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BIEE Oxford 2023 Research Conference

Green hydrogen in Germany’s energy transition – a scenario-based energy system modelling.

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The Energy Transition in Germany

The aim of the German „*Energiewende*“ is climate neutrality by 2045

- How can this decarbonization be achieved (cost efficiently)?
- What is the role of renewable energy technologies (RETs)?
- What about security of supply in a RETs-dominated energy system?

- **What role can green hydrogen play in the German and European transition and energy system of the future?**
- **What will a German and European hydrogen economy look like (exporters, importers, infrastructure, ...)?**

Overarching aims

Decarbonization policies and targets in Germany

1 Commitment to international (i.e., UN) and European (i.e., EU) climate targets,
Translation into national policies, incl. additional increases in levels of ambition (vs. climate neutrality 2050)

2 Existence of a national "roadmap" to climate neutrality with sector-specific targets:
by 2030 overall -65% emissions; by 2045 climate-neutrality

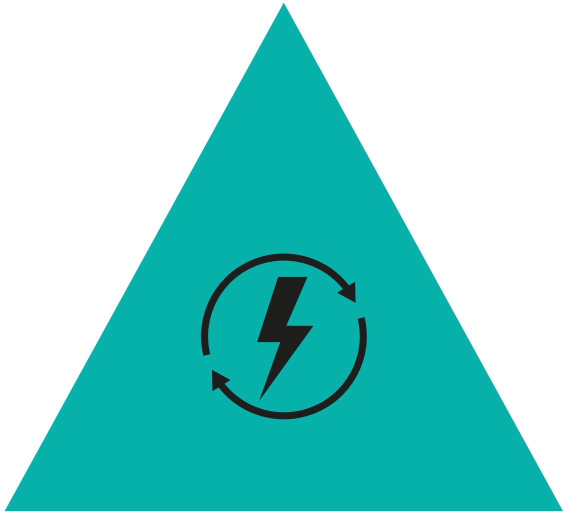
3 For energy supply sector: by 2030 already 80% gross electricity production from renewable sources,
simultaneous phase out of fossils (i.e., coal by 2038, "ideally by 2030") and nuclear (by 4/2023),
and increasing direct and indirect electricity demand

Project: Long term scenarios for the transformation of the energy system in Germany
funded by the Federal Ministry of Economy and Climate BMWK
Analytical focus: energy supply and conversion sector
Methodology: energy system modelling and optimization

Operationalizing the Energy Transition

Different decarbonization pathways to climate neutrality in 2045 exist

direct **electrification**



indirect electrification via **PtG, PtL**

indirect electrification via **green hydrogen**

Techno-economic analysis of decarbonization pathways

- Pathway of direct electrification > “electrification scenario”
- Pathway of indirect electrification via the use of green hydrogen > “hydrogen scenario”
- Pathway of indirect electrification via the use of PtG/PtL > “PtG/PtL scenario”

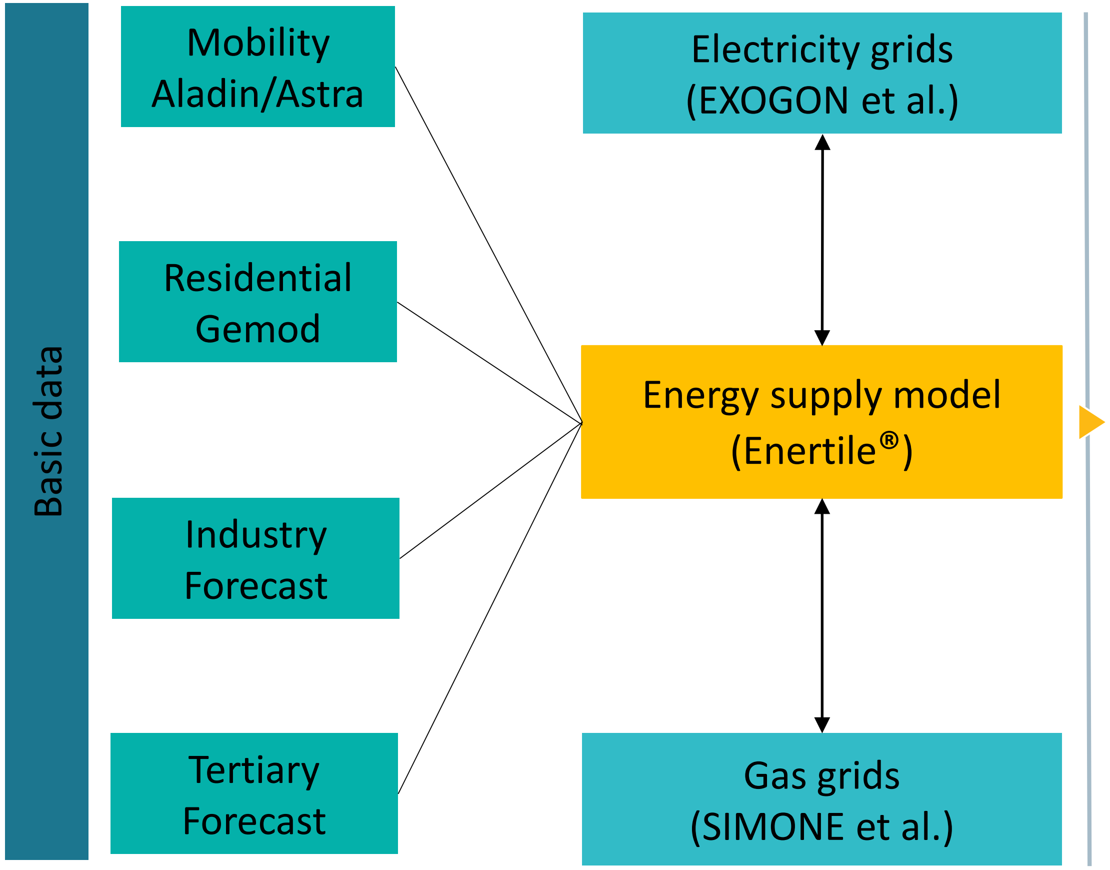
Scenario-based energy system modelling exercise

Comparative analytical approach

Focus of this presentation: electrification scenario vs. hydrogen scenario

Methodology

Modelling the future energy system: demand, supply and infrastructure models



Proceeding in Enertile

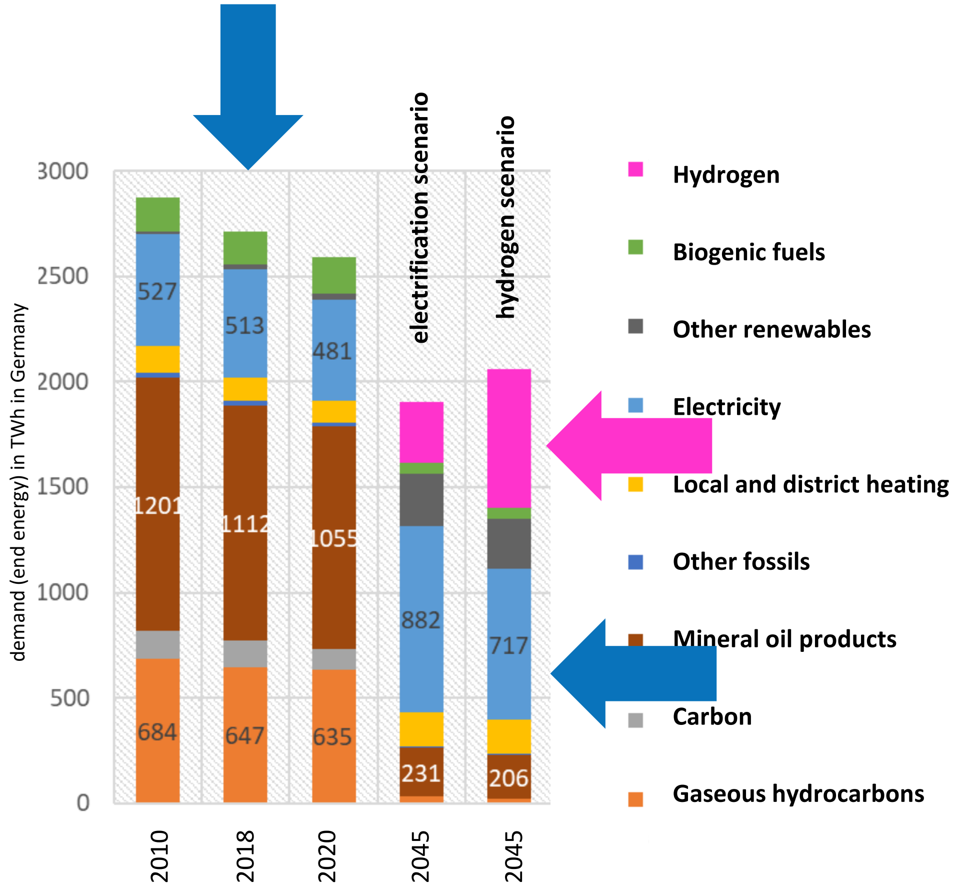
- Regionalization of energy demand
- Potentials for Renewable Energies are calculated based on a very high spatial (6.4x6.4km) and time (all hours of the year, 5 year steps 2025-45) resolution
- Technology cost and learning curves
- Optimization (macro economic cost minimization) of the energy supply, given all restrictions, such as policy targets
- Infrastructure need is calculated

Computation

- > 188 million variables in the energy system that are jointly optimized
- System of equations of around 7 million lines

Starting point 1: Demand data

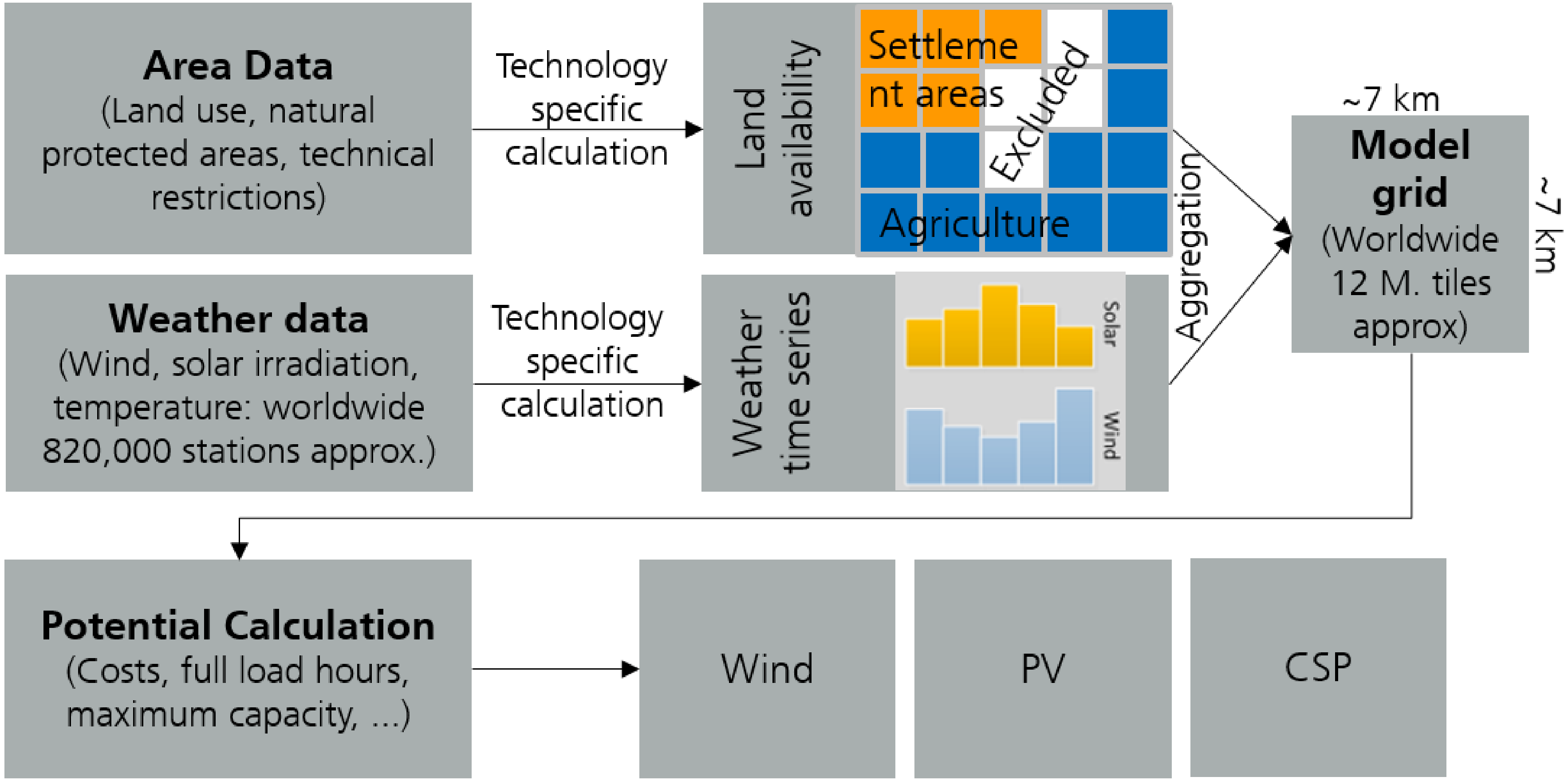
Aggregated demand by energy carrier stemming from the demand sectors (results of their modelling)



- Overall, the end energy demand decreases
- The demand for specific energy carriers changes fundamentally
- Specifically, there is a large increase in the demand for (renewable) electricity and (green) hydrogen
- ...implications for the supply side

Renewable potential calculation

Real land use and weather data is used



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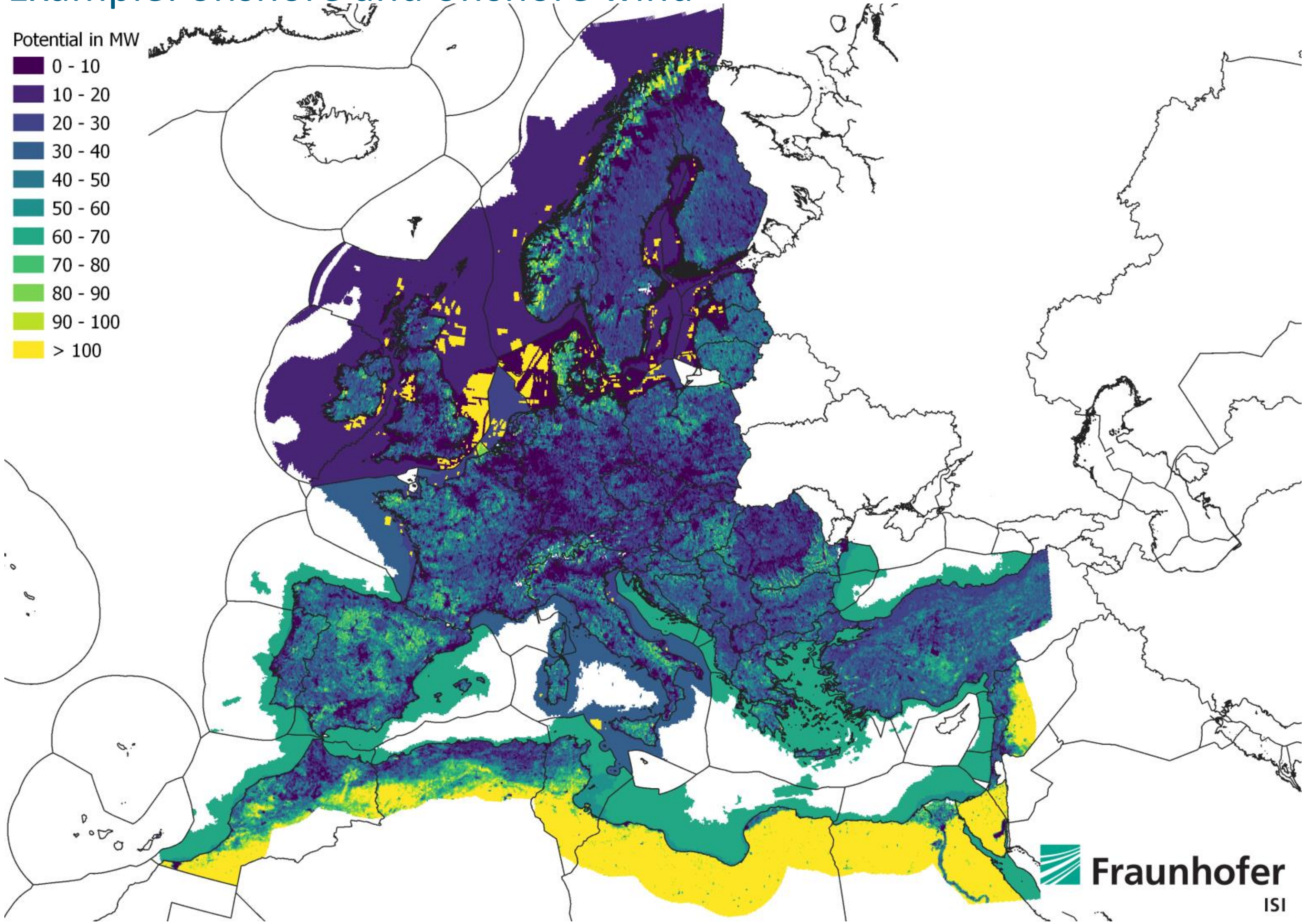
Starting point 2: Renewable potentials

Example: onshore and offshore wind



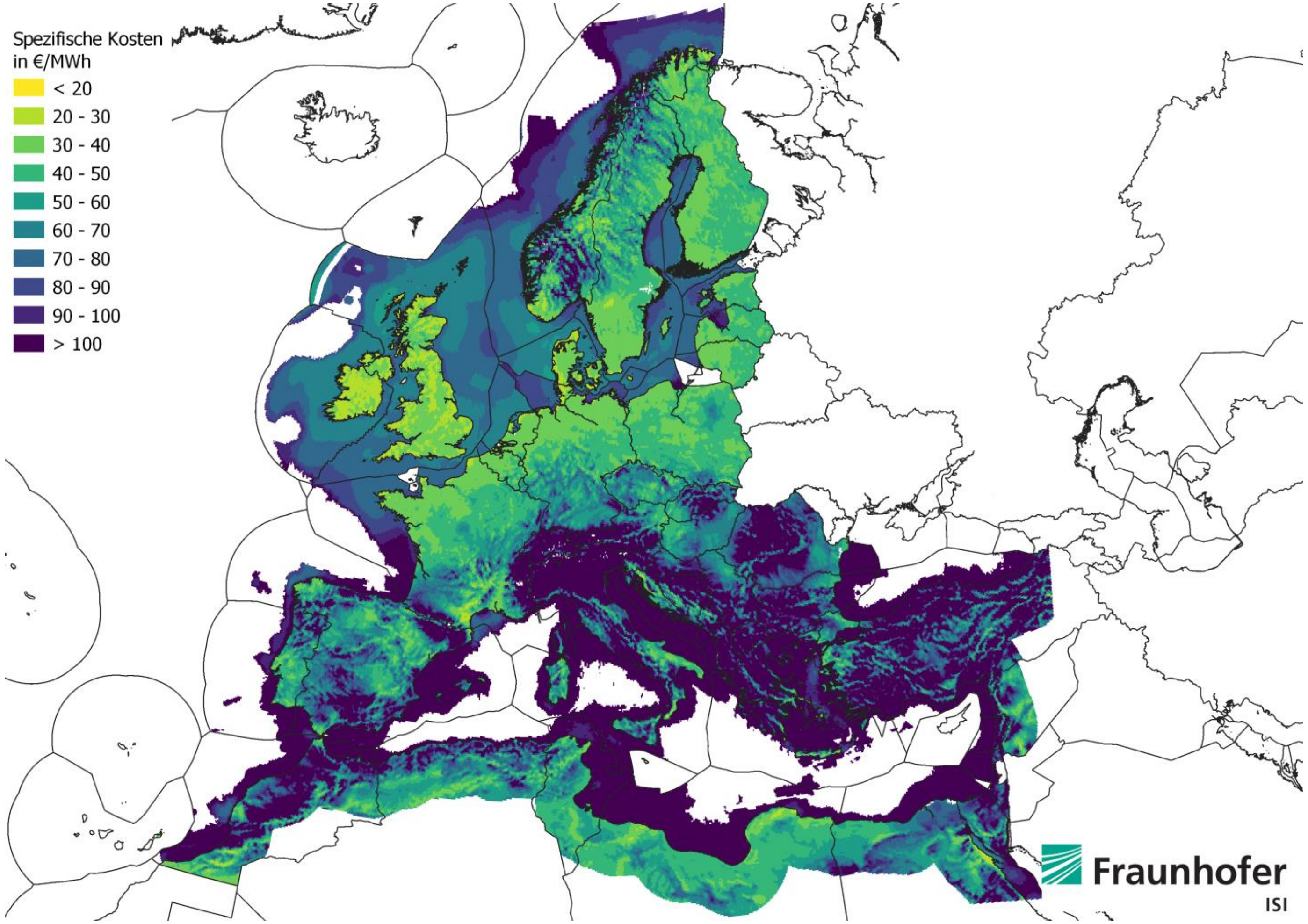
Potential for installed capacity in MW per tile (6.3x6.3km)
incl. real land use and yearly weather/climate conditions

Fallow land and (especially) offshore with very large potentials

The MENA region has large amounts of available fallow land

Starting point 2: Renewable potentials

Example: onshore and offshore wind



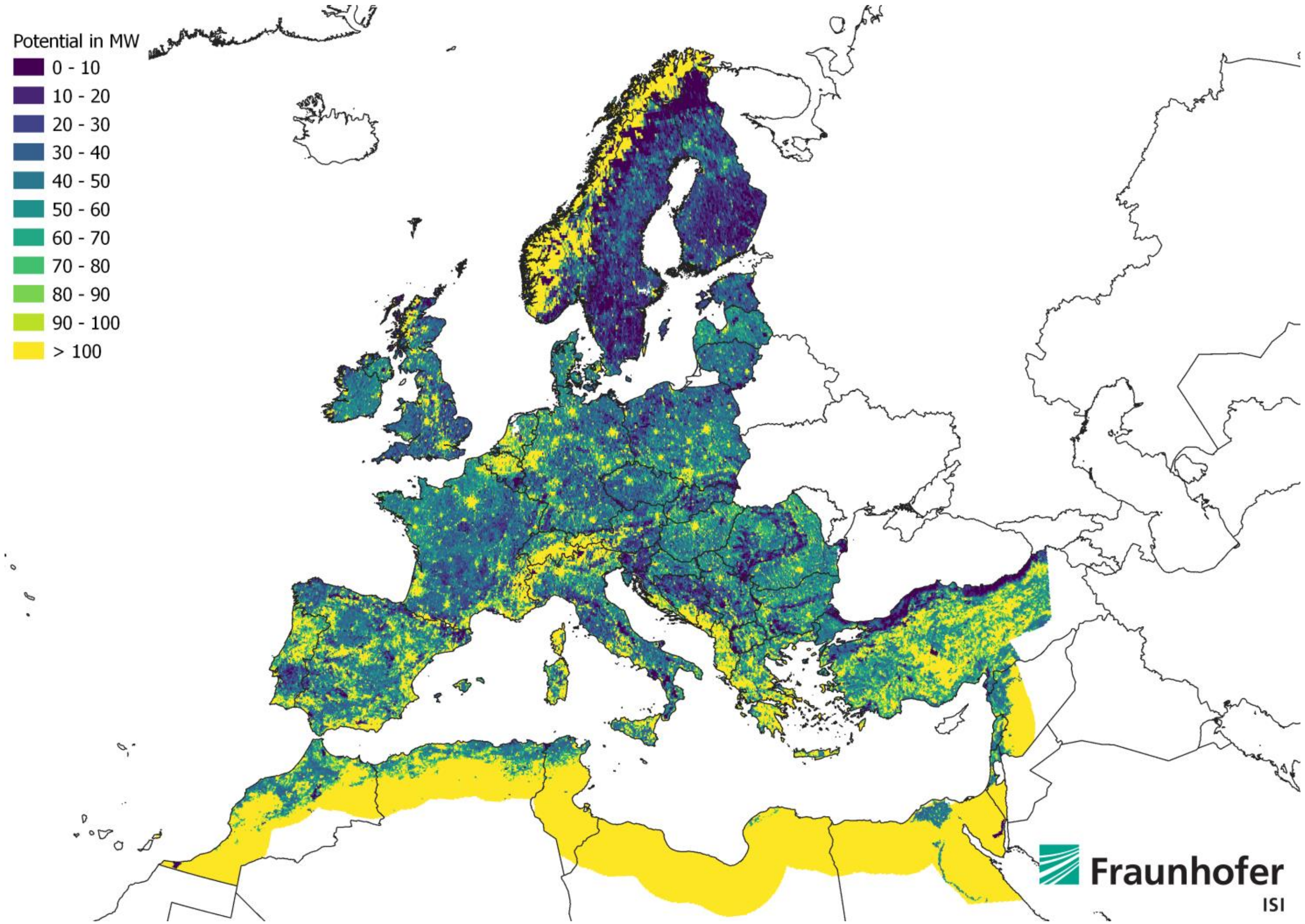
Specific cost of generation in Euro/MWh in 2045

Low(est) generation cost in Northern Europe

Some competitive locations in Southern Europe (Spain, South of France)

Starting point 2: Renewable potentials

Example: PV (utility scale and rooftop)



Potential for installed capacity in MW per tile (6.3x6.3km)
incl. real land use and yearly weather/climate conditions

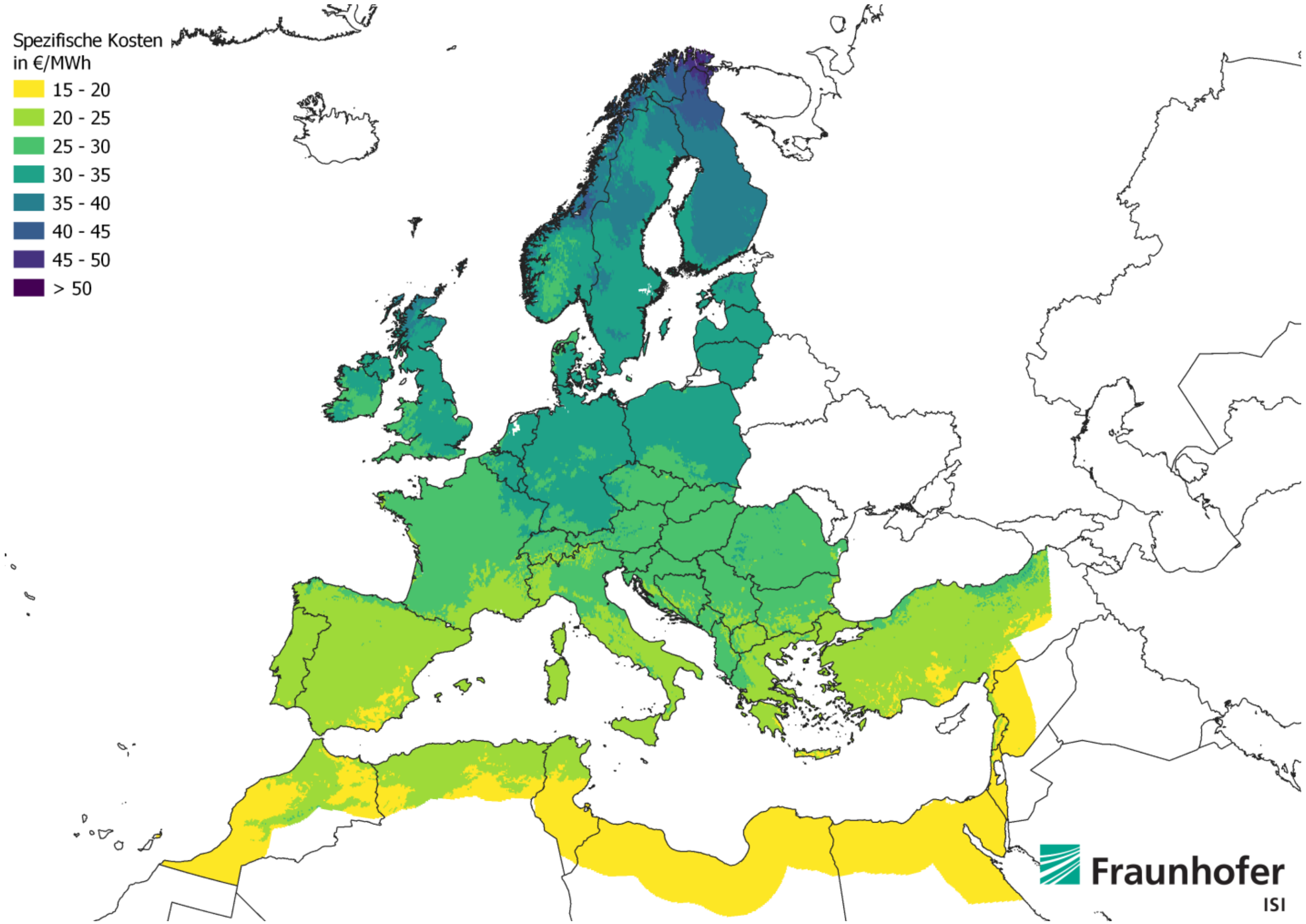
Fallow land and urban areas with large potentials

Large potentials in the Alps (high radiation; but difficult to utilize)

The South of Europe and the MENA region have large amounts of available fallow land

Starting point 2: Renewable potentials

Example: PV (utility scale only)



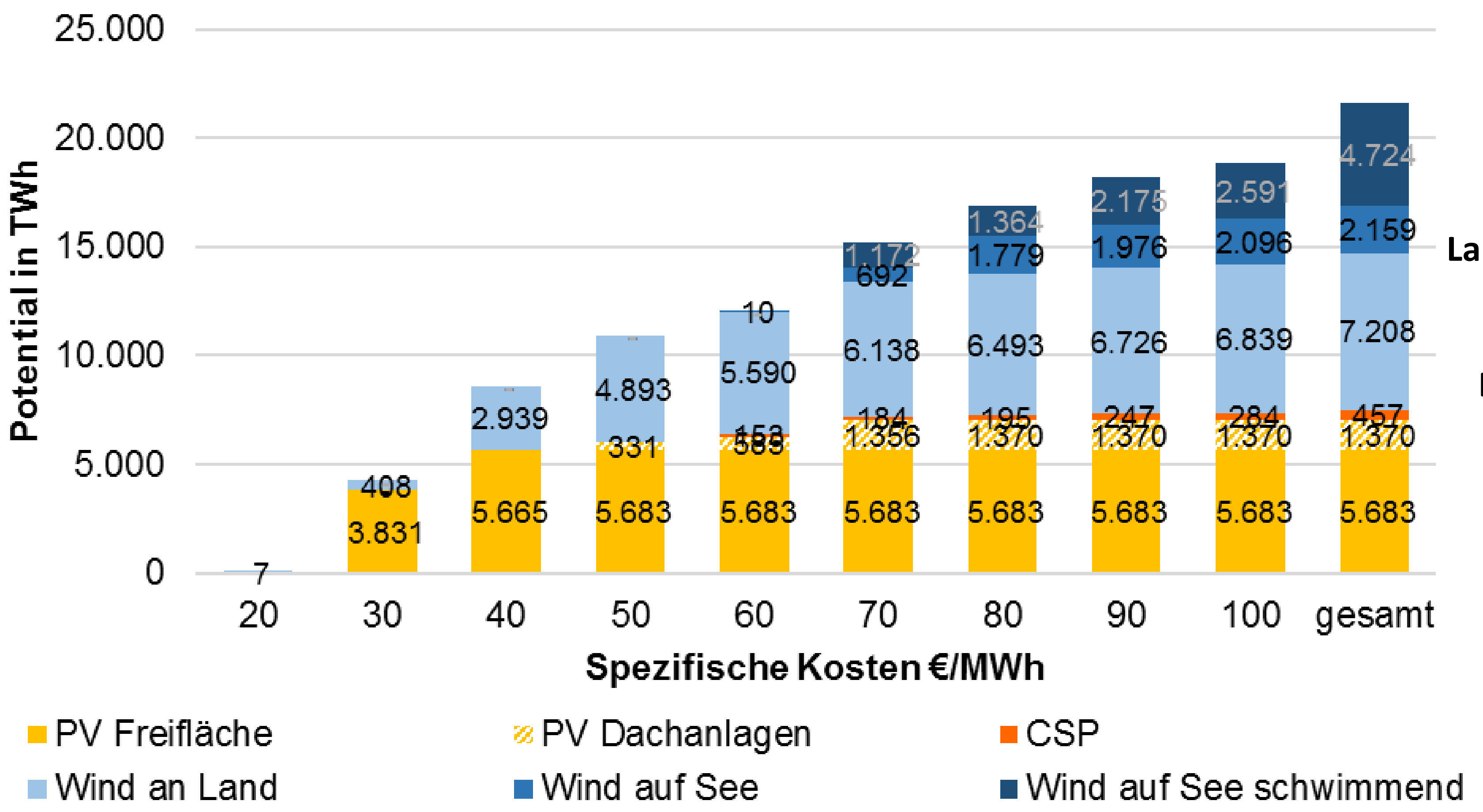
Specific cost of generation in Euro/MWh in 2045

Low cost of electricity generation in Central Europe (below 35 Euro/MWh)

Lowest cost in Southern Europe and MENA (15-25 Euro/MWh)

Starting point 2: Renewable potentials

Available potentials per technology and cost level (2045)



Large potentials are available in Europe (and Germany)

Below 60 Euro/MWh of generation cost, around 12.000 TWh could be sourced

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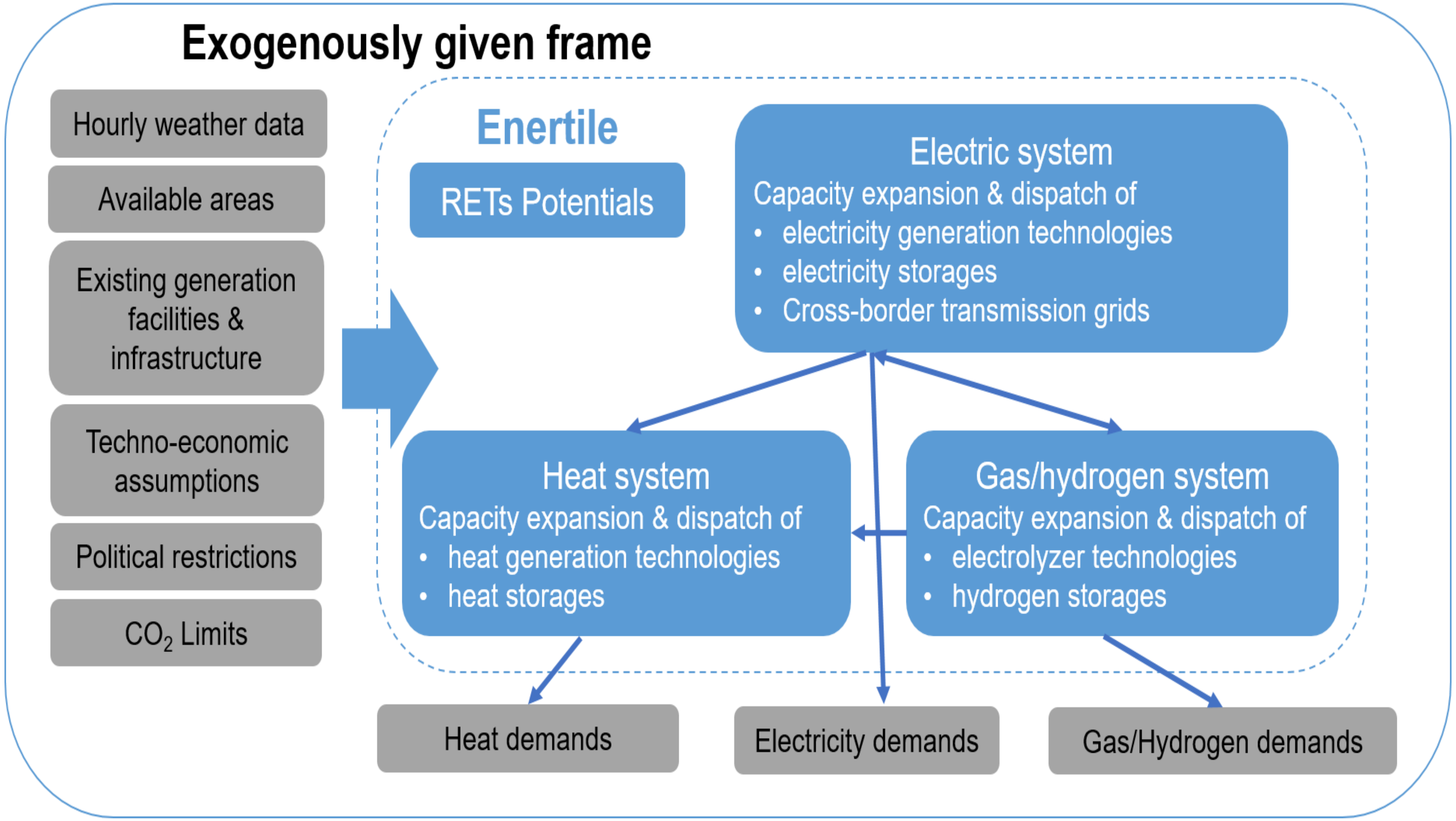
Energy system optimization
Modelling framework



Objective:

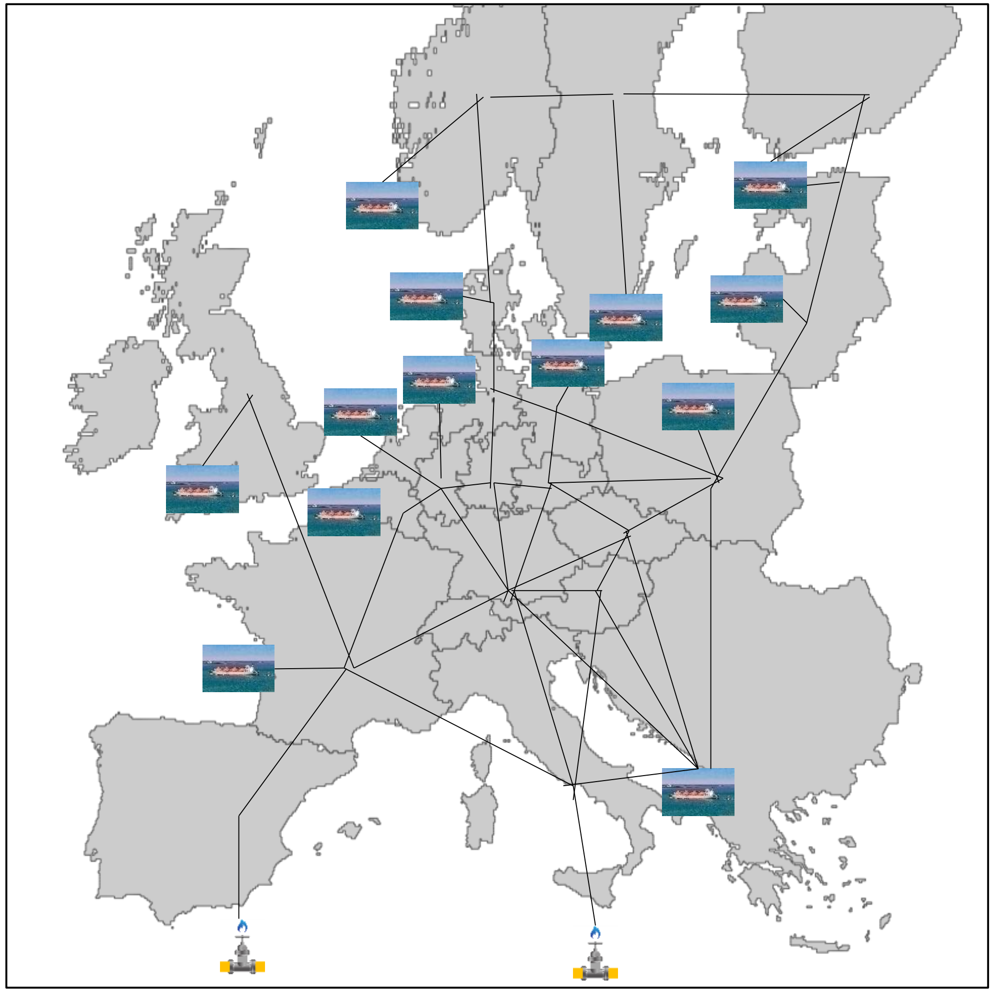
- **Cost-efficient coverage of specified energy demands**

Solution approach:

- Simultaneous cost optimization of the addition and deployment of power plants, CHP, renewables, interconnection capacity, storage, heat pumps, electrolysers, etc.
- Mapping of Europe for 2025, 2030, 2035, 2040 and 2045 in hourly resolution.

Energy system optimization

Hydrogen infrastructure and imports: What possibilities exist?



Differentiation between pipeline and ship

Ship

- Only countries with a coast
- Imports possible from “best of the world” (most price-competitive) regions at 82,50 Euro/MWh (this tends to underestimate real cost)
- Higher transport cost (vs. pipeline)

Pipeline

- Only countries with borders
- MENA pipeline imports into Europe possible (at around 73,40 Euro/MWh)
    - Spain via Tarifa interconnector, Italy via Sicily interconnector

The model decides whether to produce hydrogen locally in Europe (quantities and prices are model results) or to import hydrogen from abroad. Import decision is made when price import + associated infrastructure < price local production + associated infrastructure (shadow price in Europe is roughly 65 Euro/MWh)

Aim: More precise representation of reality
And better representation of a possible future hydrogen transport network (model result)

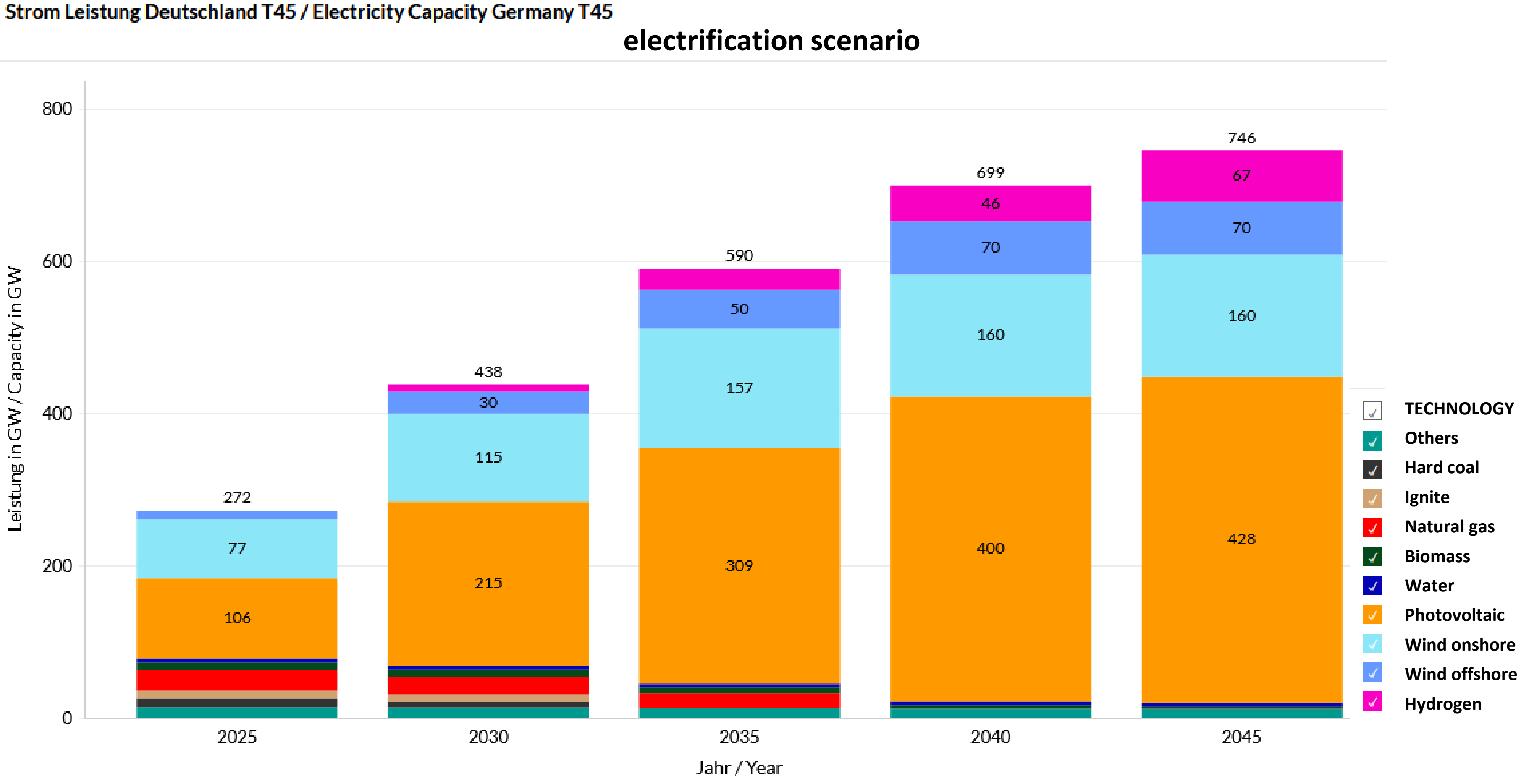
Energy system optimization

German energy policy and energy targets

- **Nuclear and coal will be phase out**
- **Wind on shore**
  - 2030: 115 GW
  - 2040: 160 GW
- **Wind off shore**
  - 2030: 30 GW
  - 2035: 40 GW
  - 2045: 70 GW
- **Photovoltaic**
  - 2030: 215 GW
  - 2035: 309 GW
  - 2040: 400 GW
- **National hydrogen strategy is implemented**
  - 2030: 10 GW Electrolysers
- Almost phase-out of Biomass in conversion sector in 2030

Electricity sector in Germany

Dominance of non-manageable renewable energies require flexibility provision



Transition years

- Expectedly, PV and wind dominate the electricity system
- Especially PV is scaled up very quickly (!)
- Hydrogen perform backup services (flexible RET-dominated system)

2045

- **Policy targets define the electricity system** (almost no variation across scenarios – see next slide)
- PV + wind: 630 GW, over 700 GW in total
- Only hydrogen varies (and is less in the hydrogen scenario)

Electricity sector in Germany

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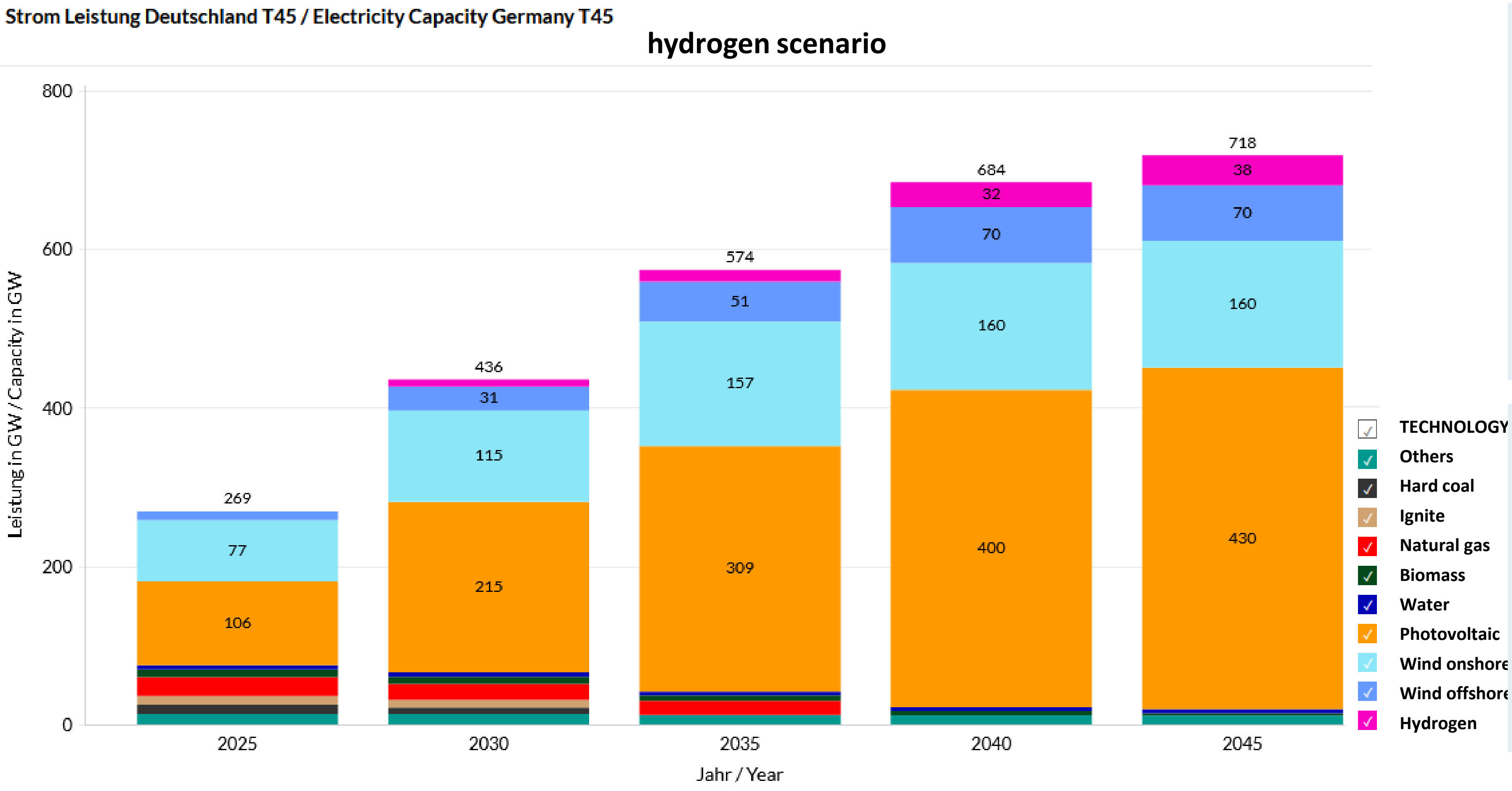

Transition

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2045

- **Policy targets define the electricity system** (almost no variation)
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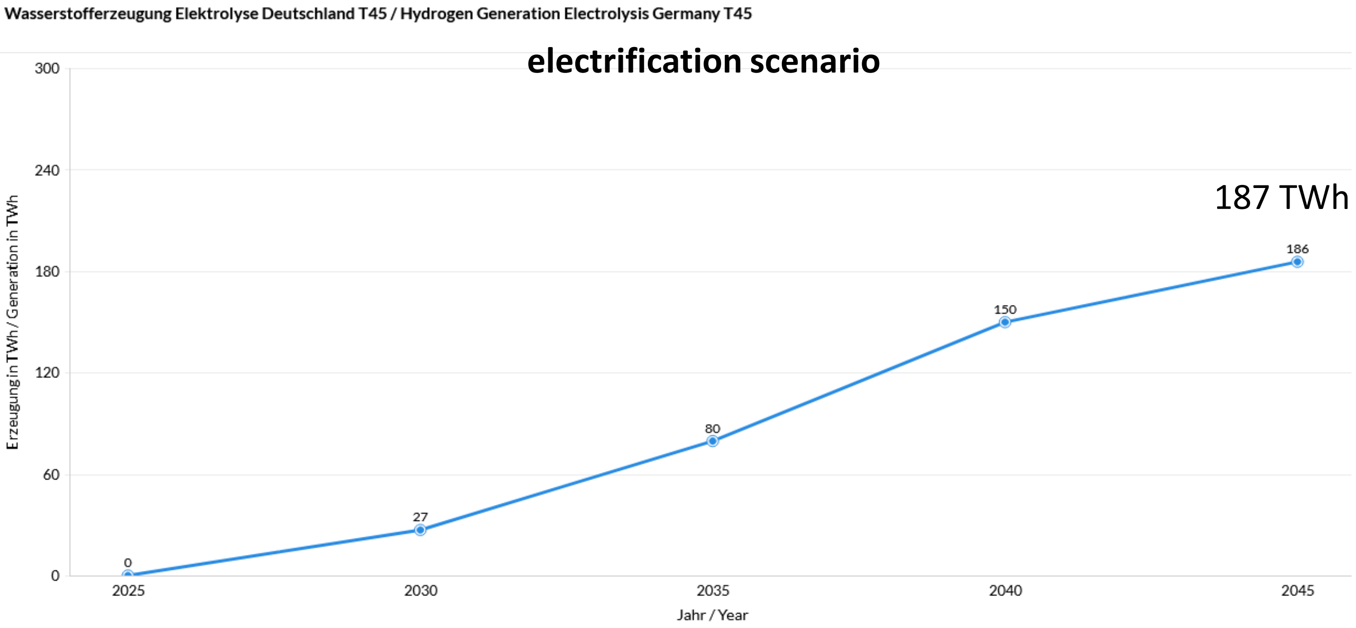
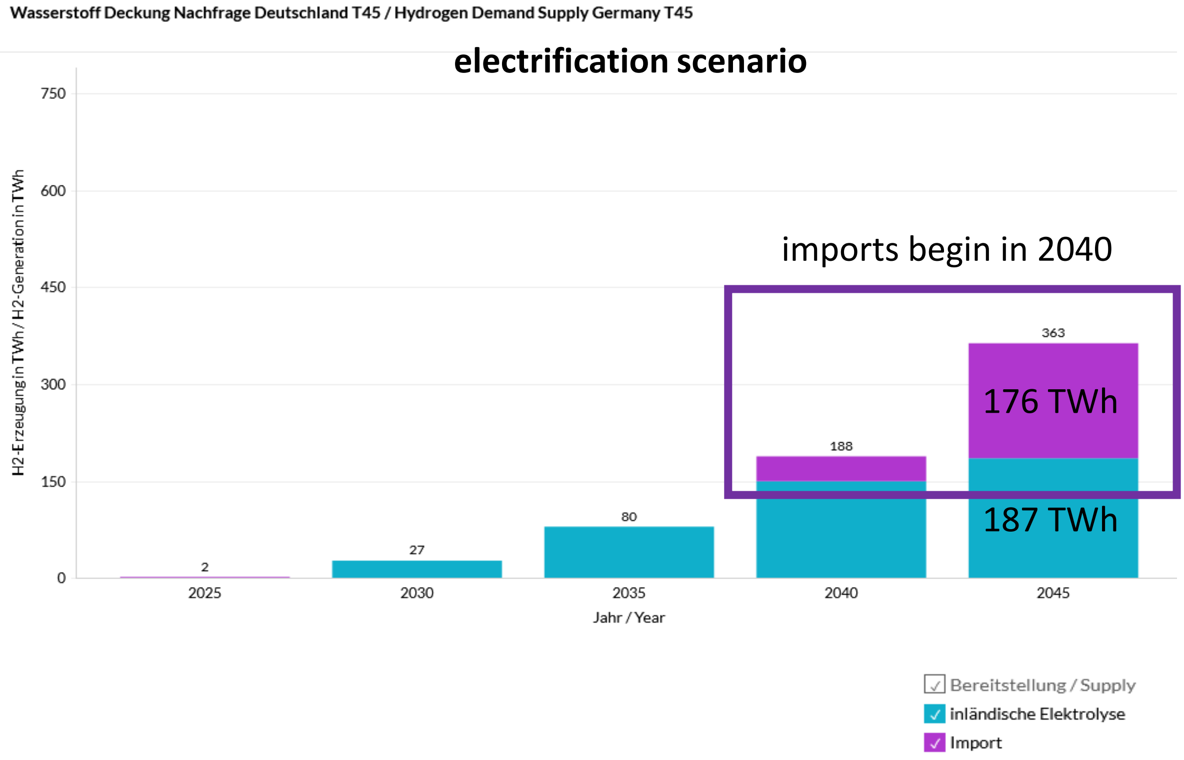
Hydrogen sector in Germany

Germany can produce large amounts of hydrogen nationally, but also needs imports

The national (German) hydrogen generation....



...is complemented by imports
(via pipeline from Europe, not via ship from outside)



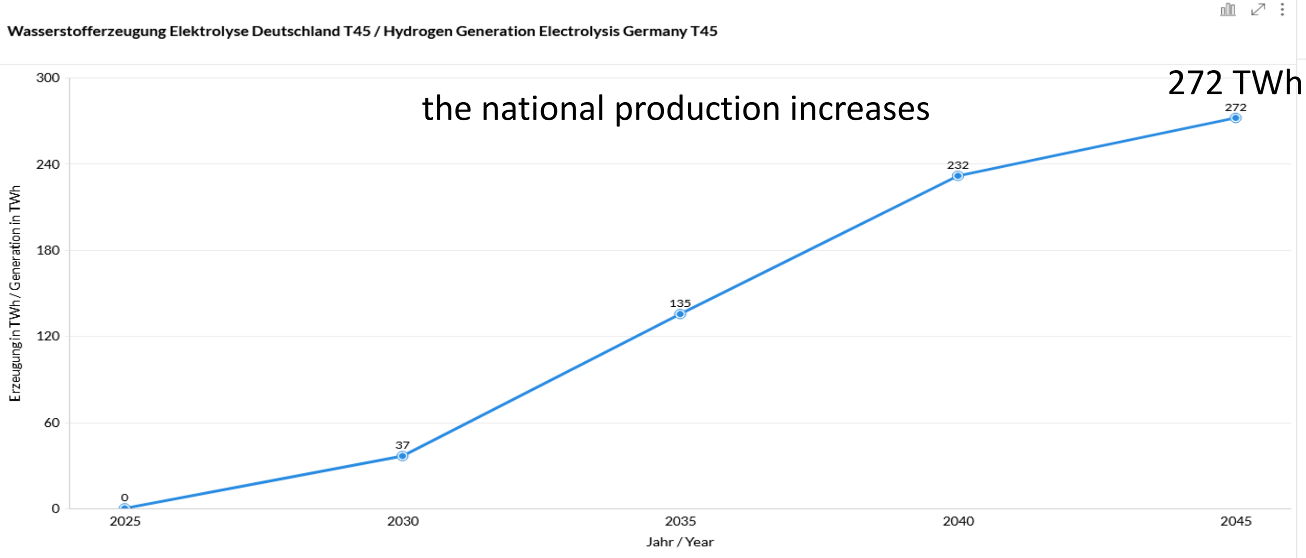
Hydrogen sector in Germany

Germany can produce large amounts of hydrogen nationally, but also needs imports

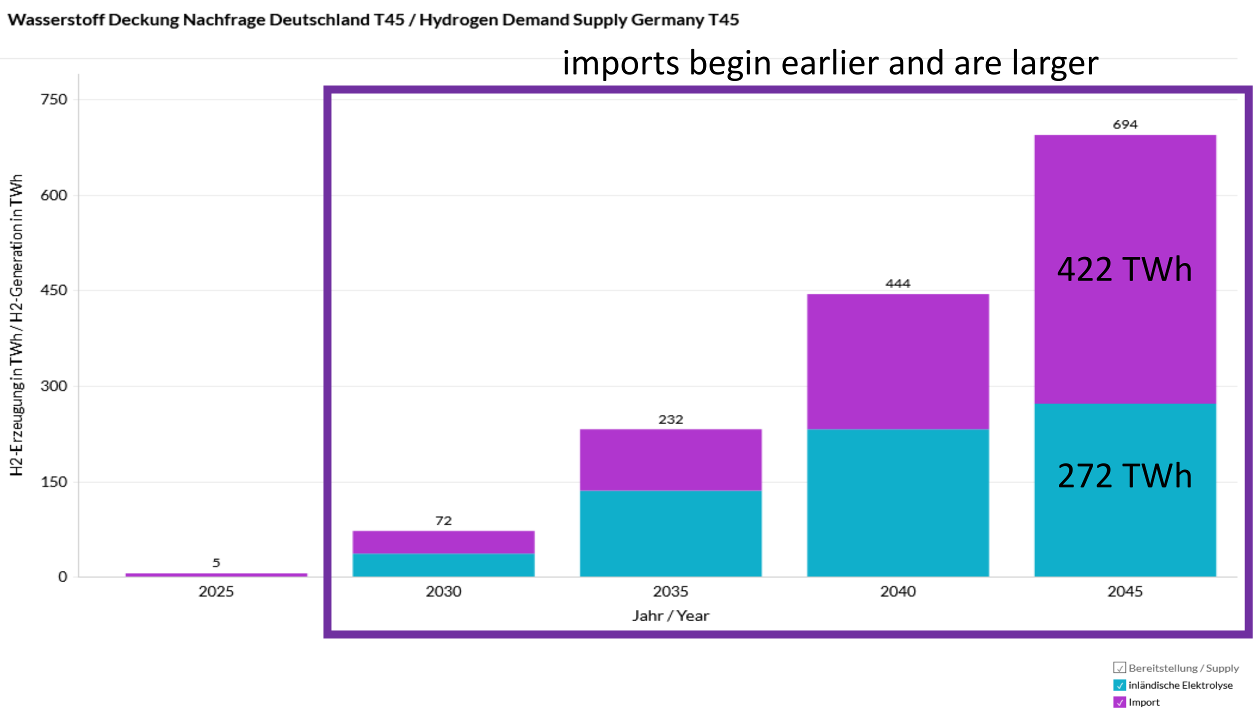
The national (German) hydrogen generation....

...is complemented by imports (still only via pipeline from Europe)

hydrogen scenario



hydrogen scenario



Hydrogen sector in Germany

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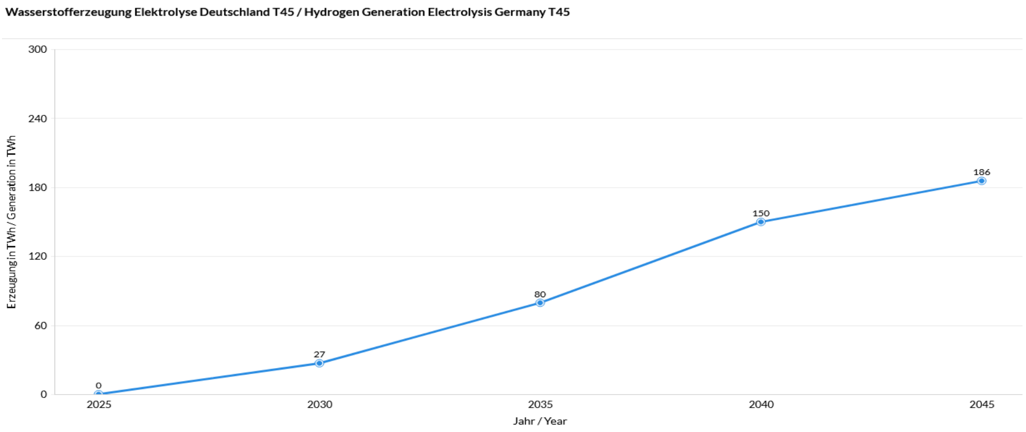
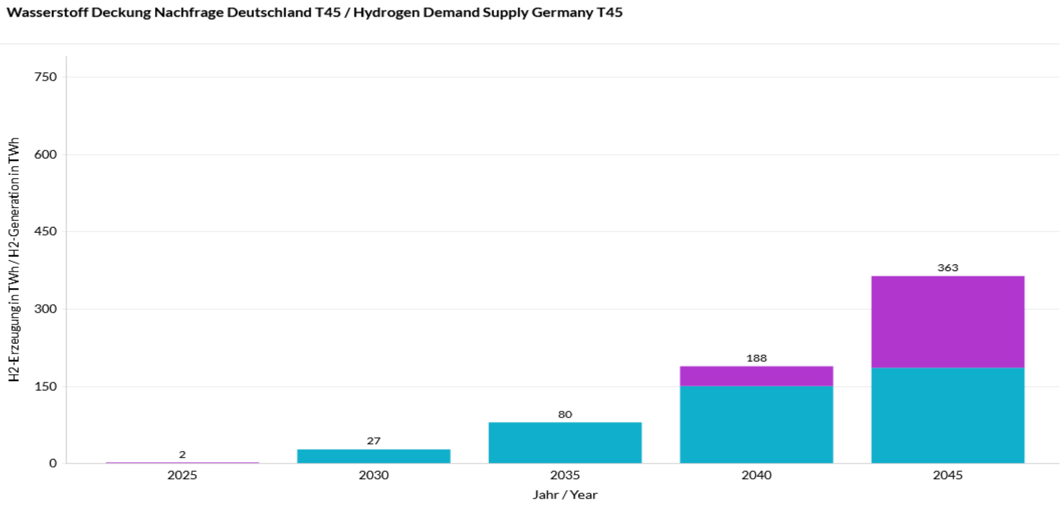
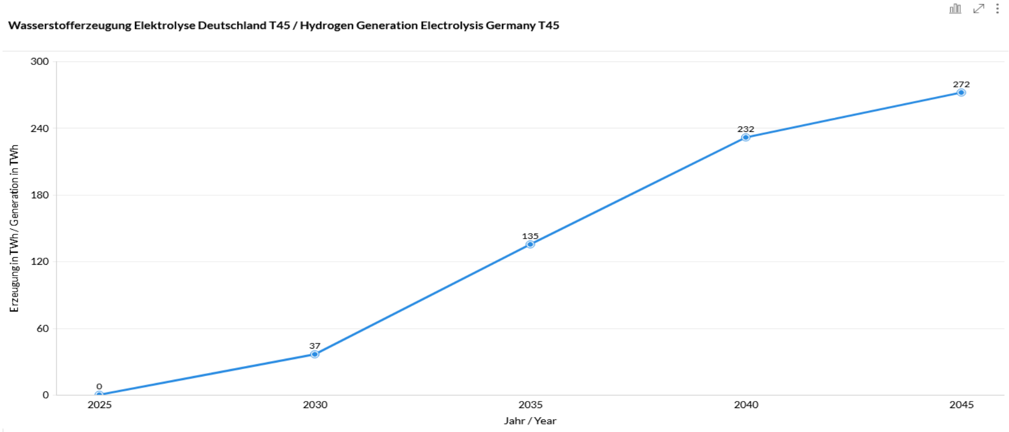
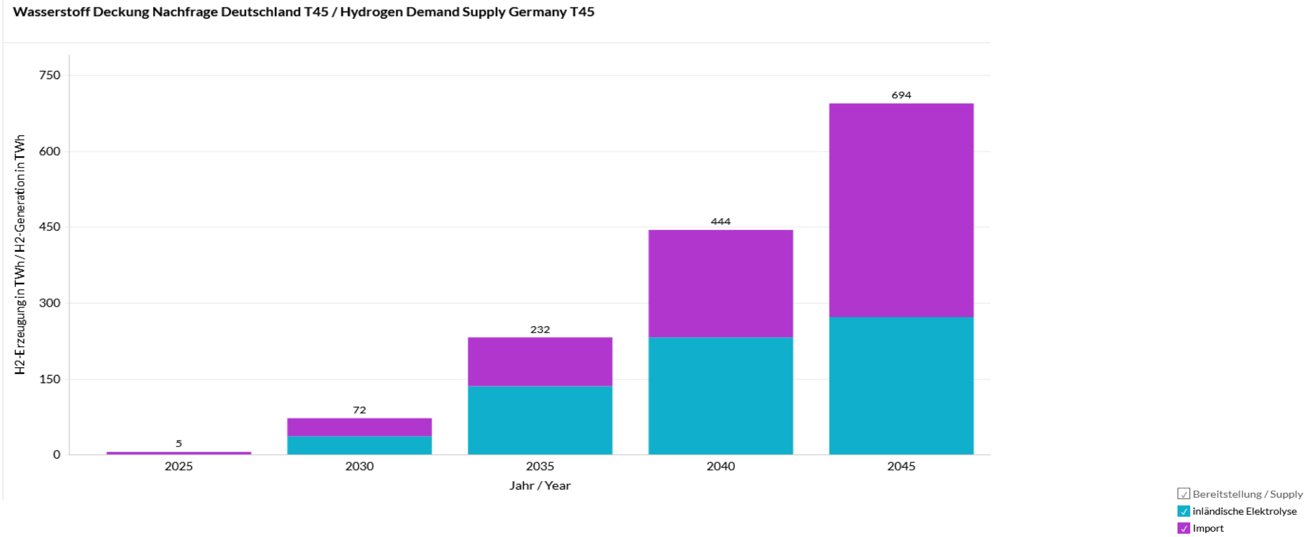
electrification scenario





hydrogen scenario





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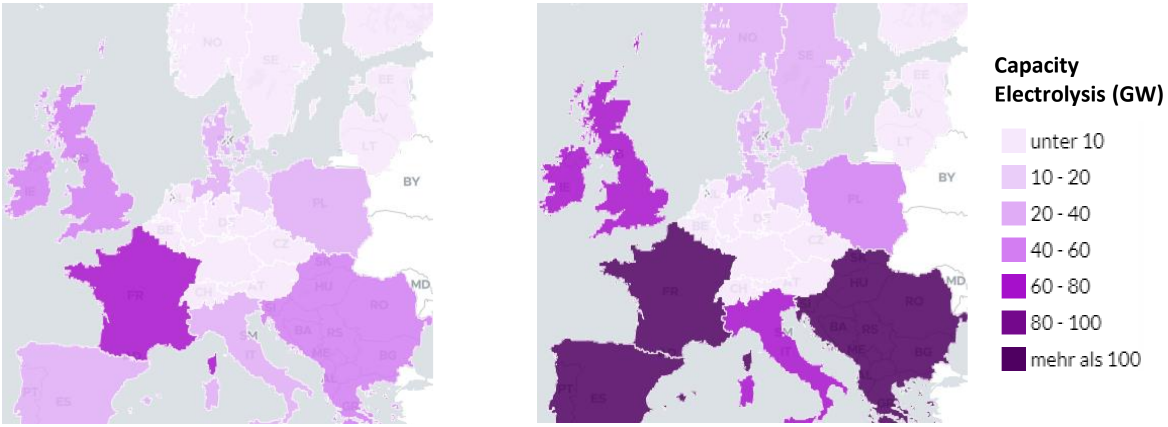
Hydrogen sector in Europe in 2045

Europe has vast potentials to produce green hydrogen

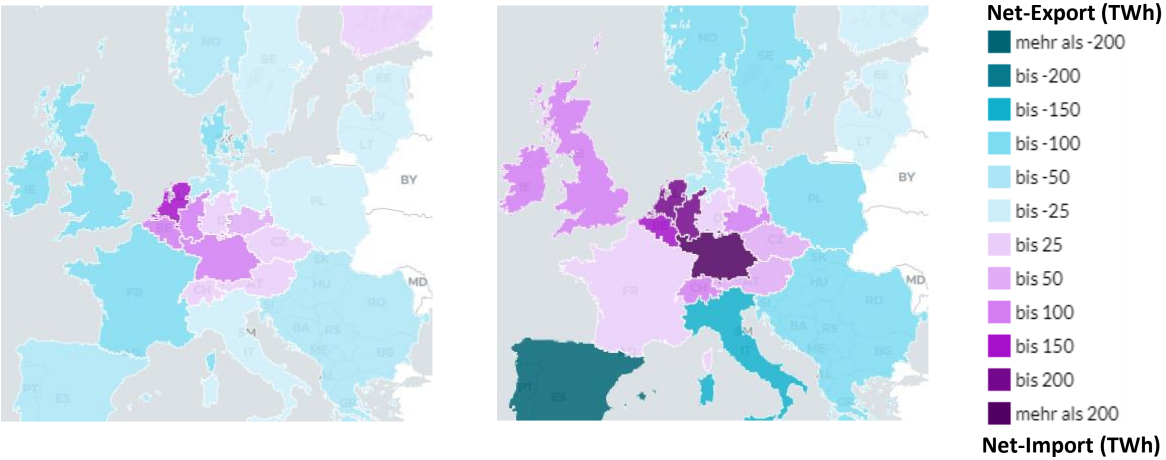
Electrolysis capacity



electrification scenario | hydrogen scenario

- Many European countries have large electrolysis potentials and use them: Iberian Peninsula, Northern Countries, Southeast Europe,...
- Central European countries have lower potentials
- The expansion is scenario dependent. Some regions reach over 100 GW electrolysers (ES, FR, Balkans) in the h2 scen.

Hydrogen import/export activity



electrification scenario | hydrogen scenario

- Central European countries (DE, Benelux) are robust net-importers
- Peripheral countries (ES, North, Balkans) are robust net-exporters
- The role of certain countries (FR, UK) changes as per scenario

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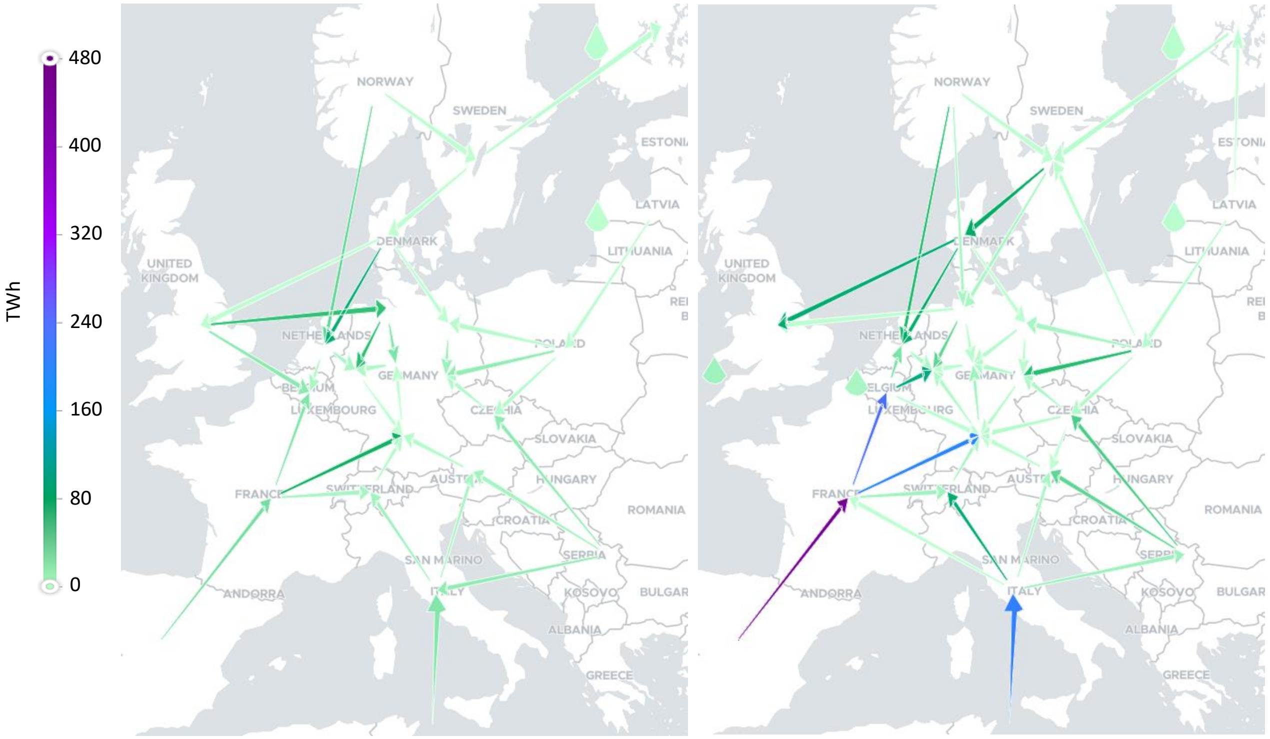
Hydrogen trade in Europe in 2045

A European hydrogen trade will emerge from the peripherals to the center. Non-EU-imports are small

electrification scenario | **hydrogen scenario**

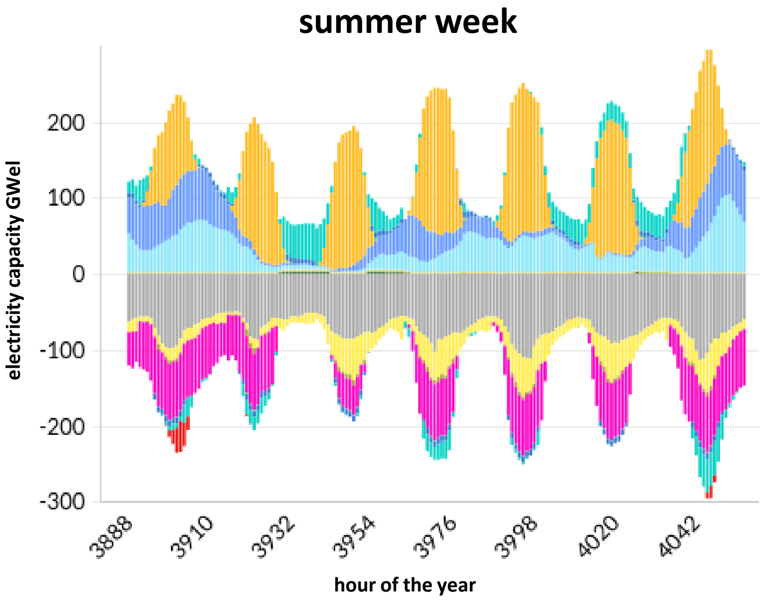


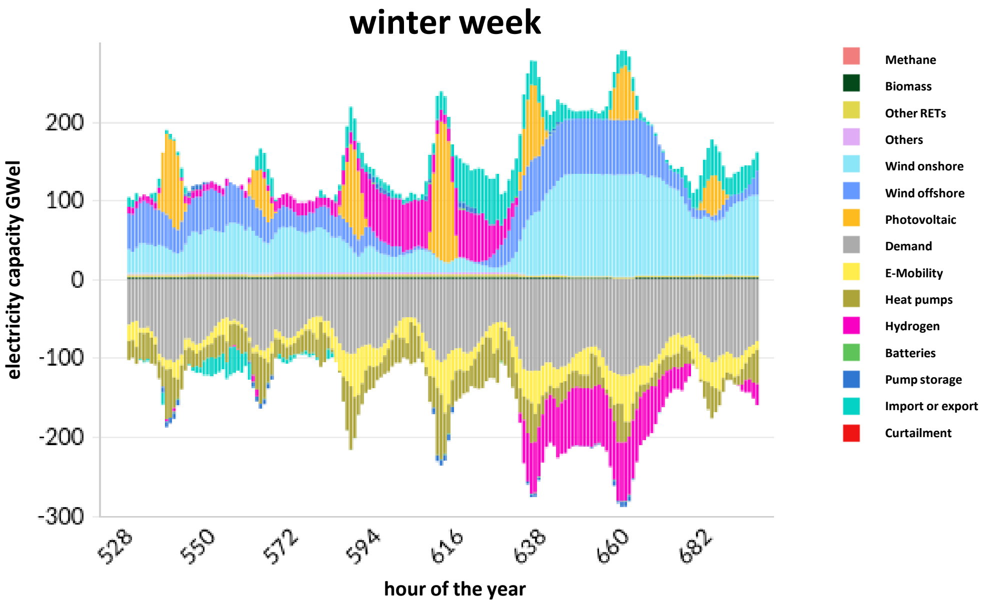
Results

- In all scenarios a European hydrogen network surges (robust result (!) - just the trade volumes differ)
- Mayor hydrogen routes: South-to-north European corridors with up to 480 TWh in the hydrogen scenario; North-to-south corridors ("many ways lead to Germany")
- In Germany, north-to-south hydrogen flows
- France is an important transit country (from Spain to Germany, Benelux and Switzerland)
- Italy is an important transit country for MENA hydrogen (but Spain is not)
- Some countries use very small amounts of ship imports (UK, three Baltic states, Finland) in the hydrogen scenario

Sector coupling in Germany

A look at the electricity sector: Sector coupling provides additional flexibility





Situation in summer

- hydrogen is produced when electricity is available cheaply and abundantly (PV midday peaks)
- hydrogen is not used to generate electricity
- other demand types partly follow this pattern, too

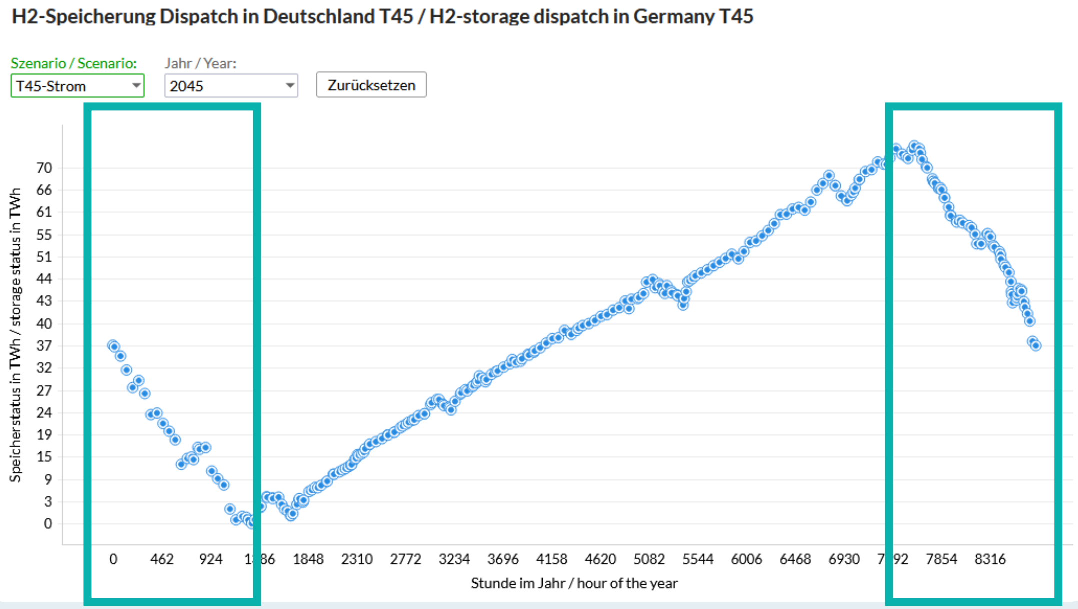
Situation in winter

- hydrogen is produced much less (only with "wind bands")
- hydrogen is used to cover electricity demand during low PV + wind generation

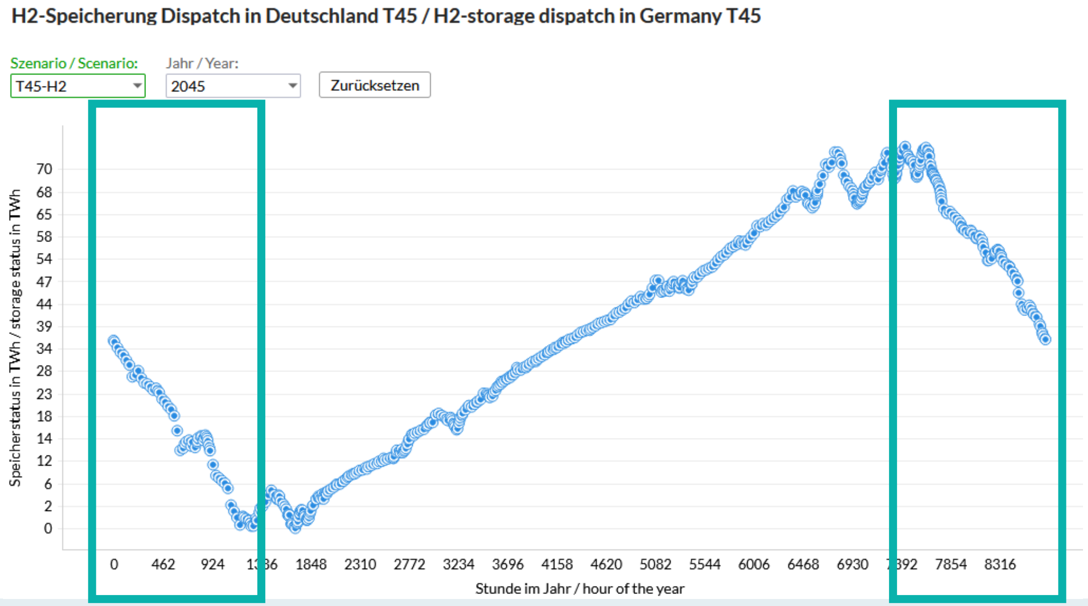
Hydrogen storage in Germany

Storage provides additional flexibility

electrification scenario



hydrogen scenario



- Storage needs and storage patterns are similar in the electrification and hydrogen scenarios
- Hydrogen storage follows a seasonal profile, indicating a corresponding flexibility provision (hydrogen is not used for short term flexibility)
- In winter months, between 10 and 20 TWh of hydrogen are used for generating electricity. During the rest of the year: less than 1 TWh/month
- Large volumes of hydrogen storage need to be ready for the system beginning 2030 (potential in salt caverns in DE is 35-50 TWh, thus not enough)

Summary of main findings

Analyzing the role of green hydrogen in Germany‘s energy transition

Regarding the use of hydrogen as an energy carrier

- hydrogen has an important role in the energy system. Its role is more important in a more electrified economy than in a more hydrogen-based economy (...prices!)
- functions in energy supply: flexibility provision in a fluctuating RETs-dominated system. This changes over the year.

Regarding infrastructure

- both a inner-German and European hydrogen infrastructure must be available soon and scaled-up rapidly, including:
- hydrogen inland storage and European networks

Regarding the need for policy intervention

- the ambitious German policy basically “defines” the future energy system, very little variation between scenarios
- Germany depends largely on policy action undertaken elsewhere in the EU for securing its energy demand
- imports from outside the EU are possible, but not essential (EU hydrogen is cost competitive) – derivates do come from outside of the EU
- besides techno-economic aspects, there are uncertainties i.e., regarding social acceptance (RETs and transport infrastructure) and political willingness (i.e., exporting and transit countries)
- a focus on diversifying transport (import) routes, as well as diversifying energy carrier infrastructure (hydrogen and electricity) is considered beneficial for risk mitigation

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