REflex
Analysis of the European Energy System

THE OPTIMAL COMBINATION OF FLEXIBILITY OPTIONS IN THE EUROPEAN ELECTRICITY AND HEAT SECTOR

TU Dresden and AGH Kraków
Steffi Schreiber (TUD), Christoph Zöphel (TUD), Dominik Möst (TUD),
Maciej Raczyński (AGH), Artur Wyrwa (AGH)

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Structure of the Presentation on

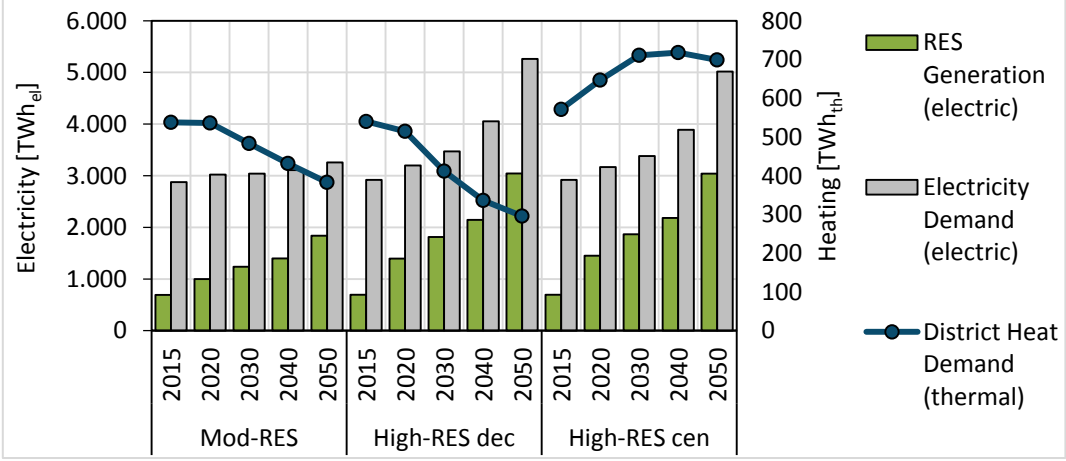
"The optimal combination of flexibility options in the European electricity and heat sector"

1. Summary of **main assumptions**
2. The **role of storages** within the REFLEX scenario framework
3. Results on **sector coupling technologies**
4. Optimal combinations of **electricity generation technologies**
5. Influence of a **faster RES expansion** on the results in the electricity sector
6. **LCOE** and **CO_2 abatement costs** in the electricity market
7. Optimal combinations of **heating technologies**
8. **Summary** and **conclusion**

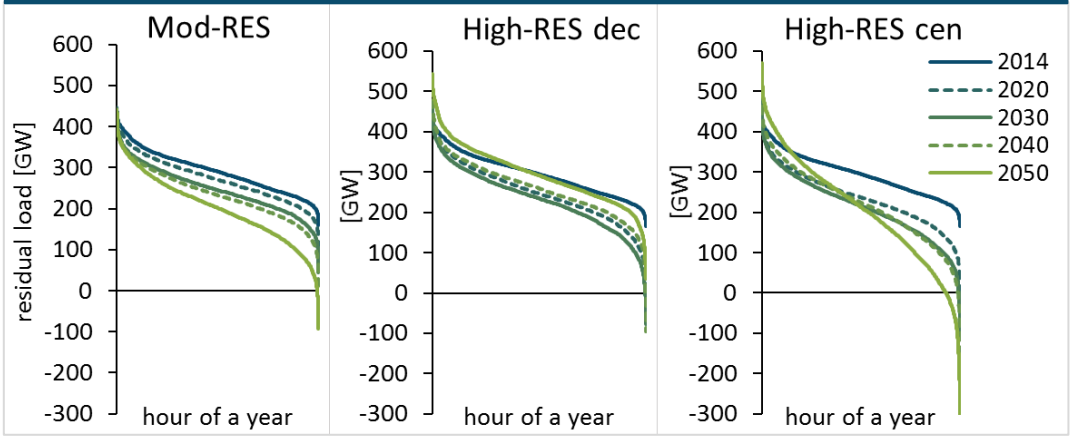
Main assumptions for the electricity generation and district heating sector based on the normative scenario framework

- Higher RES electricity generation in High-RES scenarios overlapped by **increasing electricity demand from different sectors**
- Increasing **district heat demand** in central scenario
- **Smoothed hourly electricity demand** due to DSM applications (within eLOAD)
- Decentral **hydrogen production** in High-RES decentral (within eLOAD)
- **Further input for ELTRAMOD and TIMES-Heat**
  - Scenario specific increase in fuel and CO_2 prices (in 2050 ca. 90 EUR/t_{CO2} in Mod-RES and ca. 150 EUR/t_{CO2} in High-RES)
  - Power plant decommissioning based on age
  - Investment restrictions for selected electricity generation technologies
  - Maintained relative CHP share in electricity generation in Mod-RES and High-RES central scenario

RES generation, electricity and district heating demand across all modelled countries



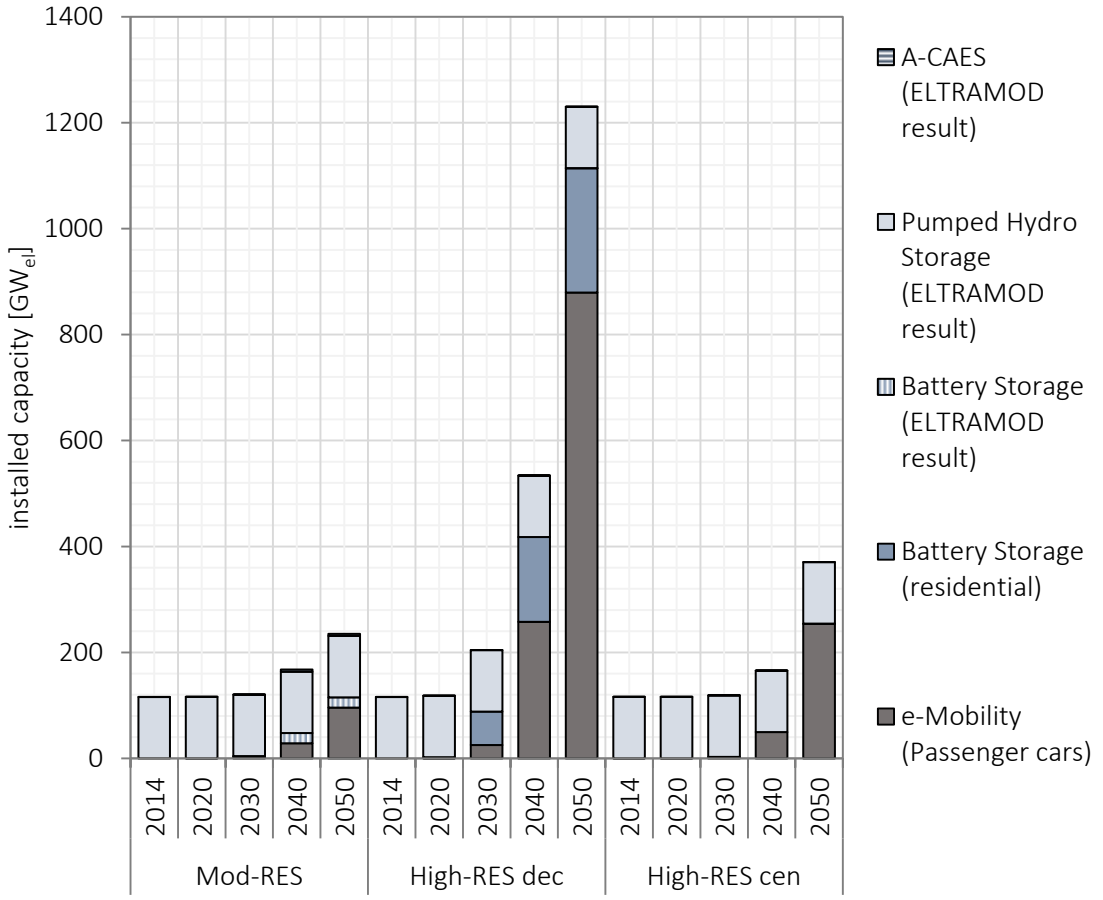
Development of aggregated and sorted residual load across all modelled countries



When exploiting residential storage and DSM capacities, only few additional storage capacities are needed in central electricity market

- Batteries from e-vehicles and residential PV-battery systems are dominating the storages mix particularly in the High-RES decentral scenario
- **Low additional model endogenous storage capacities** for the electricity market mainly due to:
  - **Smoothing of residual load** by DSM measures (incl. storages) in the residential sector
  - **Increased** and further **smoothed residual load** by sector coupling

Installed storage capacities in the electricity market across all modelled countries



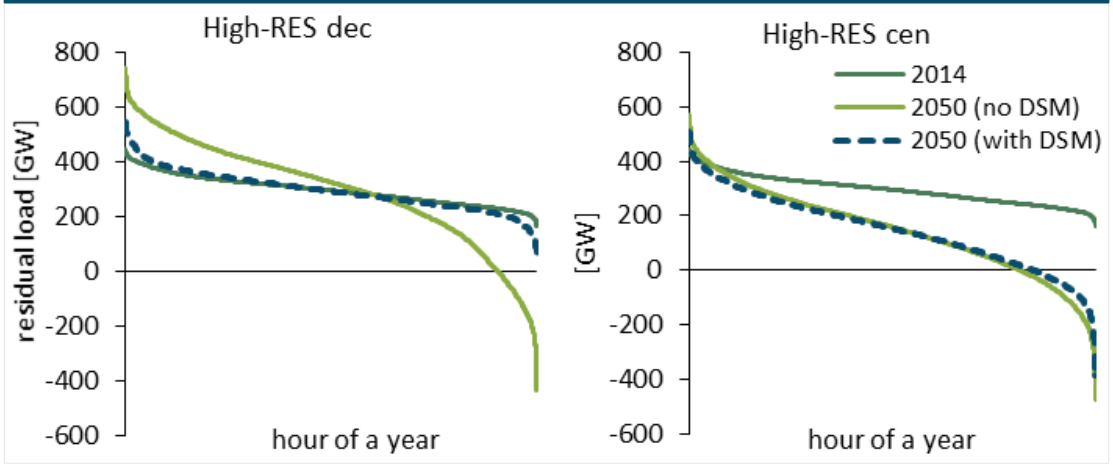
Two sensitivities to identify influencing factors for storage investments in the electricity market

Non-flattened system load (without DSM)

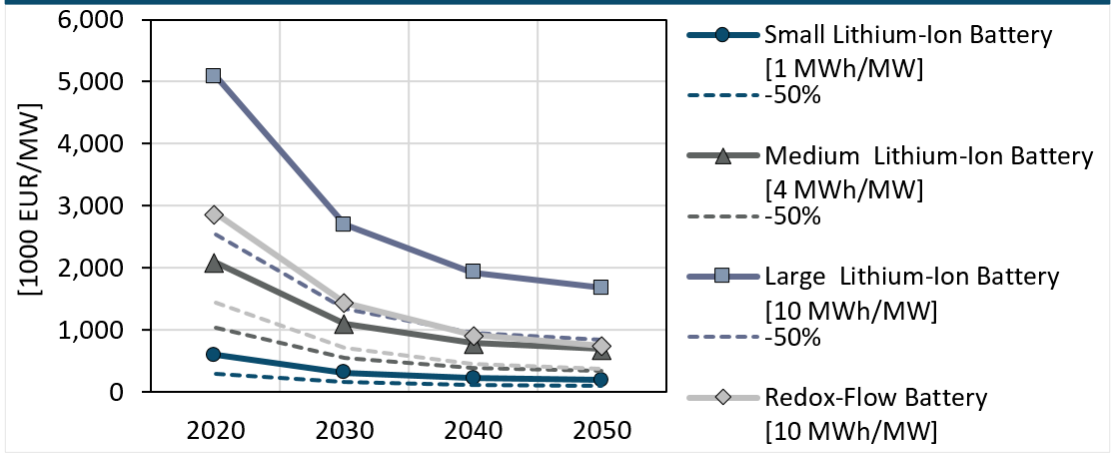
- Huge effect for High-RES decentral scenario
- Slightly steeper sorted residual load in High-RES central without DSM

Battery investment costs reduced by -50%

Development of aggregated and sorted residual load across all modelled countries



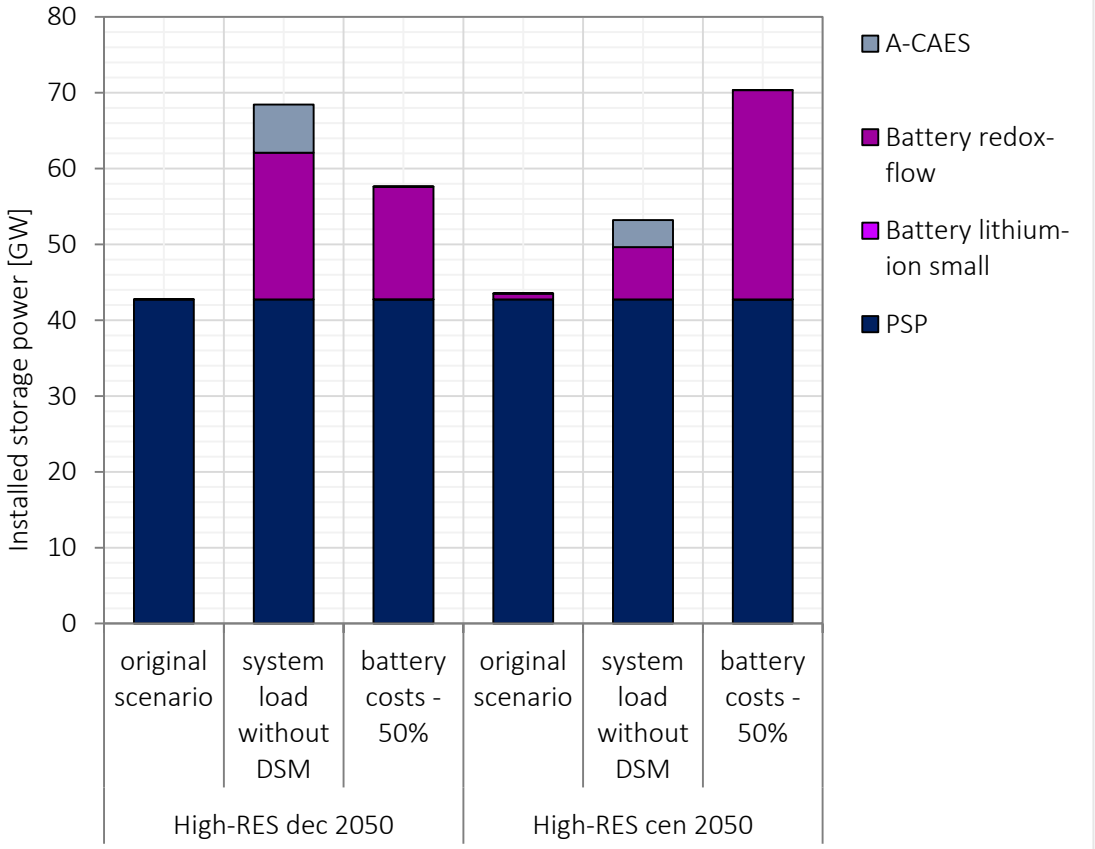
Development of aggregated and sorted residual load across all modelled countries



Sensitivities - Increasing storage value in electricity market with non-optimized system load and reduced battery costs

- **With non-optimized system load** (without DSM) more storage capacities are required in 2050 in all scenarios, particularly for High-RES decentral
- **With reduced investment costs** more batteries are installed in 2040 and 2050 (mainly redox-flow batteries), particularly in High-RES central

Installed storage capacity mix in the electricity market across all modelled countries (ELTRAMOD result)



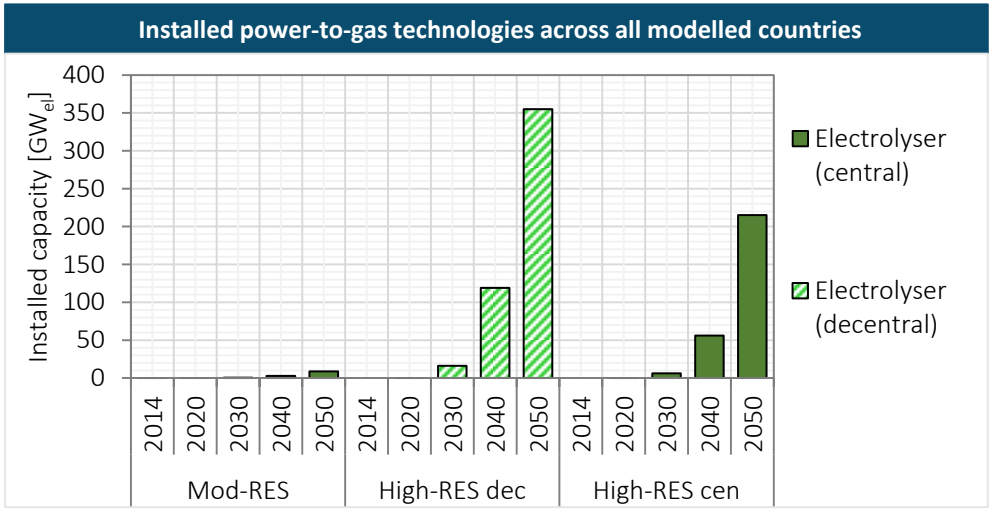
Optimal investment in power-to-x technologies strongly depend on developments in other sectors

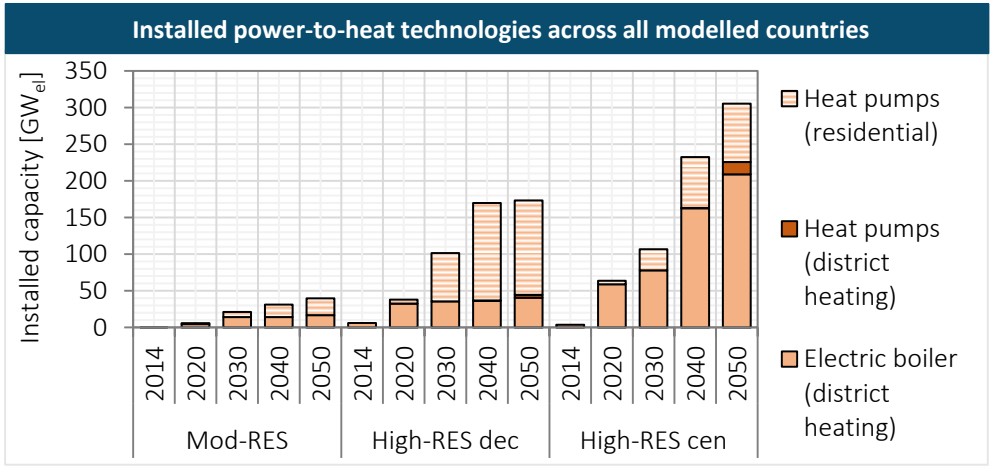
Power-to-gas

- Significant hydrogen demand in transport and industry sector from 2030 on
- Within scenario framework up to 350 GW decentral (High-RES decentral) and 200 GW central (High-RES central) electrolysers

Power-to-heat

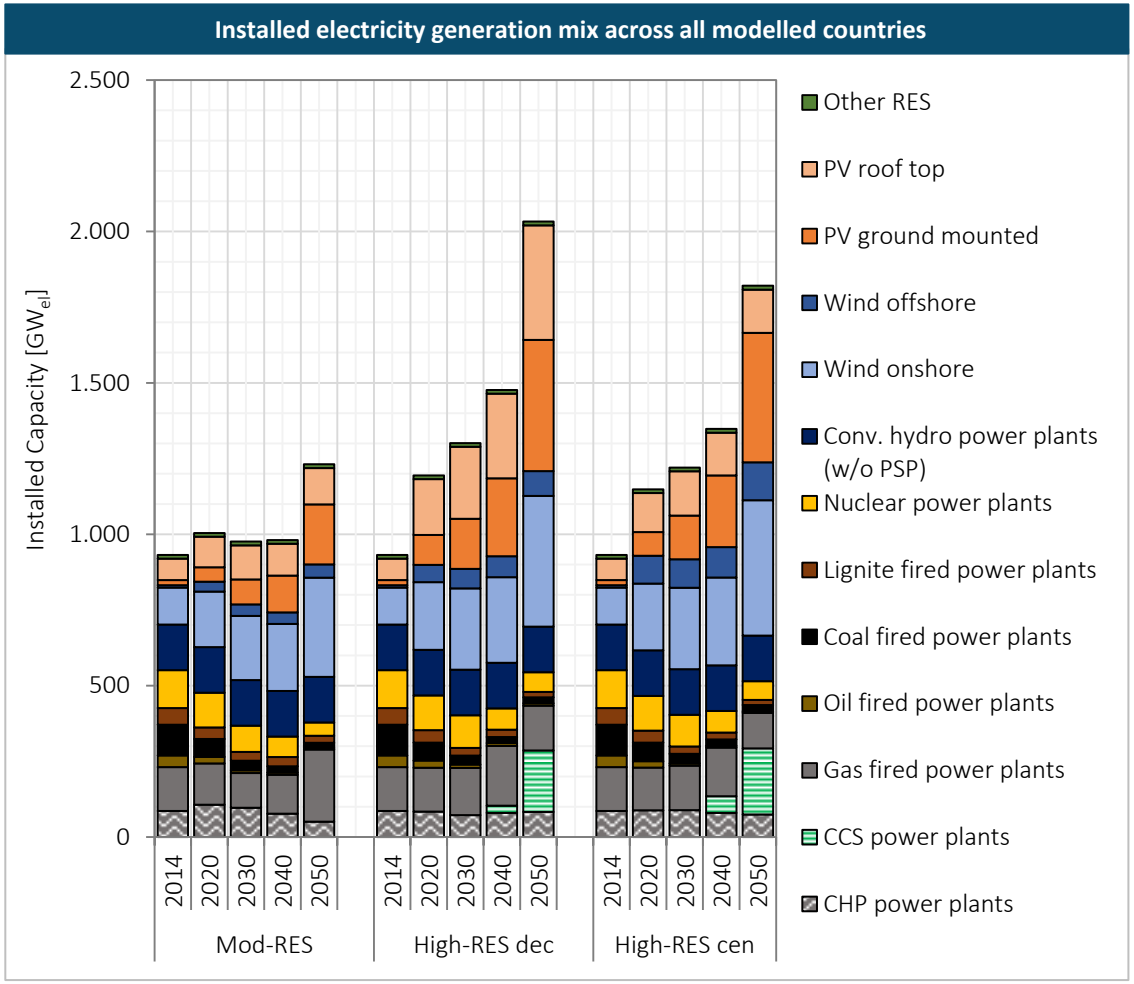
- High share of residential heat pumps in High-RES decentral scenario
- Higher share of electric boilers compared to heat pumps for district heating





CO_2 price driven fuel switch to low-carbon technologies in the optimal power plant mix

- **RES capacities become dominating electricity generation technologies**
- High shares of gas in fossil fuel based electricity generation
- Decrease of emission intensive technologies, but no final phase-out of coal and lignite
- **In total more fossil fuel based technologies in the High-RES scenarios compared to Mod-RES scenario due to higher electricity demand**
- From 2040 on CCS gains in importance in generation mix in High-RES scenarios due to increase in CO_2 prices

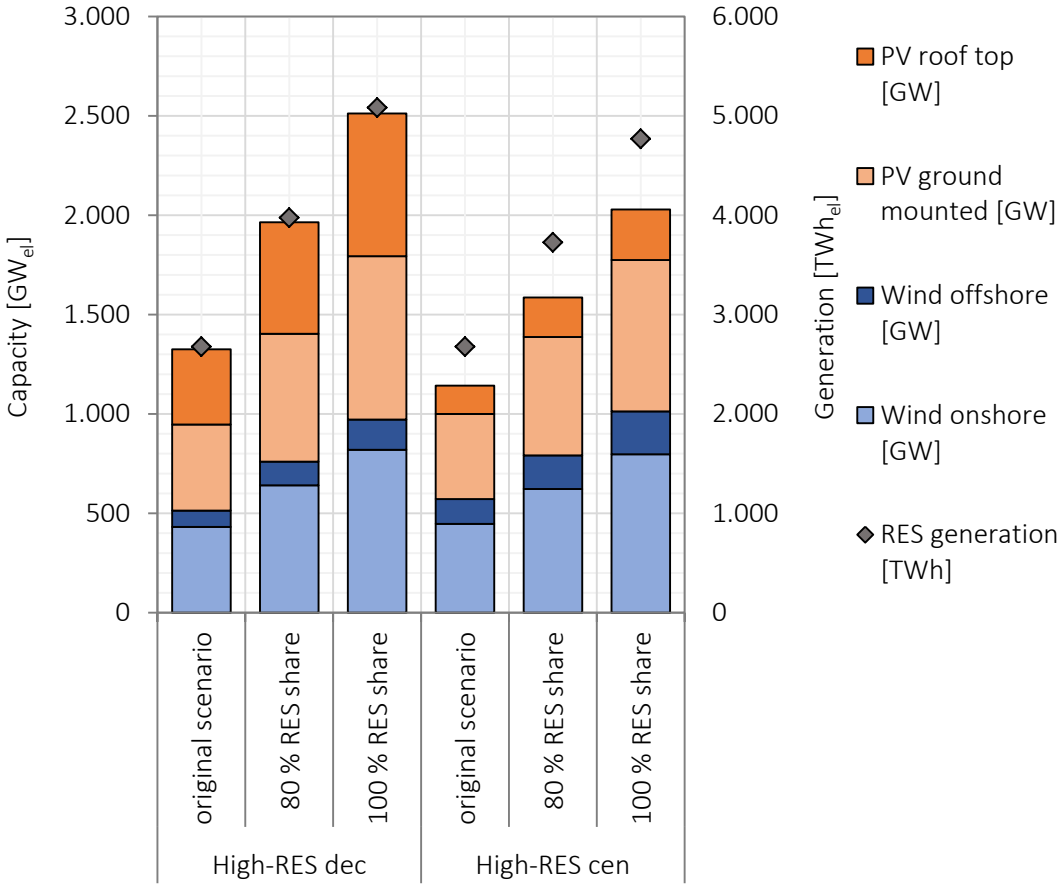


Sensitivities - High electrification of all sectors requires substantial RES expansion to achieve high RES shares

- **Original scenario RES share: 80 % of today's electricity demand* (≈ 3,000 TWh)**
- **Increase of electricity demand due to electrification** by sector coupling up to ≈ **5,000 TWh** in 2050 in the High-RES scenarios
- **RES based generation has to increase to ≈ 4,000 TWh (5,000 TWh)** to achieve a theoretical RES share of 80 % (100 %) within the REFLEX High-RES scenarios

* EU28 + NO + CH + Balkan countries

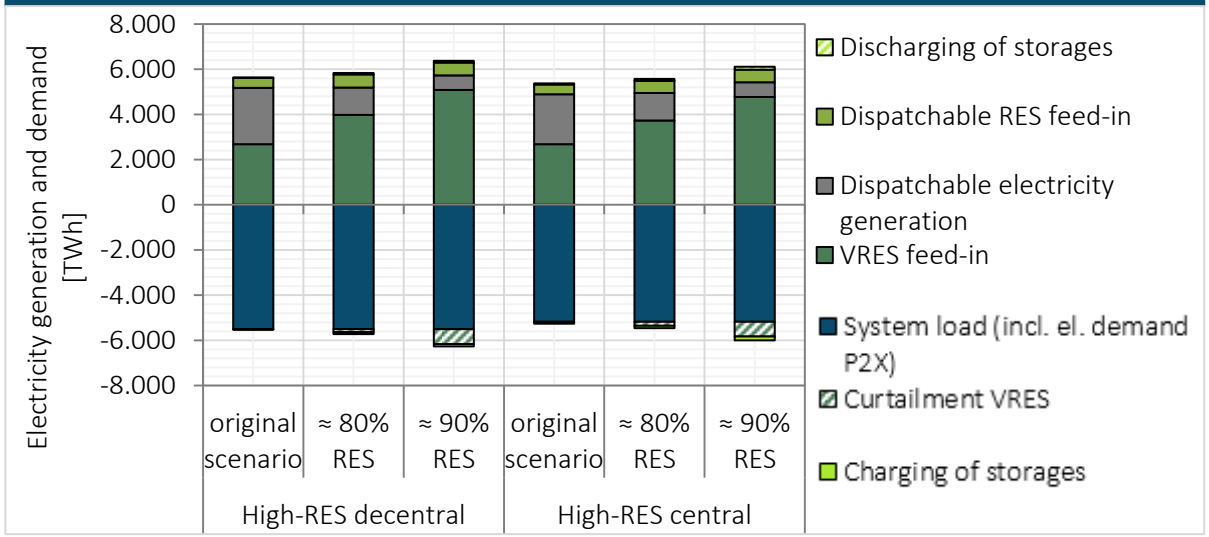
PV and Wind capacities and generation across all modelled countries in 2050



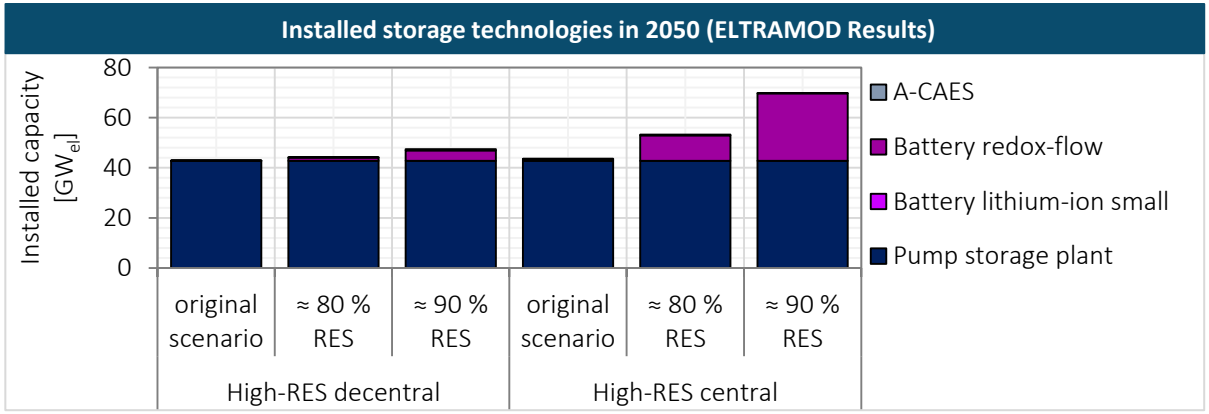
Sensitivities - Increase in RES capacities further reduces fossil fuel based electricity generation

- **Conventional capacities still necessary** for peak residual load
- Compared to original scenario:
  - **Reduction** of fossil fuel based electricity generation **by 70 – 75 %**
  - **Increase of curtailed RES** amounts up to **12 %** (of total RES el. generation)
  - 100 % RES share requires significant **more flexibility options**
- Longer surplus and deficit phases **in High-RES central** (more wind), require **more storages with higher capacity**

Aggregated electricity generation and demand across in 2050 (ELTRAMOD Results)



Installed storage technologies in 2050 (ELTRAMOD Results)

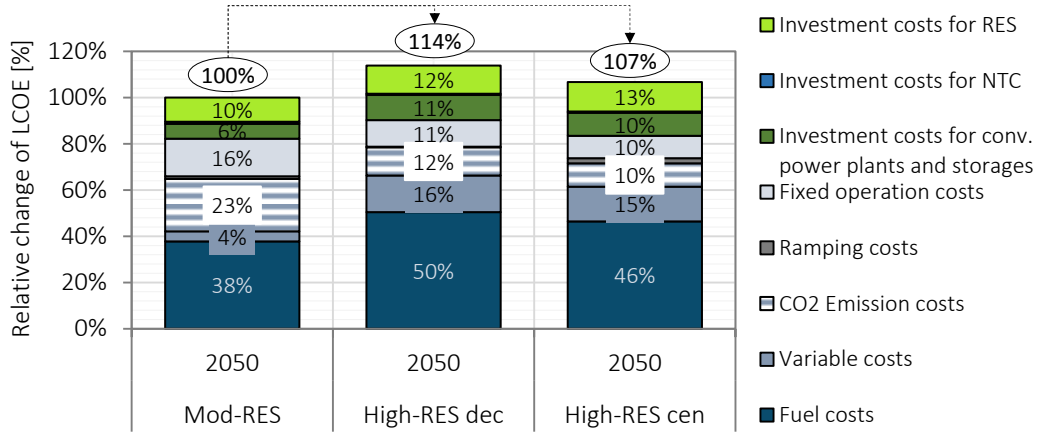


* ≈ 80% RES i.e. RES share on total electricity generation

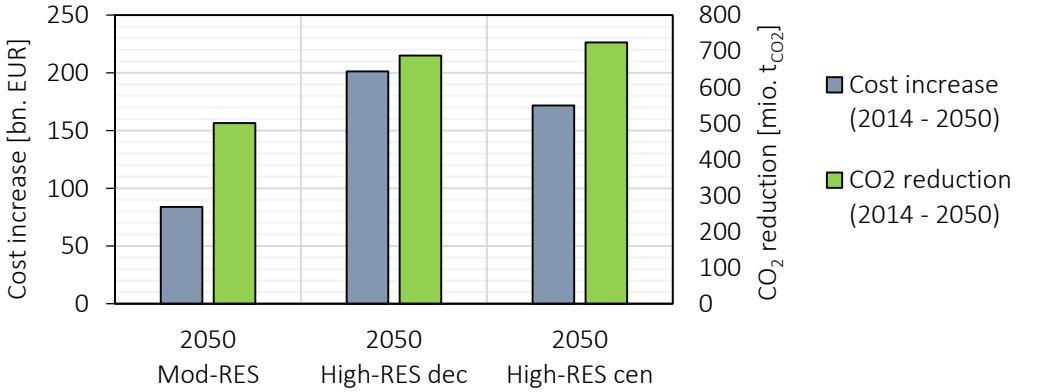
Similar range of levelized costs of electricity in 2050 in all scenarios

- **Higher share of fuel costs in High-RES** due to more electricity generation
- Dispatch of low-carbon technologies results in **lower share of emission costs in High-RES scenarios**, although CO_2 price increases significantly (from ca. 90 EUR/t_{CO2} to 150 EUR/t_{CO2})
- **Higher LCOE in decentralized scenario** due to slightly more electricity generation
- Lower cost increase and higher CO_2 emission reductions compared to 2014 leads to **lower specific CO_2 abatement costs in High-RES central 237 EUR/t_{CO2}** as in High-RES **decentral 292 EUR/t_{CO2}**
- Less CO_2 emission reductions in **Mod-RES** compared to High-RES scenarios lead to low CO_2 abatement costs of around **167 EUR/t_{CO2}**

Relative change of levelized costs of electricity compared to Mod-RES (ELTRAMOD Results – without PtX)

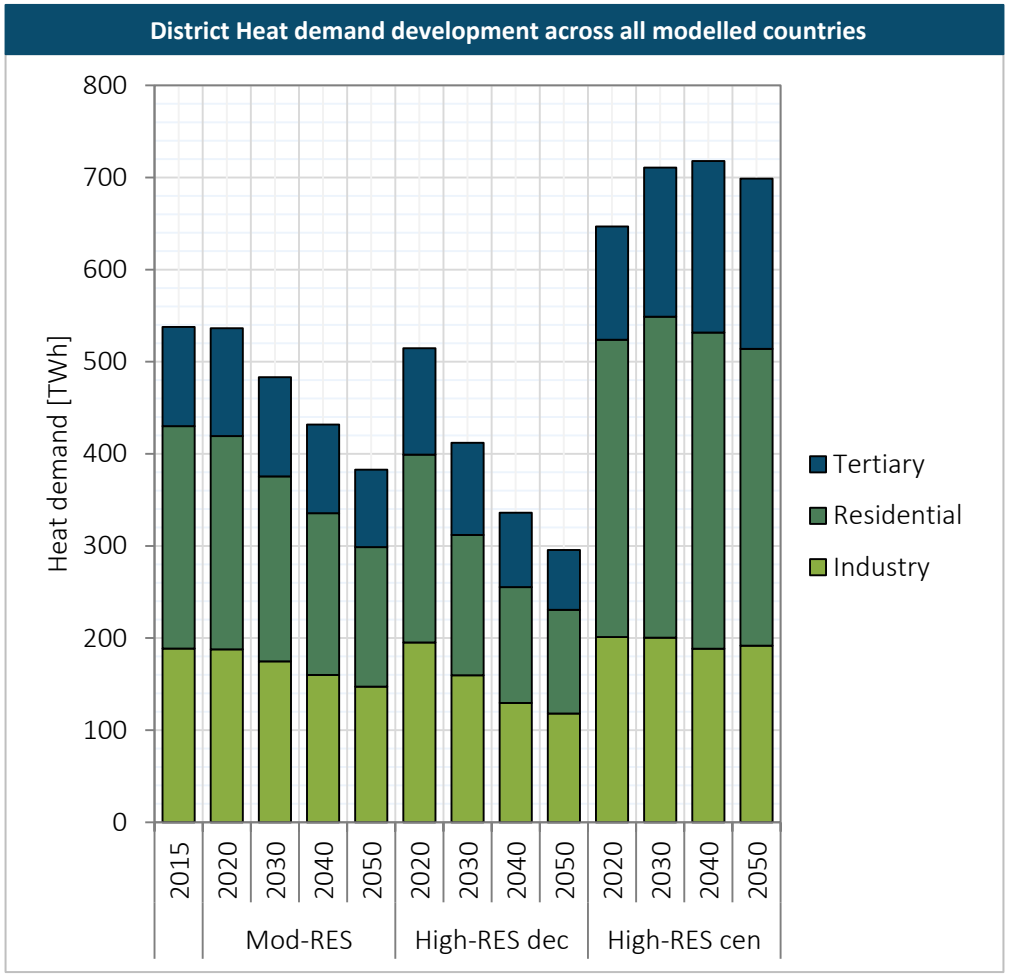


Cost increase and emission reduction in 2050 compared to 2014 (ELTRAMOD Results – without PtX)



District Heat demand increases only in High-RES centralized scenario

- **Exogenous input** to TIMES-HEAT-EU model **from FORECAST model**
- Strongest **decrease in district heat demand in High-RES decentralized** scenario due to residential heat generation
- **Increase in district heat demand in High-RES centralized** scenario mainly caused by increase in tertiary sector

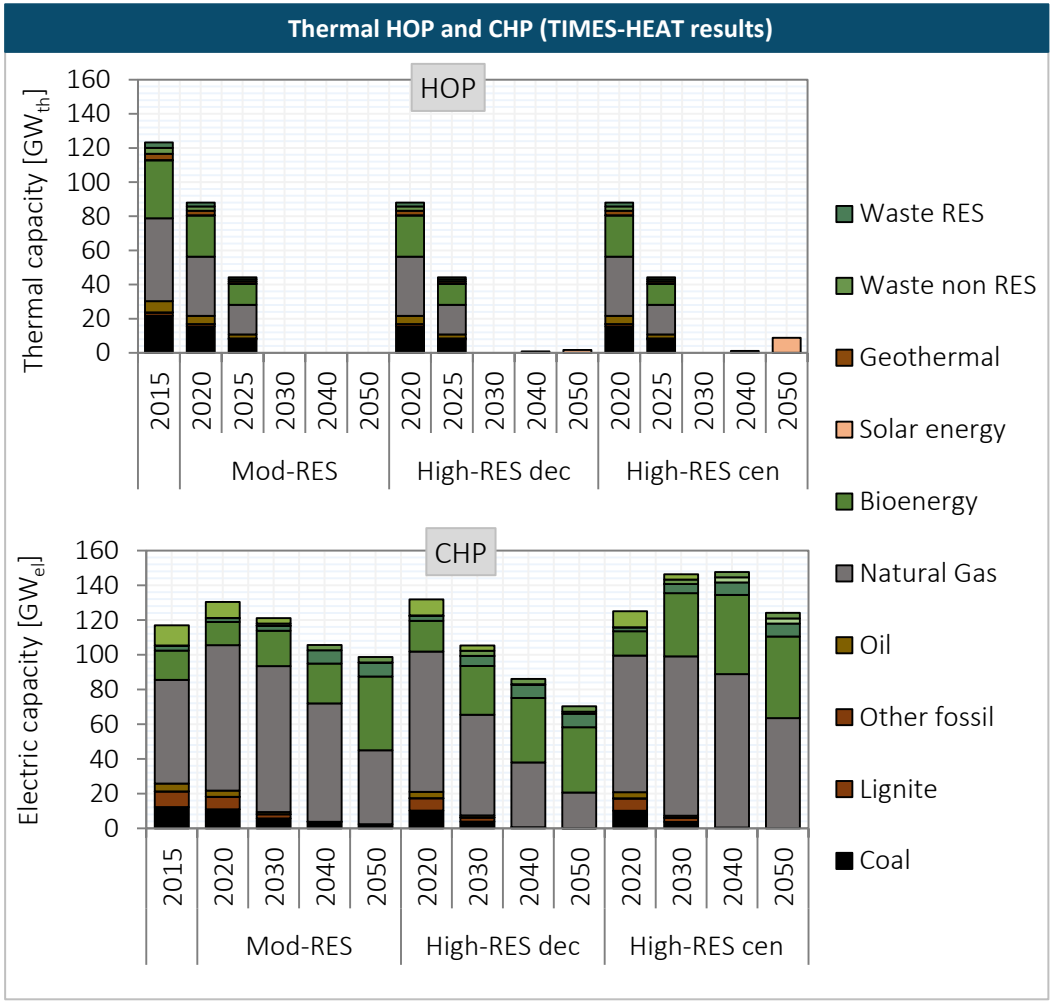


Heat-only-plants are loosing competition with combined-heat-and-power plants

Heat-only-plants (**HOP**) **loosing competition** with combined-heat-and-power plants (CHP):

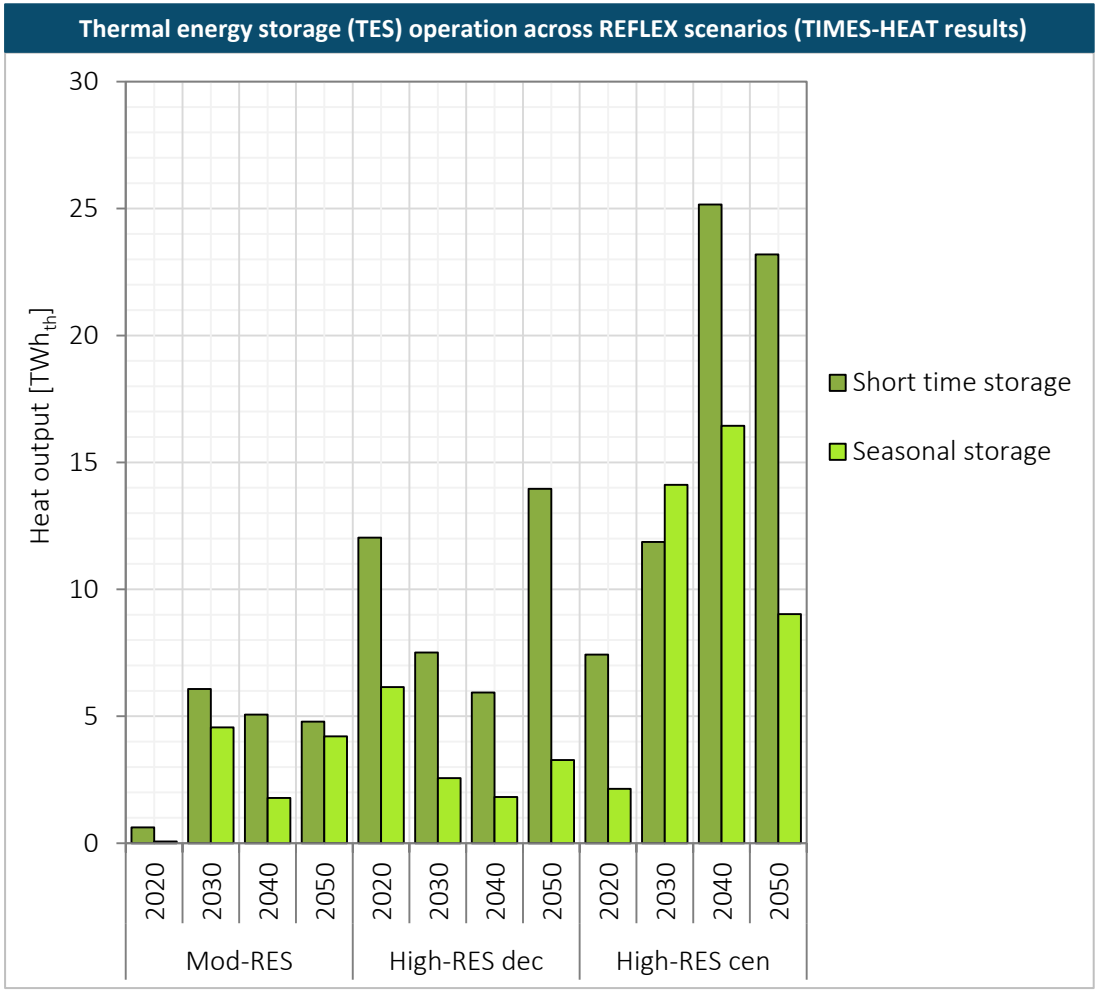
- Heat prices < wholesale electricity prices
- Revenue of CHPs > HOPs

- In all scenarios **tendency towards biomass** (zero CO_2 emissions) and natural gas (**CCGT** plants because of high flexibility and high electrical efficiency)
- High-RES centralized scenario **assumption** of „**maintaining CHP share**" leads to **less bioenergy**, so gas fired plants are installed to meet electricity demand



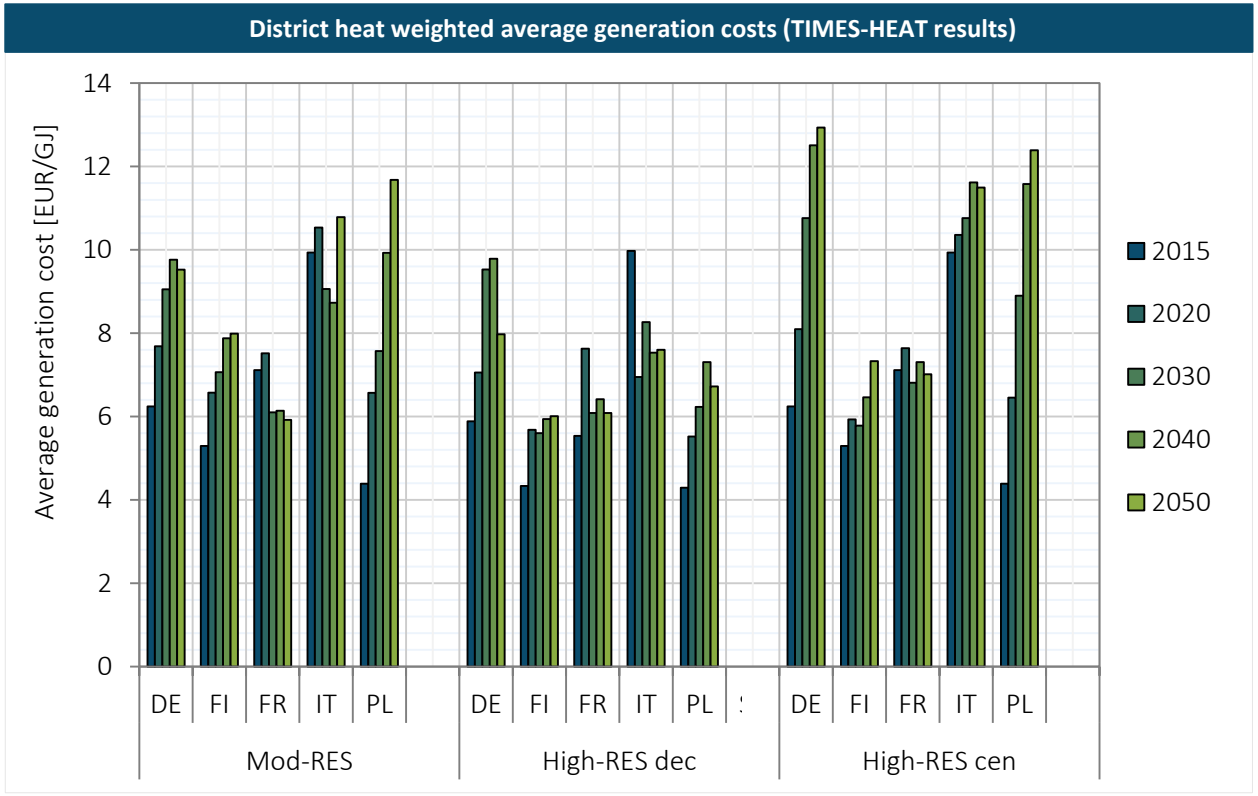
Total district heat demand and RES generation have an influence on thermal energy storage demand

- Higher district heat demand in **centralized scenario requires higher seasonal thermal energy storage (TES) capacities**
- **Higher RES shares increase the demand for short time TES** to use RES surplus for heat generation in both High-RES scenarios



Weighted average heat generation cost across REFLEX scenarios in selected countries

- In general **heat generation cost increases** throughout model horizon
- Increase / decrease depends mainly on
  - District heat demand development and,
  - Biomass availability in comparison to district heat demand



Summary and conclusion

- The decentral vs. central High-RES scenarios are characterized by **different approaches of sector coupling**, e.g. decentral onsite hydrogen supply vs. central larger scale hydrogen production
- **Decentral (residential) flexibility options decrease the value of electricity market based technologies**, particularly storages
- While the differences between the Mod-RES scenario and the High-RES scenarios are significant, the **optimal mix of flexible power plants in the High-RES central and decentral scenario is rather similar**
- Back-up capacities still relevant, at **high CO_2 prices (> 70 EUR/t_{CO2}) CCS is an important** decarbonisation option
- **Higher RES shares** can significantly **reduce fossil fuel** based electricity generation
- **Decentralized world** results in **higher levelized costs of electricity (+ 7 %)** compared to the High-RES **centralized world** and higher system costs (+ 23 %)
- **CHPs are more economically competitive** in the future than heat-only-plants (HOP)
- **Heat Storage increases operation flexibility** of district heat generation units
- **Biomass can play an important role** in substituting fossil fuels in district heat generation

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Thank you! Questions?

Steffi Schreiber
steffi.schreiber@tu-dresden.de

Christoph Zöphel
christoph.zoephel@tu-dresden.de

Dominik Möst
Dominik.moest@tu-Dresden.de

TU Dresden, Chair of energy economics , Germany

Artur Wyrwa
awyrwa@agh.edu.pl

Maciej Raczyński
maciej.raczynski@agh.edu.pl

AGH University of Science and Technology in Kraków, Poland

www.reflex-project.eu

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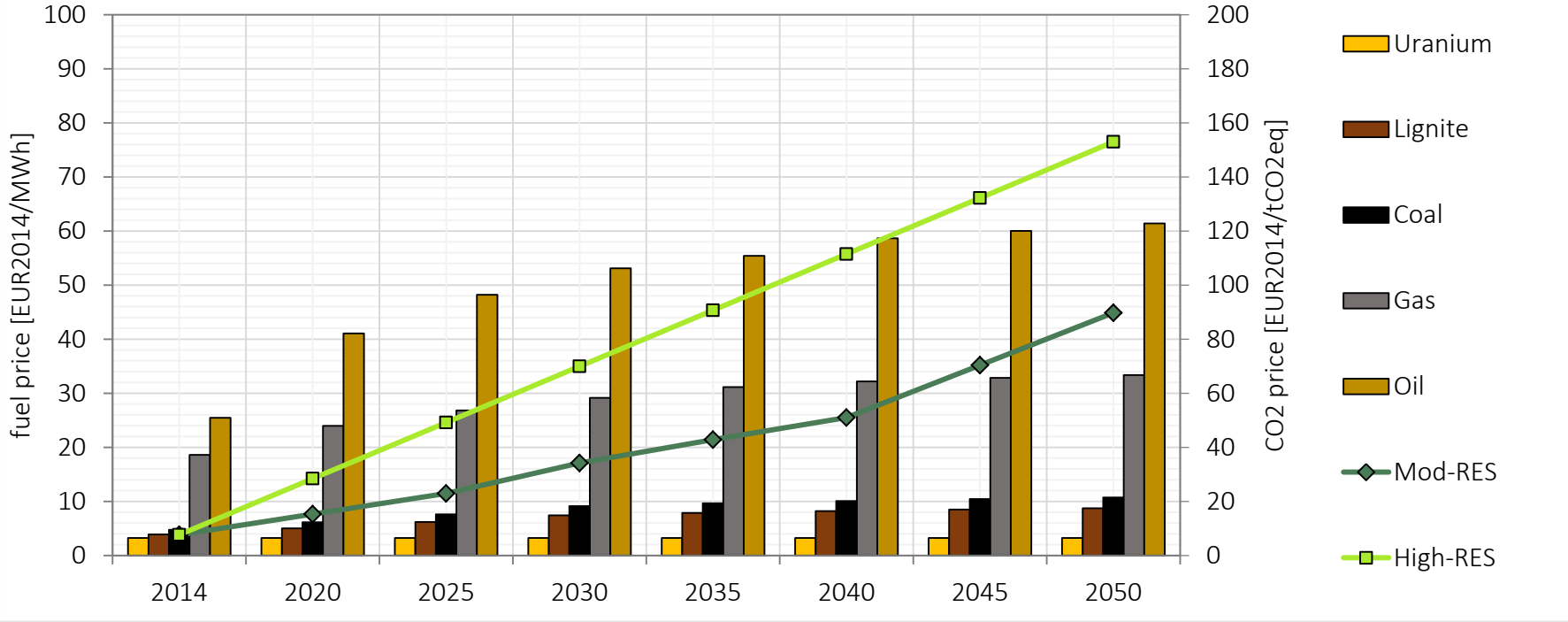
Back-Up: Scenario specific increase in CO_2 and fuel prices as exogenous input for ELTRAMOD which has strong influence on the modelling results

Fuel and CO_2 price development across the Reflex scenarios



Sensitivity results: The less DSM applications the higher the total system costs in High-RES scenarios due to higher residual load

- **Generation costs** are **increasing** in sensitivity with **non-optimized system load**
- The less DSM applications (non-smoothed system load), the higher the generation costs due to additional needs for low-carbon generation by **CCGT** and **gas CCS**
- No significant differences regarding other investment costs or fixed operational costs across the different sensitivities in one scenario
- **Highest total system costs** in **High-RES decentral** scenario mainly due to higher generation costs because of higher electricity demand