Modelling District Heating Supply Patterns of EU-27 in a Decarbonized Energy System in 2050

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IAEE 2023

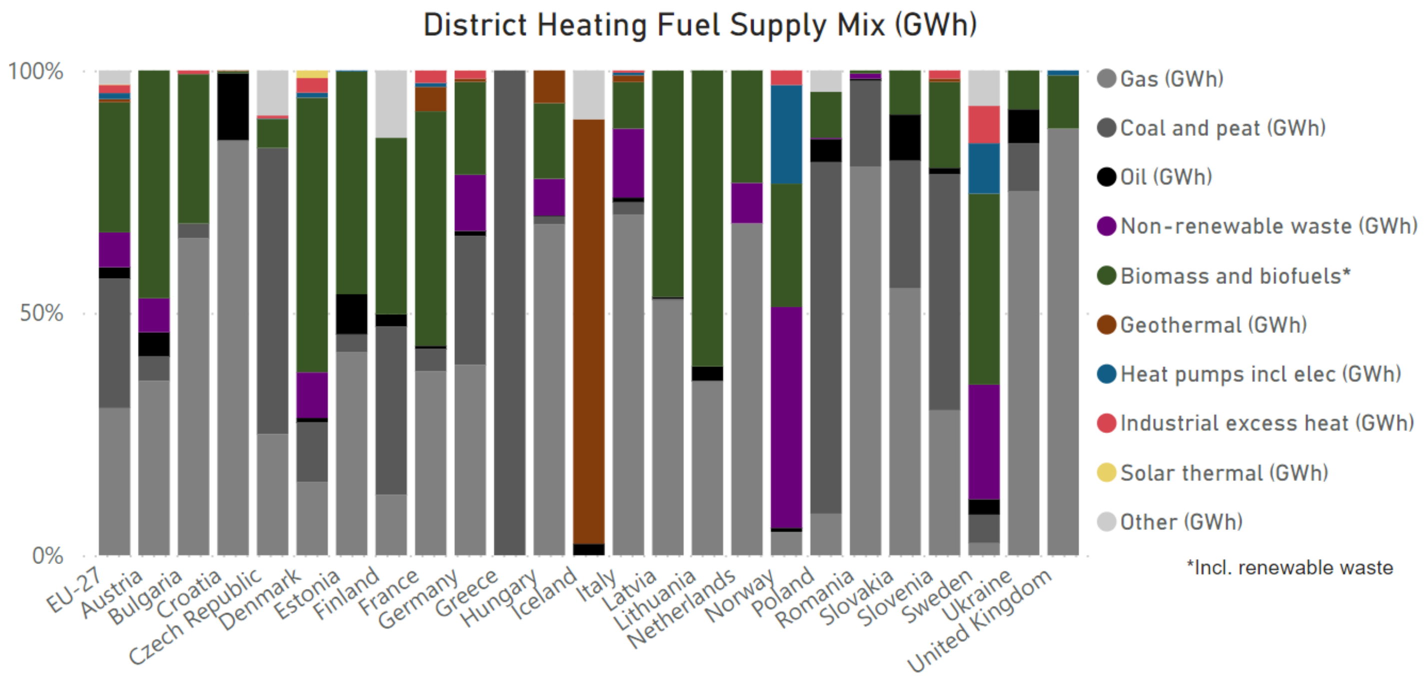
Outline

- Motivation and Research Question
- Methodology
  - Modeling chain
  - Hotmaps DH Gen model
  - Scenario design
- Results
- Conclusion

Motivation and Objective

Motivation

- District Heating (DH) supply of EU-27 is highly based on fossil fuels



Source: https://irees.de/en/2020/11/11/district-heating-and-cooling-trend-en/

Research Question

- What are the cost-minimal decarbonized DH generation portfolios of **EU-27** in **2050**, considering:
  - DH grid expansion,
  - **Availability** of renewable energy source (RES) and industrial excess heat (IEH) **potentials**?

Methodology

The modeling chain: Comprehensive modeling of DH Ecosystem

1. Building Stock

- Modeled using INVERT/EE-Lab[1]

2. DH Expansion

- Modeled using the Renovation Effect tool of Hotmaps [1] and the DH expansion model of [2]
- Possible future DH areas are identified based on the distribution costs

3. RES Potential

- RES and IEH potentials are calculated and mapped with a high spatial resolution. Potentials are mapped with the possible DH areas [3]
- DH areas are clustered into up to four groups for each MS [3]

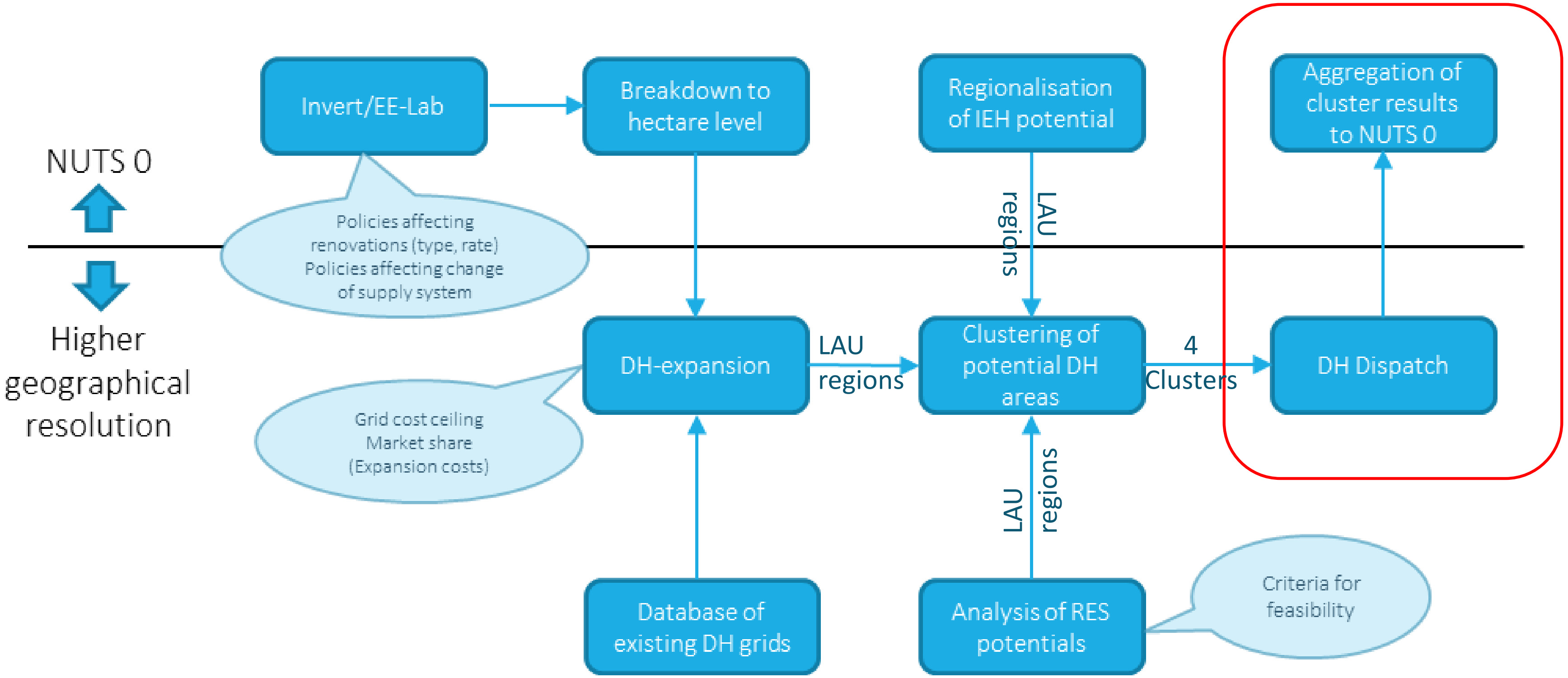
4. DH Generation

- Modelled using Hotmaps DH Gen module [4]
- The cost-minimal DH supply is calculated for each cluster

[1] WWW.INVERT.AT/METHODOLOGY.PHP

Methodology

The modeling chain: High geographical resolution



Methodology

Hotmaps DH Gen Model

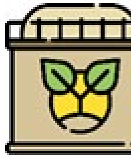
- Mixed-integer linear program
- Minimizes (total costs - revenues)
- Optimizes both investments and operation of technologies
- Works on an hourly level
- Efficiencies of heat pumps modeled as a function of source, flow, and return temperatures
  - Fixed efficiencies for all other technologies

$$\min\,(c_{total} - rev_{total}) \quad (1)$$

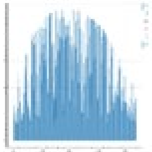
$$rev_{total} = \sum_{j,t} x_{el_{jt}} \cdot p_{s.el_{j,t}} \quad (2)$$

$$c_{total} = OPEX_{fix} + OPEX_{var} + c_{cold} + c_{ramp} + IC \quad (3)$$

Heat Stora

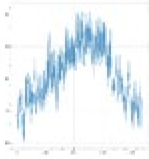


$$OPEX_{fix} = \sum_{j} CapNom_j \cdot opex_{fix_j} + \sum_{hs} sCap_{hs} \cdot opex_{fix_{hs}} \quad (4)$$

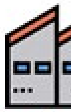


$$OPEX_{var} = \sum_{j,t} x_{th_{j,t}} \cdot \left(opex_{var_j} + \frac{p_{ec_{j,t}}}{\eta_{th_{j,t}}} + \frac{f_{em_{ec_j}} \cdot p_{CO_2}}{\eta_{th_{j,t}}} \right) \quad (5)$$

es



$$c_{cold} = \sum_{j,t} ColdInd_{j,t} \cdot p_{cold_j} \quad (6)$$



$$c_{ramp} = \sum_{j,t} RampP_{j,t} \cdot p_{ramp_j} \quad \forall j \quad (7)$$

Gas and S

$$IC = \sum_{j} (Cap_j - cap_j) \cdot i_j \cdot \alpha_j + \sum_{hs} sCap_{hs} \cdot i_{hs} \cdot \alpha_{hs}$$

$$\alpha_{j,hs} = \frac{(1+r)^{LT_{j,hs}} \cdot r}{(1+r)^{LT_{j,hs}} - r}$$

$$s.t. \sum_{j,t} x_{th_{j,t}} + \sum_{hs,t} \left(x_{unload_{hs,t}} - x_{load_{hs,t}} \right) = demand_{th_t}$$ pply-dispatch

Methodology

Main Assumptions: 2050

- Greenfield investment optimization → nothing exists at the beginning
  - Pre-installed capacities for Waste to Energy (WtE) plants
- RES and industrial excess heat potentials → upper limit for heat generation
- Technoeconomic data based on the ENER/C1/2018-494[1] project
  - Country and size-specific
- Energy carrier prices (incl. taxes and fees) and emission factors based on the ENER/C1/2019-481 project
  - Hydrogen: country-specific, 148 €/MWh on average
  - Electricity: hourly and country-specific, 127€/MWh on average
  - Biomethane: country-specific, 108 €/MWh on average
- Depreciation time = lifetime of plants
- Biomass: 35 €/MWh, IEH: 10 €/MWh, and CO2 price: 500 €/tCO2
- waste: 0 €/MWh → also 0 emission factor

[1] KRANZL, L., FORTHUBER, S., FALLAHNEJAD, M., MÜLLER, A., HUMMEL, M., FLEITER, T., MANDEL, T., BAGHERI, M., DEAC, G., BERNATH, C., MIOSGA, J., KIEFER, C., FRAGOSO, J., BRAUNGARDT, S., BÜRGER, V., SPASOVA, D., VIEGAND, J., NAERAA, R., 2021. ENER/C1/2018-494 – RENEWABLE SPACE HEATING UNDER THE REVISED RENEWABLE ENERGY DIRECTIVE. FINAL REPORT. DOI: 10.2833/525486

Methodology

Technologies

1. Natural gas boiler
2. Natural gas CHP
3. Biomass boiler
4. Biomass CHP
5. WtE CHP
6. River water & lake heat pump
7. Wastewater heat pump
8. **Other heat pumps (air-source, low temp excess heat and geothermal, data centers)**
9. Solar thermal
10. Industrial excess heat (direct)
11. Geothermal direct (hydrothermal)
12. Geothermal direct (petrothermal)
13. Hydrogen boiler
14. Hydrogen CHP
15. Biomethane boiler
16. Heat storage

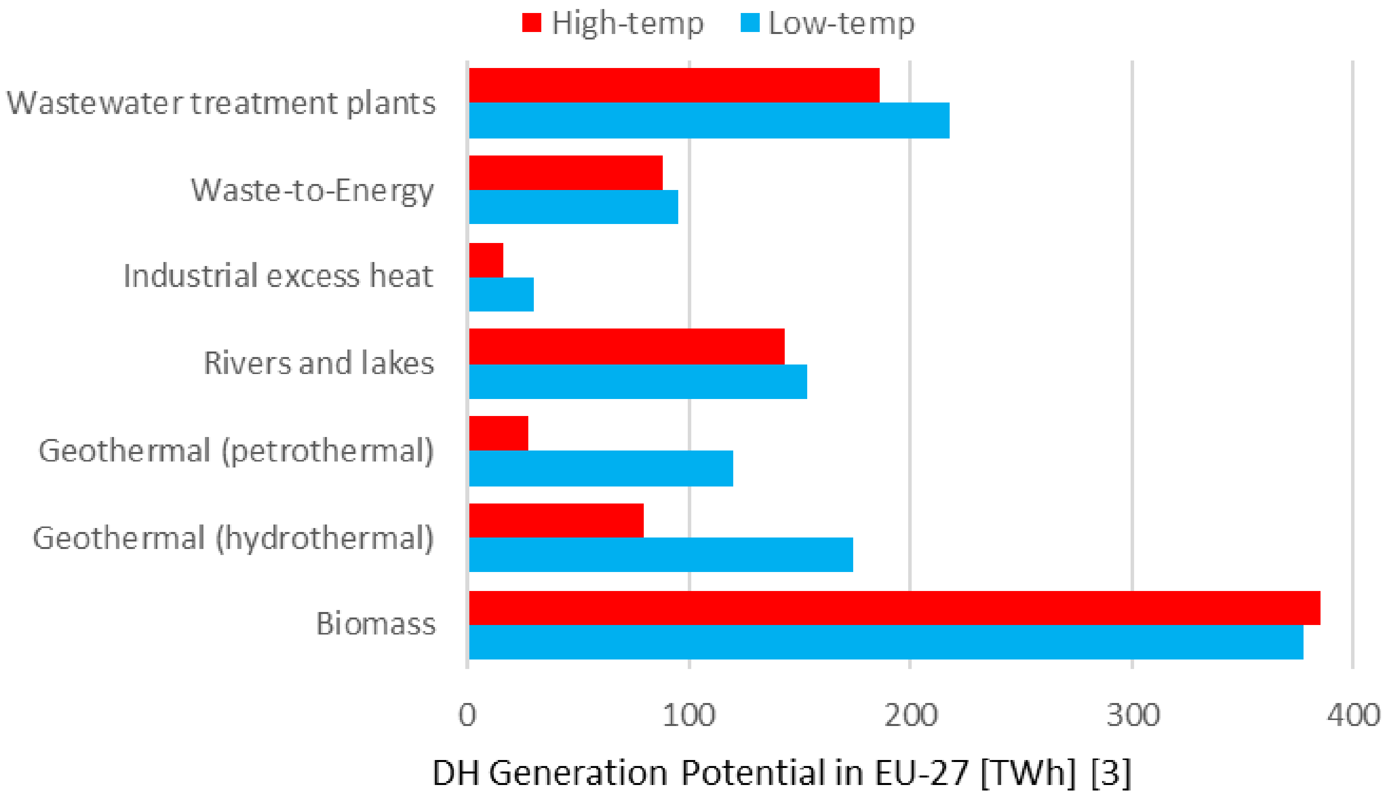
Methodology

Scenario Design: System Temperatures

Two main scenarios:

1. High temperature
   - Flow temperature: 95-85°C
   - Return temperature: 60°C
2. Low temperature
   - Flow temperature: 65-55°C
   - Return temperature: 30°C

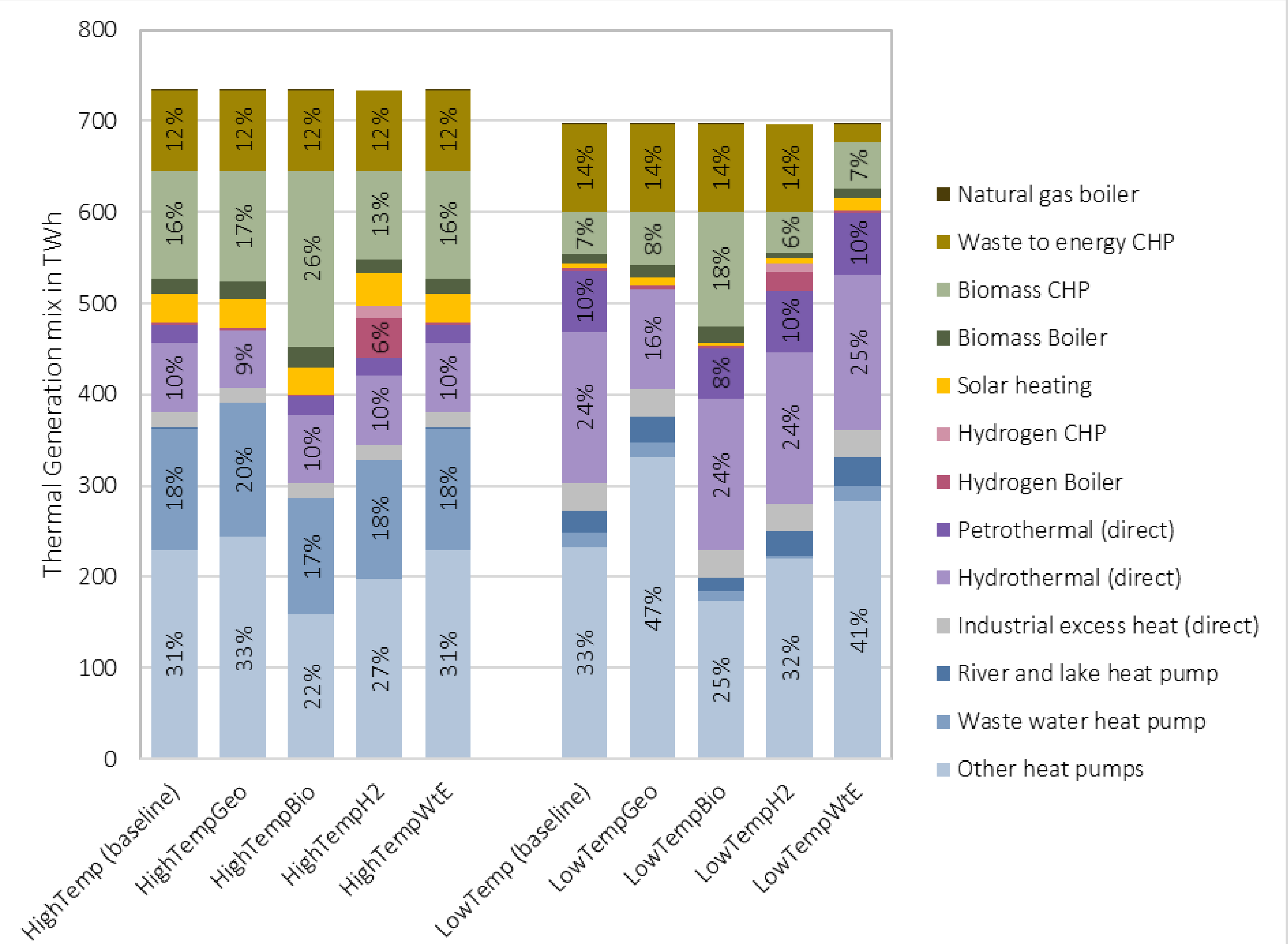
- Direct impact only on heat pumps
- Indirect impact through potentials



Results: EU-27

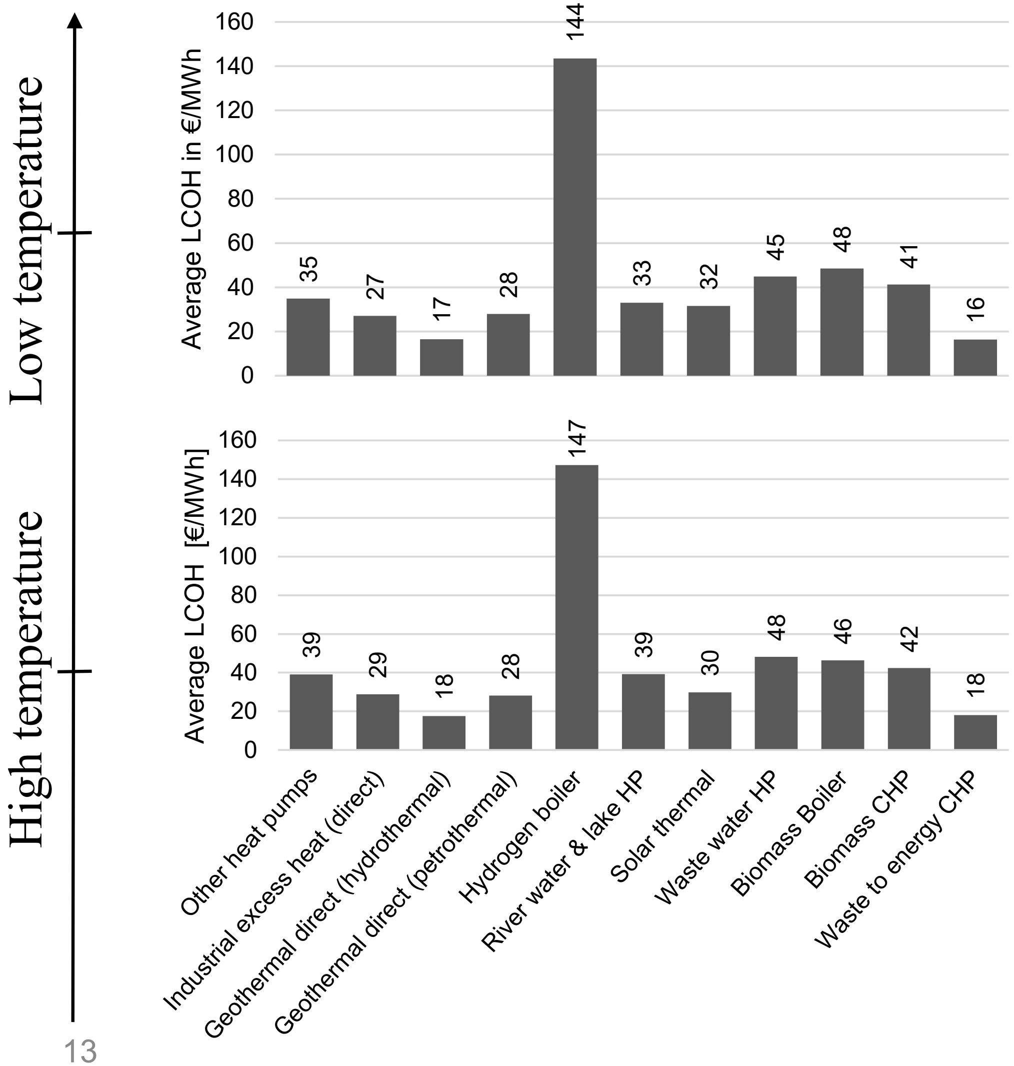
DH Generation

- Sensitivities:
  - High geothermal investment cost → Geo
  - Low biomass price → Bio
  - Low hydrogen price → H2
  - Carbon price for WtE → WtE

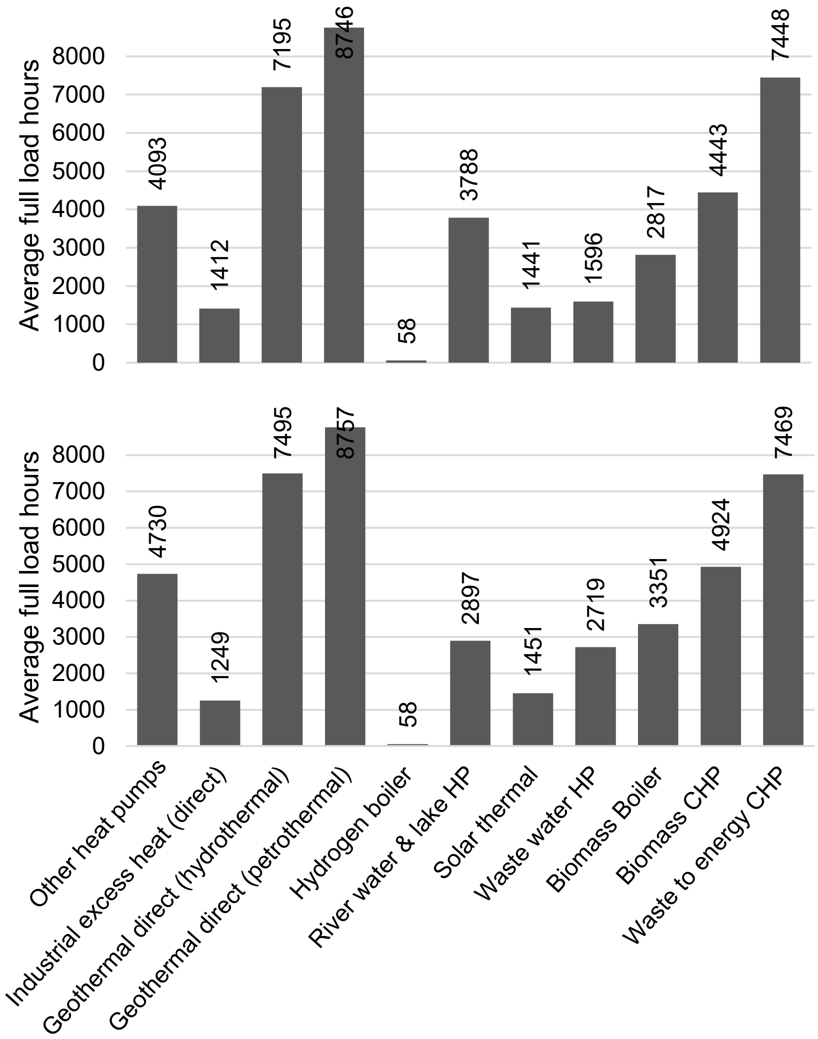


Results: EU-27

Levelized Cost of Heat Generation



Full Load Hours



Conclusions

Heat pumps and geothermal could play an important role in the decarbonisation of the European DH sector

- Natural gas is phased out with a carbon price of 500€/tCO2
- Clear impact of system temperatures on the DH supply mix
- Heat pumps have a significant share in DH supply in all scenarios
  - Waste-water HPs play a more important role in high-temperature scenario
  - River water & lake HPs only in low-temperature scenario
- Geothermal has a significant contribution in the low-temperature scenario
  - Geothermal might partly replace heat pumps in the low-temperature scenario
    - highly depends on the investment cost
- Hydrogen plays a minor role in the future DH supply of the EU
- Biomass depends on policy choices regarding biomass allocation and is sensitive to the price

Thank you for your attention!

Questions?

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References

- [1] https://www.hotmaps.eu/
- [2] Fallahnejad, M., Kranzl, L., & Hummel, M. (2022). District heating distribution grid costs: a comparison of two approaches. International Journal of Sustainable Energy Planning and Management, 34, 79–90. https://doi.org/10.54337/ijsepm.7013
- [3] Manz, P., Billerbeck, A., Kök, A., Fallahnejad, M., Fleiter, T., Kranzl, L., Braungardt, S., Eichhammer, W. (2023). Spatial analysis of renewable and excess heat potentials for climate-neutral district heating in Europe. Renewable Energy, submitted.
- [4] https://github.com/tuw-eeg/hotmapsDispatch/tree/reshc_pathways