Expanding district heating in Europe
- a key to reach the energy efficiency target by 2020

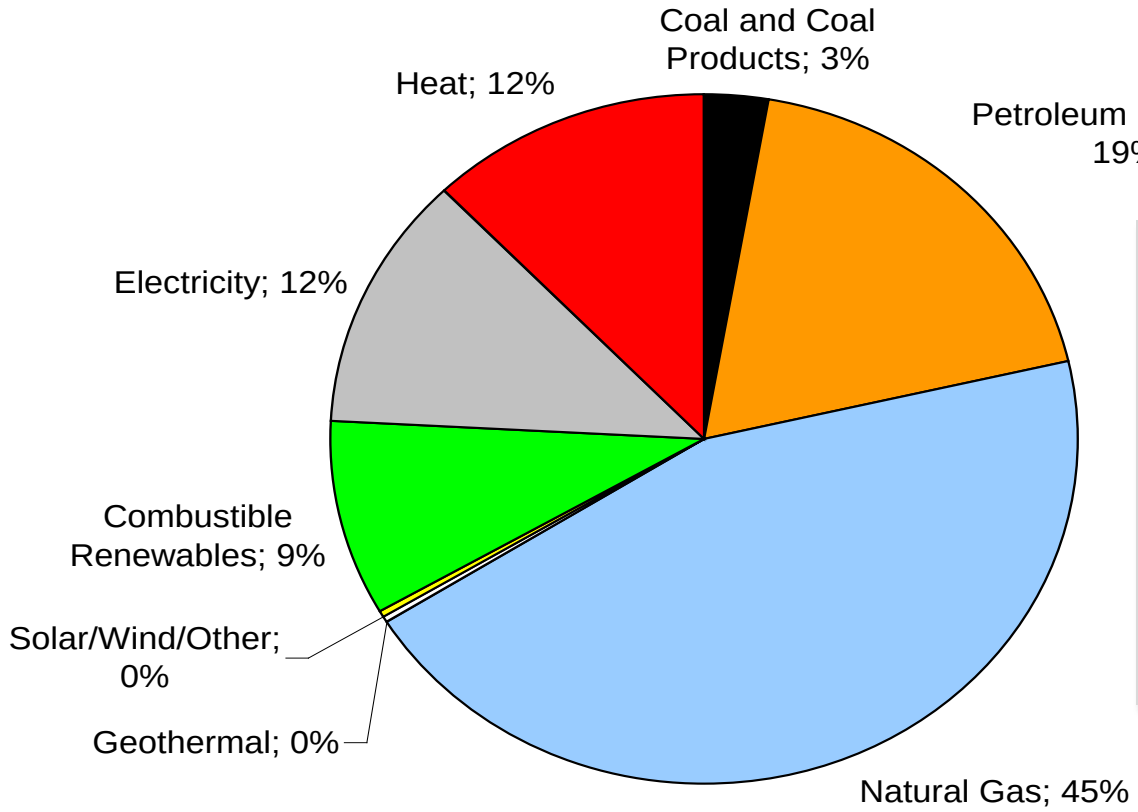
A research presentation by PhD-student Urban Persson,
Halmstad University & Chalmers University of Technology

Linnaeus University Växjö
29th of January, 2013

Expanding district heating in Europe – Why?

EU27 during 2008, Origin of heat supply for heat demands in residential and service sector buildings

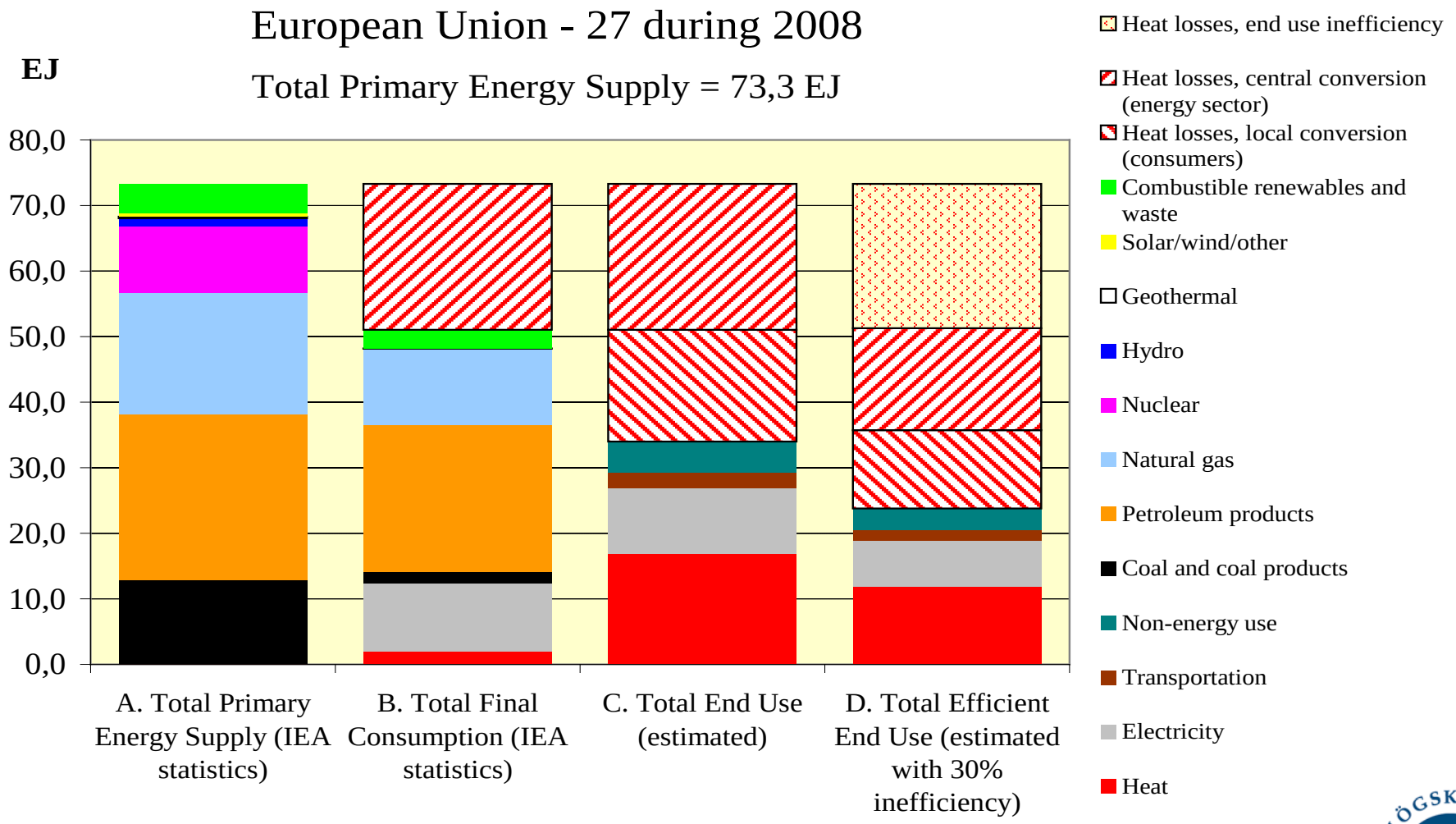
Total heat supply was 11.5 EJ, not including indirect heat supply from all indoor electricity use



≈ 3/4 of total heat supply consisted of high exergy fuels and energy carriers – to satisfy low temperature heat demands!

Source: Heat Roadmap Europe 2050 - First Pre-study 2012, by a cooperation between the Aalborg and Halmstad Universities.

Improving general energy efficiency!

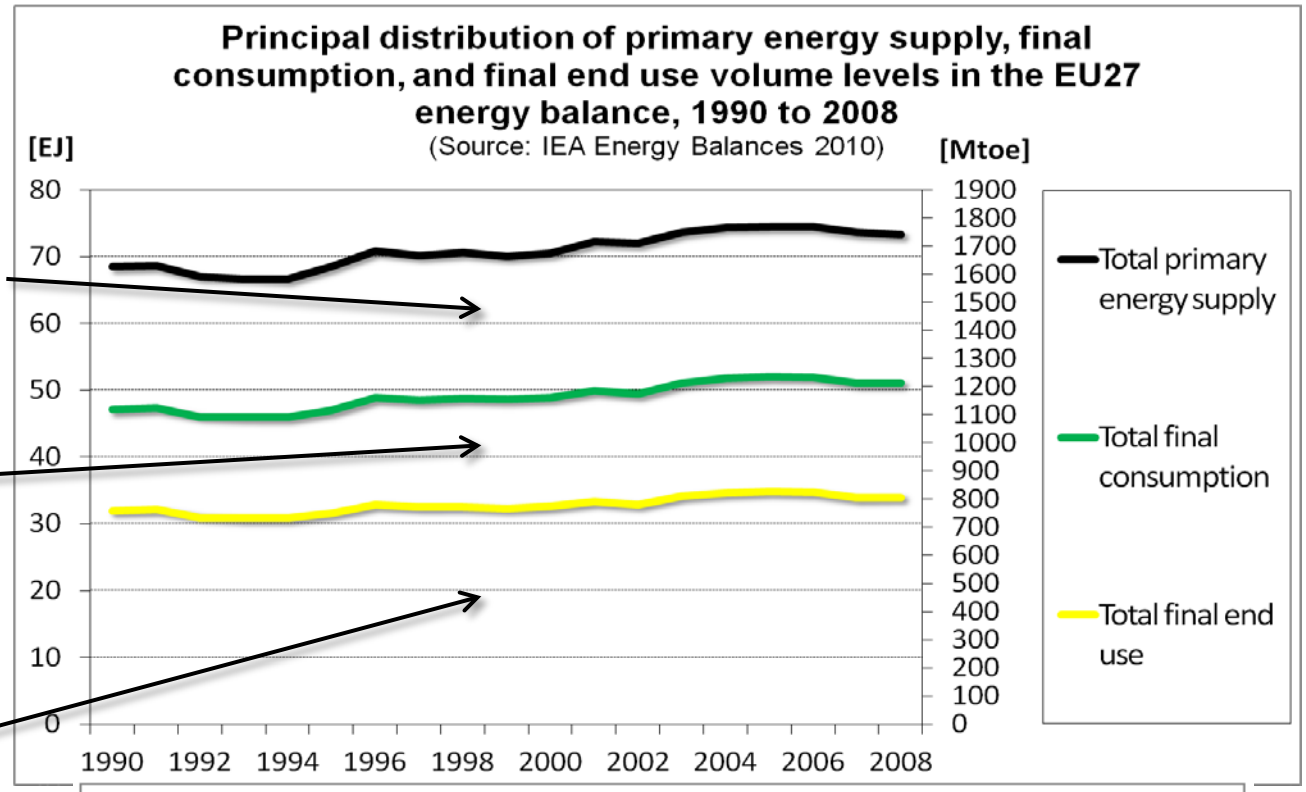


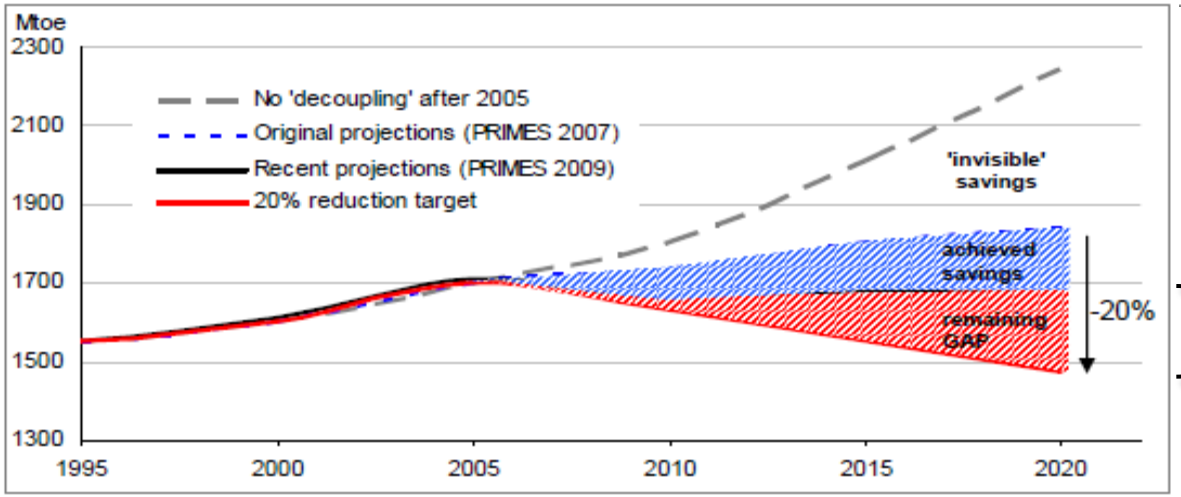
Source: Sven Werner data management: IEA, Energy Balances for OECD and non-OECD countires. 2010 editions, Paris 2010.

Central conversion processes

Local conversion processes

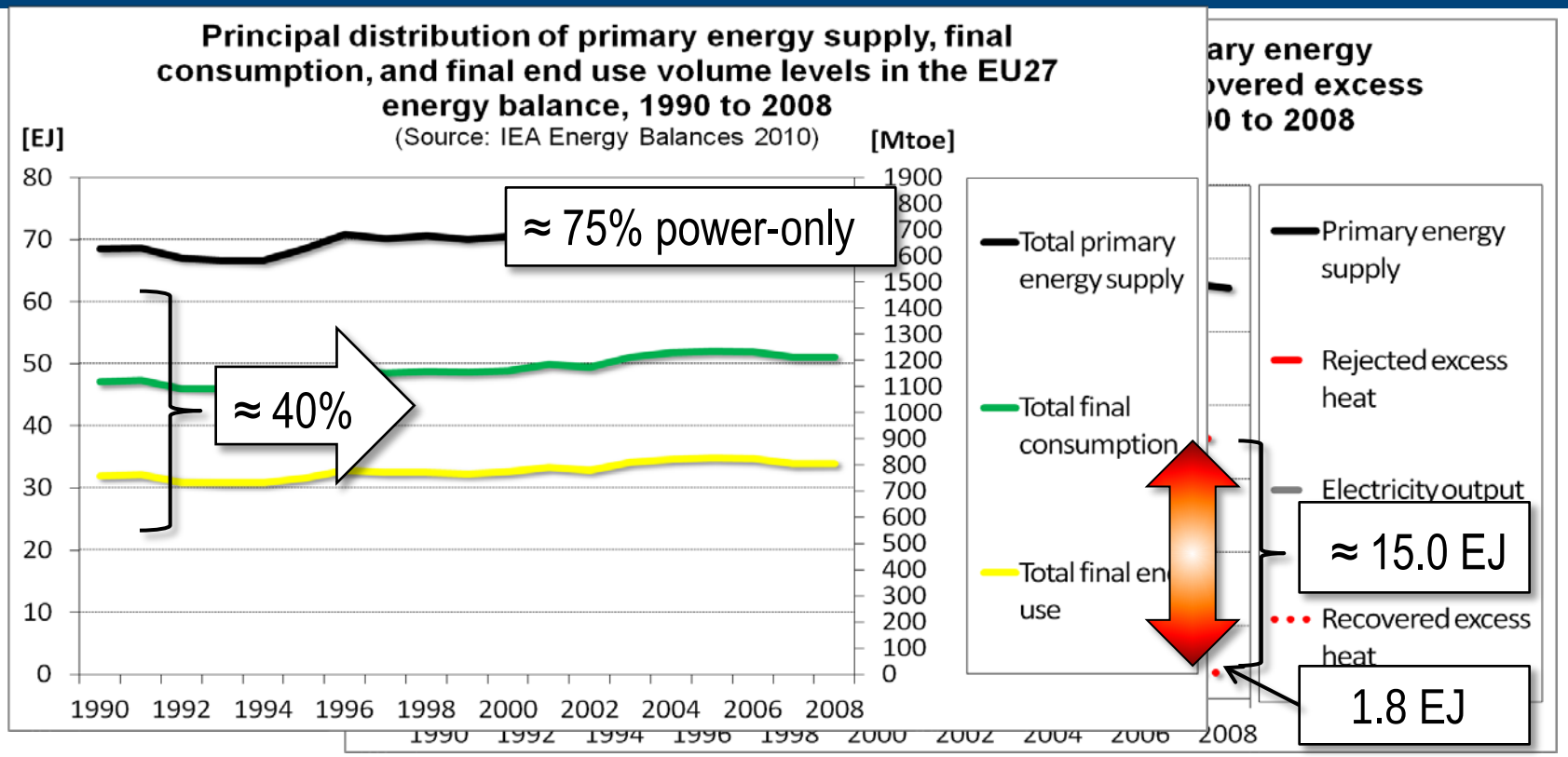
Final end use





≈ 8.5 EJ (204 Mtoe)

Development and projection of primary energy use for EU27 by 2020.



European district heating can contribute to reduced future primary energy demands and reduced CO2 emissions by:

- Extended excess heat recovery from TPG and Industry
- Extended utilisation of local renewable heat sources
- Substitution of high exergy fuels and energy carriers

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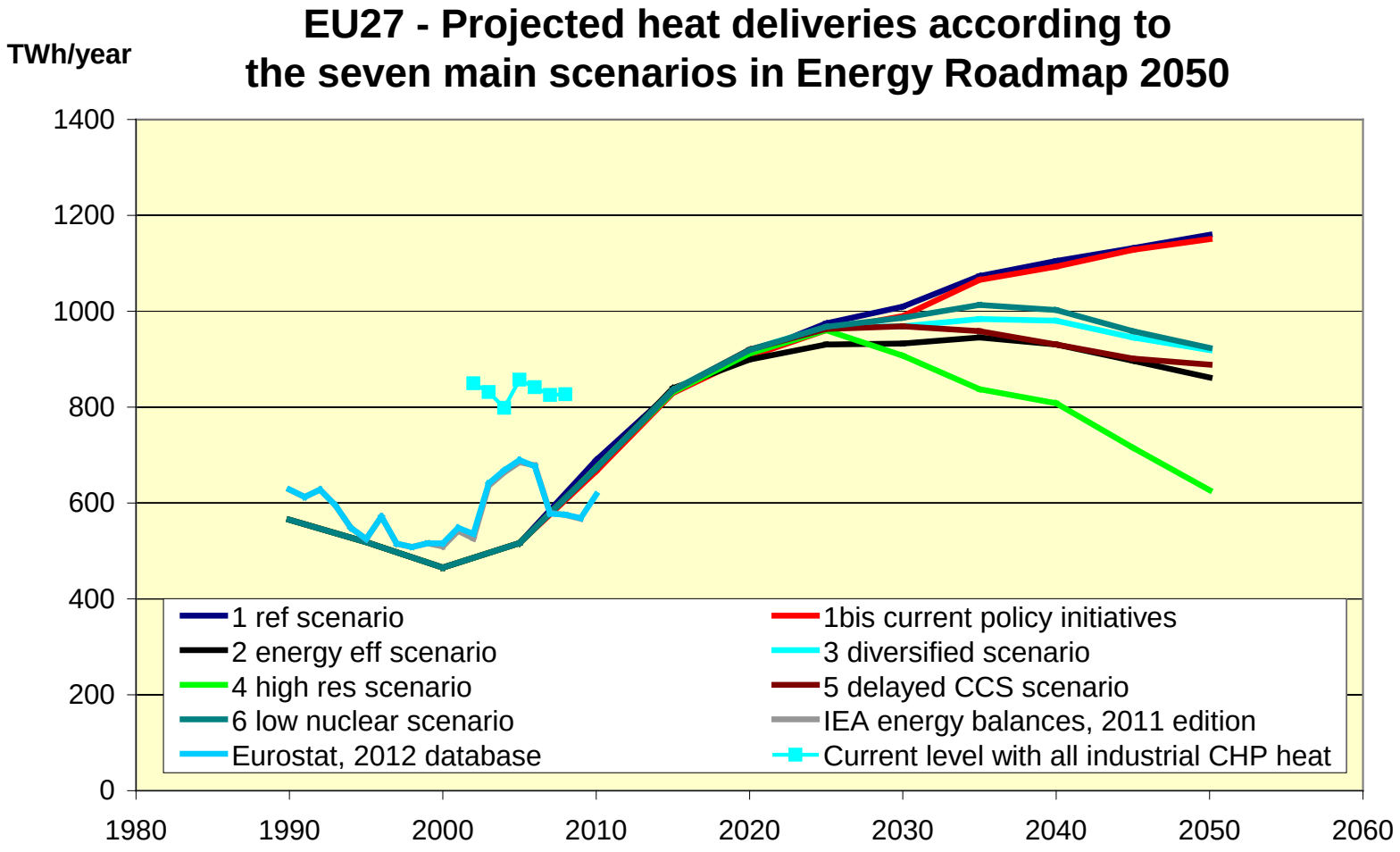
- Energy Roadmap 2050: Published by the EC on December 15, 2011
- Two reference scenarios and five additional policy scenarios until 2050
- Based on energy modelling by the PRIMES model from Greece



Source: Heat Roadmap Europe 2050 - First Pre-study 2012, by a cooperation between the Aalborg and Halmstad Universities.

Outline

- Background
  - Research questions, projects, and publications
- General information on district heating and cooling
  - Fundamentals of district heating and cooling
  - District heating and cooling in Europe today
- 1st research issue: The economy of heat distribution
  - The distribution capital cost model
- 2nd research issue: The energy efficiency of district heating
  - Concepts to define sequential energy supply
- 3rd research issue: The locations of European heat synergy regions
  - Spatial mapping of excess heat activities and local heat sources
- Conclusions
  - Research issues
  - Future research

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Background

- Research questions, projects, and publications
- The Pathway project; Swedish System Solutions (2008-2010)
  - Swedish Energy Agency
- The District Heating within the Energy System project (2011)
  - Fjärrsyn, the Swedish district heating research programme
- The IEA DHC/CHP Annex X project - Towards 4th Generation District Heating (2012 & 2013)
  - International Energy Agency
- The Heat Roadmap Europe 2050 project, prestudy 1 & 2 (2012 & 2013)
  - Euroheat & Power, Brussels
- The 4DH Strategic Research Center, Aalborg University (2012 – 2017)
  - Funded partly by Danish Strategic Research Council and Danish DH Industry
- Additional financial support (2011)
  - School of Business and Engineering at Halmstad University
    - Main Supervisor: Prof. Sven Werner at Halmstad University
    - Examiner & 2nd Supervisor: Prof. Filip Johnsson at Chalmers Univ. of Technology
    - 3nd Supervisor: Dr. Mei Gong at Halmstad University

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Background

- Research questions, projects, and publications
- The Pathway project; Swedish System Solutions (2008-2010)
  - Research area 4a (Local markets and infrastructure for heating and cooling – including trade-offs on the user side)
  - Overall research interest: How can district heating contribute to a sustainable development in Europe?
    - Main objective 1: *Identify parameters and conditions to assess feasibility thresholds for cost effective heat distribution in district heating systems*
    - Main objective 2: *Develop quantities to express and estimate the potential for excess heat recovery and utilisation in European district heating systems*

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Background

Main research question: To what extent can Europe's 5000 district heating systems contribute to a sustainable development?

- Research questions, projects, and publications
- The Pathway project; Swedish System Solutions (2008-2010)
  - Research questions:
  - How can the potential for increased energy efficiency be best utilized when expanding the present DH-systems of today?
  - To what extent can sequential chains of provision be a pathway to a sustainable development in Europe?
  - How should such a sustainable development be organized with low resource utilization and the demand of simple and continous delivery on the user-side?
  - Documented in three papers:
    - *Heat Distribution and the Future Competitiveness of District Heating (2011)*
    - *Effective Width – the Relative Demand for District Heating Pipe Lengths in City Areas (2010)*
    - *District Heating in Sequential Energy Supply (2012)*

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Background

- Research questions, projects, and publications
- The Heat Roadmap Europe 2050 project, prestudy 1 & 2 (2012 & 2013)
  - First pre-study: January to April 2012
  - Report published June 4th, 2012 (www.euroheat.org)
  - Cooperation: Aalborg and Halmstad Universities
  - Second pre-study: January to March 2013
  - Methodological approach:
    - Traditional energy system modelling
    - Mapping of local conditions:
      - Geographic information system (GIS) analysis
    - Documented in one paper:
      - *Mapping Local European Heat Resources - a Spatial Approach to Identify Favourable Synergy Regions for District Heating (2012)*

Background

- Research questions, projects, and publications
- The Heat Roadmap Europe 2050 project, prestudy 1 & 2 (2012 & 2013)
- Initiative by Euroheat & Power, Brussels
  - Alternative projections of the future European heat market
  - Strategic aim to the Intelligent Energy Europe program
  - Full study planned for 2014-2017

    - Main objective 1: *Model an alternative European energy forecast including heat synergy opportunities and DHC*

    - Main objective 2: *Identify NUTS3 region excess heat and renewable heat "hot spots" – European areas with beneficial conditions for DHC*

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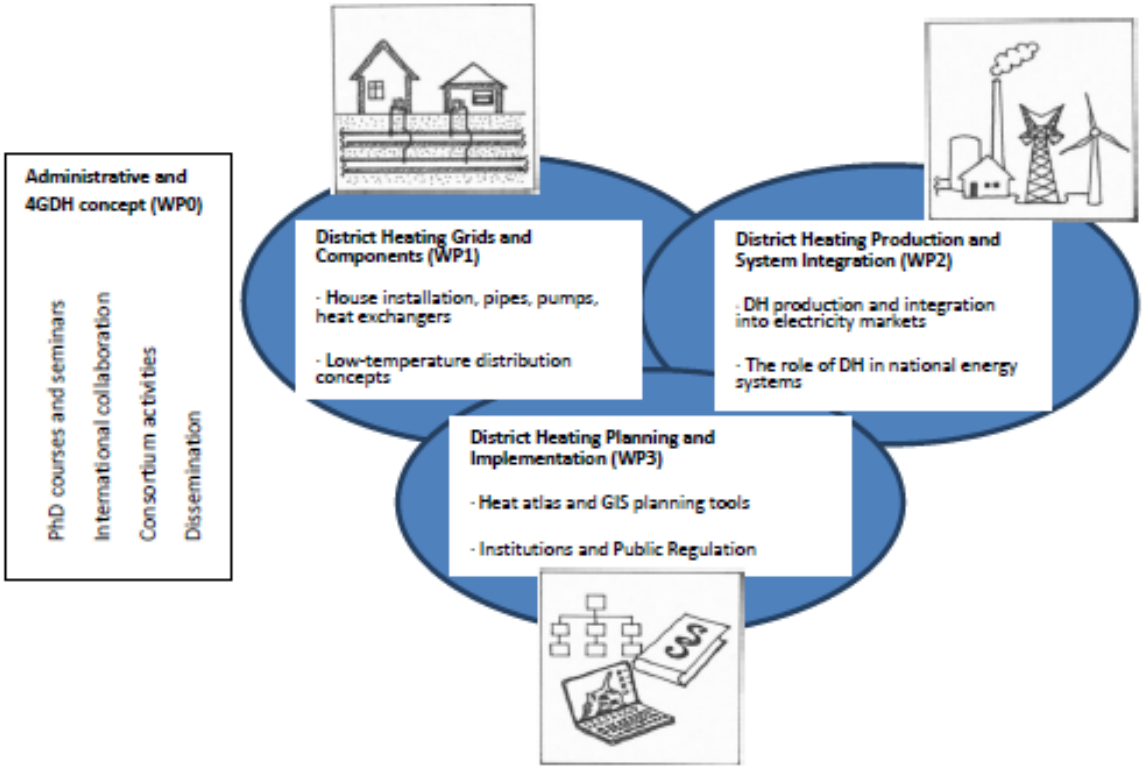
Background

- Research questions, projects, and publications
- The 4DH Strategic Research Center, Aalborg University (2012 – 2017)
  - Aim ➔ to assist in the development of 4th Generation DH Technologies and Systems
  - Hypothesis ➔ DH has potential for playing an important role in the future ➔ utilisation of essential heat resources such as CHP, geothermal energy, industrial surplus heat, waste, solar, and biomass
  - Scientific objective ➔ to establish a platform for the coherent development of 4th Generation DH Technologies and Systems in which:
    - *Synergy is created between the development of grids and components, house installations, DH production and system integration as well as planning and implementation tools and methodologies*

Background

- Research questions, projects, and publications
- The 4DH Strategic Research Center, Aalborg University (2012 – 2017)



No.	Title/subject (working title)
1.1	Heating of existing buildings by low-temperature DH
1.2	Supply of domestic hot water at comfort temperatures without legionella
1.3	Conversion of existing DH to low temperature operation and extension of new areas of buildings
1.4	Minimising losses in the DH distribution grid
2.1	Energy Scenarios for Denmark
2.2	Thermal storage in district heating systems
2.3	Distributed CHP-plants optimized across more electricity markets
2.4	Low-temperature energy sources for district heating
2.5	The role of district heating in the Chinese energy system
3.1	Strategic energy planning in a municipal and legal perspective
3.2	Price regulation, tariff models and ownership as elements of strategic energy planning
3.3	Geographical representations of heat demand, efficiency and supply
3.4	Geographical representations of renewable energy systems

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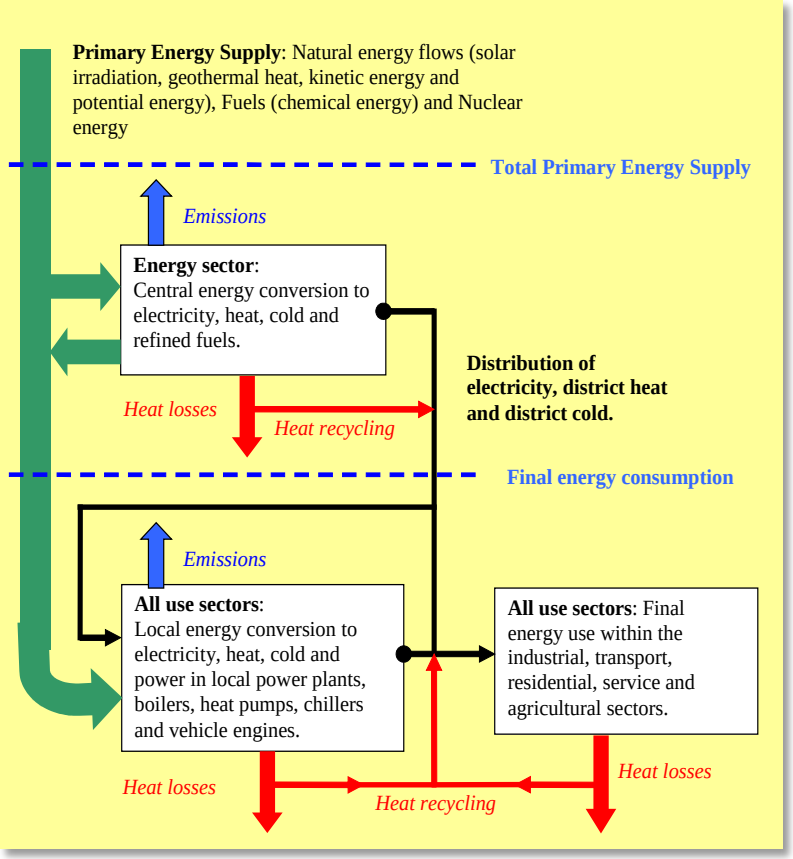
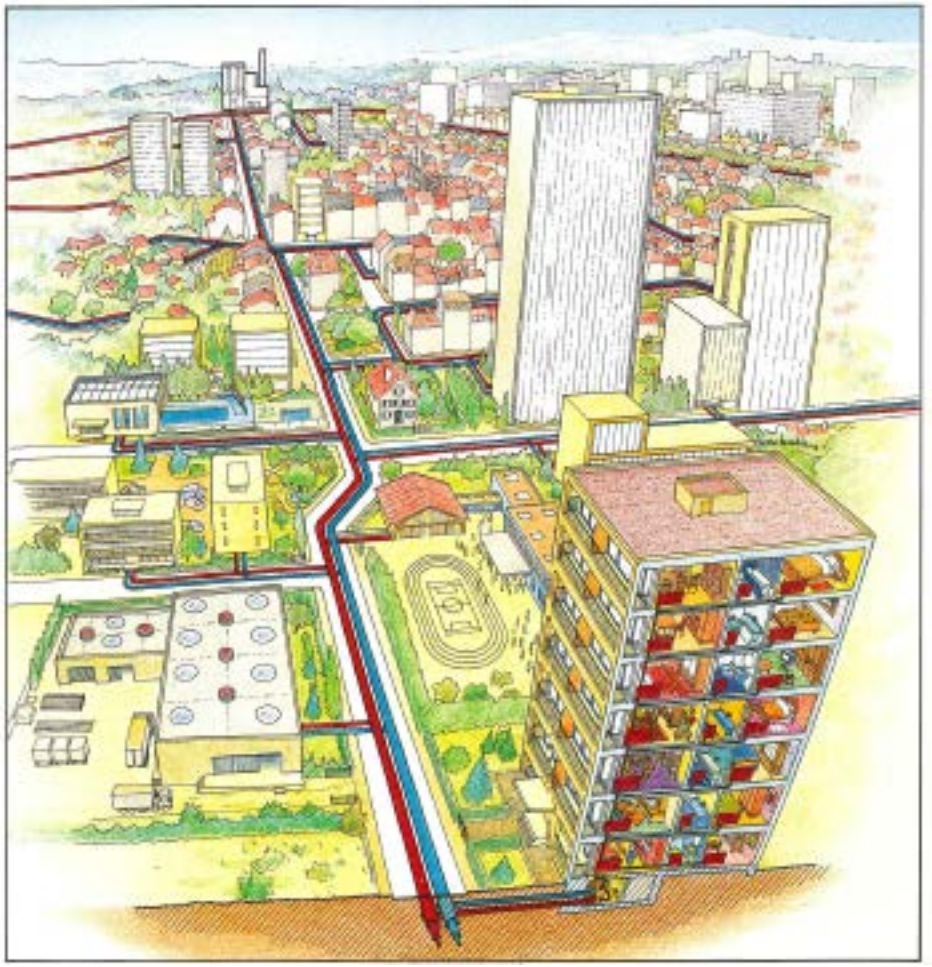
General information on district heating and cooling

- Fundamentals of district heating and cooling

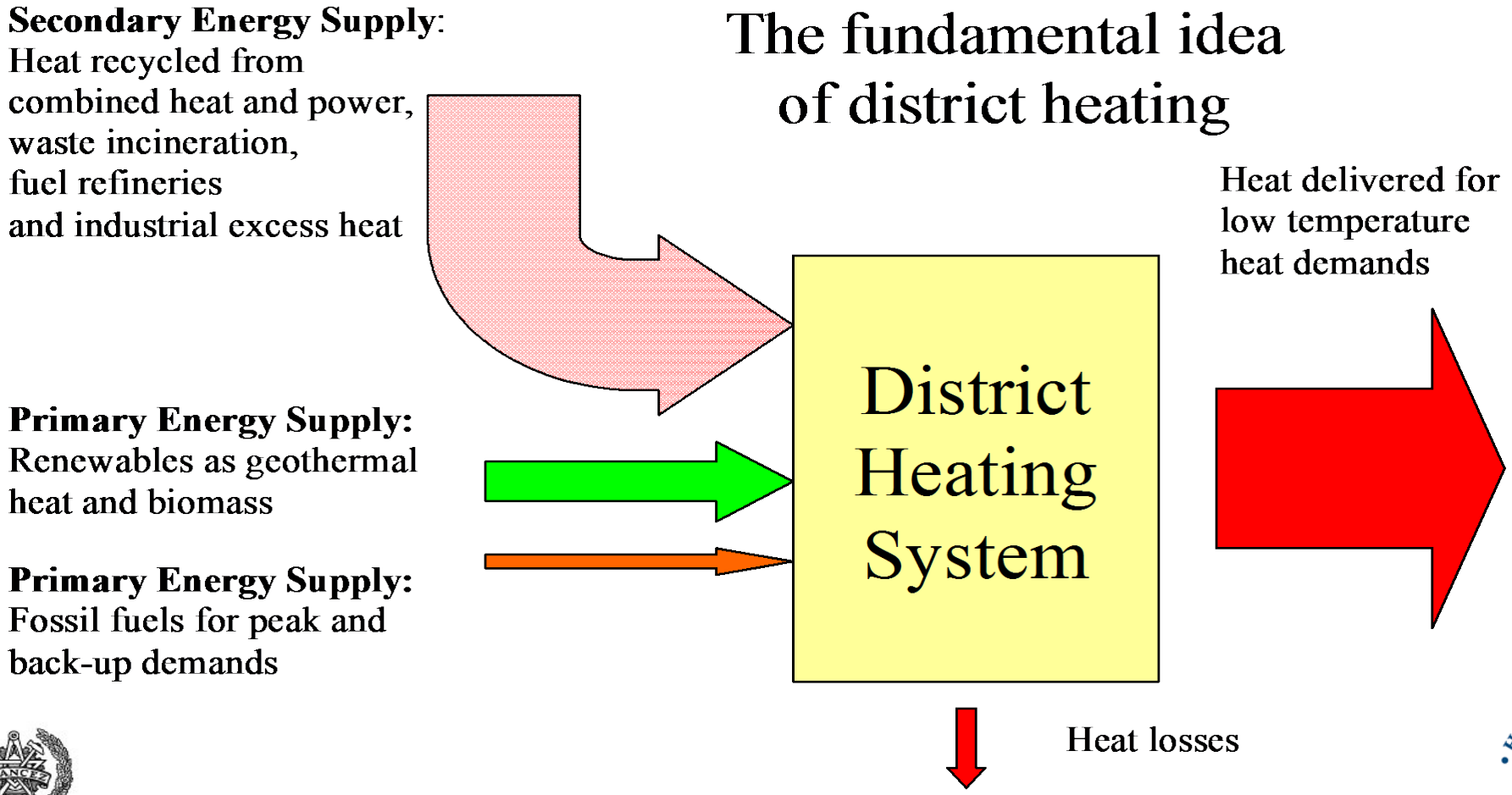


The energy system structure. Source; S. Werner 2010.



General information on district heating and cooling

- Fundamentals of district heating and cooling



Source: Frederiksen S, Werner S, District Heating and Cooling. Coming english textbook on DHC.

General information on district heating and cooling

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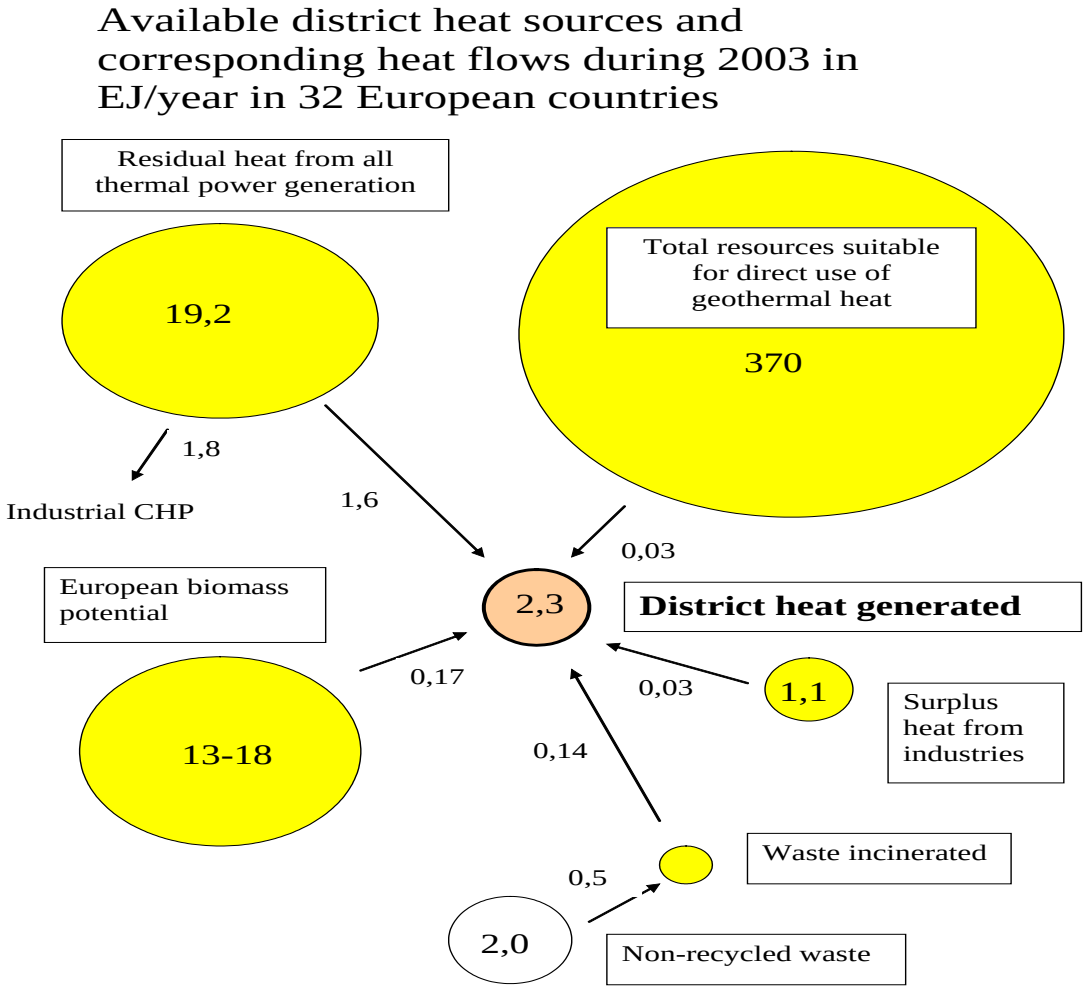

Source: Werner S, Possibilities with more district heating in Europe. Ecoheatcool WP4 , Euroheat & Power, Brussels 2006.

General information on district heating and cooling

- Fundamentals of district heating and cooling
  - 1st generation (1880-1930) - low pressure steam as heat carrier, relatively high supply temperatures (t > 100 ºC)
  - 2nd generation (1930-1970) - pressurised hot water as heat carrier, relatively high supply temperatures (t ≥ 100 ºC)
  - 3rd generation (1970 -) - pressurised hot water as heat carrier, reduced supply temperature levels (t < 100 ºC)
  - 4th generation (2015 -) – low pressurised hot water, supply temperatures as low as 60 ºC
    - Heat “moving” networks
    - “Smart heat grids”

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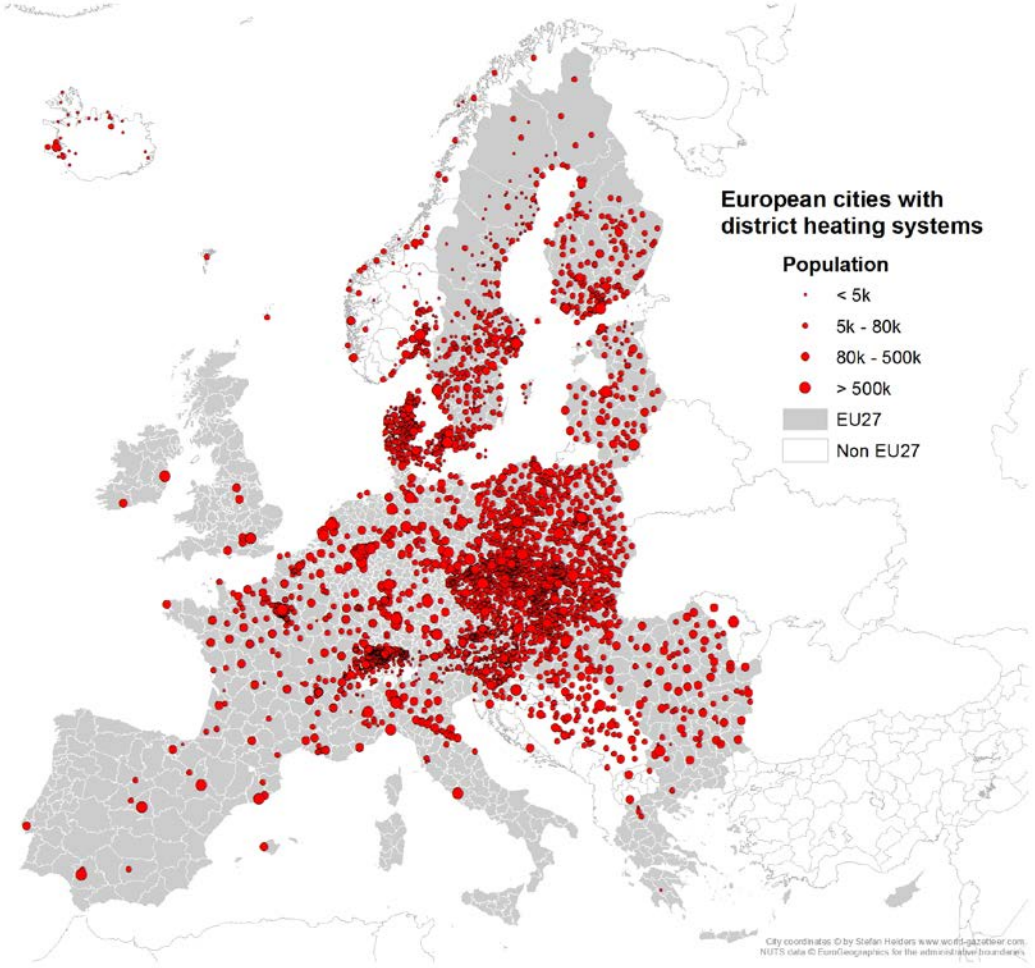
General information on district heating and cooling

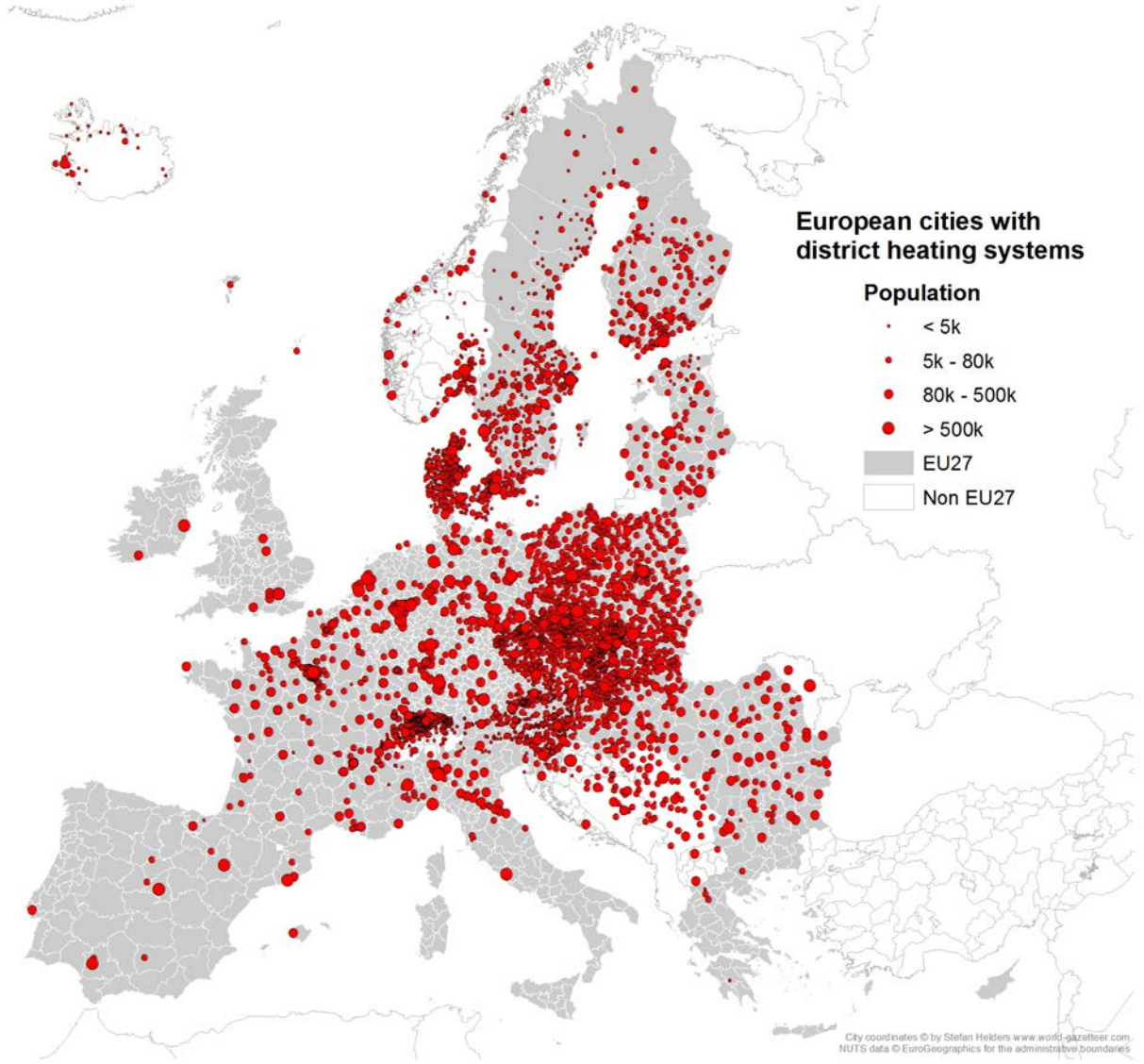
- District heating and cooling in Europe today



- Approximately 6000 DHC networks in Europe today
- Covering 12% of residential and service sector heat demands

Halmstad University District Heating and Cooling Database (HUDHC). Created in June 2010: updates June 2011, May 2012.

Parameter	DH	DH EU27
Number of countries with systems	38	25
Number of systems	4209	3584
Number of systems – in cities with population > 5000	2793	2445
Number of cities with systems	3766	3268
Number of cities with systems and population > 5000	2447	2188
Number of NUTS3 regions with systems	663	603
Number of systems with complete data	1487	1316
Number of systems with heat data	2404	2064
Number of systems with length data	1537	1341
Sum of annually sold heat/cold (PJ)	1009	939
Sum of pipe trench length (km)	70779	69343



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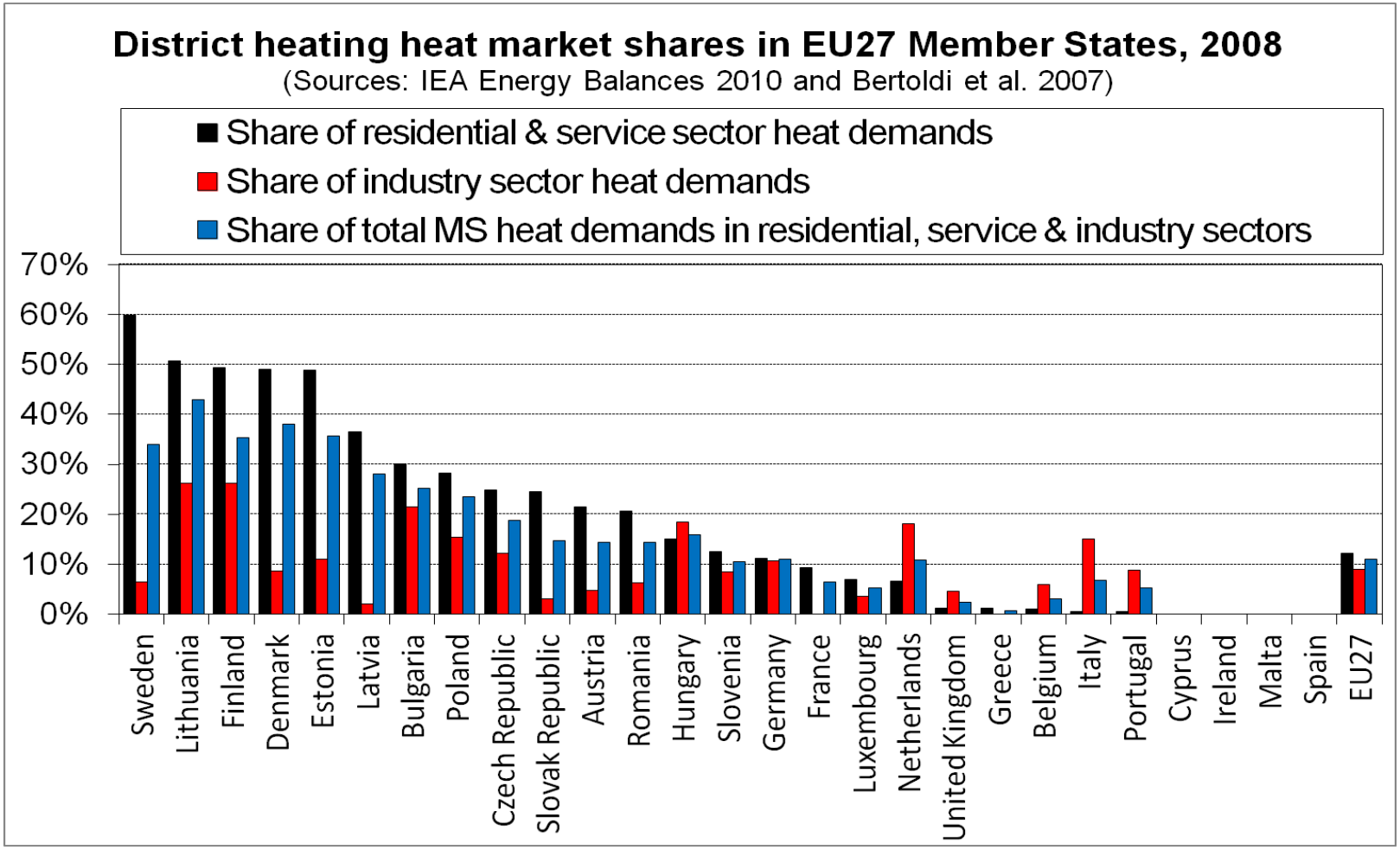
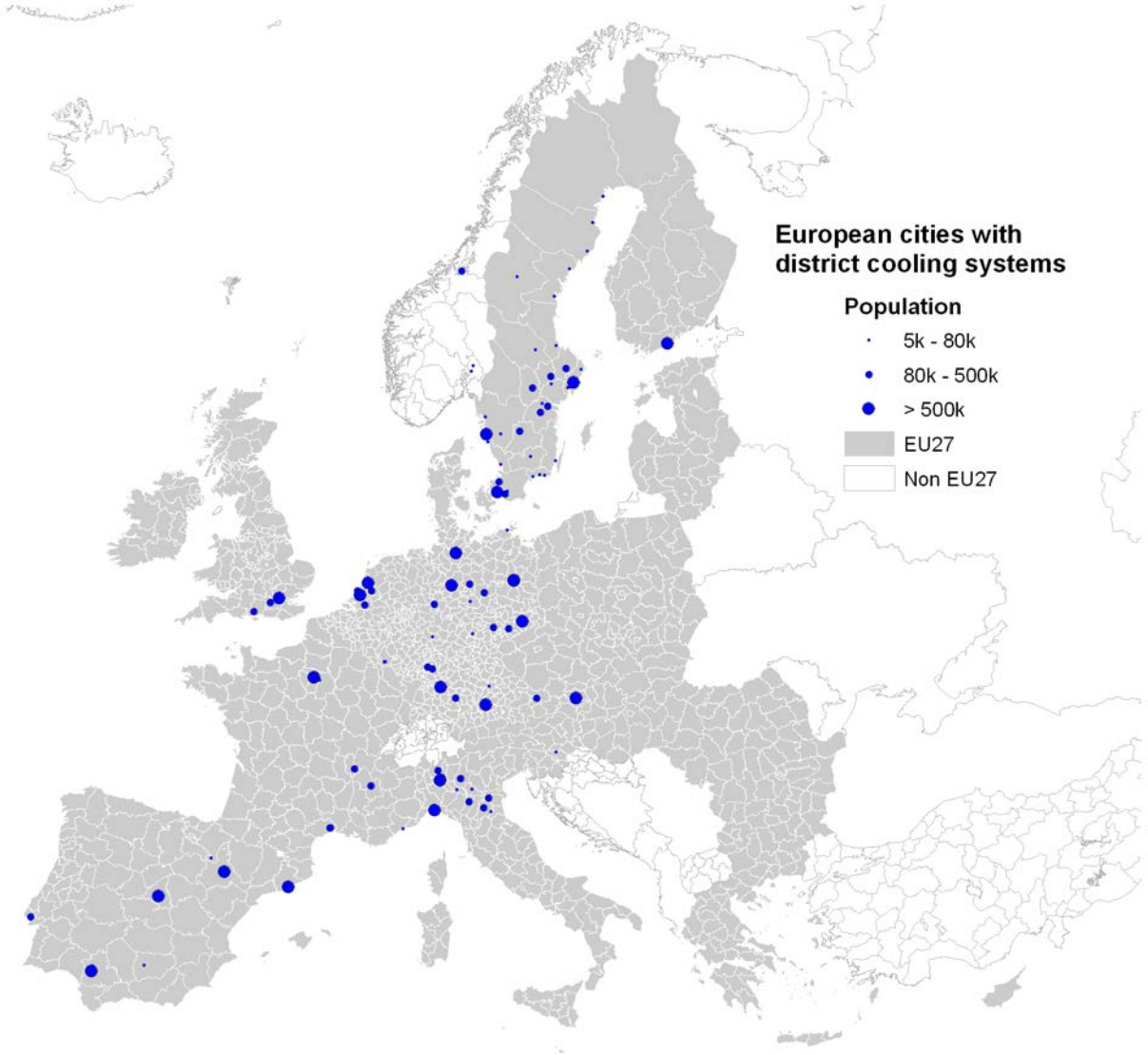
General information on district heating and cooling

- District heating and cooling in Europe today



Source: U. Persson, 2011. Realise the Potential! Cost Effective and Energy Efficient District Heating in European Urban Areas. Licentiate Thesis. Chalmers University of Technology.

Parameter	DC	DC EU27
Number of countries with systems	14	13
Number of systems	109	105
Number of systems – in cities with population > 5000	106	103
Number of cities with systems	107	103
Number of cities with systems and population > 5000	104	101
Number of NUTS3 regions with systems	81	79
Number of systems with complete data	5	5
Number of systems with heat data	55	55
Number of systems with length data	5	5
Sum of annually sold heat/cold (PJ)	7	7
Sum of pipe trench length (km)	86	86



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1st research issue: The economy of heat distribution

- The distribution capital cost model
  - What are the current distribution capital cost levels and possible district heat market shares in European cities?
  - By how much will distribution capital costs increase when future heat demands decrease?
  - How will this increase influence the future heat market shares for DH?

  - Methodological approach:
  - Theoretical reformulation of traditional quantity of Linear Heat Density
  - Modeling of heat demand distributions on city district levels
  - Assessments of specific investment costs for (new) District Heating systems

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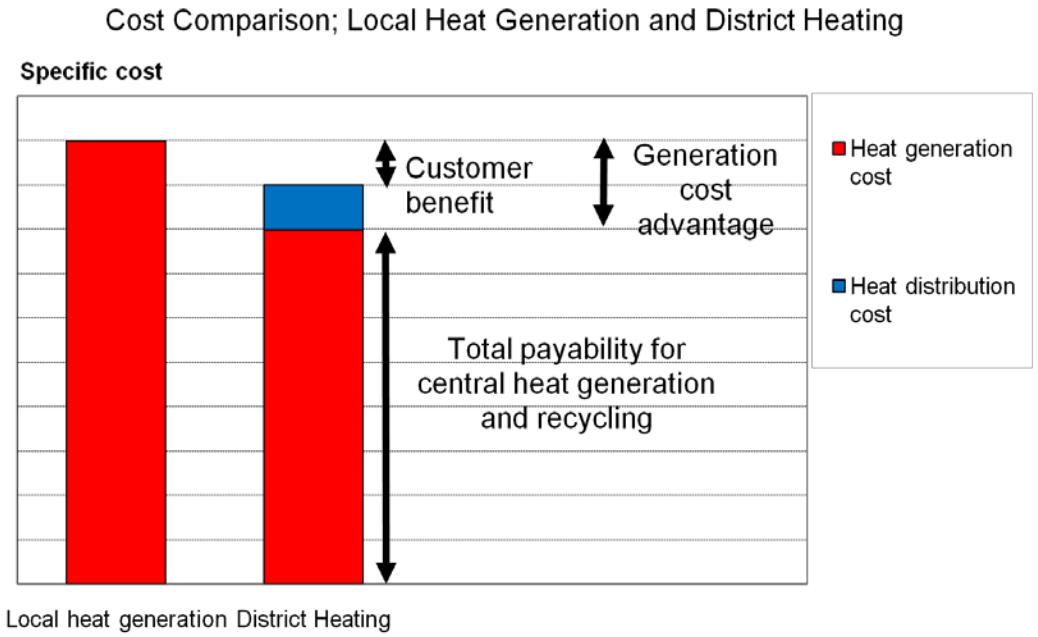
1st research issue: The economy of heat distribution

- The distribution capital cost model



The Distribution Capital Cost, C_d [EUR/GJ]:

$$C_d = \frac{a(C_1 + C_2 \cdot d_a)}{\left(\frac{Q}{L}\right)}$$

a = Annuity

C_1 = Construction cost constant [EUR/m]

C_2 = Construction cost coefficient [EUR/m^2]

d_a = Average Pipe Diameter [m]

Q = Annual Heat [GJ/a]

L = Total Trench length [m]

Q/L = Linear Heat Density [GJ/ma]

To be competitive:"*The total cost of district heat must be lower than the cost of any local heat generation alternative!*"

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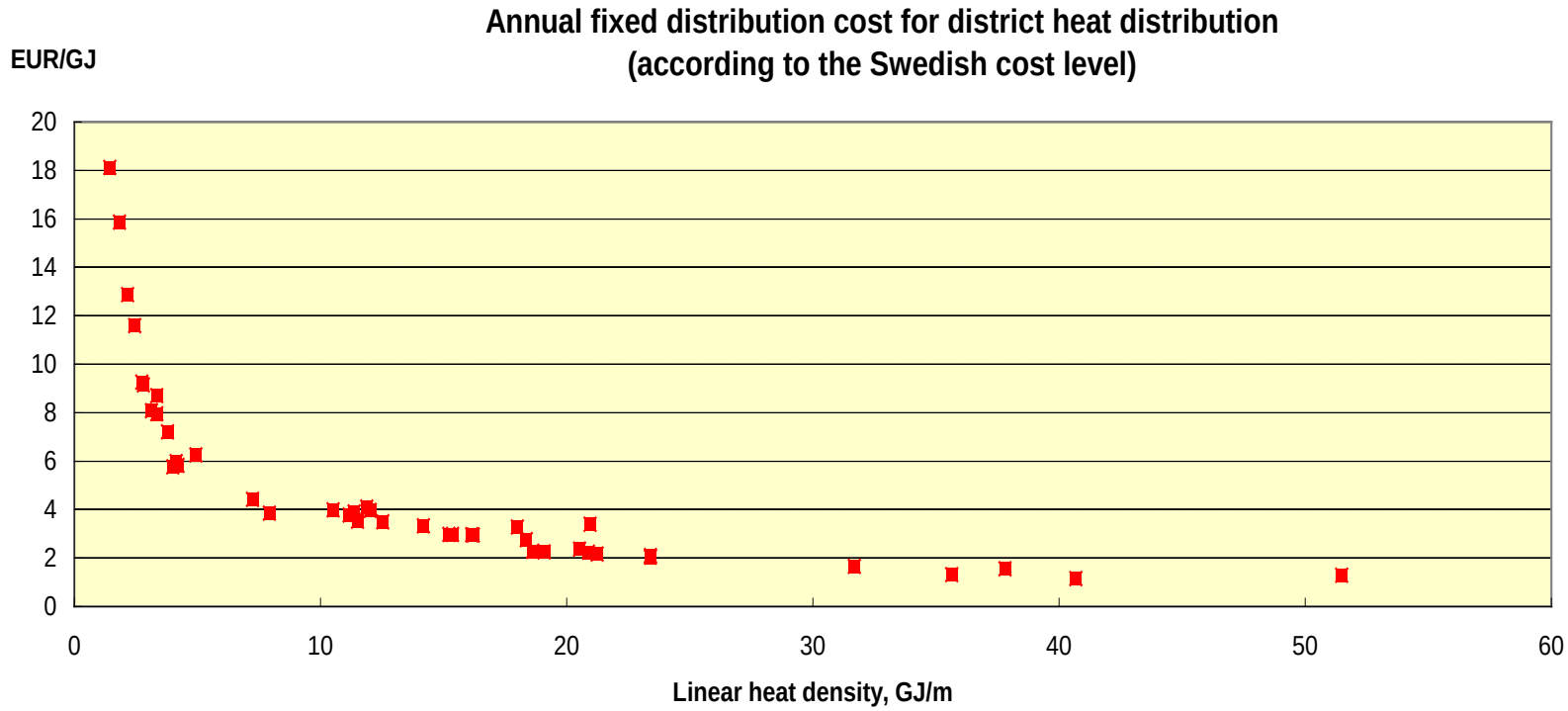
1st research issue: The economy of heat distribution

- The distribution capital cost model
  - How to estimate linear heat densities before district heating is established in a city district?

Traditionally established on the basis of empirical evidence (C_d, Q and L).



1st research issue: The economy of heat distribution

- The distribution capital cost model
- Theoretical reformulation of the traditional expression for linear heat density, (Q/L)

$$C_d = \frac{a(C_1 + C_2 \cdot d_a)}{\left(\frac{Q}{L}\right)}$$

- Enabled modelling of future district heat distribution capital costs, Cd [€/GJ] through the use of:
- Alternative data categories:
  - Specific heat demand (q)
  - Plot ratio (e = pα)
    - Population density (p)
    - Specific building space (α)

$$C_d = \frac{a \cdot (C_1 + C_2 \cdot d_a)}{q \cdot e \cdot w}$$

… and Effective Width, $w = A_L / L$!

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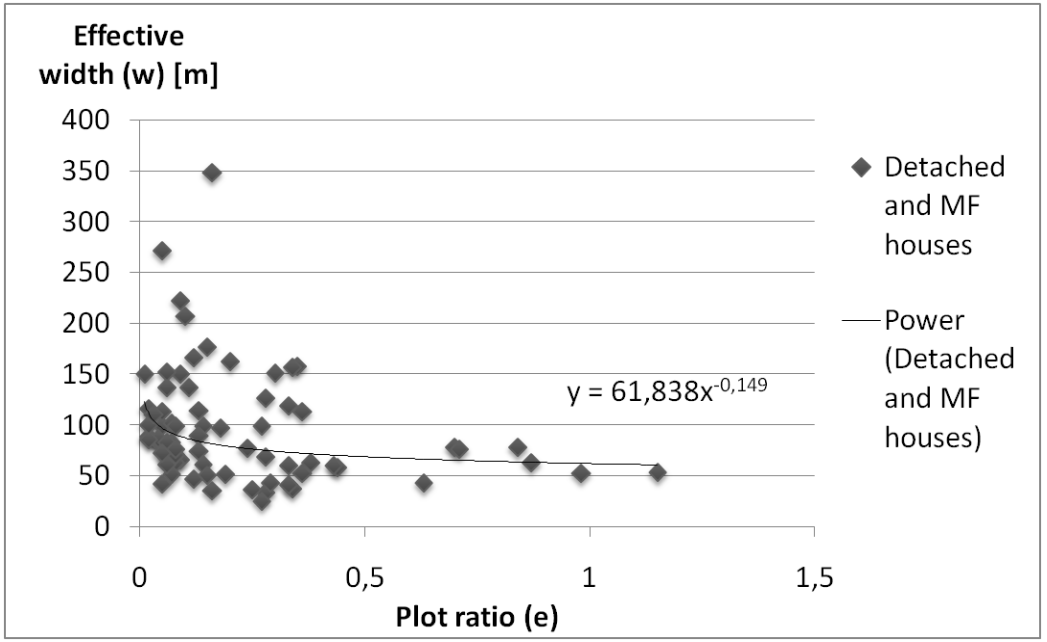
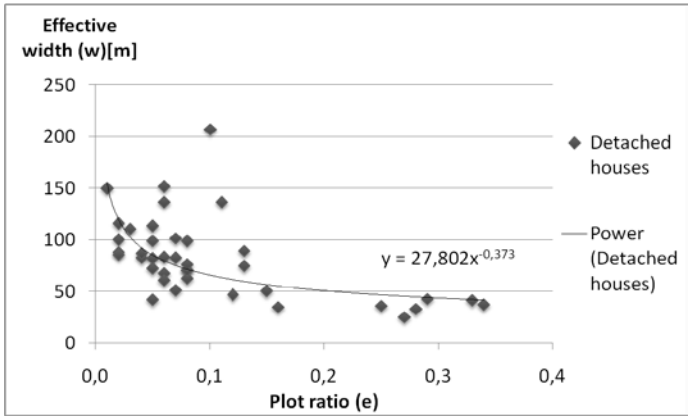
1st research issue: The economy of heat distribution

- The distribution capital cost model

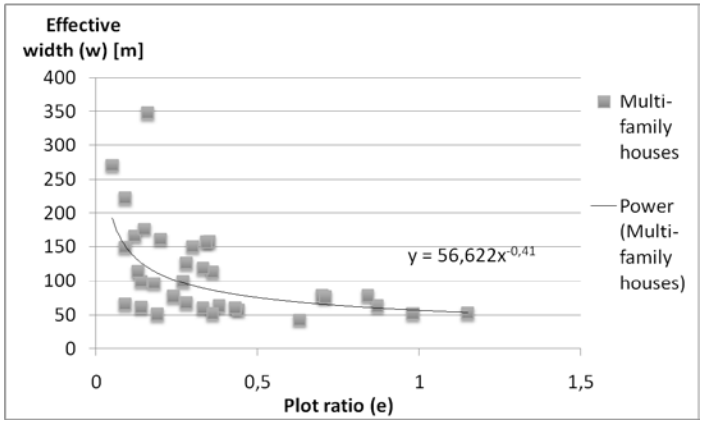
$$C_d = \frac{a \cdot (C_1 + C_2 \cdot d_a)}{q \cdot e \cdot w}$$



Combination of detached house and multi-family housing DH systems 73 observations



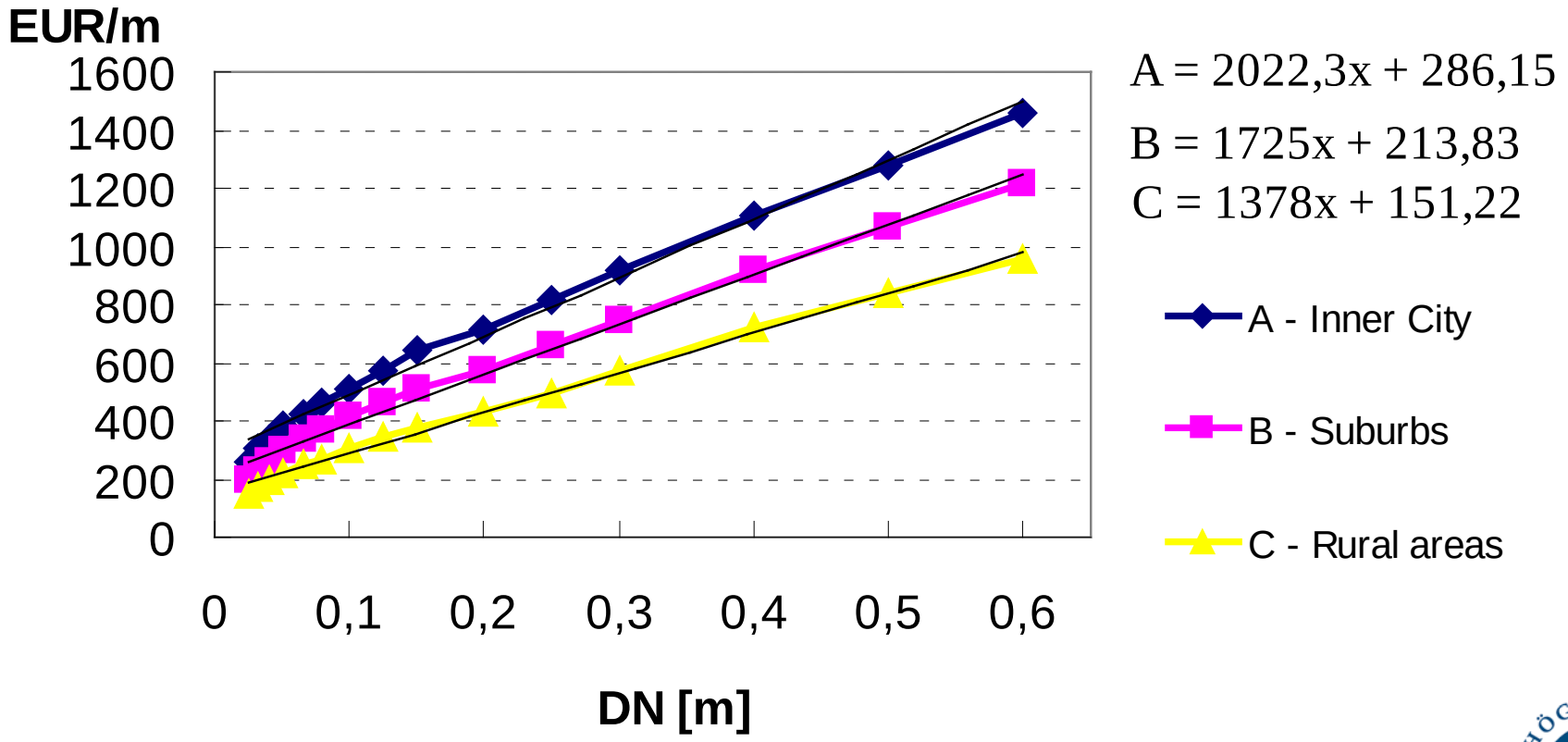
39 detached house DH systems



34 multi-family housing DH systems

1st research issue: The economy of heat distribution

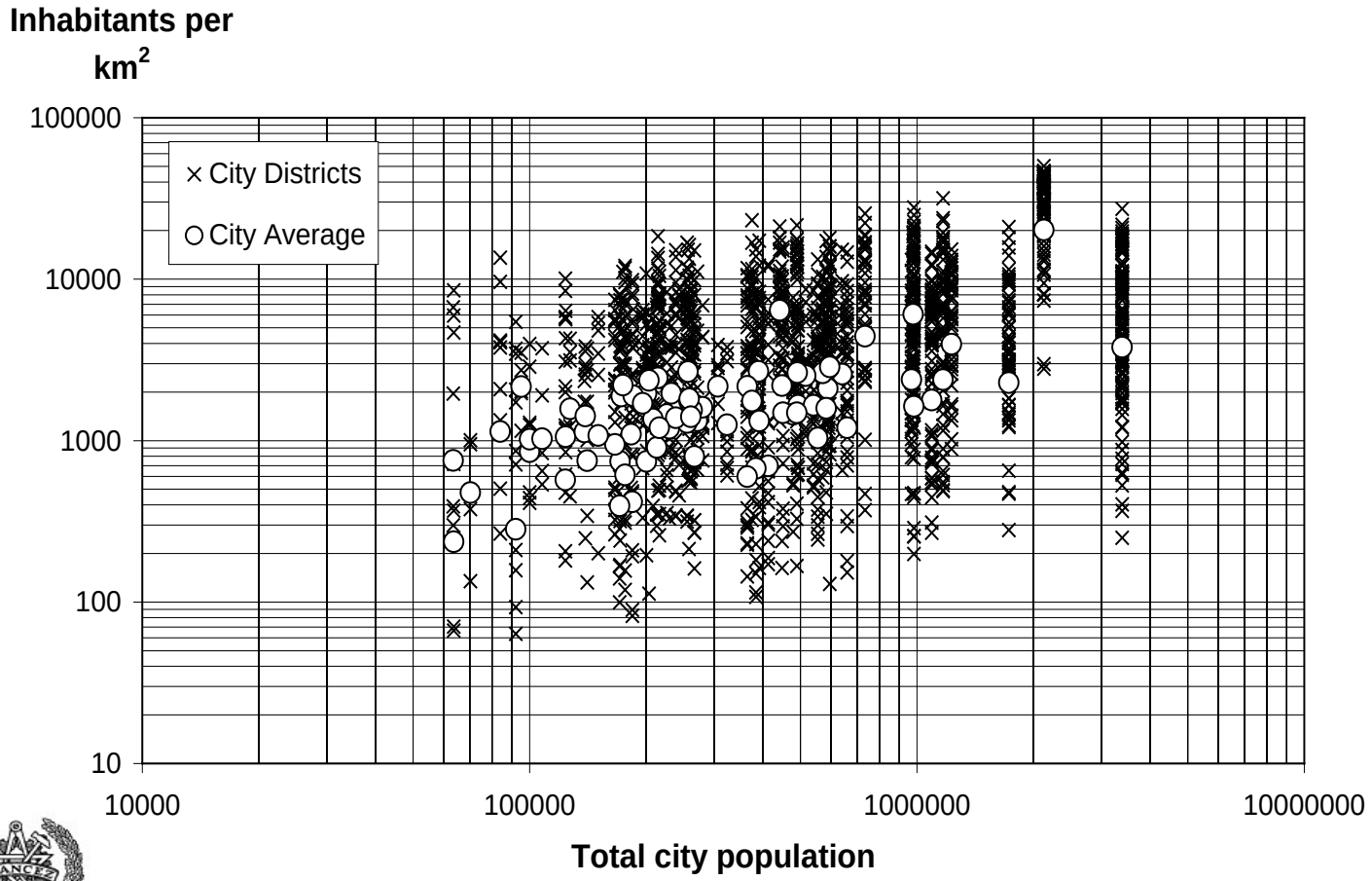
- The distribution capital cost model
  - Construction costs



Source; Svensk Fjärrvärmes Kulvertkostandskatalog 2007, Svensk Fjärrvärme

1st research issue: The economy of heat distribution

- The distribution capital cost model
  - Population density



Combinations of total city populations and population densities in city districts and for total city averages in 1703 city districts and 83 cities.

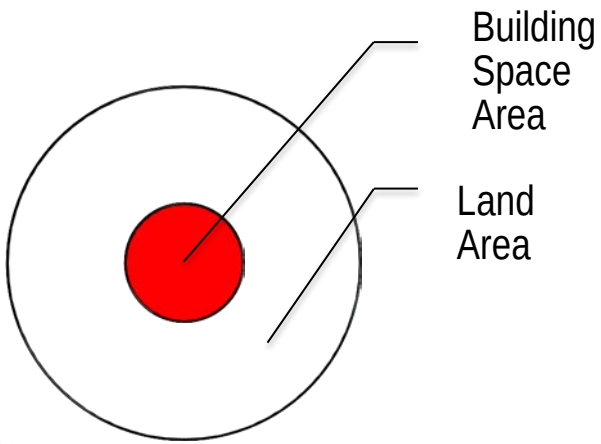
Source: U. Persson & S. Werner, 2011. Heat Distribution and The Future Competitiveness of District Heating. Applied Energy 88 (2011) 568–576

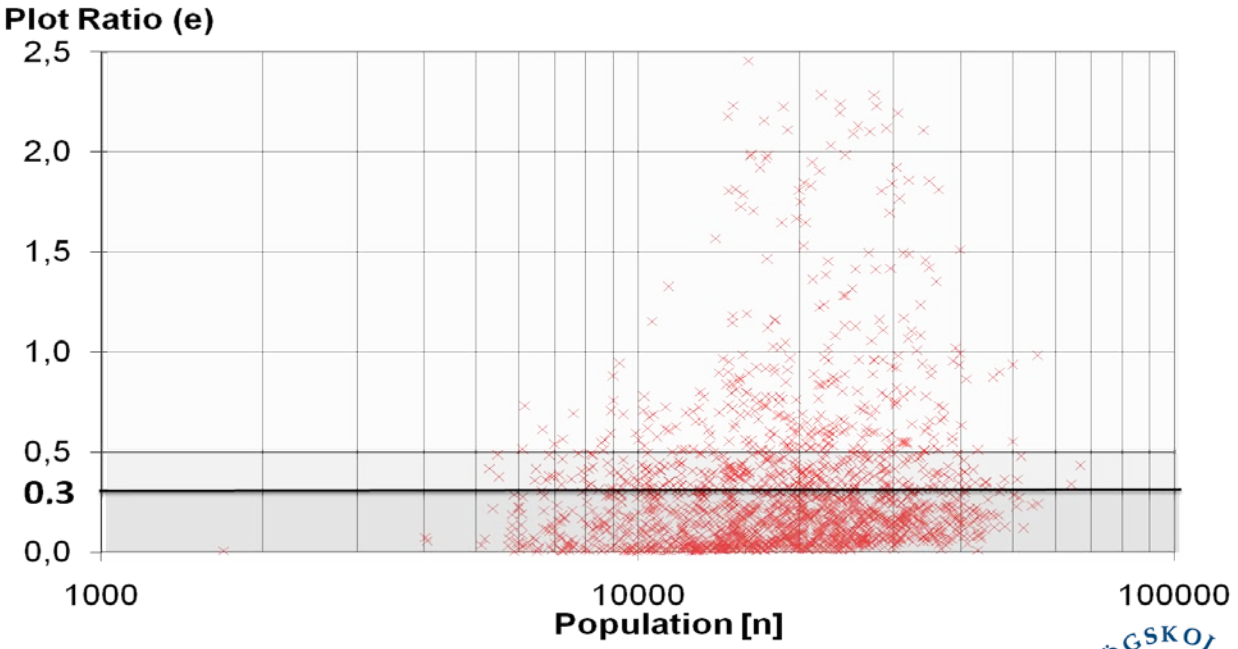
1st research issue: The economy of heat distribution

- The distribution capital cost model
- Plot ratio:
- $e = A_B/A_L = p\alpha$ [-]

Area characteristics	Plot Ratio (e)
Inner city areas (A)	$e \geq 0.5$
Outer city areas (B)	$0.3 \leq e < 0.5$
Park areas (C)	$0 \leq e < 0.3$

- A_B= Total build. space area [m^2]
- A_L= Total land area [m^2]





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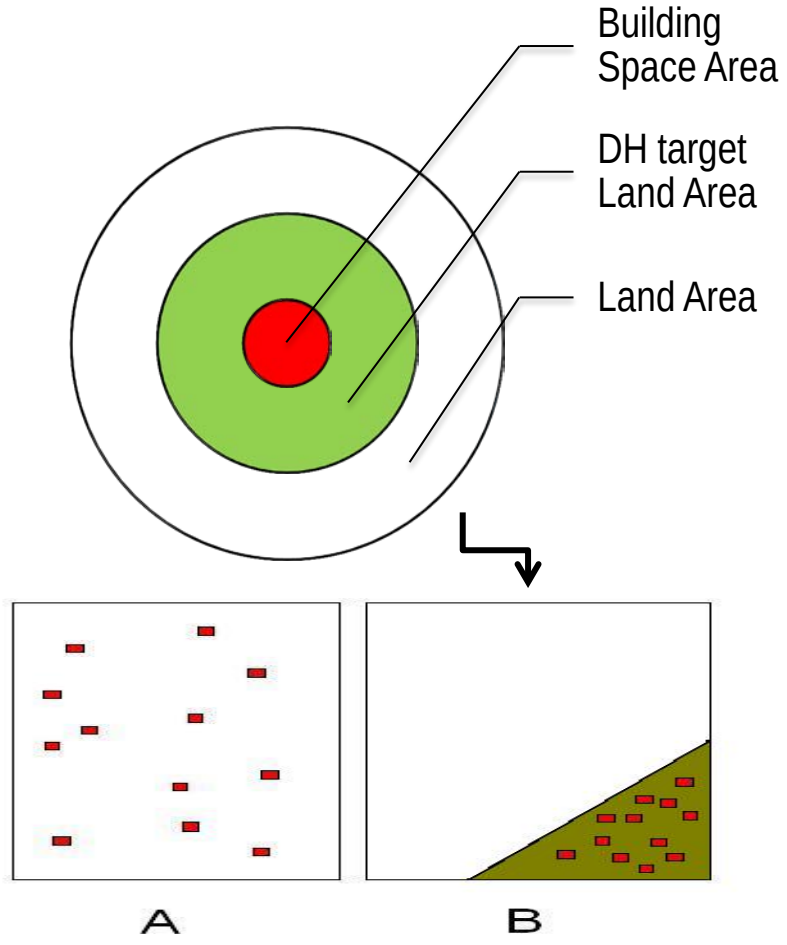
1st research issue: The economy of heat distribution

- The distribution capital cost model
- Use of Land Area information in low Plot Ratio areas is hazardous:
- Widely distributed park area settlements (A) may prove unfeasible for DH expansions, due to insufficient Linear Heat Densities
- Depending on settlement structure, the Land Area may include territory not to be targeted by DH (B)
- Potential risk of overestimating network investment costs



Widely distributed (A) and concentrated (B) low Heat Density area settlements

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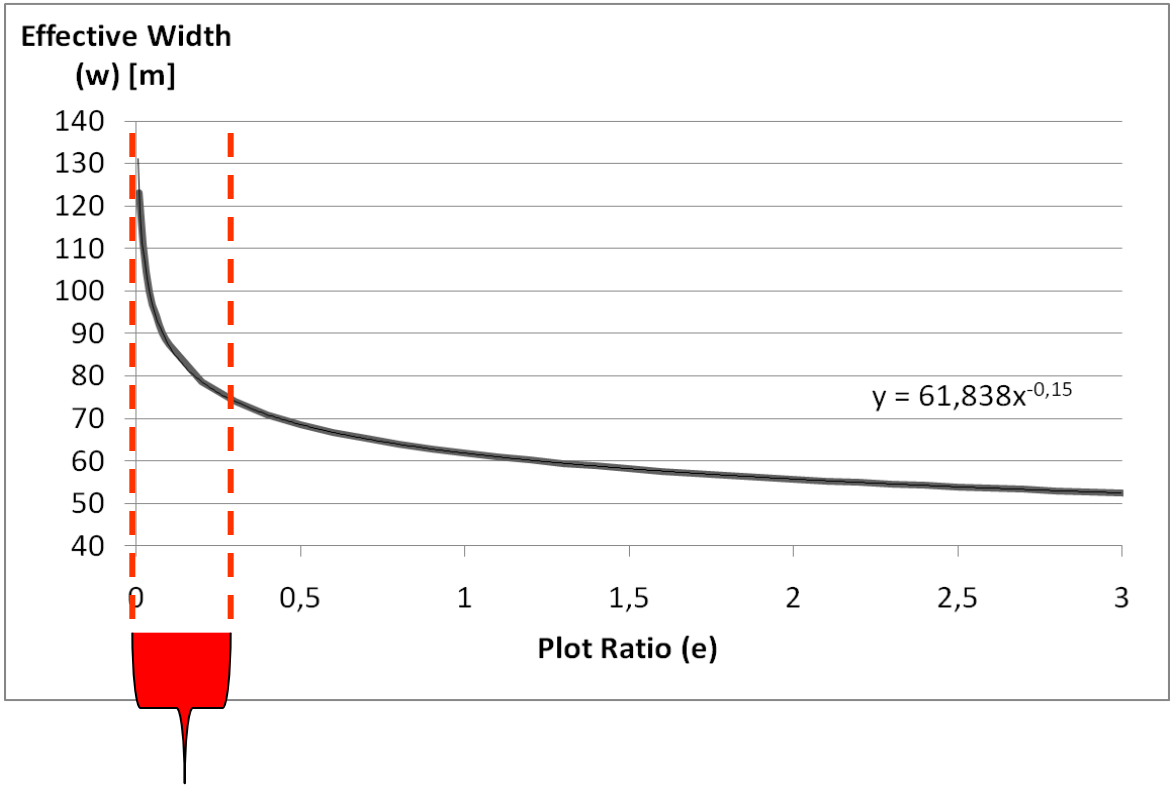
1st research issue: The economy of heat distribution

- The distribution capital cost model



- Effective Width values following eq. compensates the inclusion of non-target areas in low Plot Ratio areas

$$w = 61.8 \cdot e^{-0.15}$$

- At high and moderate Heat Density conditions, Effective Width seem to converge in the 55 – 65 meters interval

Low Heat Density Segment - At low Heat Densities ➔ Effective Width values increase rapidly!

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1st research issue: The economy of heat distribution

- The distribution capital cost model
  - Study model and data
  - Excel-based model (DCM – Distribution Cost Model)
  - Data - Independent data categories:
    - Eurostat, Urban Audit, 2001:
      - Population (P), Land Area (A_L), Population density (p)
    - Enerdata, Odyssee, 2005:
      - Average area of living accommodation (α)
    - IEA Energy statistics and EU Housing statistics
      - Specific heat demand (q)
      - Annuity (a), interest rate (r) and economical life time (n)) - assumed
    - Data - intermediate data categories:
      - Effective width (w) - statistically derived
      - Construction costs (C_1, C_2) - statistically derived
      - Average grid pipe diameters (d_a) - statistically derived

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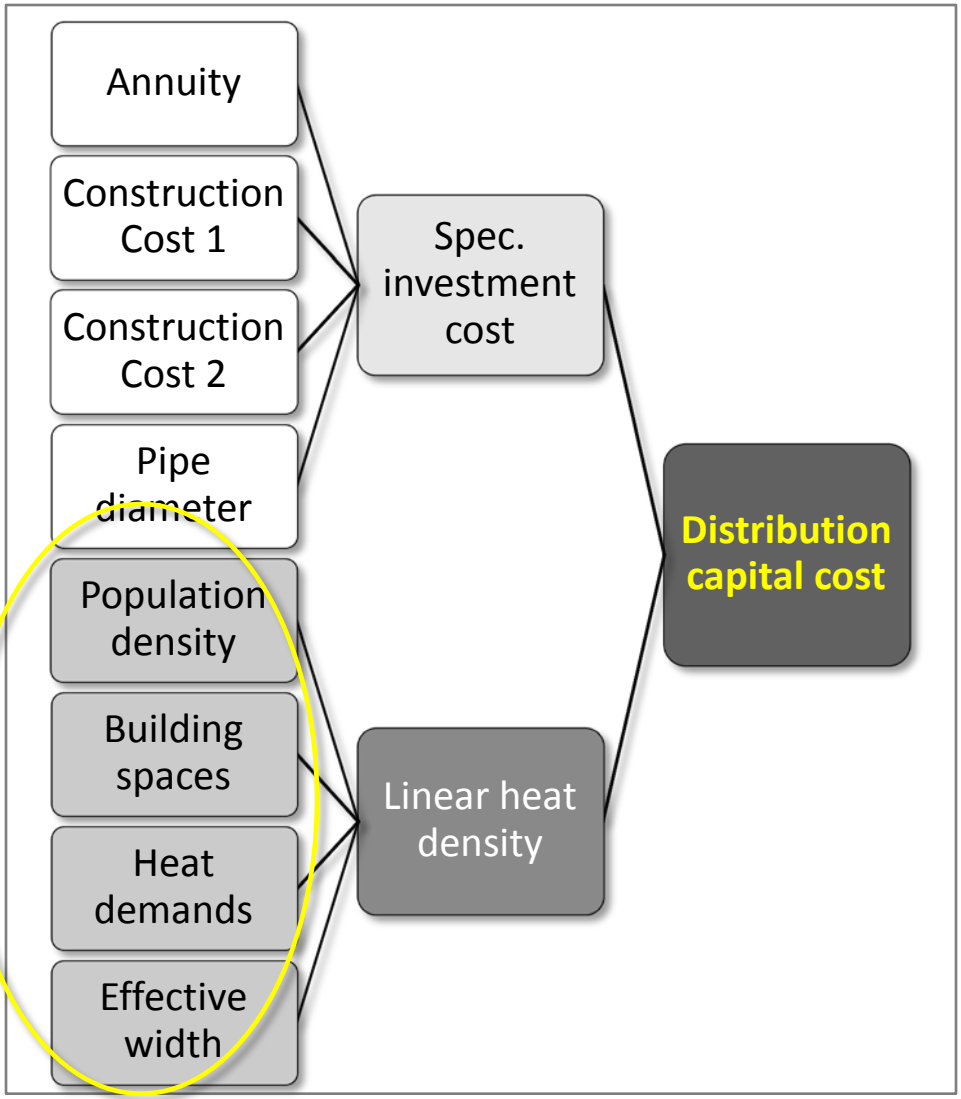
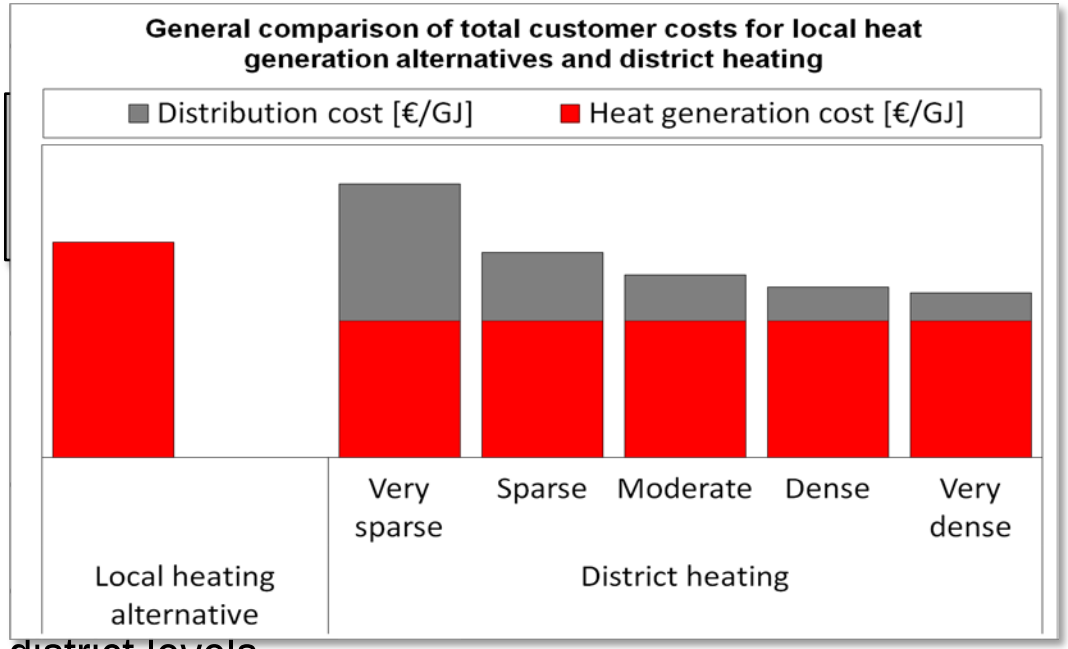


Principal overview of the distribution capital cost model



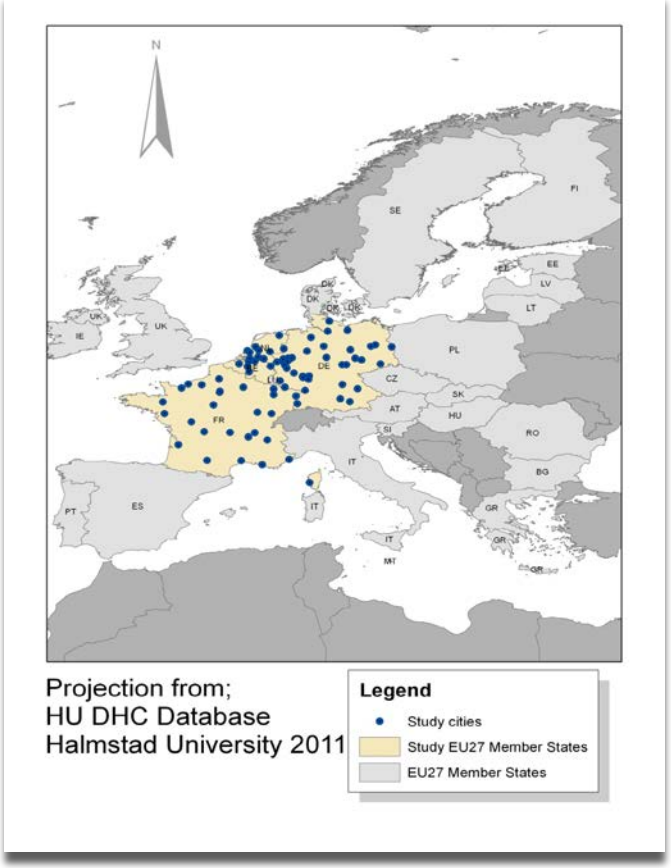
district levels

- 3rd generation conditions – long term investment strategy (3%, 30 years)

- Assessment of investment costs for (new) district heating systems

1st research issue: The economy of heat distribution

- The distribution capital cost model
  - Study objects – investigated cities
    - 83 Cities
    - 1703 City Districts
    - Four Countries:
    - France, Belgium, Germany, the Netherlands
  - Population coverage: 21 % (35 million of 170)
  - Av. Heat Demand; 0.5 GJ/m^{2}a (≈ 140 kWh/m^{2}a)
  - Av. Building Space; 49 - 56 m^2/capita
  - Av. Res. Building Space; 35 – 40 m^2/capita



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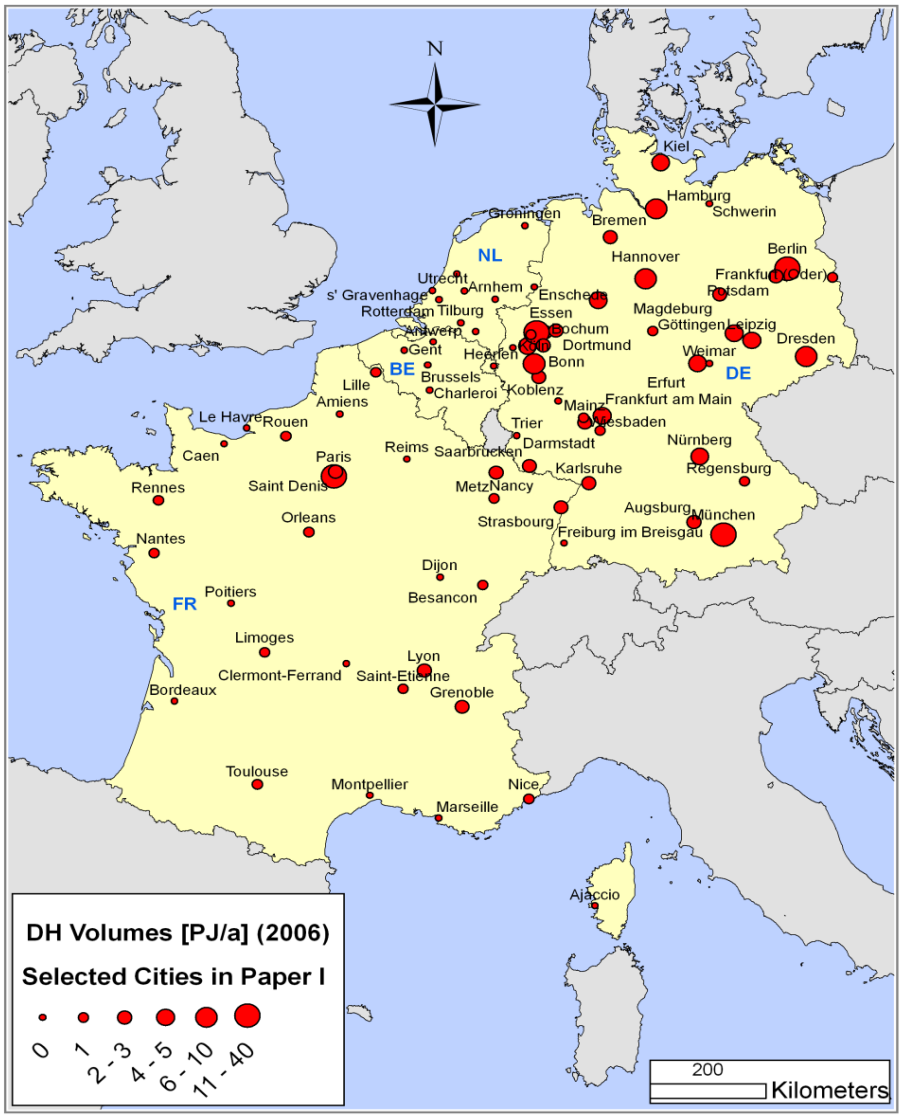

Current levels of district heating

- Av. urban DH heat market share: 21%
  - France: 11%
  - Belgium: 0%
  - Germany: 29%
  - the Netherlands: 21%

- Wide presence, but at relatively low levels: 69 out of 83 cities have DH systems

- 10 study cities have urban DH heat market shares above 40%:
  - Utrecht (NL): 79%
  - Erfurt (DE): 67%

Annual district heat deliveries in 83 studied cities

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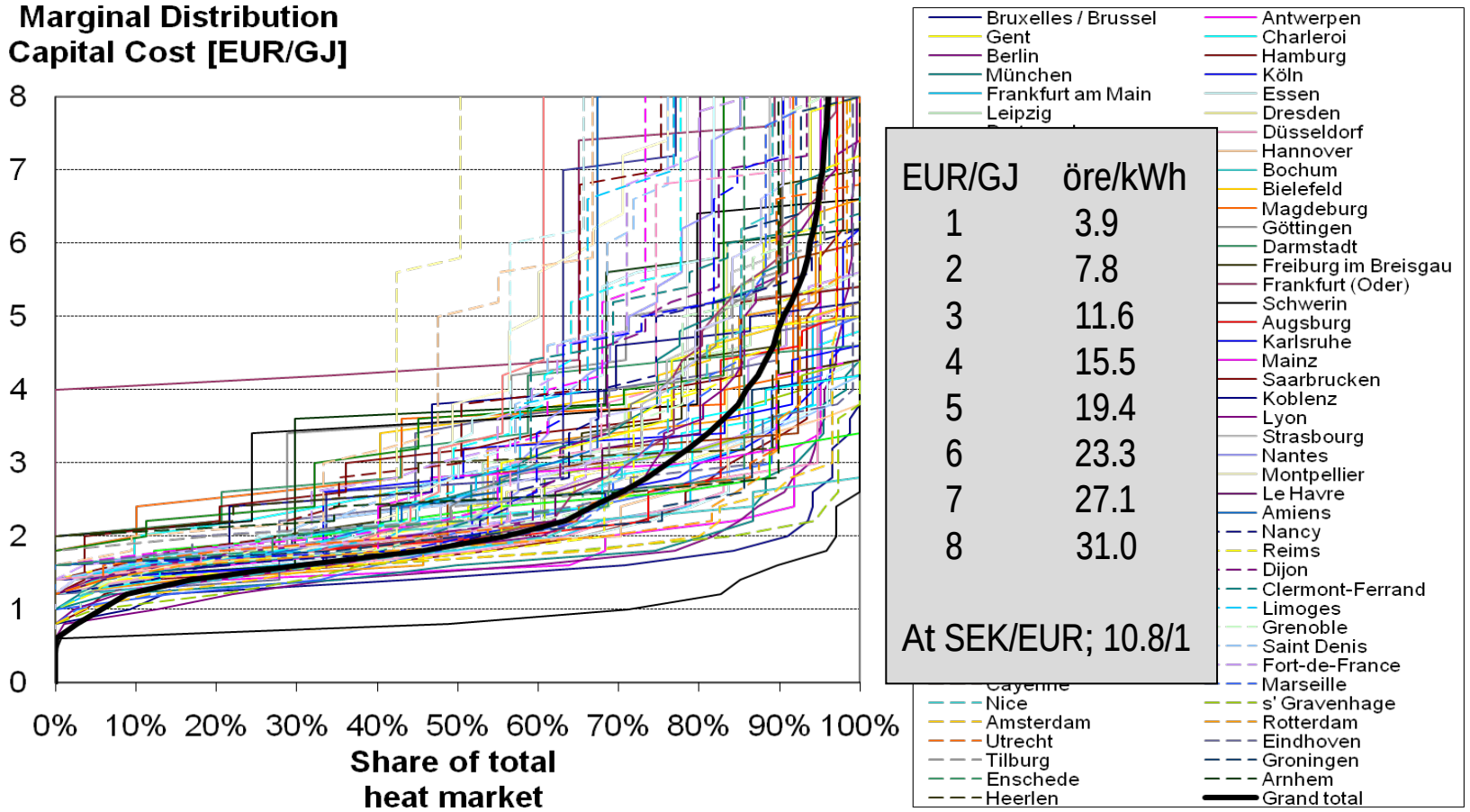
1st research issue: The economy of heat distribution

- The distribution capital cost model
  - Study results



EUR/GJ	öre/kWh
1	3.9
2	7.8
3	11.6
4	15.5
5	19.4
6	23.3
7	27.1
8	31.0

At SEK/EUR; 10.8/1

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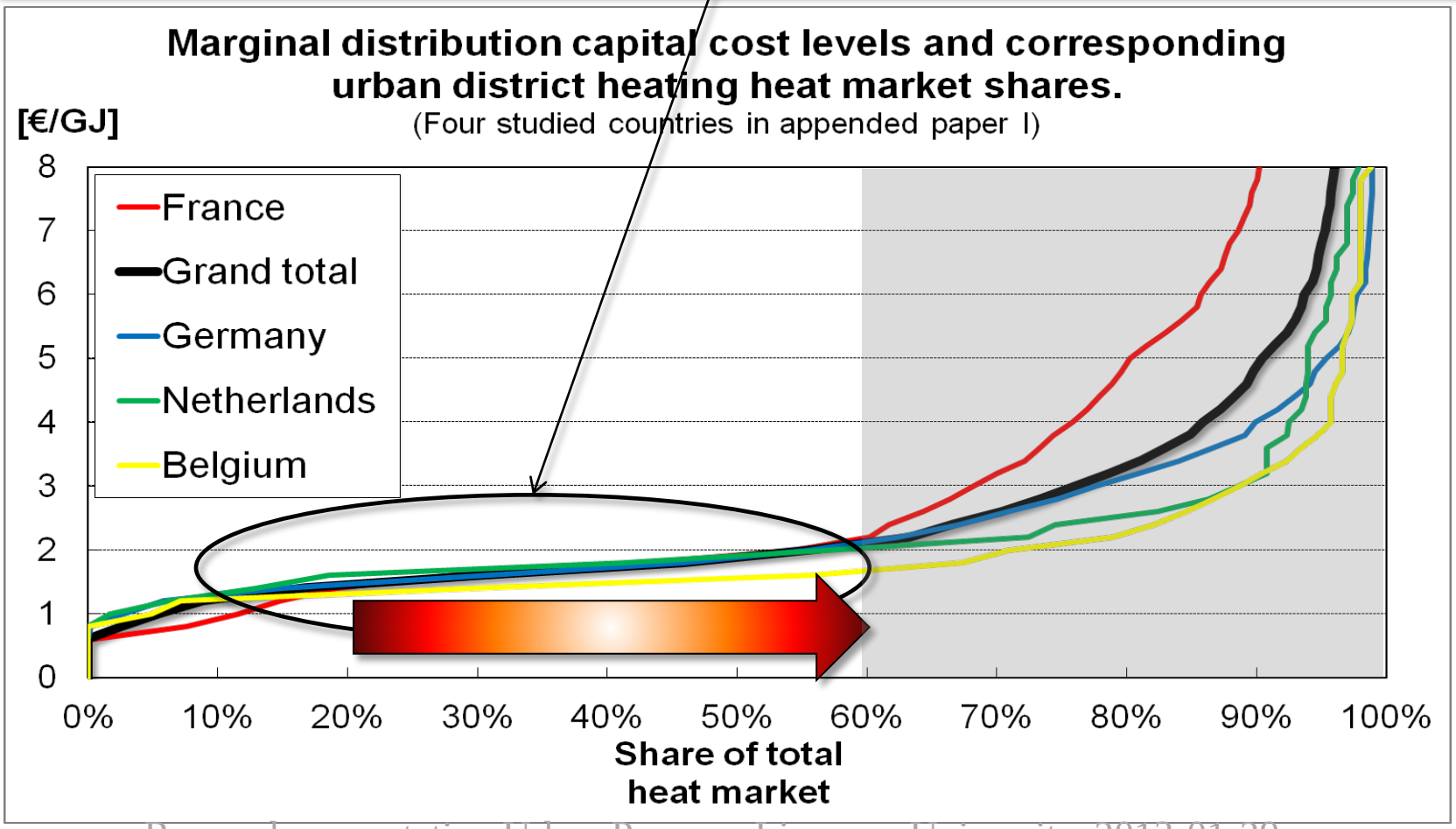
Study results:

- Coherent conditions in all four studied countries up to 60% heat market shares
- Three-fold directly feasible expansion possibility: 20% → 60% (2.1 €/GJ)
- Rem
- Red

Major finding:
Relatively flat GT curve in heat market segment 10% to 60%!



1st research issue: The economy of heat distribution

- The distribution capital cost model
  - Study results

Area characteristics	Number of city districts	Average distribution capital cost, $C_{d,a}$ [€/GJ]	Model-estimated heat demands, Q_s [PJ/a]	Required investment in heat distribution networks, I [G€]
Inner city areas	317	1.2	182 (19 %)	4.3
Outer city areas	296	1.6	160 (17 %)	5.1
Park areas, feasible	355	1.8	236 (25 %)	8.2
Total, directly feasible	968	1.6	578 (61 %)	17.6
Park areas, less feasible	735	4.5	373 (39 %)	32.9
Total	1703	2.7	951 (100 %)	50.5

Comparison to natural gas, If NG for domestic space heating were part of ETS;
At P_e of 20 EUR/tCO_2 ➔ C_e = 1,3 EUR/GJ
At P_e of 40 EUR/tCO_2 ➔ C_e = 2,6 EUR/GJ

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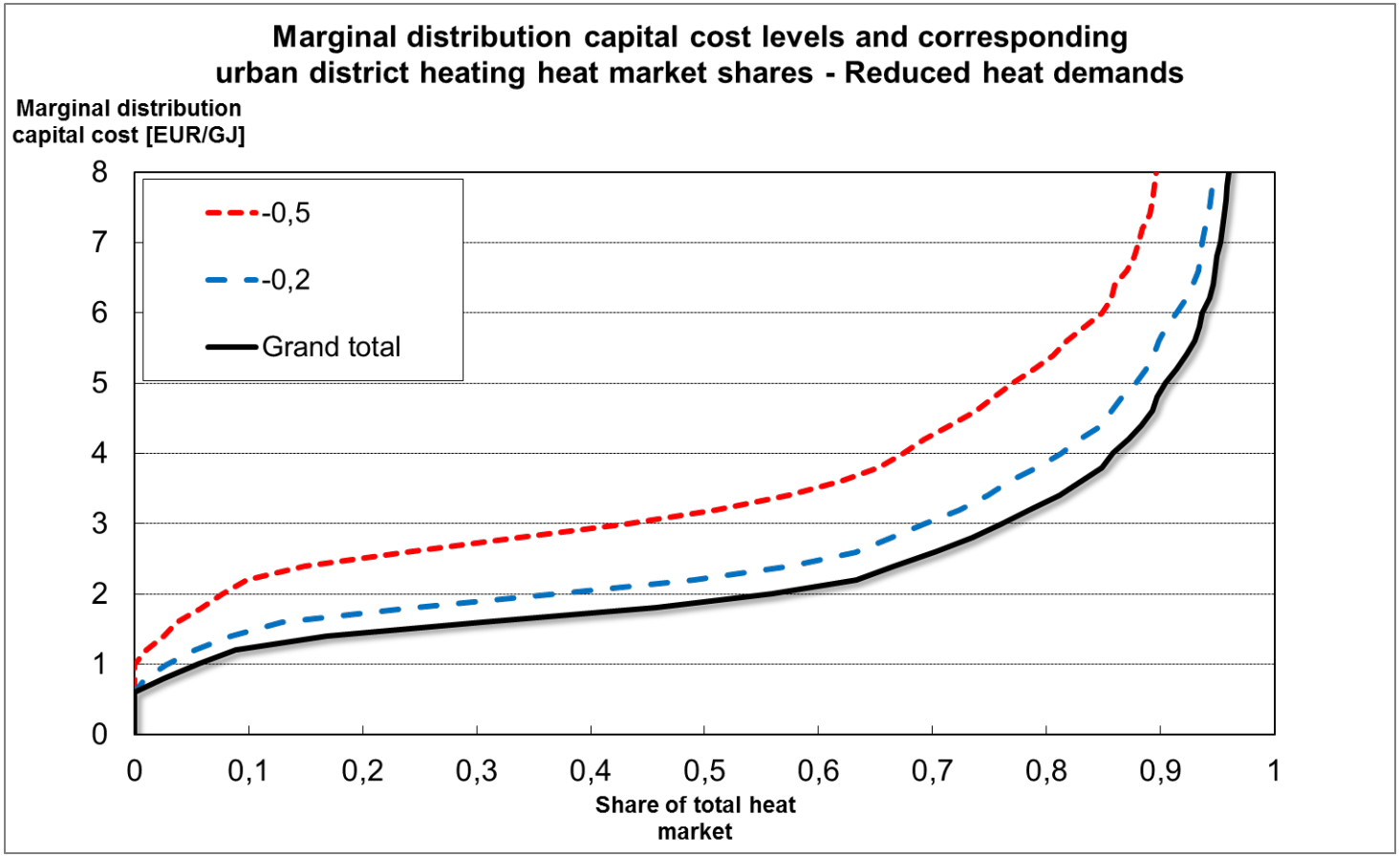
1st research issue: The economy of heat distribution

- The distribution capital cost model
  - Study results



Source: U. Persson & S. Werner, 2011. Heat Distribution and The Future Competitiveness of District Heating. Applied Energy 88 (2011) 568–576

1st research issue: The economy of heat distribution

- The distribution capital cost model
  - Study results
  - Current average DH heat market share of 21% in the four studied countries (FR; 11%, BE; 0%, DE; 29%, NL; 21%, 2006)
  - Large potential for increased heat market shares
    - Appr. 60% heat market shares up to spec. investment cost levels of 2.1 €/GJ
      - Indicative Plot Ratio Threshold; 0.15 – 0.20
      - Corresponding Heat Density; 90 TJ/km^2 (equalling 25 GWh/km^2)
  - Low risk from reduced future heat demands in large cities and inner city areas!

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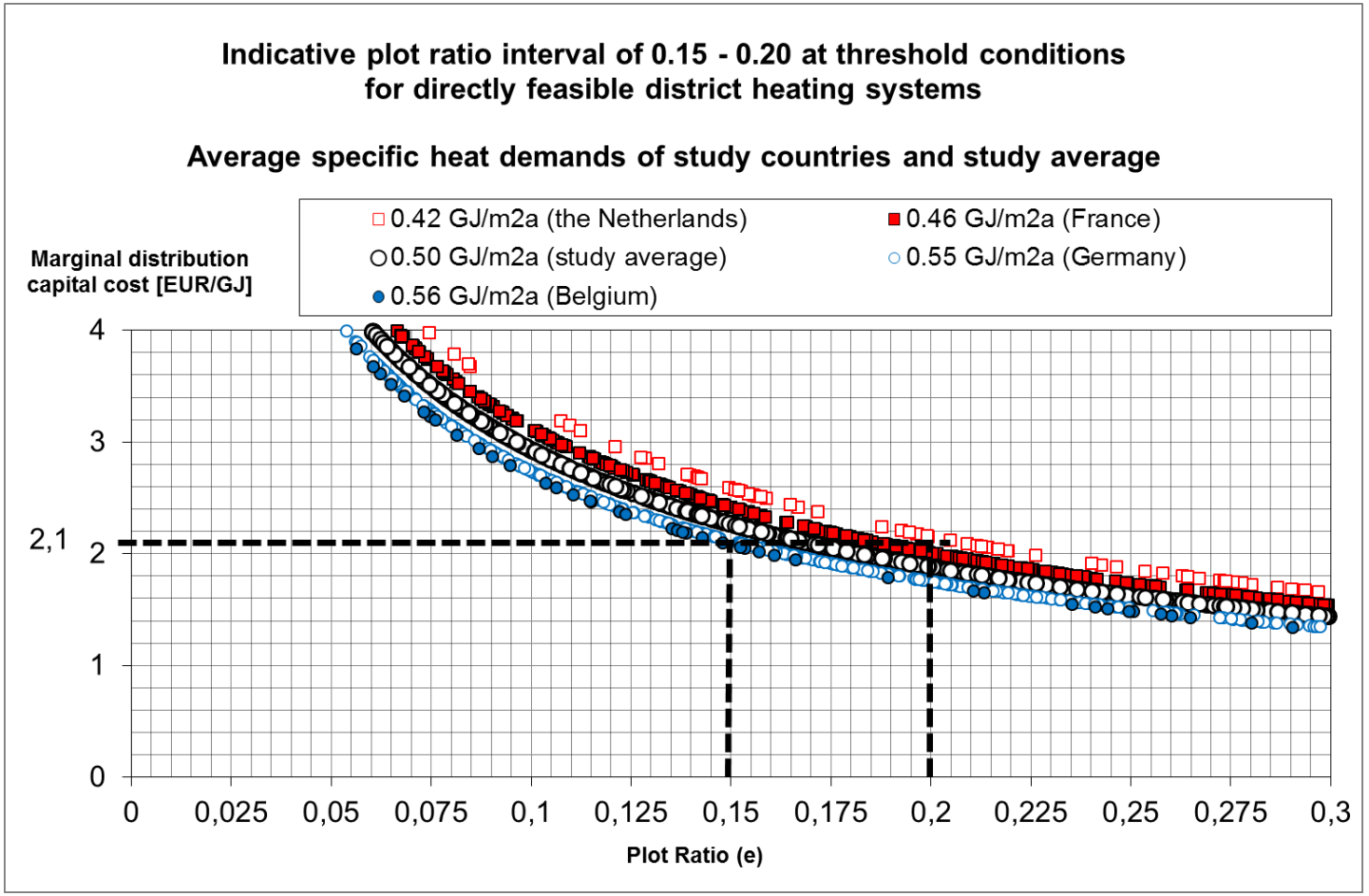
1st research issue: The economy of heat distribution

- The distribution capital cost model
  - Study results



Source: U. Persson, 2011. Realise the Potential! Cost Effective and Energy Efficient District Heating in European Urban Areas. Licentiate Thesis. Chalmers University of Technology.

Outline

- Background
  - Research questions, projects, and publications
- General information on district heating and cooling
  - Fundamentals of district heating and cooling
  - District heating and cooling in Europe today
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  - Concepts to define sequential energy supply
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  - Spatial mapping of excess heat activities and local heat sources
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  - Future research

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2nd research issue: The energy efficiency of district heating

- Concepts to define sequential energy supply

  • Three main objectives regarding the vital role of DH systems as necessary bottom cycles for recovery of various sources of industrialised society excess heat flows:

  1. General principle of serial utilisation of primary fuel and energy conversion excess flows – Sequential energy supply

  2. Comparative analysis of current levels of excess heat recovery in EU27

  3. Discuss some general conditions, i.e. driving forces, for increased realisation of potential

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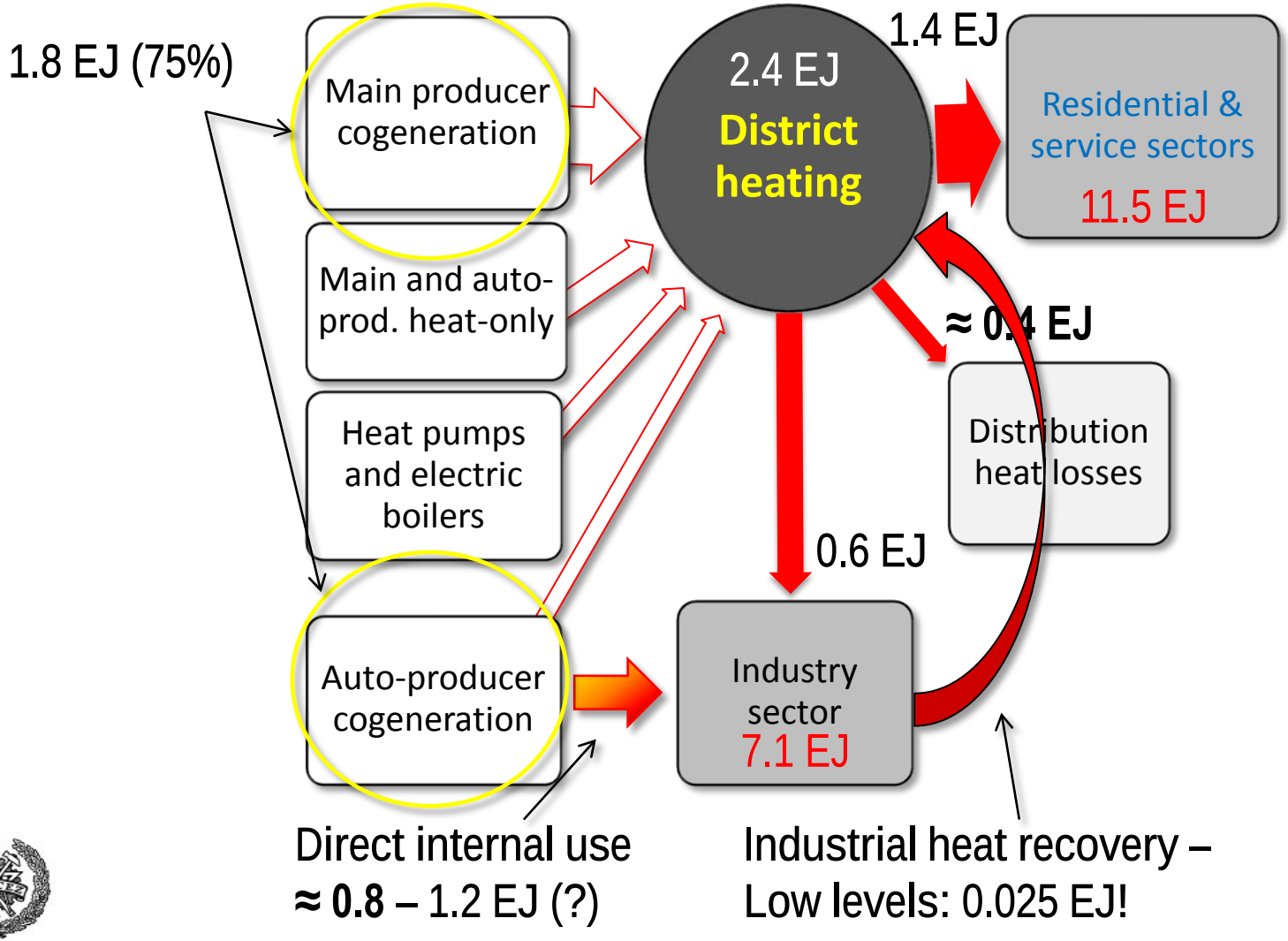
2nd research issue: The energy efficiency of district heating

- Concepts to define sequential energy supply



2nd research issue: The energy efficiency of district heating

- Concepts to define sequential energy supply
- New quantities: $E_{prim} = E_{abs} + E_{excess}$
  - *Recovery efficiency:*

Objective:

Develop quantities to express and estimate the potential for excess heat recovery and utilisation in European DH systems

$$\eta_{heat} = \frac{E_{heat}}{E_{prim}}$$

E_{heat} = Recovered excess heat [J]
E_{prim} = Primary energy supply [J]

Share of total primary energy supply recovered as heat

In Swedish: “Återvinningsverkningsgrad”

2nd research issue: The energy efficiency of district heating

- Concepts to define sequential energy supply
- New quantities: $E_{prim} = E_{abs} + E_{excess}$
  - *Heat recovery rate:*

Objective:

Develop quantities to express and estimate the potential for excess heat recovery and utilisation in European DH systems

$$\zeta_{heat} = \frac{E_{heat}}{E_{excess}}$$

E_{heat} = Recovered excess heat [J]
E_{excess} = Rejected excess heat [J]

Share of total rejected excess heat recovered as heat

In Swedish: “Återvinningsgrad”

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2nd research issue: The energy efficiency of district heating

- Concepts to define sequential energy supply
- New quantities: $E_{prim} = E_{abs} + E_{excess}$
  - *Heat utilisation rate:*

Objective:

Develop quantities to express and estimate the potential for excess heat recovery and utilisation in European DH systems

$$\xi_{heat} = \frac{E_{heat}}{Q_{tot}}$$

E_{heat} = Recovered excess heat [J]
Q_{tot} = Total heat demand [J]

Share of total heat demand supplied by recovered excess heat

In Swedish: “Utnyttjandegrad”

2nd research issue: The energy efficiency of district heating

- Concepts to define sequential energy supply

Thermal generation by fuel	E_{prim} [EJ]	E_{abs} [EJ]	E_{excess} [EJ]	E_{heat} [EJ]	η_{abs} [%]	η_{heat} [%]	ζ_{heat} [%]
Coal and coal products	9.30	3.35	5.95	0.60	36	6	10
Peat	0.10	0.03	0.07	0.03	32	33	49
Petroleum products	1.01	0.38	0.63	0.13	38	12	20
Natural gas	5.90	2.83	3.07	0.77	48	13	25
Nuclear	10.2	3.37	6.86	0.01	33	0	0
Combustible renewable/waste	1.49	0.40	1.09	0.27	27	18	24
Total	28.0	10.4	17.6	1.8	37	6	10

Thermal power generation by fuel in EU27, with conversion efficiencies and heat recovery rates, 2008. Absorbed energy is equal to electrical energy generated. Source: IEA. Energy Balances 2008. International Energy Agency, Paris; 2010.

Thermal generation by fuel	E_{prim} [PJ]	E_{abs} [PJ]	E_{excess} [PJ]	E_{heat} [PJ]	η_{abs} [%]	η_{heat} [%]	ζ_{heat} [%]
Coal and coal products	162	62.8	99.5	33.0	39	20	33
Peat	0	0	0	0	-	-	-
Petroleum products	11.3	4.1	7.2	3.4	36	30	46
Natural gas	67.5	24.9	42.6	30.2	37	45	71
Nuclear	0	0	0	0	-	-	-
Combustible renewable/waste	56.4	14.1	42.2	32.1	25	57	76
Total	297	106	191	98.6	36	33	52

Thermal power generation by fuel in Denmark, with conversion efficiencies and heat recovery rates, 2008. Absorbed energy is equal to electrical energy generated. Source: IEA. Energy Balances 2008. International Energy Agency, Paris; 2010.

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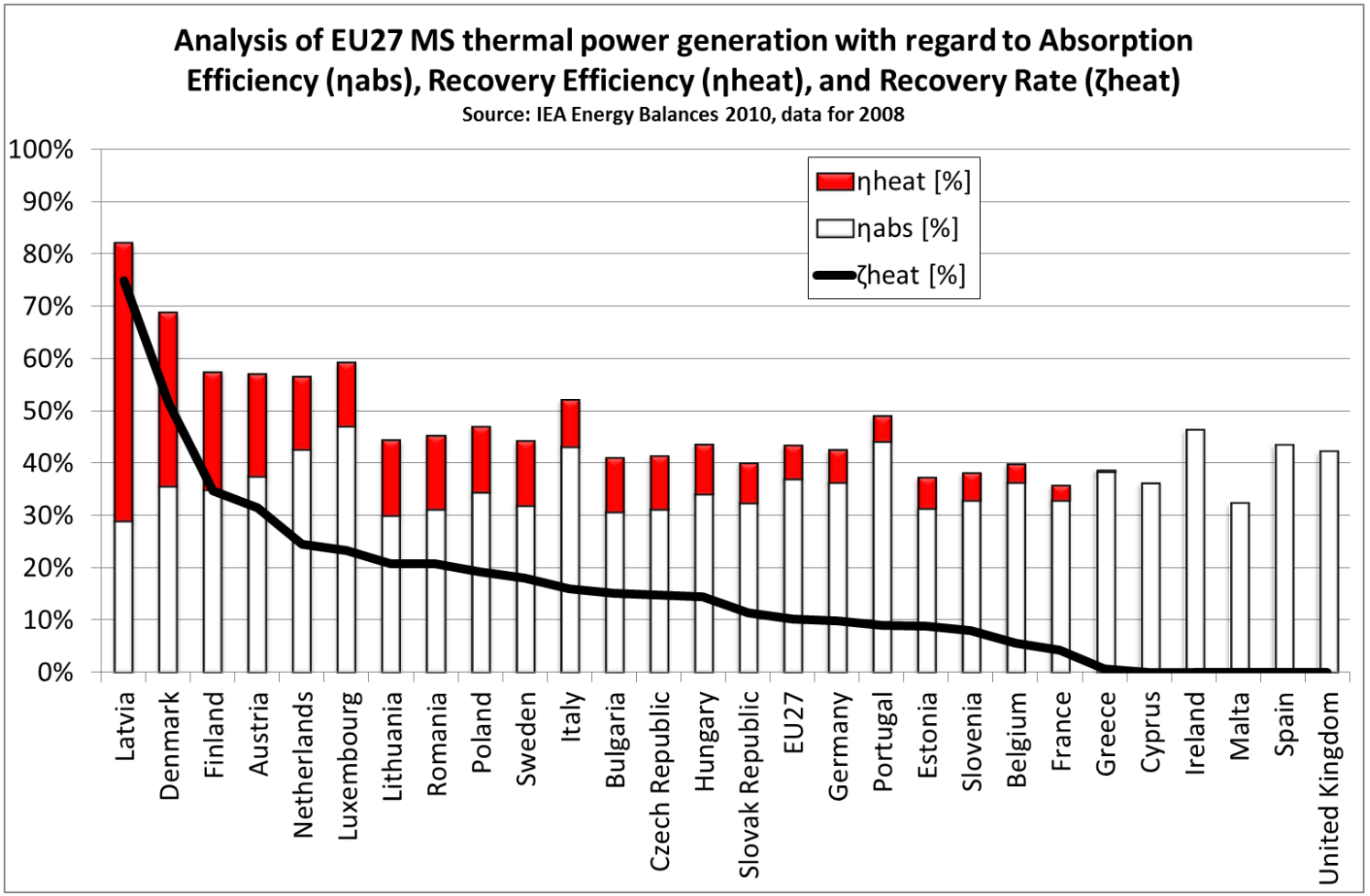
2nd research issue: The energy efficiency of district heating

- Concepts to define sequential energy supply



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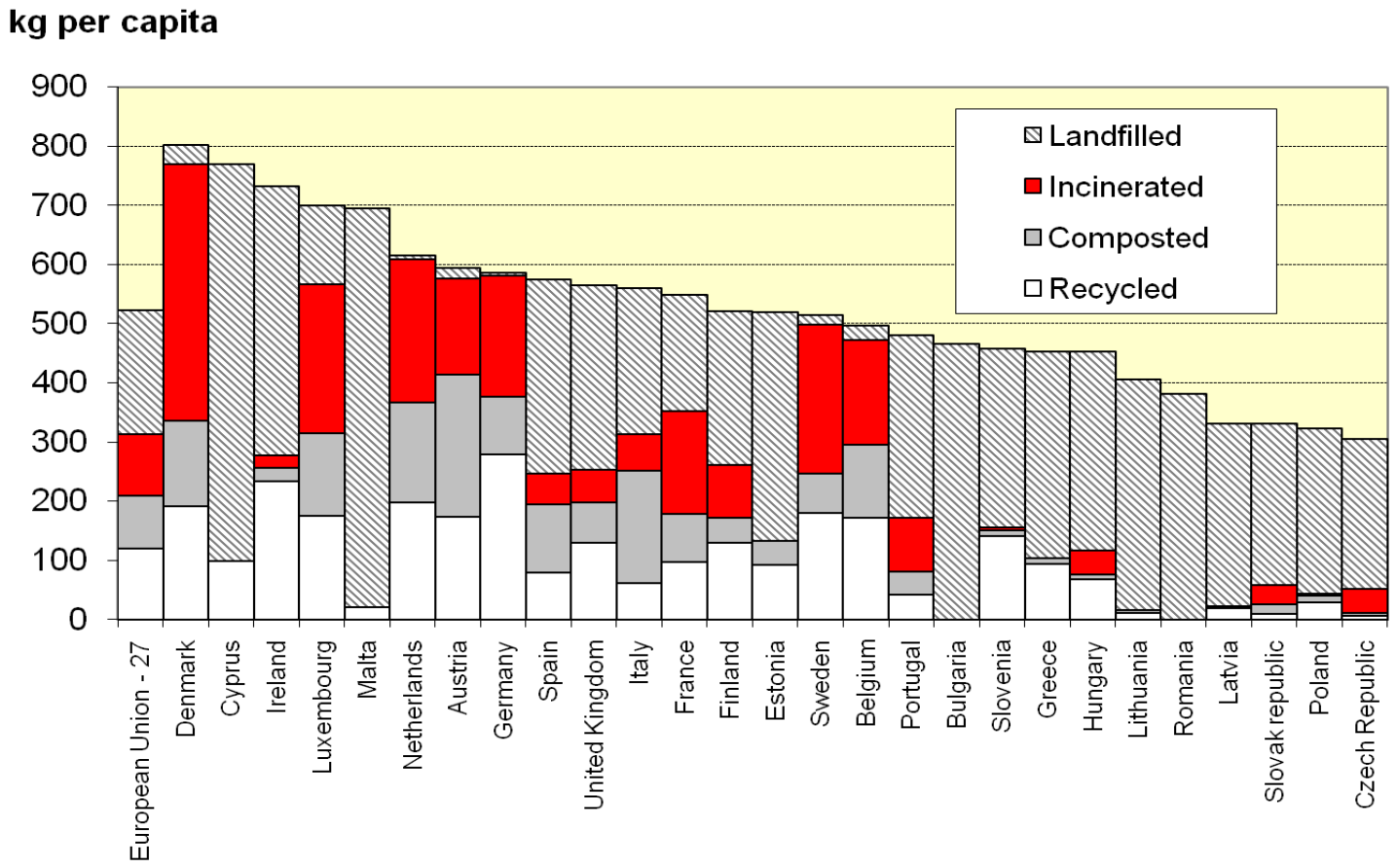

MSW management, EU27, 2008. Persson & Werner 2012. Source; Eurostat

2nd research issue: The energy efficiency of district heating

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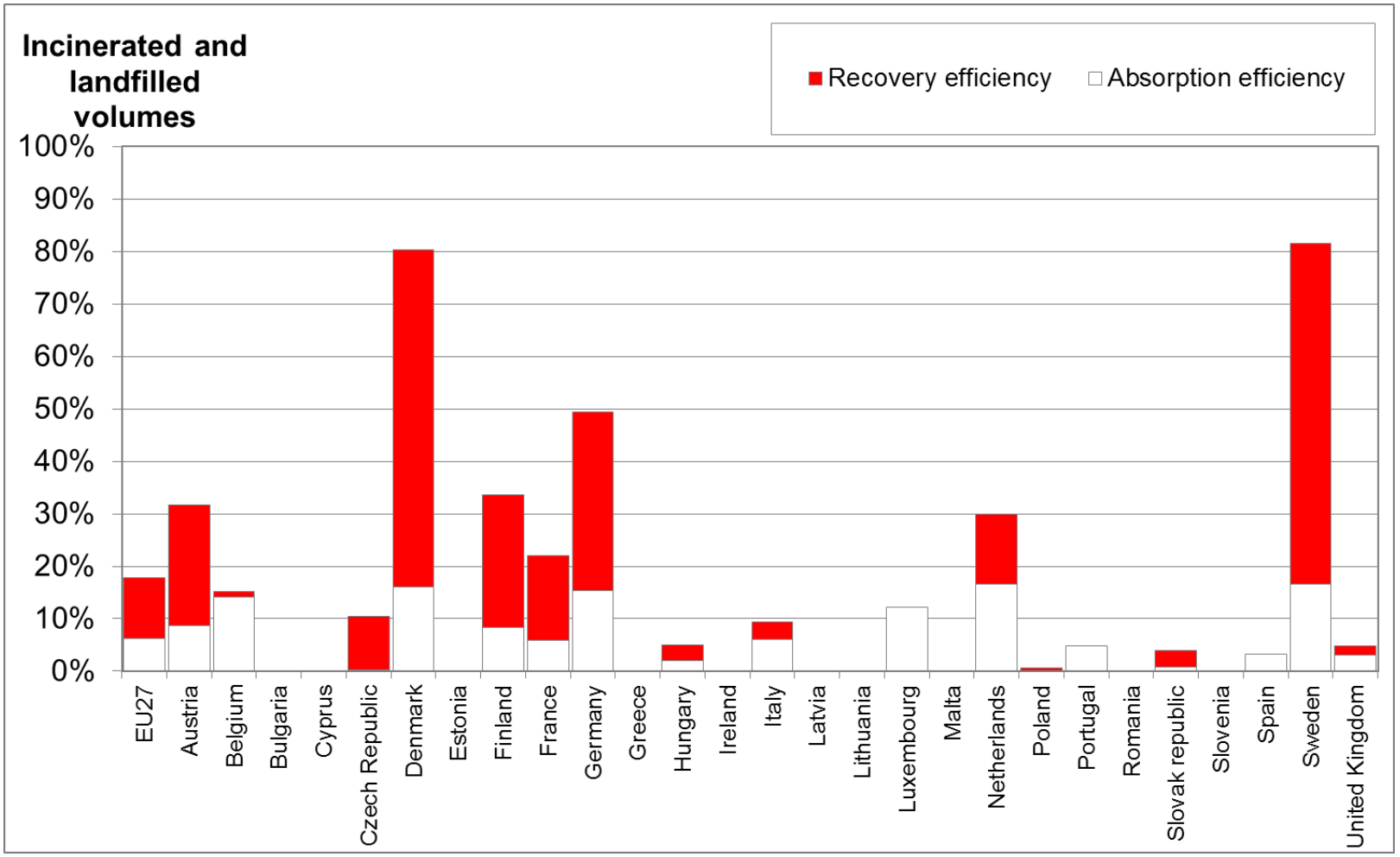
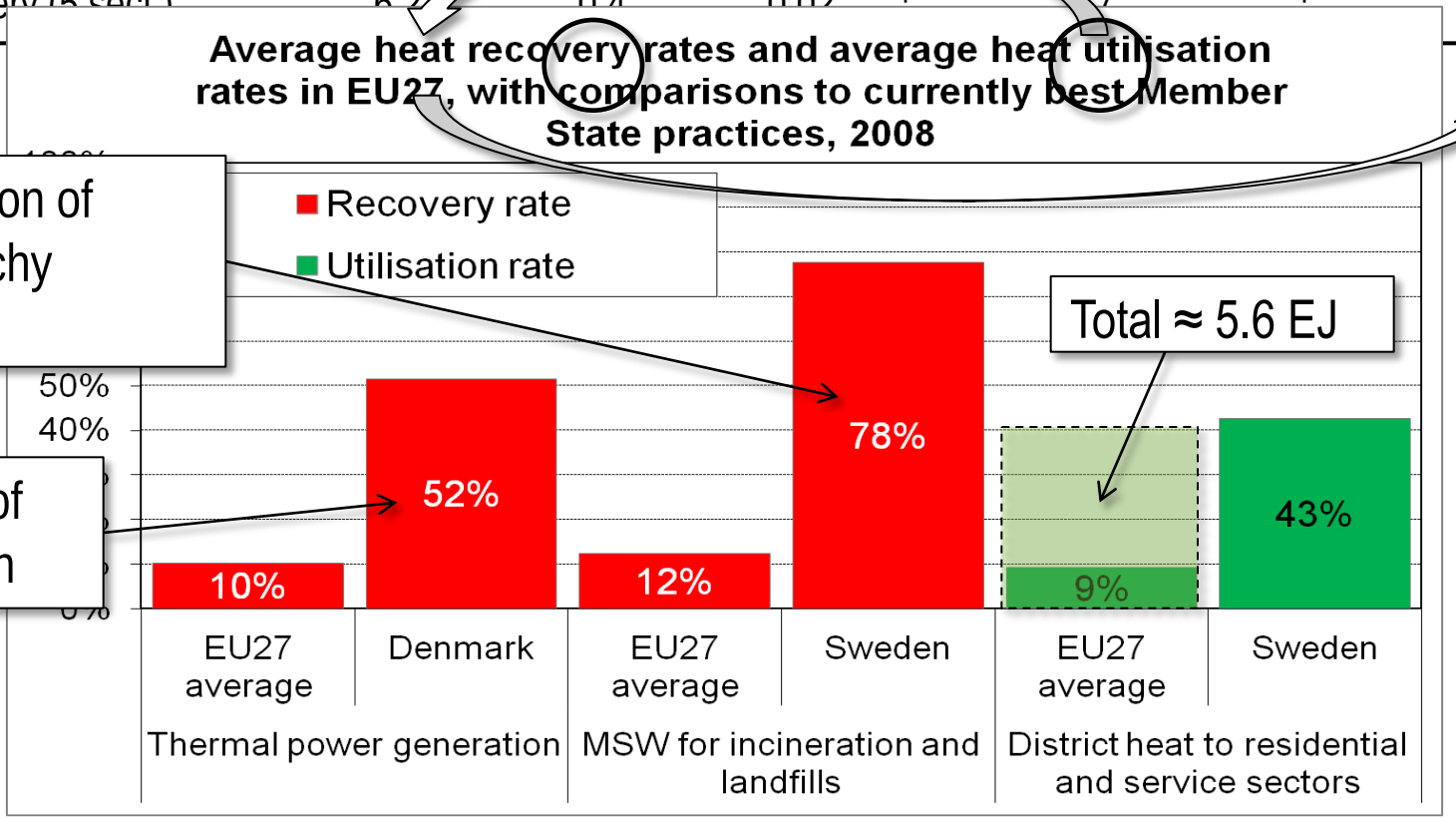


MSW management, EU27, 2008. Persson & Werner 2012. Source; Eurostat

Study results: European excess heat recovery and utilisation potential

- Total recovery potential of 10.2 EJ
  - ≈ 90% of Q_{tot} in res & serv. sectors
- Four-fold plausible potential for excess heat utilisation by means of DH distribution to res. & serv. sectors

Excess heat activity	EU27 E_{prim} [EJ]	EU27 η_{heat} [%]	EU27 E_{heat} [EJ]	Best MS practice η_{heat} [%]	Recovery potential E_{heat} [EJ]
Thermal power generation	26.3	6	1.60	33	8.68
Waste-to-energy (Inc. & L-f)	1.69	12	0.20	65	1.10
Ind. heat recovery (5 sect.)	6.24	0.4	0.02	7	0.43
Total					10.2



Implementation of waste hierarchy principles

High share of cogeneration

2nd research issue: The energy efficiency of district heating

- Concepts to define sequential energy supply
  - Study results
    - Infrastructure investments
      - A basic prerequisite for large scale recovery of excess heat is the presence of DH systems ➔ up-front investment costs for networks are a key factor to solve
    - Collaboration agreements
      - At least three parties: The owner of the excess heat, the heat distributor, and the customers ➔ Benefit sharing
    - Maintained value chains
      - To support the allocation of synergies when several market actors are engaged in utilising a common supply structure
    - Policy support
      - How to solve common inefficiency problems with local actions without harmonisation through European legislation?
    - Local initiative and communication
      - DH concept ➔ creating local solutions from local possibilities

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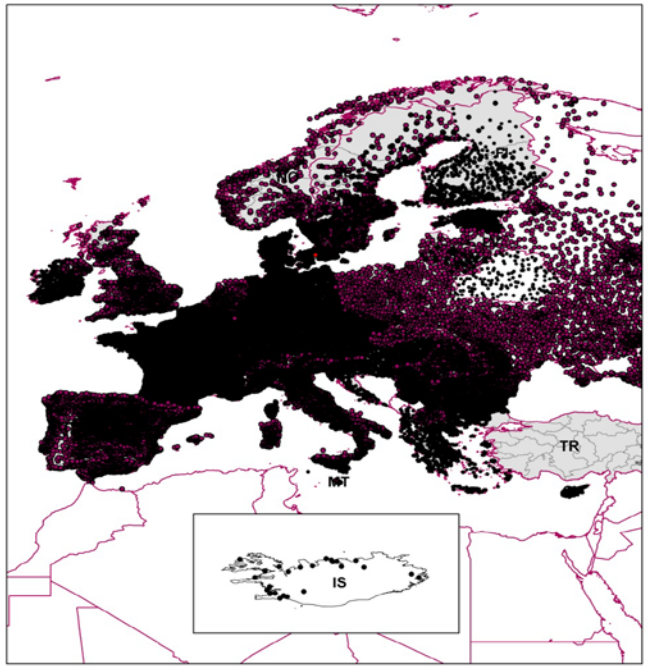
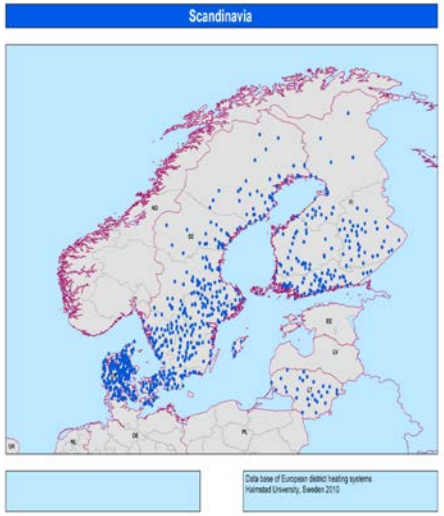
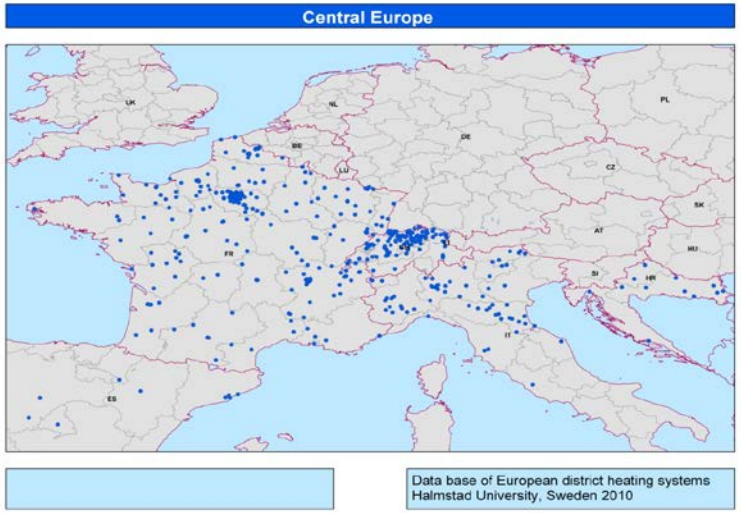
3rd research issue: The locations of European heat synergy regions

- Spatial mapping of excess heat activities and local heat sources







- First attempts to project geographical information in maps

- Key feature in ArcGIS: If anything can be spatially determined (coordinates) ➔ no limit on additional data that can be associated with the location!!!

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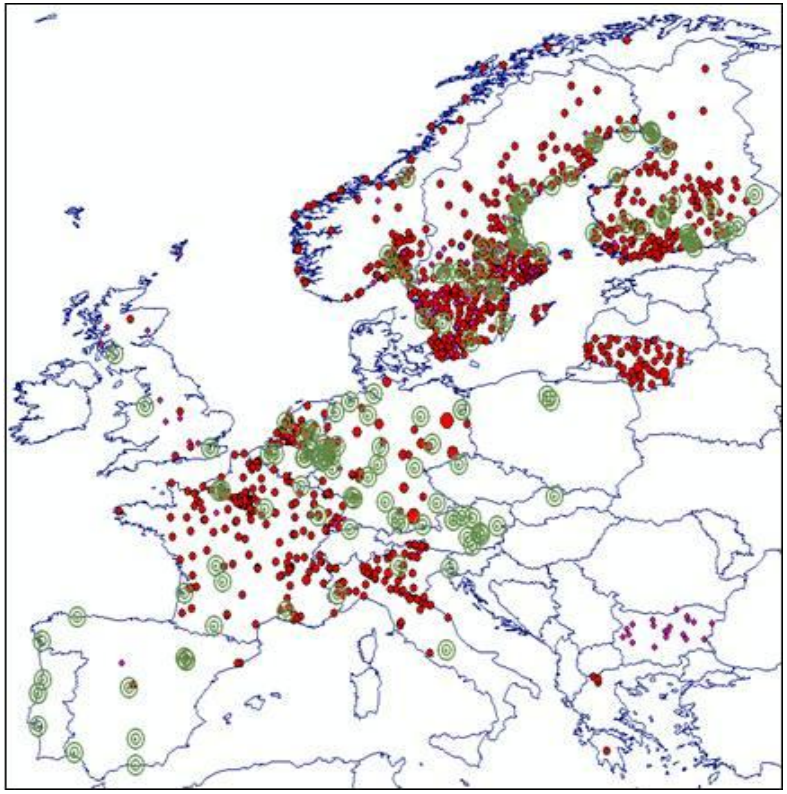
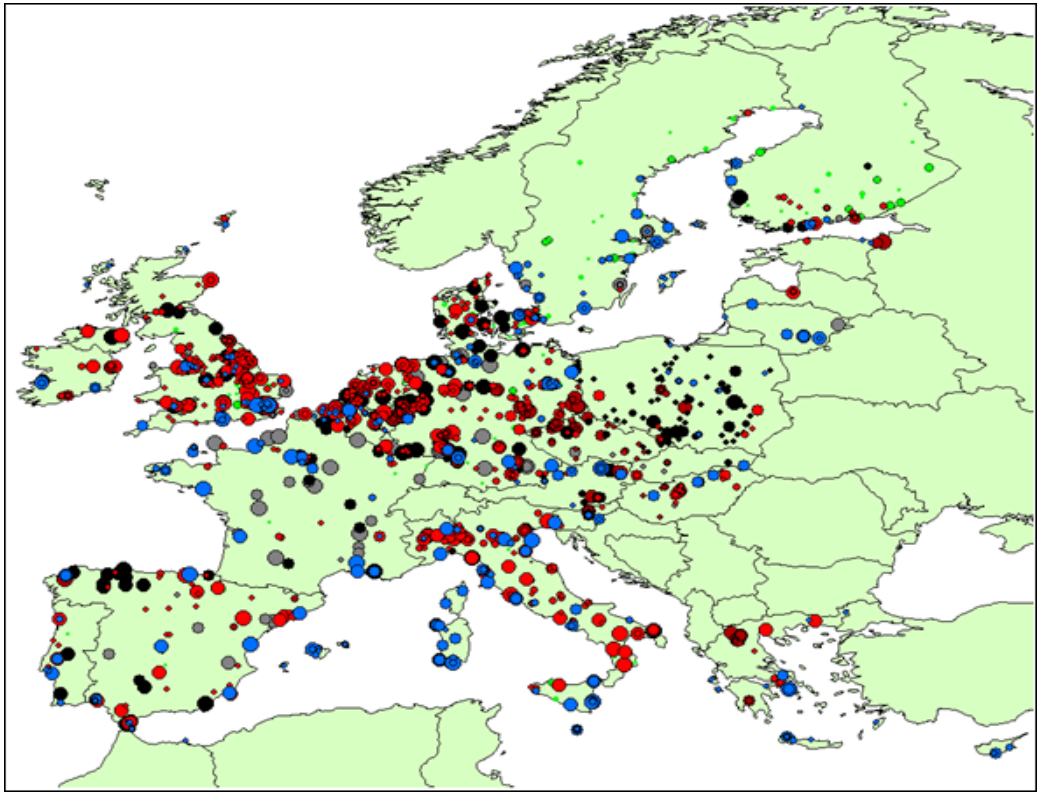
3rd research issue: The locations of European heat synergy regions

- Spatial mapping of excess heat activities and local heat sources



Preliminary parallell work by J. Jönsson & D. Johansson, Chalmers.

Paper and/or pulp mills in green circles, known DH systems in pink, with known heat deliveries in red.
With permission from D. Johansson.



Operating thermal plants in EU-25. Red denotes gas fuelled plants, black coal, brown lignite, blue oil, yellow nuclear while green denotes biomass/waste plants. Simplified picture from the Chalmers power plant data base.
Source; The European power plant infrastructure – Presentation of the Chalmers energy infrastructure database with applications. Kjärstad, J. & Johnsson, F. Energy Policy 35 (2007), 3643-3664.

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3rd research issue: The locations of European heat synergy regions

- Spatial mapping of excess heat activities and local heat sources

  - Example of GIS application
  - Danish study
  - Supply cost analysis

- Blue areas: DH is feasible compared to heat pumps:
- Dark blue: allocation of cost mainly to the electricity side
- Light blue: allocation of of costs mainly to heat side

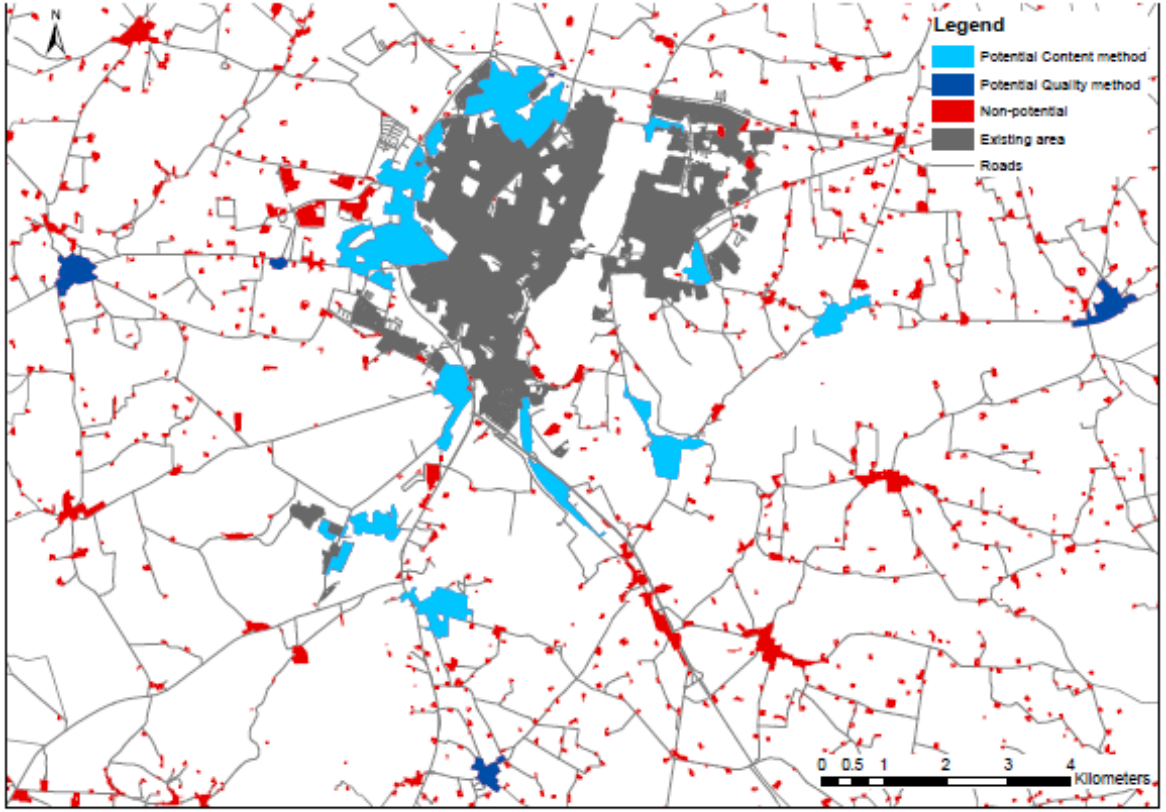

Figure 3: Example of output from GIS-model

GIS BASED ANALYSIS OF FUTURE DISTRICT HEATING POTENTIAL IN DENMARK
S. Nielsen and B. Möller
Aalborg University, Department of Development and Planning
DHC13, the 13th International Symposium on District Heating and Cooling
September 3rd to September 4th, 2012, Copenhagen, Denmark

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3rd research issue: The locations of European heat synergy regions

- Spatial mapping of excess heat activities and local heat sources

Heat Roadmap Europe 2050 project - Central hypothesis:

Current future projections for the European energy system are lacking a proper assessment of district heating!

General Consensus:
”Combined heat & power (CHP) and district heating (DH) are important”

. . . but they fail to quantify to which extent these options can be used in the future energy system . . .

- Another - new - future projection for the whole EU heat market - with a proper assessment of DHC
- Considering local heat assets!

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3rd research issue: The locations of European heat synergy regions

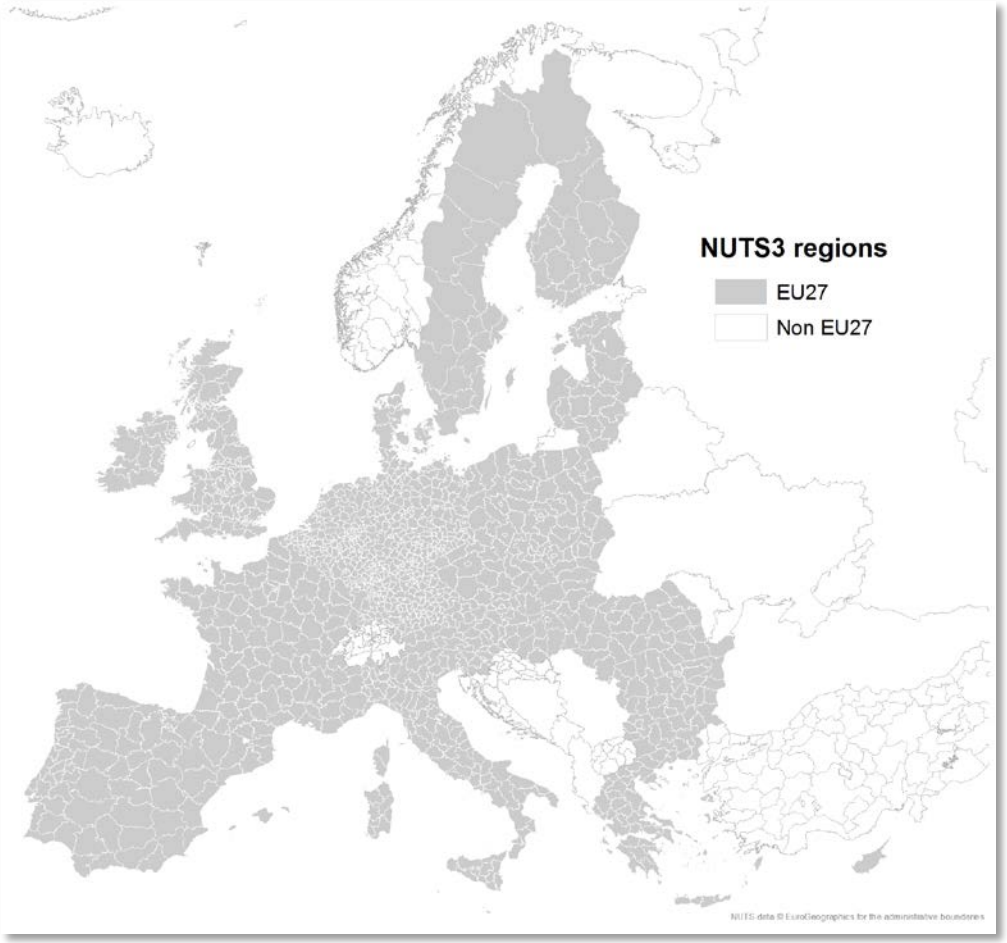
- Spatial mapping of excess heat activities and local heat sources

- Aggregation of local conditions up to EU27

- Gathering of local conditions data in administrative regions below national levels

- 1461 NUTS3 regions in Europe

- 1303 are located within EU27



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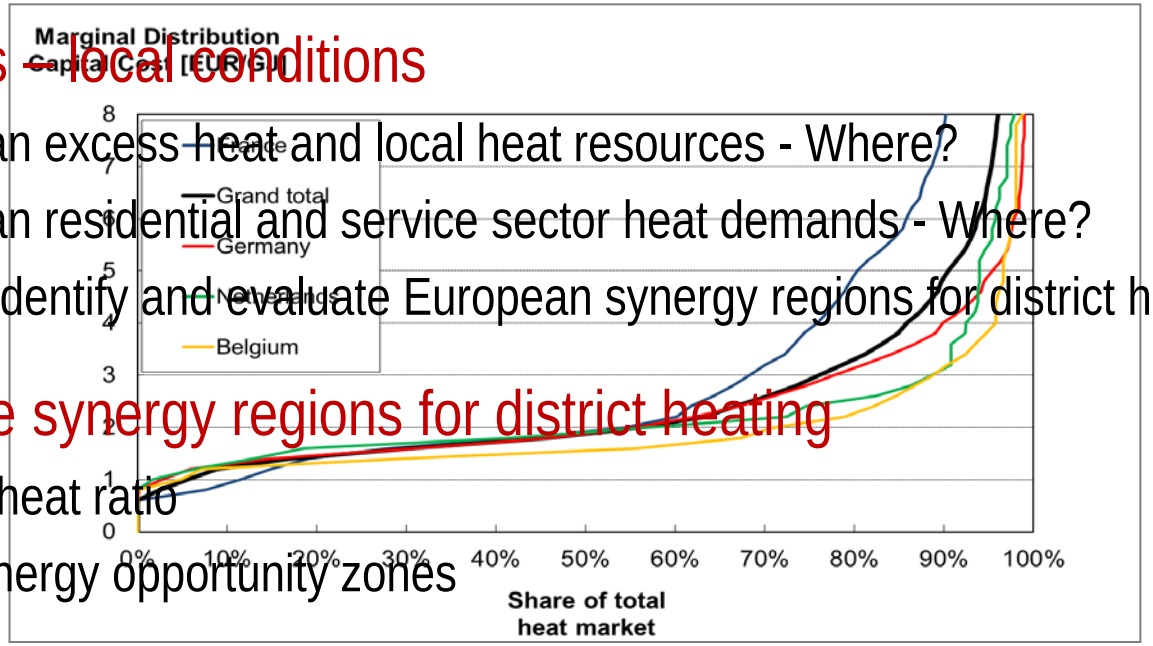
3rd research issue: The locations of European heat synergy regions

- Spatial mapping of excess heat activities and local heat sources
  - General conditions – HRE 2050 project – Mapping part
    - Presence of excess heat (TPG & Energy intensive industry)
    - Presence of local heat resources (biomass, solar, geothermal)
    - DH systems – excess heat recovery and local heat resource utilisation, general system efficiency, fuel substitution
    - DH expansion possibilities in European urban areas
  - Key issues – local conditions
    - European excess heat and local heat resources - Where?
    - European residential and service sector heat demands - Where?
    - How to identify and evaluate European synergy regions for district heating?
  - Favourable synergy regions for district heating
    - Excess heat ratio
    - Heat synergy opportunity zones



3rd research issue: The locations of European heat synergy regions

- Spatial mapping of excess heat activities and local heat sources
- Five main data categories & data sources – Mapping part
  - Spread of urban fabric
    - EEA Corine land cover 2000 database
    - Eurostat
  - Heat demands for SH & DHW in residential and service sectors
    - International Energy Agency (IEA)
    - Eurostat
  - Excess heat activities
    - EEA European Pollutant Release and Transfer Register (E-PRTR)
    - Confederation of European Waste-to-Energy Plants (CEWEP)
    - International Solid Waste Association (ISWA)
  - Local heat resources
    - Eurostat
    - WP4 Ecoheatcool
    - European Commission
    - European Geothermal Energy Council (EGEC)
  - European district heating systems
    - The Halmstad University District Heating and Cooling Database (HUDHC)

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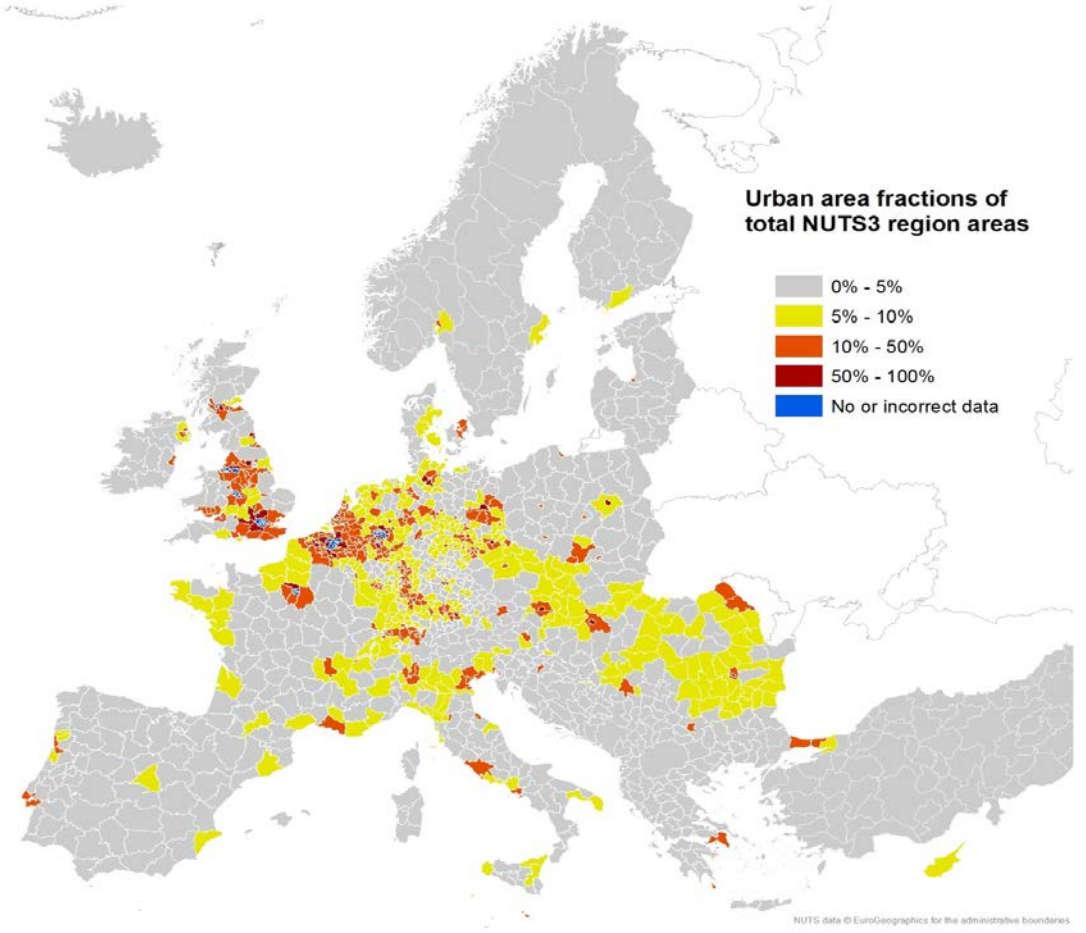
3rd research issue: The locations of European heat synergy regions

- Spatial mapping of excess heat activities and local heat sources
- Spread of urban fabric
  - Division of artificial areas in Corine land cover 2000 database:
    - Continuous urban fabric
    - Discontinuous urban fabric
    - Industrial and commercial areas
  - Total urban fabric areas divided by total NUTS3 region land areas
  - Urban area fraction: Indicating high population and high heat density regions
  - High resolution and additional data categories



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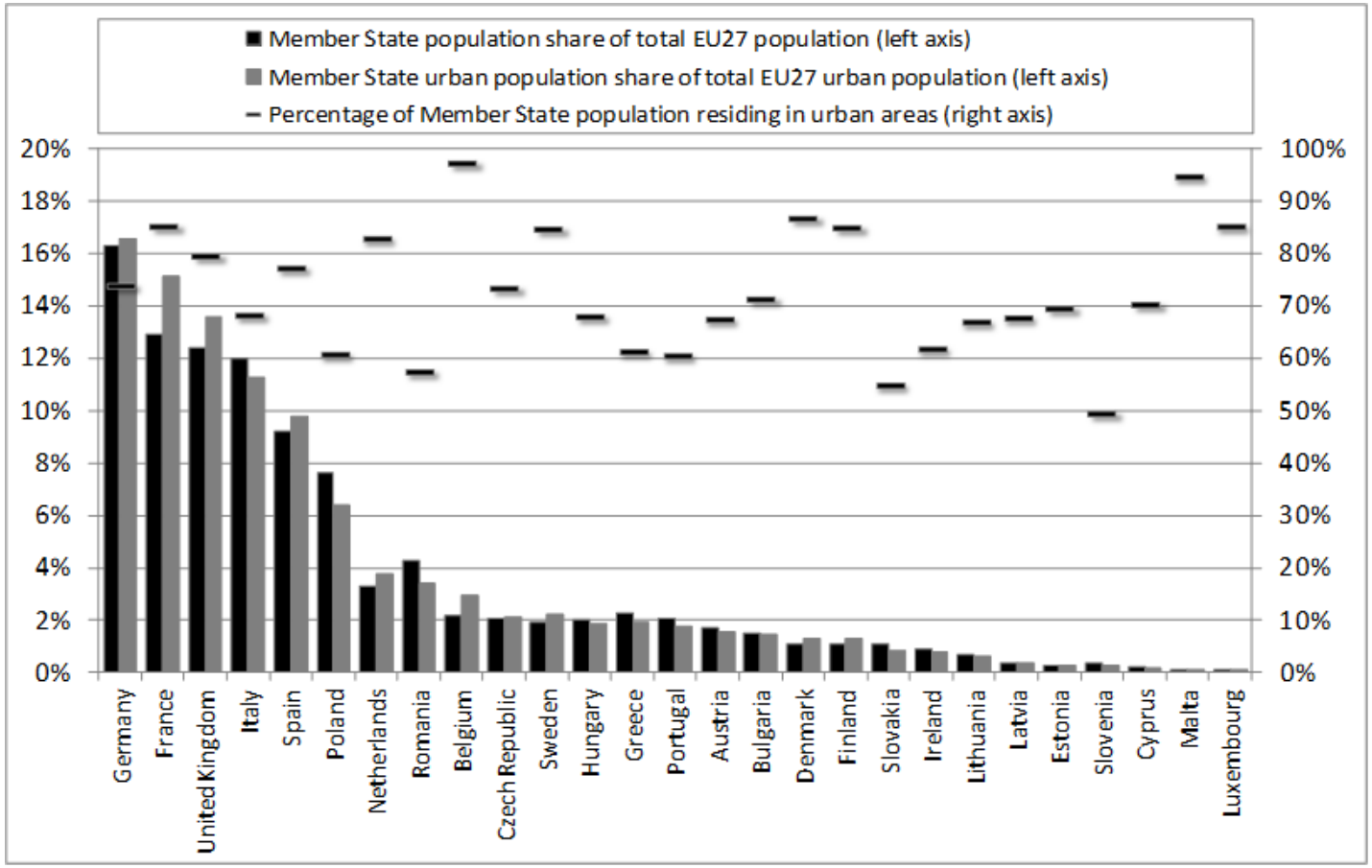

Left axis:
Distribution of total and urban EU27 Member State populations in 2010.

Right axis:
Percentage of EU27 Member State populations residing in urban areas in 2010.

Sources: United Nations. World Urbanization Prospects: The 2009 Revision. Data in digital form (POP/ DB/WUP/Rev.2009). Department of economic and social affairs, Population division, New York, NY, USA; 2010. Available at: http://esa.un.org/unpd/wup/index.htm (2011-09-20).
ES. Downloaded data category: Demographic balance and crude rates [demo_gind], average population - total. Eurostat, Luxembourg; 2011. Available at: http://epp.eurostat.ec.europa.eu (2011-08-31).

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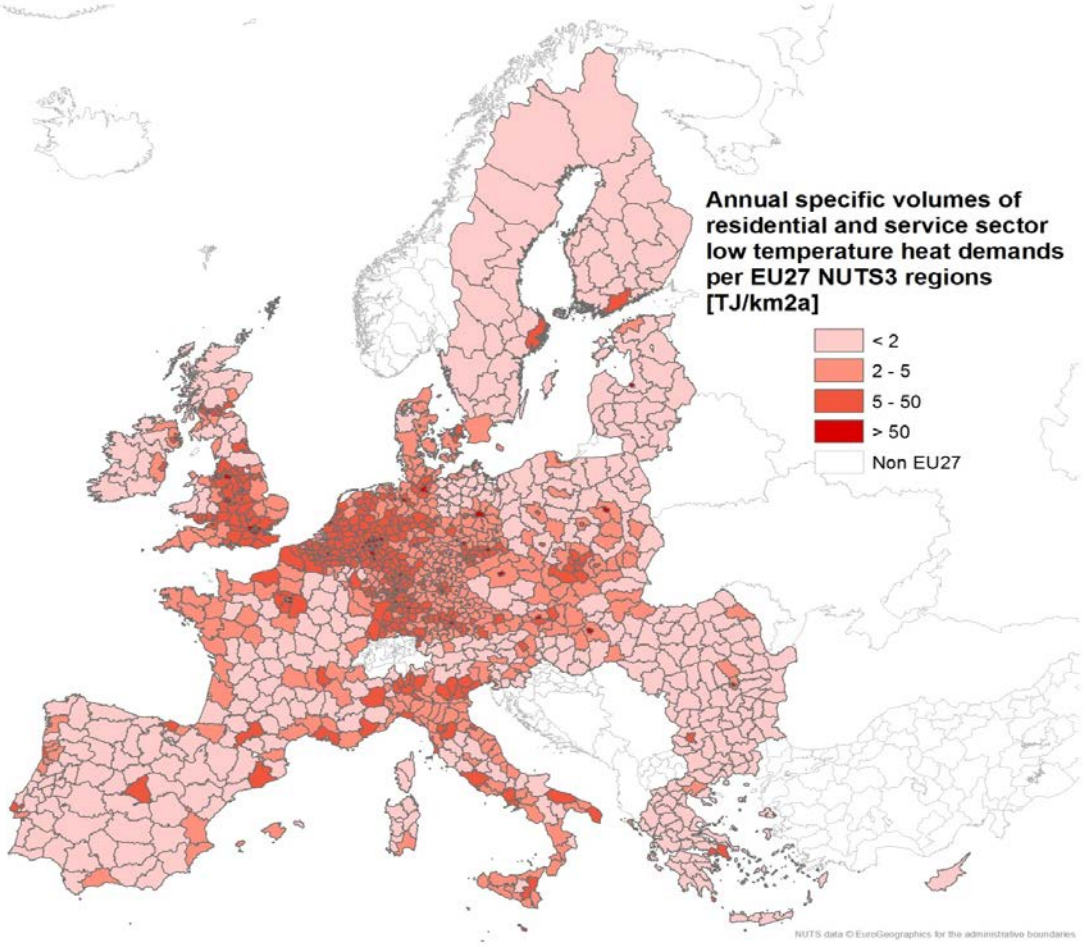
3rd research issue: The locations of European heat synergy regions

- Spatial mapping of excess heat activities and local heat sources

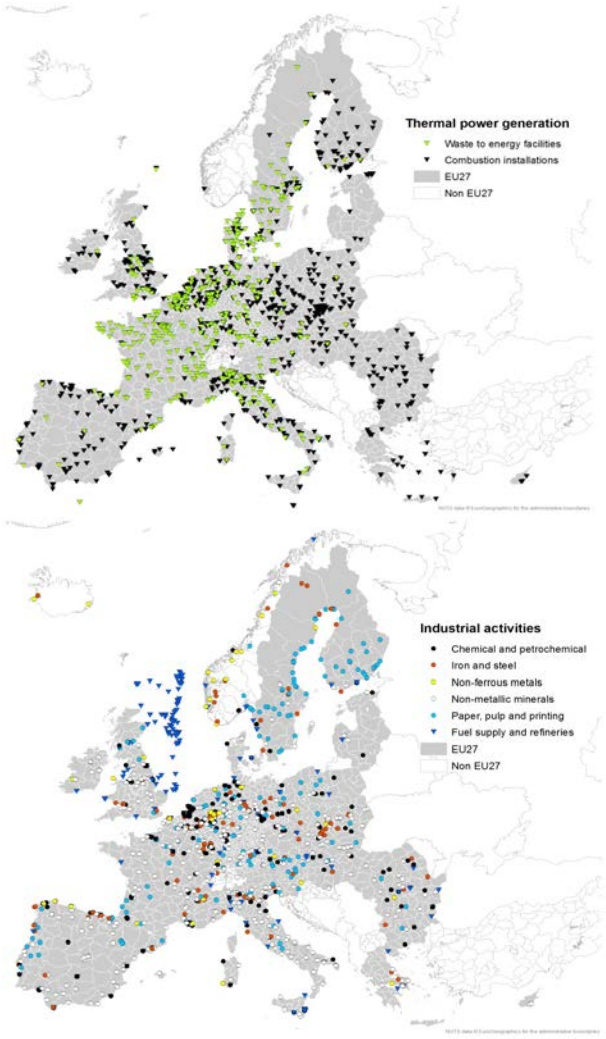
	$Q_{Res\&serv}$ [EJ/a]	P_{tot} [kn]	$q_{Res\&serv}$ [GJ/na]
Austria	0.247	8355	30
Belgium	0.343	10753	32
Bulgaria	0.064	7607	8
Cyprus	0.010	797	13
Czech Republic	0.236	10468	23
Denmark	0.183	5511	33
Estonia	0.039	1340	29
Finland	0.196	5326	37
France	1.702	64350	26
Germany	2.733	82002	33
Greece	0.162	11260	14
Hungary	0.220	10031	22
Ireland	0.119	4450	27
Italy	1.099	60045	18
Latvia	0.060	2261	26
Lithuania	0.057	3350	17
Luxembourg	0.019	494	39
Malta	0.002	414	4
Netherlands	0.503	16486	31
Poland	0.709	38136	19
Portugal	0.105	10627	10
Romania	0.293	21499	14
Slovakia	0.109	5412	20
Slovenia	0.039	2032	19
Spain	0.520	45828	11
Sweden	0.258	9256	28
United Kingdom	1.473	61595	24
EU27	11.50	499687	23



Estimated low temperature heat demands in residential and service sectors in EU27 Member States, 2008.

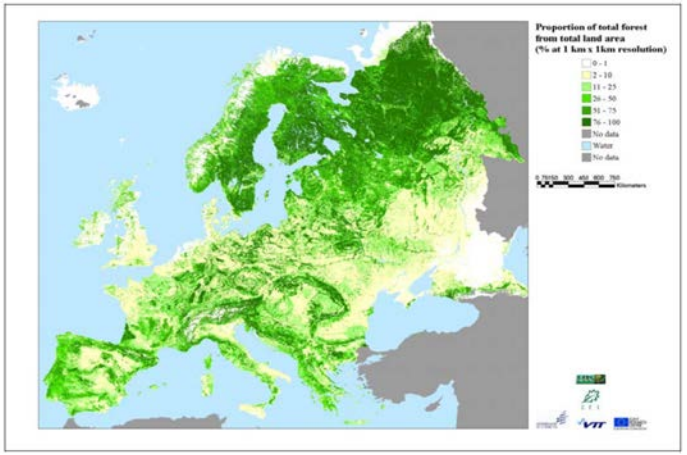
3rd research issue: The locations of European heat synergy regions

- Spatial mapping of excess heat activities and local heat sources
- Excess heat activities
  - Thermal power generation (≈ 15 EJ/a)
    - 961 TPG plants > 50 MW
    - 407 Waste-to-Energy facilities
  - Industrial activities (? EJ/a)
    - 231 Chem. & petrochemical plants
    - 140 Iron & steel works
    - 30 Non-ferrous metal works
    - 421 Non-metallic mineral facilities
    - 172 Paper & pulp plants
    - 191 fuel supply & refineries
  - 2556 European excess heat activities, given performed interpretations of data
    - Wide geographical distribution of activities

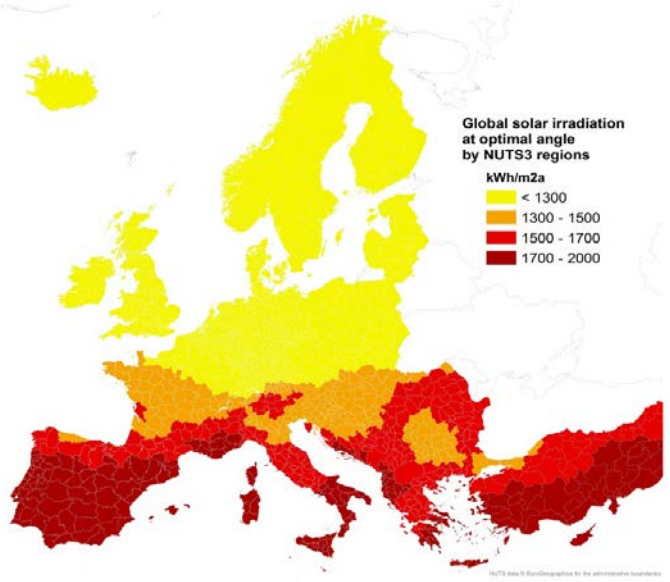


3rd research issue: The locations of European heat synergy regions

- Spatial mapping of excess heat activities and local heat sources
- Local heat resources
  - Availability and magnitude of renewable heat streams heterogeneously spread:
    - Biomass (forestry propagation)
    - Solar (geographic location)
    - Geothermal (earth crust composition)



  - Biomass – 241 PJ supply to EU27 district heating systems in 2009



  - Global solar irradiation - twice as intense in Southern compared to Northern Europe
  - Solar heat – 0.108 PJ supply to Danish district heating systems in 2009

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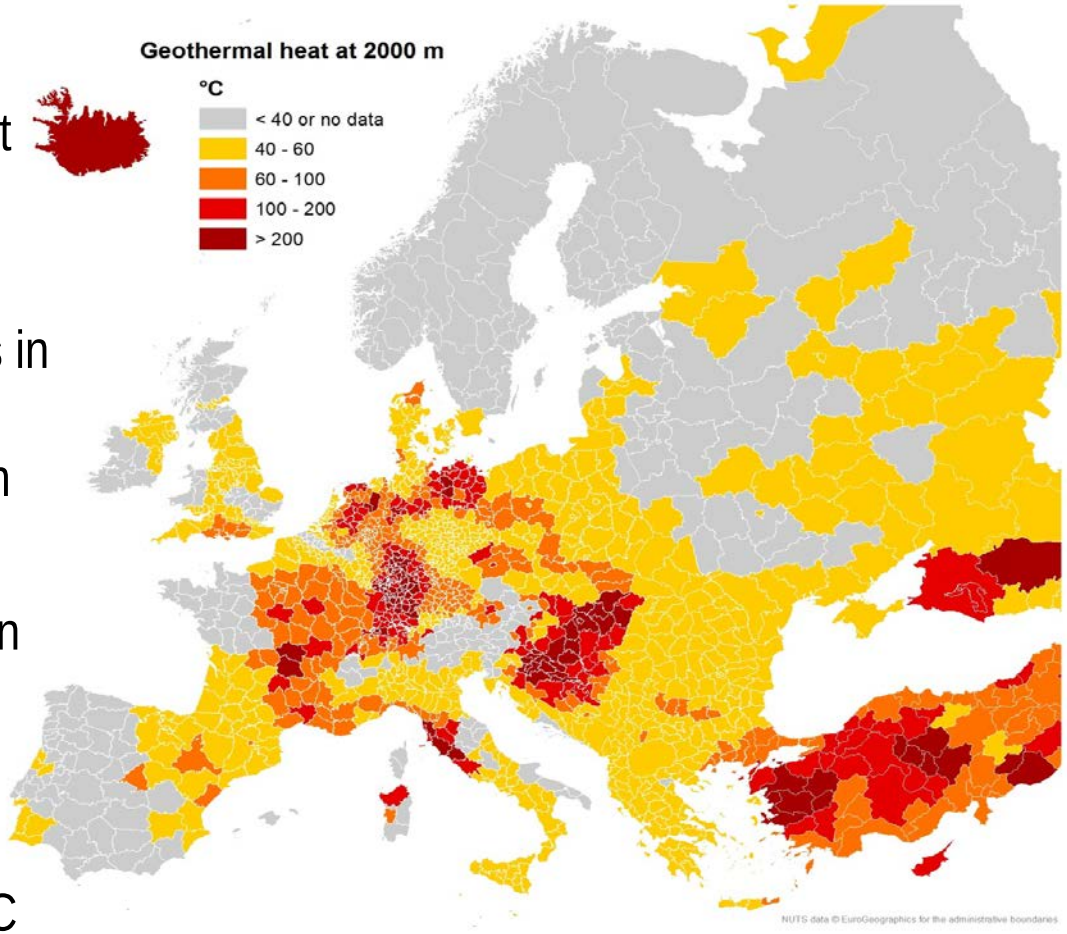
3rd research issue: The locations of European heat synergy regions

- Spatial mapping of excess heat activities and local heat sources
- Local heat resources
  - Geothermal assets represents vast heat resources in Europe!
  - ¼ of the total European population lives in urban areas that can be reached by geothermal heat through DH distribution
  - 4 % of the total EU27 population lives in NUTS3 regions with geothermal temperatures at or above 200 °C
  - 8 % in NUTS3 regions: 100 °C to 200 °C
  - 19 % in NUTS3 regions: 60 °C to 100 °C



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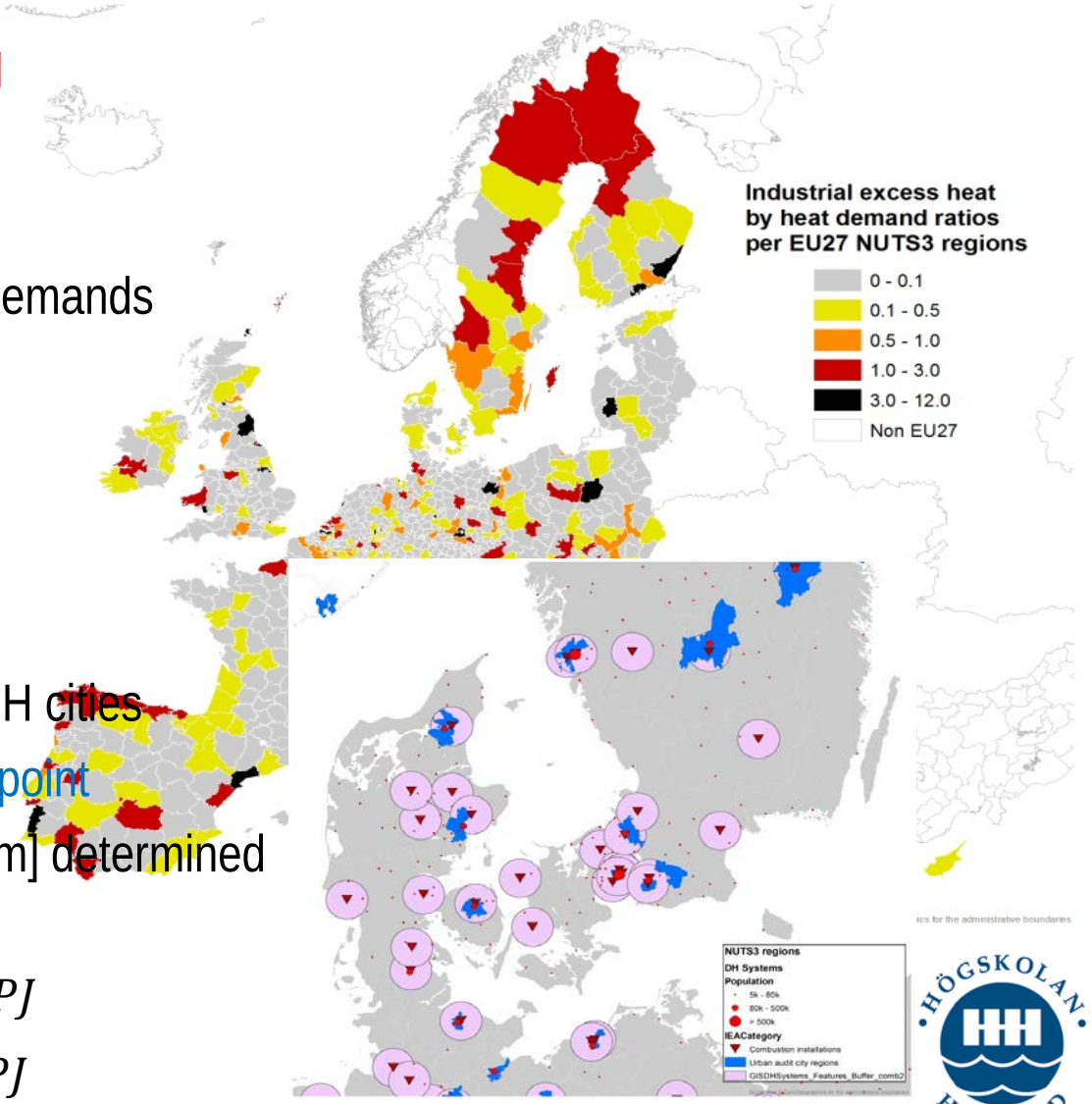
3rd research issue: The locations of European heat synergy regions

- Spatial mapping of excess heat activities and local heat sources
- Synergy regions for district heating
  - The excess heat ratio concept
    - NUTS3 region characterization
    - Quota of excess heat and heat demands
  - Heat synergy opportunity zones
    - Site characterization
      - Excess heat activities
      - District heating systems
    - HUDHC database – European DH cities
    - Existing DH systems as starting point
    - Feasible transmission distance [m] determined by heat demand magnitude

$$f(x) = \begin{cases} \frac{x}{3.6} * 100 & x \leq 1.08\ PJ \\ 30 & x > 1.08\ PJ \end{cases}$$



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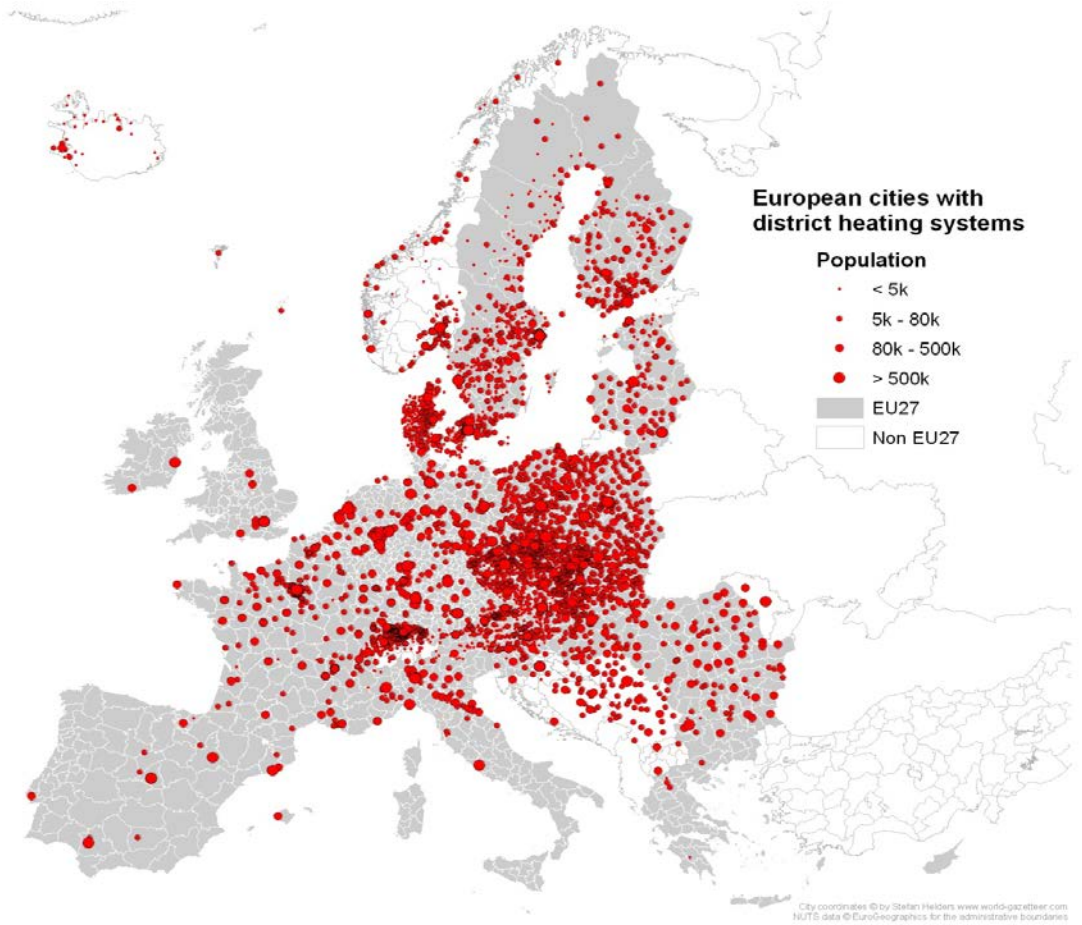
3rd research issue: The locations of European heat synergy regions

- Spatial mapping of excess heat activities and local heat sources

	Total	HSOZ	[%]
European NUTS3 regions and land areas			
NUTS3 regions	1303	979	75
Land area (km^2)	4267644	1283185	30
Energy intensive industrial activities			
Chem. & petrochemical	231	151	65
Iron & steel	140	101	72
Non-ferrous metals	30	17	57
Non-metallic minerals	421	204	48
Paper, pulp & printing	172	110	64
Fuel supply & refineries	191	63	33
Thermal power generation activities			
Comb. installations	961	595	62
Waste-to-Energy	410	280	68
Grand Total	2556	1521	60



23 GJ/na (average EU27) ➔
30 km ➔ ≈ 50000 residents

General properties of assessed EU27 heat synergy opportunity zones (HSOZ) at max 30 km.

3rd research issue: The locations of European heat synergy regions

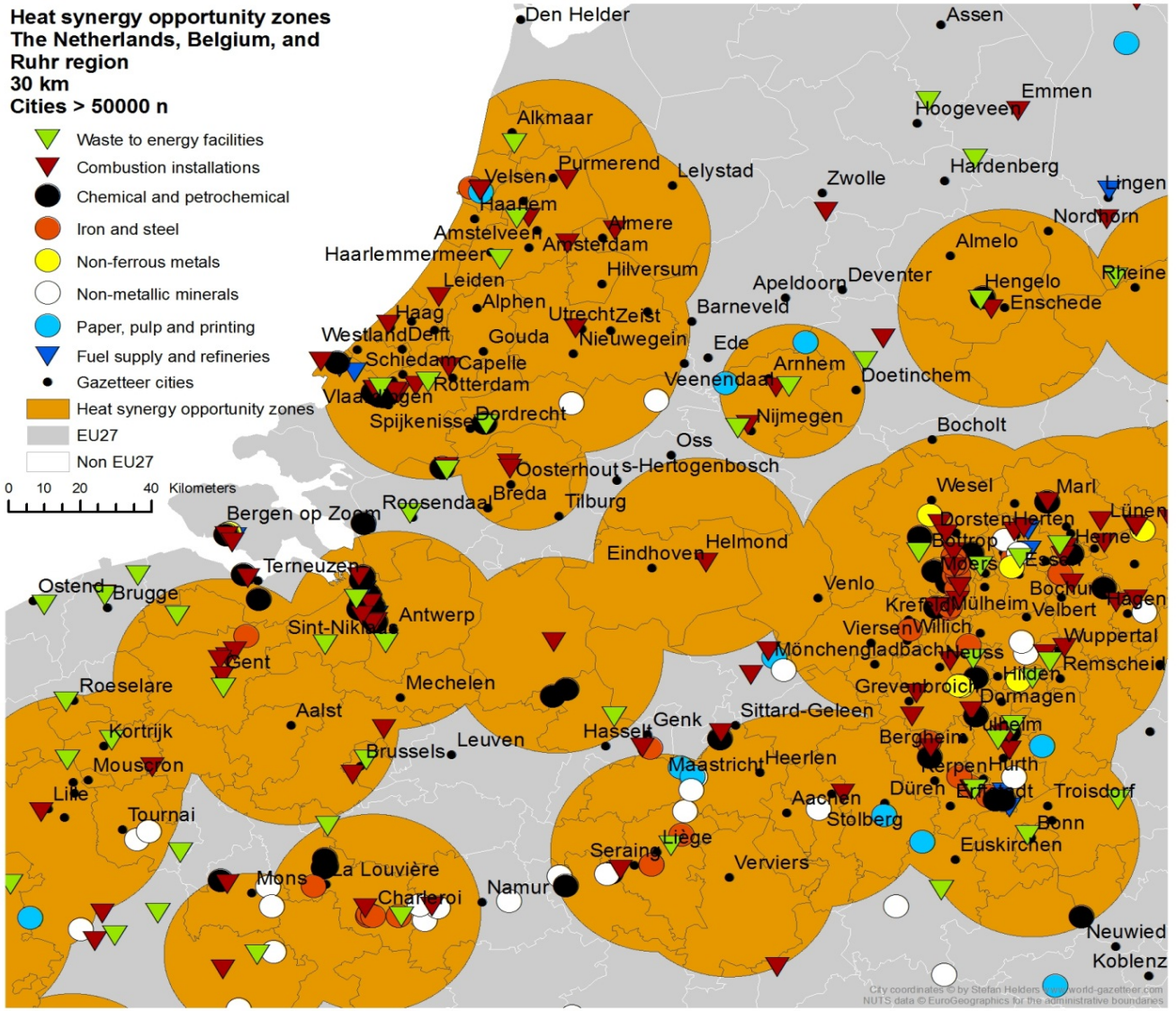
- Heat synergy opportunity zones
  - Close-up:

The Netherlands, Belgium, and Ruhr region

With excess heat activities…

High correspondence with study results (60%)

Synergy regions for district heating



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3rd research issue: The locations of European heat synergy regions

- Heat synergy opportunity zones
  - Close-up:

Denmark,

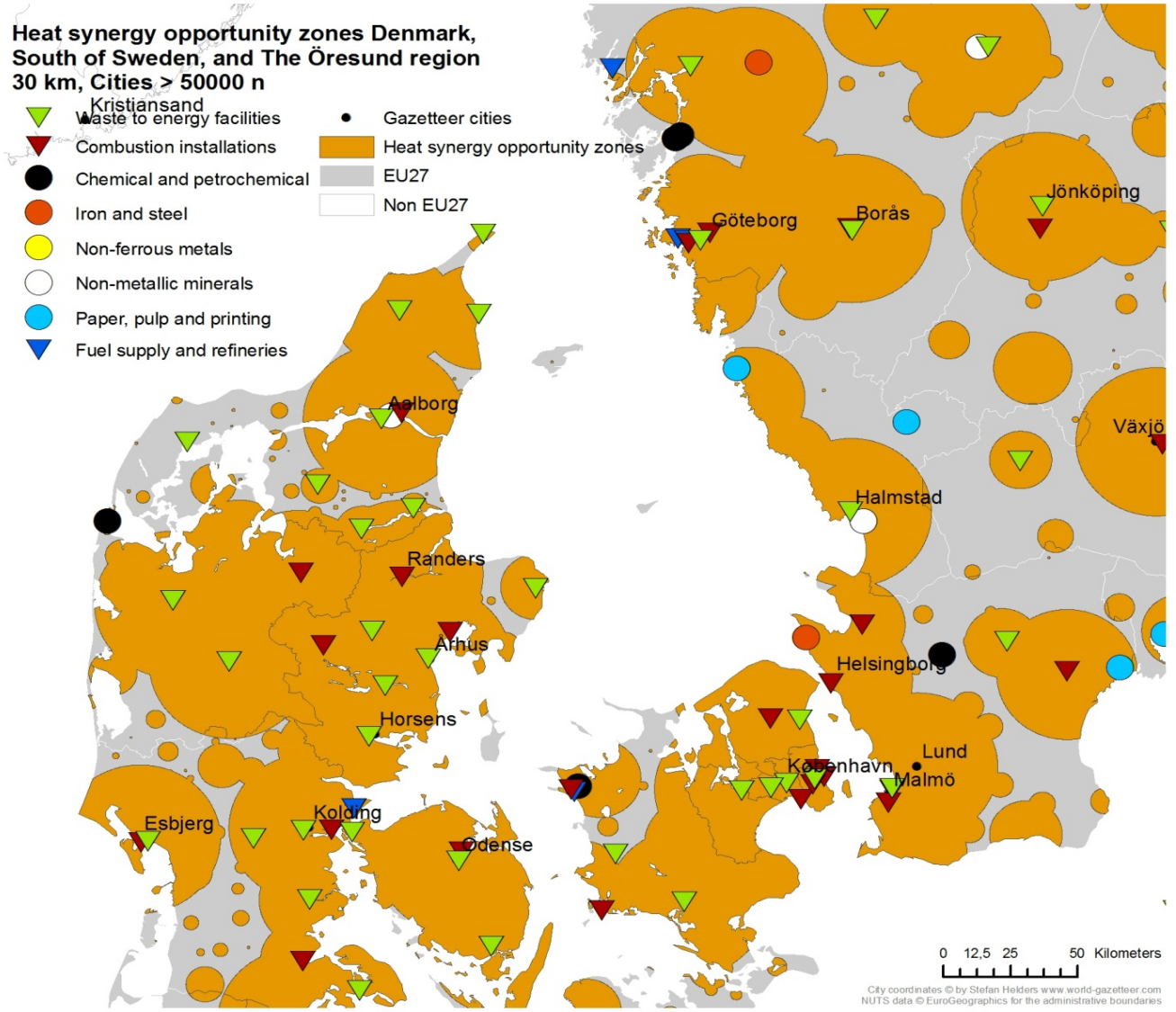
South of Sweden,

and the Öresund region

With excess heat activities…

High correspondence with study results (60%)

Substantial geographical coverage in Denmark



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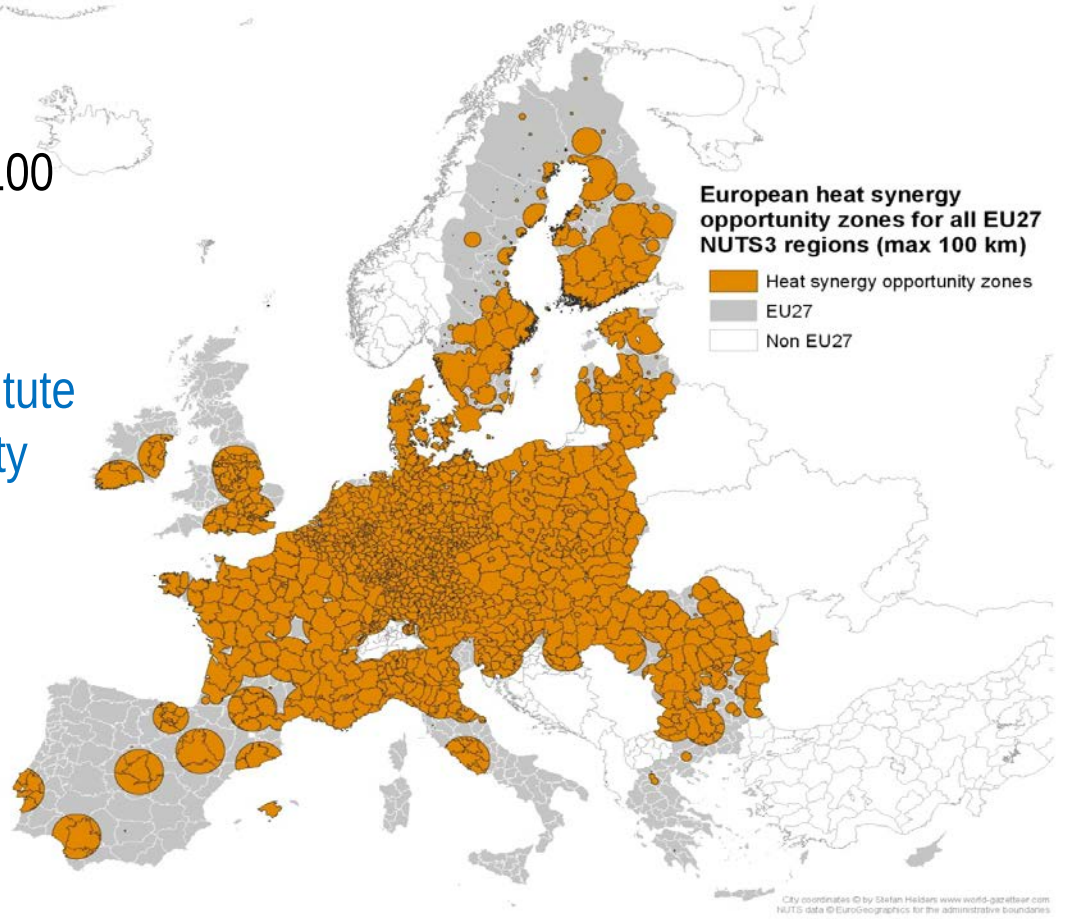
3rd research issue: The locations of European heat synergy regions

- Spatial mapping of excess heat activities and local heat sources
- Heat synergy opportunity zones
  - If extending transmission distances to 100 km…
  - All of central and eastern Europe constitute one continuous heat synergy opportunity zone!
  - Feasibility issues?
  - Heat demand concentrations
  - Future increase of European urban populations



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3rd research issue: The locations of European heat synergy regions

- Spatial mapping of excess heat activities and local heat sources
  - Study results
  - Including local conditions in energy modelling produce alternative forecast
    - Increased recognition of DH systems as energy efficiency infrastructure
  - Dynamic range of possible future heat supply for modern district heating
    - Local heat resource utilisation by DH distribution
  - Geographic Information System (GIS) software – useful tool!
    - Convenient association of other data to any spatially defined location
    - High capacity processing of spatial information
    - Highly communicative map outputs
    - GIS based analysis – supporting real life heat synergy collaborations in Europe
  - Heat synergy opportunity zones – 30 km
    - 60% of EU27 excess heat activities in heat synergy opportunity zones
    - 30% of EU27 land area within heat synergy opportunity zones

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Outline

- Background
  - Research questions, projects, and publications
- General information on district heating and cooling
  - Fundamentals of district heating and cooling
  - District heating and cooling in Europe today
- 1st research issue: The economy of heat distribution
  - The distribution capital cost model
- 2nd research issue: The energy efficiency of district heating
  - Concepts to define sequential energy supply
- 3rd research issue: The locations of European heat synergy regions
  - Spatial mapping of excess heat activities and local heat sources
- Conclusions
  - Research issues
  - Future research

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Conclusions

- Research issues
- 1st research issue: The economy of heat distribution
- Cd is sensitive for reduced heat loads
  - Competitiveness of DH decreases if system heat loads are reduced
  - DH is more expensive to distribute at lowered heat densities
- When heat densities decrease, it is the distribution cost that increases
  - The heat generation cost remains in general constant
- DH heat market shares of 60 % would require acceptance of Cd at estimated
  - 2,4 EUR/GJ (-20 %)
  - 3,5 EUR/GJ (-50 %)
- A counteracting factor; raise of population density within cities and city districts
  - Compact cities is foreseen as one major climate change mitigation measure
  - Compact cities have better conditions for DHC than sparse cities, high plot ratios

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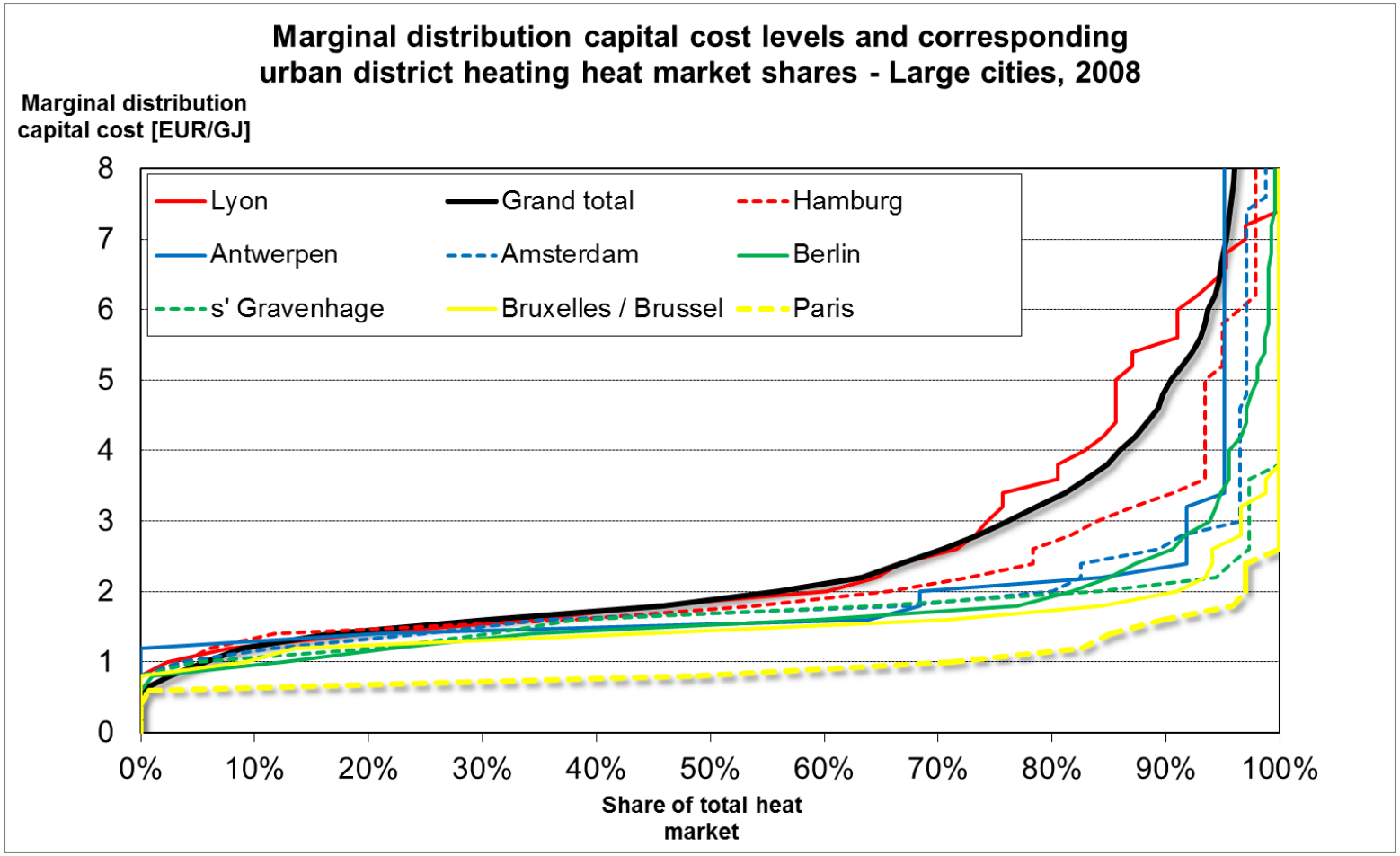
Conclusions

- Research issues
- 1st research issue: The economy of heat distribution



Source: U. Persson, 2011. Realise the Potential! Cost Effective and Energy Efficient District Heating in European Urban Areas. Licentiate Thesis. Chalmers University of Technology.

Conclusions

- Research issues
- 1st research issue: The economy of heat distribution
  - The General Competitiveness of District Heating:
    - The future competition on European heat markets
      - Geographical dimension: Urban areas/rural areas (DH/heat pumps)
      - Energy prices and taxation schemes on alternative heat sources
      - Availability of alternative fuels and heat sources
    - The current use of District Heating
      - Mature DH nations reach >50% of total heat markets
      - 69 out of the 83 studied cities have DH systems in operation
      - 10 study cities have DH heat market shares >40%
    - The shapes of future cities
      - Smart city planning in search of synergies
      - Policy support for efficient energy supply structures

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Conclusions

- Research issues

Assessment of EU27 Member State heat utilisation rates by district heat deliveries to residential and service sectors in 2008

- 2nd research issue: The energy efficiency of district heating

EU27 Member States	Industrial heat recovery in district heating systems [EJ]	District heat deliveries to residential and service sectors [EJ]	Share of recovered heat in total district heat deliveries [%]	Q_{tot} [EJ]	ξ_{heat} [%]
Sweden	0.0175	0.154	71	0.258	43
Denmark	0.0027	0.090	82	0.183	40
Finland	0	0.097	74	0.196	37
Lithuania	0	0.029	50	0.057	25
Bulgaria	0	0.019	84	0.064	25
Czech Republic	0	0.059	78	0.236	19
Latvia	0	0.022	53	0.060	19
Poland	0	0.200	64	0.709	18
Romania	0	0.060	78	0.293	16
Austria	0	0.053	68	0.247	15
Estonia	0	0.019	29	0.039	14
Slovak Republic	0	0.027	53	0.109	13
Hungary	0	0.033	70	0.220	11
Slovenia	0	0.005	78	0.039	10
EU27	0.0247	1.394	75	11.502	9
France	0.0012	0.157	98	1.702	9
Germany	0.0003	0.304	74	2.733	8
Luxembourg	0	0.001	100	0.019	7
Netherlands	0	0.033	89	0.503	6
Greece	0	0.002	100	0.162	1
Belgium	0	0.004	100	0.343	1
Italy	0.0001	0.006	100	1.099	1
Portugal	0	0.001	100	0.105	0
United Kingdom	0	0.018	0	1.473	0
Cyprus	0	0	-	0.010	-
Ireland	0	0	-	0.119	-
Malta	0	0	-	0.002	-
Spain	0	0	-	0.520	-

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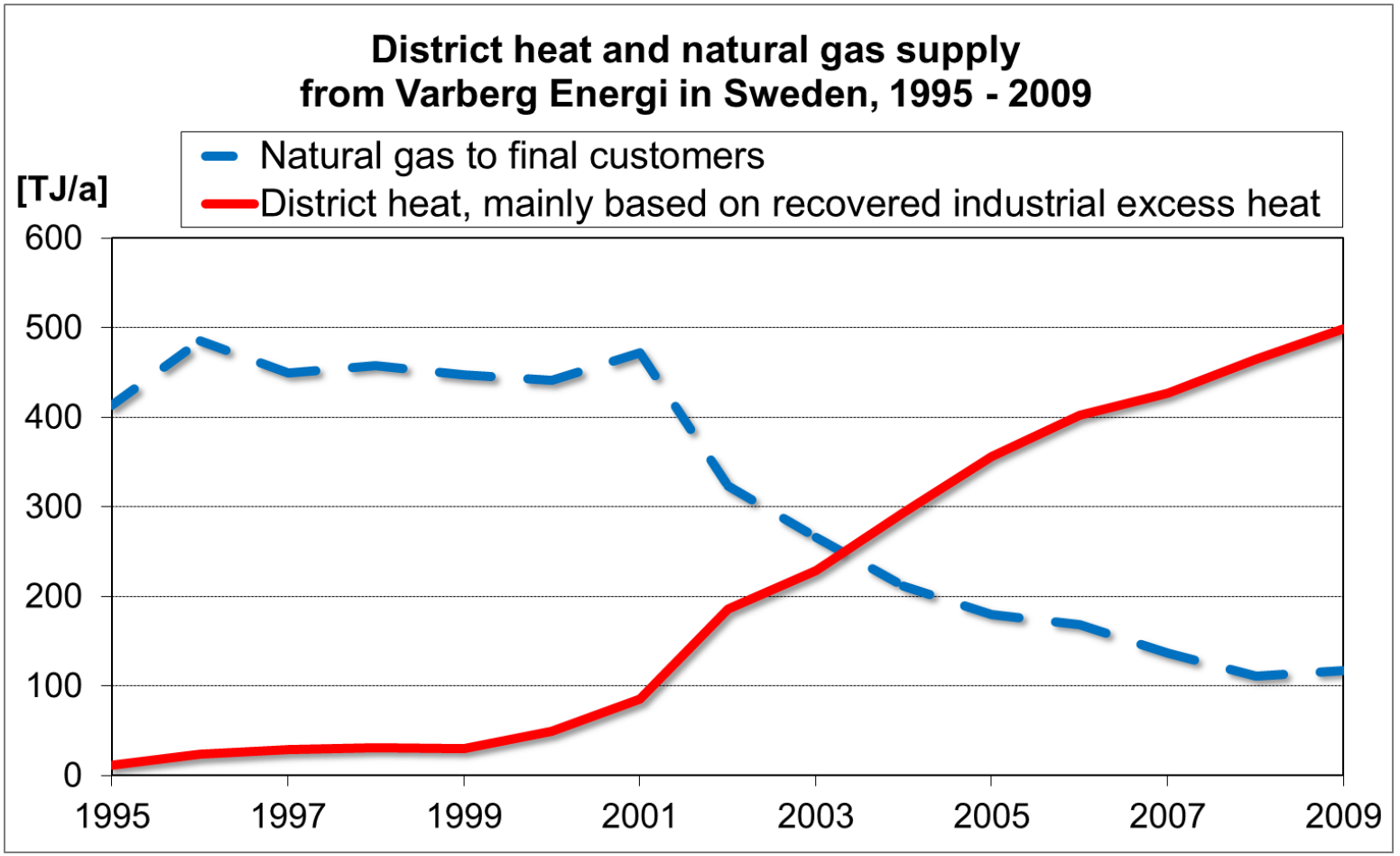
Conclusions

Example of rapid substitution!

- Research issues
- 2nd research issue: The energy efficiency of district heating



Source: U. Persson & S. Werner, 2012. District heating in sequential energy supply. Applied Energy 95 (2012) 123-131.

Conclusions

- Research issues
- 3rd research issue: The locations of European heat synergy regions
    - The European Commision does not foresee a bright future for DHC in urban areas
    - This conclusion must be questioned since Energy Roadmap 2050 is missing information about local conditions vital for DHC
    - Energy Roadmap 2050 is mainly based on large scale use of electricity and gas provided by large scale organisations
    - Local condition analysis reveals local heat synergy opportunities!

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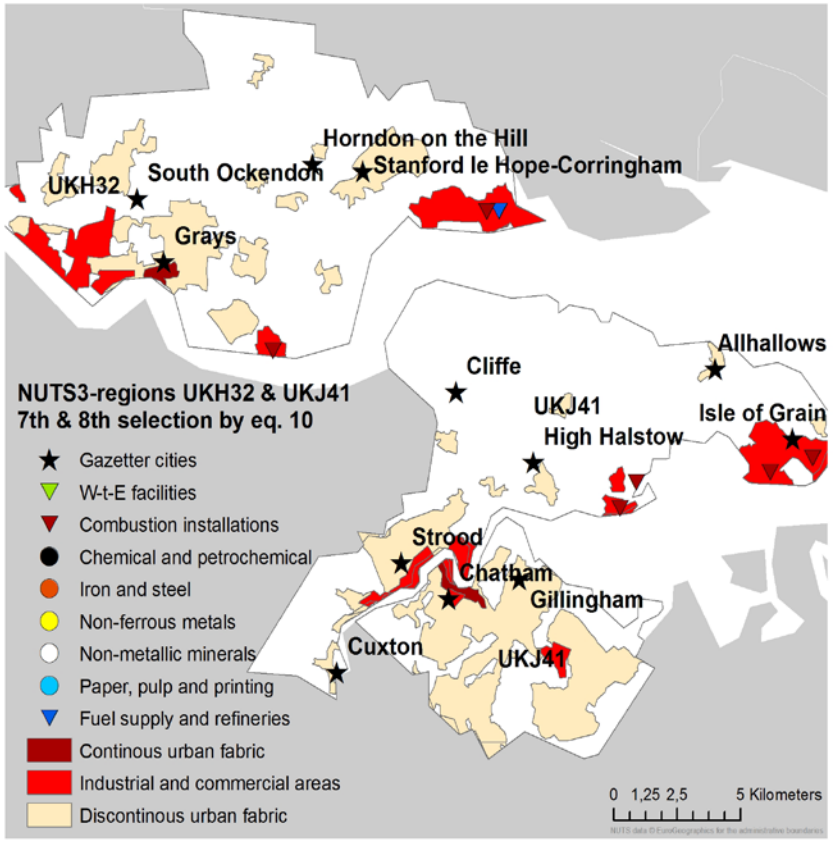
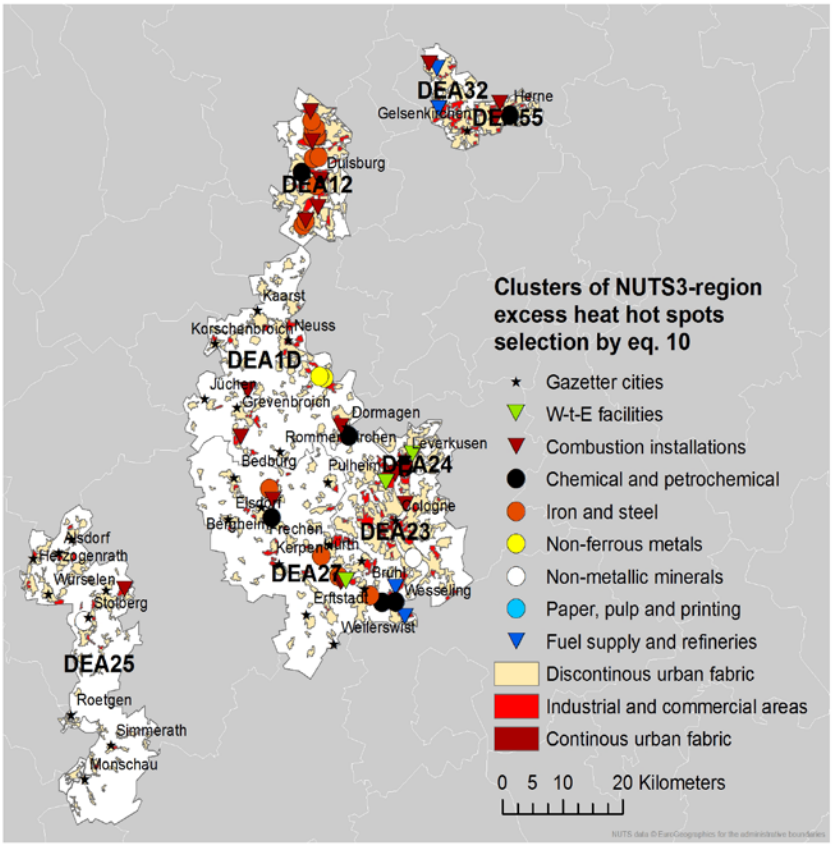
Conclusions

- Research issues
- 3rd research issue: The locations of European heat synergy regions





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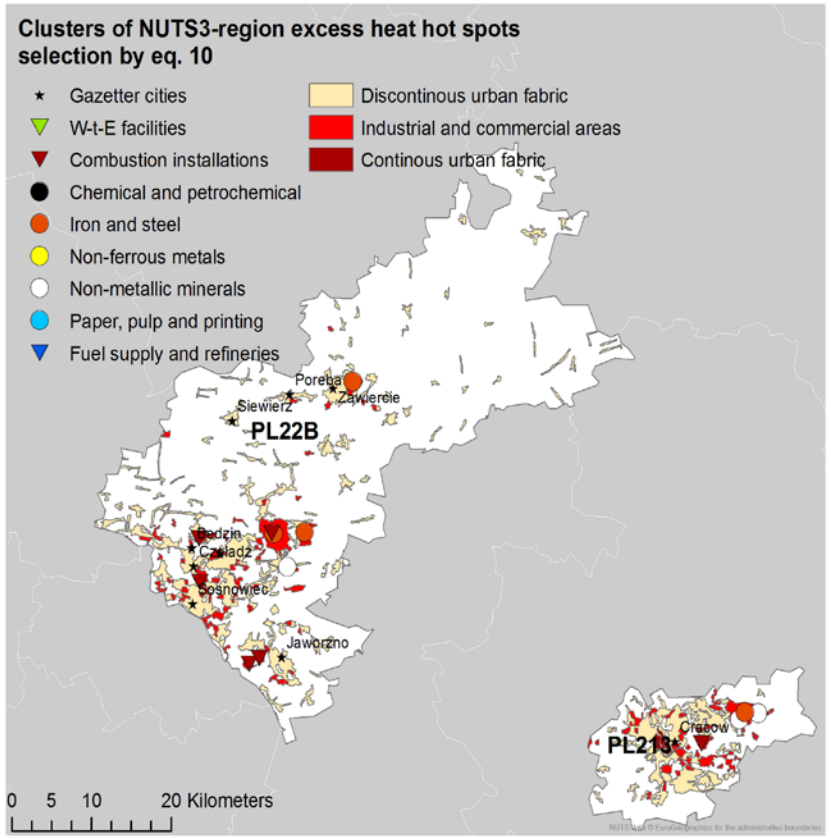
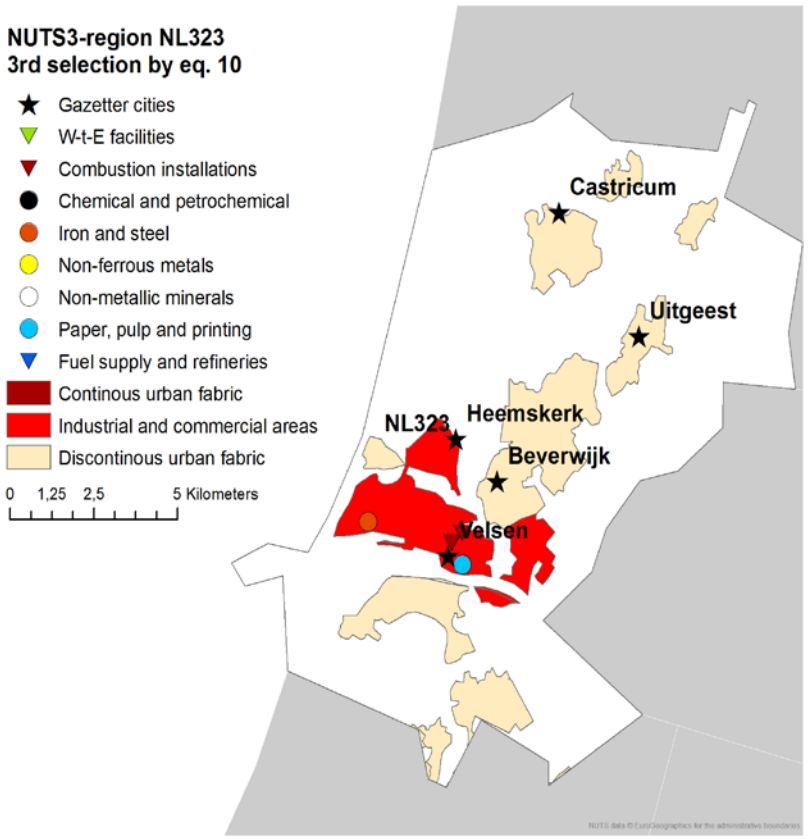
Conclusions

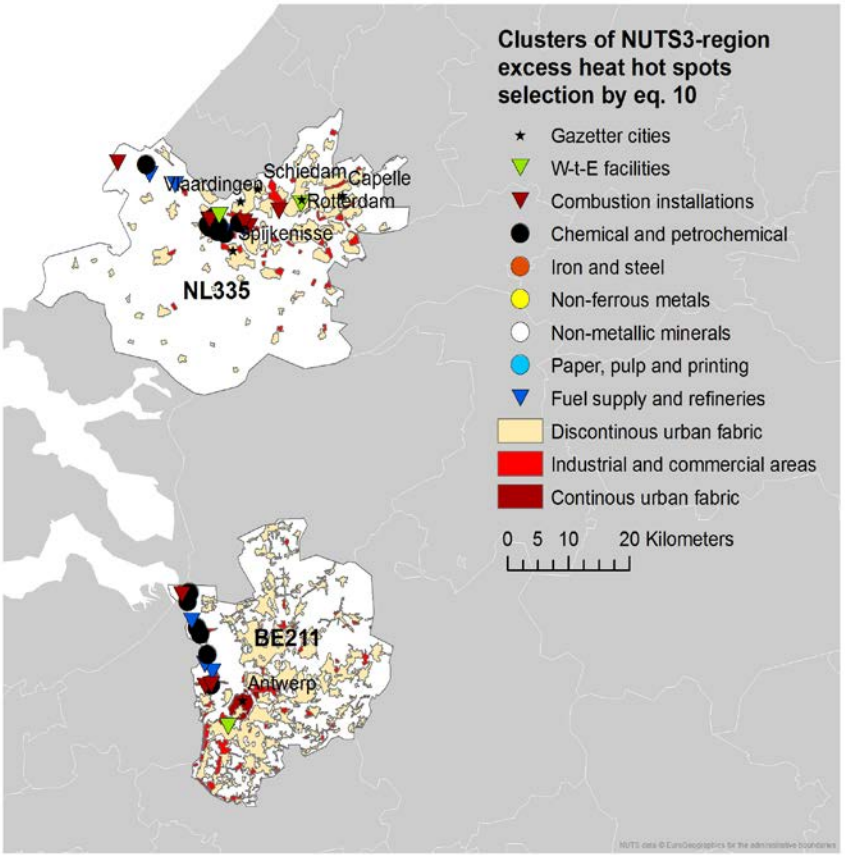
- Research issues
- 3rd research issue: The locations of European heat synergy regions

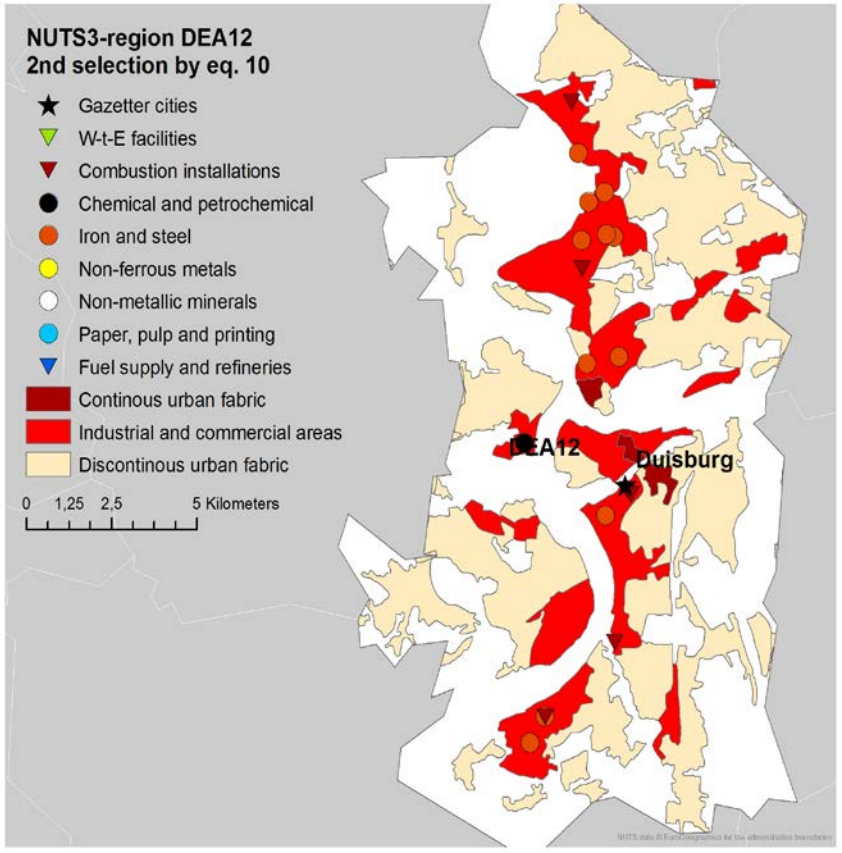




Conclusions

- Research issues
- 3rd research issue: The locations of European heat synergy regions





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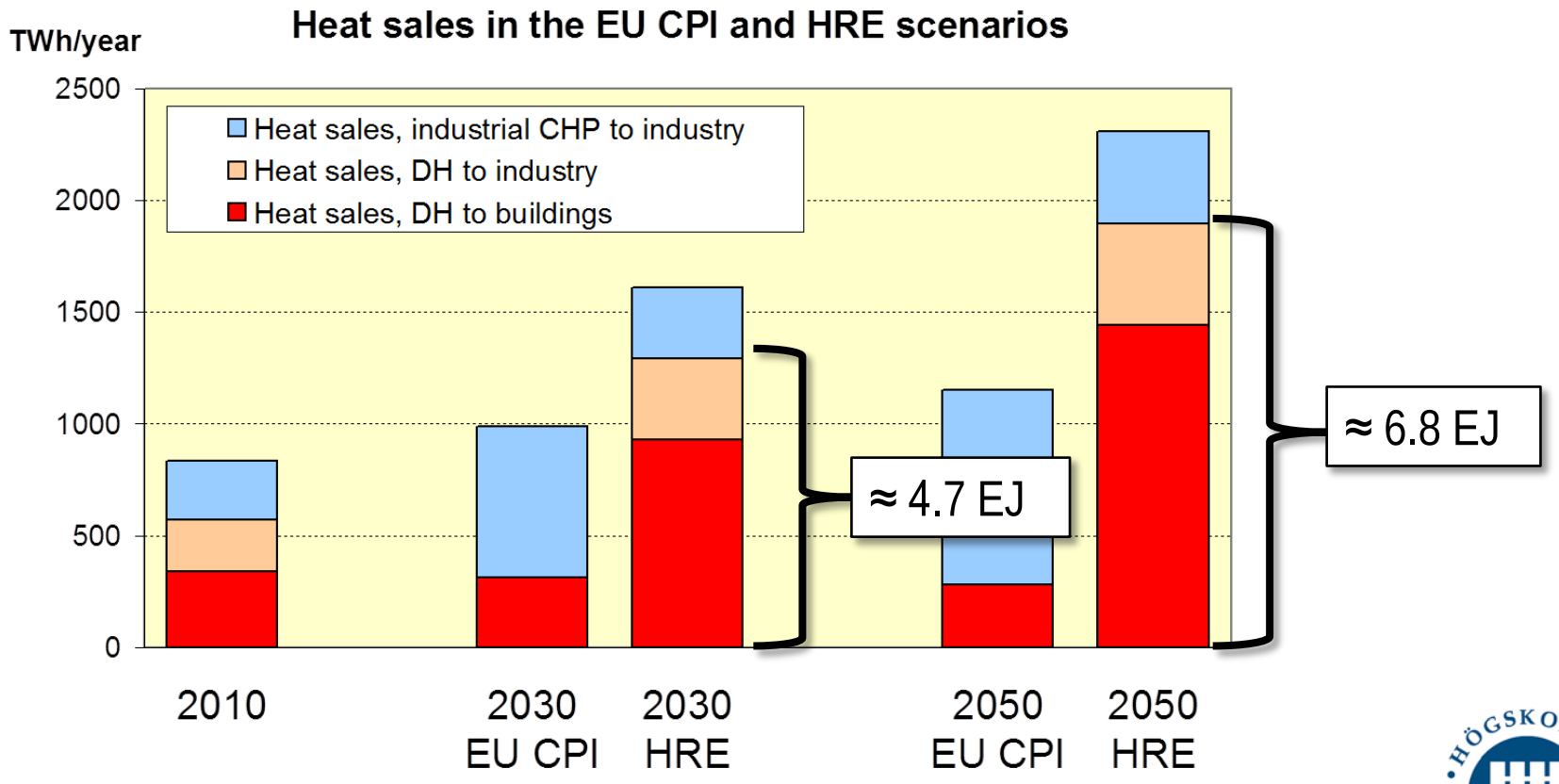
Conclusions

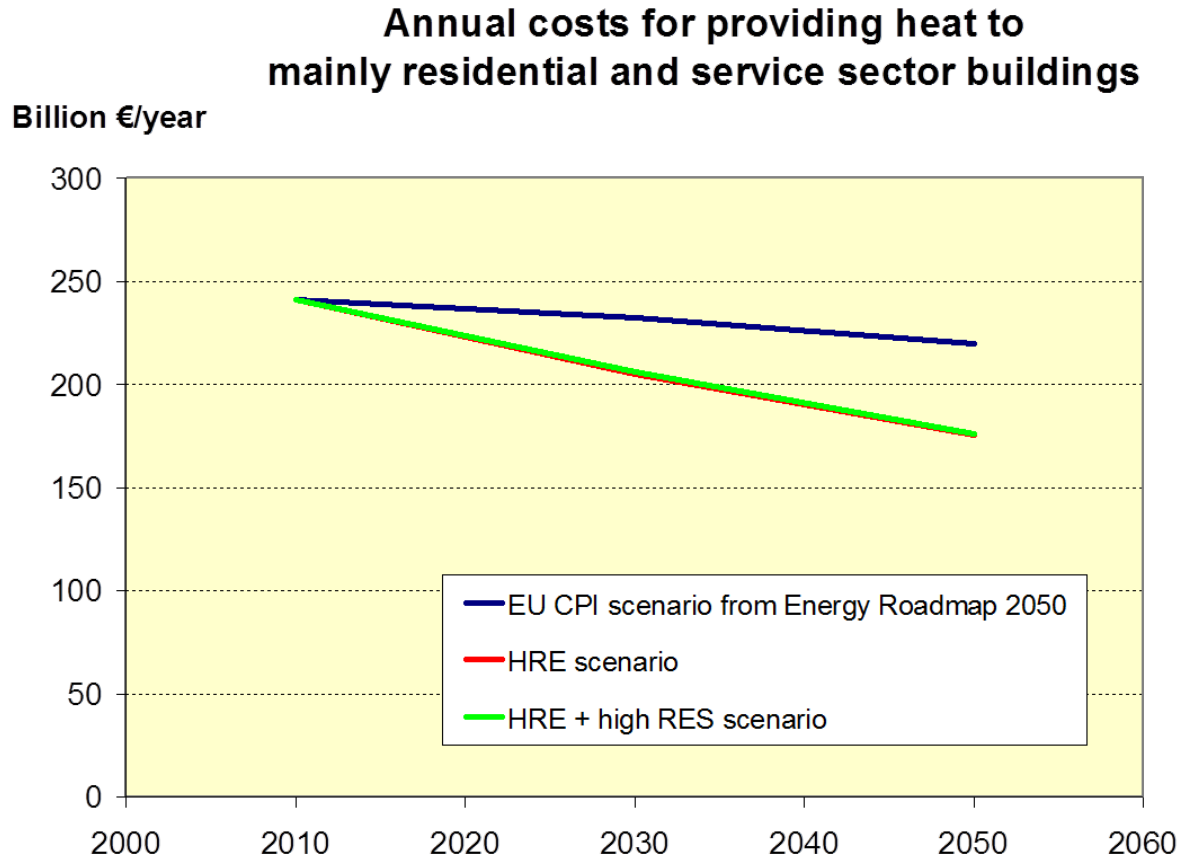
- Research issues
- 3rd research issue: The locations of European heat synergy regions



Source: Heat Roadmap Europe 2050 - First Pre-study 2012, by a cooperation between the Aalborg and Halmstad Universities.

Conclusions

- Research issues
- 3rd research issue: The locations of European heat synergy regions



Source: Heat Roadmap Europe 2050 - First Pre-study 2012, by a cooperation between the Aalborg and Halmstad Universities.

Conclusions

- Research issues
- 3rd research issue: The locations of European heat synergy regions
- Heat Roadmap Europe 2050 project – 1st pre-study:
  - Lower energy system cost in the European energy system with more DH
  - Substituted fossil fuels will give lower carbon dioxide emissions and lower energy import
  - More DH will generate more local investments and corresponding job creation
  - More DH will provide more reliable balancing power in both directions to the future European electricity system with considerable variable power supply sources.

Source: Heat Roadmap Europe 2050 - First Pre-study 2012, by a cooperation between the Aalborg and Halmstad Universities.

Conclusions

- Future research
  - The excess heat ratio concept
    - Excess heat volumes – compatibility of data, recovery factors
    - Concept definition – population density, availability of heat source, distances etc – Journal publication 2013
  - Continuation of the Heat Roadmap Europe project
    - Second pre-study January to March 2013 – 2nd report!
    - Consolidation of data and methods
    - Future heat demands
    - Dissemination of European heat ”hot spots” – Conference papers
  - Continuous updating of HUDHC
    - Q and L data for existing entries
    - Data on new district heating and cooling systems

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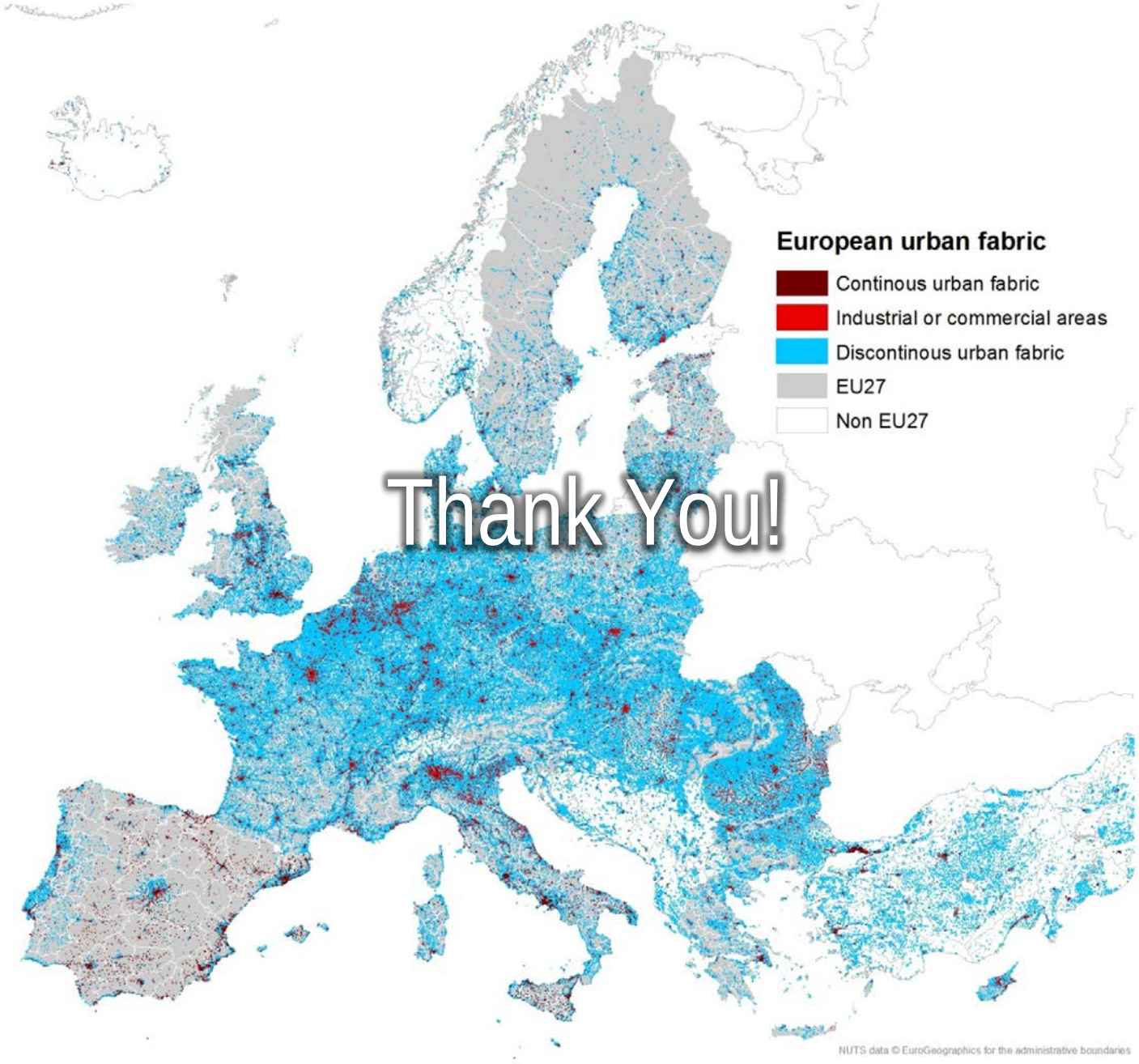
European urban fabric
Continous urban fabric
Industrial or commercial areas
Discontinous urban fabric
EU27
Non EU27
NUTS data © EuroGeographics for the administrative boundaries

Thank You!