3RD INTERNATIONAL CONFERENCE ON

SMART ENERGY SYSTEMS AND 4TH GENERATION DISTRICT HEATING

COPENHAGEN, 12–13 SEPTEMBER 2017

AALBORG UNIVERSITY
DENMARK

SESSION 27

ENERGY PLANNING AND PLANNING TOOLS

COPENHAGEN, 13 SEPTEMBER 2017

SESSION 27

HEAT ROADMAP EUROPE: HEAT DISTRIBUTION COSTS

KEYNOTE: URBAN PERSSON

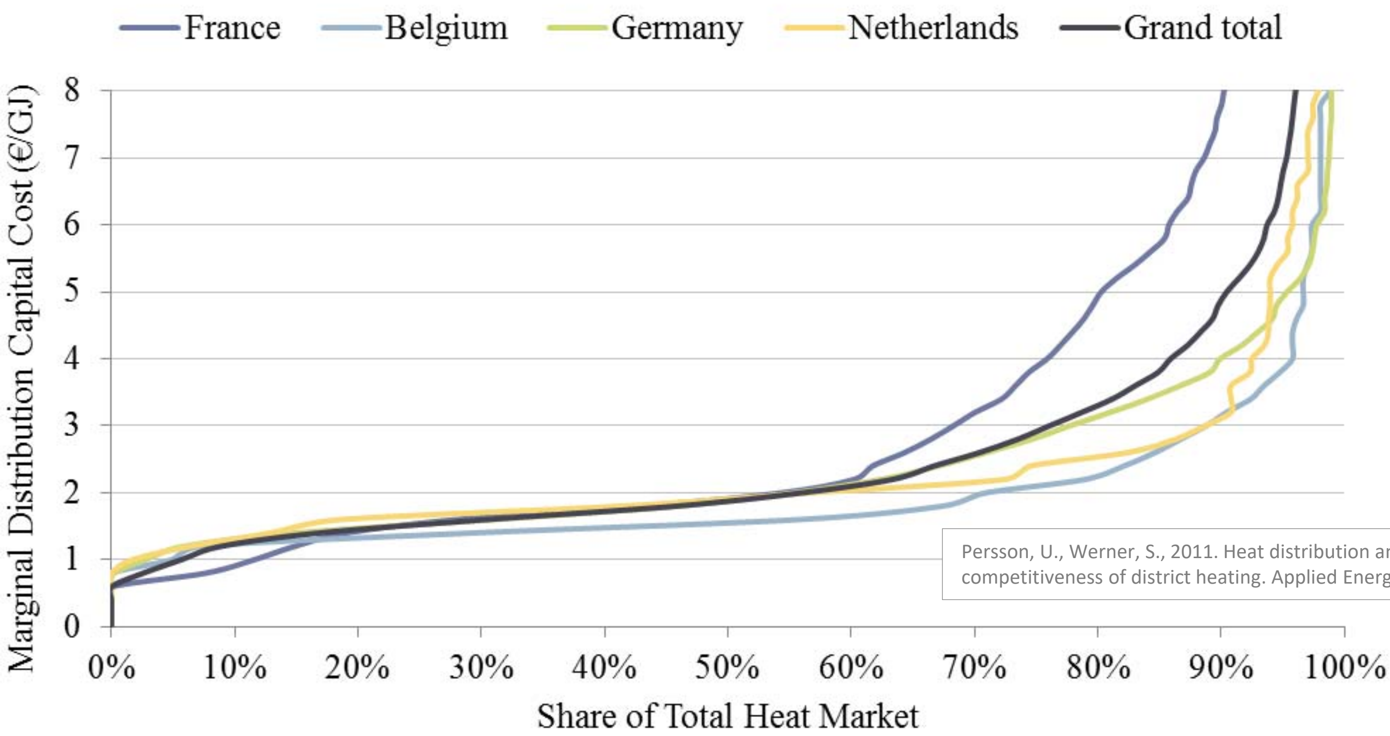
INTRODUCTION

- 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

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

INTRODUCTION

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



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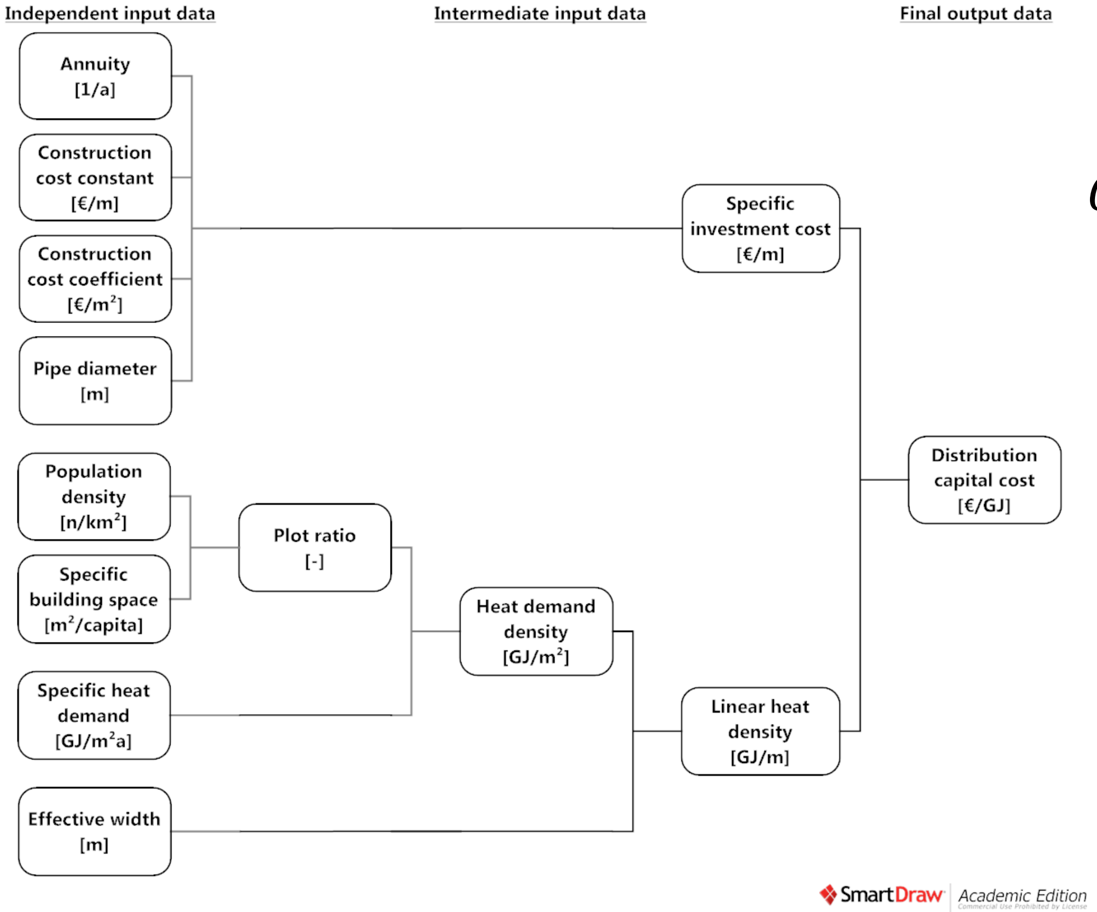
INTRODUCTION

- **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**



Distribution capital cost:

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

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

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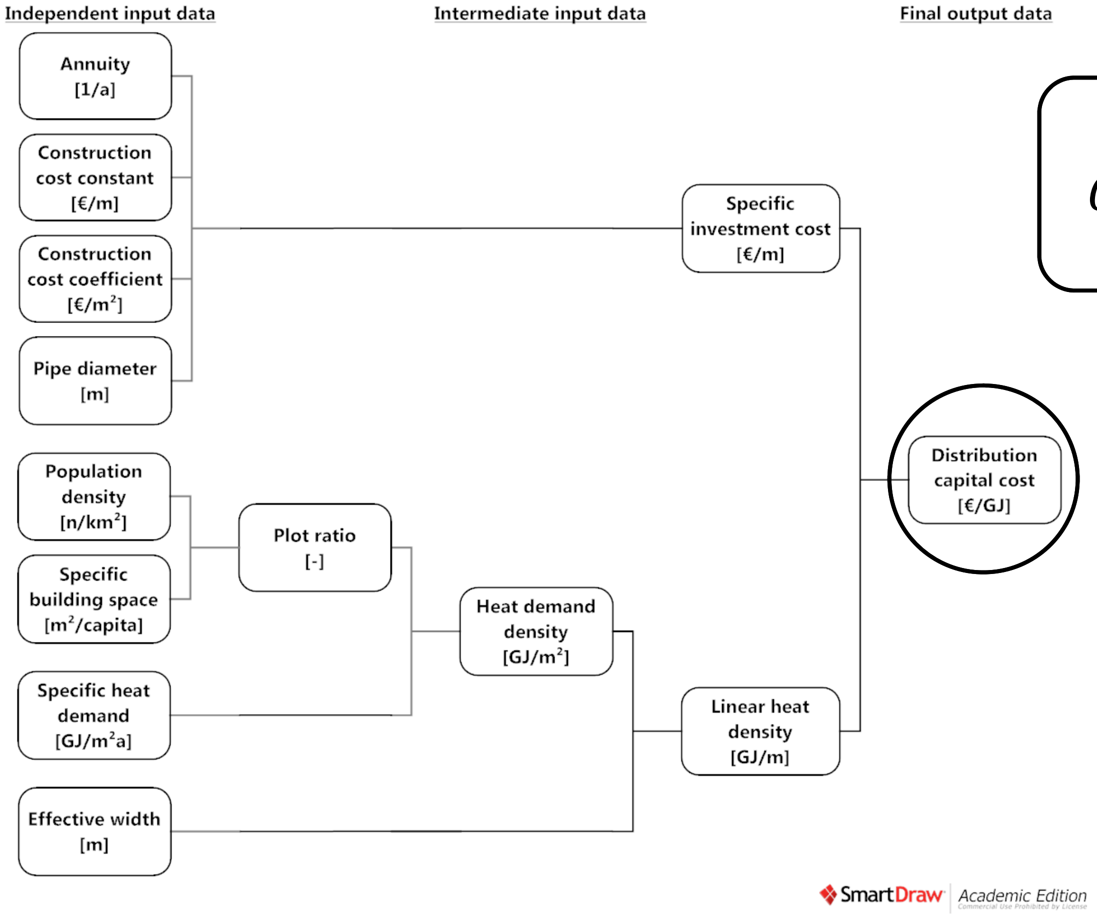

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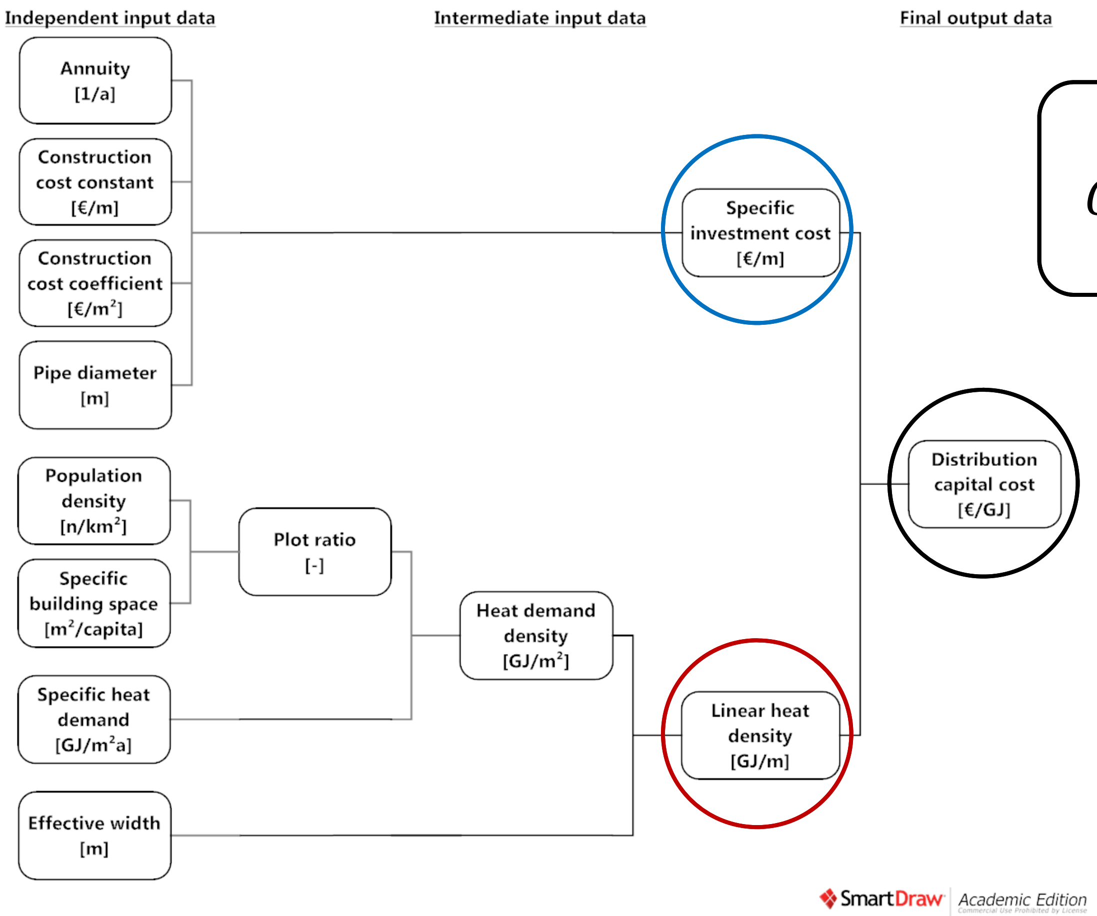
DISTRIBUTION COST MODEL

- **Specific investment cost & linear heat density**



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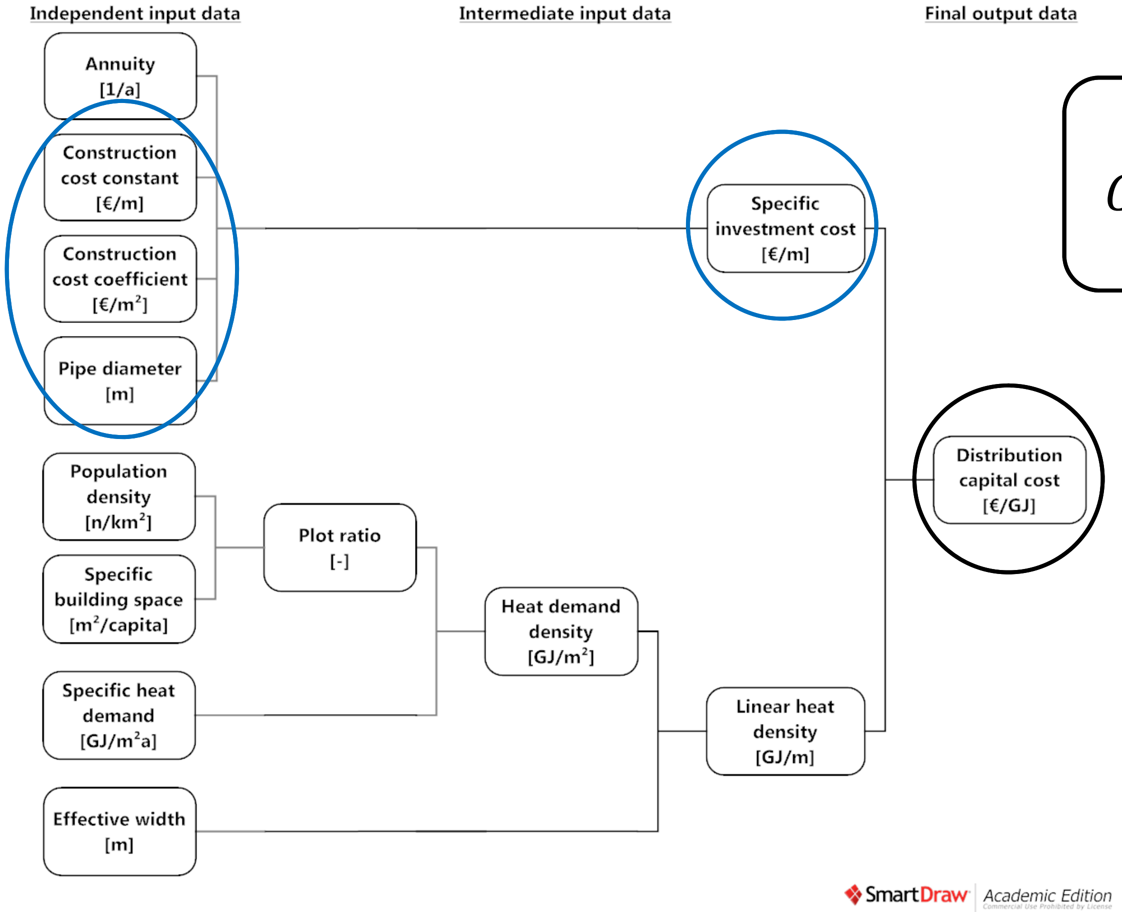
DISTRIBUTION COST MODEL

- **Specific investment cost**



Distribution capital cost:

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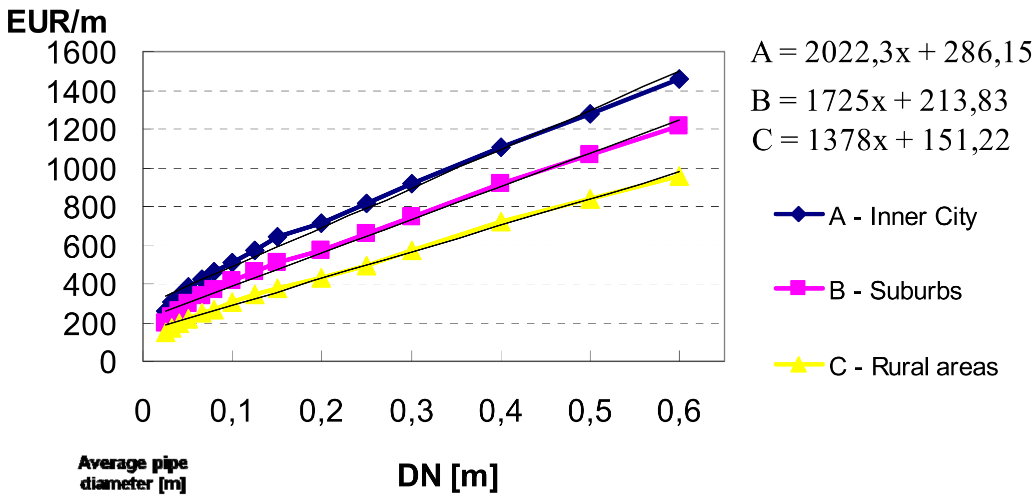
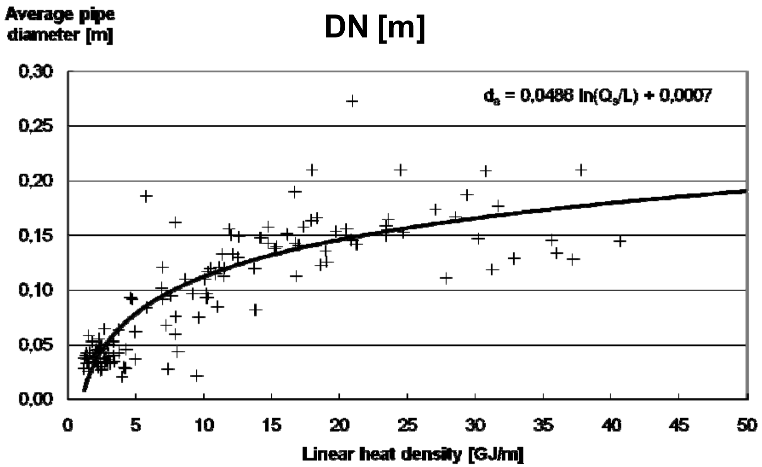
DISTRIBUTION COST MODEL

- **Specific investment cost**





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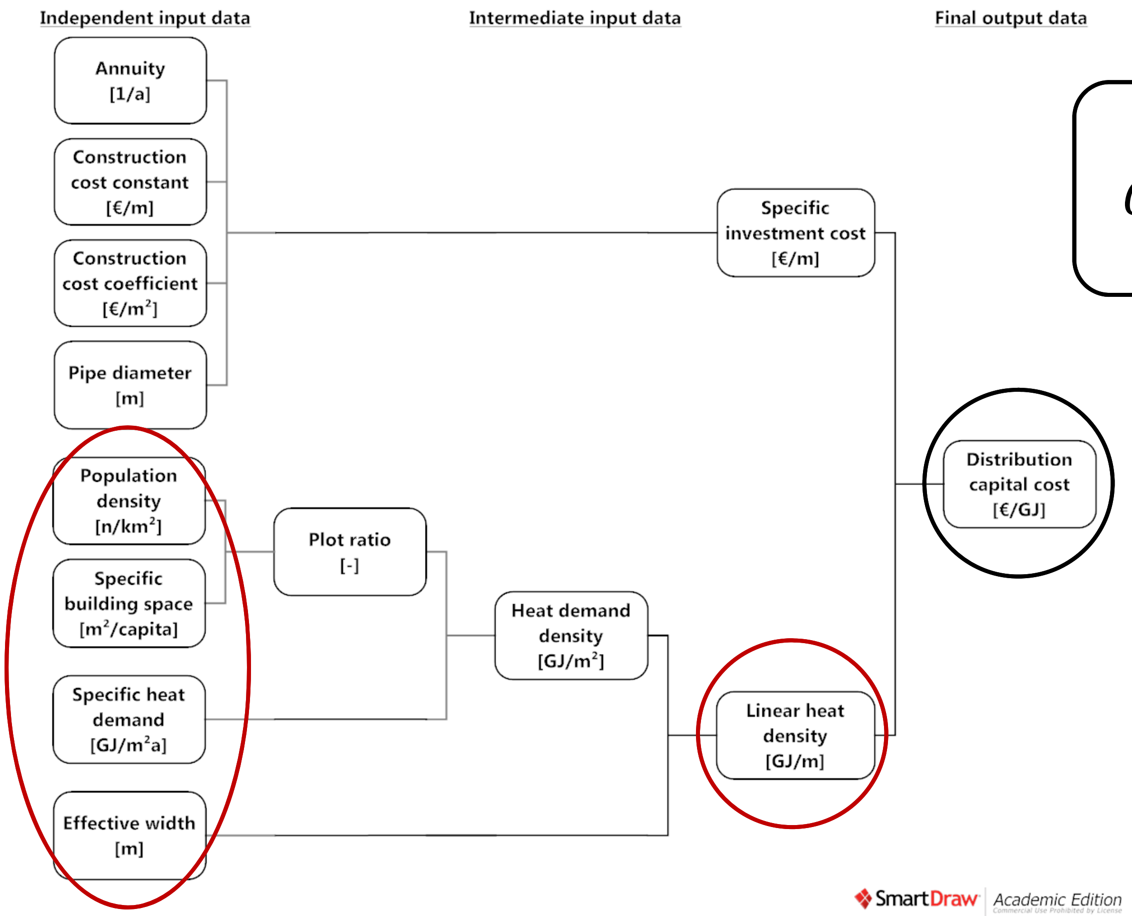
DISTRIBUTION COST MODEL

- **Linear heat density**



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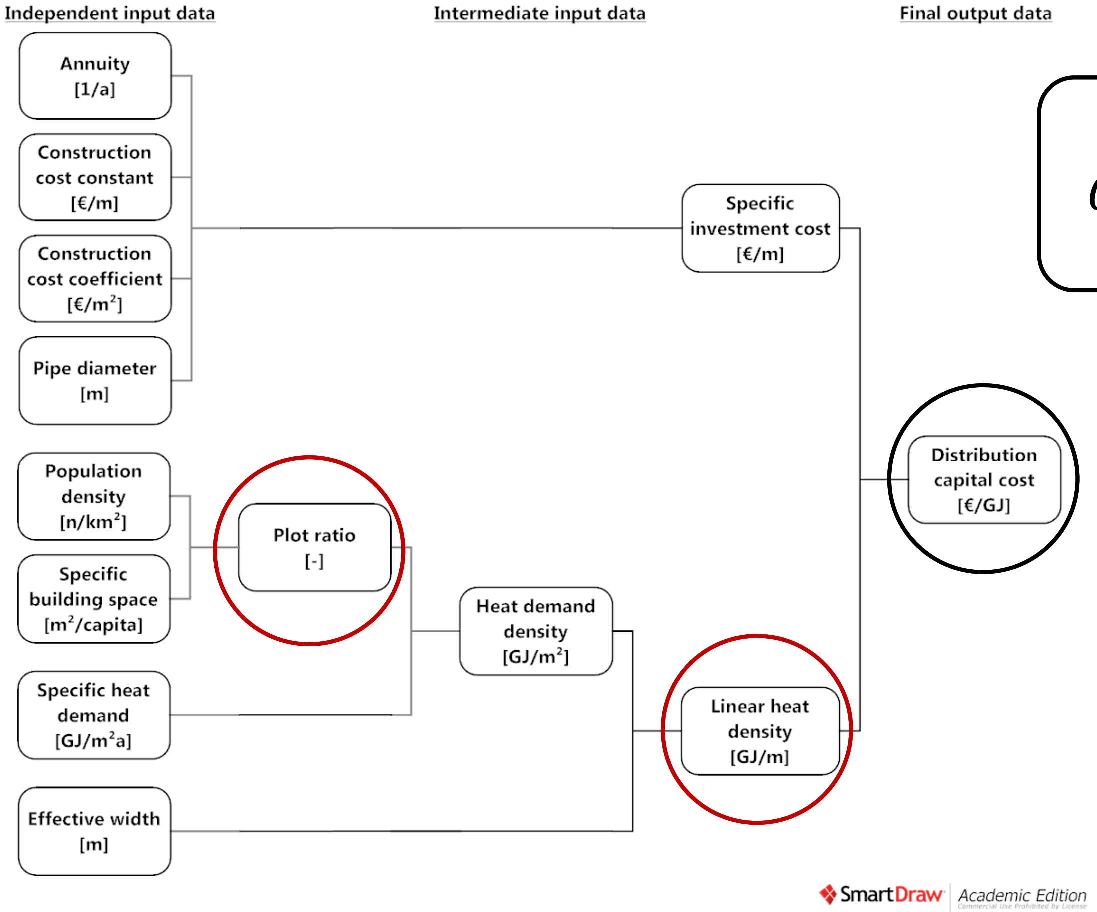
DISTRIBUTION COST MODEL

- **Plot ratio**



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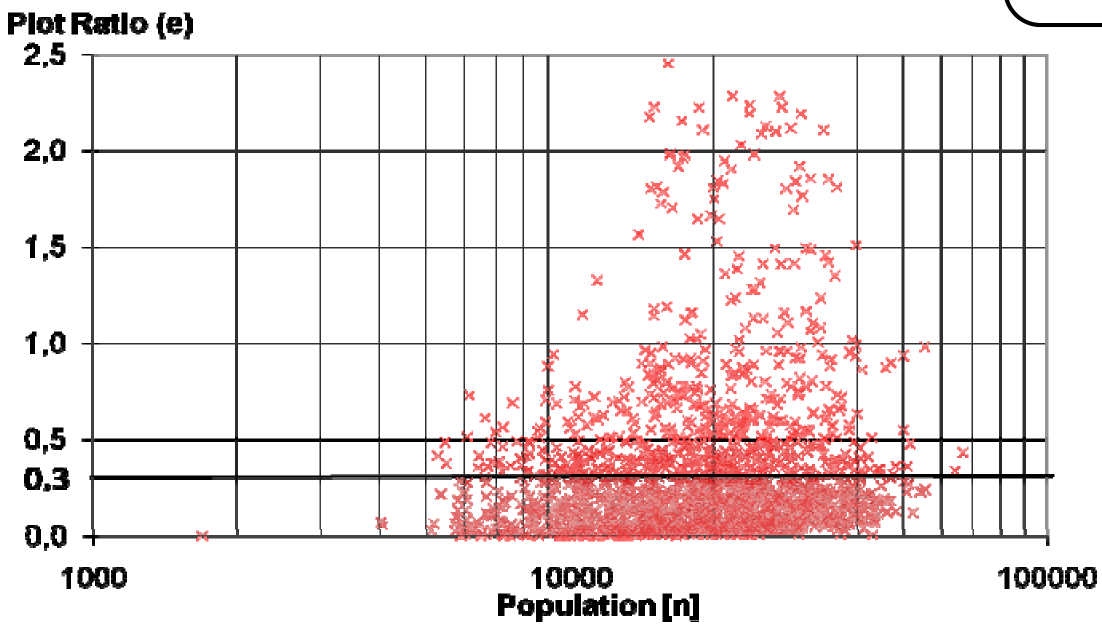
DISTRIBUTION COST MODEL

- **Plot ratio**

Area characteristics	Plot Ratio (e)
Inner city areas (A)	e ≥ 0.5
Outer city areas (B)	0.3 ≤ e < 0.5
Park areas (C)	0 ≤ e < 0.3



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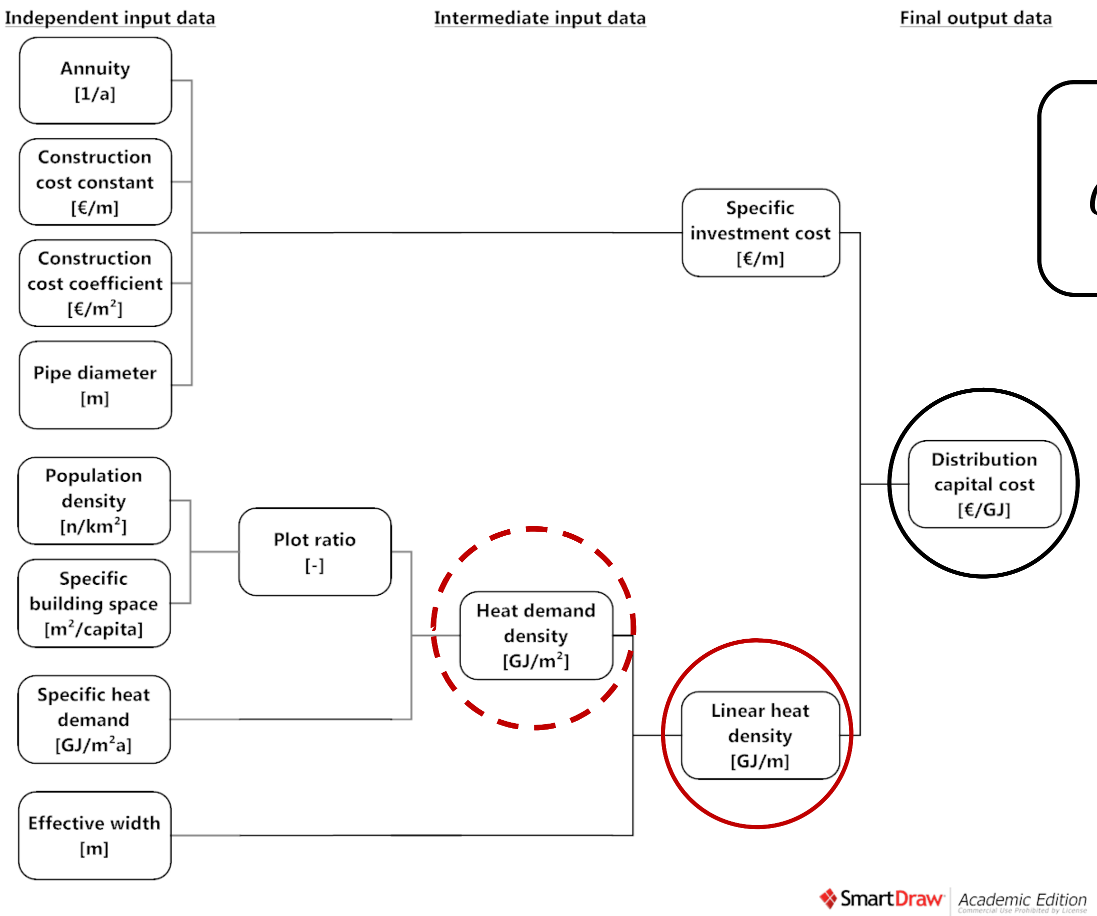
DISTRIBUTION COST MODEL

- **Heat demand density**



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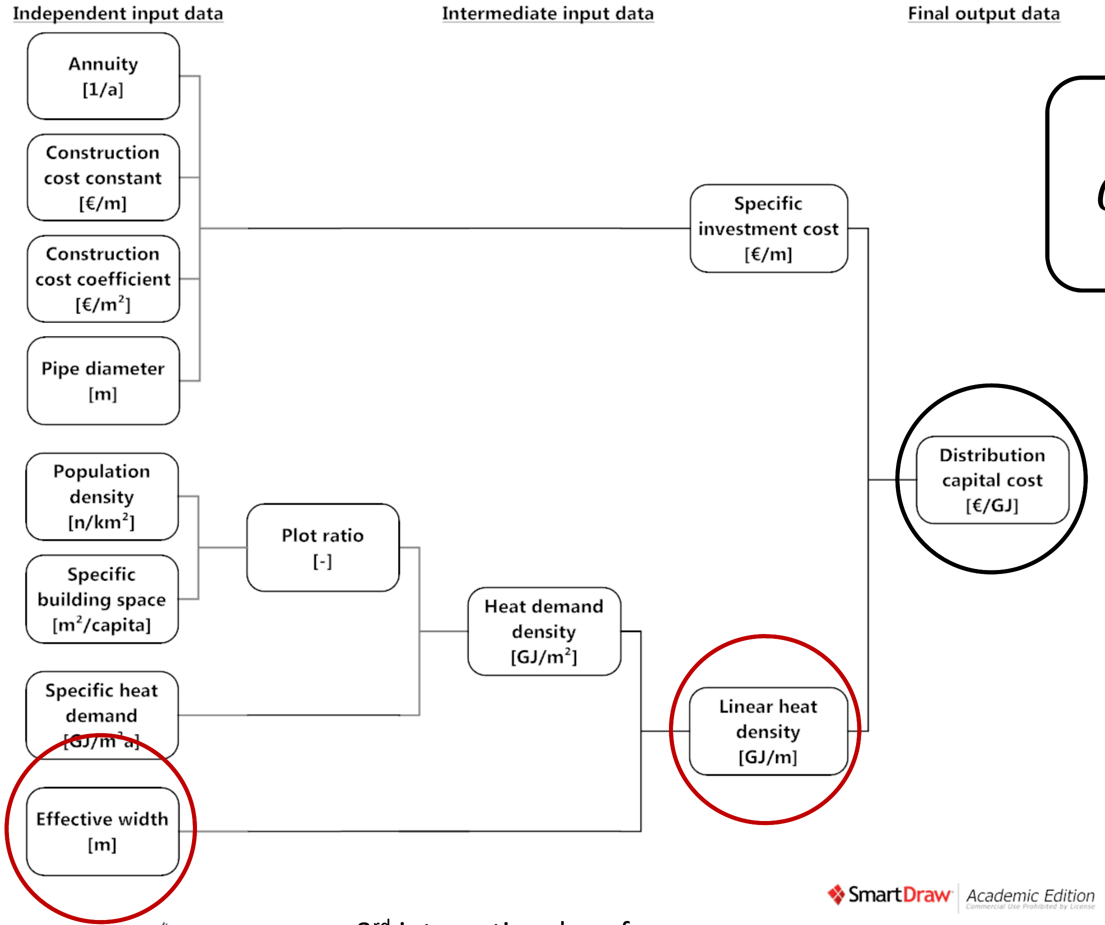
DISTRIBUTION COST MODEL

- **Effective width**



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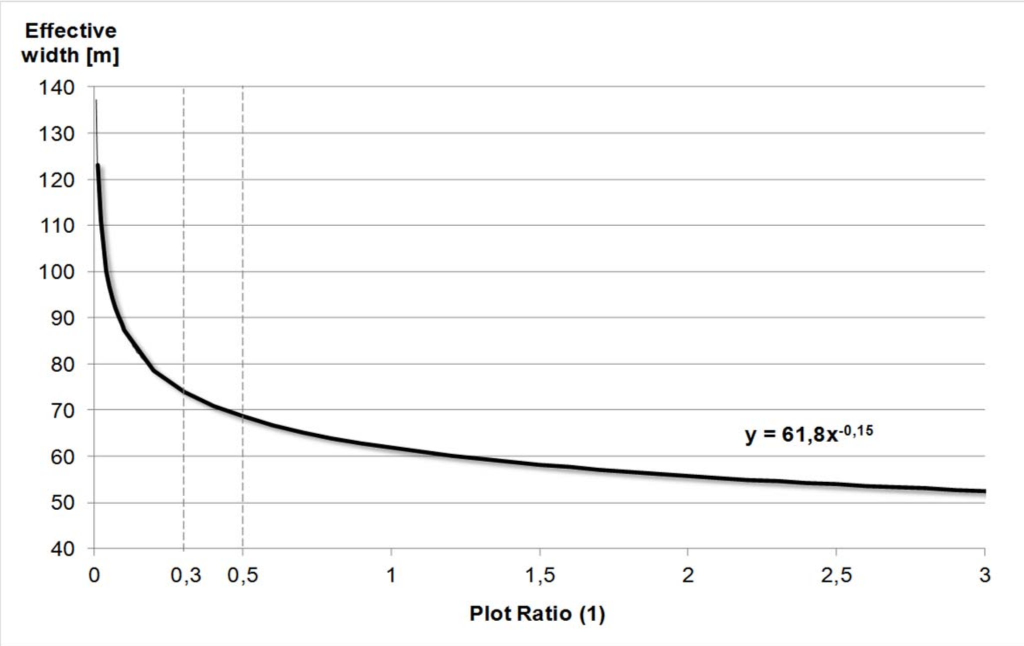
DISTRIBUTION COST MODEL

- **Effective width**



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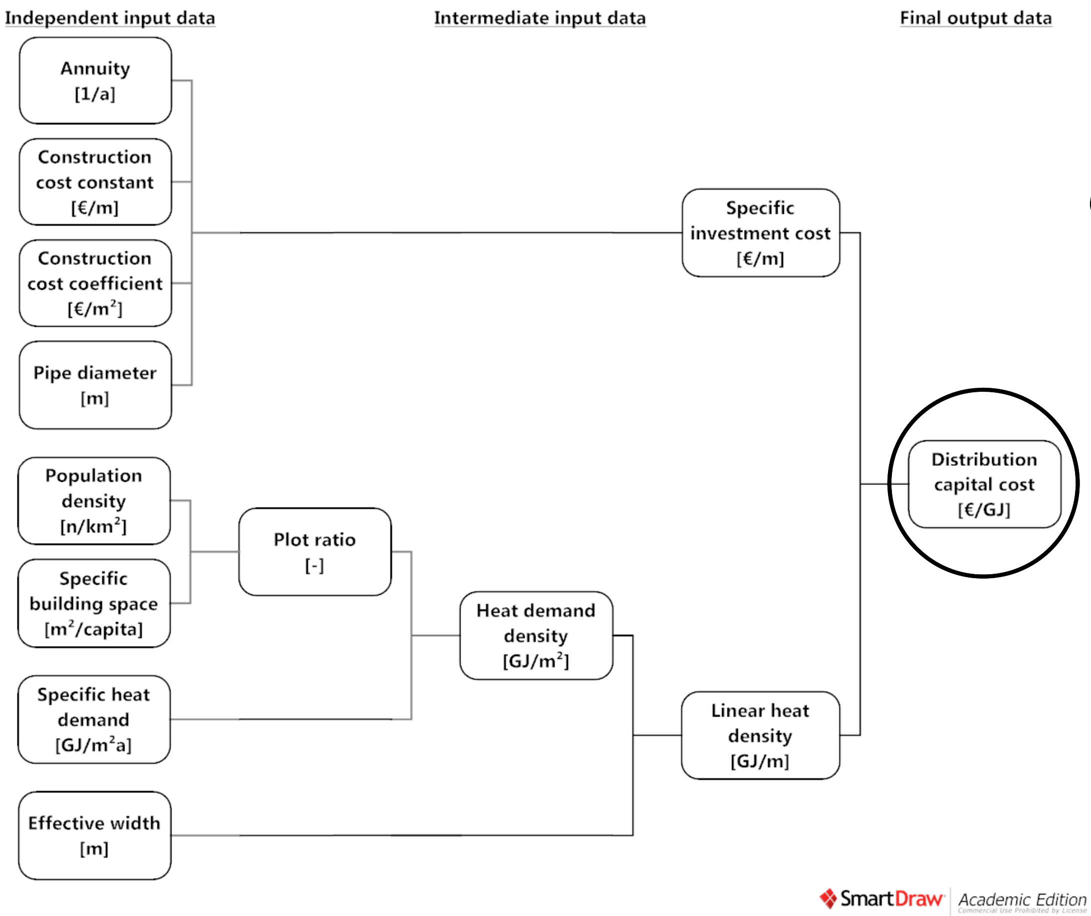
DISTRIBUTION COST MODEL

- **The distribution capital cost model**



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THE FIRST STEP

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

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Heat Roadmap Europe

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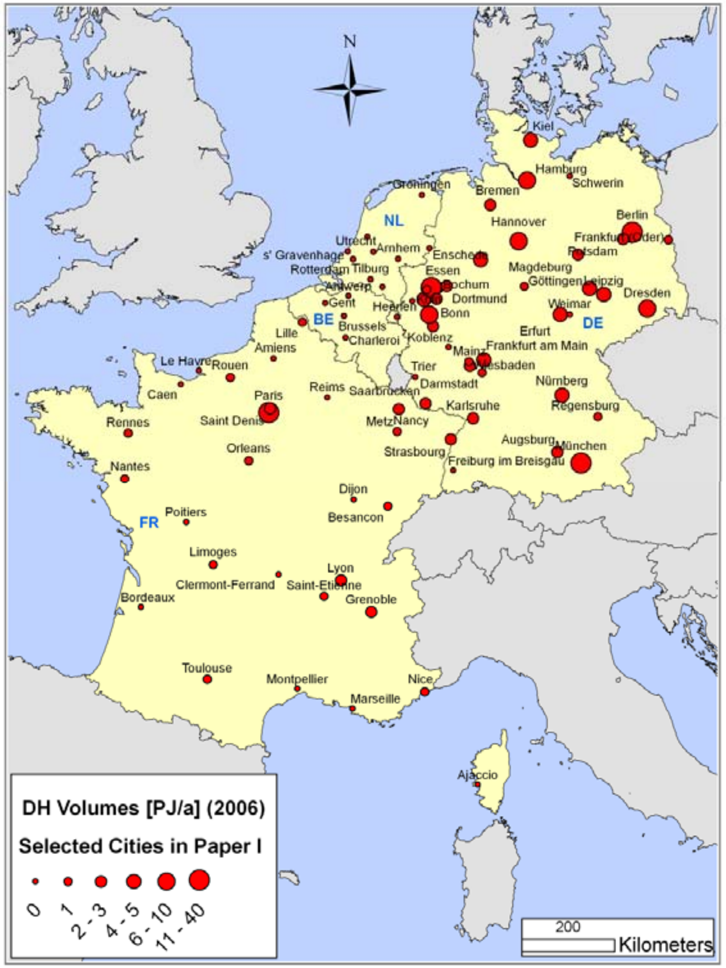


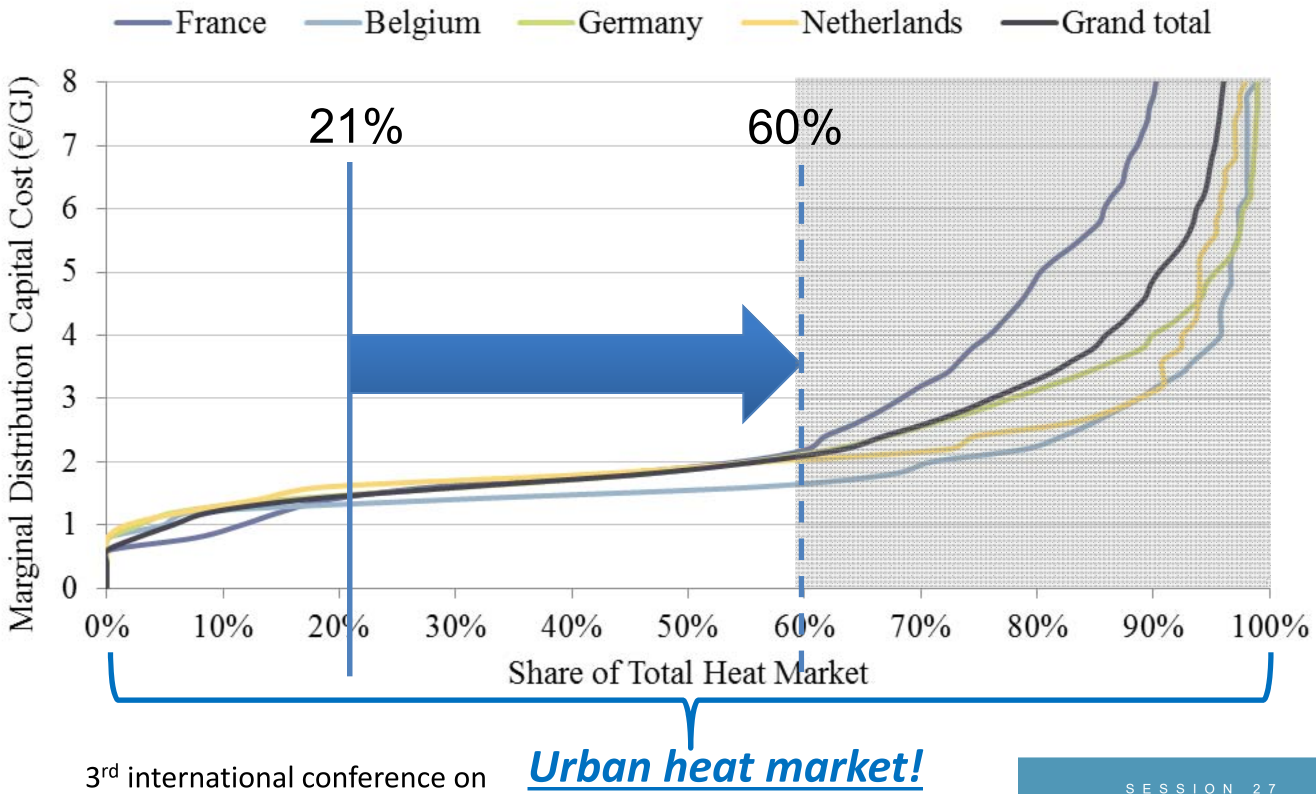
- **Urban Audit dataset:**
  - 83 cities, 1703 city districts
  - France, Belgium, Germany and the Netherlands
  - Population coverage; ~21 % (~35 million out of ~170 million)

Table 4.1
Aggregated district heat market shares in the study cities by country.

Country	Current district heat sales (PJ/a) in the study cities, according to [26–28]	Model estimated heat demands in the study cities (PJ/a)	Estimated present heat market shares for district heat in the study cities (%)
Belgium	0.1	51	0
Germany	153	523	29
France	34	307	11
Netherlands	14	70	21
Total	201	951	21

THE FIRST STEP

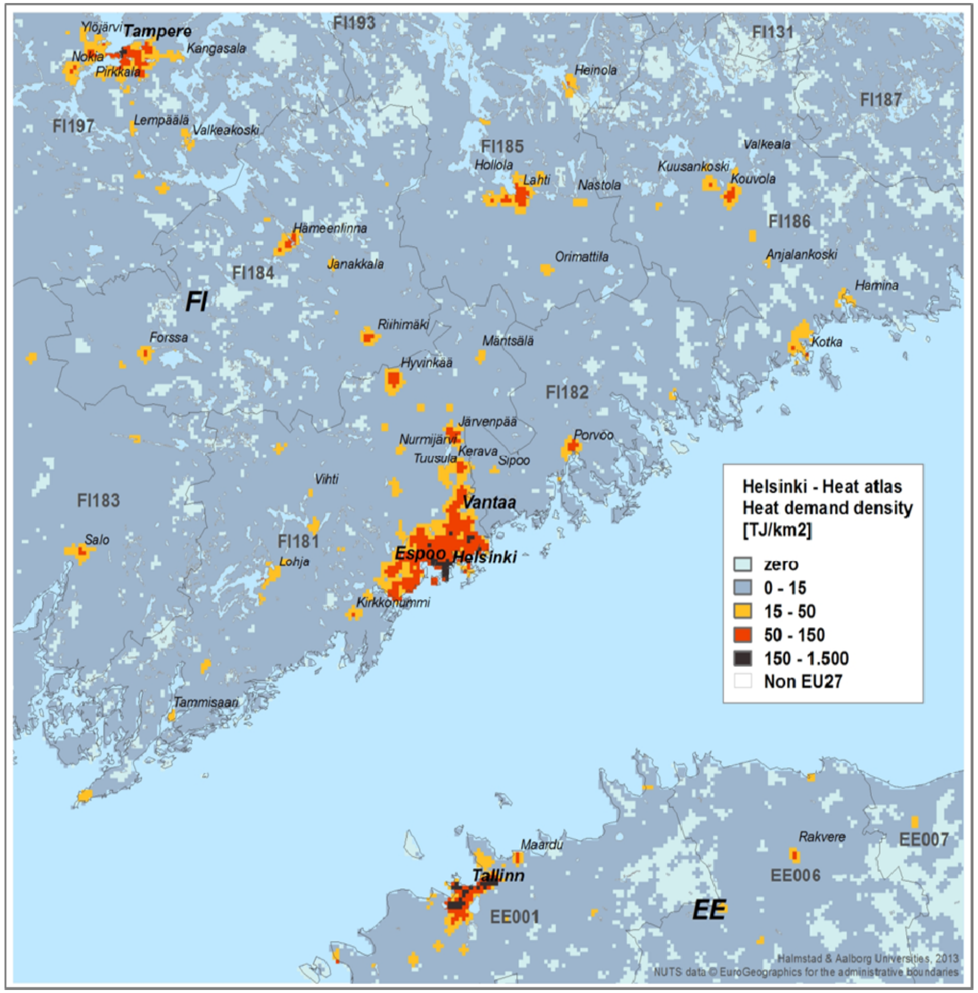
- Three-fold directly feasible expansion from current levels
- Indicative plot ratio threshold: 0.15 – 0.20
- Corresponding heat density: 90 TJ/km² (~25 GWh/km²)



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

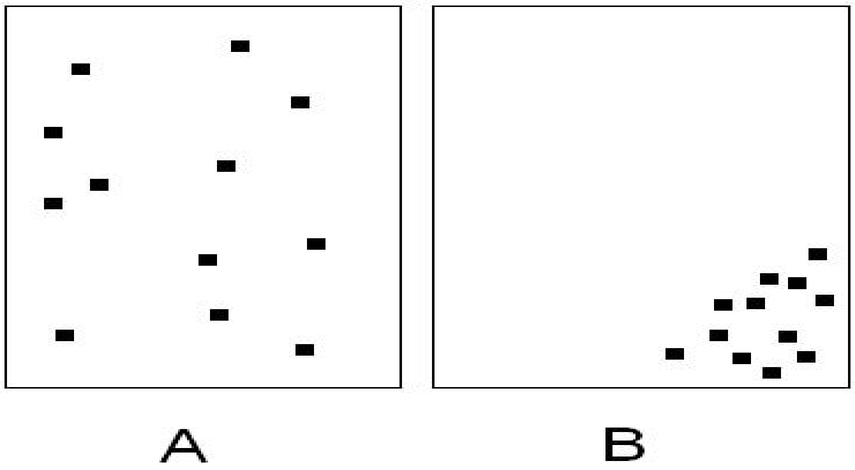
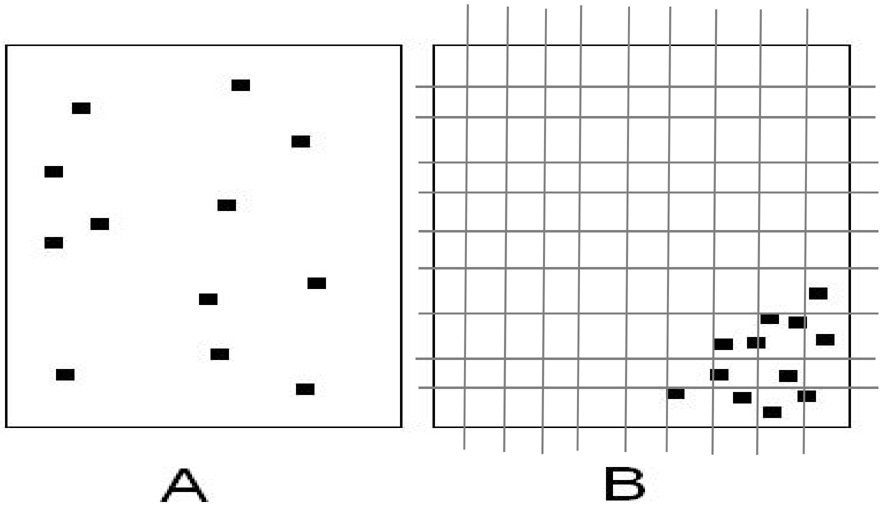


Figure 1. Low plot ratio land areas, scenario A with wide dispersion of buildings and scenario B with high concentration of buildings.

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

TOWARDS HECTARE RESOLUTION



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- **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?

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?

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 Mkm^2, ~440 Mha
    - Gross land area of HRE4 14 MS: ~3.7 Mkm^2, ~370 Mha (84%)

MS	A_{Land} [Mkm^2]	A_{Land} [Mha]	$A_{Land,qL}$ [Mha]	Share [%]
AT	0.08	8.39	0.91	11%
BE	0.03	3.05	0.69	22%
CZ	0.08	7.89	0.86	11%
DE	0.36	35.74	5.77	16%
ES	0.51	50.59	1.55	3%
FI	0.34	33.84	0.83	2%
FR	0.63	63.32	7.95	13%
HU	0.09	9.30	0.77	8%
IT	0.30	30.21	3.96	13%
NL	0.04	4.15	1.09	26%
PL	0.31	31.27	3.68	12%
RO	0.24	23.84	1.61	7%
SE	0.44	43.86	1.36	3%
UK	0.25	24.85	2.77	11%
HRE4	**3.70**	**370.30**	**33.79**	**9%**

SPATIAL DEMAND DENSITY MODEL

Source: Persson, U., Möller, B., Wiechers, E., 2017. Methodologies and assumptions used in the mapping. Deliverable 2.3: A final report outlining the methodology and assumptions used in the mapping. August 2017, Heat Roadmap Europe 2050, A low-carbon heating and cooling strategy.

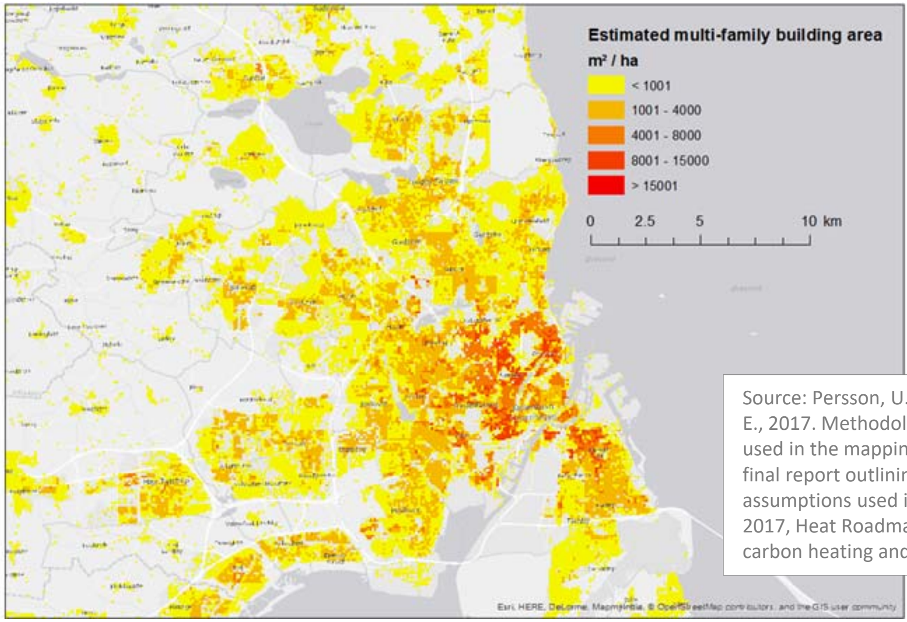
- **Input data:**
  - From the FORECAST model (HRE4 WP3 partners)
    - By settlement type, prepared as specific demands
    - Adjustments for local climate and population density

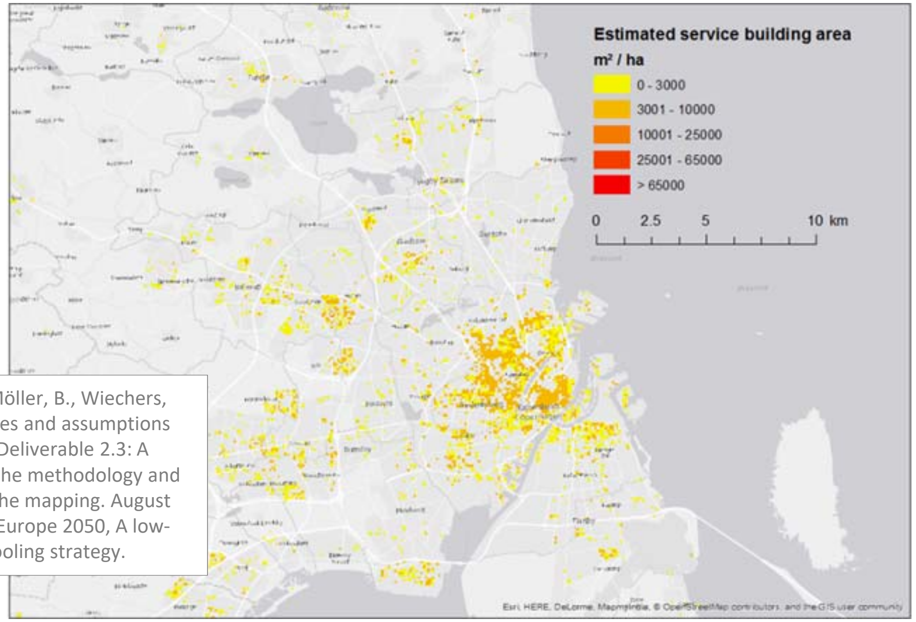
MS	P [Mn]	Q_{tot} [TWh/a]	Q_{res} [TWh/a]	*$Q_{res,SFH}$ [TWh/a]*	*$Q_{res,MFH}$ [TWh/a]*	Q_{ser} [TWh/a]
AT	8.6	64.5	44.2	*32.2*	*12.0*	20.4
BE	11.3	90.1	62.0	*48.1*	*13.9*	28.1
CZ	10.5	65.9	47.3	*27.1*	*20.2*	18.6
DE	81.2	670.4	443.8	*284.5*	*159.3*	226.6
ES	46.4	130.8	92.5	*35.1*	*57.4*	38.2
FI	5.5	62.9	43.2	*32.0*	*11.2*	19.7
FR	66.4	420.6	306.5	*231.3*	*75.2*	114.1
HU	9.9	58.3	40.4	*39.1*	*1.3*	17.9
IT	60.8	354.7	270.4	*93.3*	*177.1*	84.3
NL	16.9	118.1	80.0	*65.3*	*14.6*	38.2
PL	38.0	182.7	138.6	*89.9*	*48.7*	44.1
RO	19.9	50.8	38.5	*26.6*	*11.9*	12.3
SE	9.7	82.3	54.4	*32.0*	*22.3*	27.9
UK	64.9	377.8	280.2	*261.6*	*18.7*	97.6
HRE4	**450.0**	**2730.0**	**1942.0**	***1298.3***	***643.7***	**788.0**

MS	[GJ/na] q_{tot}	q_{res}	q_{ser}
AT	27.1	18.5	8.6
BE	28.8	19.8	9.0
CZ	22.5	16.2	6.3
DE	29.7	19.7	10.0
ES	10.1	7.2	3.0
FI	41.4	28.4	12.9
FR	22.8	16.6	6.2
HU	21.3	14.8	6.5
IT	21.0	16.0	5.0
NL	25.2	17.0	8.1
PL	17.3	13.1	4.2
RO	9.2	7.0	2.2
SE	30.4	20.1	10.3
UK	21.0	15.5	5.4
HRE4	**21.8**	**15.5**	**6.3**

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





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OUTPUTS

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 695989.

Heat Roadmap Europe 2050
A low-carbon heating and cooling strategy

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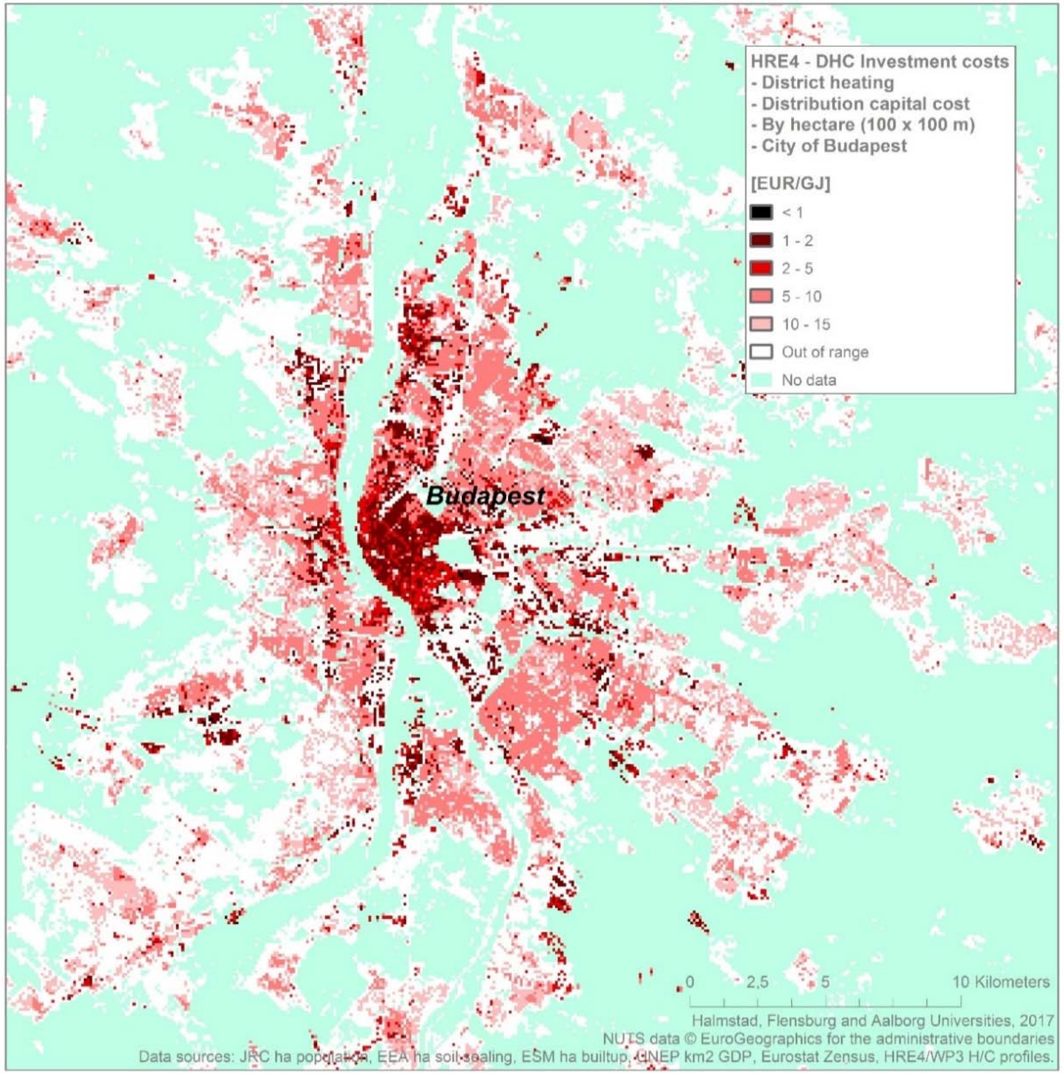
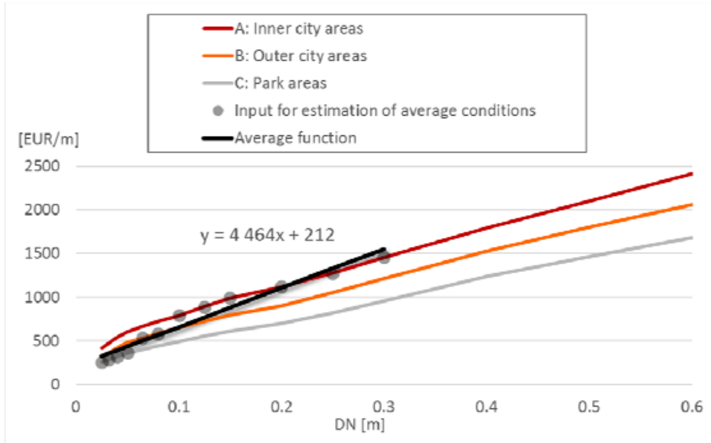


- **Outputs:**
  - **Budapest**
  - Construction cost values updated to represent average 2015 cost levels



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Heat Roadmap Europe 2050
A low-carbon heating and cooling strategy

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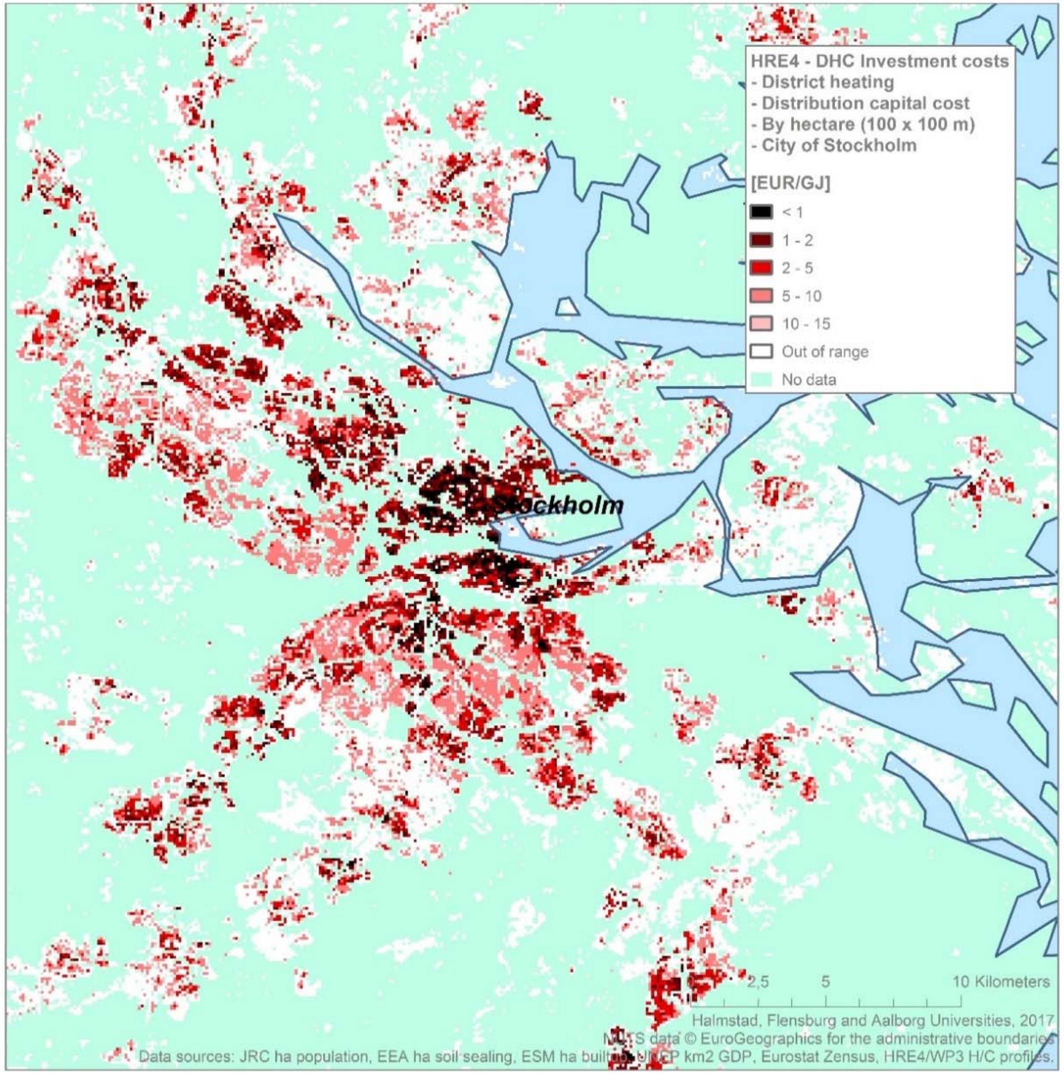

- **Outputs:**
  - Stockholm
  - The plot ratio value of each hectare grid cell used to determine the corresponding effective width value, according to:

$$0 < e \le 0.4; w = 137.5 \cdot e + 5, e > 0.4; w = 60 \quad [m]$$

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Copenhagen, 12-13 September 2017

www.4dh.eu www.reinvestproject.eu www.heatroadmap.eu

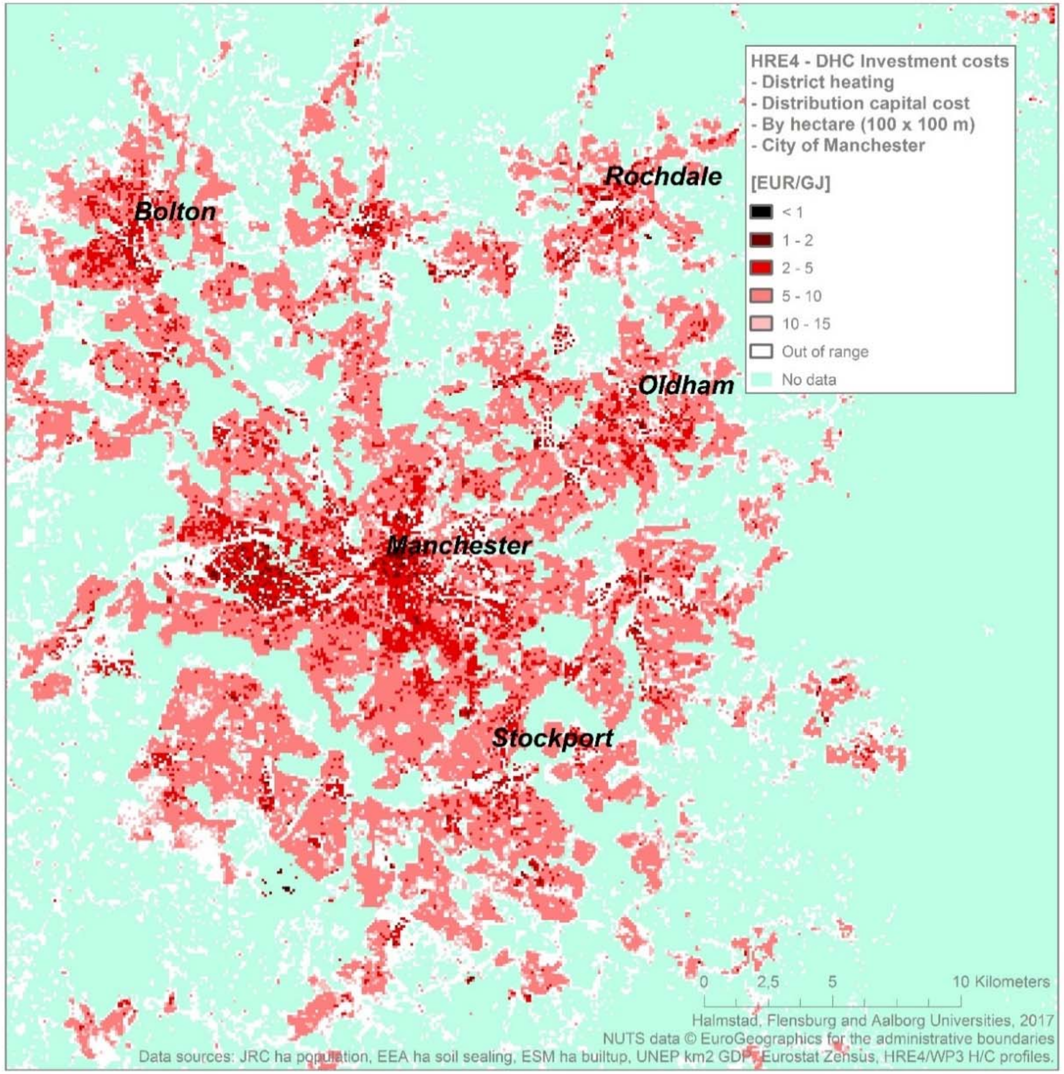
SESSION 27
HEAT ROADMAP EUROPE: HEAT DISTRIBUTION COSTS
KEYNOTE: URBAN PERSSON

HALMSTAD UNIVERSITY

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 695989.

Heat Roadmap Europe 2050 — A low-carbon heating and cooling strategy

4DH — Heat Roadmap Europe — reINVEST



- **Outputs:**
  - Manchester
  - 84% of all building heat demands in the UK are located in areas with heat demand densities above 50 TJ/km^2, but only 3% in areas above 300 TJ/km^2

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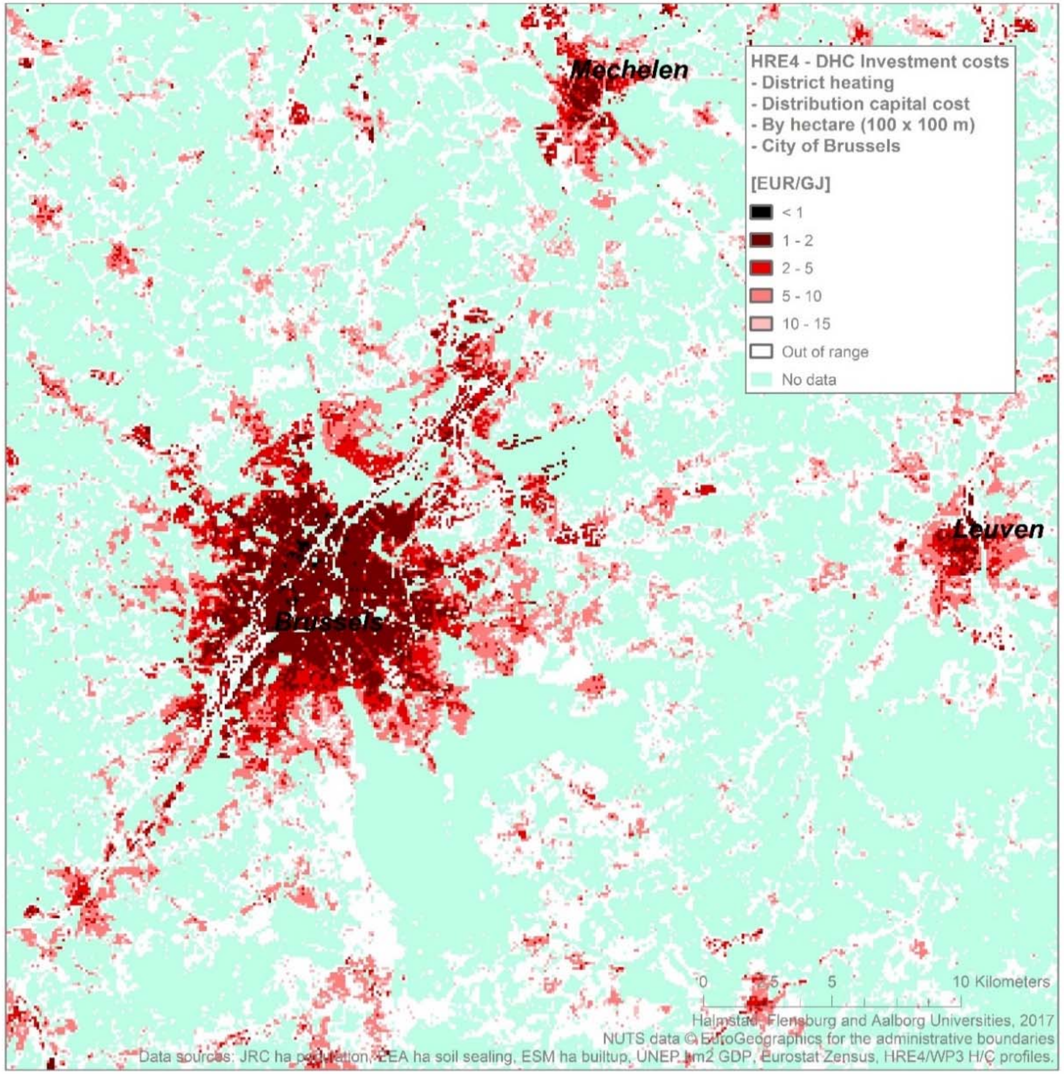
Heat Roadmap Europe 2050
A low-carbon heating and cooling strategy

4DH
Heat Roadmap Europe
reINVEST



- **Outputs:**
  - **Brussels**
  - 70% of all building heat demands in BE are located in areas with heat demand densities above 50 TJ/km^2, and 10% in areas above 300 TJ/km^2

EARLY RESULTS

Source: Persson, U., Möller, B., Wiechers, E., 2017. Methodologies and assumptions used in the mapping. Deliverable 2.3: A final report outlining the methodology and assumptions used in the mapping. August 2017, Heat Roadmap Europe 2050, A low-carbon heating and cooling strategy.

- 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)

MS	Q_{tot} [PJ/a]	<20 TJ/km² [%]	20-50 TJ/km² [%]	50-120 TJ/km² [%]	120-300 TJ/km² [%]	>300 TJ/km² [%]
AT	228	18	24	31	14	13
BE	320	10	20	47	13	10
CZ	234	15	26	27	20	11
DE	2380	11	12	39	26	11
ES	453	16	16	20	26	23
FI	221	28	18	32	17	5
FR	1487	18	27	31	13	11
HU	208	13	55	20	9	4
IT	1257	13	12	25	32	17
NL	417	10	8	39	33	9
PL	648	20	34	22	17	7
RO	181	51	22	13	12	2
SE	290	24	20	29	17	10
UK	1334	7	8	56	25	3
HRE4	**9658**	**14**	**18**	**35**	**22**	**10**

EARLY RESULTS

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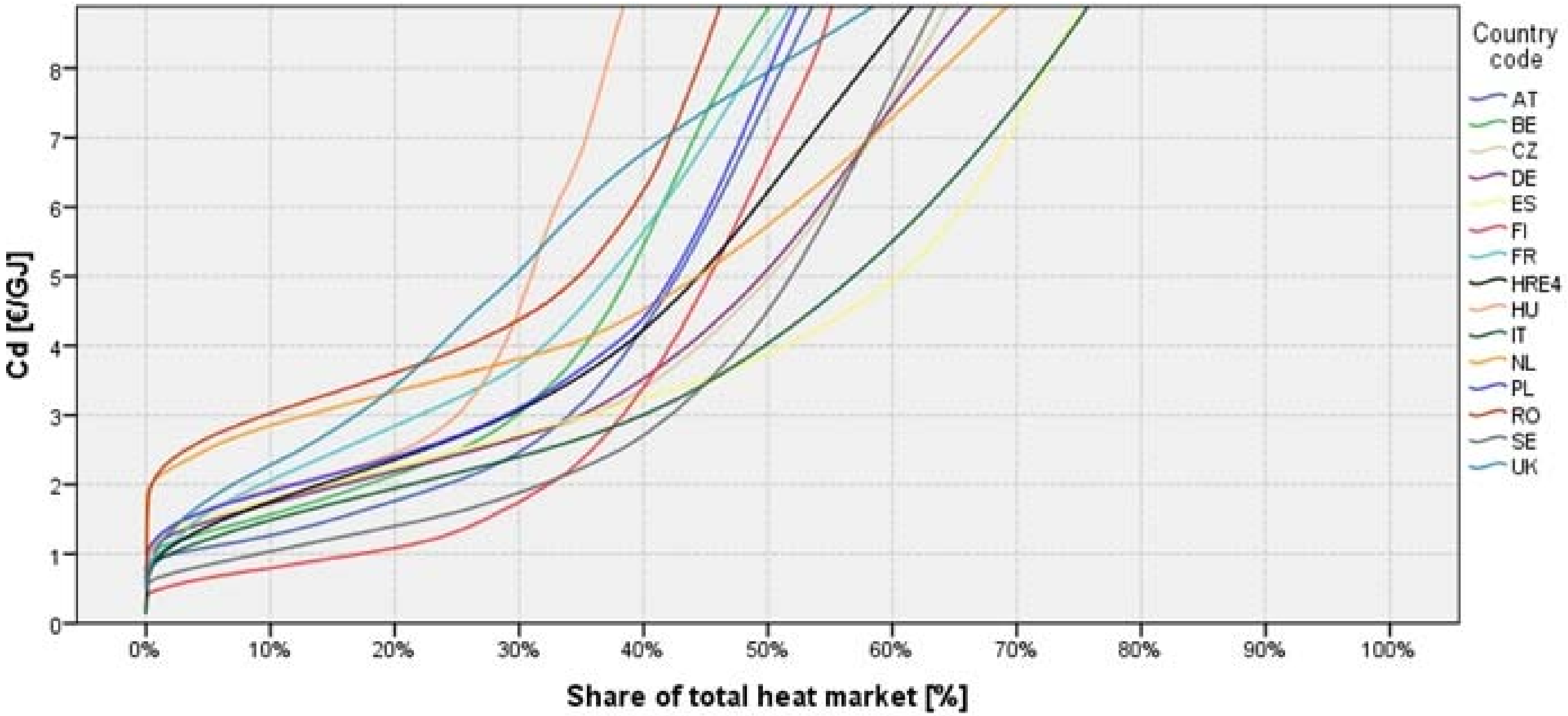
- Current distribution capital cost levels per hectare
  – Cumulative cost curves indicating shares of total national heat markets at different distribution capital cost levels



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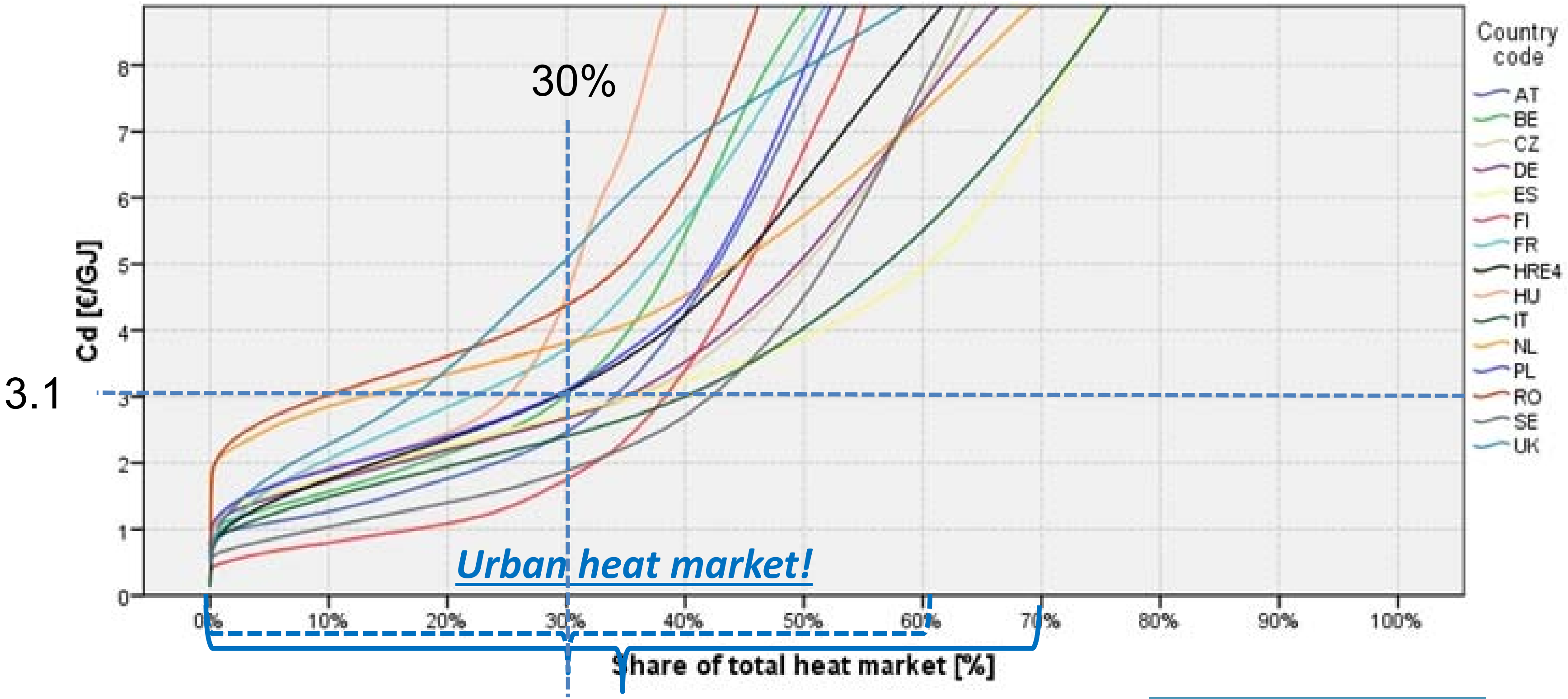

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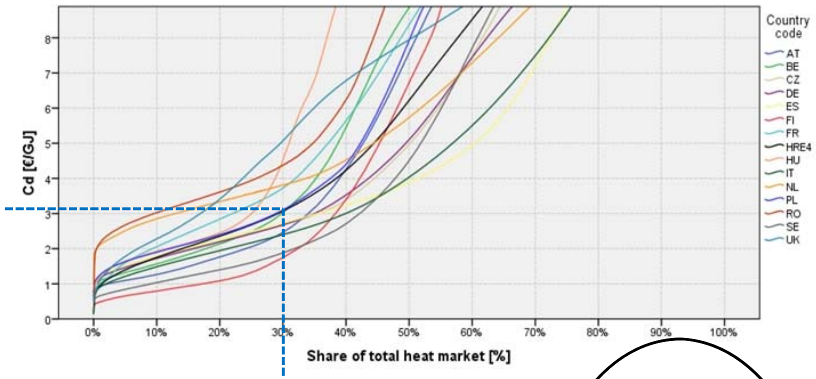
- National and urban heat market shares for district heating
  - ~30% district heating heat market shares at marginal cost levels of 3.1 €/GJ
  - ~32% of total heat demands at heat demand densities above 120 TJ/km²
  - Directly feasible European district heating sector of approximately 3.1 EJ/a



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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**?

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THANK YOU!

QUESTIONS?

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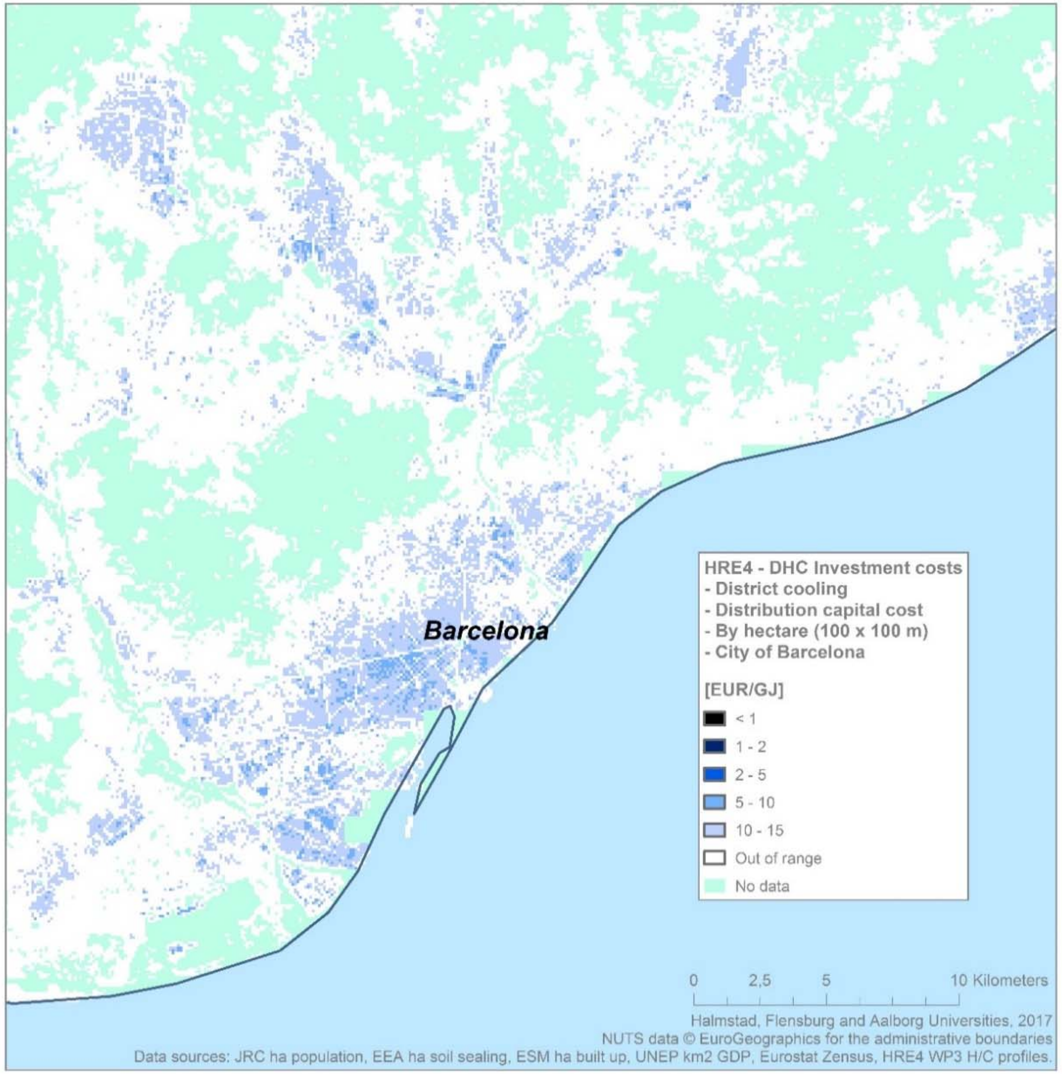

- **Outputs:**
  - **Marginal cold distribution capital costs by hectare level:**
  - **Barcelona**