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Interactions of flexibility demand and flexibility provision in a multi-coupled energy system

Impact on optimal capacity expansions

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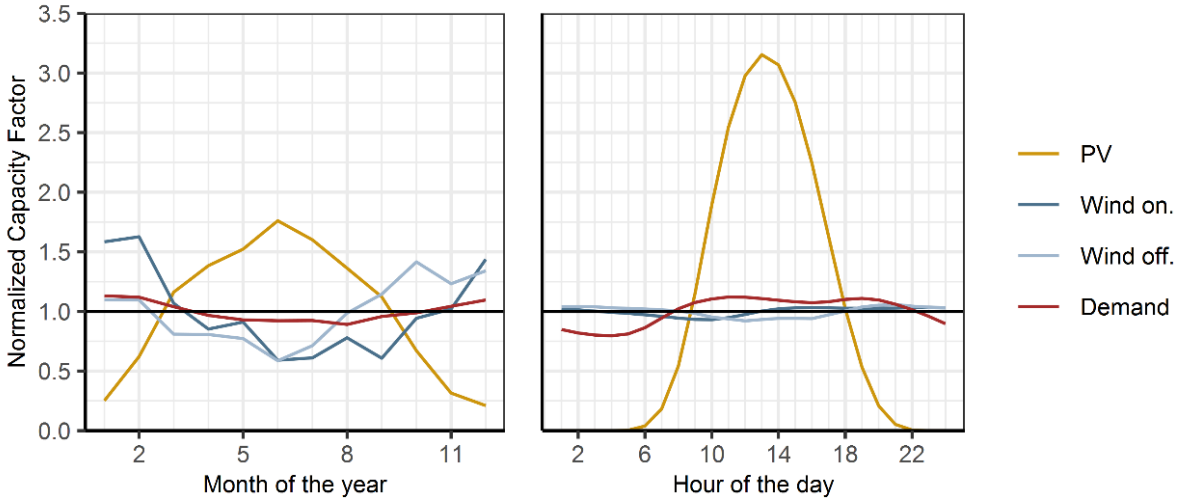
Agenda

1. Electricity generation characteristics of PV and Wind
2. High RES scenarios with different wind-PV ratios in central western Europe
3. Model approach including different flexibility options and sector coupling technologies
4. Optimal capacity expansion for selected PtX and shifting technologies
5. Summary

Future European renewable energy expansion mainly based on fluctuating renewable energy sources



vRES-technology	Mean hourly correlation	Mean seasonal correlation
PV	0,78	0,98
Wind onshore	0,25	0,72
Wind offshore	0,29	0,75

Data: EMHIRES Dataset; Meteorological data for 30 years across EU-28 and neighbouring countries

Differences in the electricity generation characteristics for wind and PV

- **Availability**
- **Temporal**
  - PV is correlating daily with demand
  - Wind is correlating seasonally with electricity demand
- **Spatial**
  - Day-night dependency of PV generation results in high spatial correlation
  - Stronger local variability of wind generation leads to spatial balancing effects

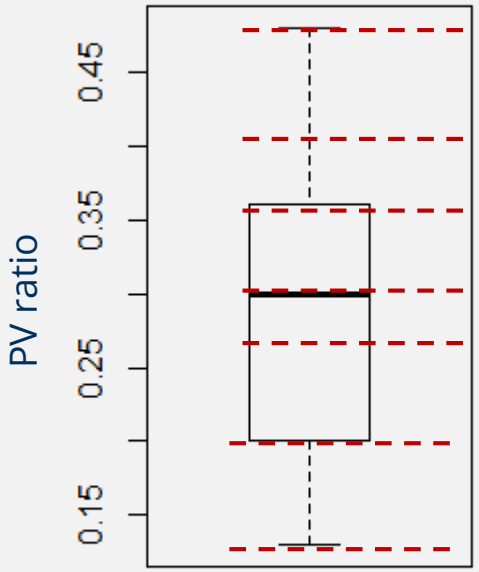
⇨ Additionally, future RES expansion not only driven by techno-economical factors, but also by challenges regarding land use and acceptance

Varying future PV ratios in literature as basis for scenario development

Studies included with

- Europe as observed region
- Scenarios for the years beyond 2030
- Data for installed capacities or generation

PV share in RES generation mix



TYNDP Scenario DG 2040

Roadmap 2050

Greenpeace Revolution Scenario (100 % RES)

EU Reference Scenario 2050

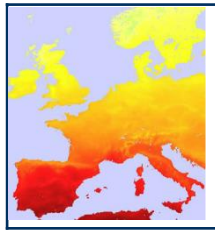
Europe 2017 (EEA (2017))

BMWi long-term scenarios, Base scenario 2050

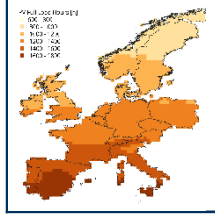
Eurelectric Power Choices, Scenario 2050

Scenario	PV-Wind ratio
High PV	50:50
REF	30:70
High Wind	10:90

Weather- and GIS-Data based optimal wind and PV expansion achieving shares of 80% of today's electricity demand in CWE



MERRA 2 weather data for
- Solar radiation & temperature
- Wind speed and roughness



Transformation in PV and wind electricity generation time series

GIS based restriction of raster areas
- Nature reserve
- Height and slope
+ urban areas and meadows

Land use potentials for wind and PV

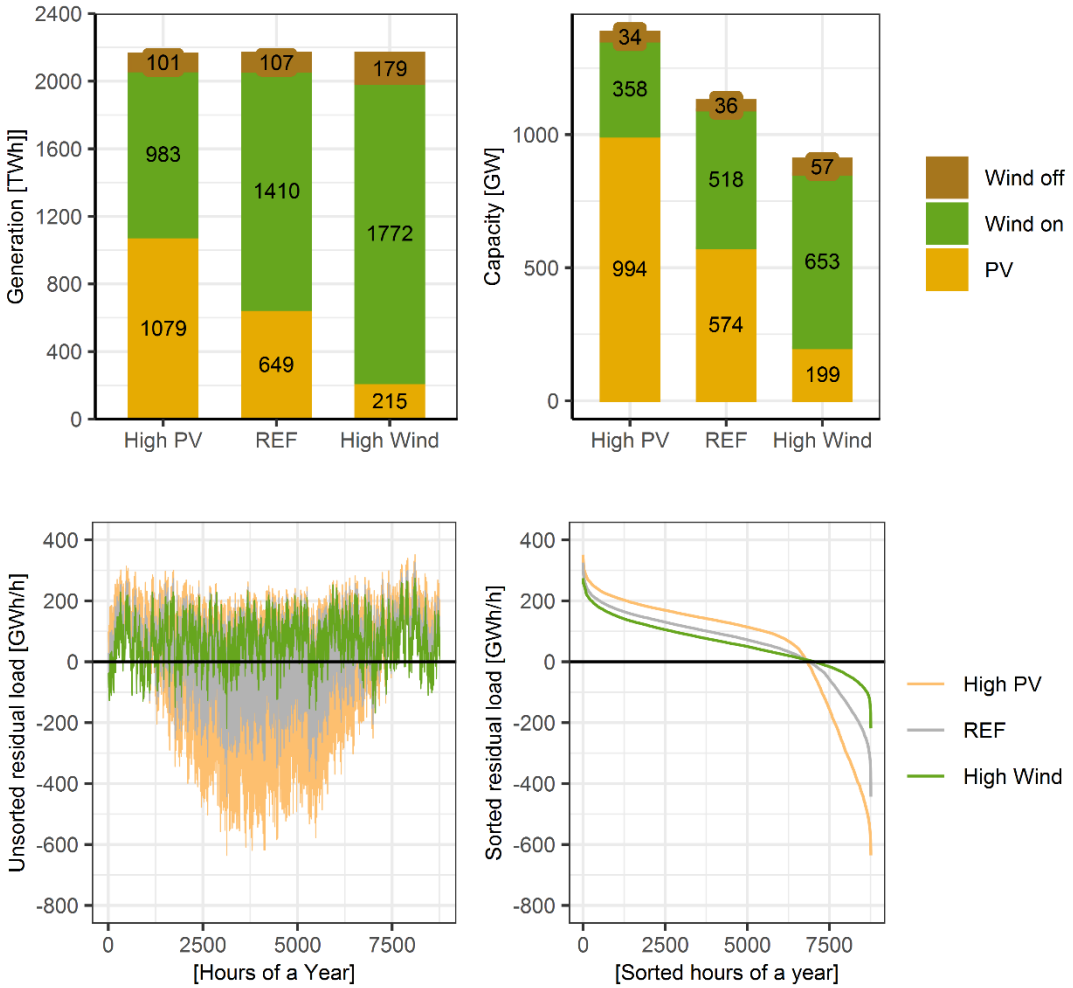
RES potentials for 17 countries (1481 raster à 0,5 ° x 0,625 ° / 68 x 68 km)

Optimal wind onshore and PV expansion for each of the scenarios and countries

Objective: Minimizing specific investment costs

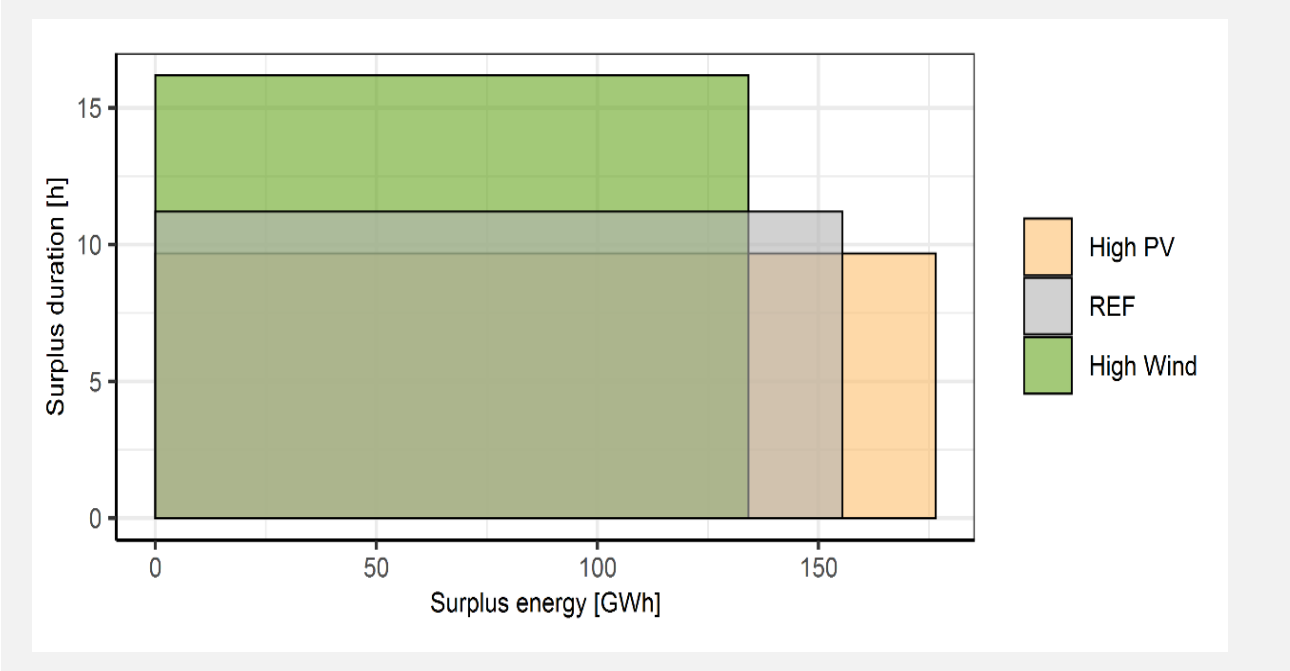
Restrictions:
- Wind and PV share of 80% of today's CWE electricity demand (~ 2,700 TWh)
- Restriction of land use
- Country specific minimal and maximal RES expansion

Resulting overall RES installations and flexibility needs



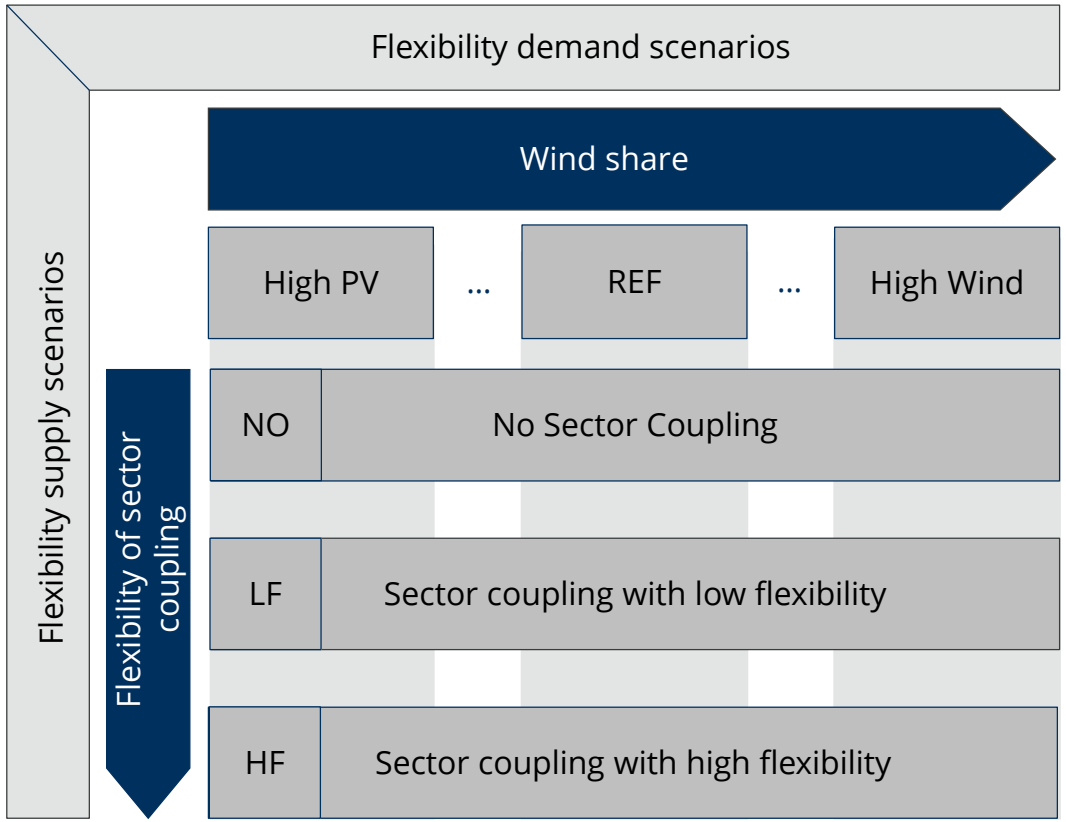
- More than 1000 GW fluctuating RES in each scenario
- Lower availability of PV results in higher capacity requirements
- Small differences in positive residual load peak
- With increasing PV share increasing amount of surplus energy and negative peaks
- Southern countries with very high surplus peaks during the summer days

Average power and duration of surplus across all 17 countries



- Higher PV ratios result in shorter but larger surplus periods due to day-dependency and simultaneity of PV generation
  - In *High PV scenario* on average + 16 % surplus energy compared to *High Wind scenario*
  - In *High PV scenario* on average - 40 % surplus duration compared to *High Wind scenario*

Sector coupling as additional dimension in the scenario framework



- **Flexibility demand scenarios** with different Wind-PV ratios
- **Flexibility supply scenarios** for optimal combinations of flexibility options considering selected PtX technologies
- **Enforced sector coupling**: minimum restriction to cover 50 % of energy demand in each sector by electricity
- **Flexibility of sector coupling:** low flexibility (LF) without additional energy storages vs. high flexibility (HF) with energy storages

Model based analysis of optimal combinations of flexibility options

Input

Infrastructure

- 17 countries
- Technology specific power plant characteristics
- 3 storage types, 6 DSM processes
- Heat pumps, E-vehicles, electrolyser
- European transmission capacities (NTC)

Supply Side

- RES capacity and generation profiles per country
- Prices for fuel und emission
- Costs of flexibility options

Demand Side

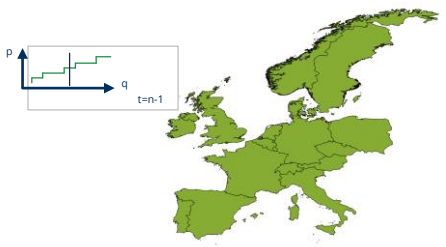
- 4 hourly demand profiles per country
- Electricity demand (ENTSO-E 2018)
- Temperature dependent district heat demand profiles
- Charging and parking profiles for e-vehicles per country
- Constant industrial hydrogen demand

Modelling

Electricity market model (ELTRAMOD)

Endogenous Investment
(Greenfield)

Objective:
Cost minimization of investments and dispatch
Temporal resolution:
Hourly resolution for an entire year



Bottom-up electricity market model

Simplified representation of selected energy demand sectors

Assumed CO_2-Price: 80 EUR/t

Output

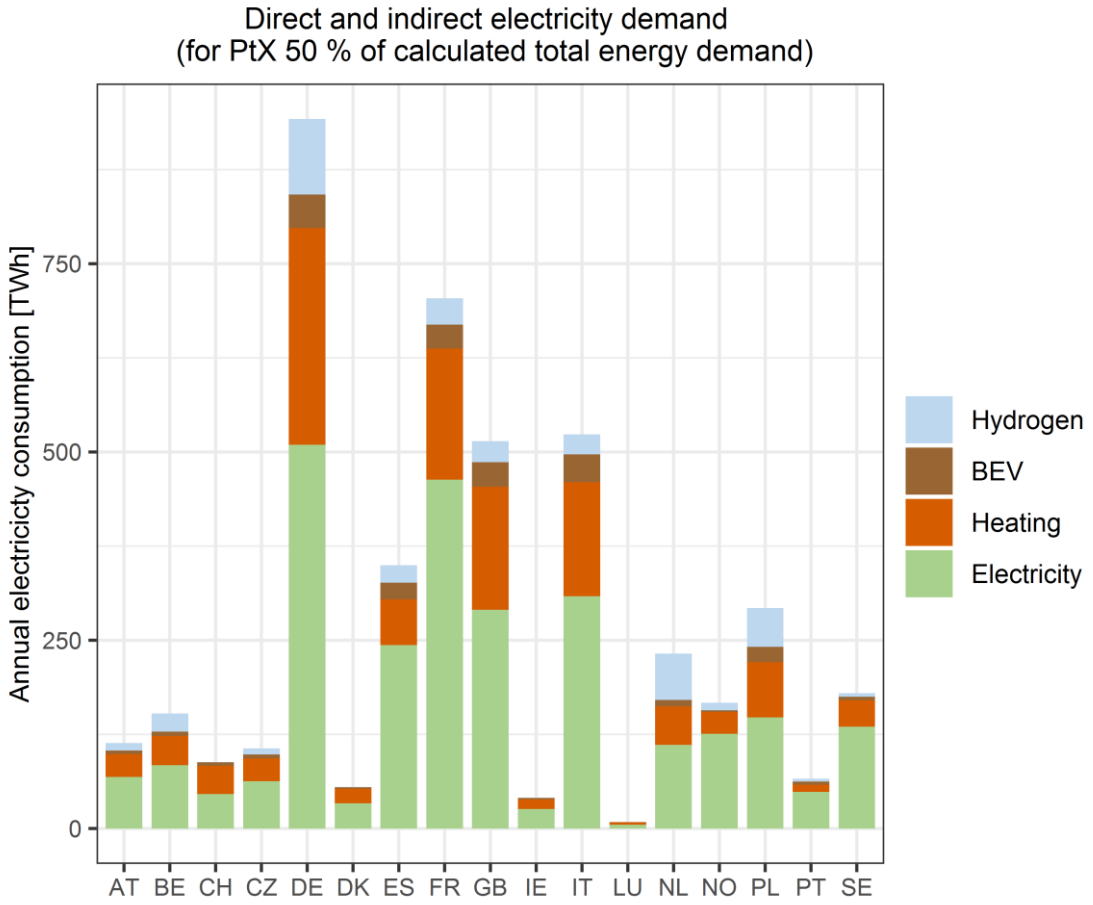
- Installed conventional and renewable capacities
- Installed storage and DSM capacities
- NTC-expansion
- Investment in Power-to-X technologies
- Investment costs

Optimal flexibility mix in an electricity market perspective

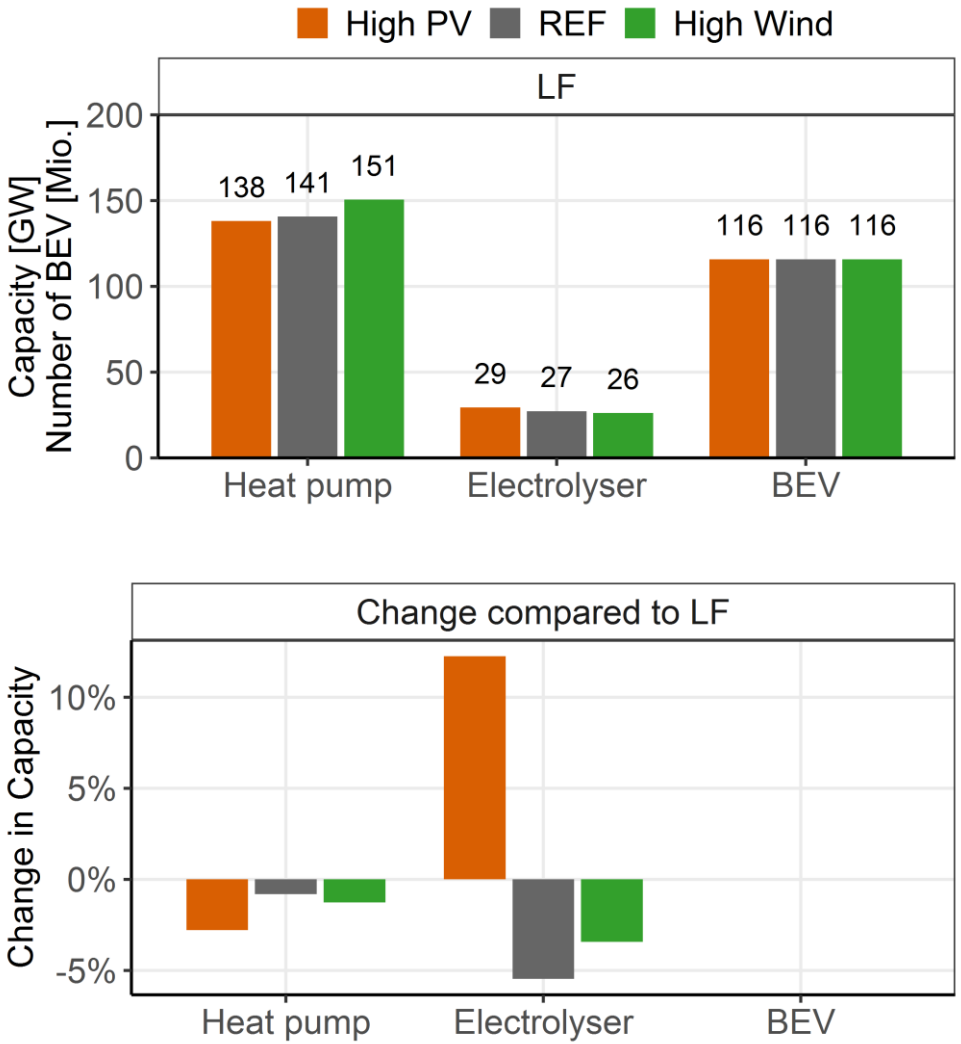
- Technology specific dispatch Export-Import flows
- Integrated/curtailed RES
- CO_2-emissions
- Dispatch costs

Assumed enforced electrification of energy demand sectors due to decarbonisation targets

	Power-to-Heat	Power-to-Vehicle	Power-to-Gas
Selected applications	• Heat supply by heat pumps to cover **50% of district heat demand** • Total additional electricity demand: 242 TWh	• **50 % BEV for passenger transport** • Charging power: 11 kW • Total additional electricity demand: 260 TWh	• **50 % of industries hydrogen demand** by electrolysers • Total additional electricity demand: 195 TWh
Low flexibility (LF)	• Without thermal energy storages	• Uncontrolled charging	• Constant electrolyser dispatch
High flexibility (HF)	• With thermal energy storages	• Bi-directional charging	• With hydrogen storages



Surplus availability influences optimal PtX investments

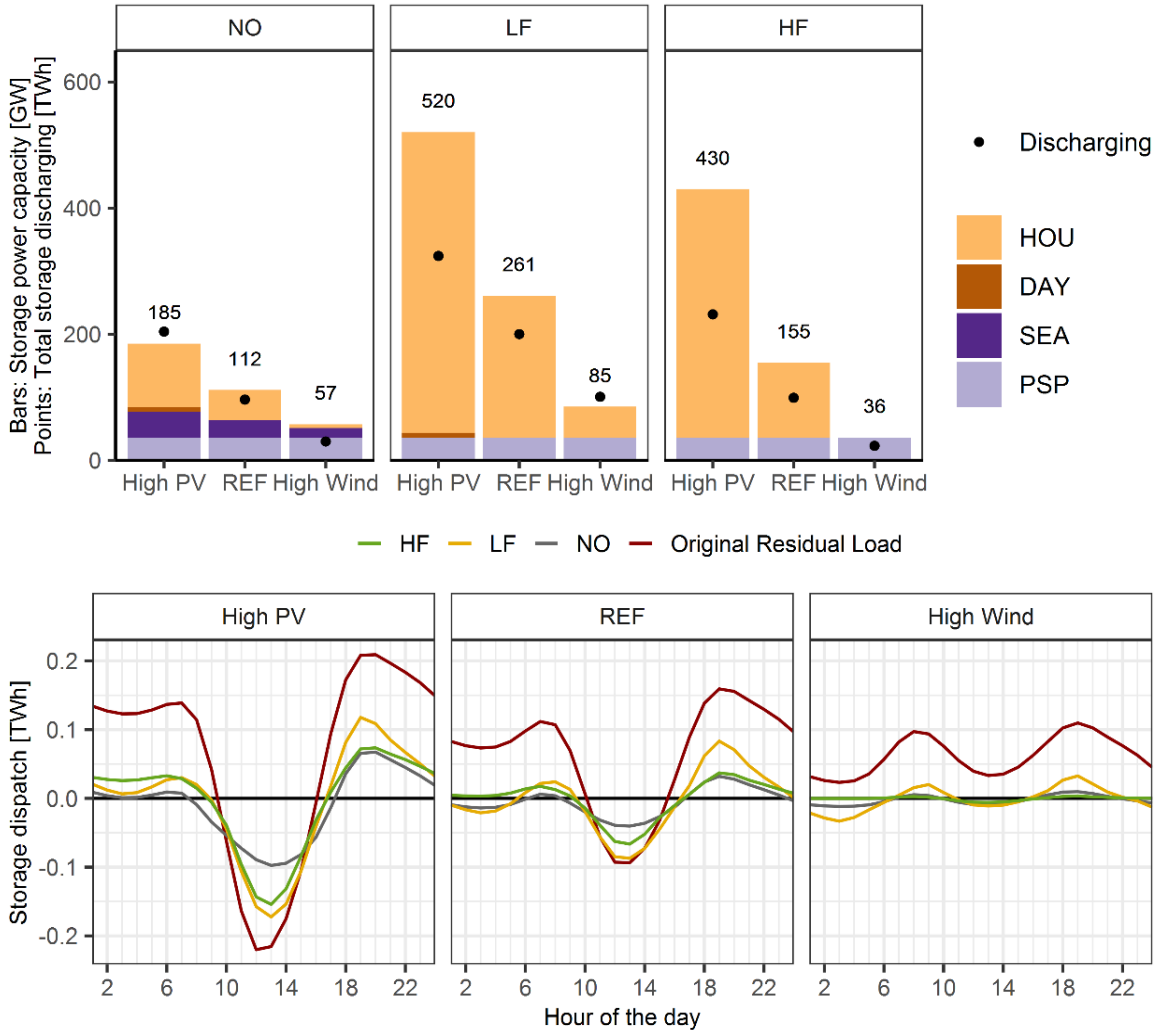


- Higher **heat pump** capacities with increasing wind share due to more vRES surpluses in winter
- Heat storages allow for lower heat pump capacities and more constant PtH supply

- **Electrolyser** investments driven by vRES surplus during spring and summer → increasing capacities with higher PV shares
- More flexible hydrogen production (with hydrogen storages) leads to significantly higher PtG capacities in the *High PV scenario*

- V2G potential does not endogenously increase number of **BEV**

High PV shares and sector coupling leads to large storage demand



- Due to rather daily consumption pattern of PtX technologies:
  - **Hourly (battery) storages** play most important role for temporal shifting
  - With sector coupling **seasonal and daily storages** are not required
- High value of PV surpluses for sector coupling → increasing storage capacities with higher midday PV feed-in peaks
- Temporal flexibility provision provided by electricity storages also with flexible sector coupling (*HF*)

Summary

- Lower availability and high spatial correlation of PV generation lead to higher flexibility requirements in PV dominated energy systems
- Wind-PV share in total RES generation **strongly** influences optimal flexibility provision
- An enforced sector coupling (e.g. resulting from subsidies or funding) requires additional flexible capacities in the electricity sector
- Hourly storages (batteries) are strongly influenced by PV share in RES technology mix
- Temporal (and spatial) shifting technologies are required to get access to RES surplus energy across multiple countries in Europe
- The demand for energy storages in other energy demand sectors are driven by two influencing factors:
  - Reduction of (capital intensive) PtX investments → mainly in wind dominated scenarios
  - Ability to access (cheap) electricity surplus periods → mainly in PV dominated scenarios

Thank you for your attention