Realizing sector coupling in Europe and beyond: the future role of electricity and gas grids

Hans Christian Gils[1], Manuel Wetzel[1], Hedda Gardian[1], Jens Schmugge[1]

[1] German Aerospace Center (DLR), Institute of Networked Energy Systems

18th IAEE European Conference

Milan, 24-27 July, 2023 – Bocconi University

KOPERNIKUS PROJEKTE
Ariadne
Die Zukunft unserer Energie

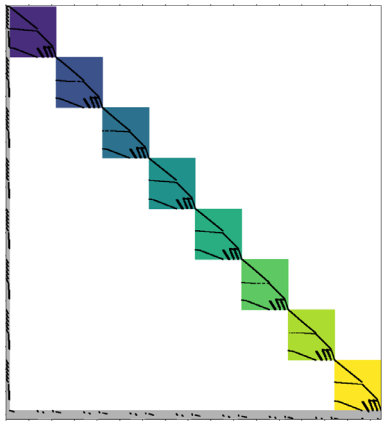
SPONSORED BY THE
Federal Ministry of Education and Research

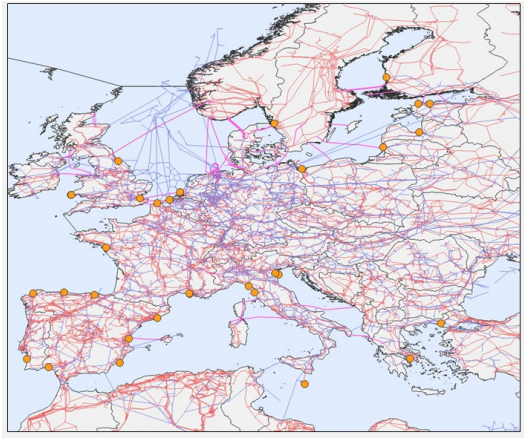
DLR

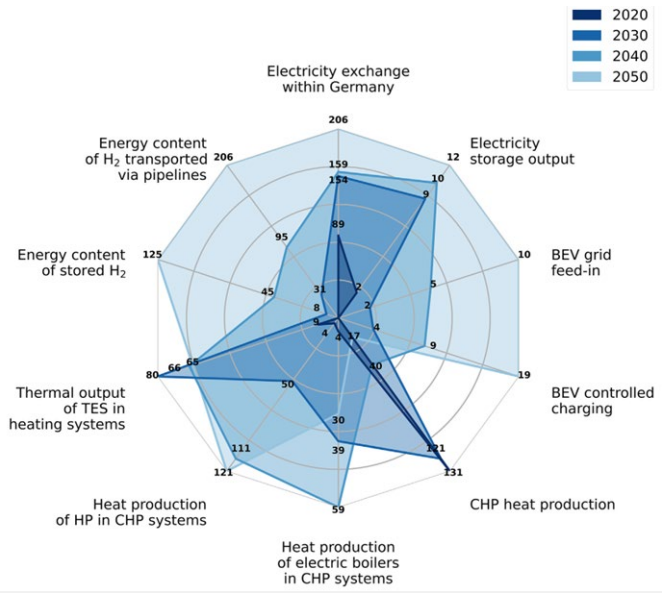
Background

Modelling robust pathways to a sustainable, economic and secure energy system

- Improving energy system models and data
- Comprehensively modelling sector coupling and flexibility
- Deriving policy recommendations for the implementation







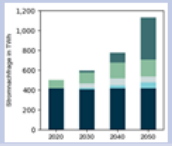
Modelling framework

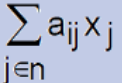
Input

Model scope

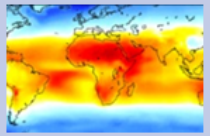
Power Heat Transport Gas

Energy demand scenario

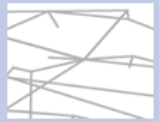




Energy resources



Infrastructure data



Technology data

€ η

REMix energy system optimisation framework

Minimisation of system costs

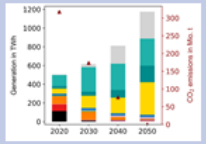
$$\text{Min} \sum_{j \in n} c_j x_j \quad \sum_{j \in n} a_{ij} x_j \geq b_i \quad ,\forall i \in 1...m \quad x_j \geq 0$$

GAMS python

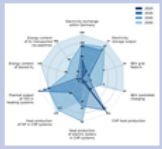
CO_2 targets, domestic supply shares, …

Output

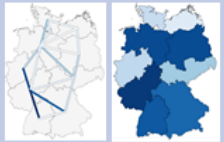
Energy conversion



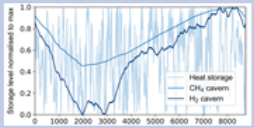
Load balancing



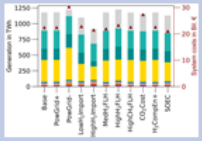
Infrastructures



System operation



Scenario variants



Open source release in Sept 2023 on https://gitlab.com/dlr-ve/esy/remix

Integrated optimization of capacities and dispatch of all technologies

Model set-up

Model scope

Exogenous

Power sector
- Renewable energy potentials and timeseries
- Power demand not linked to sector coupling
- Hydroelectric plants and pumped storage
- Existing and planned power grids (HVAC/HVDC)

Transport sector
- Electricity demand for BEVs
- Hydrogen demand for FCEVs

Residential and commercial heating
- Heat demand per technology group and sector
- Potentials for district and town heating

Industry
- Electricity and heat demand
- Non-energetic gas demand

Gas infrastructure
- Cross border pipeline capacities
- Existing cavern storages

Wetzel et al. 2023

Scenario set-up

Climate neutral energy system in 2050

Scenarios on energy partnerships, domestic sourcing, network expansion

Main limitations:

One node per country approach

Connection to LNG terminals not modelled explicitly

Wetzel et al. 2023

Continental Europe (CE)

Energy souvereignity in continental Europe

- All energy carriers are produced in continental Europe to the extent possible.
- Cross-border trade with Maghreb contries and British Isles has neutral energy balance.

Energy partnerships enable imports

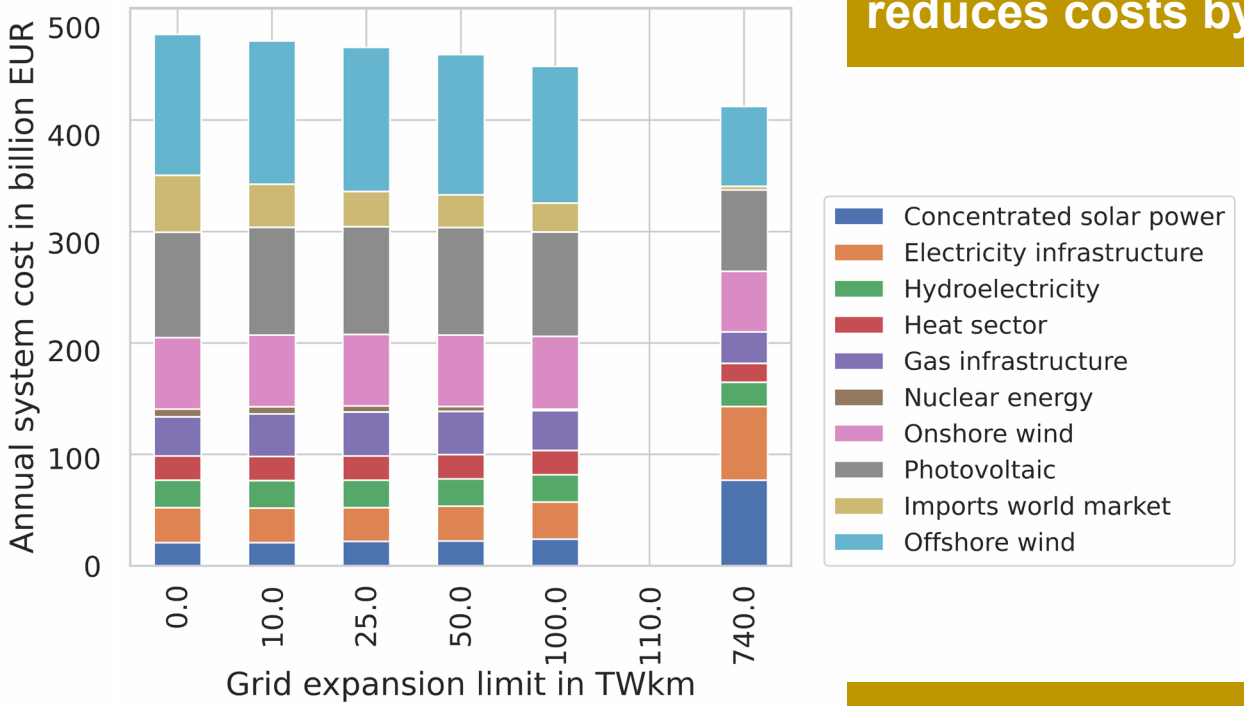
- Energy partnerships ensure imports from Maghreb countries and British Isles for all energy carriers.

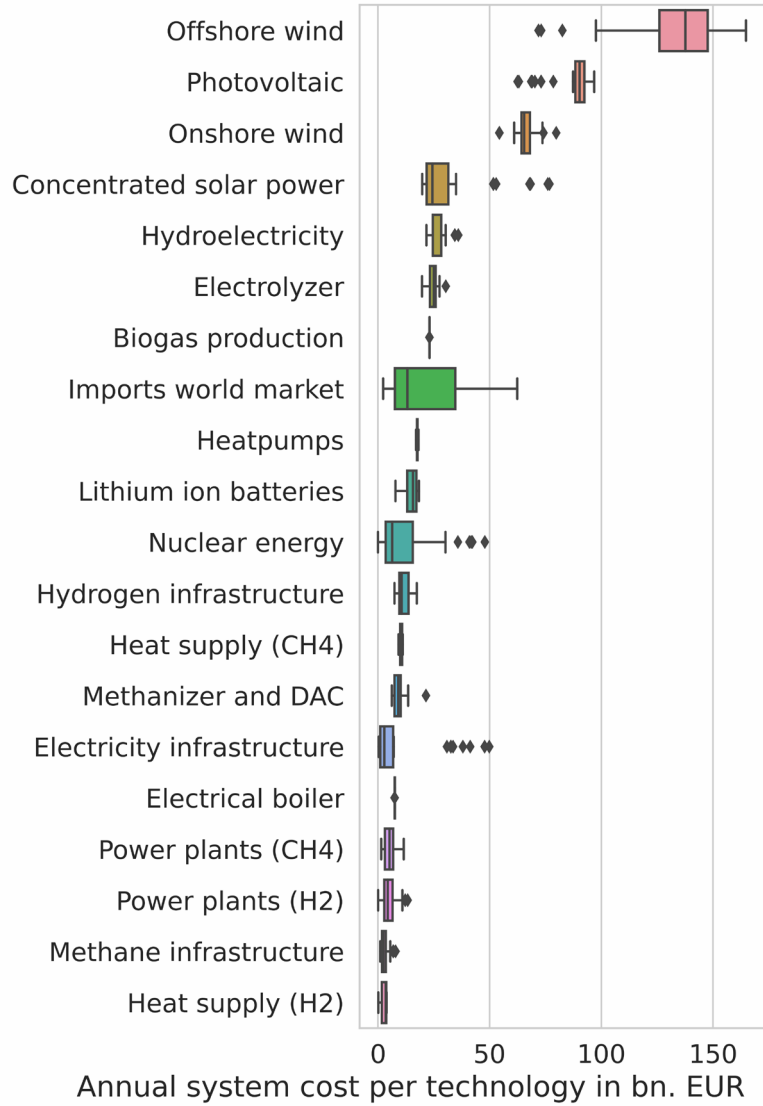
Energy Partnerships (EP)

Results on system costs

System costs by 3% lower in European Partnership scenarios

Further grid expansion reduces costs by up to 16%





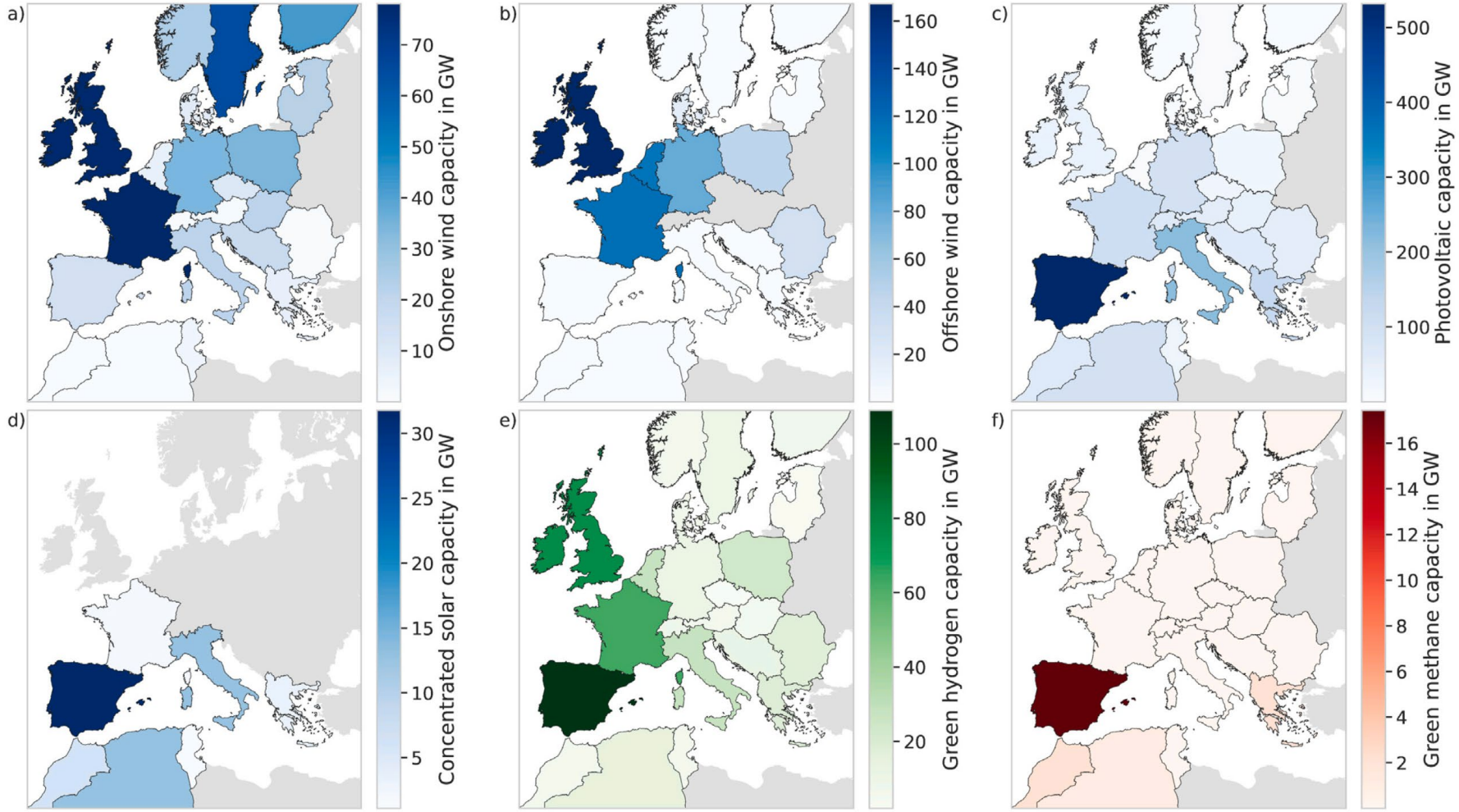
Highest variations for nuclear, wind offshore, CSP, fuel imports

Wetzel et al. 2023

Results on spatial allocation of renewables

Broad distribution of onshore wind and PV

Spatial concentration of offshore wind, CSP and hydrogen production

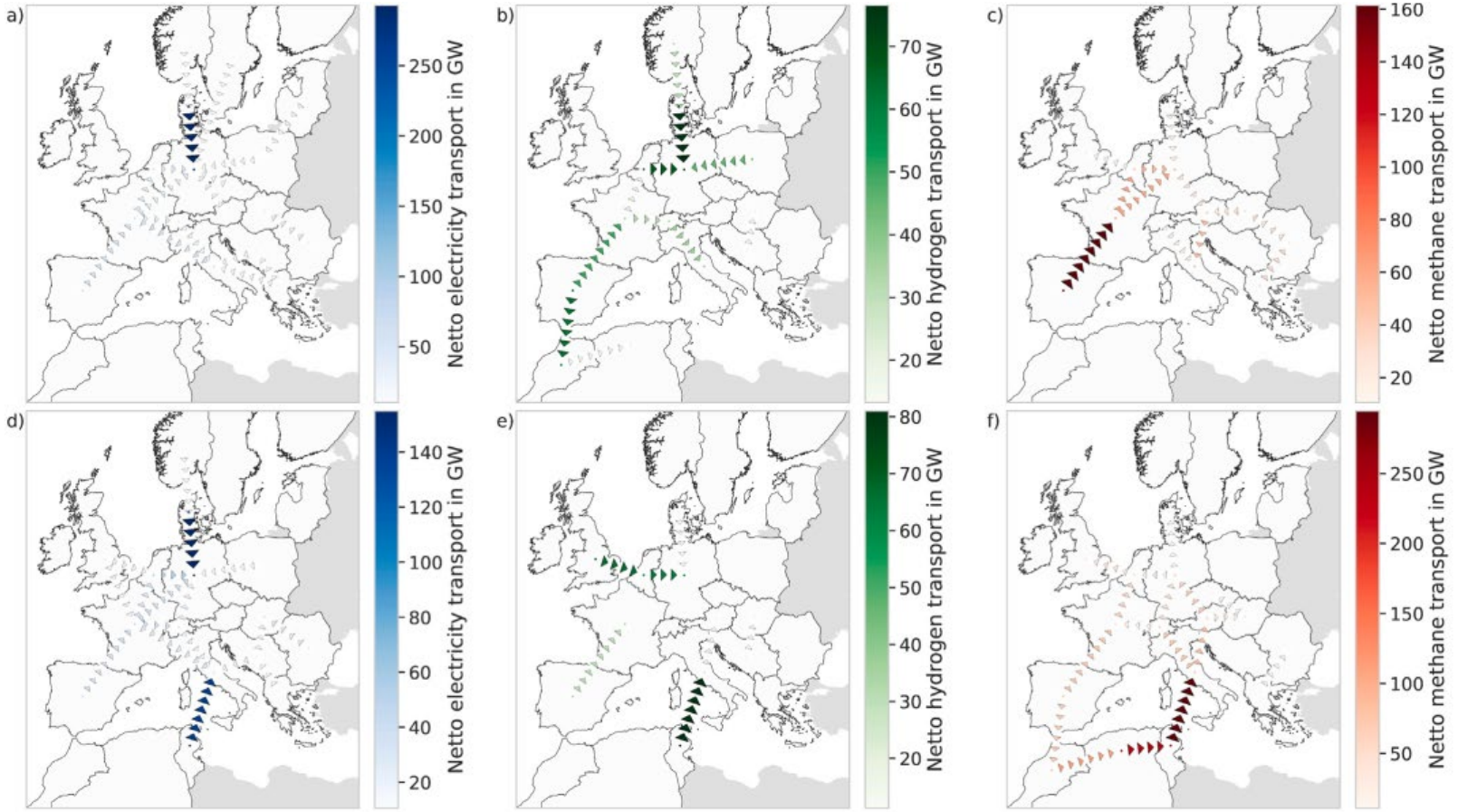


Wetzel et al. 2023

Results on large-scale grid infrastructure

Energy souvereignity in continental Europe

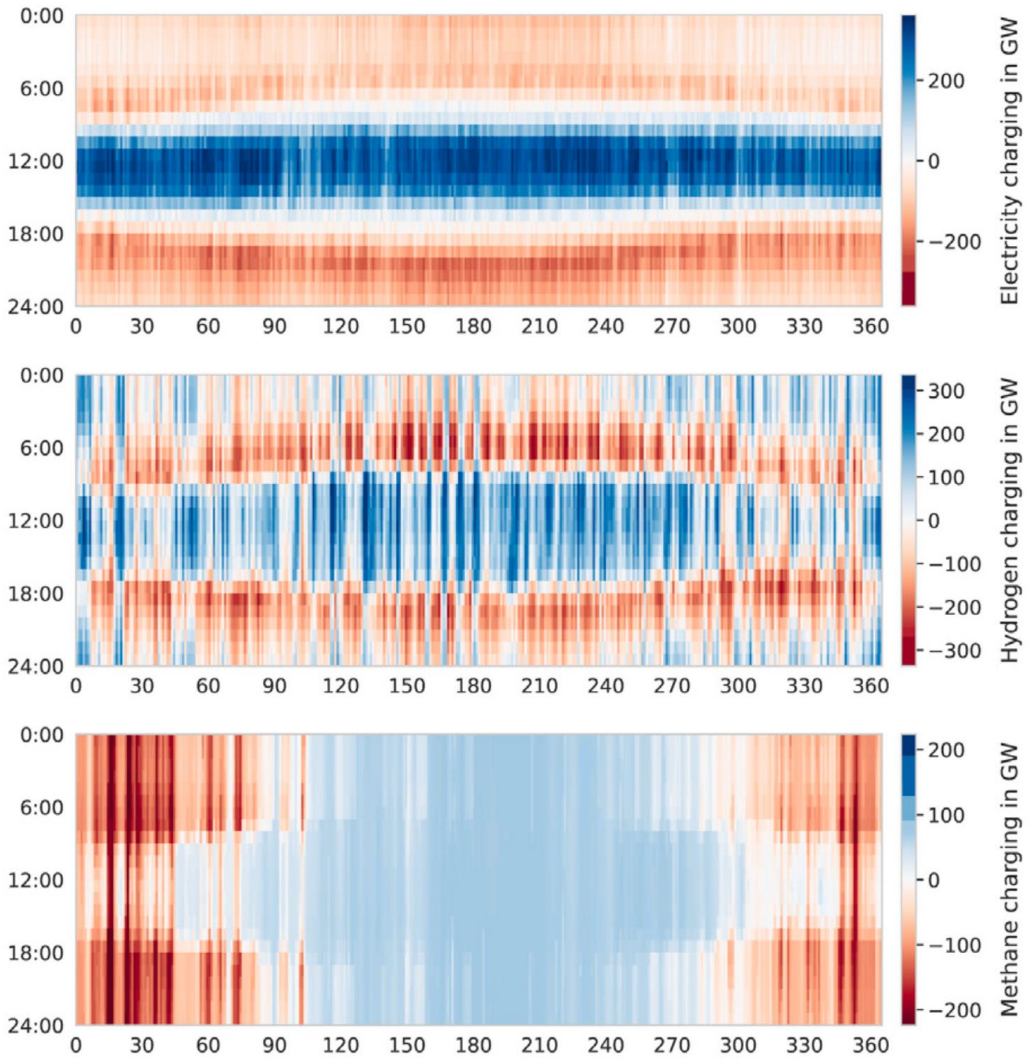
Energy partnerships enable imports



Network structure heavily dependent on energy policy, with some trends, e.g. central Europe being a major importer from the peripheral regions

Wetzel et al. 2023

Results on flexibility and green hydrogen imports



Wetzel et al. 2023

Daily balancing by electric energy storage, may be partly covered by flexible vehicle charging

H_2 production compensates follows RE power generation

Seasonal operation of methane storage, driven by (exogenous) demand in the heating sector

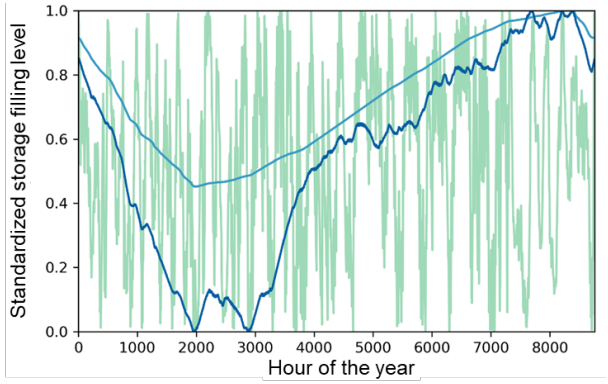
World market imports of H_2 only start to gain relevant shares at prices of ~50 €/MWh

Key insights

- Partial repurposing of gas infrastructures to H_2 is favourable
- Hydrogen corridors from renewable rich regions to demand centres
- Fully decarbonized energy system profits from H_2 in the power sector
- Pipeline imports of green H_2 to Europe, e.g. from MENA are promising
- Electrolyzers should be considered part of the energy system, not industry

Relation to other REMix modelling results

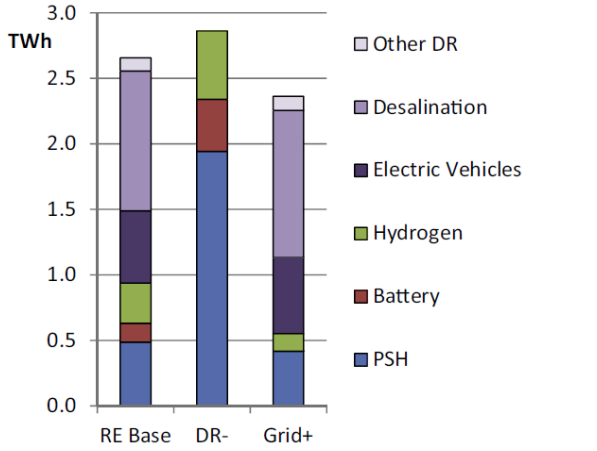
Role of sector coupling is much driven by regional energy system characteristics



Gils et al. 2021, Schaffert et al. 2022

H_2 is key element for providing seasonal balancing

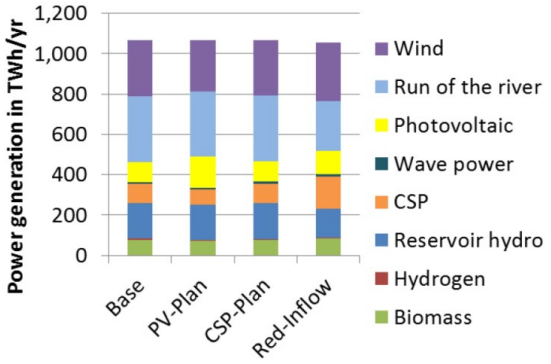
Power system benefits justify domestic H_2 production



Gils and Simon 2017

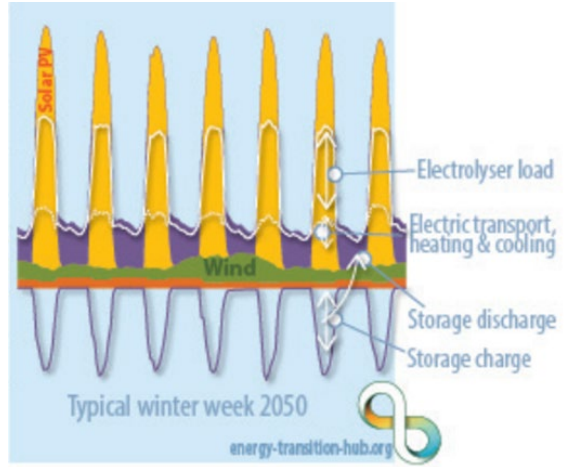
Missing solutions for seasonal storage on islands that other sector coupling cannot cover

High potential for dispatchable renewable generation limits role of flexible sector coupling



Gils, Simon, Soría 2017

Sector coupling in transport, heating and cooling of limited importance in potential hydrogen exporting countries



In a nutshell

Using the flexibility in sector coupling is cheaper than electricity storage

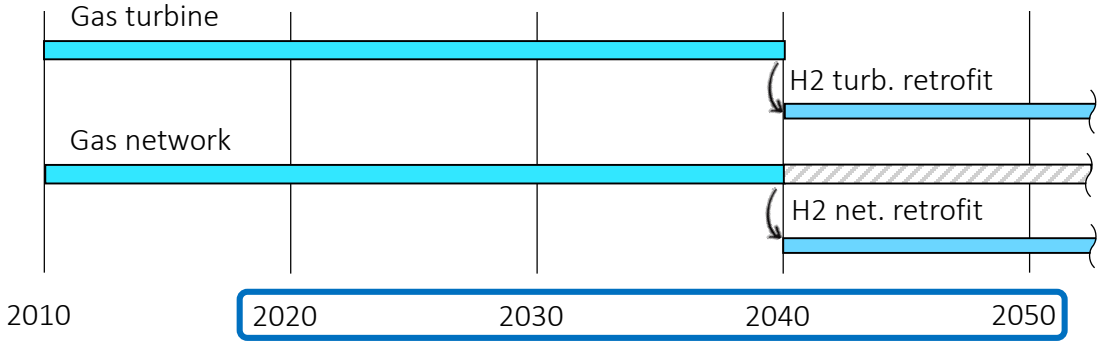
- Cost reduction is highest for long-term storage and pipelines for hydrogen, as well as flexible heat supply
- Demand side management of sector coupling loads notably reduce peak loads
- Load balancing focus shifts from heat to hydrogen with stronger emission reduction

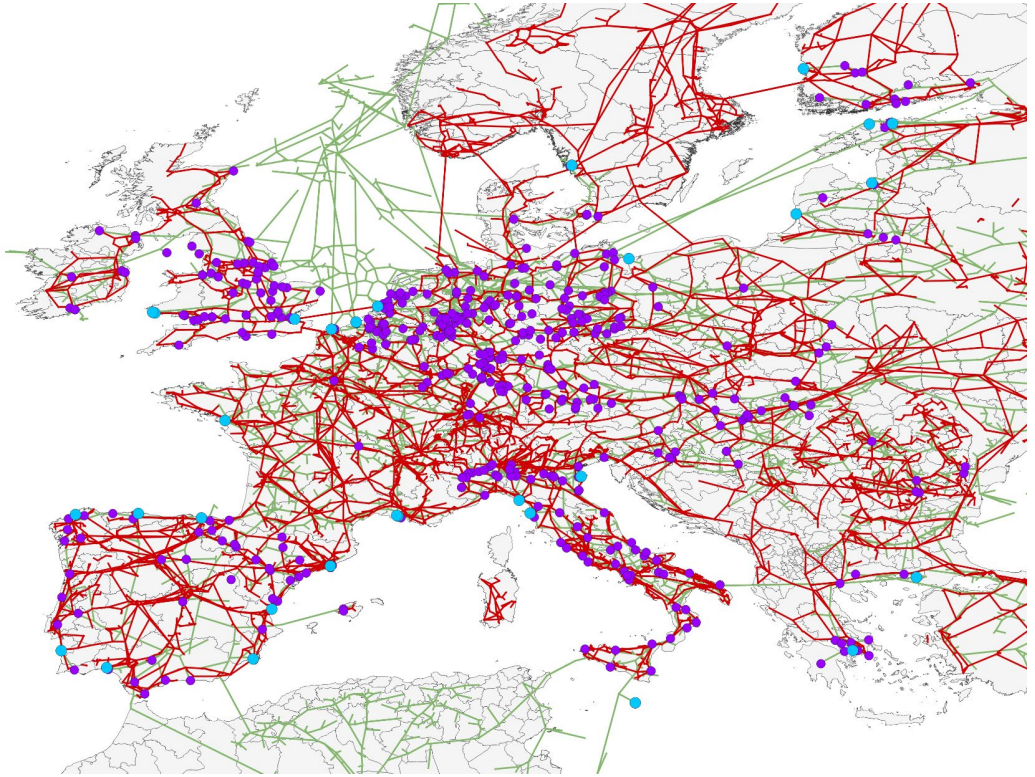
Often, there is more than one technology option

- The numerous options available are partly complementary and partly competing
- Regional power generation and grid infrastructure matters

Outlook

- Move to transformation pathway optimization
- Increase spatial detail
- Increase sectoral coverage
- Look beyond cost minimization





Contact

Dr. Hans Christian Gils,

Department of Energy Systems Analysis, Institute of Networked Energy Systems,
German Aerospace Center (DLR)

Curiestr. 4 | 70563 Stuttgart | Germany

Telefon +49 711 6862-477 | hans-christian.gils@dlr.de

This presentation is based on results of the project “Ariadne funded by the German Federal Ministry of Research and Education (BMBF) under grant number 03SFK5B0.

KOPERNIKUS PROJEKTE
Ariadne
Die Zukunft unserer Energie

SPONSORED BY THE
Federal Ministry of Education and Research

THANK YOU