# Research presentation
# by
# PhD-student Urban Persson

*Halmstad University/Chalmers University of Technology*

*4DH PhD Seminar*
*7th of March, 2013*
*Aalborg, Denmark*

For the Development of Organisations, Products and Quality of Life

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# Outline

- Research presentation
  - Research focus
    - District heating and cooling systems
    - Heat and cold demands
    - Excess heat recovery
    - Local heat resources
    - Spatial mapping

*A European perspective on heating and cooling networks as structural energy efficiency measures in the general energy system*

- Research fit with the 4DH project
  - PhD 2.4 Low-temperature energy sources for district heating
- Collaborations
  - Other PhD projects in 4DH
  - Private partners from industry/consultancy

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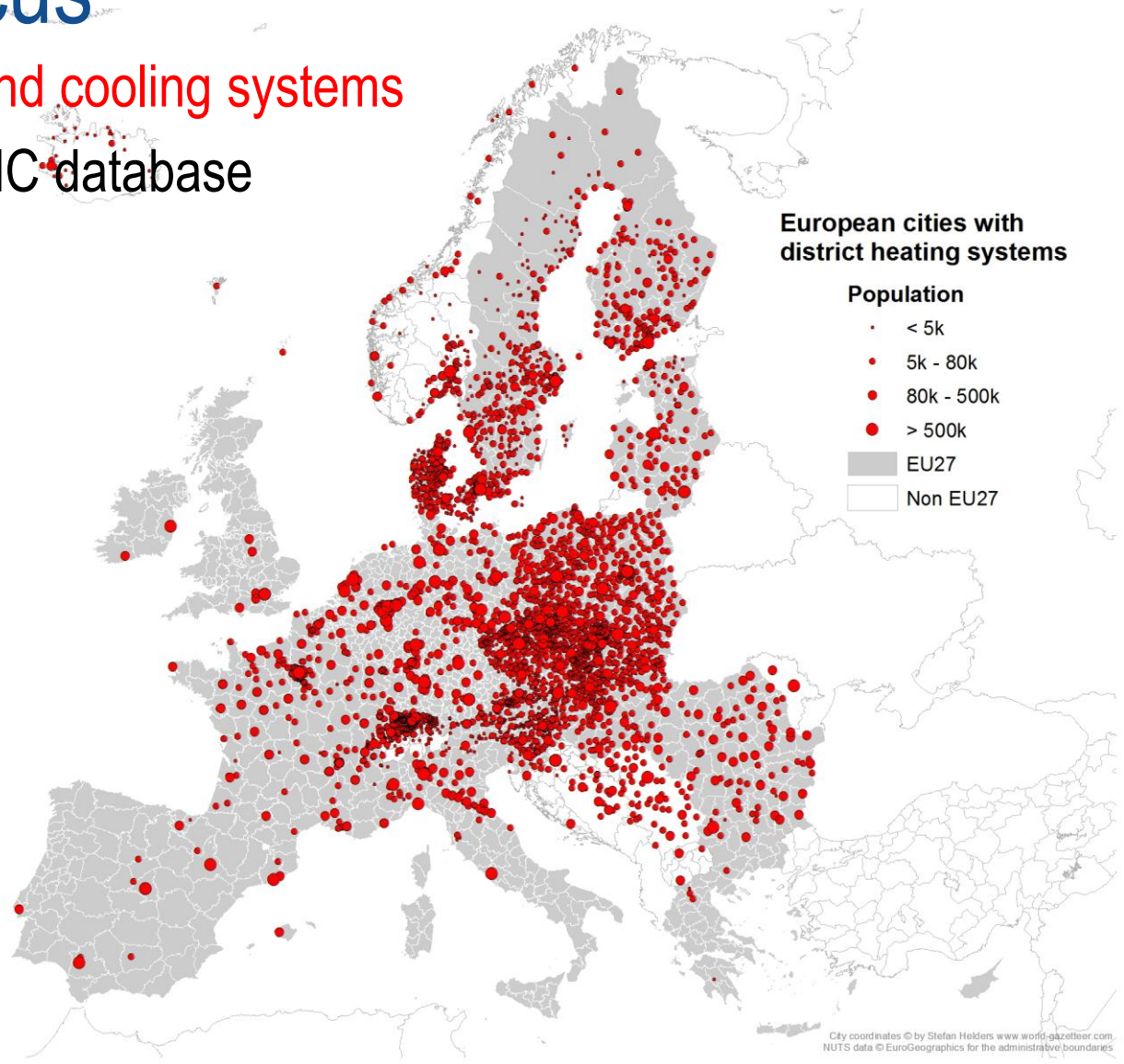
# Research focus

- District heating and cooling systems
  - European DHC database

| Parameter | DH | DH EU27 |
|---|---|---|
| Nr. of countries with systems | 38 | 25 |
| **Nr. of systems** | **4209** | **3584** |
| Nr. of systems – in cities with population > 5000 | 2793 | 2445 |
| Nr. of cities with systems | 3766 | 3268 |
| Nr. of cities with systems and population > 5000 | 2447 | 2188 |

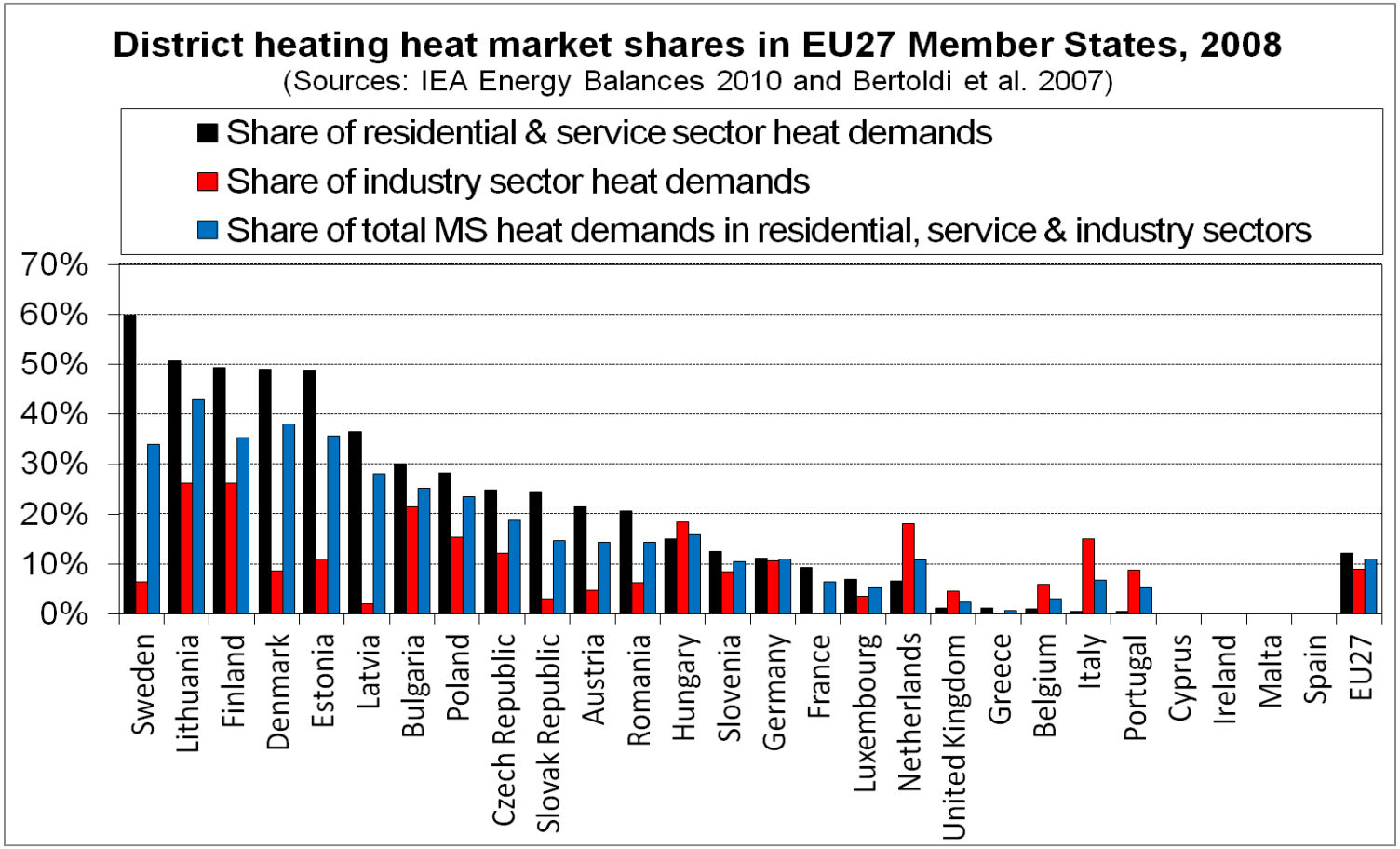



Halmstad University District Heating and Cooling Database (HUDHC).
Created in June 2010: updates June 2011, May 2012.

# Research focus

- District heating and cooling systems
  - Heat and cold markets

*District heat in EU27 at appr. 12% of total HD (17-20% of urban HD) to res. & serv. Sectors in 2008.*




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

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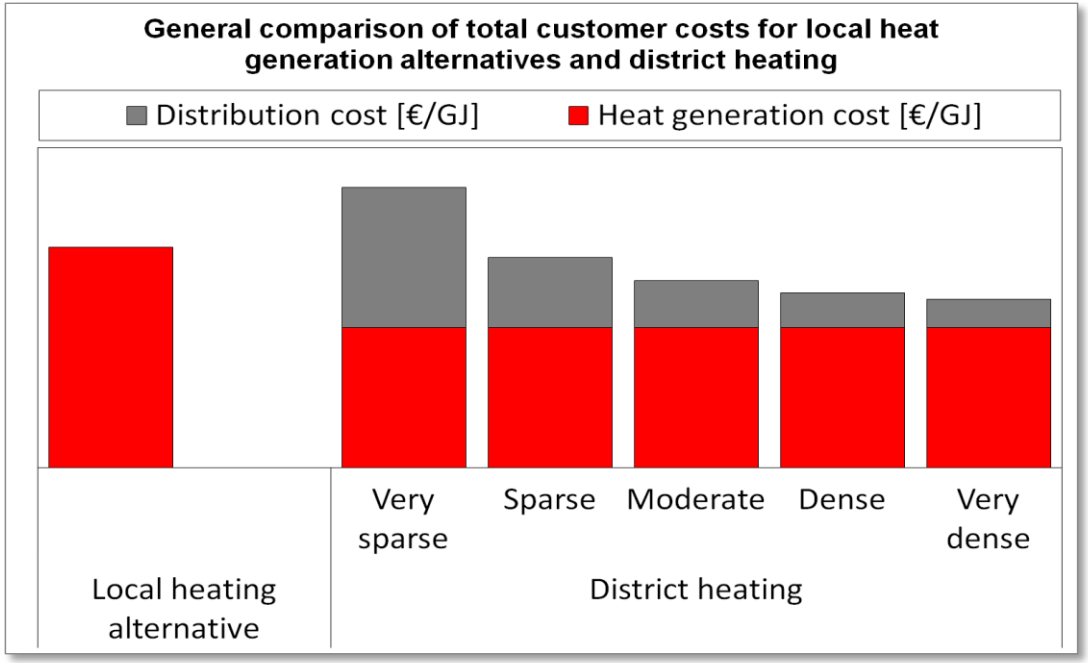
# Research focus

- District heating and cooling systems
  - Economy of heat and cold distribution
  - Specific investment costs




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/m²]* |
| *$d_a$ = 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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# Research focus

- District heating and cooling systems
  - Economy of heat and cold distribution
  - Specific investment costs
- Theoretical reformulation of traditional expression for linear heat density, (Q/L)

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

- Alternative data categories:
  - Population density (p)
  - Specific building space (α)
  - Specific heat demand (q)
  - Effective Width, w = AL / L !

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

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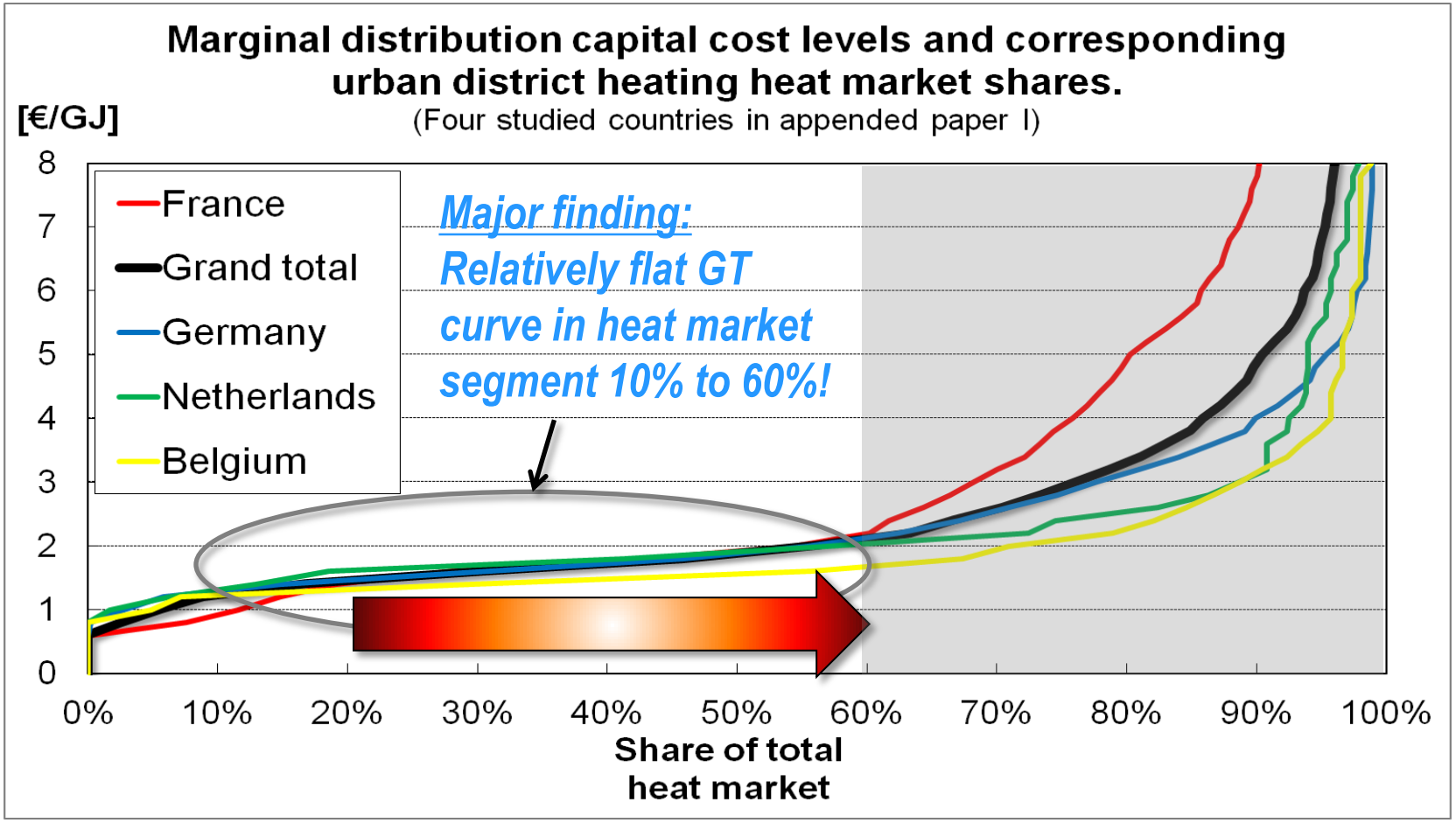
# Research focus

- District heating and cooling systems
  - Specific investment costs

- *Coherent conditions in study*
- *Three-fold directly feasible expansion possibility: 20% → 60% (2.1 €/GJ)*
- *Remaining 40% → dominated by local heating alternatives (low density areas)*

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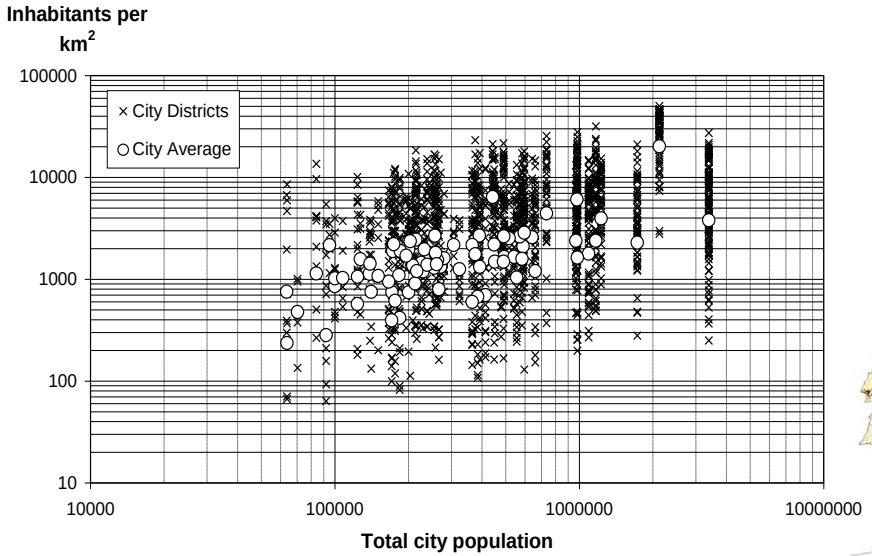
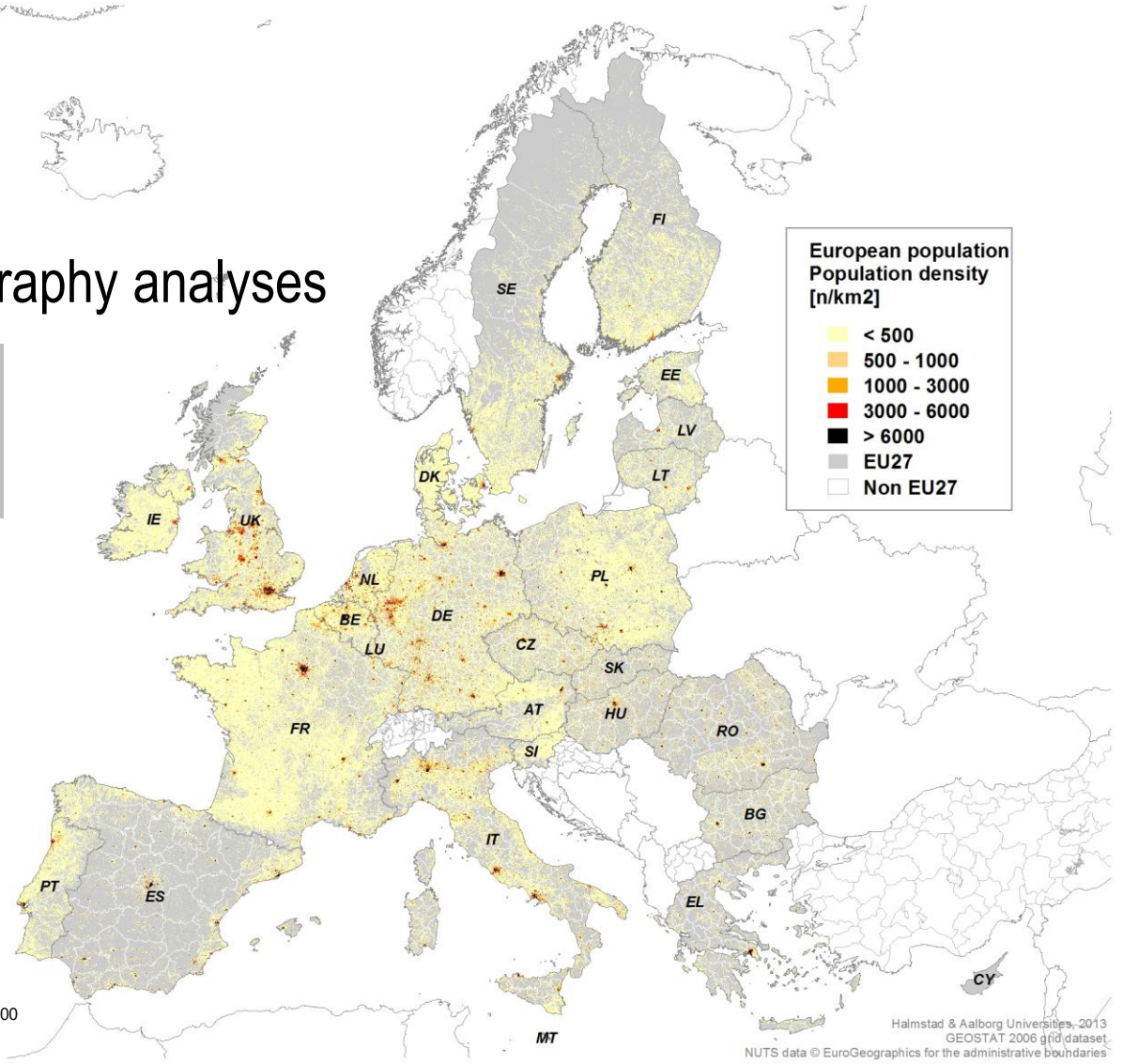
# Research focus

- Heat and cold demands
  - Population and demography analyses

*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




➔ *City average population density values hide secrets!*

➔ *Competitive distribution conditions exist in high density sub-city districts – not detectable in city average values!*

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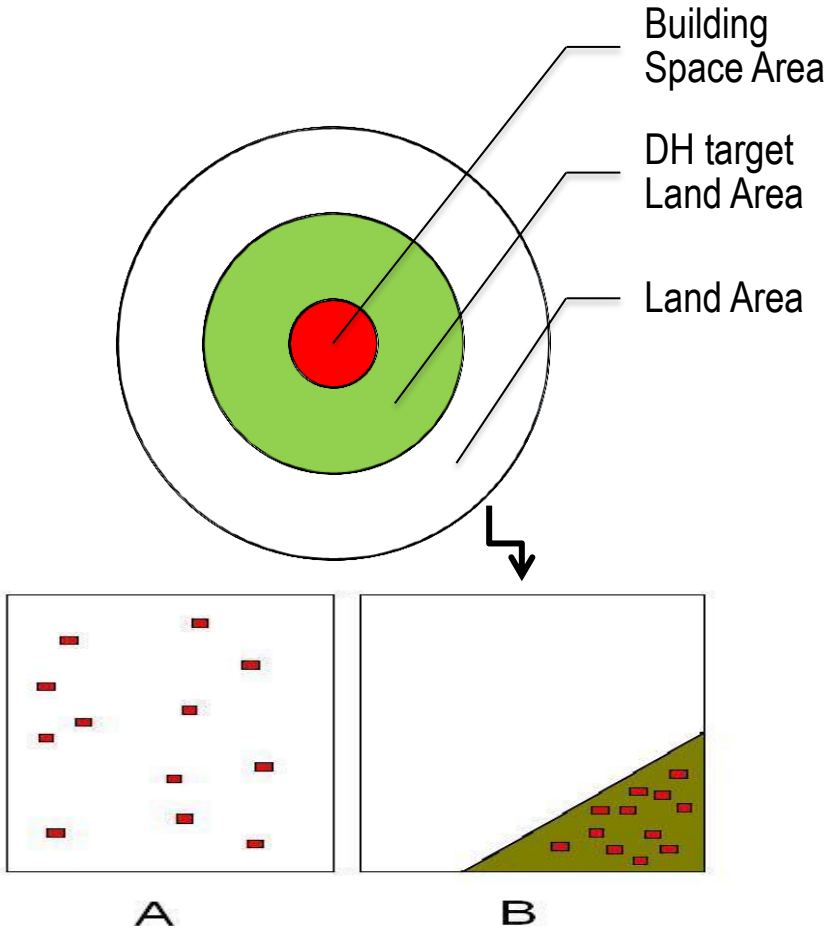
# Research focus

- Heat and cold demands
  - Demand distributions
- 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)
- A matter of resolution level in population data – DH is a local solution not favoured by low resolutions
- DH opportunities may be overlooked or depreciated by population and heat density data established on mean values!




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

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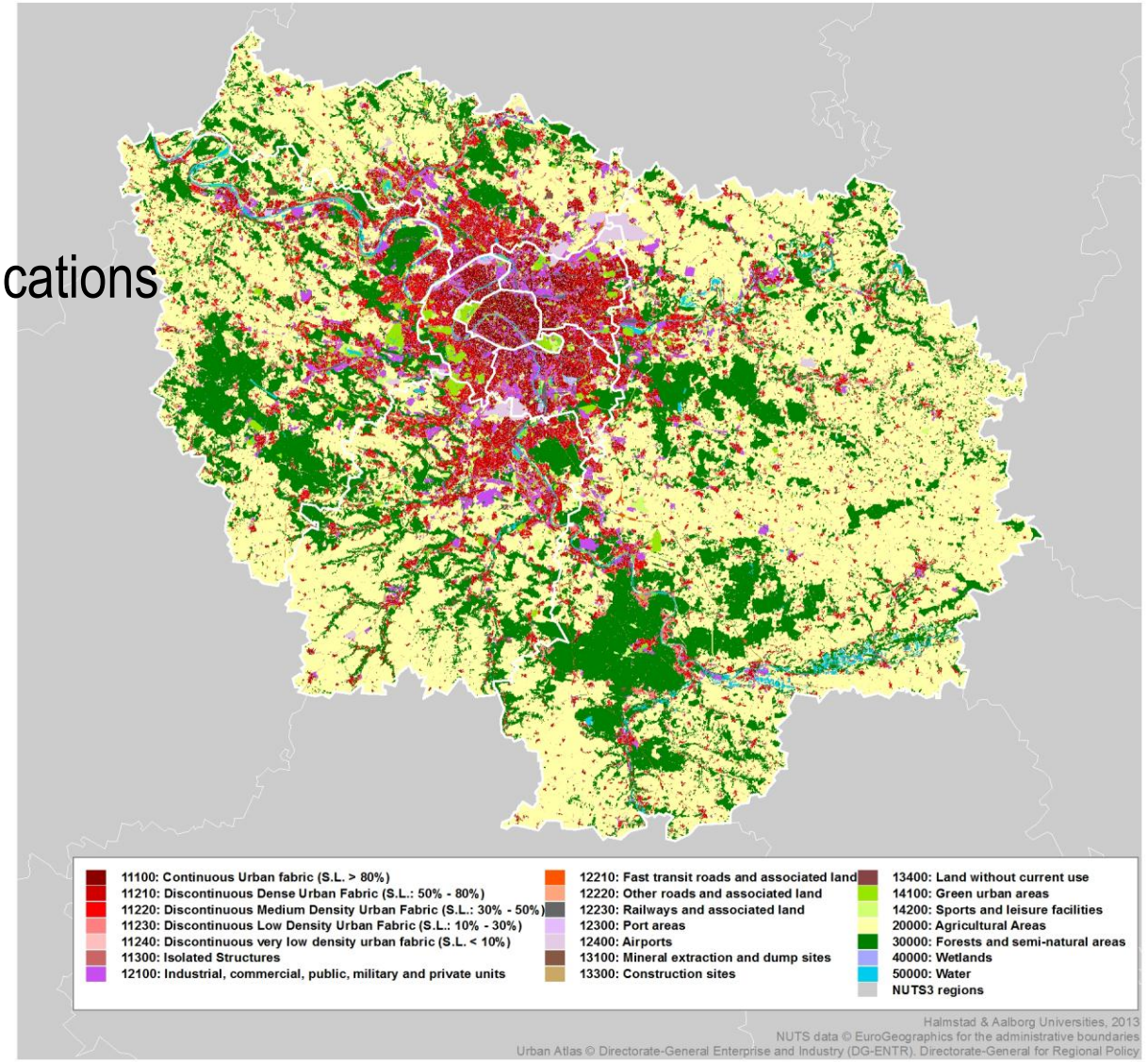
# Research focus

- Heat and cold demands
  - Land use data classifications

*Hereby: Key issue in meta-planning:*
*Population and heat densities by what land areas?*

- *Nation land areas?*
- *Regional land areas (NUTS3)?*
- *Municipal land areas?*

*Goal: To obtain as high resolution as possible in population and heat density spatial data!*




Land use data from the Urban Atlas dataset: French NUTS3 regions surrounding FR101 Paris in center.

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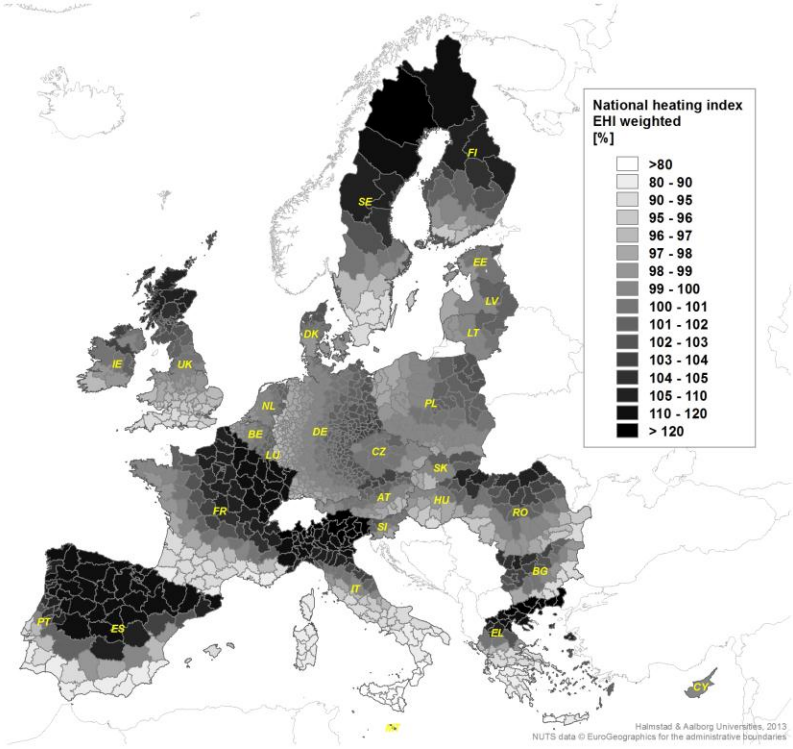
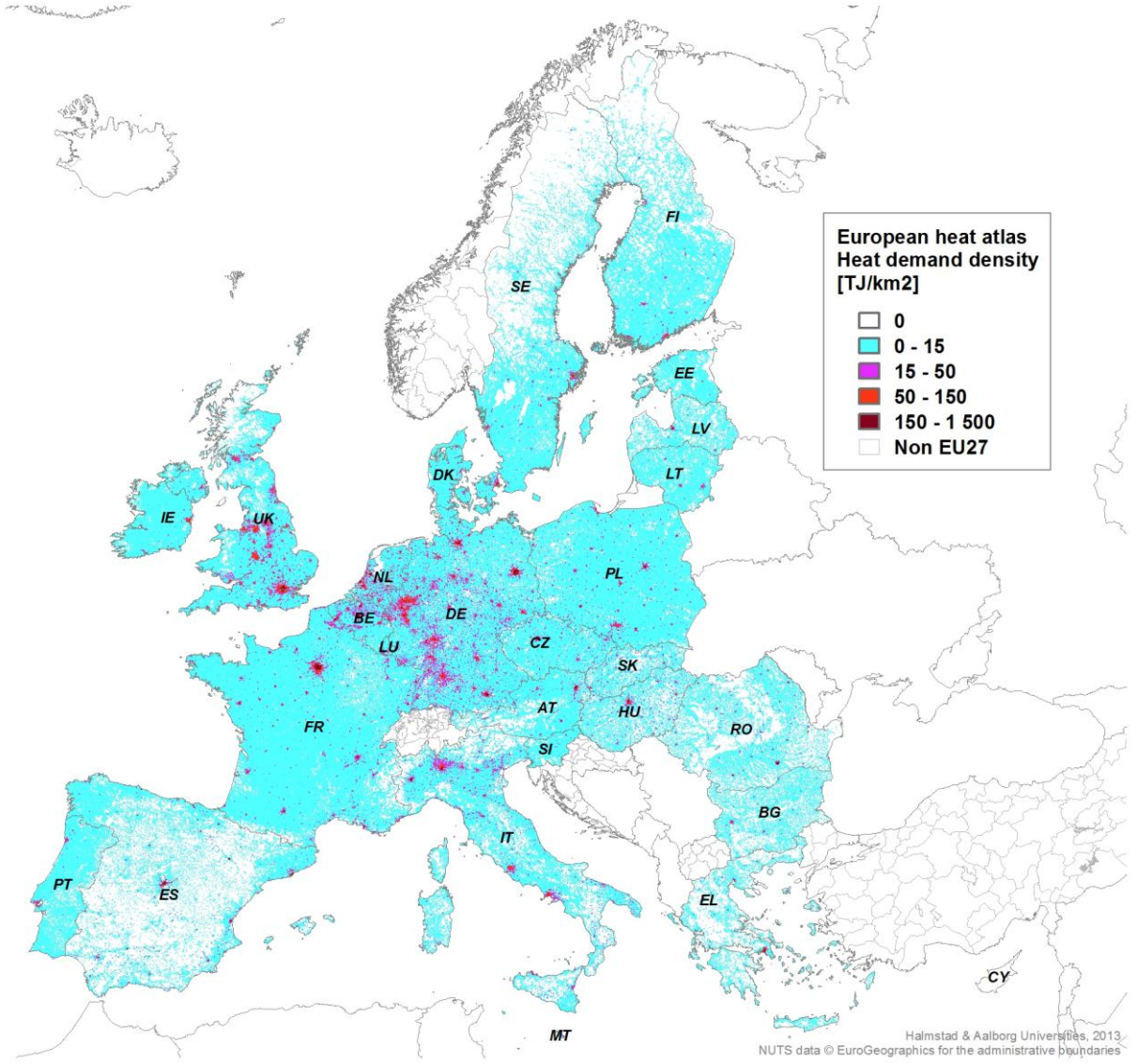
# Research focus

- Heat and cold demands
  - Heat and cold atlases




| HD | $Q_{Res\&serv}$ [EJ/a] | $P_{tot}$ [Mn] | $q_{Res\&serv}$ [GJ/na] |
|---|---|---|---|
| Denmark | 0.183 | 5.5 | 33 |
| Sweden | 0.258 | 9.3 | 28 |
| EU27 | 11.50 | 500.0 | 23 |

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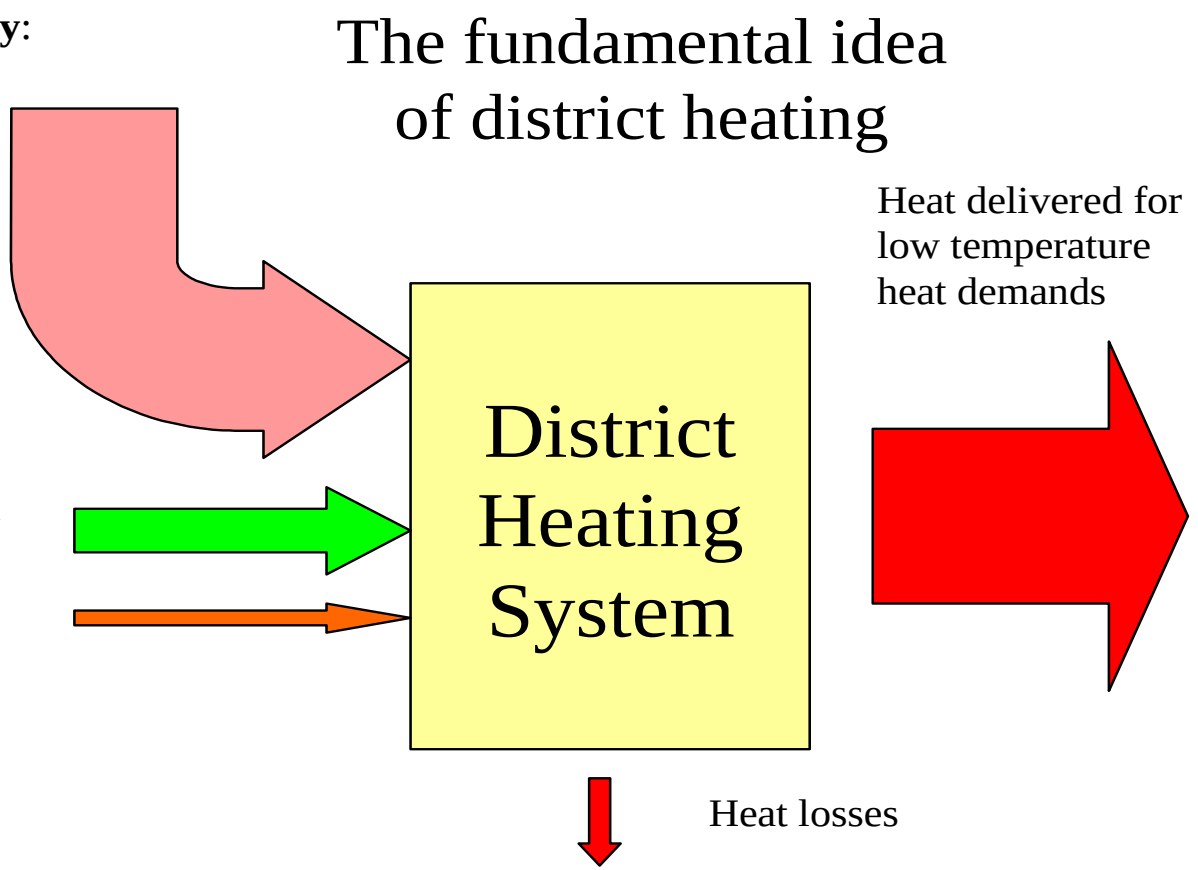
# Research focus

- Excess heat recovery
  - Theory and concepts of excess heat recovery and utilisation

**Secondary Energy Supply**:
Heat recycled from combined heat and power, waste incineration, fuel refineries and industrial excess heat

**Primary Energy Supply:**
Renewables as geothermal heat and biomass

**Primary Energy Supply:**
Fossil fuels for peak and back-up demands




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

# Research focus

$$E_{prim} = E_{abs} + E_{excess}$$

- Excess heat recovery
  - Theory and concepts of excess heat recovery and utilisation

- *Recovery efficiency:* $\eta_{heat} = \frac{E_{heat}}{E_{prim}}$
- *Heat recovery rate:* $\zeta_{heat} = \frac{E_{heat}}{E_{excess}}$
- *Heat utilisation rate:* $\xi_{heat} = \frac{E_{heat}}{Q_{tot}}$

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

$E_{prim}$ = Primary energy supply [J]

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

$Q_{tot}$ = Total heat demand [J]

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# Research focus

- Excess heat recovery
  - Theory and concepts of excess heat recovery and utilisation

Thermal power generation by fuel in EU27 and Denmark, with conversion efficiencies and heat recovery rates, 2008.

Absorbed energy is equal to electrical energy generated.
Persson & Werner 2012.
Source: IEA. Energy Balances 2008. International Energy Agency, Paris; 2010.

| Thermal generation by fuel – EU27 | $E_{prim}$ [EJ] | $E_{abs}$ [EJ] | $E_{excess}$ [EJ] | $E_{heat}$ [EJ] | $\eta_{abs}$ [%] | $\eta_{heat}$ [%] | $\zeta_{heat}$ [%] |
|---|---|---|---|---|---|---|---|
| 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 generation by fuel - Denmark | $E_{prim}$ [PJ] | $E_{abs}$ [PJ] | $E_{excess}$ [PJ] | $E_{heat}$ [PJ] | $\eta_{abs}$ [%] | $\eta_{heat}$ [%] | $\zeta_{heat}$ [%] |
|---|---|---|---|---|---|---|---|
| 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** |

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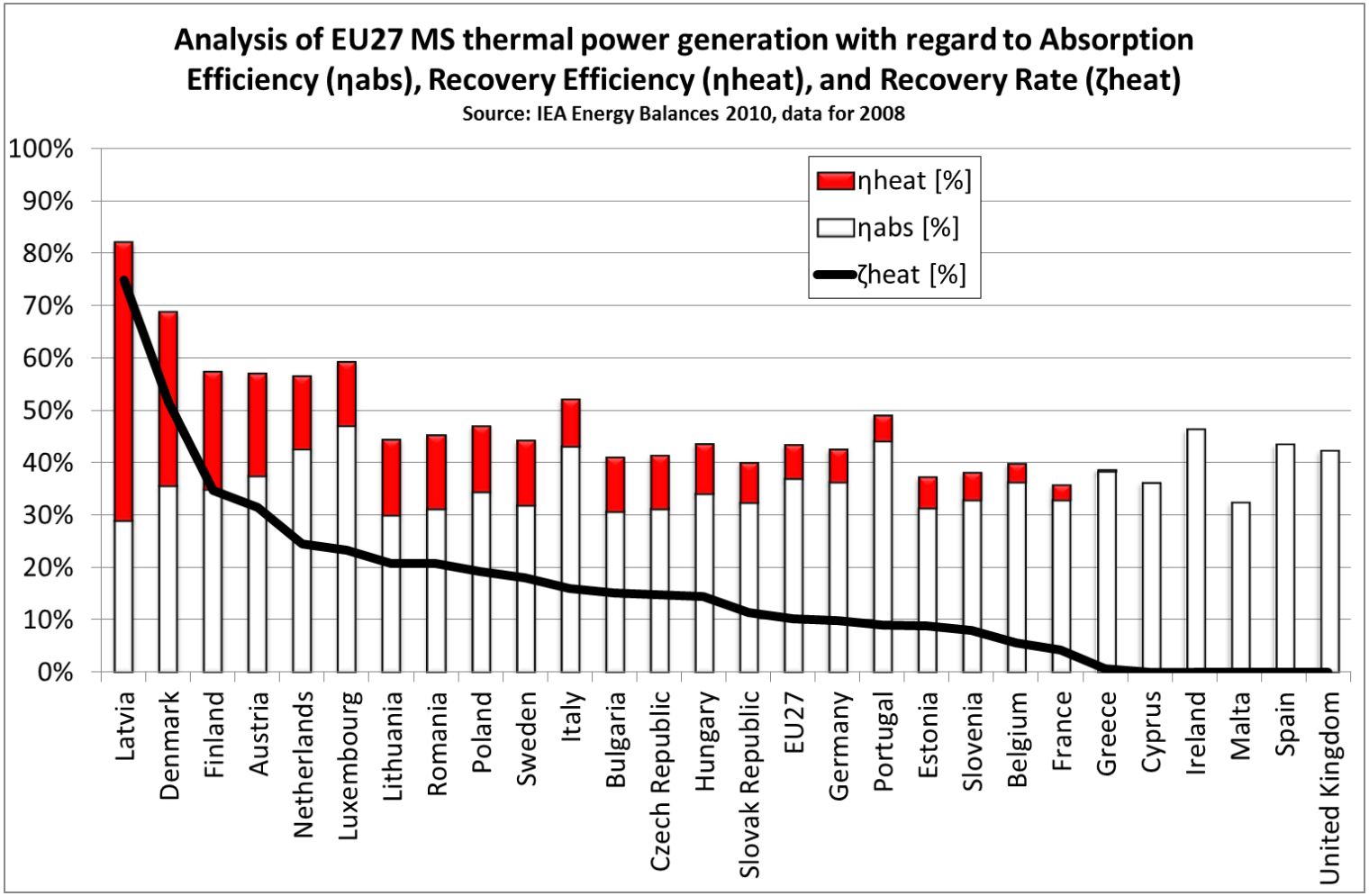
# Research focus

- Excess heat recovery
  - Theory and concepts of excess heat recovery and utilisation

| Excess heat activity | EU27 $E_{prim}$ [EJ] | EU27 $\eta_{heat}$ [%] | EU27 $E_{heat}$ [EJ] | Best MS $\eta_{heat}$ [%] | 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** | **34.2** | **5** | **1.82** | **30** | **10.2** |




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

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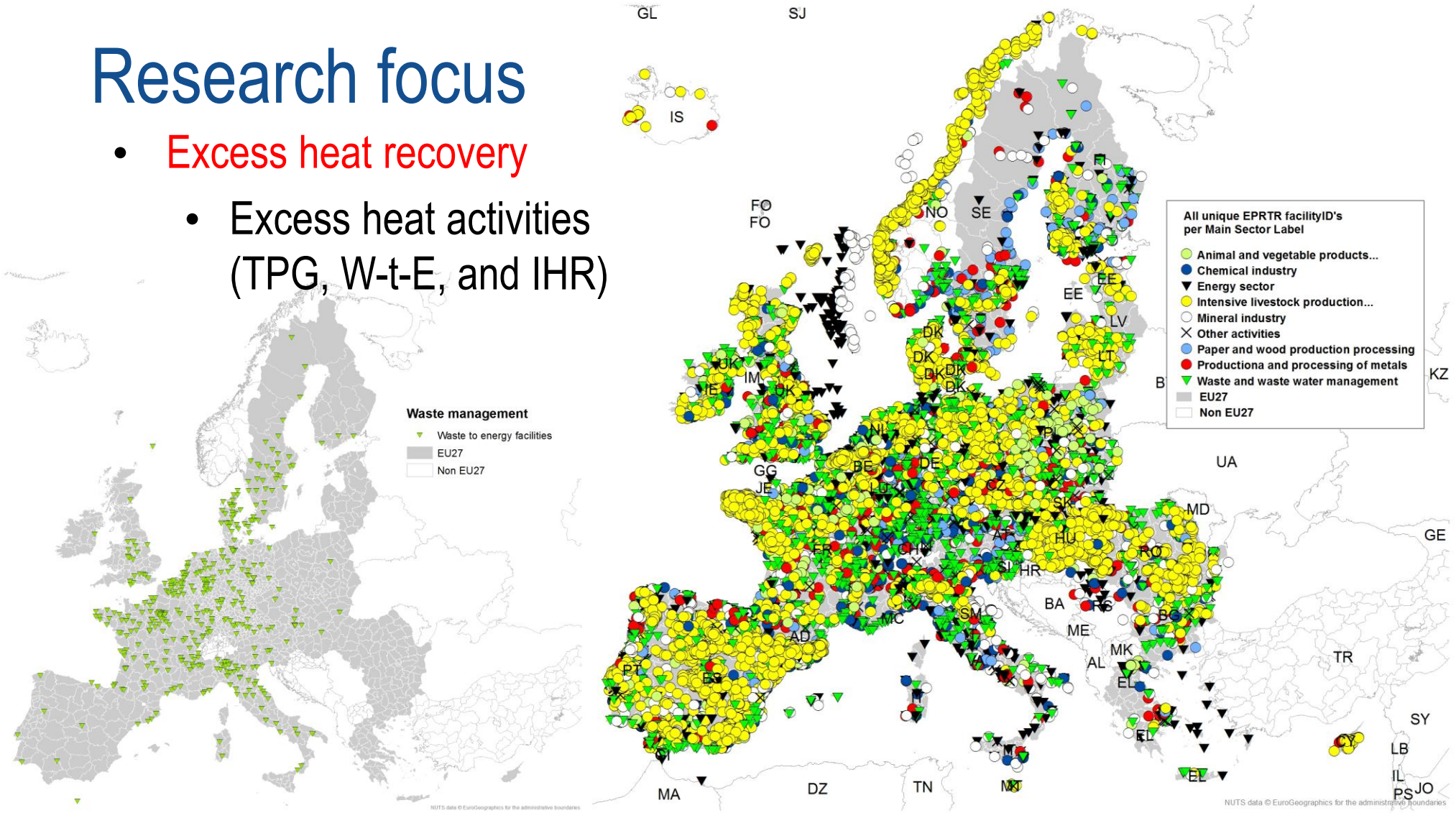
# Research focus

- Excess heat recovery
  - Excess heat activities (TPG, W-t-E, and IHR)




*407 identified EU27 W-t-E facilities in the HRE 2050 Project – Several data sources*

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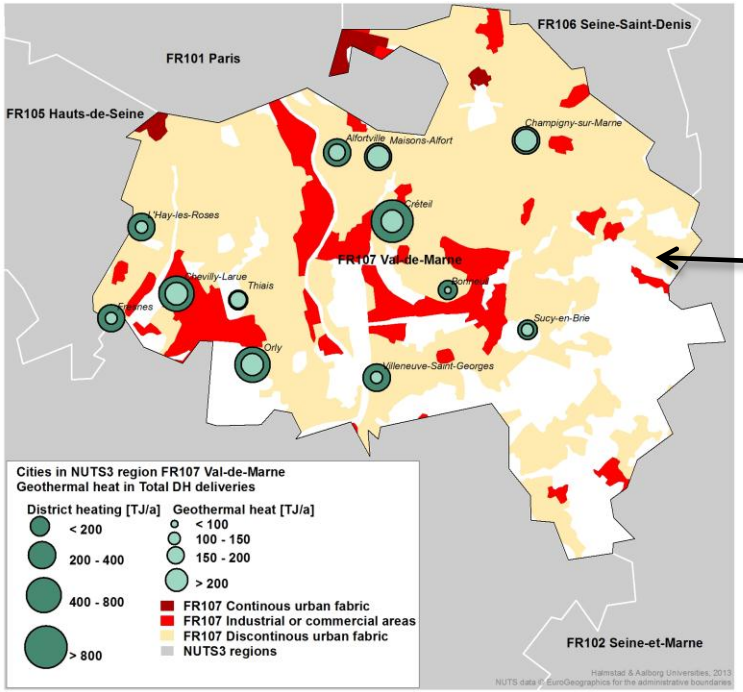
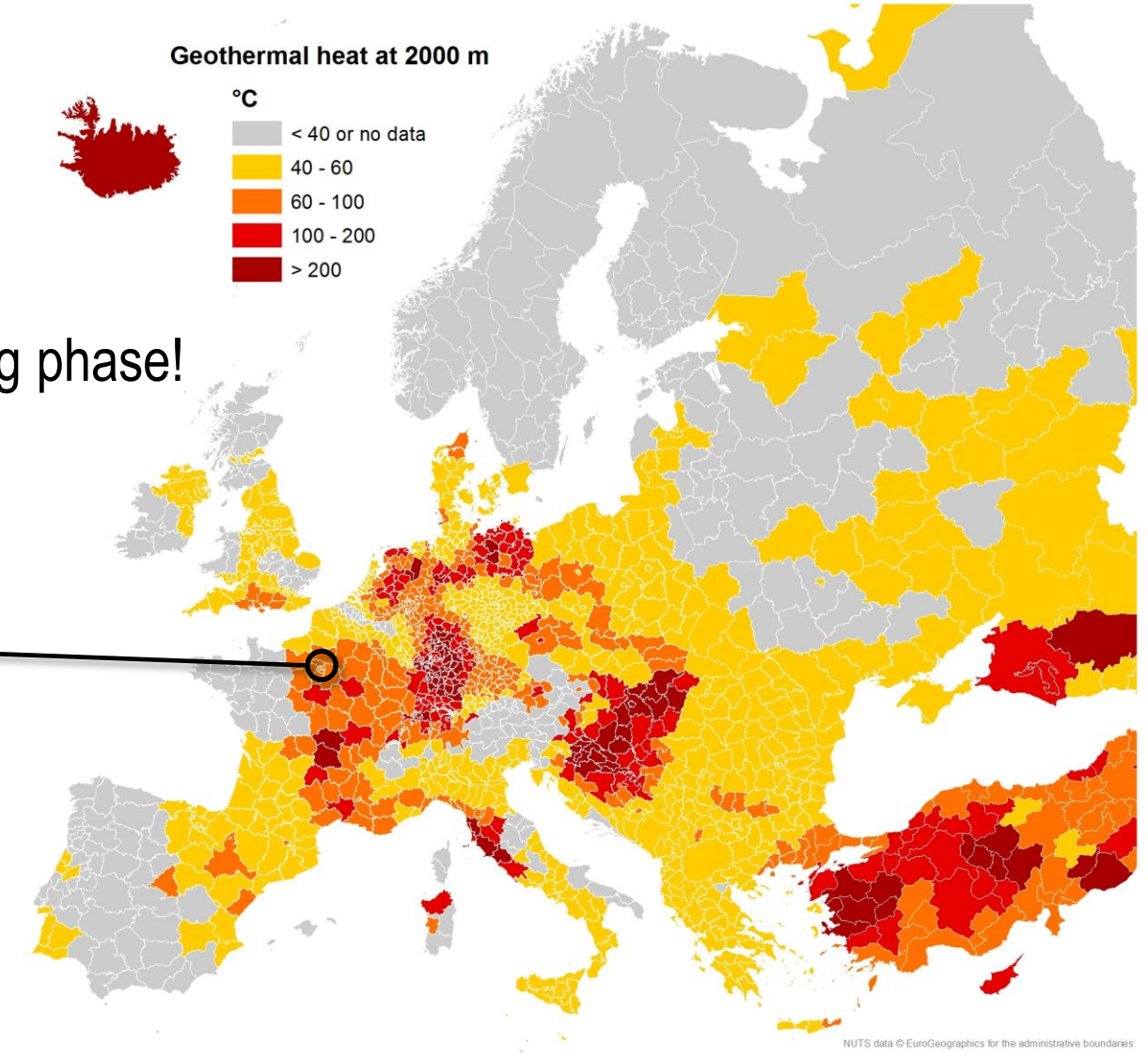
# Research focus

- Local heat resources
  - Geothermal heat
  - Solar & Bio – Learning phase!




*Geothermal heat in FR107 cities with geothermal heat: 2.2 [PJ/a]*
*Heat demand in FR107 cities with geothermal heat: 12.4 [PJ/a]*
*Share of Geothermal heat in FR107 geothermal cities heat demand: 18% [%]*

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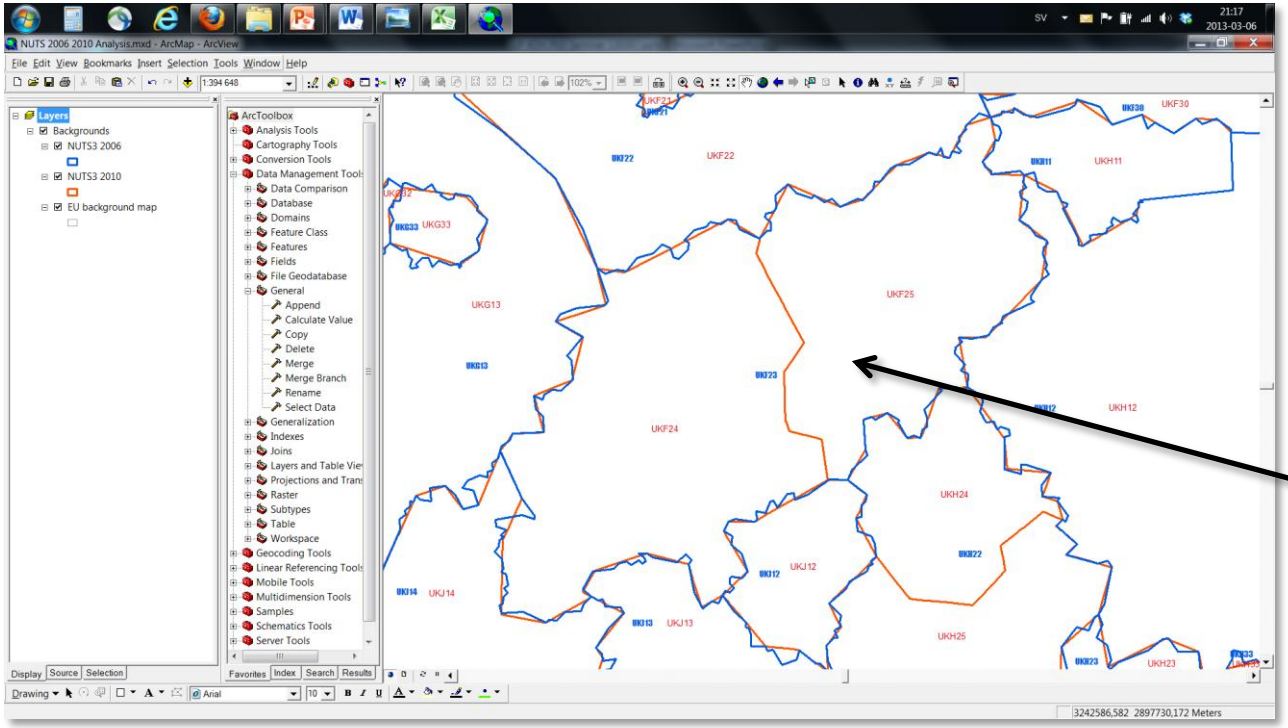
# Research focus

- Spatial mapping
  - ArcGIS applications




- Geographic Information System (GIS) software:
  - Convenient association of data to any spatially defined location
  - High capacity processing of spatial information
    - Data analysis
    - Correlations
    - Distributions
    - Comparisons
  - Highly communicative map outputs

*Using the ArcGIS interface to identify and edit NUTS3 region nomenclature and border differences between NUTS classification 2006 and 2010…*

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# Research focus

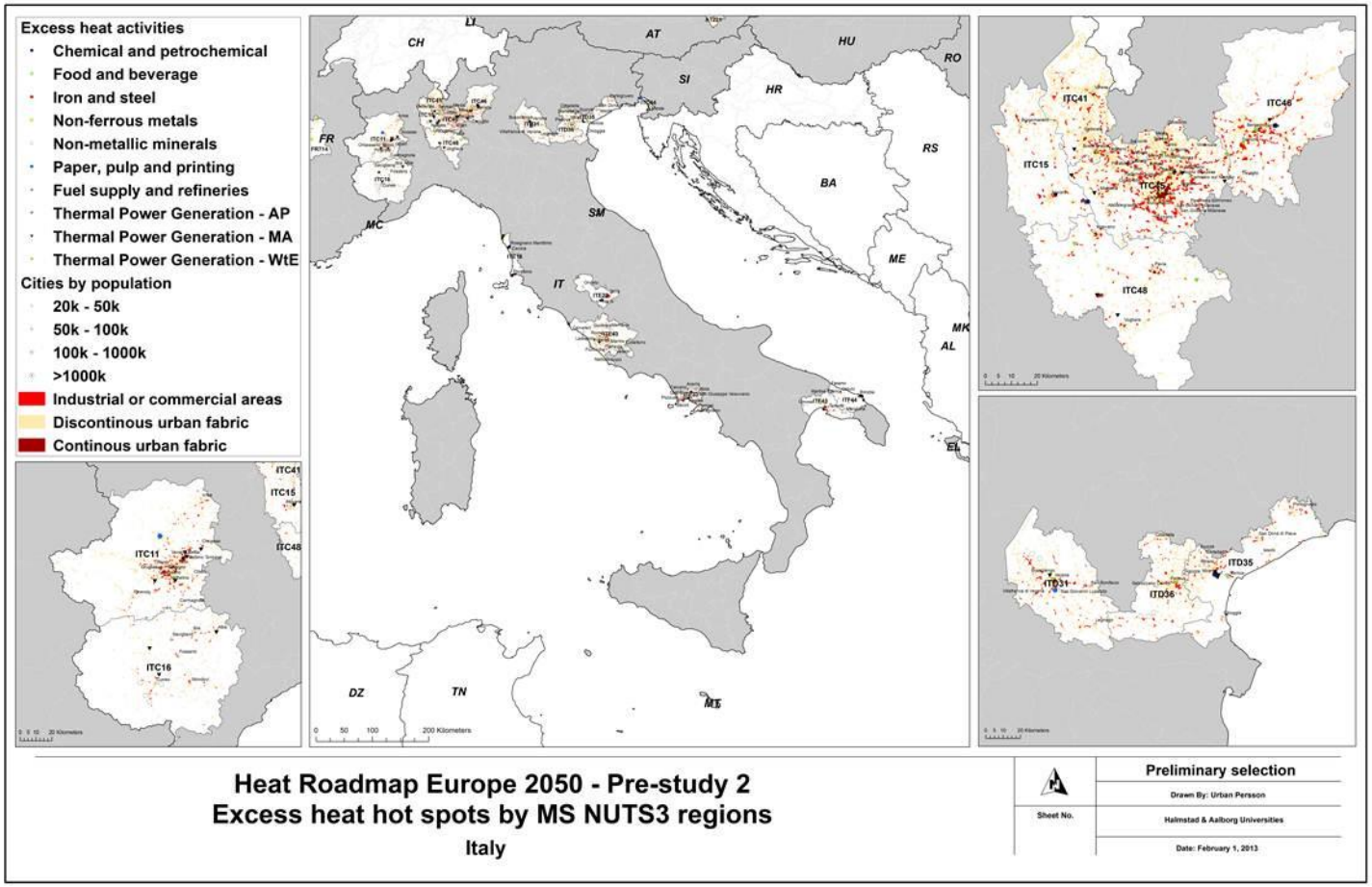
- Spatial mapping
  - Identification of “hot spots”

*Methodological approach:*

➔ *Assess total available NUTS3 region excess heat volumes*

➔ *Establish total NUTS3 region heat demands*

➔ *Calculate the Excess Heat Ratio (EHR) for any NUTS3 region*

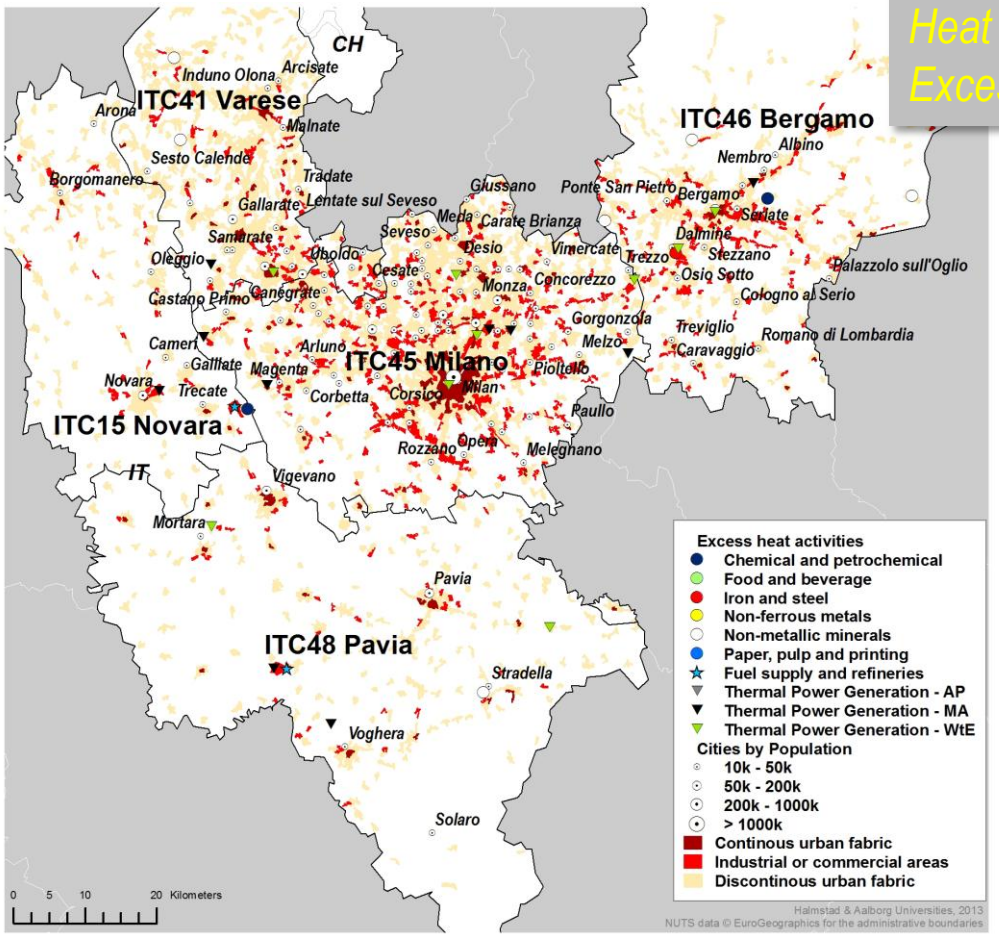



Preliminiary selection of NUTS3 region excess heat “hot spots” for the second pre-study of the HRE 2050 project.

# Research focus

- Spatial mapping
  - Identification of “hot spots”

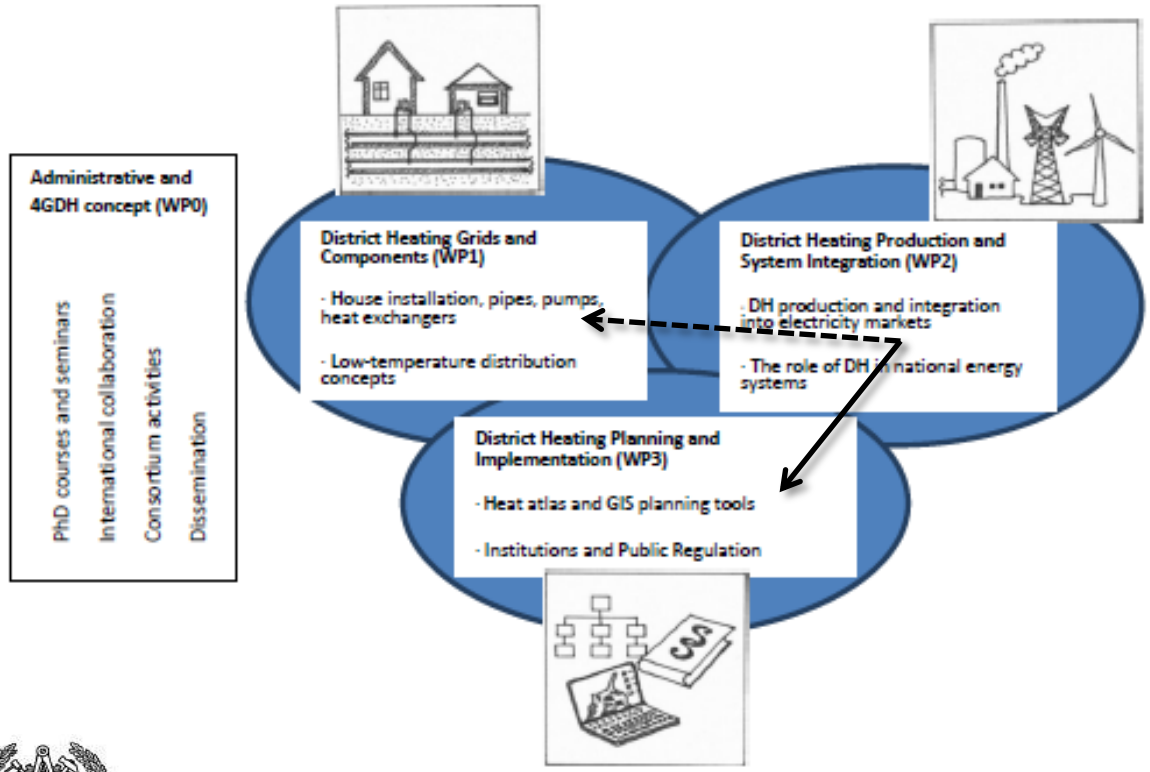
*ITC45 Milano:*
*Population: 3.9 Mn*
*Land area: 1984 km2*
*Population density: 2034 n/km2*
*Excess heat: 28 PJ/a*
*Heat demand: 83 PJ/a*
*Excess heat ratio: 0.34*




Preliminiary selection of NUTS3 region excess heat “hot spots” for the second pre-study of the HRE 2050 project.

# Research fit with the 4DH project

- PhD 2.4 Low-temperature energy sources for district heating




| 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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# Collaborations

- Other PhD projects in 4DH

➔ *Electricity and heat productions are moving away from storable fossil fuels and combustible biomass and waste resources are being limited in quantity*

➔ *Transition to six strategic future supply sources*

➔ *Future heating systems will therefore to a higher extent be based on absorption or compression heat pumps exploiting heat resources at modest temperatures*

➔ *Transition to 4th generation temperatures*

➔ *Investigations of various sources of low temperature heat, their applicability in national energy systems as well as their potentials for energy savings (geothermal, industrial processes, Waste-to-Energy heat)*

➔ *Data, statistics, methodology, spatial analysis, mapping*

➔ *Waste-to-Energy plays an important role. A model for determining the waste available for district heating plants, seen in company, macro-economic, and European perspectives, is developed*

➔ *Needs to be further discussed*

| No. | Title/subject (working title) |
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| 1.1 | Heating of existing buildings by low-temperature DH |
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# Collaborations

- Private partners from industry/consultancy
  - Contact with Forsyningsvirksomhederne, Aalborg Forsyning, Varme
    - Study visit to Portland Cement, Aalborg 130308
      - Industrial process excess heat – recovery to district heating network of Aalborg (c:a 20% of total DH heat delivery)
    - Contact person: Jesper Møller Larsen, Afsnitsleder
    - Invititation for a longer visit/cooperation…
  - Contact with PlanEnergi Nordjylland
    - Discussions on a study visit to one or more of the Danish solar district heating systems. No date set.
      - Solar heat intergation with DH systems, and seasonal storage technologies.
    - Contact person: Morten Vang Jensen

# Thank You!

# Questions?

# Additional slides

- Excess heat recovery
  - Theory and concepts of excess heat recovery and utilisation

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

| 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] | $\xi_{heat}$ [%] |
|---|---|---|---|---|---|
| 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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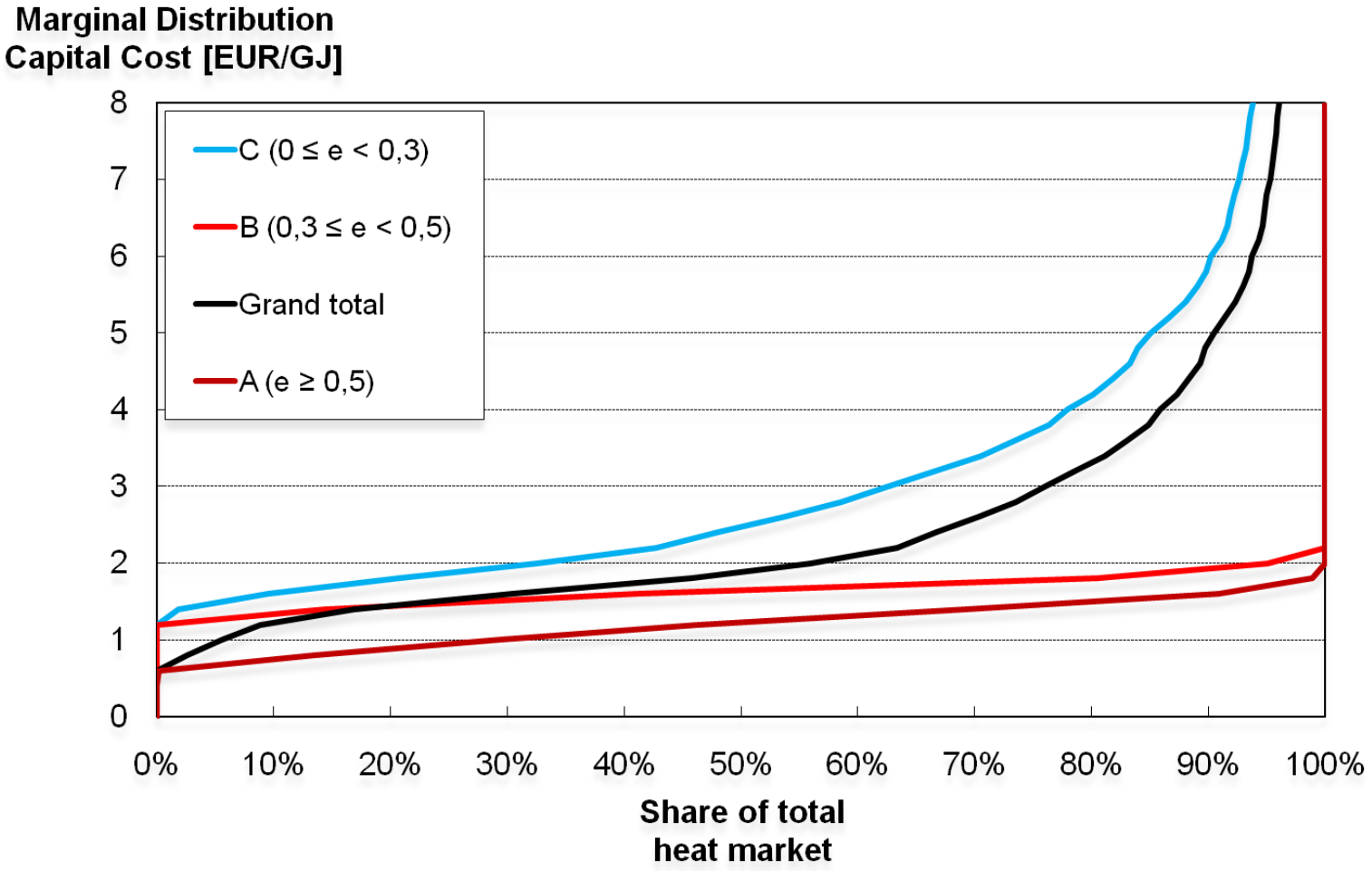
# Additional slides

- District heating and cooling systems
  - Specific investment costs



# Additional slides

- District heating and cooling systems
  - Specific investment costs