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WHAT IS THE COST OF ENERGY AUTONOMY?

Assessing import independence for a multi-modal, climate-neutral European energy system

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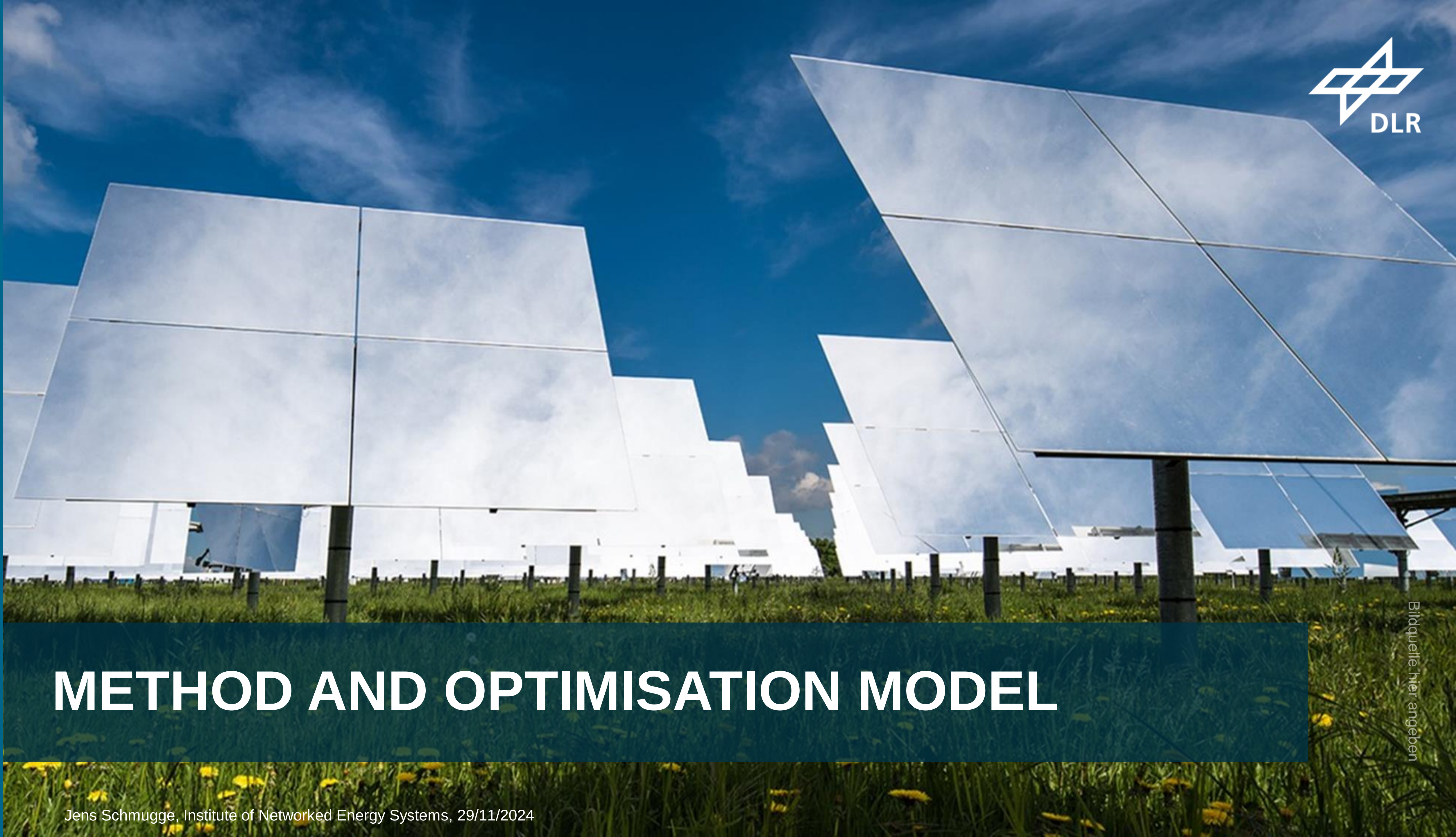
DLR

Why is it worthwhile to take the gas infrastructure into account in energy system optimisation?

- IEA, “Net Zero by 2050”: all fossil fuels are predicted to decrease in use soon
- **renewable energies pose risks to energy security** because of their volatility
- but: possible alternative (imported) **gas also risk to energy security** due to geopolitical considerations as seen in recent years

How would a future gas/H_2-import independence of Europe influence its optimal energy system?



METHOD AND OPTIMISATION MODEL

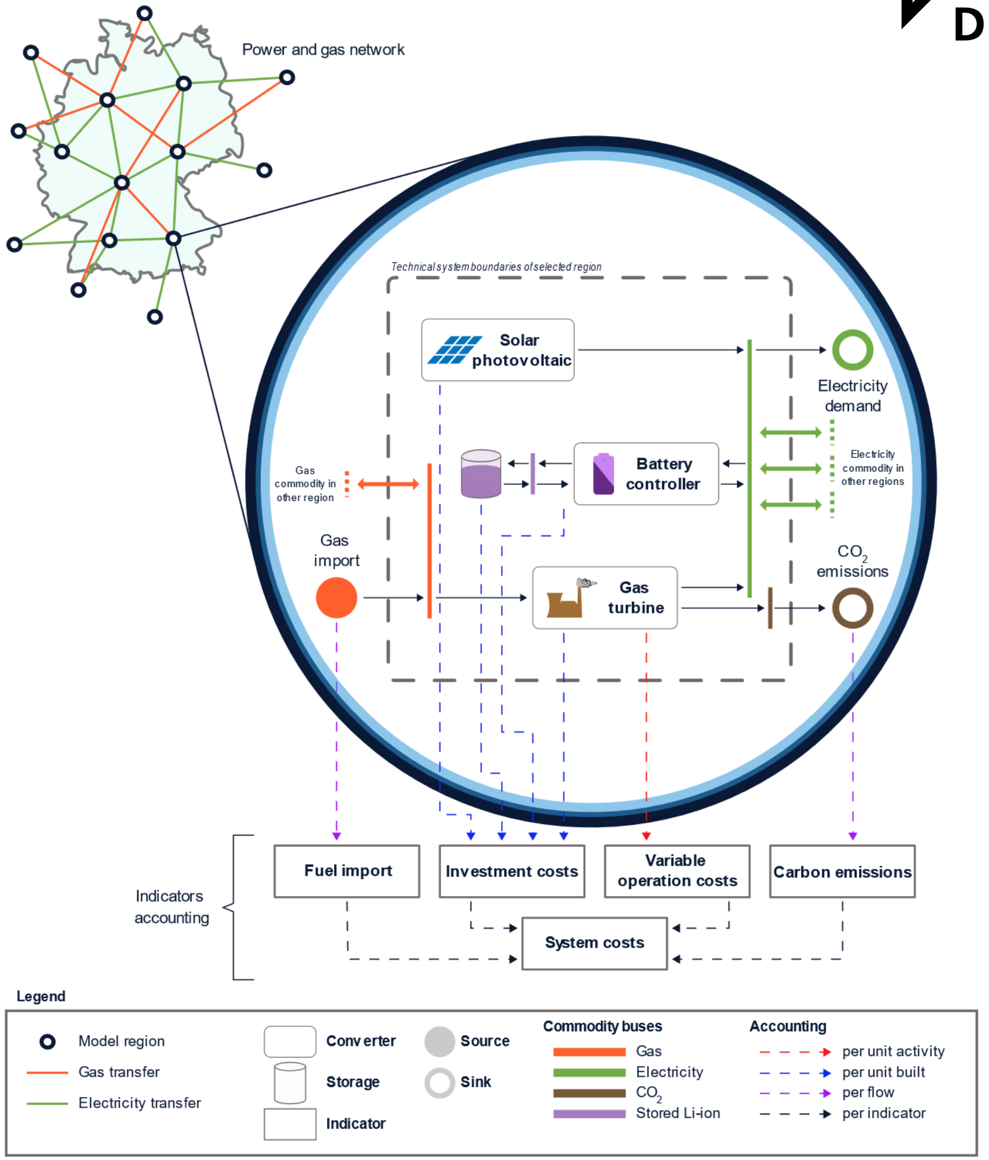
Bildquelle hier angeben

Energy system optimisation with REMix

REMix
Renewable Energy Mix

1

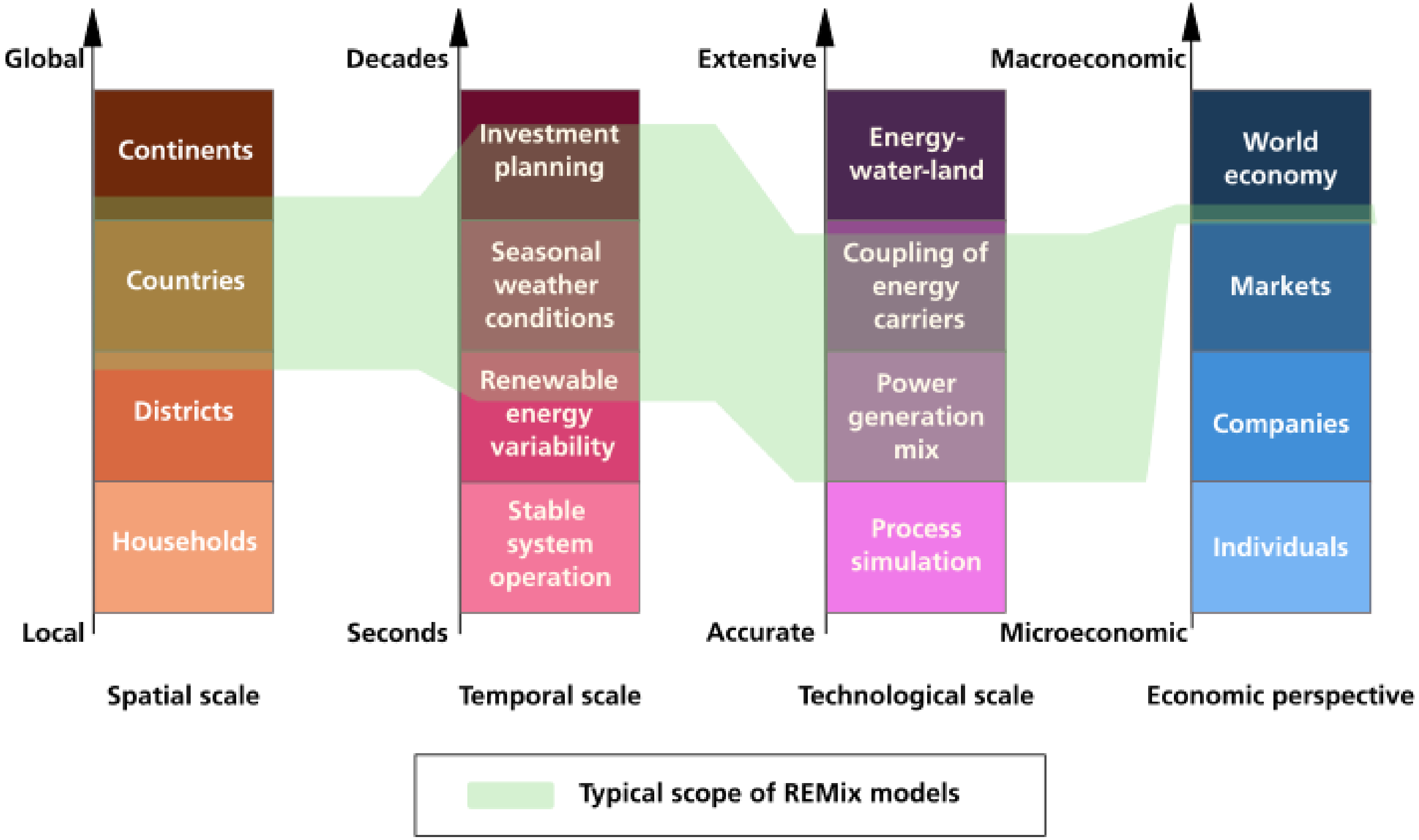
- linear cost minimisation
- REMix Renewable Energy Mix
- open-source energy system optimisation framework
- designed for modelling large-scale energy systems
- capacity expansion and dispatch of all assets
- sector-integrated models
- written in GAMS, data preprocessing with Python



REMix energy system optimisation framework[1] schema

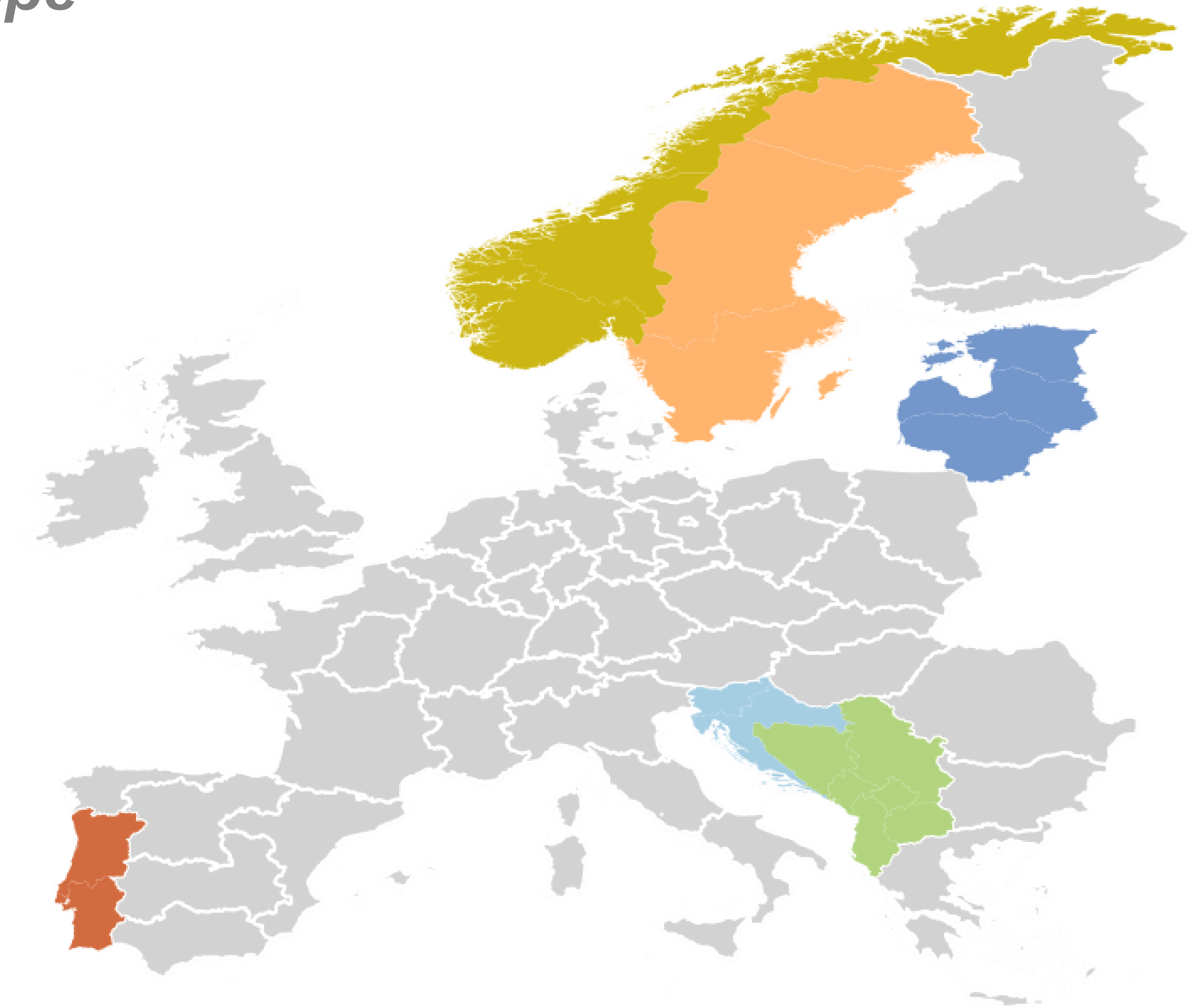
[1]REMix repository: https://gitlab.com/dlr-ve/esy/remix/framework.

Typical scope of a REMix model



Cao et al.: Bridging granularity gaps to decarbonize large-scale energy systems—the case of power system planning. *Energy Science & Engineering*, 9(8):1052–1060, May 2021. doi:10.1002/ese3.891.

The optimisation model
Spatial and temporal scope



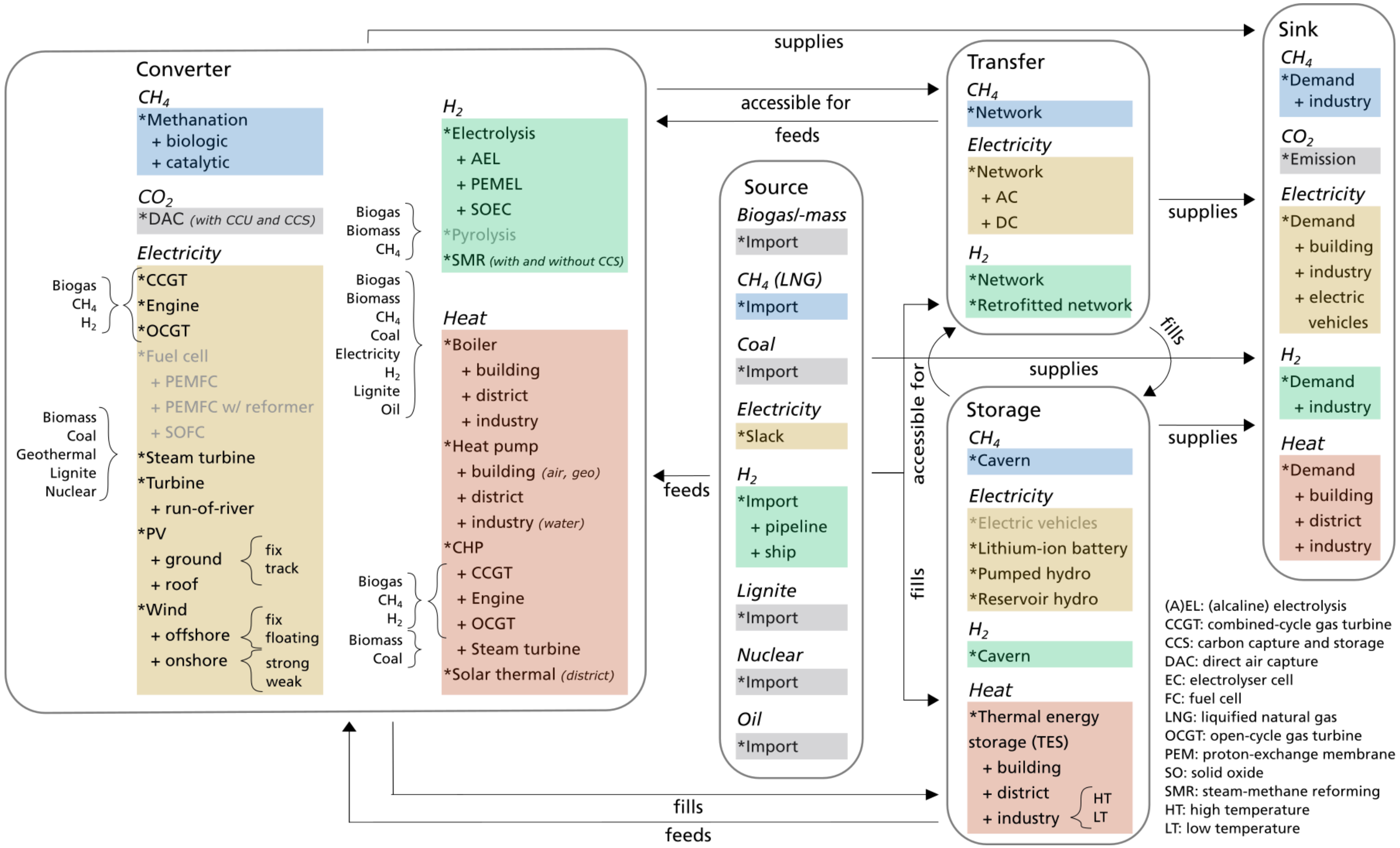
spatial

- data for Europe in 70 regions
- partially aggregated to 57 model nodes (to speed up calculations)

temporal

- optimisation of target year 2050
- hourly resolution
- weather year: 2012
- reference year for installed capacities: 2020

The optimisation model
Technological scope



- >100 technologies modelled
- power-to-X via boilers, heat pumps, electrolysis, methanation, and electric vehicles
- transfer grids for three commodities: electricity, hydrogen, methane
- ~50 heat technologies split in 17 heat groups, 7 with storage, e.g.,
  - district heat
  - industry heat
  - high/low temperature
- direct-air capture for CCU and CCS
- retrofitting of methane pipelines

The optimisation model
Scenarios

"import autonomy"

- cost of hydrogen imports between ~7.1 ct/kWh (North Africa, pipeline) and ~15.2 ct/kWh (South Africa, ship)[1]
- techno-economic data from Danish Energy Agency (DEA) technology sheets, DEA scenario "ctrl"[2,*]
- **imports not prohibited, but rather expensive**

"forced H2 imports"

- cost of hydrogen imports between ~4.2 ct/kWh (Non-EU Europe, pipeline) and ~12.6 ct/kWh (South Africa, ship)[3]
- techno-economic data changed just for for proton-exchange membrane electrolyser to value of DEA scenario "lower"[4]
- **forced import of hydrogen from region Mid East (100 TWh) and Northern Africa (200 TWh)**

[1]derived from Fraunhofer IEE, University of Kassel: *Global PtX Atlas*, https://maps.iee.fraunhofer.de/ptx-atlas/, value "Mean".
[2]Danish Energy Agency: https://ens.dk/en/our-services/technology-catalogues (April 2024).
*"ctrl" stands for "central" meaning an average value.

[3]derived from Fraunhofer IEE, University of Kassel: *Global PtX Atlas*, https://maps.iee.fraunhofer.de/ptx-atlas/, value "Min".
[4]to be consistent with that assumption in comparison with the Global PtX Atlas.

RESULTS

Energy system in 2050
Expansion of the power plant park (electricity)

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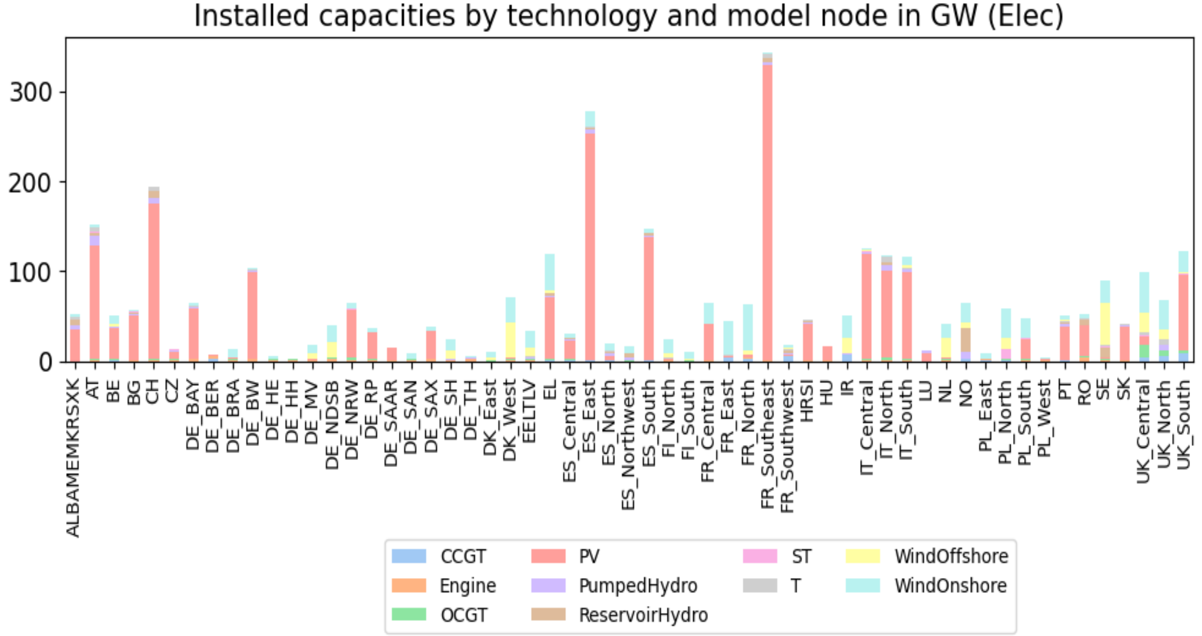
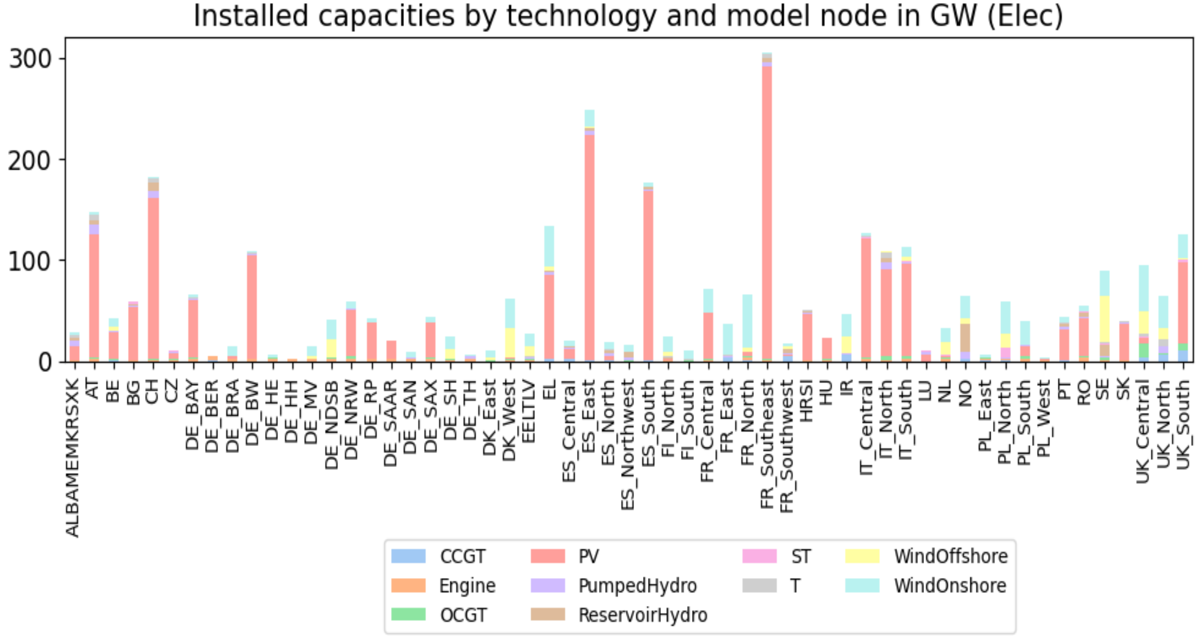
scenario: "import autonomy"



scenario: “forced H2 imports”

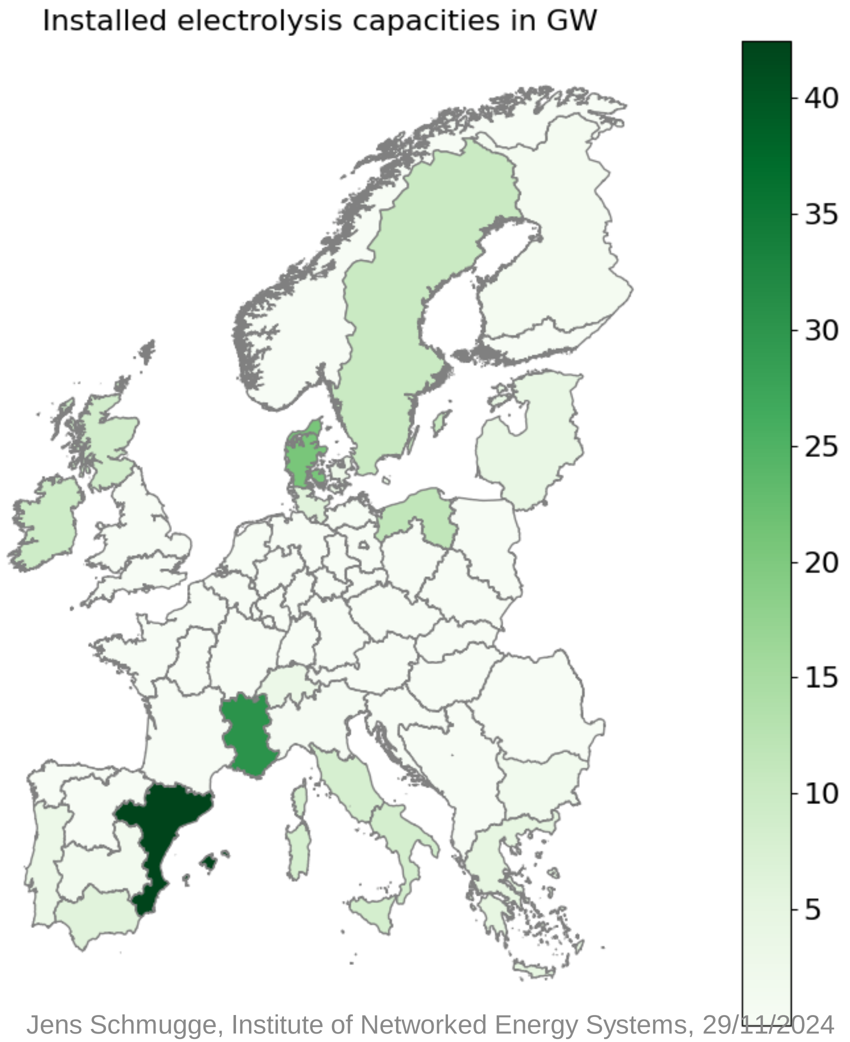


➡ renewables are dominating the system in both scenarios with solar PV having by far the largest share

➡ only slight differences between scenarios in total installed capacity and distribution of plants

Energy system in 2050
Electrolysis capacities per region

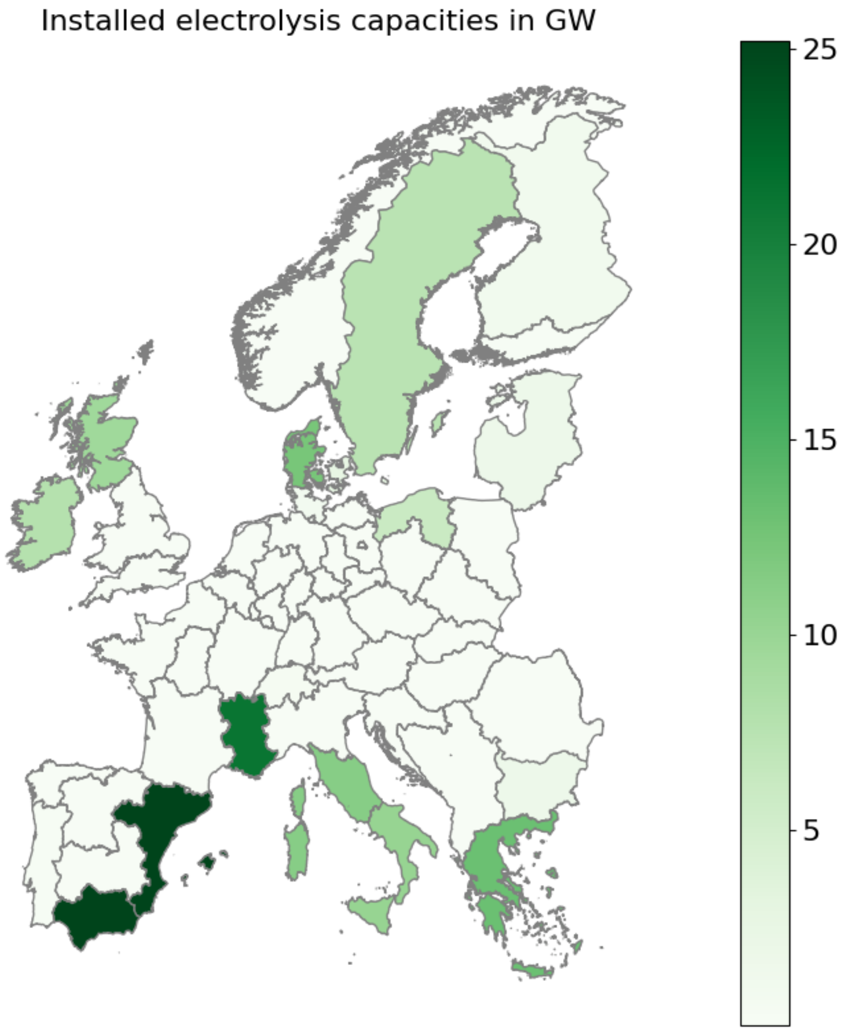
scenario: "import autonomy"



more electrolysis capacities installed in the scenario without imports

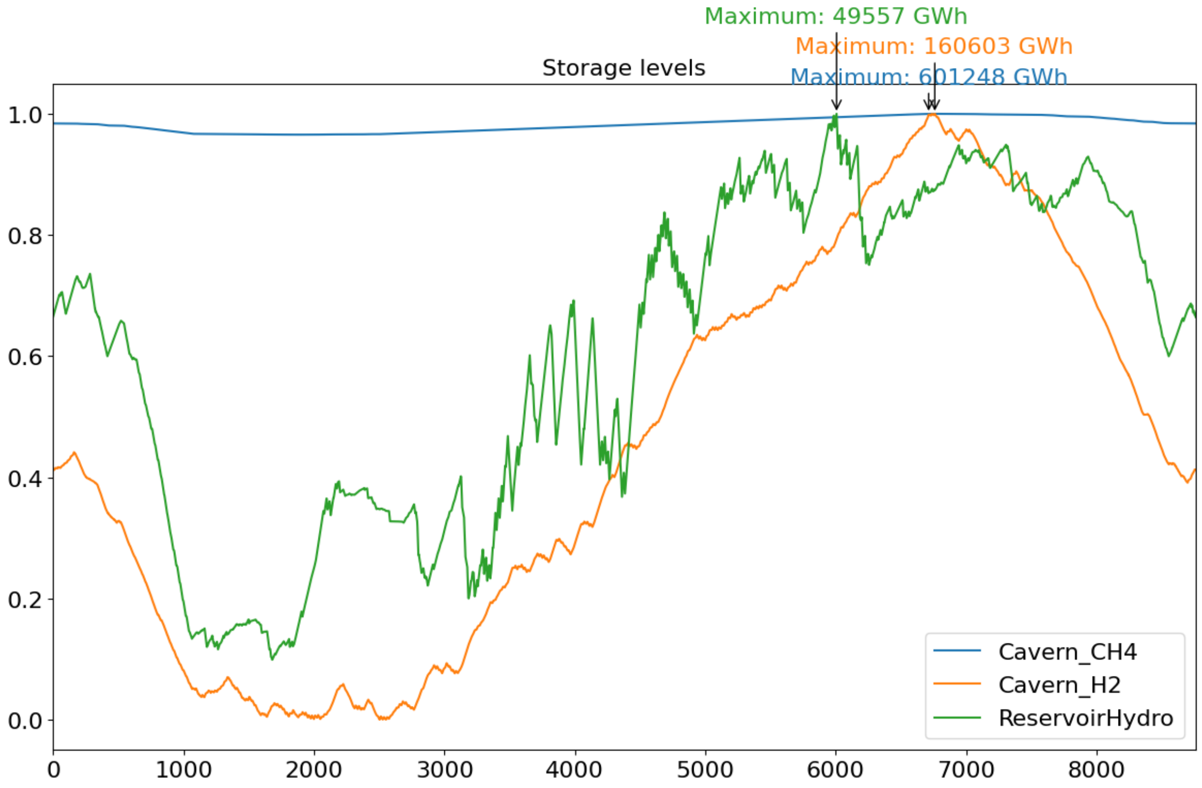
electrolysis locations slightly more diverse in case of forced hydrogen imports

scenario: “forced H2 imports”

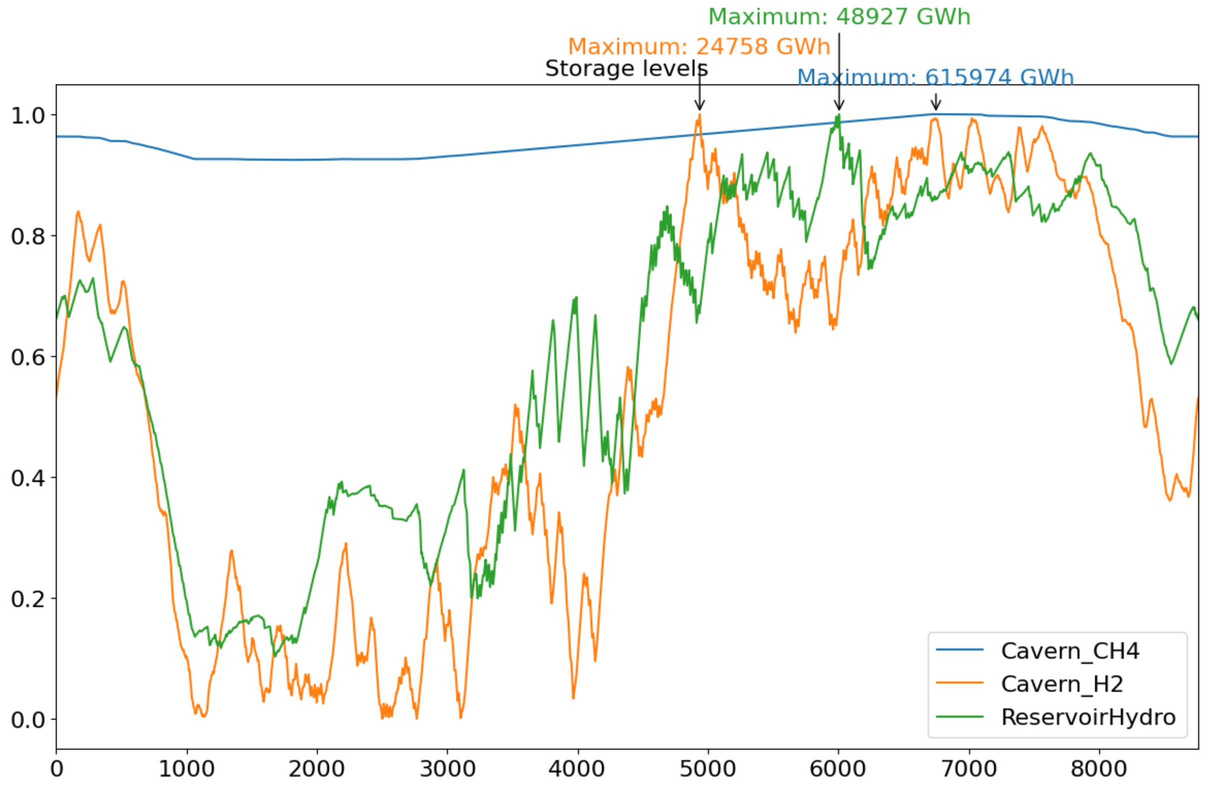


Energy system in 2050
Flexibility from seasonal energy storage

scenario: "import autonomy"



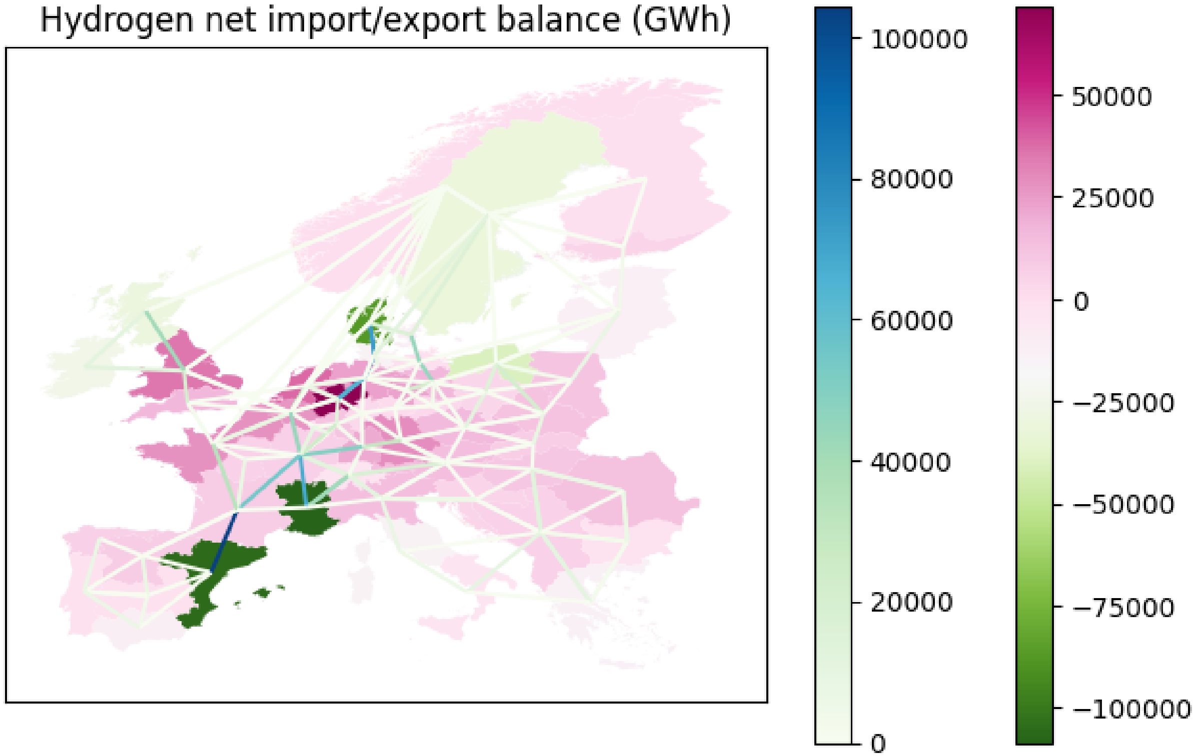
scenario: “forced H2 imports”



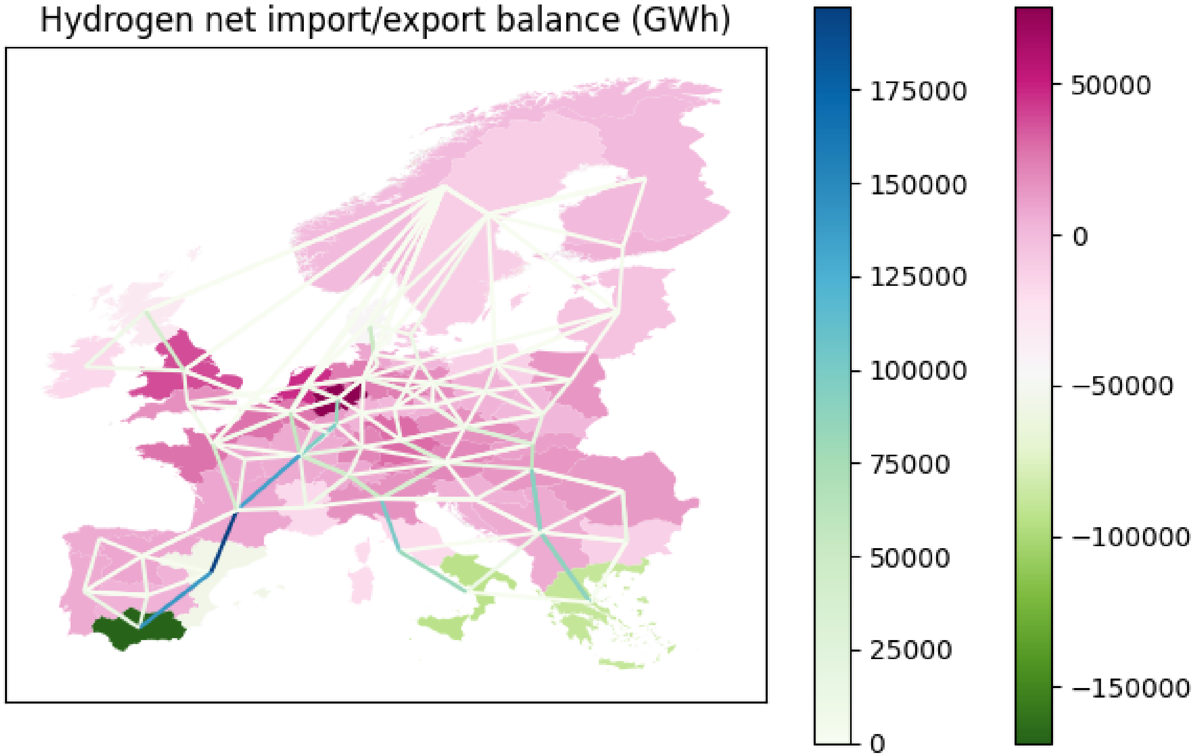
- caverns for CH_4 and H_2 as well as reservoir hydro plants act as seasonal storage in the model
- storage size differs significantly for H_2, where it is around 6.5 times smaller when H_2 imports are enforced

Energy system in 2050
Energy transfer infrastructure (hydrogen)

scenario: "import autonomy"



scenario: “forced H2 imports”



- expansion of hydrogen transfer network almost twice as big in case of forced imports
- countries of hydrogen import change and become more diverse

CONCLUSION

Photo: Heinke Meinen

Summary and conclusion

- highly resolved optimisation model of the European energy system
- investigation of two scenarios: "import autonomy" versus “forced H_2 imports”
- in both scenarios:
  - significant ramp-up of renewables
  - electrification of heat and industry
  - hydrogen production within Europe on large scale
- a significant expansion of H_2 transfer infrastructure can be observed for higher H_2 imports
- H_2 caverns, on the other hand, are built up significantly less (factor of ~6.5) if more H_2 imports are available

Conclusions and outlook

- cost of energy autonomy depends on hydrogen import costs to large degree
- with our import cost assumptions the overall system costs differ by 2 billion €
- other metrics than pure costs—like energy security—can have a decisive impact on which pathway is eventually chosen

- outlook on next steps:
  - calculate actual pathway to 2050 with support years in between (not only target year)
  - analyse additional flexibility that vehicle-to-grid technology would provide

Imprint

topic:	**What is the cost of energy autonomy?** *Assessing import independence for a multi-modal, climate-neutral European energy system*
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