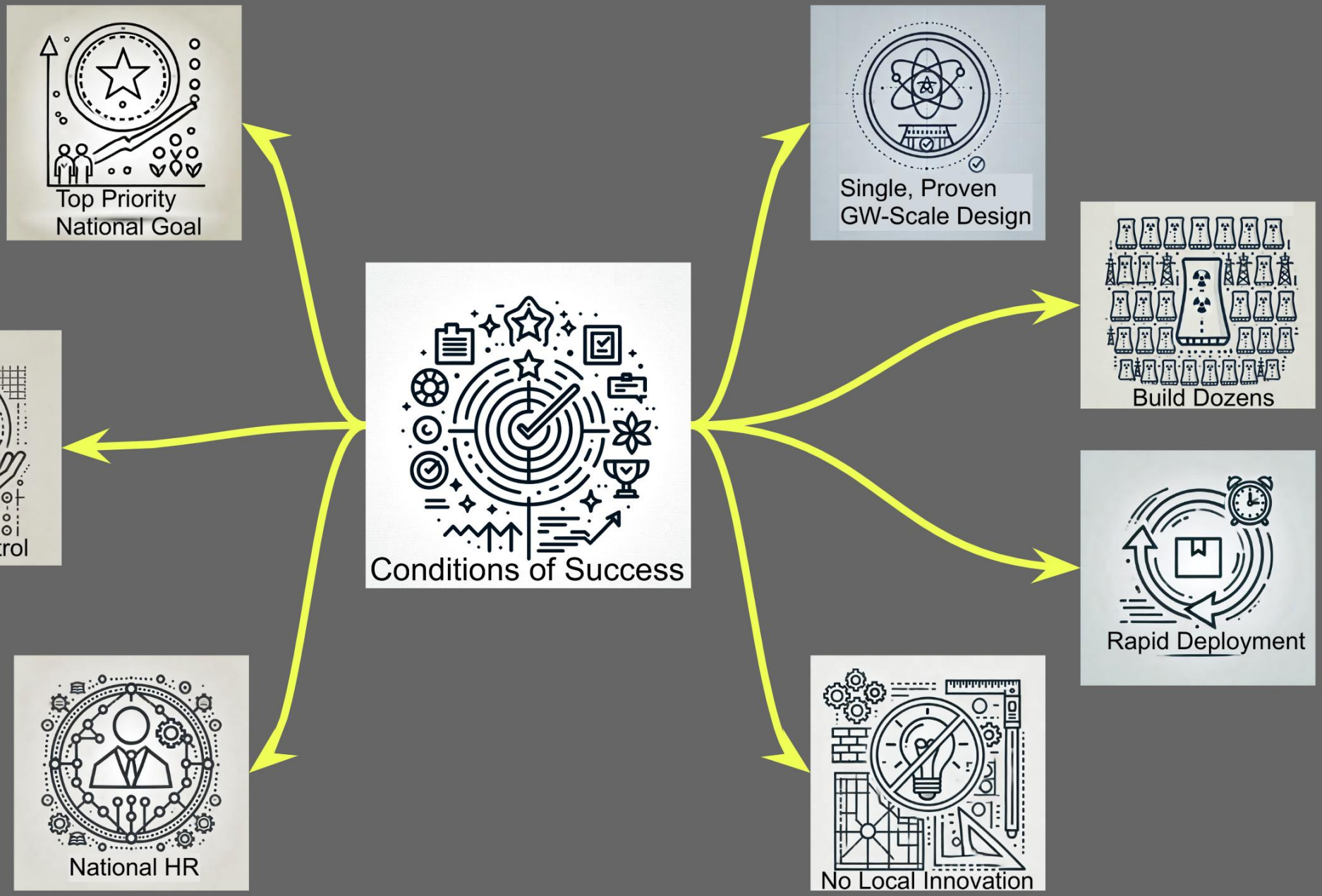
- In what group would you place fusion?

Guess the project

- **ITER**, experimental **fusion** reactor



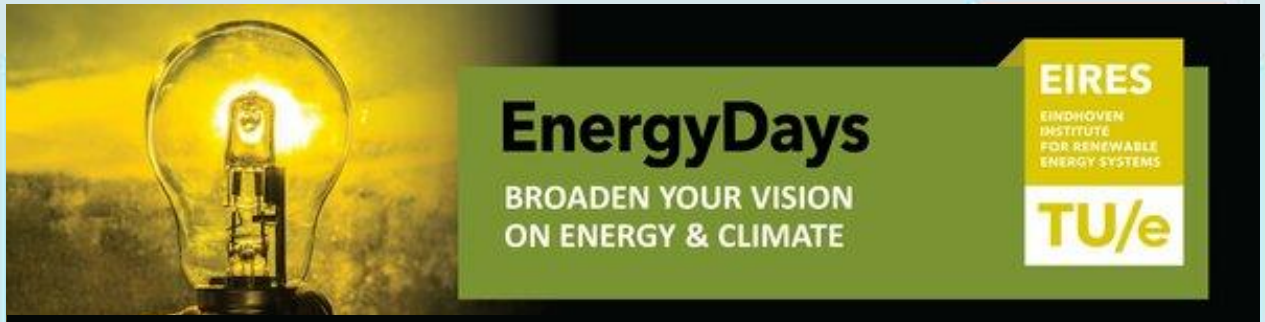
Successful, scaled nuclear programs shared these conditions for success



Source: Michael Barnard

My best guess for the role of fusion

- Probably too complex and thus expensive to play a dominant role
- Interesting for meeting load growth after 2050 from battery electrification of shipping and aviation 
  - Again, in regions with too little renewable potential and difficulties to bring in even more transmission: Frankfurt Airport, Port of Antwerp or Singapore
- If it can't even compete there, there is always spacecraft 



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