District heating and deep retrofits of buildings

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Agenda

01 | Background
The need for model-based assessments in the scope of the EE1st principle

02 | Methodology
Models, assumptions and conceptual aspects

Q&A Session

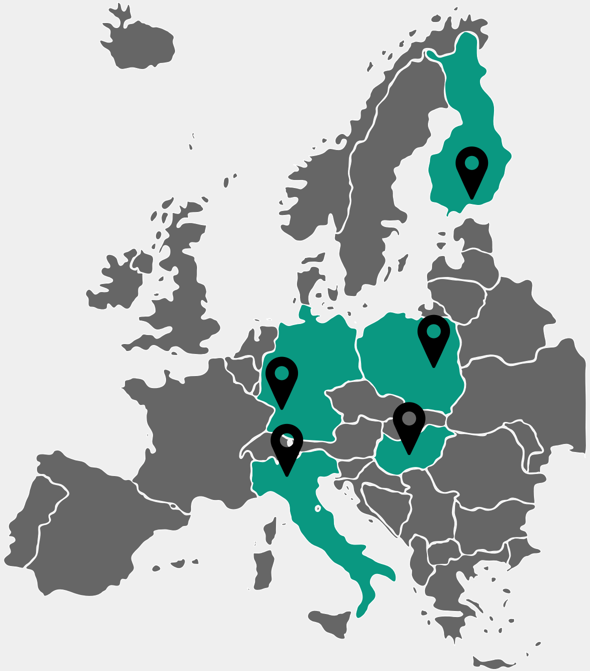
03 | Results
Building sector efficiency is compatible with district heating, but there are limitations

04 | Discussion and Conclusion
Model-based results interpretation

Background

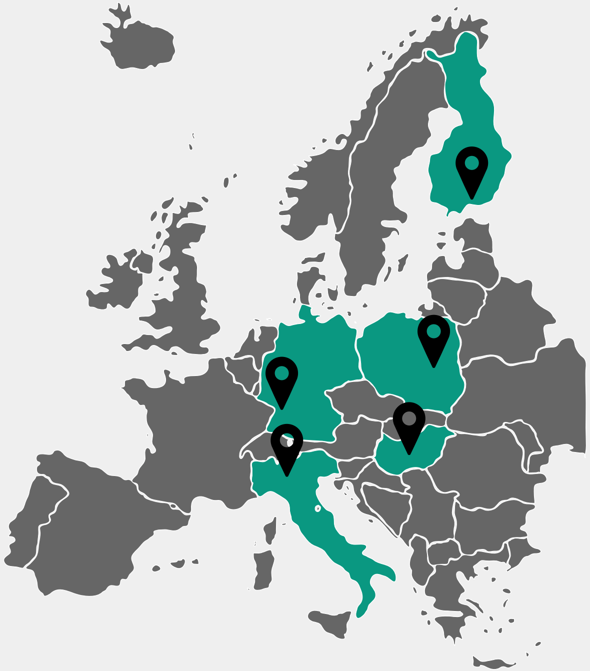
Objectives

- **Research question:** Expected trade-offs of a district heating system compared to different building retrofit strategies achieving the same GHG saving target?
- **Methodology:** Spatial analysis to estimate heat distribution costs for district heating based on heat density maps combined with building energy simulation of energy efficiency measures and decentralized heating supply
- **Case study objects:** Five cities with more than 100.000 inhabitants from four climate zones
- **Scope:** Meso-level (municipal heat/urban planning)



Case study objects status-quo

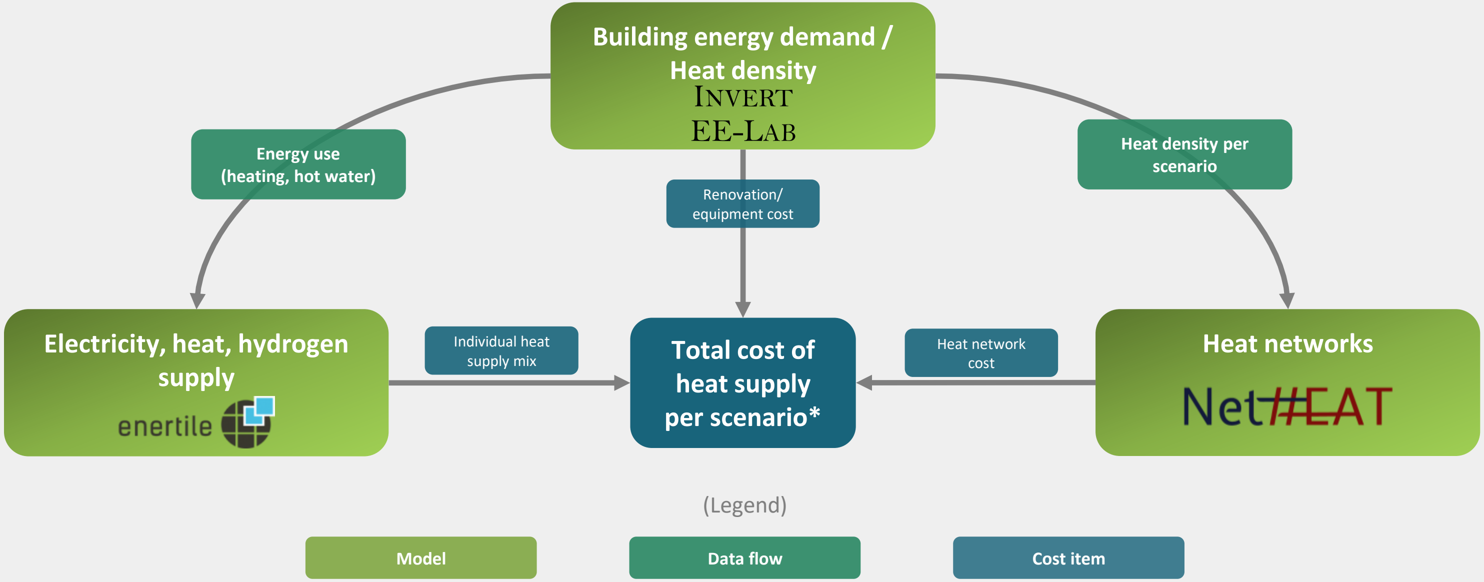
	Karlsruhe	Budapest	Milan	Warsaw	Helsinki
Total population [Mil. inhabitants]	0.31	1.75	1.35	1.76	0.63
Population density [inh/km²]	1,800	3,351	7,700	3,460	2,986
Climate zone	4	3	1&2	3	5
HDD 2019	2,650	2,293	1,859	2,764	4,142
DH Installed capacity [MWth]	800	2,345	901	5,329	3,630
DH Heat Production [GWh]	900	2,184	1,226	9,472	7,200
DH network length [km]	222	460	317	1,735	1,390
Liner heat density [MWh/m]	**4.05**	**4.75**	**3.87**	**5.46**	**5.18**
DH density[km/ 1000 inh]	**0.71**	**0.26**	**0.23**	**1.02**	**2.2**
DH Market share [%]	**30%**	**30%**	**10%**	**80%**	**92%**



Sources: (City of Helsinki, 2019; Galindo Fernandez et al., 2021; Mataszsz, 2019; PGNIG, 2019; Stadtwerke Karlsruhe, 2020; Waciega, 2016)

Methodology

Three models are coupled to assess total cost of heat per scenario



*** Three different buildings heat demand scenarios were calculated for varying refurbishment rates of 1%, 2%, and 3% of the total gross floor area being renovated annually until the year 2050**

Three models are coupled to assess total cost of heat per scenario

* Three different demand projection scenarios were calculated for varying refurbishment rates of 1%, 2%, and 3% of the total gross floor area being renovated annually until the year 2050

NetHEAT basic principle and input data

1 Input: Heat demand and heat density

- Development of the heat demand on a hectare level (100 x 100 m)

2 Input: Buildings

- Number of buildings on a hectare level (100 x 100 m)

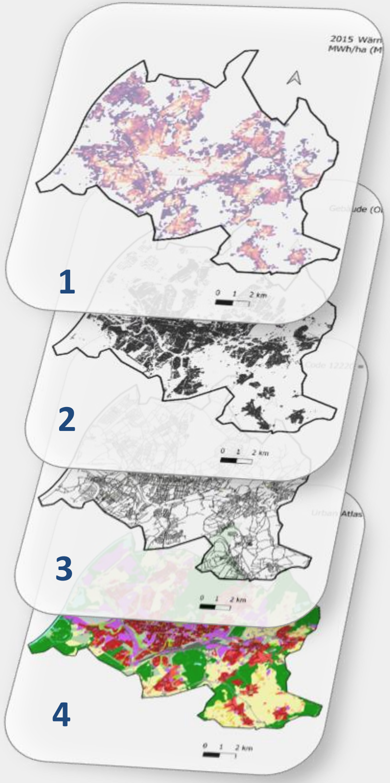
3 Input: Streets

- Pipe length as a function of the street length and the number of buildings on a hectare level (100 x 100 m)

4 Input: Topography (imperviousness density)

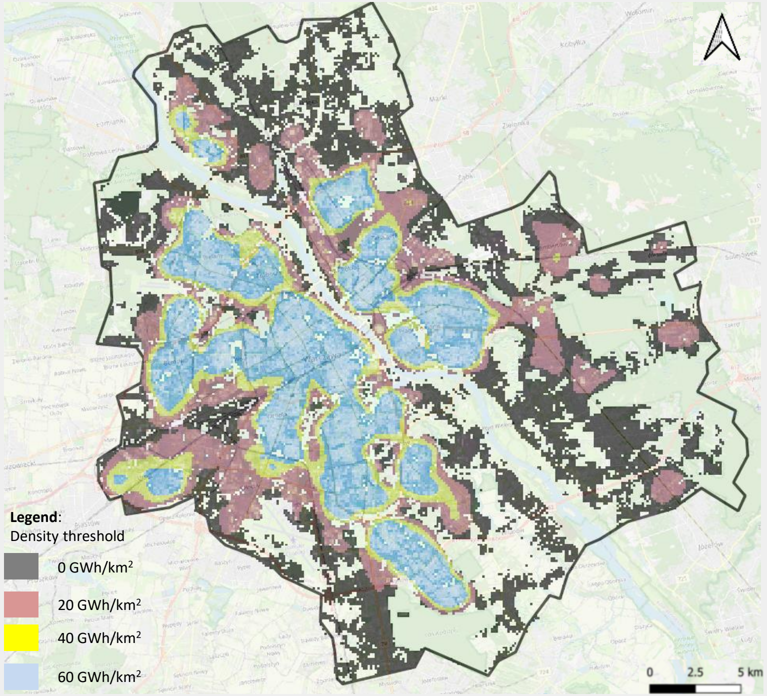
- Imperviousness density on a hectare level (100 x 100 m)

Output: We calculate matrices by stacking the raster file on top of each other



NetHEAT Heat demand and heat density

Regions within a predefined heat density threshold in Warsaw in 2017



Source: Invert EE-Lab and Hotmaps tool

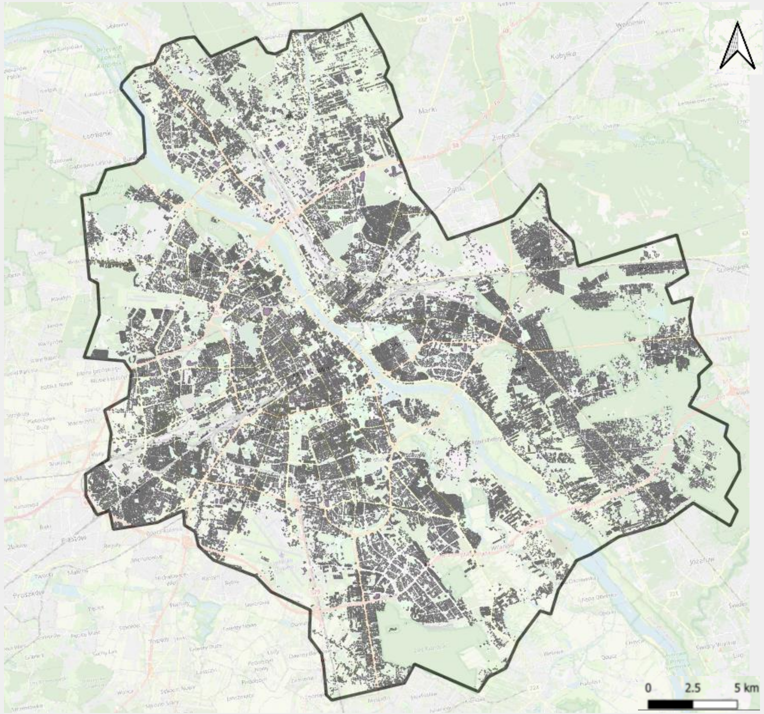
Heat density [MWh/ha*a]	Assessment of the suitability for the construction of district heating networks
0 – 70	No technical potential
70 – 175	Recommendation for district heating networks in new buildings
175 – 415	Recommended for low-temperature networks in existing buildings
415 – 1.050	Reference value for conventional heating networks in existing buildings
> 1.050	Very high suitability for district heating networks

Source: Kommunale Wärmeplanung – Handlungsleitfaden, Klimaschutz- und Energieagentur Baden-Württemberg GmbH, 2020

Output: Suitable regions with at least 25 GWh/km² in 2050

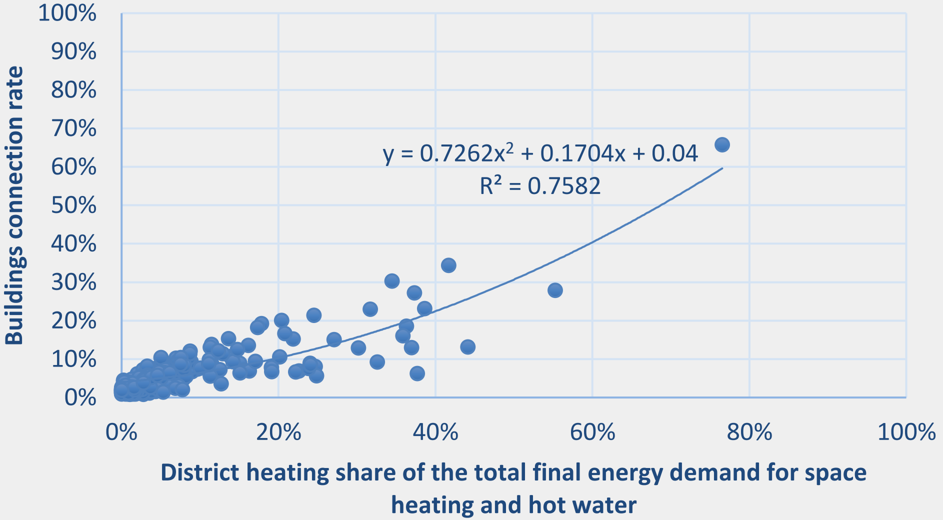
NetHEAT Buildings

OpenStreetMap filtered buildings in Warsaw in 2020



Source: “© OpenStreetMap contributors“

Correlation between district heating share and the number of connected buildings

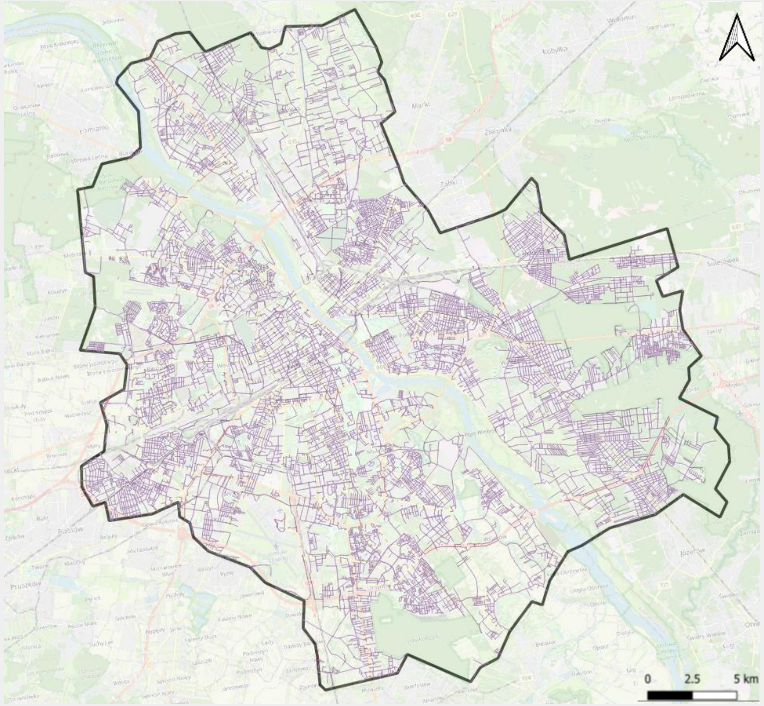


Source: Zensusdaten 2011 Gebäude: Heizungsart, AIRE Projekt

Output: Number of buildings per raster cell

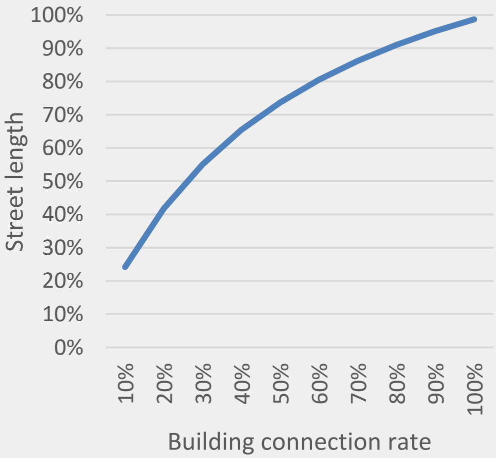
NetHEAT Streets

OpenStreetMap filtered roads in Warsaw in 2020

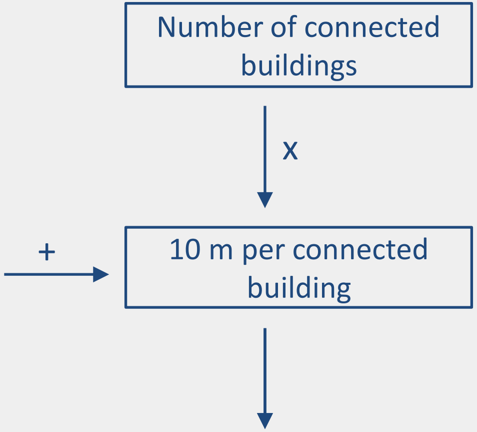


Source: "© OpenStreetMap contributors"

Share of used streets depending on the buildings connection rate



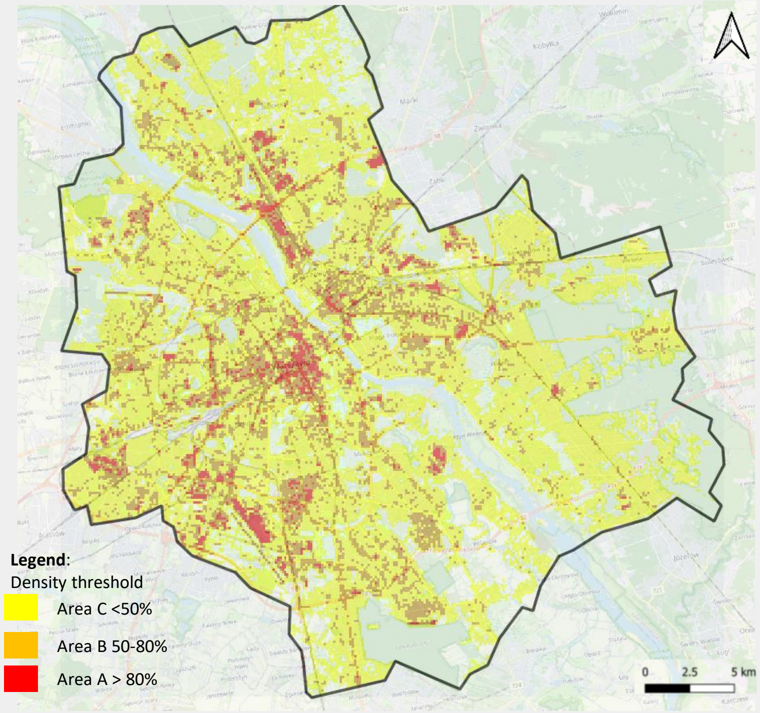
Source: Beuth, ifeu: Ableitung eines Korridors für den Ausbau der erneuerbaren Wärme im Gebäudebereich



Output: Network length per raster cell [m]

NetHEAT Topography (imperviousness density)

Warsaw imperviousness density in 2018



Source: © European Union, Copernicus Land Monitoring Service 2022, European Environment Agency (EEA)

Construction area	C1 (€/m)	C2 (€/m²)
Area 1 – Continuous urban fabric (81 – 100%)	419	3238
Area 2 –Discontinuous dens urban fabric (51 – 80%)	352	2572
Area 3 – Medium to low urban fabric (0 – 50%	229	2191

Source: Own calculation based on Eurostat and Heat Roadmap Europe

Country	Labor cost index –construction sector	Price level index for machinery and equipment
Germany	1.00	1.00
Italy	0.81	0.99
Poland	0.34	0.92
Hungary	0.28	0.94
Finland	1.18	1.13

Output: Specific construction costs per raster cell

NetHEAT Costs Calculation approach

Top-down approach (Heat Roadmap Europe)

- **Pipe length** and **pipe diameter** as a function of the plot ratio and the effective width
- **Cost coefficients** based on a plot ratio (building density)

$$C_d = \frac{a * (C_1 + C_2 * d_a)}{\frac{Qs}{L}}$$

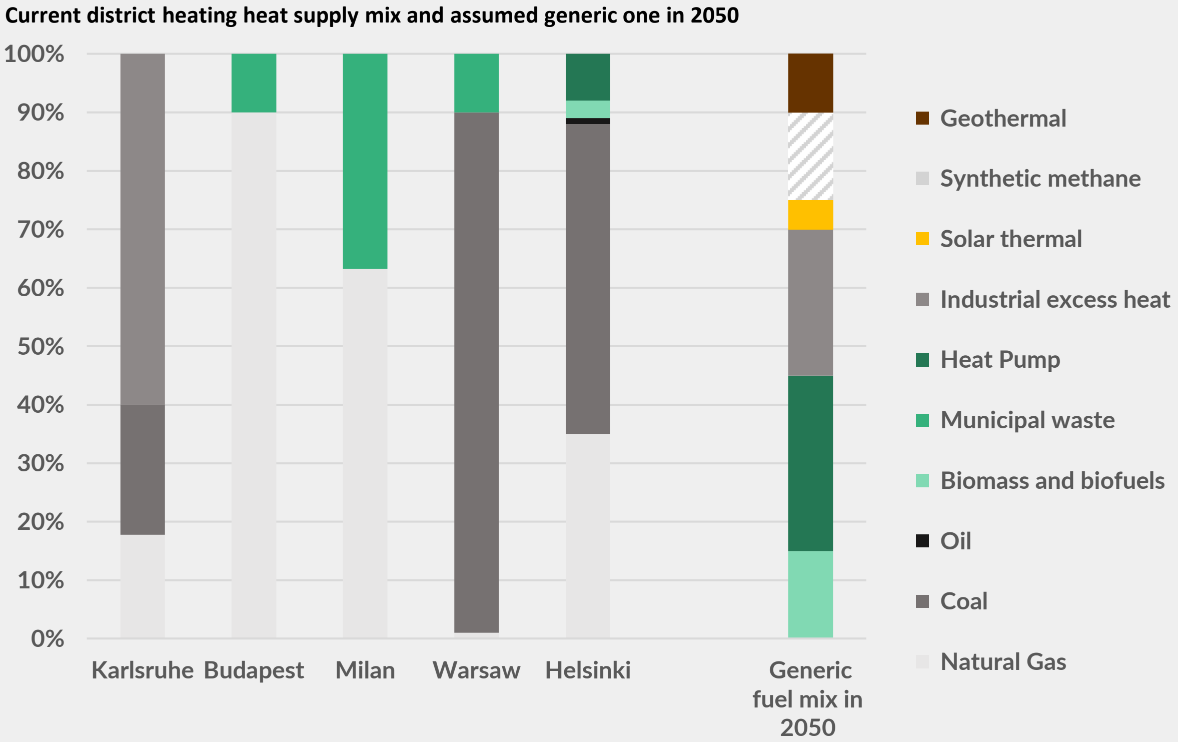
C_d specific investment costs [€/MWh]
a - Annuity
Q_s - Heat demand [MWh]
L – Network length [m]
d_a - Average pipe diameter [m]

Source: Persson U., Werner S., *Heat distribution and the future competitiveness of district heating,* Applied Energy 88 (2011) 568-576

NetHEAT bottom-up approach

- **Pipe length** calculated based on the street length and connected buildings
- **Pipe diameter** calculated based on the mass flow and the flow velocity
- **Cost coefficients** based on imperviousness density
- Specific investment costs (€/m) are calculated for each pipe DN and construction area

District heating heat supply mix



- Compare building refurbishment impact across cities and scenarios

- Assumed generic heat fuel mix in 2050 consisting of:
  - heat pumps (30%)
  - industrial excess heat (25%)
  - synthetic methane (15%)
  - biomass and biofuels (15%
  - geothermal heat (10%)
  - solar thermal (5%)

Methodology summary

1. Three building refurbishment scenarios (1%, 2%, and 3% average refurbishment rates)
2. Identification of suitable district heating regions (25 GWh/km²)
3. Varying connection rates within the DH regions (0% – 95%)
4. Remaining share of heat supplied by individual heat supply technologies

I. Single - family house	Gas boiler
II. Multi - family house	Oil boiler
III. Offices	Coal boiler
IV. Education	Direct electric
V. Health	Air-to-air heat pump
VI. Hotels and restaurants	Air-to-water heat pump
VII. Wholesale and retail	Ground source heat pump
VIII. Other non-residential	Solar thermal

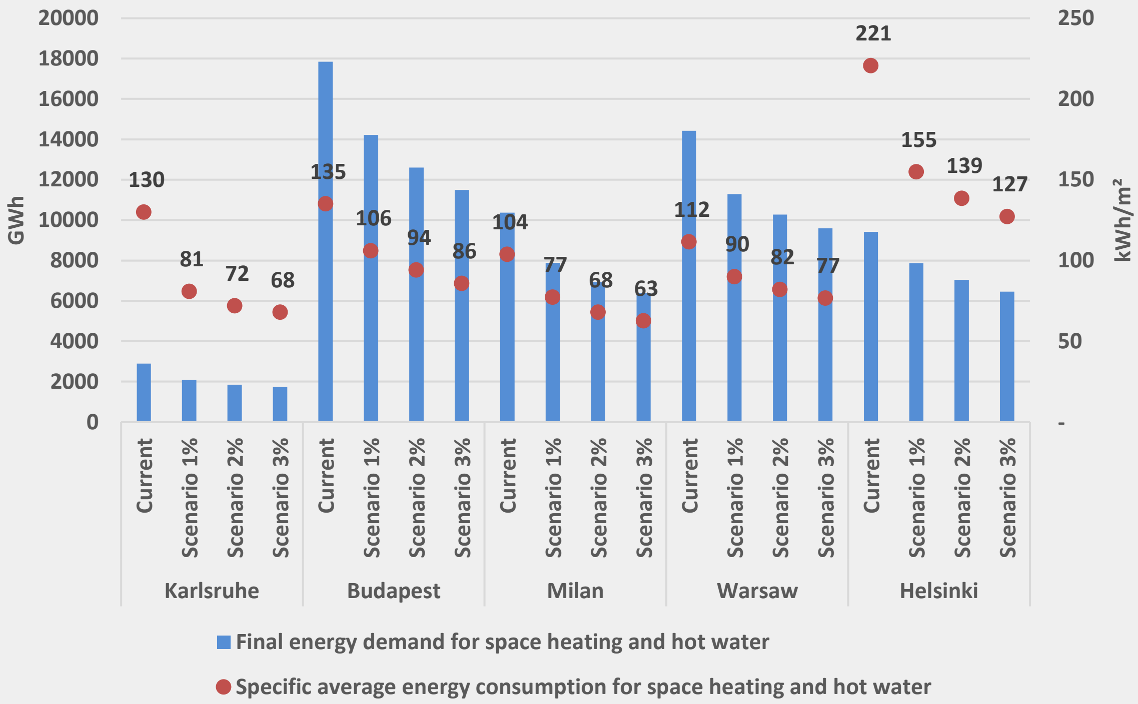
5. Total cost of heat per scenario and building connection rate
   i. Building refurbishment costs
   ii. District heating supply costs
   iii. Individual (decentral) heat supply costs

Q&A Session

Results

Morris Charts
Line Chart
Area Chart
Bar Chart
Donut Chart
Sparkline Charts
Line Chart
Bar Chart
Pie Chart
Easy Pie Charts
25%
50%
75%
100%
enefirst.

Heat demand development until 2050



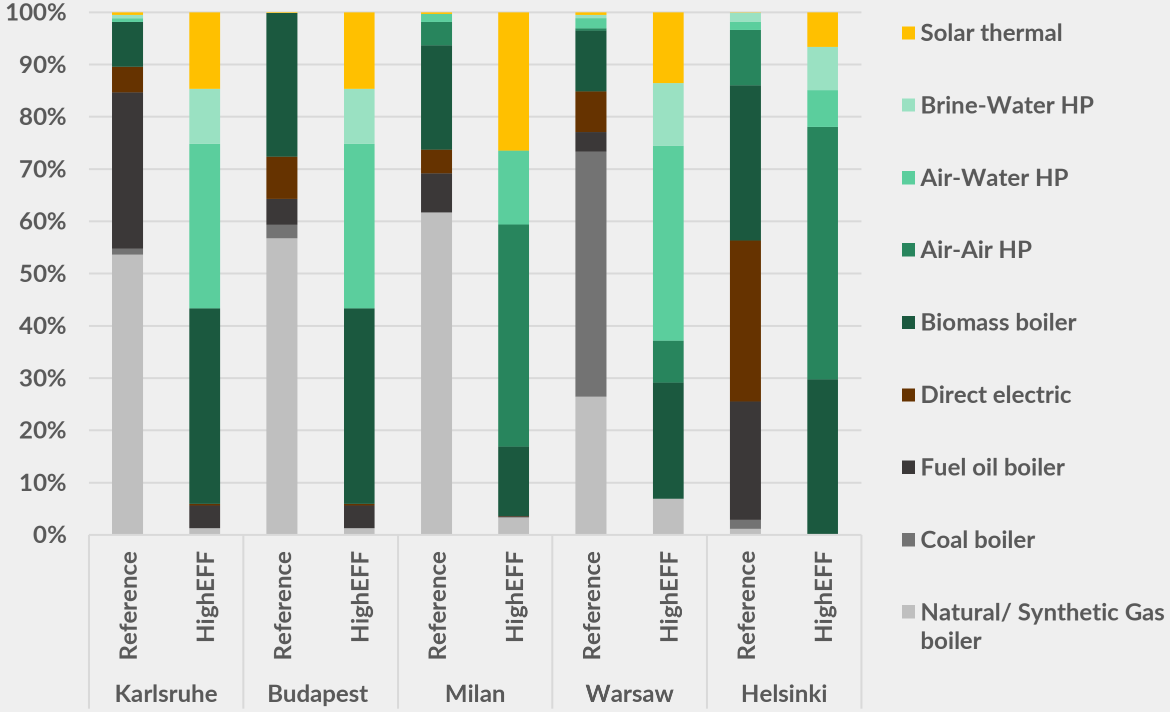
Results

- Heated floor are in 2050 in Helsinki (+19%), Karlsruhe (+14%), Budapest (+1.4%), Milan (-0.5%), and Warsaw (-3.3%)
- Specific average consumption decreases between 19% and 48%

Key message

Final energy demand savings between 16% and 40% can be expected

Individual heat supply units



Results

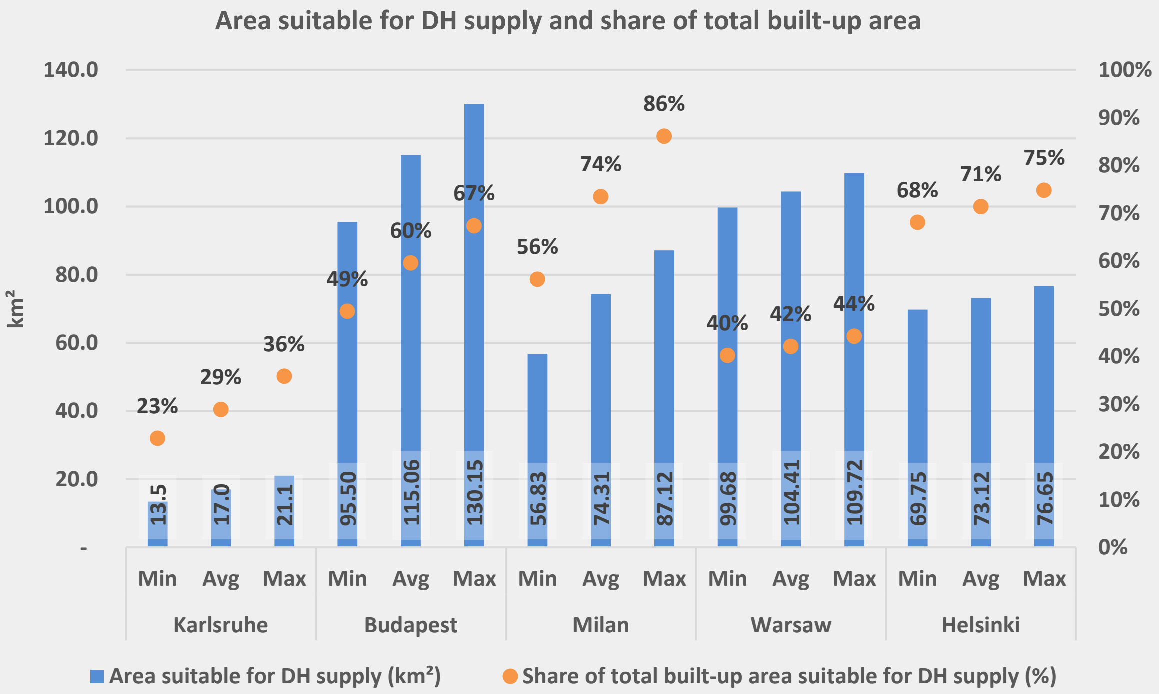
- Current individual heat supply dominated by fossil fuel boilers
- Assumption: the national results applied on a local level as well

Key message

Drastic increase in the share of individual heat supplied by solar thermal and heat pumps

Source: HighEFF scenario from ENEFIRST D3.3 report

Areas suitable for district heating supply



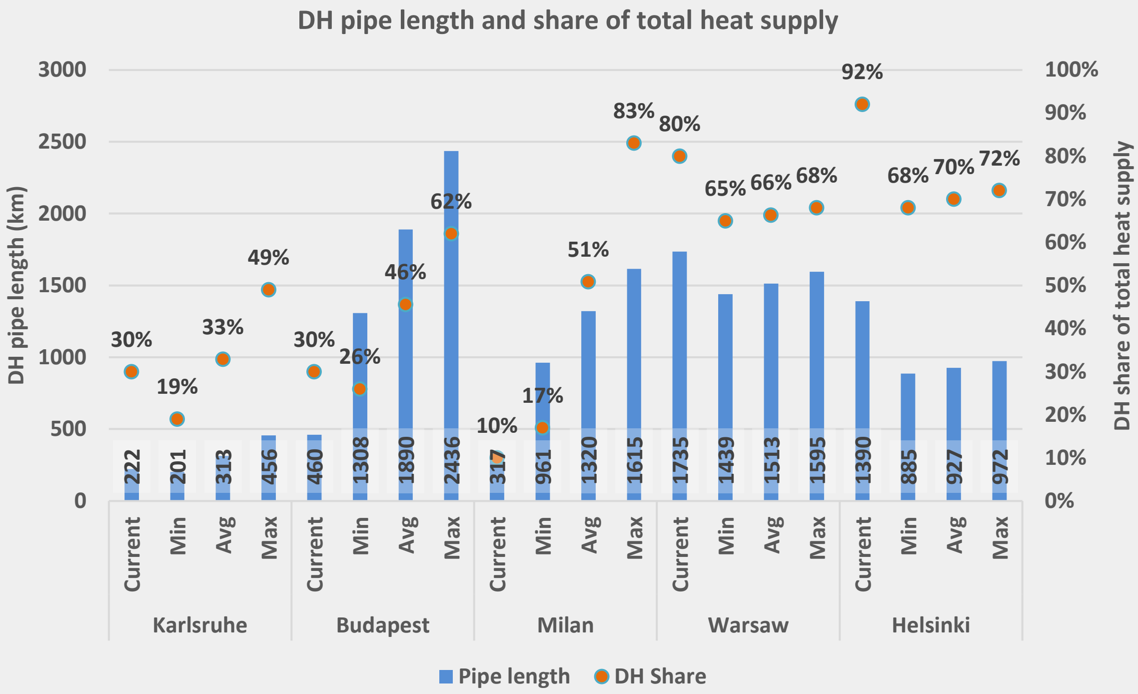
Results

- Built-up area within the identified DH regions (25 GWh/km²)
- Milan has the largest areas suitable for DH supply

Key message

Built-up area suitable for DH varies widely between the cities and the scenarios

District heating pipe length and share of district heat



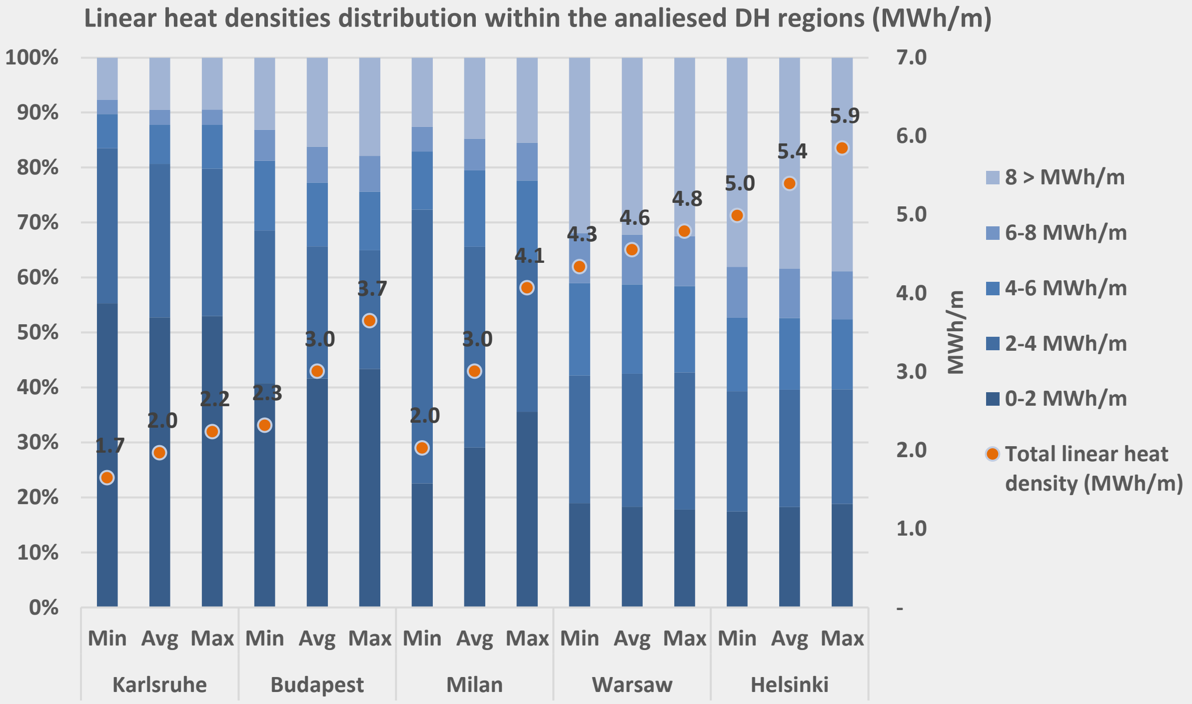
Results

- Reduction of the DH share in the cities with high shares of heat supply (Warsaw and Helsinki)
- High network expansion potentials in Budapest and Milan

Key message

The definition of suitable DH regions leads to DH reduction in the cities with high shares of DH in their current heat supply

Linear heat densities



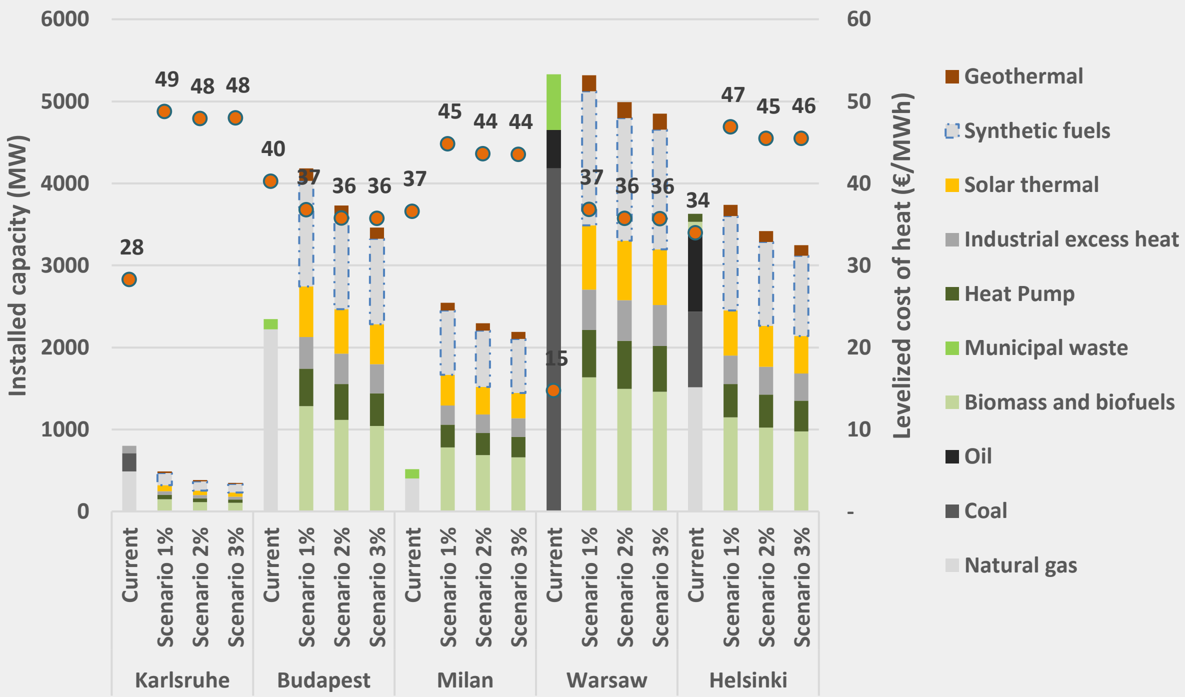
Results

- Highest linear heat densities observed in Helsinki
- Most of the hectare regions are above 2 MWh/m (apart from Karlsruhe)

Key message

From todays perspective most of the scenarios are economically feasible (> 1.5 MWh/m)

Heat generation capacities and costs



Results

- Reduced heat generation capacities due to the lower peak demand loads
- Higher cost of heat generation in almost all of the scenarios

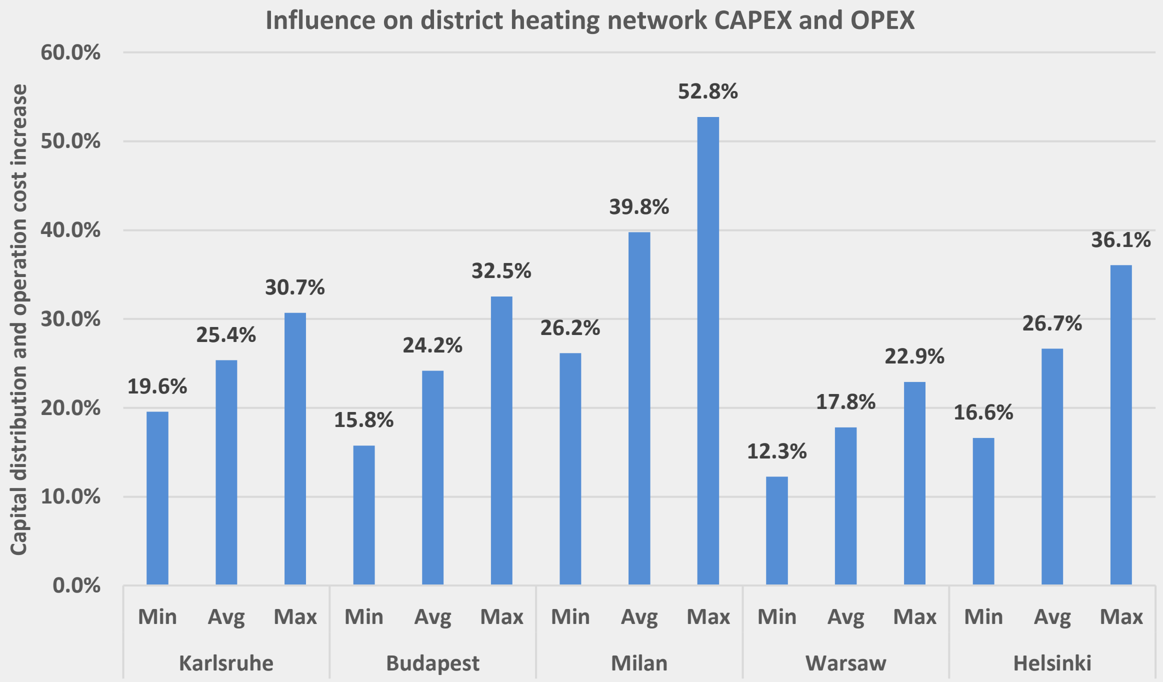
Key message

Increase in the heat generation costs can be expected due to the shift from coal-fired CHP to renewable heat.

Source: Own calculation based on Ortner et al. (2021), Grosse et al (2017), Duić et al (2017), Eurostat price level and labour cost indices.

Assumption: 50% capacity factor (geothermal, excess heat, heat pumps) and 10% for the heat only boilers (biomass, biofuels, synthetic fuels)

District heating price development



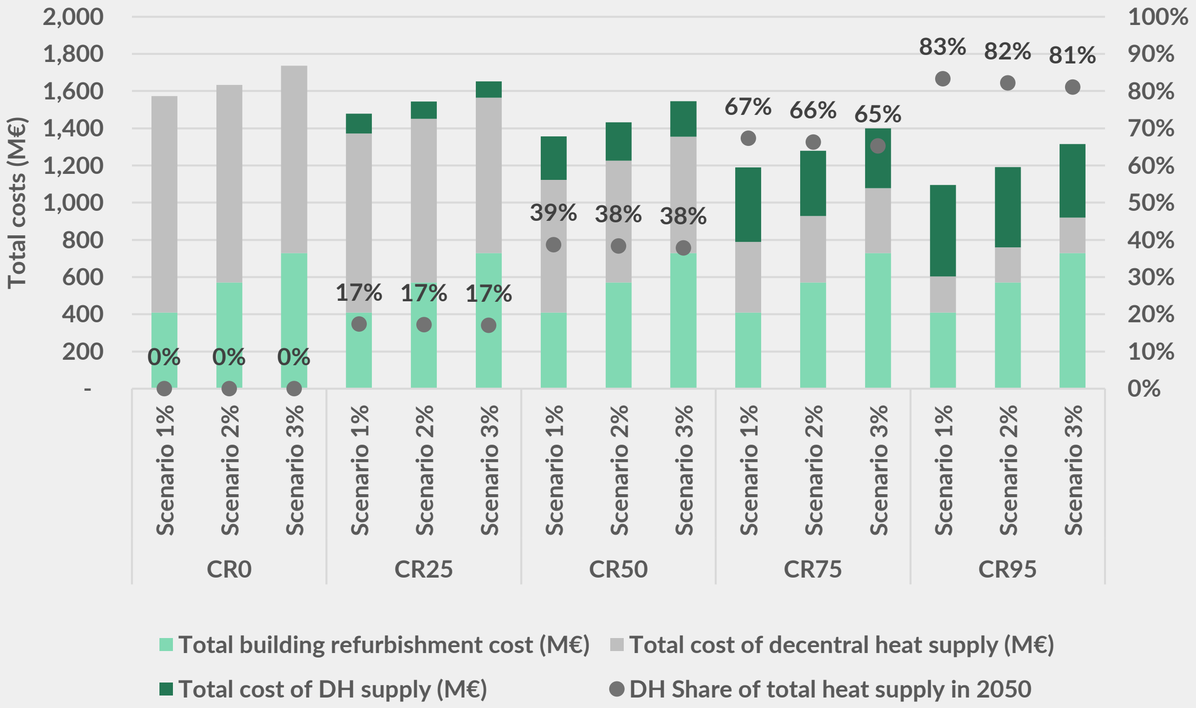
Results

- Influence on the relative cost of the distribution network in relation to the total DH supply
- Average district heating prices between 61 €/MWh and 89 €/MWh

Key message

An average price increase between 14% and 35% can be expected due to the reduced heat densities

Total costs of heat supply (Milan)



Results

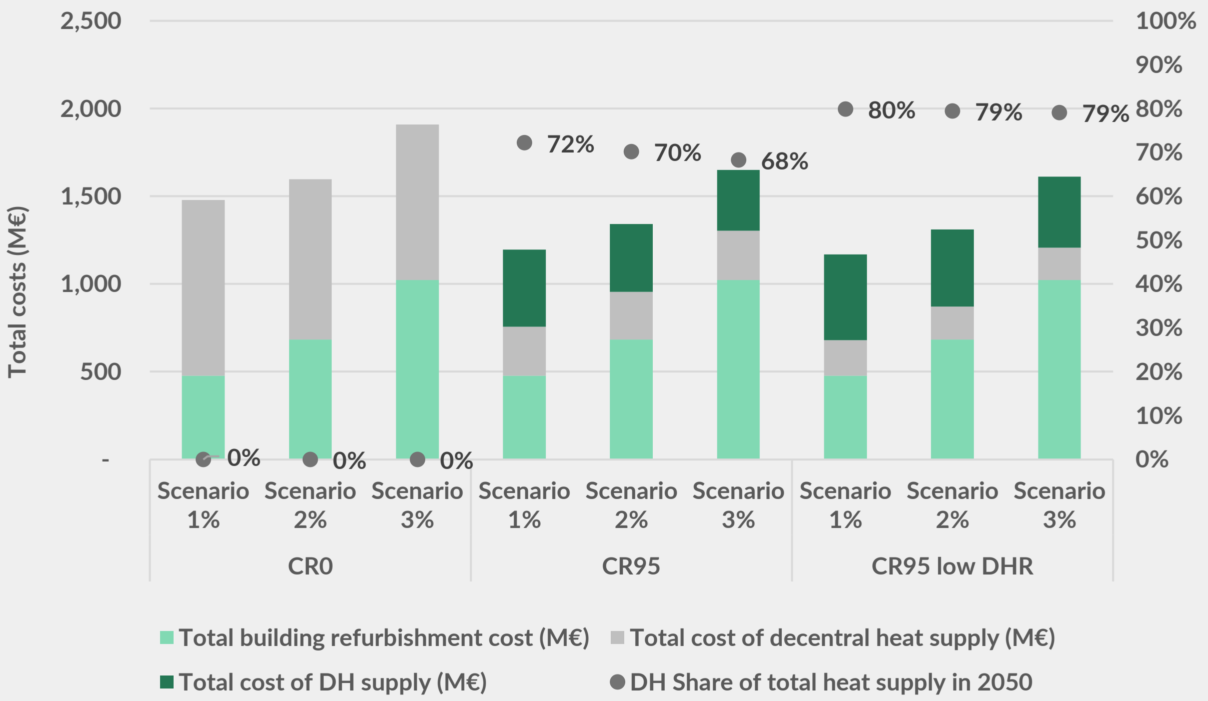
- Up to 83% of the heat can be supplied by DH in cost-effective manner
- 1% Scenario is the cheapest one in all of the DH connection rates variations

Key message

In all scenarios is cheaper to invest in DH in comparison to the individual heat supply

Building Connection Rate (CR) within the identified District Heating Regions (DHR) with 25 GWh/km²

Total costs of heat supply (Helsinki)



Results

- The predefined DHR (25 GWh/km²) reduce the current share of heat supplied by DH
- By removing this threshold ca. 80% of the heat can be supplied in a cost-effective manner

Key message

From an economic point of view it might be reasonable to reduce the DH supply from the current ca. 92% to 80% in 2050

Building Connection Rate (CR) within the identified District Heating Regions (DHR) with 25 GWh/km²

Discussion and conclusion of the model-based results

Discussion

- The improved **building efficiency** affects the boundaries of the **economic viability of the DH** networks in several ways (higher relative distribution costs, lower installed capacities, higher heat generation efficiencies)
- One of the major **strengths** of the **district heating** networks is the ability to combine many heat sources (fossil/ synthetic fuels and renewable heat) and balance the impact of high fuel prices
- Investment in buildings' envelope **energy efficiency measures** and connecting **more buildings to district heating** networks could act as a **safeguard** against high future prices and reduce the risk of **energy poverty**

Conclusion

- **Increase in district heating prices** between **14% and 35%** can be expected due to the **reduced heat densities**
- **Maximizing the connection rate** in the identified regions leads to **lower total cost of heat**
- **Municipal heat planning** as a strategic approach can ensure a climate-neutral and affordable heat supply by **properly implementing** and monitoring the **efficiency first principle**

Thank you for very much your attention

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