District heating and deep retrofits of buildings

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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

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

**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

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

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

Correlation between district heating share and the number of connected buildings

\[ y = 0.7262x^2 + 0.1704x + 0.04 \]

\[ R^2 = 0.7582 \]

Source: Zensusdaten 2011 Gebäude: Heizungsart, AIRE Projekt

Output: Number of buildings per raster cell

Source: "© OpenStreetMap contributors"
NetHEAT Streets

OpenStreetMap filtered roads in Warsaw in 2020

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]

Source: “© OpenStreetMap contributors”
NetHEAT Topography (imperviousness density)

Warsaw imperviousness density in 2018

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

Source: Own calculation based on Eurostat and Heat Roadmap Europe

<table>
<thead>
<tr>
<th>Country</th>
<th>Labor cost index – construction sector</th>
<th>Price level index for machinery and equipment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Germany</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>Italy</td>
<td>0.81</td>
<td>0.99</td>
</tr>
<tr>
<td>Poland</td>
<td>0.34</td>
<td>0.92</td>
</tr>
<tr>
<td>Hungary</td>
<td>0.28</td>
<td>0.94</td>
</tr>
<tr>
<td>Finland</td>
<td>1.18</td>
<td>1.13</td>
</tr>
</tbody>
</table>

Output: Specific construction costs per raster cell

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

\[ C_d = \frac{a \times (C_1 + C_2 \times d_a)}{Q_s / L} \]

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


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
Heat demand development until 2050

Results

- Heated floor area 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
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.
Results

- Highest linear heat densities observed in Helsinki

- Most of the hectare regions are above 2 MWh/m (apart from Karlsruhe)

Key message

From today’s 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), Duć 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
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.

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