A mix of long-duration hydrogen and thermal storage enables large-scale electrified heating in a renewable European energy system

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Decarbonization of electricity

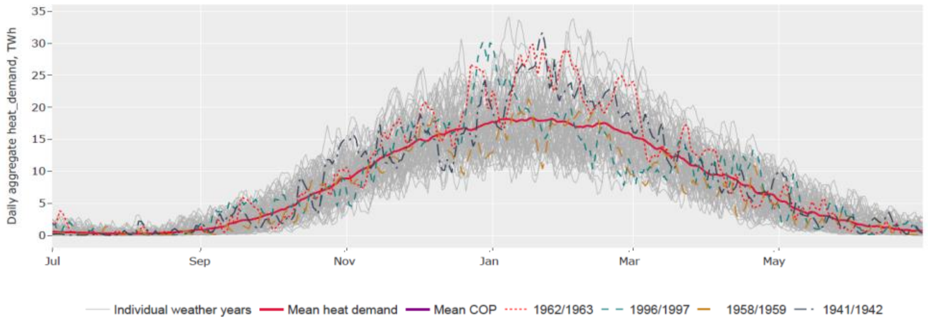
Electricity: mostly renewables (wind and solar)

- Intermittency: consequences for planning, technical, economic aspects
- Substantial amounts of long-duration storage (LDS) needed
  → H2-based storage
- Many studies taking weather variability into account

Heating: electrification

- What about its impact?

Decarbonization of heating



- **Heating demand …**
  - is substantial: e.g., in Germany ~500 TWh_{el} electricity, ~600 TWh_{th} heating
  - has a strong seasonal component
  - varies strongly from year to year
- **Electrification …**
  - will probably supply large parts of heat (limited other options available)
  - will be done mostly with **heat pumps**
- **Heating electrification interacts with the power sector through …**
  - through flexibility needs from heating sector electrification
  - interaction between variable demand-side and variable renewable supply (seasonality, kalte Dunkelflaute)
  - long-duration storage needs from heating electrification

Research questions

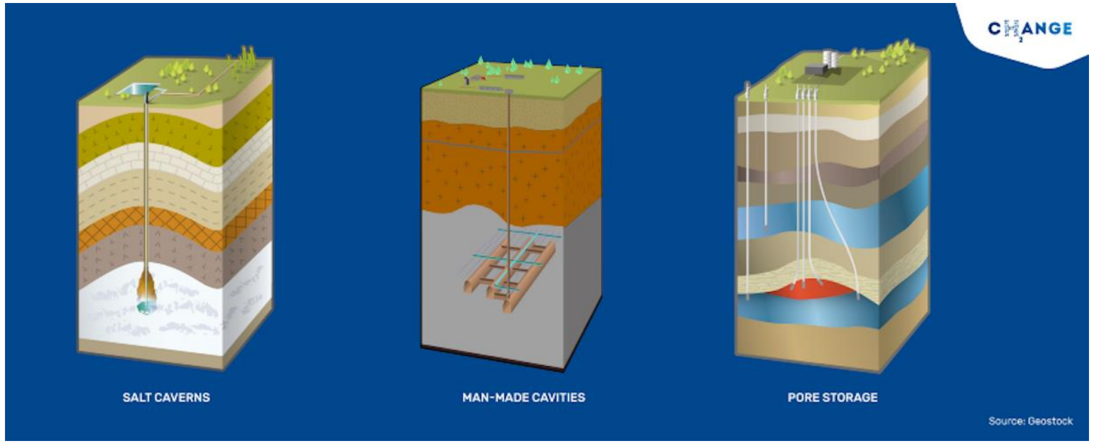
1) What is the contribution of heating to long-duration electricity storage (LDES) requirements in Europe?
   a) How large is its variance?
   b) Characteristics of specific years?
2) What is the interplay between RES availability and heat demand?
3) Which role can long-duration thermal storage play?

Methods & data

- **Model**
  - Cost-minimizing capacity expansion model, hourly resolution
  - 28-country (EU-MT-CY+CH+NO+UK) European energy system model with eelectricity and H2 interconnectors and sector-coupling
  - Year-by-year optimisation across 78 weather years
- **Setting**
  - Fully renewable 2050
  - 80% of total space and water heating demand electrified (non-industrial)
  - Decentralized (at home) and centralized heat pumps (within heating networks)
  - Four scenarios to identify drivers and interactions
- **Data**
  - Cost data from Danish Energy Agency (DEA)
  - Historical weather years from 1940 to 2018
    - Wind speeds, solar irradiation temperatures and precipitation, based on ERA-5 reanalysis
    - Converted to country-level capacity factors (Antonini et al)
    - Coefficients of performance for heat pumps using When2Heat software

Storage technologies

H2-based long-duration storage



Thermal long-duration storage

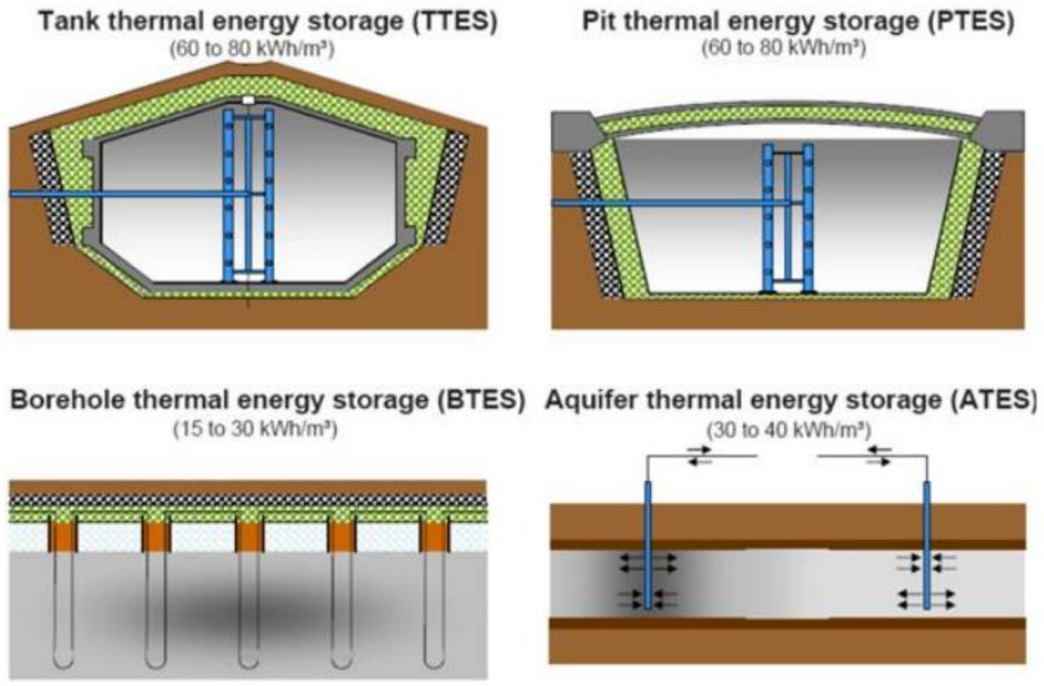


Figure 1: Concepts of thermal energy storages (Source: Steinbeis Forschungsinstitut Solites)

Scenarios

Scenario	Heat demand	LDTS	Description
No Heat			*Historical electricity demand corrected for electric heating*
Decent	Year-specific		*80% of heat demand supplied by decentralized heat pumps*
Decent - Mean	Long-run mean		*Like Decent but with mean heat demand profile*
District & Decent	Year-specific	Yes	*Like Decent but heat demand also supplied by district heating enabling LDTS*

Results

Impact of electrified heating on storage

Strong increase of average LDES

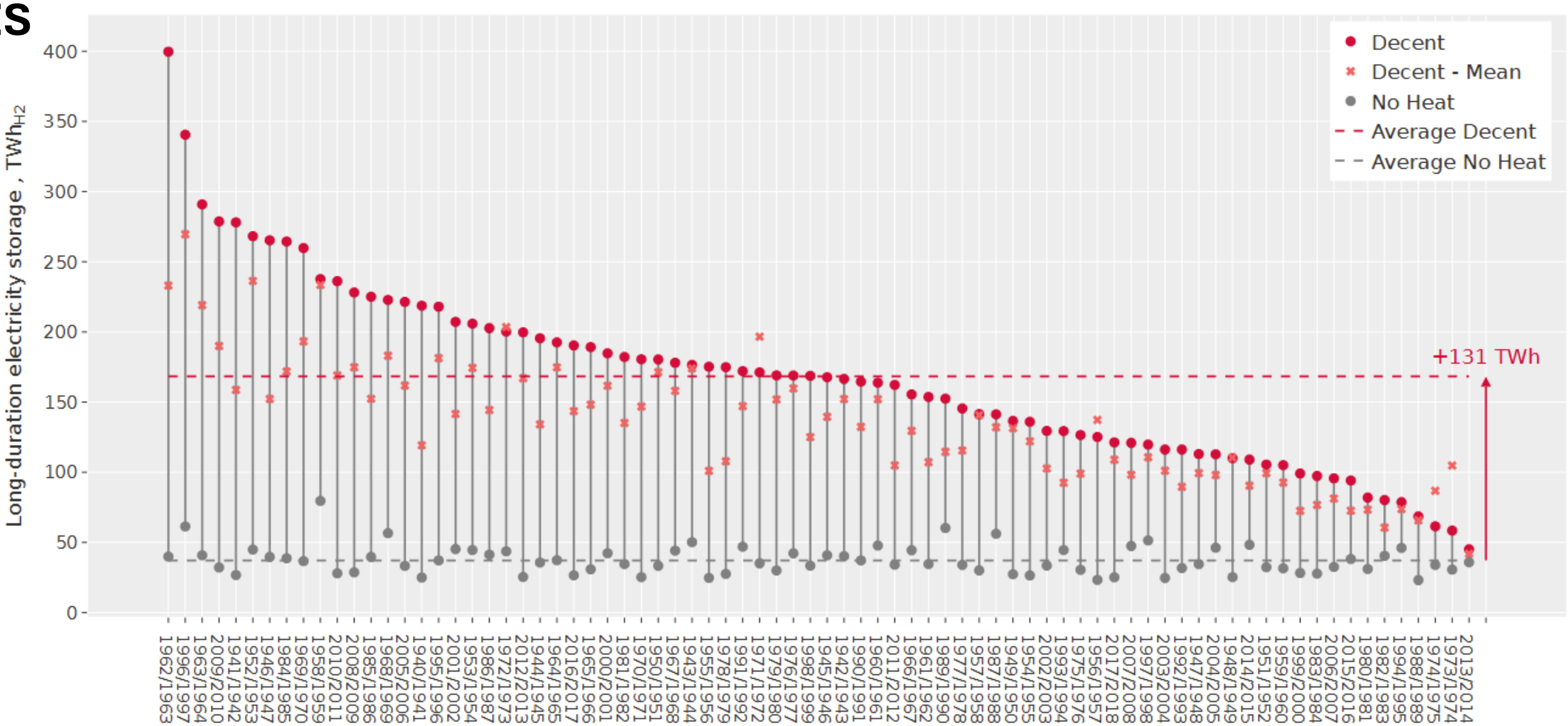
- No heat: 37 TWh
- Decent: 168 TWh
  + 131 TWh

Increase of variance

- No heat: 10 TWh
- Decent: 60 TWh

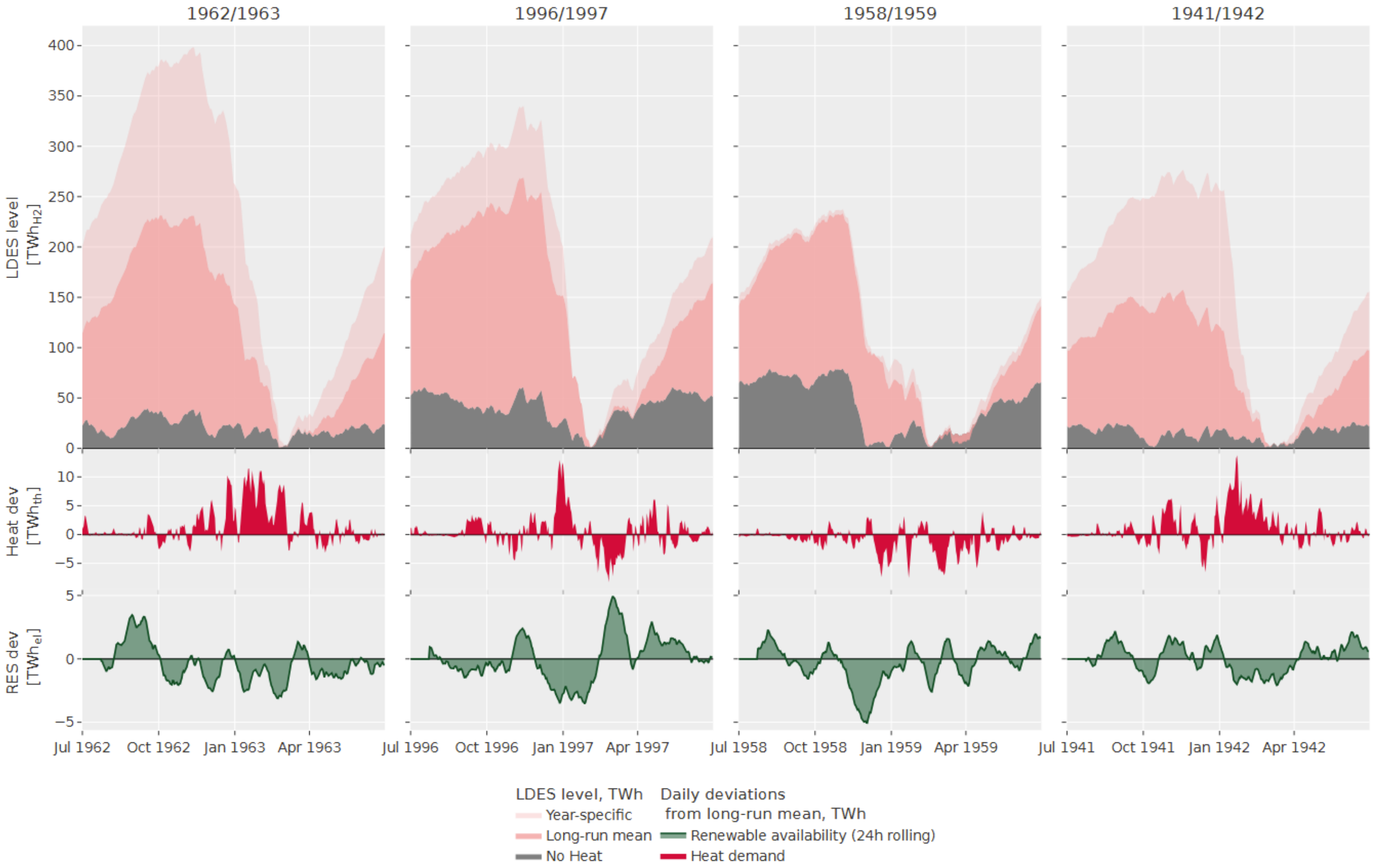
Drivers

- “Leverage effect” (additional demand in energy-scarce periods): 75%
- “Compound effect” (cold-spells coincide with energy-scare periods): 25%



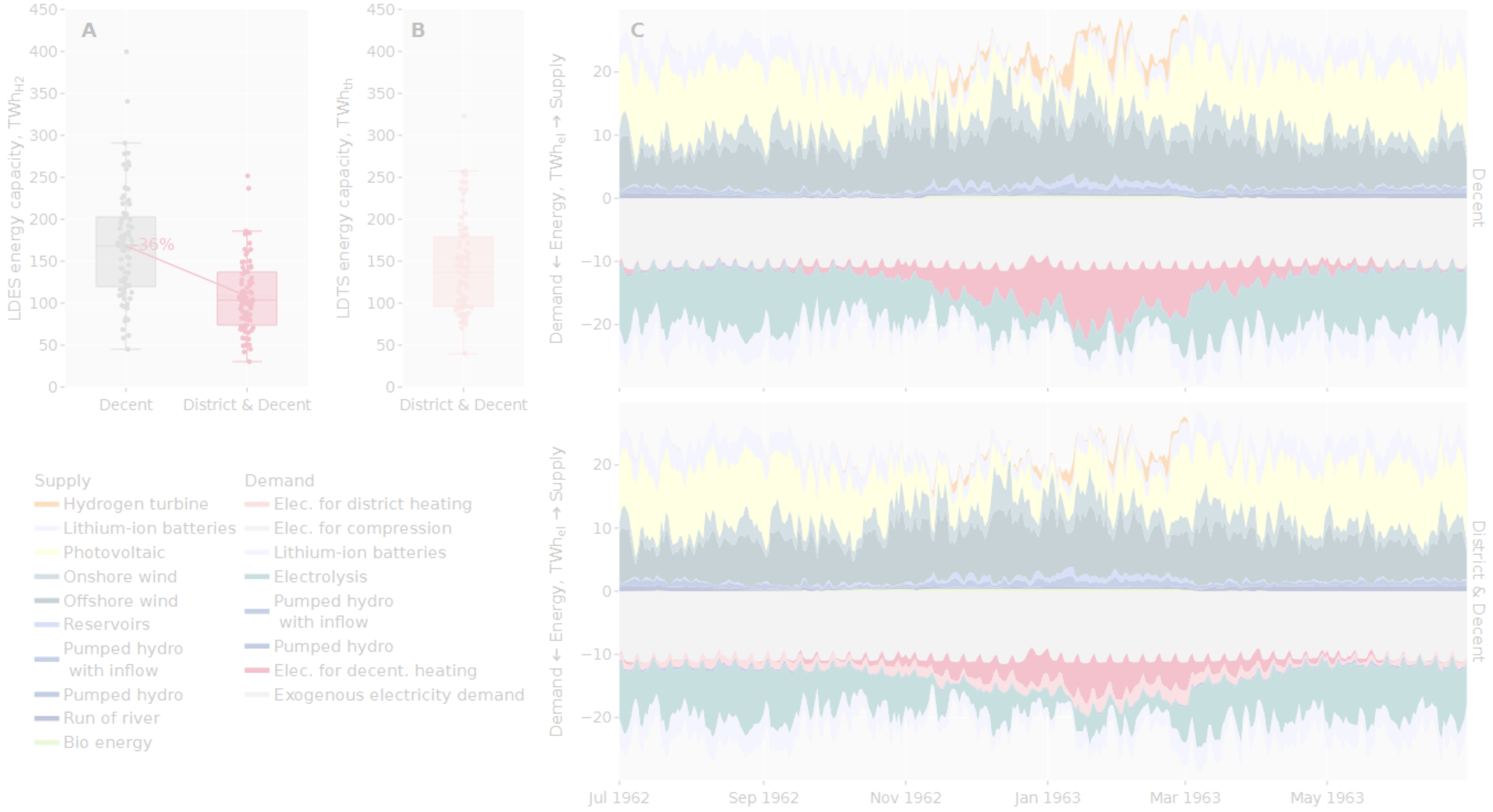
Different years

Winter	Renewables	Temperatures
1962/63	👎👎	🥶🥶🥶
1996/97	👎👎👎	🥶
1958/59	👎👎👎	😎
1941/42	👎	🥶🥶



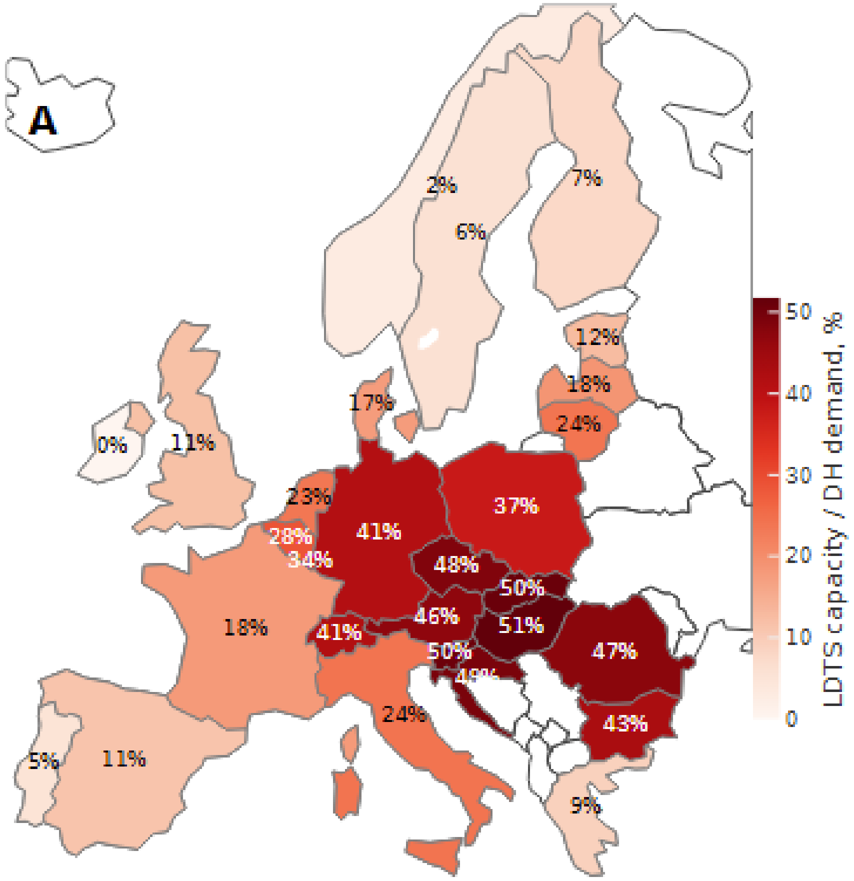
Large-scale thermal storage

- Average reduction of LDES by 36% (60 TWh) on average
- Average LDTS capacity: 143 TWh
- LDTS smooths and replaces electricity demand for heating

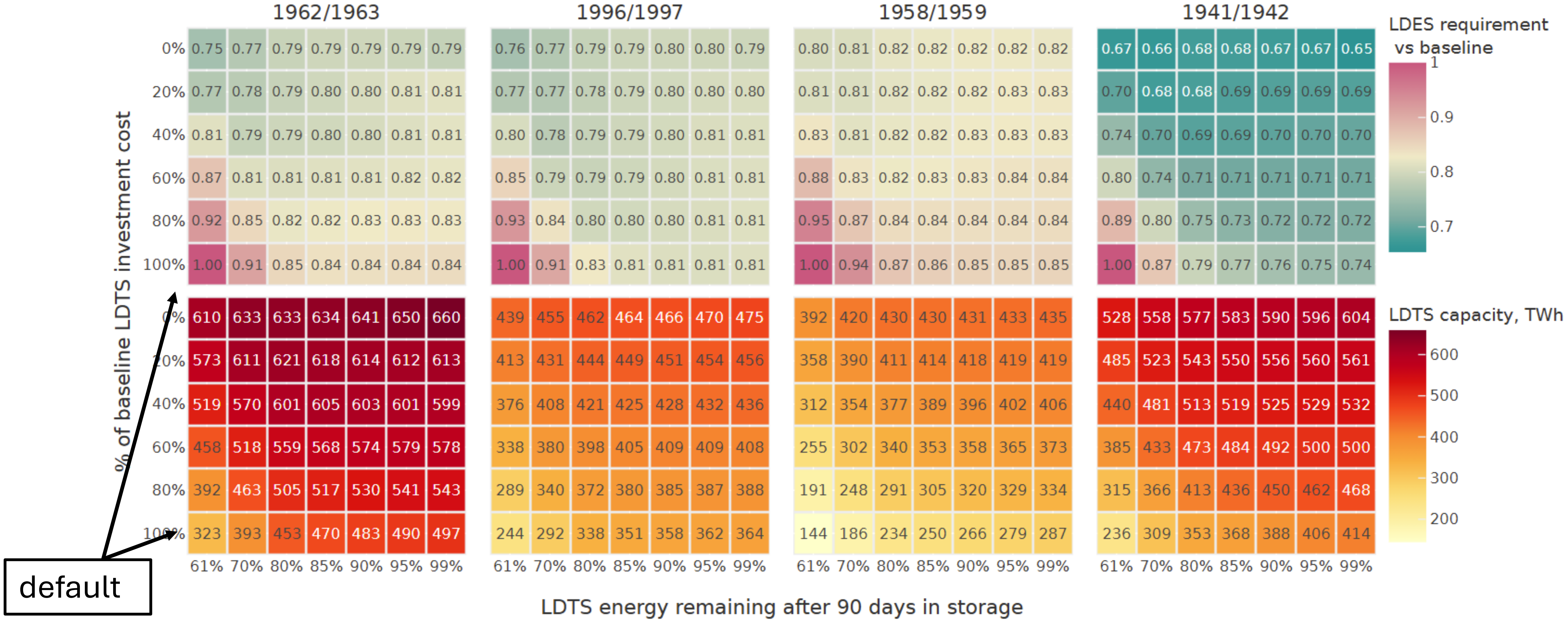


Geographical impacts

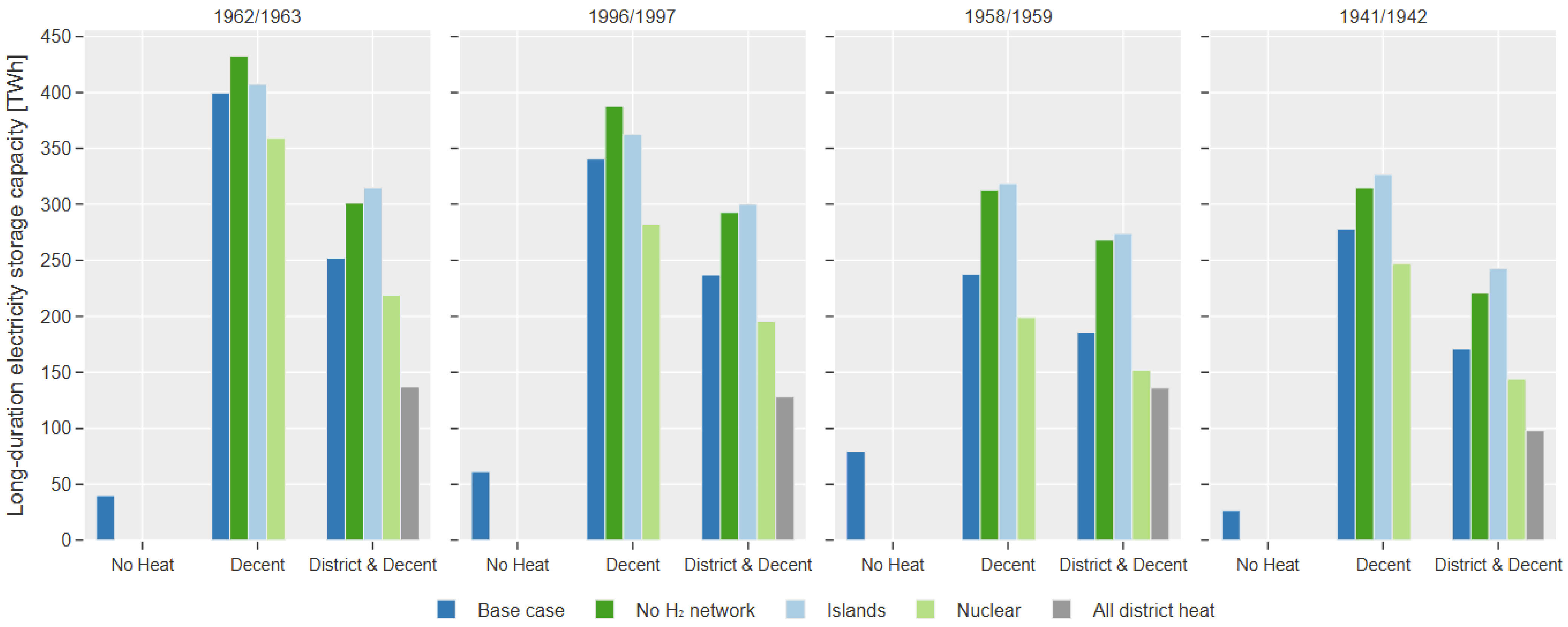
- Hydrogen-based electricity storage with limited potentials in many countries
- Long-duration thermal storage uptake especially in central-eastern Europe



Sensitivities: thermal storage



Sensitives


1962/1963
1996/1997
1958/1959
1941/1942
Long-duration electricity storage capacity [TWh]
450
400
350
300
250
200
150
100
50
0
No Heat
Decent
District & Decent
Base case
No H₂ network
Islands
Nuclear
All district heat

Conclusion

Results

- Substantial long-duration electricity storage needs from electrified heating with heat pumps (10x for 1962/63)
- Driver: 75% “leverage”, 25% “compound” effect
- Long-duration thermal storage can play an important role: it reduces electricity storage by 30%

Modelling

- Crucial aspects of weather variability
- Demand-side weather dependency
- Details of heating systems

Policy

- How to scale up needed capacities (financing, subsidies, risk)?
- Geographical role of different countries (further European integration)

Thank you!

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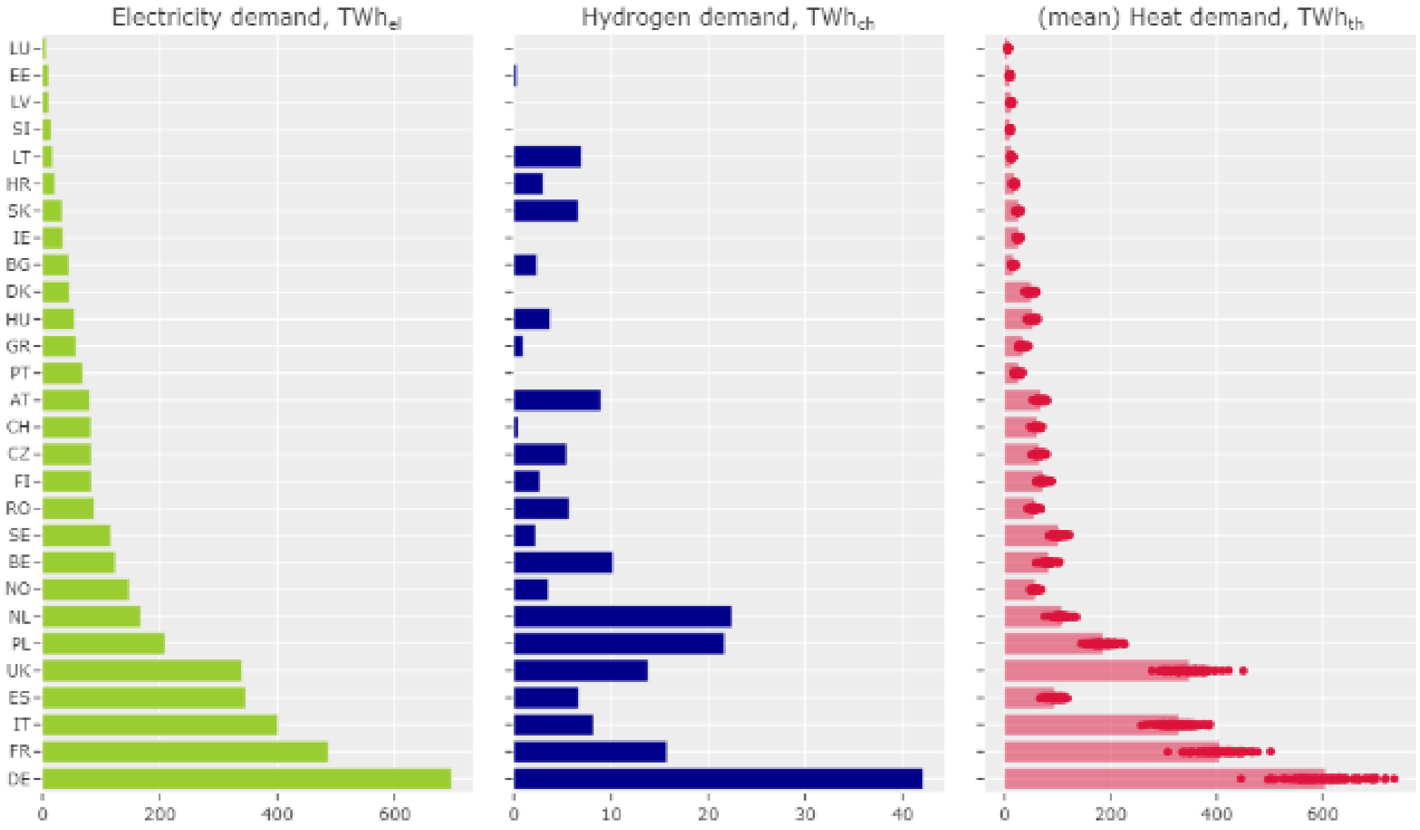
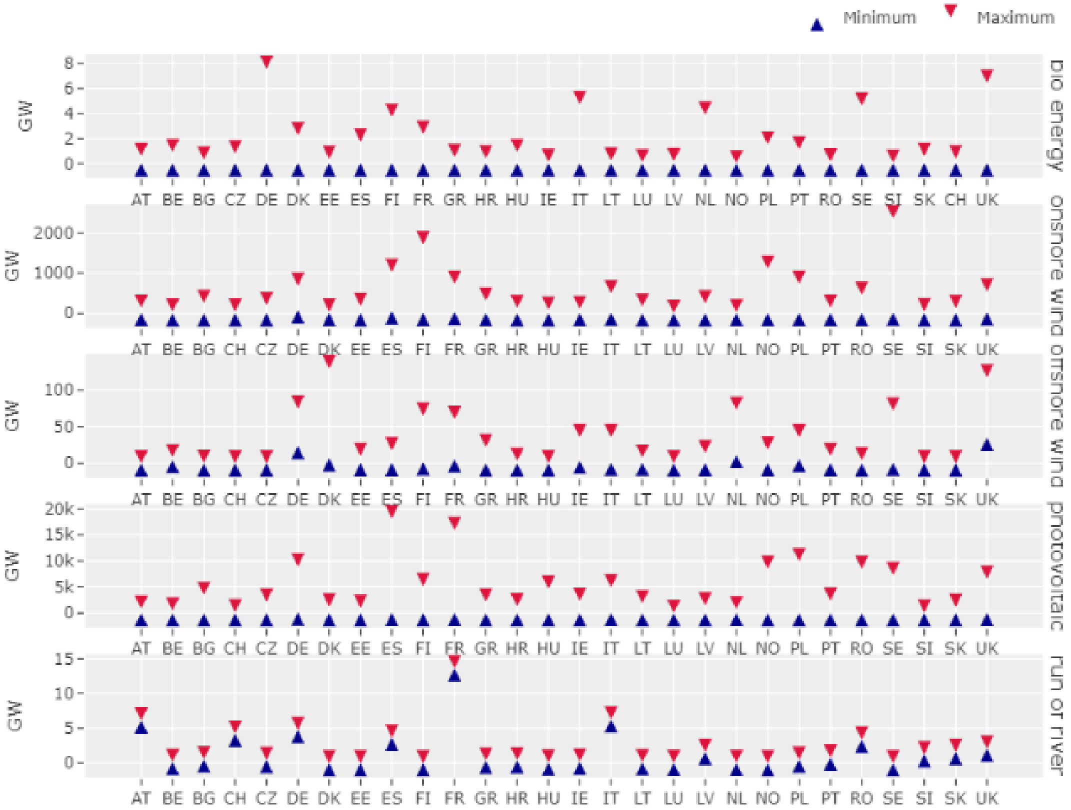
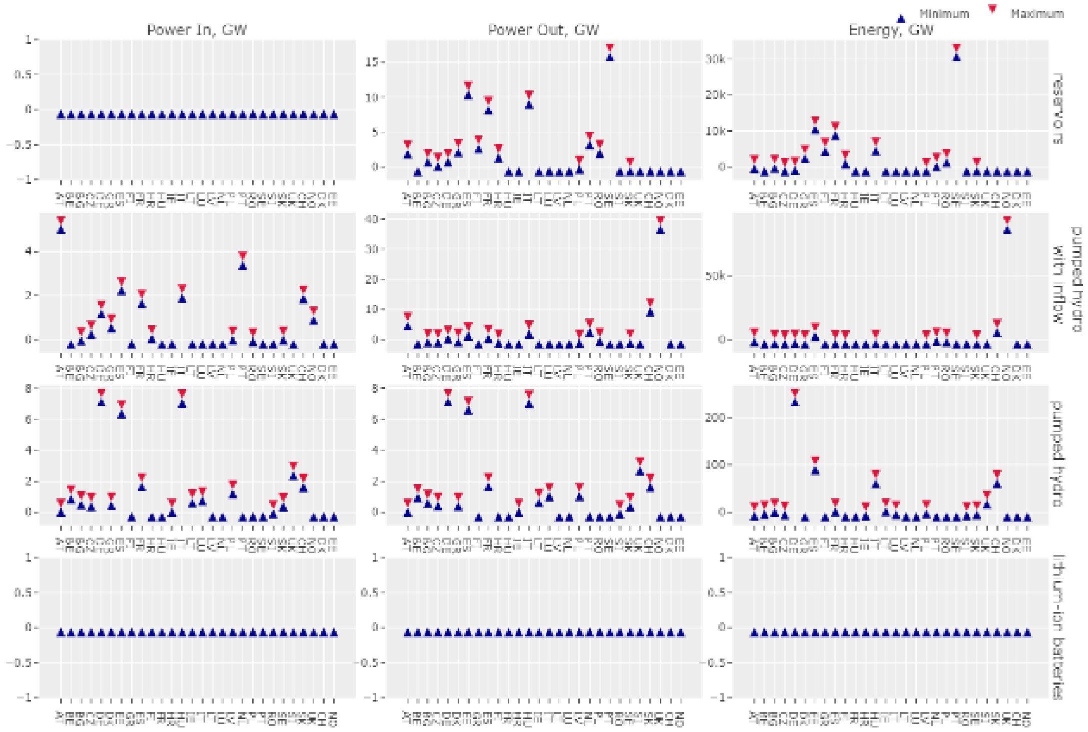
Additional material

Demand


Electricity demand, TWh$_{el}$
Hydrogen demand, TWh$_{ch}$
(mean) Heat demand, TWh$_{th}$
LU
EE
LV
SI
LT
HR
SK
IE
BG
DK
HU
GR
PT
AT
CH
CZ
FI
RO
SE
BE
NO
NL
PL
UK
ES
IT
FR
DE
0
200
400
600
0
10
20
30
40
0
200
400
600

Capacity bounds



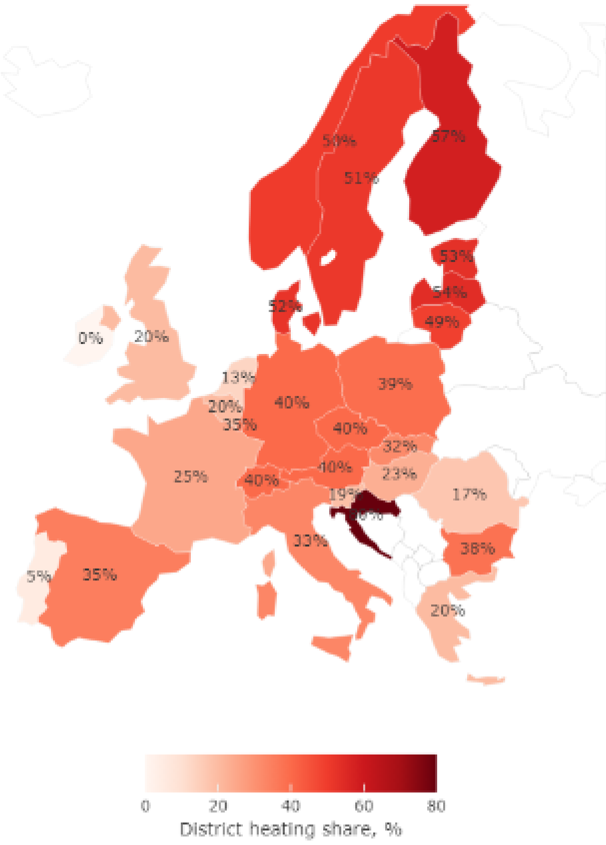


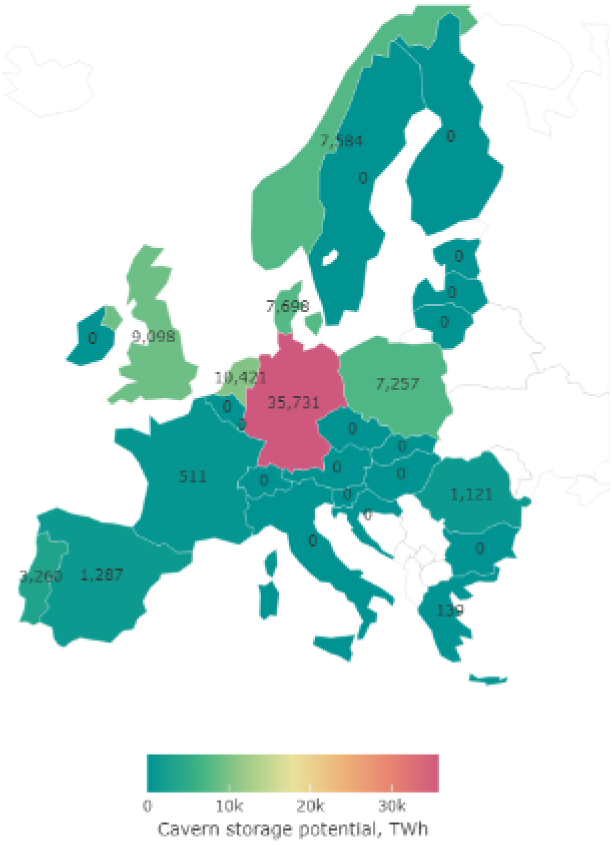
Grids

Electricity grid

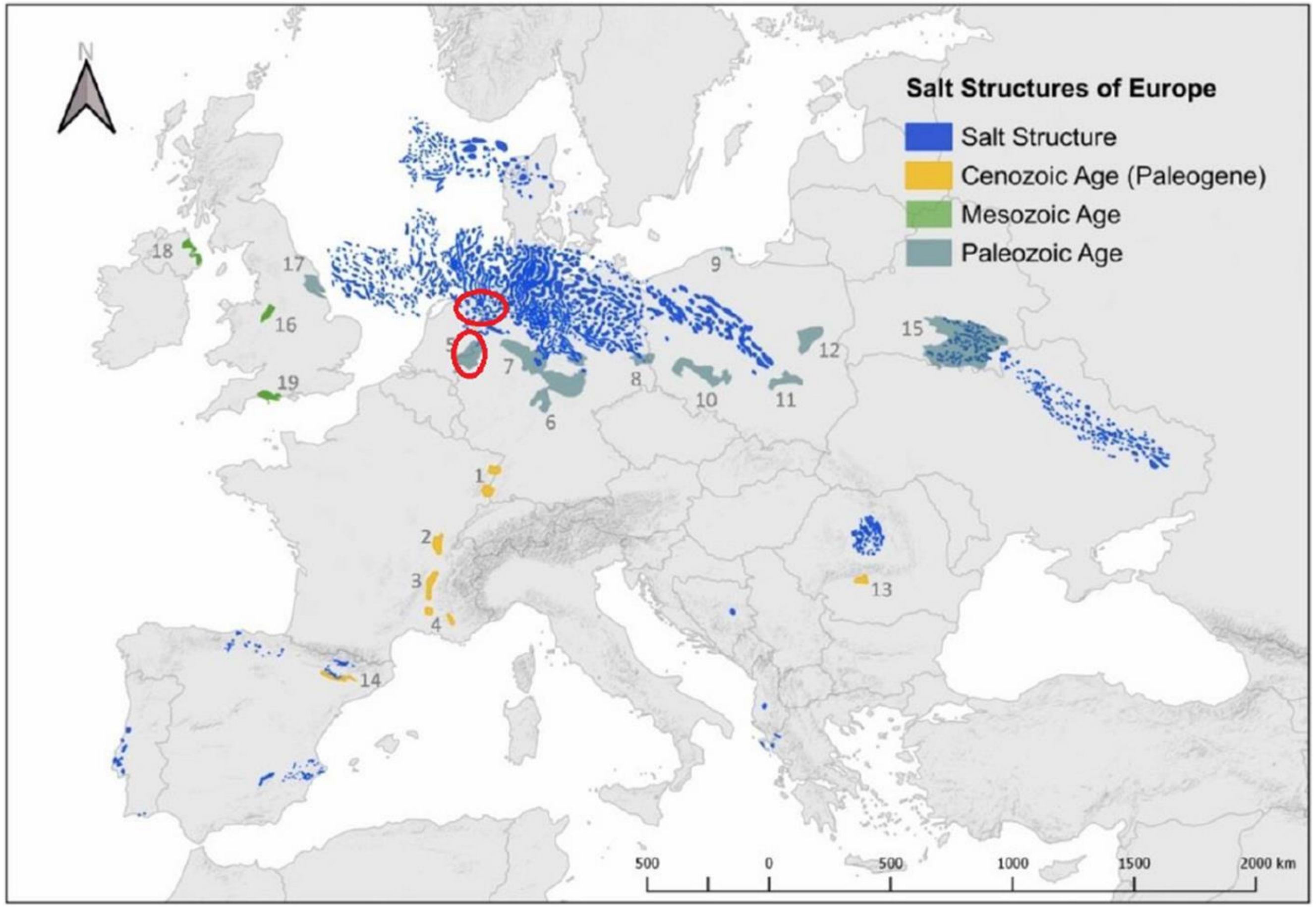
Hydrogen grid

Heating assumptions





Potentials for H2 salt caverns



Kumar et al. (2021)

Country results