3RD INTERNATIONAL CONFERENCE ON
SMART ENERGY SYSTEMS AND
4TH GENERATION DISTRICT HEATING
COPENHAGEN, 12–13 SEPTEMBER 2017
SESSION 27
HEAT ROADMAP EUROPE: HEAT DISTRIBUTION COSTS
KEYNOTE: URBAN PERSSSON
INTRODUCTION

• This work presents the second step in the development of a comprehensive distribution capital cost model for assessing investment costs for district heating systems in a European context.

• The first step, Persson and Werner (2011)*, included:
  – Theoretical reformulation of linear heat density to allow systematic feasibility analyses at new locations.
  – Model application on 1703 Urban Audit city districts in 83 cities (BE, DE, FR, and NL).
  – Identification of a three-fold directly feasible expansion possibility from current levels.

INTRODUCTION

• Have you seen this before?
  – Main result graph from the first step!
  – Three-fold feasible expansion possibility from current levels!

INTRODUCTION

• Overview
  – Some words on the distribution cost model
  – Main findings from the first step
  – Towards hectare resolution
  – Ready for the second step
  – Some words on the spatial demand density model
  – Outputs from the Heat Roadmap Europe project
  – Early results from the second step
  – Conclusions
DISTRIBUTION COST MODEL

• The distribution capital cost model

\[
C_d = \frac{a \cdot \left( \frac{I}{L} \right)}{(Q_s/L)} = \frac{a \cdot (C_1 + C_2 \cdot d_a)}{p \cdot \alpha \cdot q \cdot w}
\]

Heat demand density:

\[
q_L = p \cdot \alpha \cdot q
\]

Plot ratio:

\[
e = p \cdot \alpha = \frac{P}{A_L} \cdot \frac{A_B}{P}
\]

Effective width:

\[
w = \frac{A_L}{L}
\]
**DISTRIBUTION COST MODEL**

- The distribution capital cost model

\[
C_d = a \cdot \left( \frac{L}{Q_s} \right) = \frac{a \cdot (C_1 + C_2 \cdot d_a)}{p \cdot \alpha \cdot q \cdot w}
\]

Heat demand density:

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q_L = p \cdot \alpha \cdot q
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Plot ratio:

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Effective width:

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w = \frac{A_L}{L}
\]
DISTRIBUTION COST MODEL

- Specific investment cost & linear heat density

Independent input data

- Annuity [€/a]
- Construction cost constant [€/m]
- Construction cost coefficient [€/m²]
- Pipe diameter [m]
- Population density [n/km²]
- Specific building space [m²/Capita]
- Specific heat demand [GJ/m²a]
- Effective width [m]

Intermediate input data

- Plot ratio [-]
- Heat demand density [GJ/m²]

Final output data

- Specific investment cost [€/m]
- Linear heat density [GJ/m]
- Distribution capital cost [€/GJ]

Distribution capital cost:

\[ C_d = \frac{a \cdot \left( \frac{I}{L} \right)}{(Q_S/L)} = \frac{a \cdot (C_1 + C_2 \cdot d_a)}{p \cdot \alpha \cdot q \cdot w} \]

Heat demand density:

\[ q_L = p \cdot \alpha \cdot q \]

Plot ratio:

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DISTRIBUTION COST MODEL

• Specific investment cost

\[
C_d = \frac{a \cdot \left(\frac{I}{L}\right)}{Q_s/L} = \frac{a \cdot (C_1 + C_2 \cdot d_a)}{p \cdot \alpha \cdot q \cdot w}
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Heat demand density:

\[q_L = p \cdot \alpha \cdot q\]

Plot ratio:

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Effective width:

\[w = \frac{A_L}{L}\]
DISTRIBUTION COST MODEL

• Specific investment cost

\[
\begin{align*}
A &= 2022,3x + 286,15 \\
B &= 1725x + 213,83 \\
C &= 1378x + 151,22
\end{align*}
\]

- A - Inner City
- B - Suburbs
- C - Rural areas

**Distribution capital cost:**

\[
C_d = \frac{a \cdot \left(\frac{l}{I}\right)}{(Q_s/L)} = \frac{a \cdot (C_1 + C_2 \cdot d_a)}{p \cdot \alpha \cdot q \cdot w}
\]

**Heat demand density:**

\[
q_L = p \cdot \alpha \cdot q
\]

**Plot ratio:**

\[
e = p \cdot \alpha = \frac{P}{A_L} \cdot \frac{A_B}{P}
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**Effective width:**

\[
w = \frac{A_L}{L}
\]
DISTRIBUTION COST MODEL

• Linear heat density

\[
D_0 = \lambda \cdot \frac{I}{Q_S} = \lambda \cdot (C_1 + C_2 \cdot d_a) / (Q_S/L)
\]

Heat demand density:
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q_L = p \cdot \alpha \cdot q
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Plot ratio:
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Effective width:
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DISTRIBUTION COST MODEL

- Plot ratio

Distribution capital cost:
\[ C_d = a \cdot \left( \frac{I}{L} \right) = a \cdot \left( \frac{C_1 + C_2 \cdot d_a}{Q_s/L} \right) \]

Heat demand density:
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Plot ratio:
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DISTRIBUTION COST MODEL

• Plot ratio

<table>
<thead>
<tr>
<th>Area characteristics</th>
<th>Plot Ratio (e)</th>
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<tr>
<td>Inner city areas (A)</td>
<td>$e \geq 0.5$</td>
</tr>
<tr>
<td>Outer city areas (B)</td>
<td>$0.3 \leq e &lt; 0.5$</td>
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<tr>
<td>Park areas (C)</td>
<td>$0 \leq e &lt; 0.3$</td>
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Distribution capital cost:

$$C_d = \frac{a \cdot \left(\frac{I}{L}\right)}{(Q_s/L)} = \frac{a \cdot (C_1 + C_2 \cdot d_a)}{p \cdot \alpha \cdot q \cdot w}$$

Heat demand density:

$$q_L = p \cdot \alpha \cdot q$$

Plot ratio:

$$e = p \cdot \alpha = \frac{P}{A_L} \cdot \frac{A_B}{P}$$

Effective width:

$$w = \frac{A_L}{L}$$

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www.4dh.eu  www.reinvestproject.eu  www.heatroadmap.eu
DISTRIBUTION COST MODEL

- Heat demand density

\[
q_L = p \cdot \alpha \cdot q
\]

Distribution capital cost:

\[
C_d = a \cdot \frac{I}{(Q_s/L)} = a \cdot (C_1 + C_2 \cdot d_a) \cdot p \cdot \alpha \cdot q \cdot w
\]

Plot ratio:

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DISTRIBUTION COST MODEL

• Effective width

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DISTRIBUTION COST MODEL

• Effective width

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The distribution capital cost model

Distribution capital cost:

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THE FIRST STEP

- **Urban Audit dataset:**
  - 83 cities, 1703 city districts
  - France, Belgium, Germany and the Netherlands
  - Population coverage; ~21% (~35 million out of ~170 million)

THE FIRST STEP

• Three-fold directly feasible expansion from current levels
• Indicative plot ratio threshold: 0.15 – 0.20
• Corresponding heat density: 90 TJ/km² (~25 GWh/km²)
TOWARDS HECTARE RESOLUTION

• Considerations:
  – The Urban Audit city districts were of random sizes!
  – Using a uniform and homogenous spatial unit for land area
  – A raster grid would be better!
  – Square kilometre resolution?
TOWARDS HECTARE RESOLUTION

- Considerations:
  - In 2013, heat demand density by square kilometre raster grid cell resolution
  - Case study of the Finnish capital Helsinki and surrounding cities
  - But, still too coarse not to miss out on DHC opportunities!
TOWARDS HECTARE RESOLUTION

• Considerations:
  – DHC opportunities may very well exist below the square kilometre resolution
  – Size and concentration of settlements
  – Spatial coherency and contiguous areas

Figure 1. Low plot ratio land areas, scenario A with wide dispersion of buildings and scenario B with high concentration of buildings.
TOWARDS HECTARE RESOLUTION

• Considerations:
  – DHC opportunities may very well exist below the square kilometre resolution
  – Size and concentration of settlements
  – Spatial coherency and contiguous areas
  – Hectare resolution, but is it available?

Figure 1. Low plot ratio land areas, scenario A with wide dispersion of buildings and scenario B with high concentration of buildings.
TOWARDS HECTARE RESOLUTION

• No, not in 2011:
  – Demand for meta planning of district heating in Europe
    • Identify areas with feasible distribution conditions to promote expansion and benefit from higher energy efficiency, lower carbon dioxide emissions etc.
  – Demand for high resolution pop. grid data in Europe
    • Issue of low resolution in official population density grids (square kilometres, minimum resolution 25 ha)
    • Data on square kilometre resolution disaggregated to hectares not sufficient...
    • Feasible distribution conditions prevailing in sub-square kilometre areas remain hidden...
  – How to model heat demand densities below the square kilometre level in a justified manner?

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THE SECOND STEP

The Heat Roadmap Europe project

- Fourth Heat Roadmap Europe project (HRE4)
- Funded through the Horizon 2020 program (2016 – ongoing)
- WP2: GIS mapping of heating and cooling markets
- Study focus: 14 EU28 MS with the largest heat demands
- Austria, Belgium, Czech Republic, Finland, France, Germany, Hungary, Italy, Netherlands, Poland, Romania, Spain, Sweden, and United Kingdom.
THE SECOND STEP

• Research questions:
  – How to construct a spatial demand density model representing the distribution of residential and service sector building heat demands by hectare resolution?
  – What is the current per hectare spatial distribution of building heat demands in EU28 Member States?
  – What are the current distribution capital cost levels per hectare in EU28 Member States?
  – What are possible and competitive national and urban heat market shares for district heating in EU28 Member States with respect to general conditions and area characteristics?
SPATIAL DEMAND DENSITY MODEL

• Modelling conditions:
  – Zooming in from square kilometre to the hectare level increases the demand for computational capacity
    • Gross land area of EU27: \(~4.4 \text{ Mkm}^2, \sim440 \text{ Mha}\)
    • Gross land area of HRE4 14 MS: \(~3.7 \text{ Mkm}^2, \sim370 \text{ Mha} \,(84\%)\)

<table>
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<th>$A_{\text{Land}}$ [Mkm$^2$]</th>
<th>$A_{\text{Land}}$ [Mha]</th>
<th>$A_{\text{Land,ql}}$ [Mha]</th>
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<td>370.30</td>
<td>33.79</td>
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Input data:

- From the FORECAST model (HRE4 WP3 partners)
- By settlement type, prepared as specific demands
- Adjustments for local climate and population density

<table>
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<tr>
<th>Country</th>
<th>P [Mn]</th>
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<th>$Q_{\text{res}}$ [TWh/a]</th>
<th>$Q_{\text{res,SFH}}$ [TWh/a]</th>
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Input data:

- From the FORECAST model (HRE4 WP3 partners)
- By settlement type, prepared as specific demands
- Adjustments for local climate and population density

<table>
<thead>
<tr>
<th>Country</th>
<th>$q_{\text{hot}}$ [GJ/na]</th>
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<td>6.3</td>
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SPATIAL DEMAND DENSITY MODEL

- Geo-statistical modelling of the built environment
  - In absence of actual demand density data at hectare level, geographical distributions modelled using other available spatial data which correlate with thermal demands
  - Exploratory multilinear regression models: Pop. density at hectare level (the GHS Layer), built-up areas, land use, GDP etc.
  - Floor areas estimated for different types of buildings and settlements

SESSION 27
HEAT ROADMAP EUROPE: HEAT DISTRIBUTION COSTS
KEYNOTE: URBAN PERSSON

OUTPUTS
• Outputs:
  – Budapest
  – Construction cost values updated to represent average 2015 cost levels
• Outputs:
  – **Stockholm**
  – The plot ratio value of each hectare grid cell used to determine the corresponding effective width value, according to:

  \[
  0 < e \leq 0.4; w = 137.5 \cdot e + 5, e > 0.4; w = 60 \quad [m]
  \]
• Outputs:
  
  – **Manchester**
  
  – 84% of all building heat demands in the UK are located in areas with heat demand densities above 50 TJ/km², but only 3% in areas above 300 TJ/km²
Outputs:
- Brussels
- 70% of all building heat demands in BE are located in areas with heat demand densities above 50 TJ/km², and 10% in areas above 300 TJ/km²
EARLY RESULTS

• Distribution of building heat demands
  – ~1/3 of the total HRE4 heat demand volume (32%), originate in lower demand density areas (rural and semi-suburban areas)
  – The exact same share (32%) is found among high density areas (e.g. urban centres and inner city areas)

<table>
<thead>
<tr>
<th>MS</th>
<th>$Q_{\text{tot}}$ [PJ/a]</th>
<th>&lt;20 TJ/km² [%]</th>
<th>20-50 TJ/km² [%]</th>
<th>50-120 TJ/km² [%]</th>
<th>120-300 TJ/km² [%]</th>
<th>&gt;300 TJ/km² [%]</th>
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EARLY RESULTS

• Current distribution capital cost levels per hectare
  – Cumulative cost curves indicating shares of total national heat markets at different distribution capital cost levels

EARLY RESULTS

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  – Cumulative cost curves indicating shares of total national heat markets at different distribution capital cost levels
EARLY RESULTS

• National and urban heat market shares for district heating
  – ~30% district heating heat market shares at marginal cost levels of 3.1 €/GJ
  – ~32% of total heat demands at heat demand densities above 120 TJ/km²
  – Directly feasible European district heating sector of approximately 3.1 EJ/a

### Table: Heat Market Shares for Various Density Levels in Different Countries

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<th>Country</th>
<th>Density (TJ/km²)</th>
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CONCLUSIONS

To conclude...

- Heat demand density and distribution capital costs have successfully been established on the hectare grid cell level!
  - This in itself is a major, unprecedented research achievement that will be further elaborated in coming conference and journal papers
- By comparison to gross land areas, only 9% constitute areas with recorded heat demands at current conditions
- Marginal distribution capital costs as low as below 1 €/GJ are rare but present in the study results
- ~30% district heating heat market shares at marginal cost levels of 3.1 €/GJ – Indicative! Normative?

- WHAT IS THE VALUE OF RECOVERED EXCESS HEAT?
SESSION 27

THANK YOU!

QUESTIONS?
• Outputs:
  – Marginal cold distribution capital costs by hectare level:
  – Barcelona