European potential of waste heat recovery via district heating

Research presentation by
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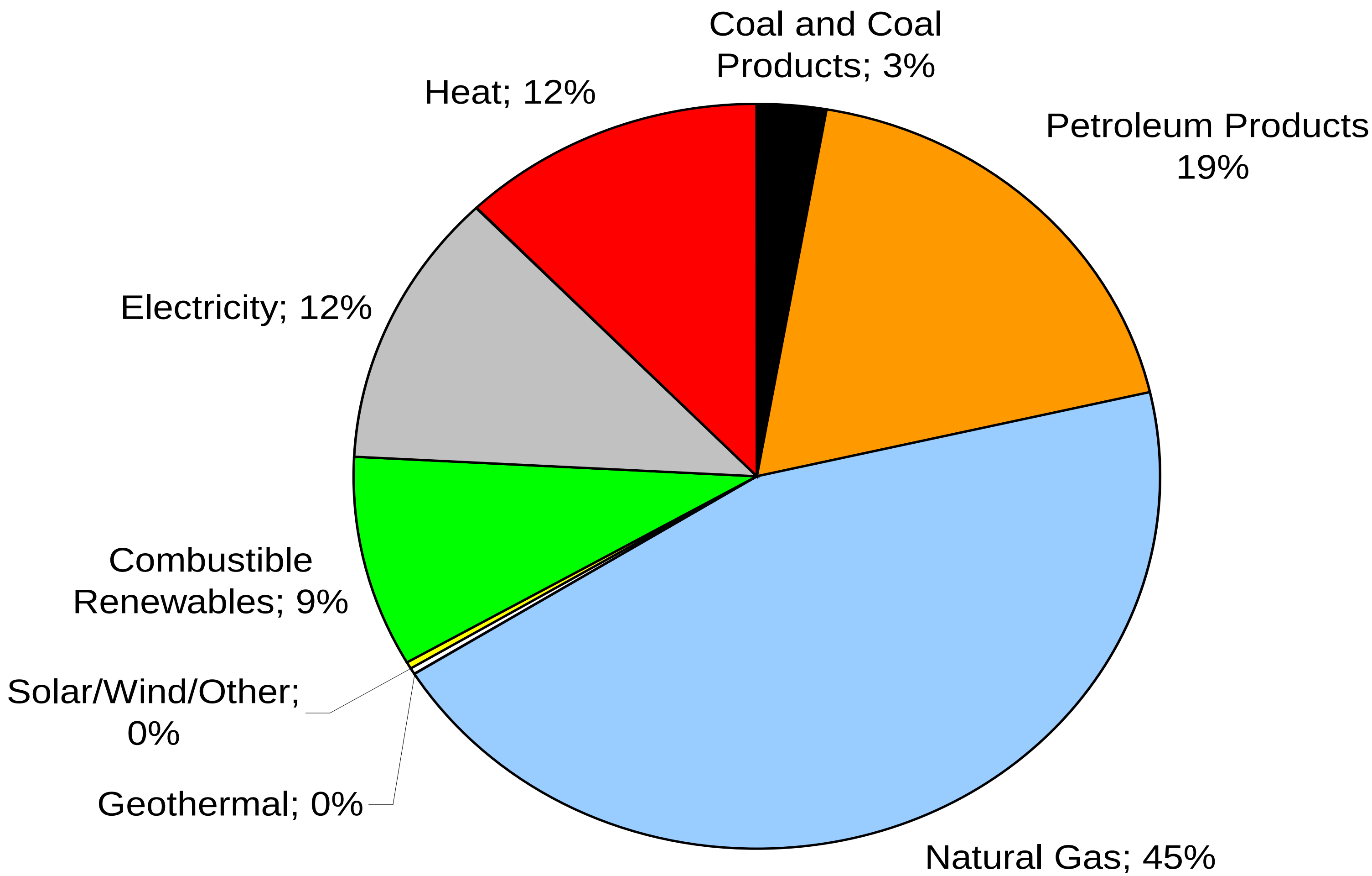
The European heating sector has large potential to contribute to improved adequacy in resource utilisation and to increased general energy system efficiency in future Europe.

Why/how?

High dependency on individual and parallel conversions of primary energy resources for low temperature heating purposes – many of which instead could be met by recycling of recovered excess heat from power and industry sectors, as well as by utilisation of local renewable heat resources.

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



Source: Heat Roadmap Europe 2050 - First Pre-study 2012, Aalborg and Halmstad Universities.

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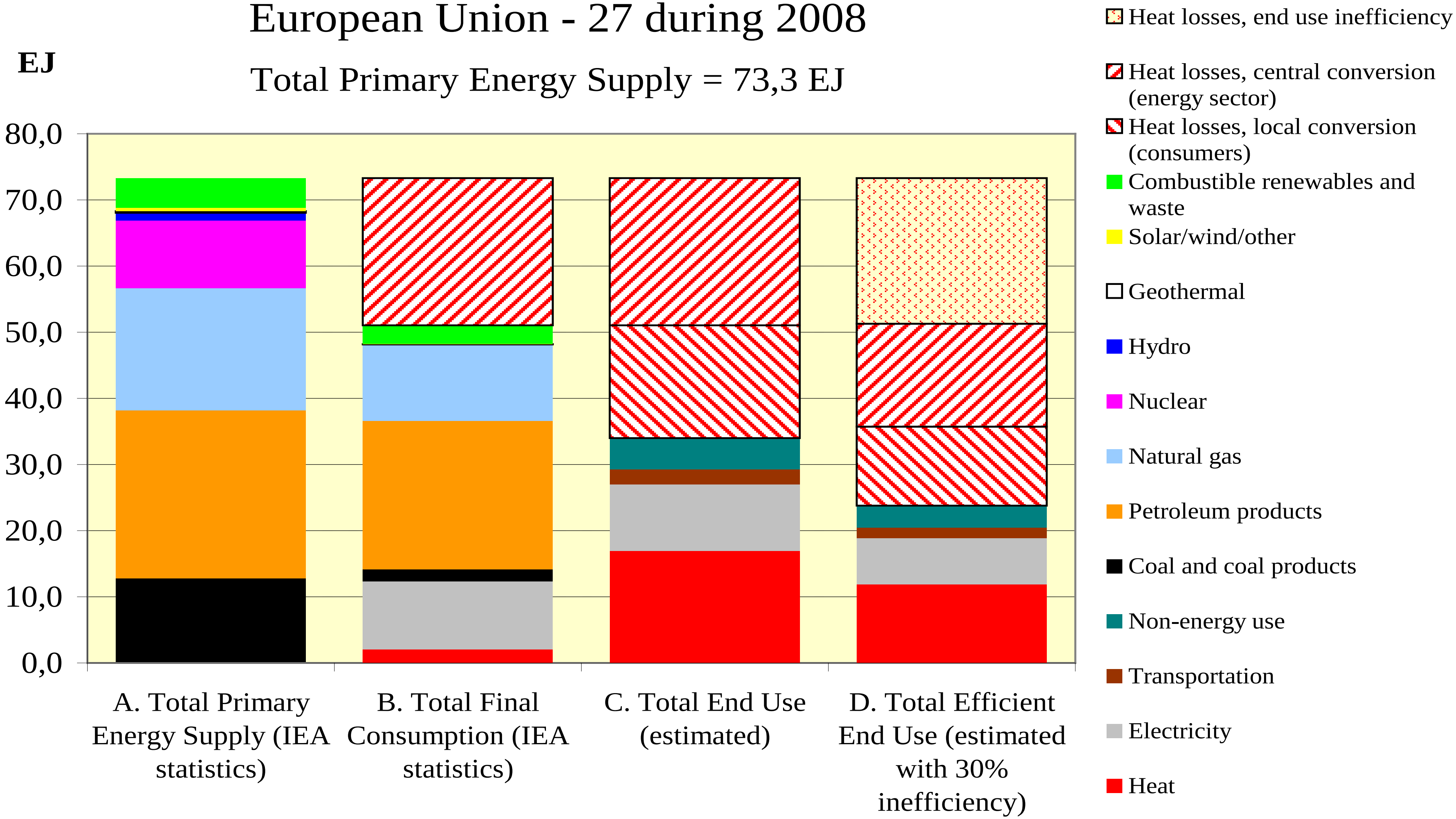
European Union - 27 during 2008

Total Primary Energy Supply = 73,3 EJ

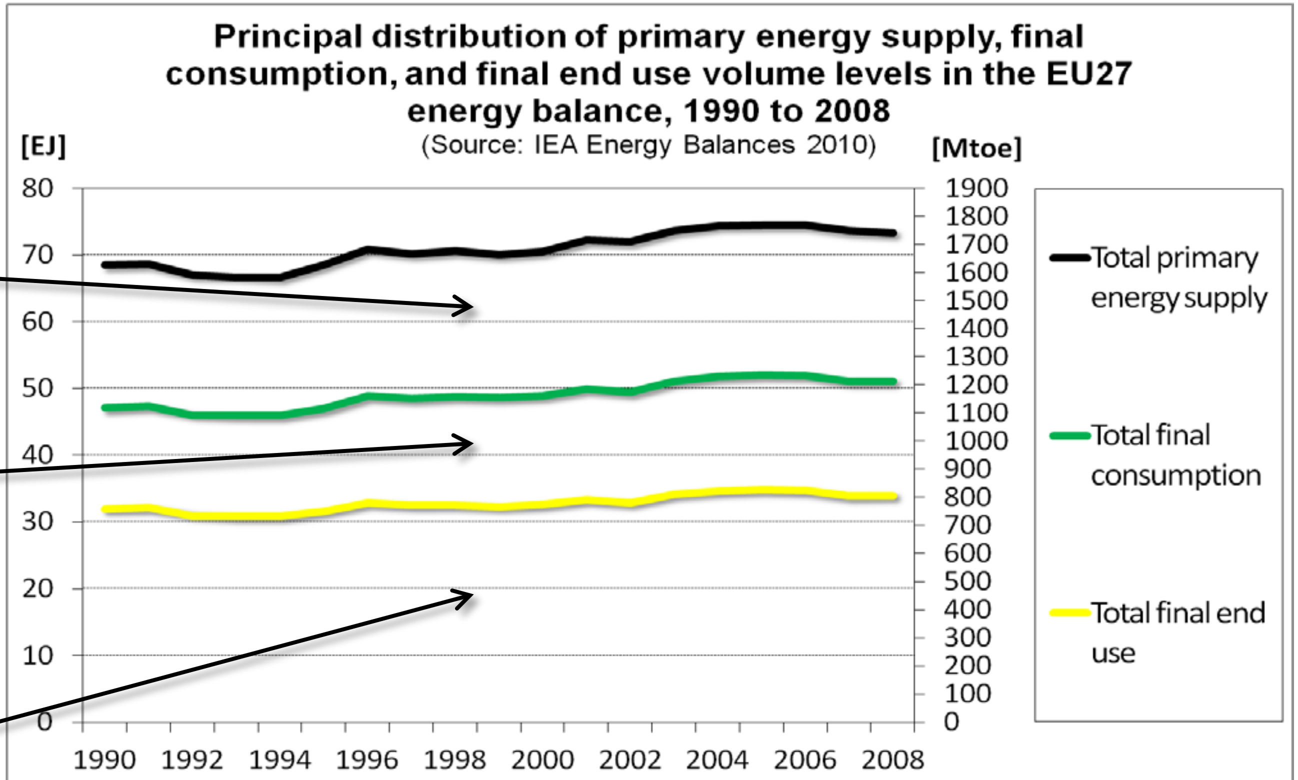


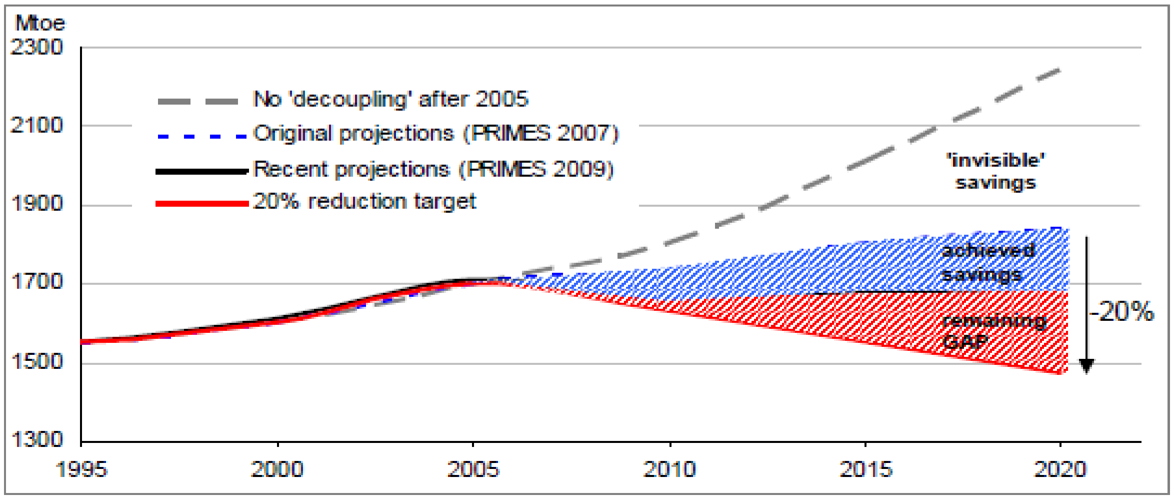
Source: Sven Werner data assembly: IEA, Energy Balances for OECD and non-OECD countires. 2010 editions, Paris 2010.

Central conversion processes

Local conversion processes

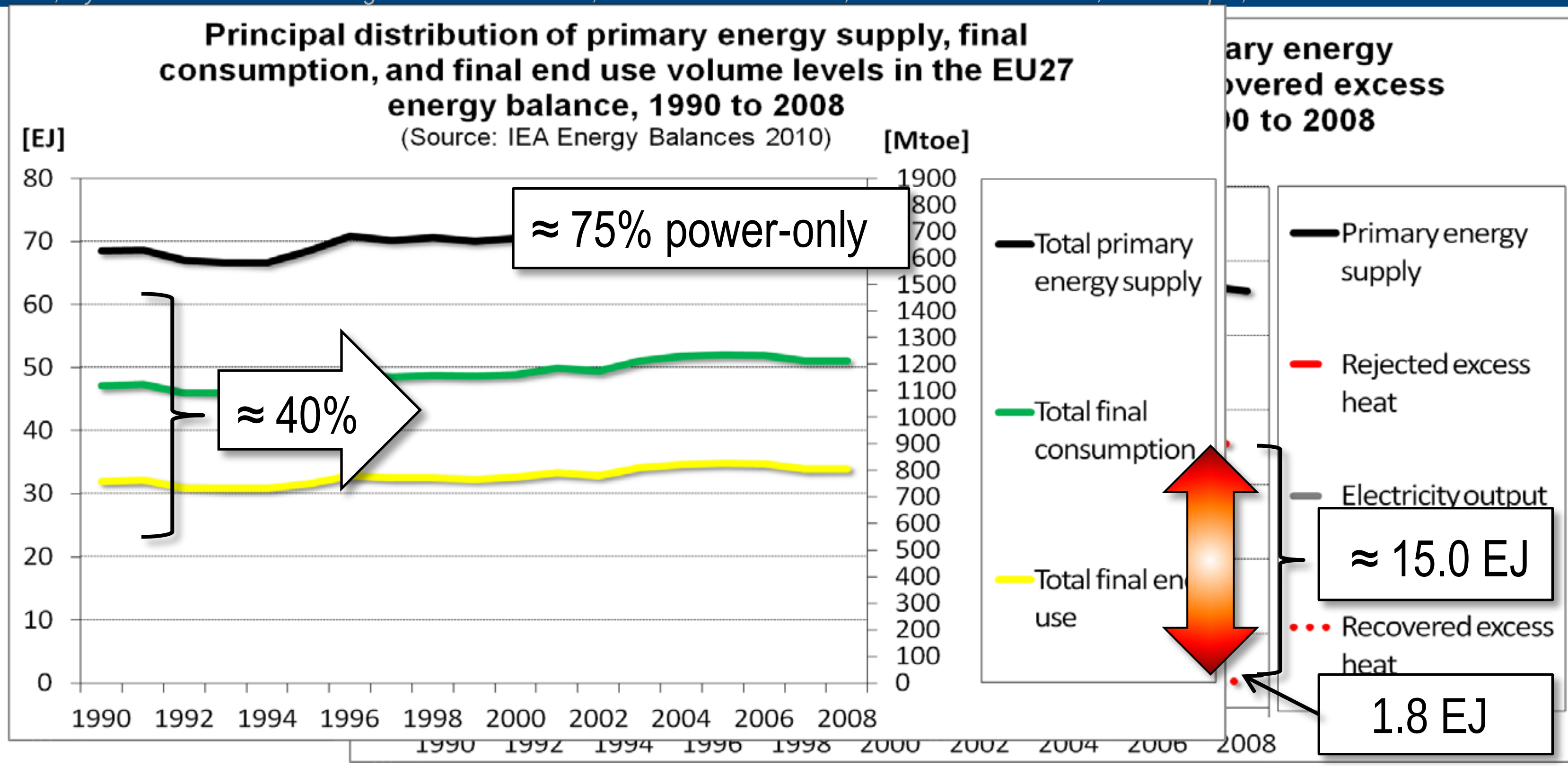
Final end use





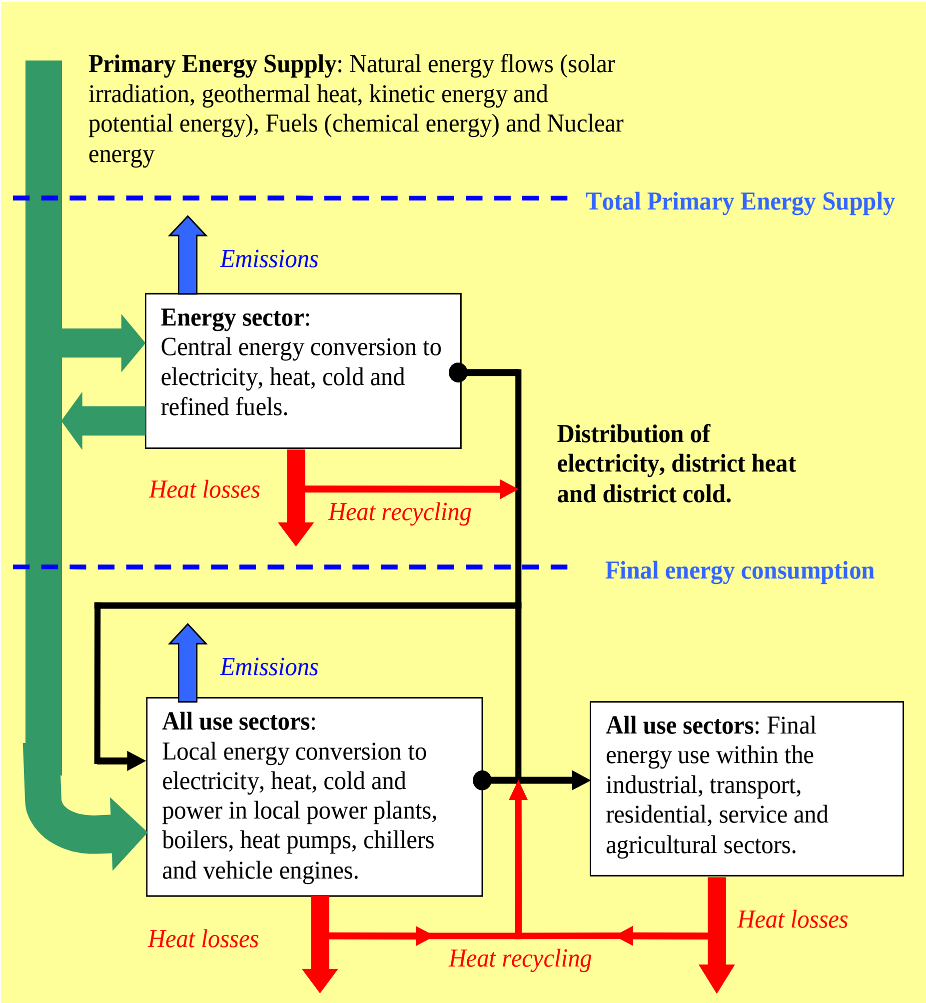
≈ 8.5 EJ (204 Mtoe)

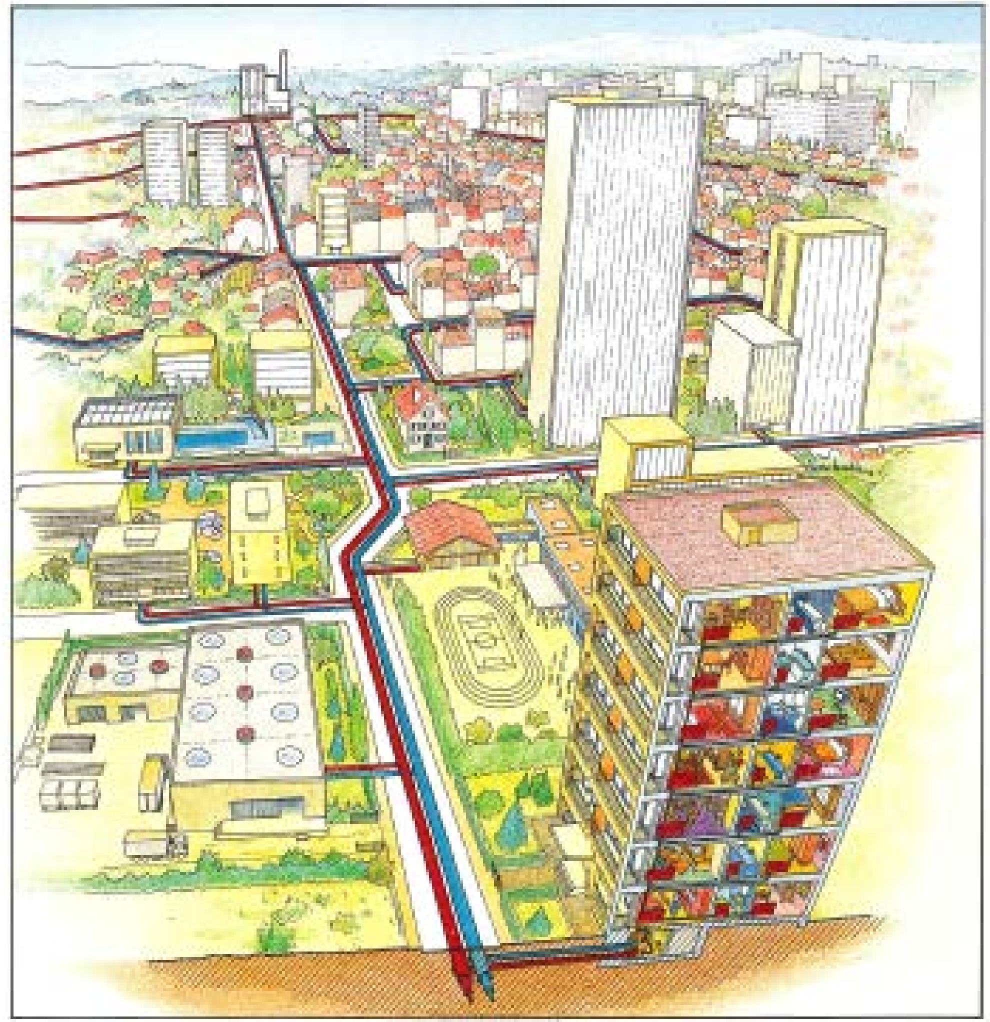
Development and projection of primary energy use for EU27 by 2020.



- Higher shares of cogeneration in TPG and Industry
- Additional electricity generation – substituting high carbon power
- Utilisation of local renewable heat sources – reducing import dependency
- Low exergy heat and energy sources for low temperature heat demands
- Sequential energy supply – a more efficient heat supply

- Sequential energy supply – a more efficient heat supply





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

- Serial utilisation of excess heat resources, implies the existence of heat distribution networks!

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Presentation outline

- Background
- District heating and cooling systems
  - District heating and cooling in Europe today
  - Basic economy of heat and cold distribution
- Heat and cold demands
  - Population and heat demand density
  - Land use data categories
- Excess heat recovery
  - Theory and concepts of excess heat recovery and utilisation
- Local heat resources
  - Excess heat activities
  - Renewable heat sources
- Spatial mapping
  - Geographic Information System (GIS)
  - Identifying excess heat hot spots
- Conclusions

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Background

- 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

- 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 May 2013
  - Methodological approach:
    - Traditional energy system modelling
    - Mapping of local conditions

  - Documented in one paper:
    - *Mapping Local European Heat Resources - a Spatial Approach to Identify Favourable Synergy Regions for District Heating (2012)*

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Currently,
district heating represents only 12% of the total EU27 residential and service sector heat market

In future Europe,
where and to what extent can district heating expand in order to harvest the benefits of a more efficient heat supply?

To answer this question,
what are basic parameters and conditions, barriers and driving forces, that influences and determines the cost effectiveness of network heat distribution?

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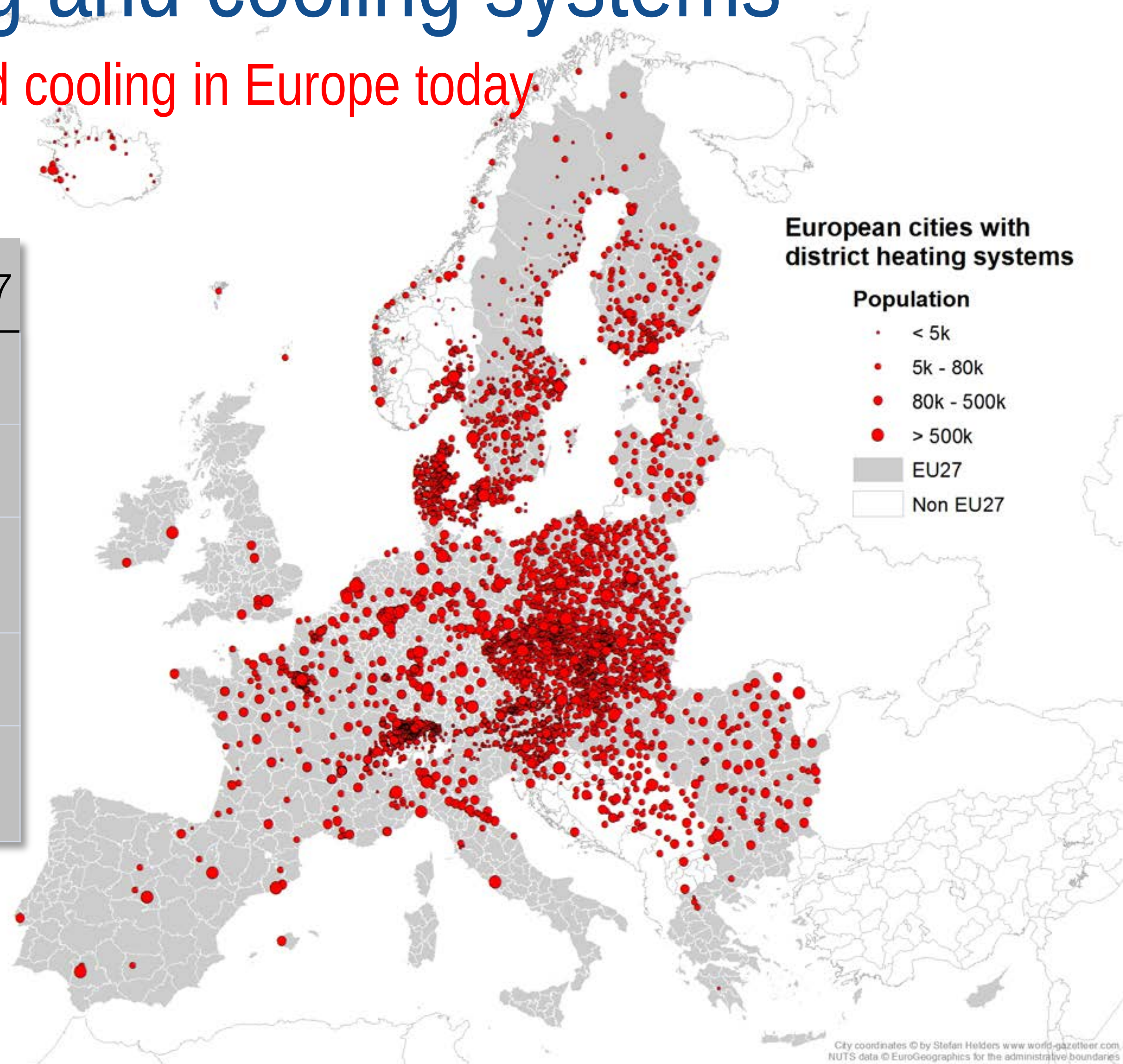
District heating and cooling systems

- District heating and cooling in Europe today

Parameter	*DH*	*DH EU27*
Nr. of countries with systems	*38*	*25*
No. 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.

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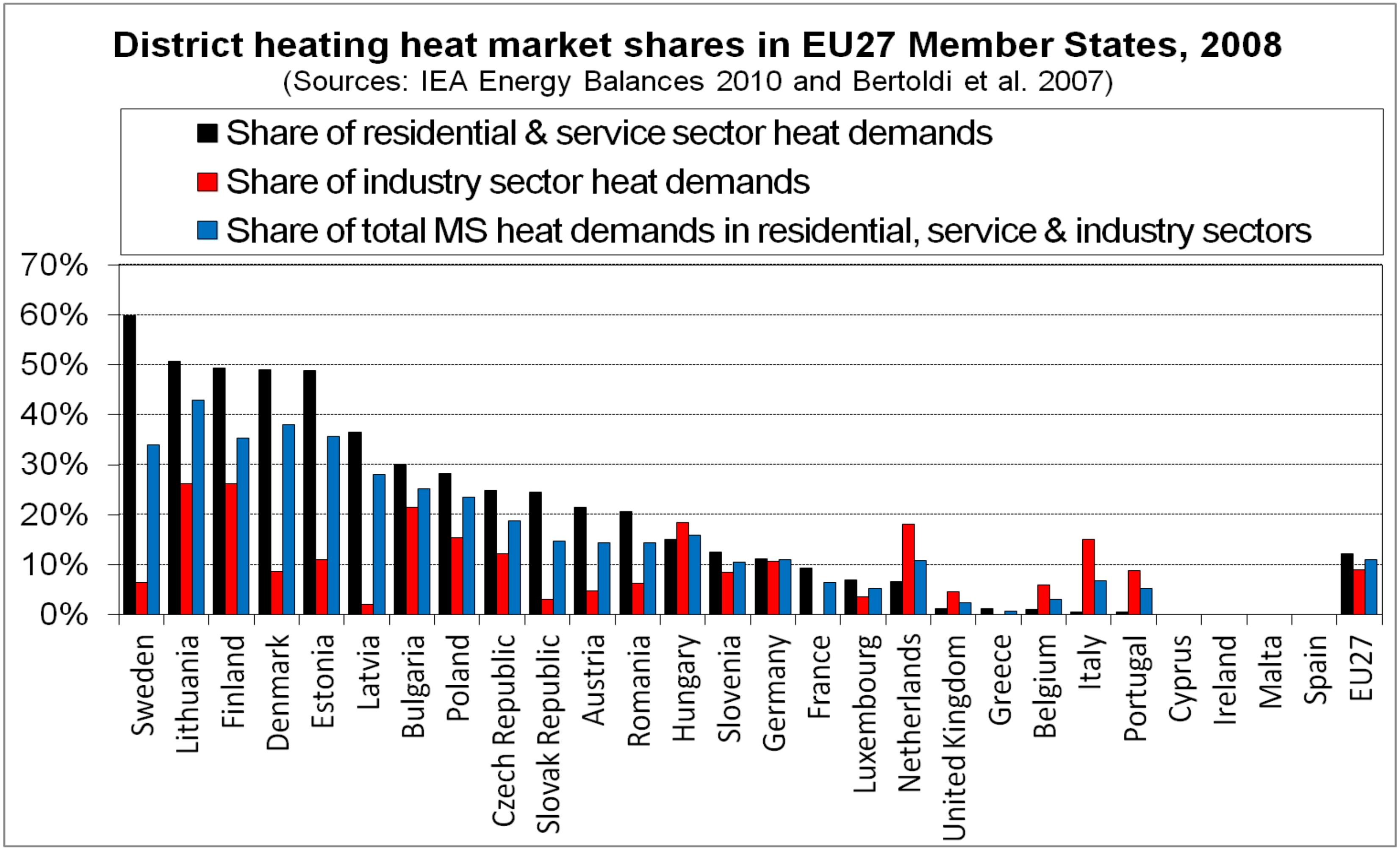
District heating and cooling systems

- District heating and cooling in Europe today

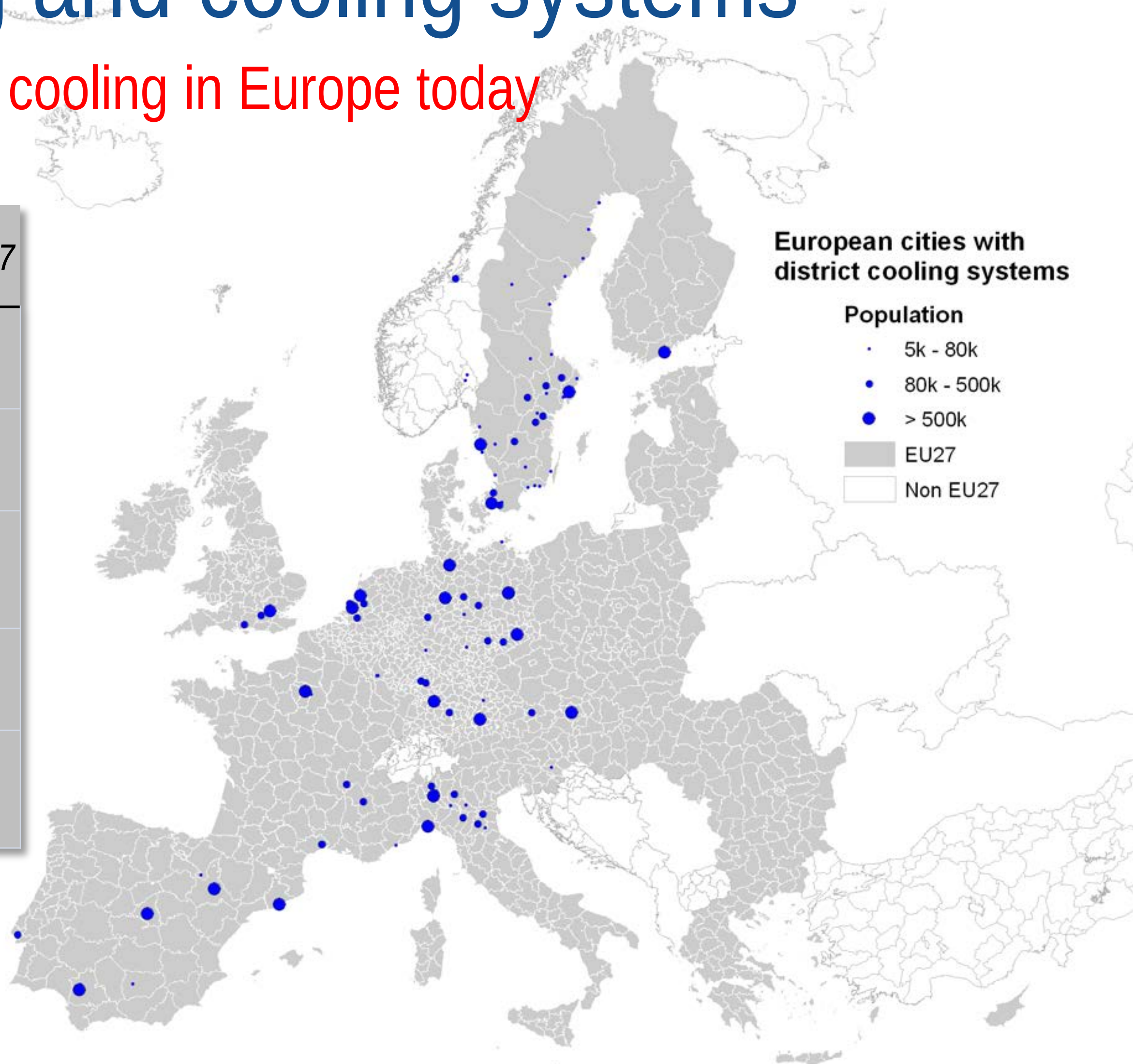


Source: U. Persson, 2011. Realise the Potential! Cost Effective and Energy Efficient District Heating in European Urban Areas. Licentiate Thesis. Chalmers University of Technology.

District heating and cooling systems

- District heating and cooling in Europe today

Parameter	DC	DC EU27
Number of countries with systems	14	13
No. 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



Halmstad University District Heating and Cooling Database (HUDHC).
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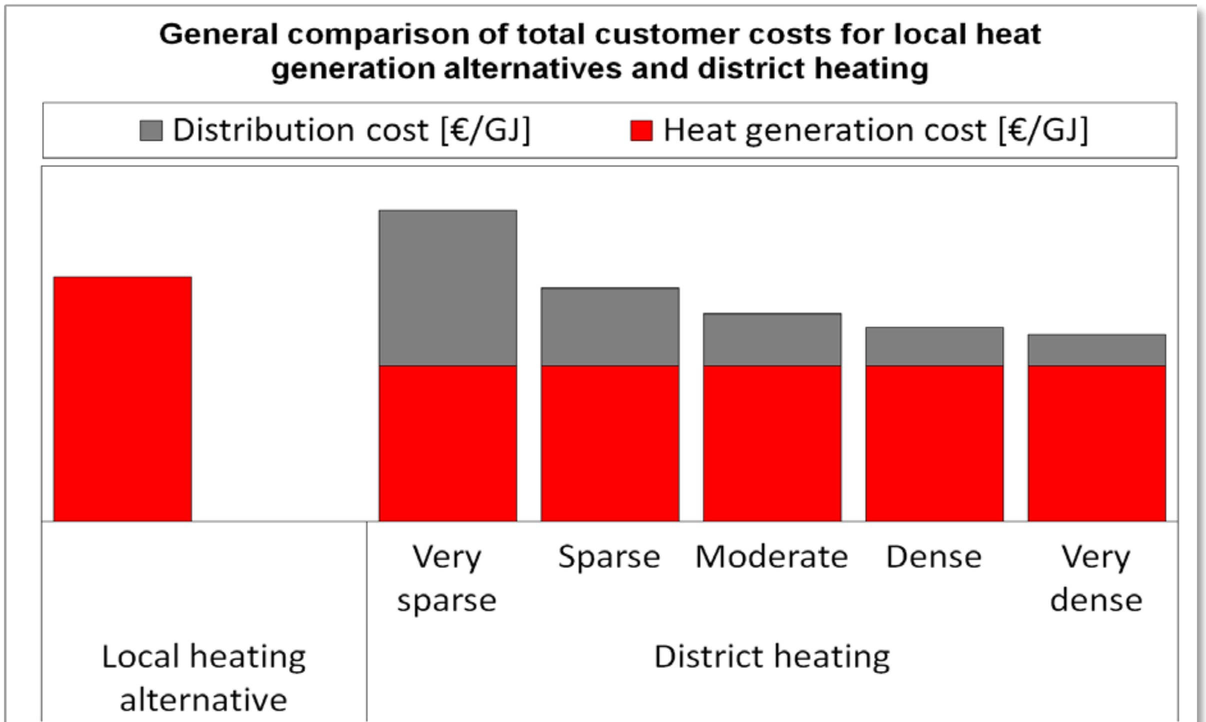
"The main additional cost for a district heating system compared to a local heat generation alternative is the unavoidable cost of heat distribution"

District heating and cooling systems

- Basic economy of heat and cold distribution



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]*

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- 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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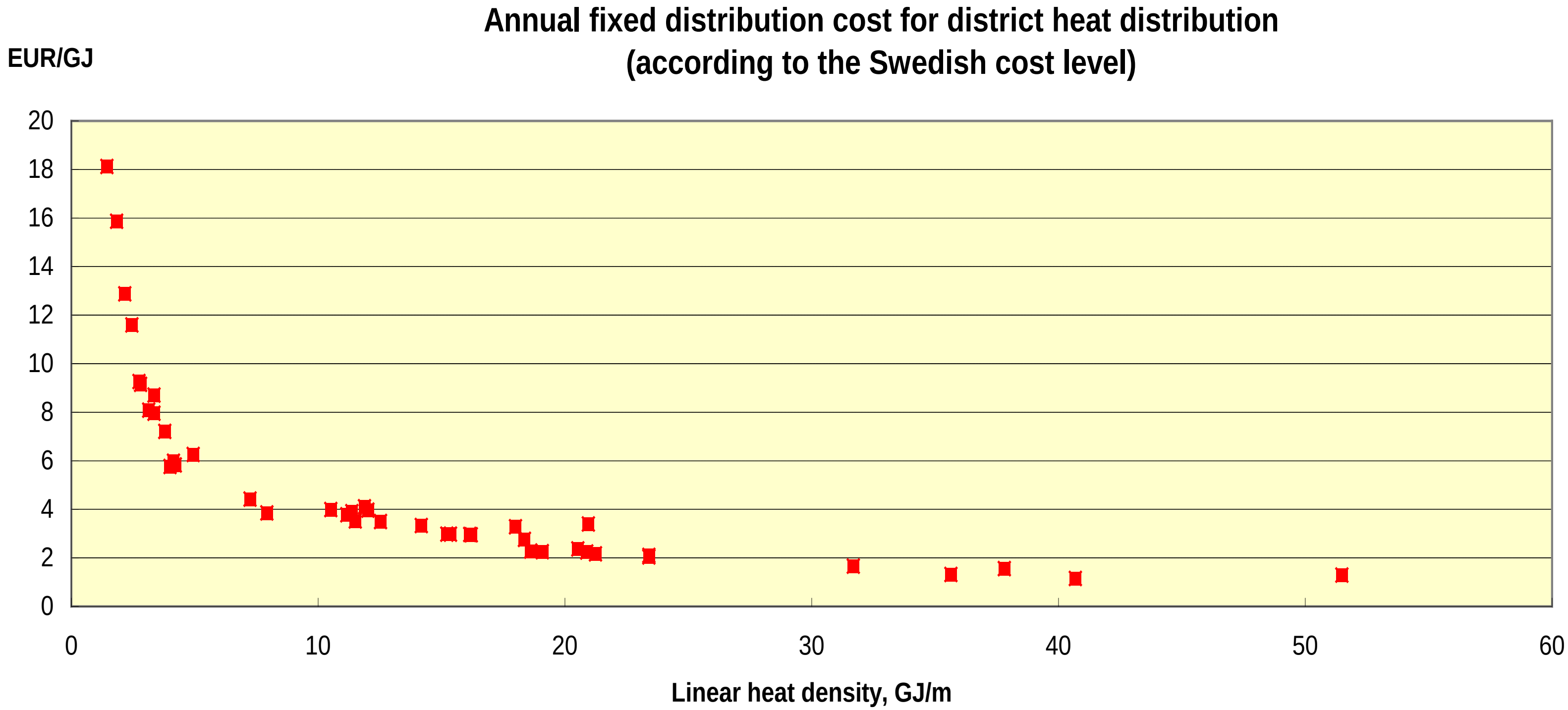
District heating and cooling systems

- Basic economy of heat and cold distribution
- Linear heat density - traditionally established on the basis of empirical evidence (C_d, Q and L).



- How to estimate linear heat densities before district heating is established in a city district?

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District heating and cooling systems

- Basic economy of heat and cold distribution

- 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 !

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

District heating and cooling systems

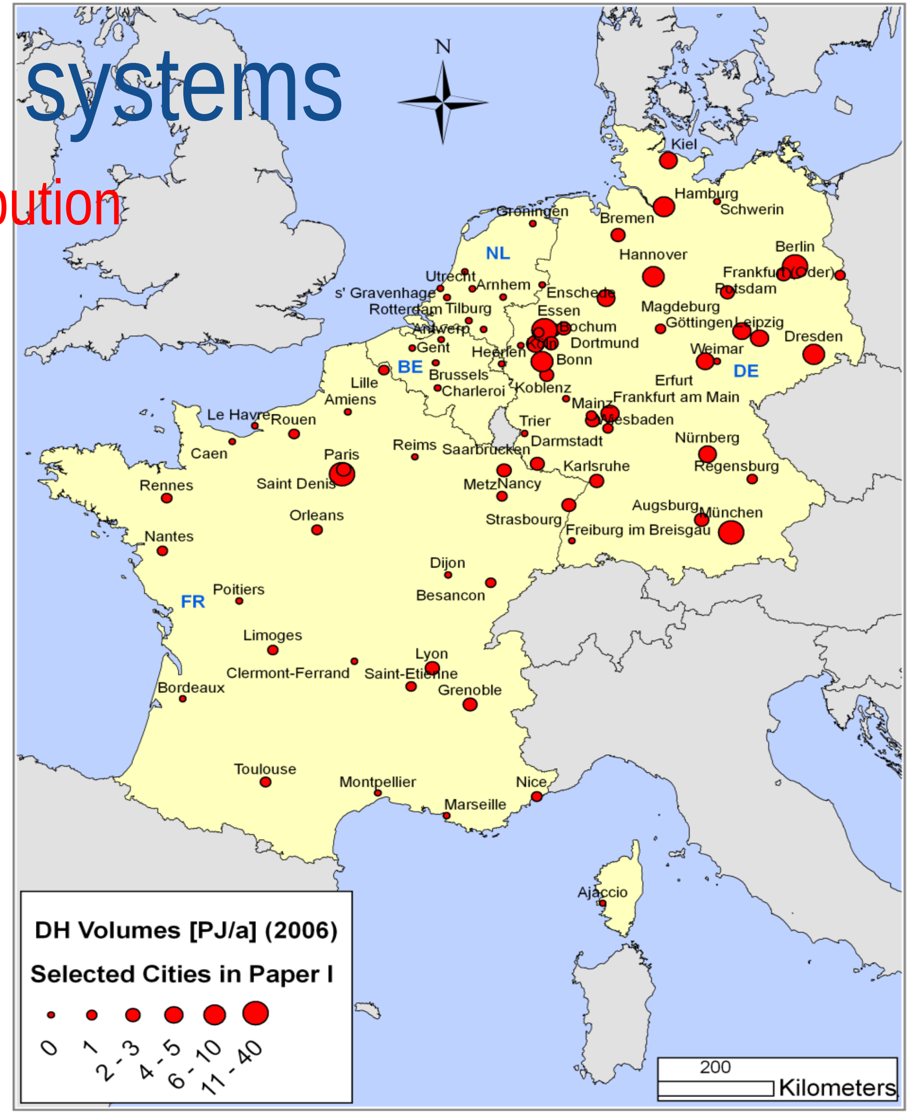
- Basic economy of heat and cold distribution

- Application of theory:
- Study objects:
  - 83 cities
  - 1703 city districts
  - Av. DH heat market share: 21%
  - Four countries: France (11%), Belgium (0%), Germany (29%), the Netherlands 21%)

- Population coverage: 21 % (35 of 170)

- Av. spec. heat demand; 0.5 GJ/m^{2}a

- Av. building space; 49 - 56 m^2/capita
- Av. Res. building space; 35 – 40 m^2/capita



Annual district heat deliveries in 83 studied cities

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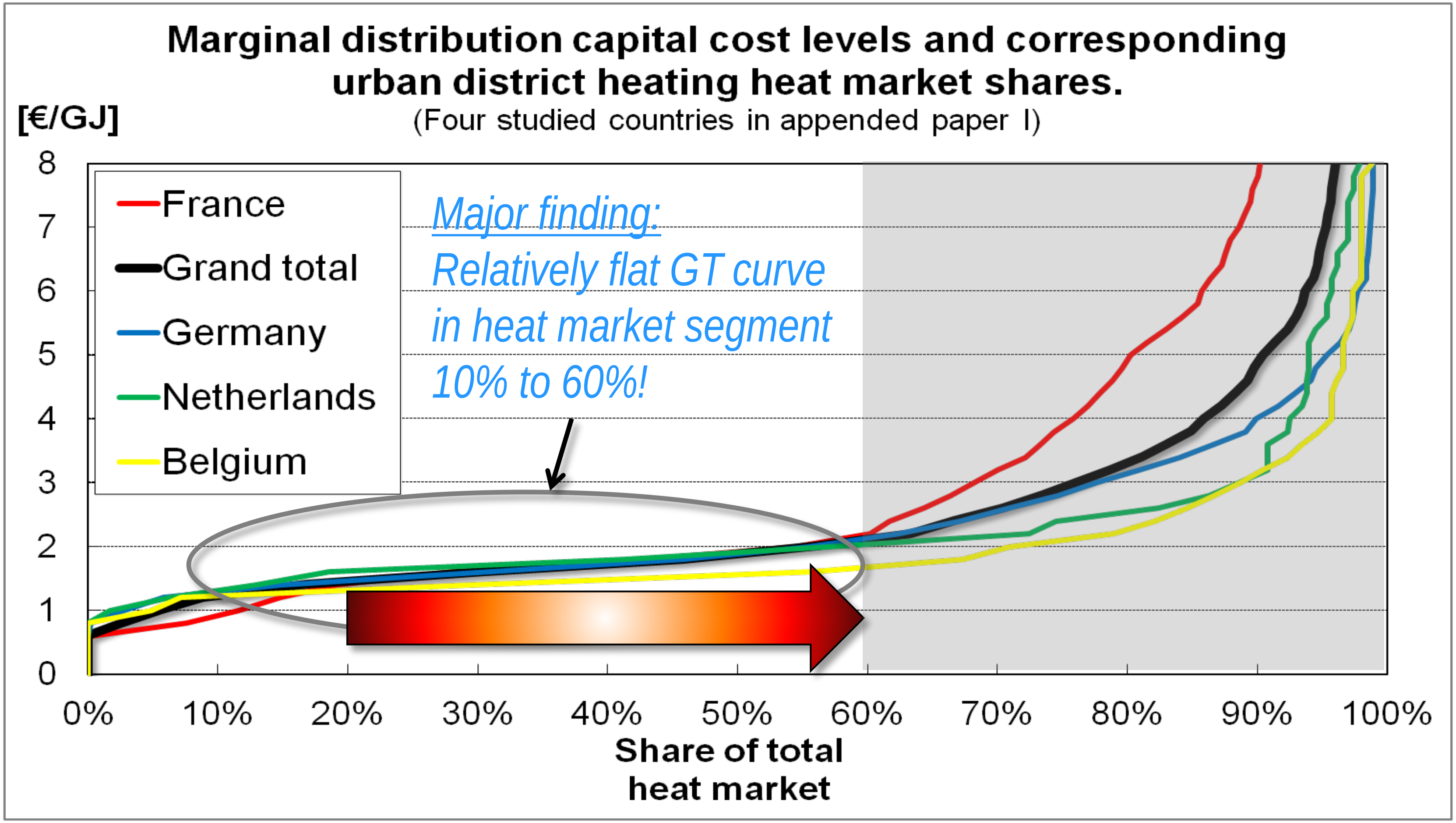
Source: U. Persson & S. Werner, 2011. Heat Distribution and The Future Competitiveness of District Heating. Applied Energy 88 (2011) 568–576

District heating and cooling systems

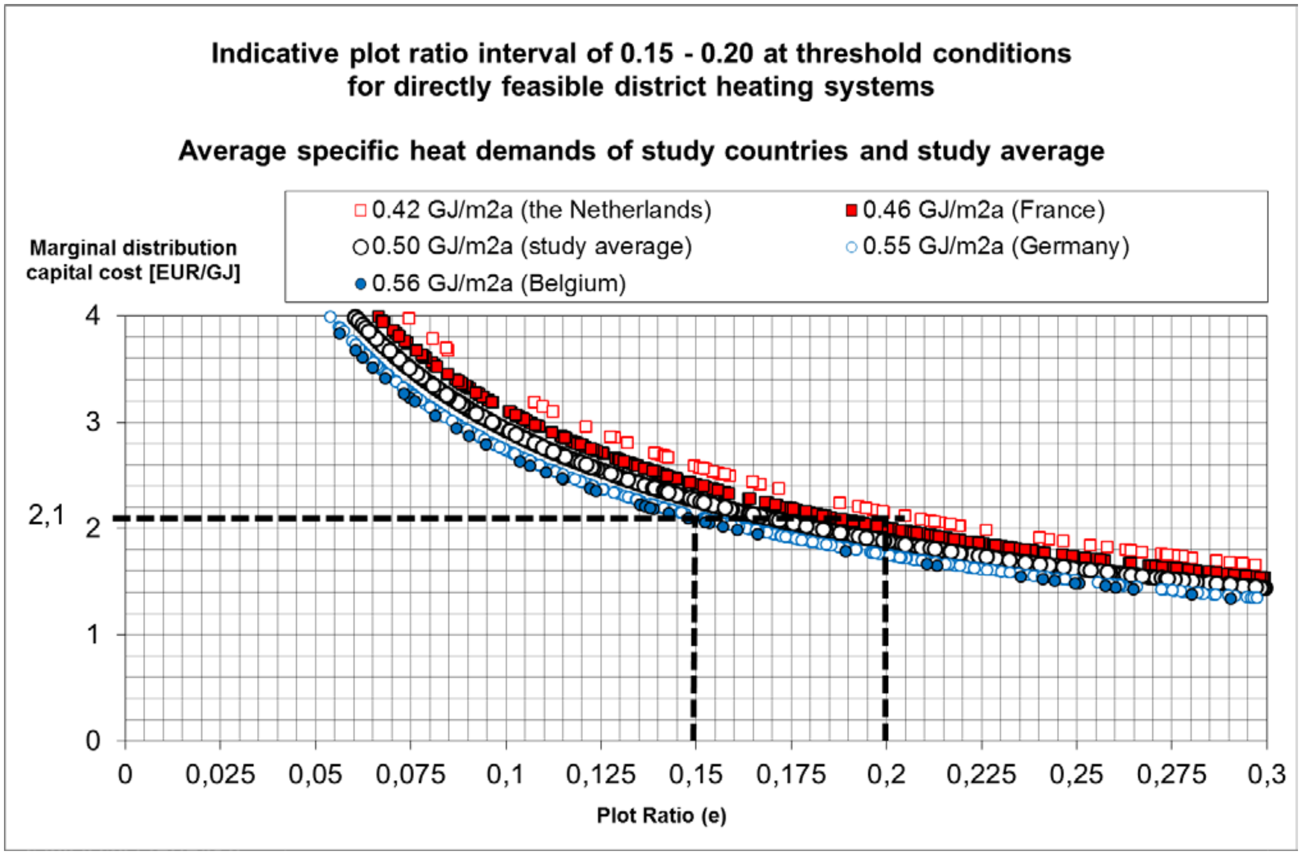
- Basic economy of heat and cold distribution



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

District heating and cooling systems

- Basic economy of heat and cold distribution
- Indicative Plot Ratio Threshold; 0.15 – 0.20
- Corresponding Heat Density; 90 TJ/km^2 (~25 GWh/km^2)



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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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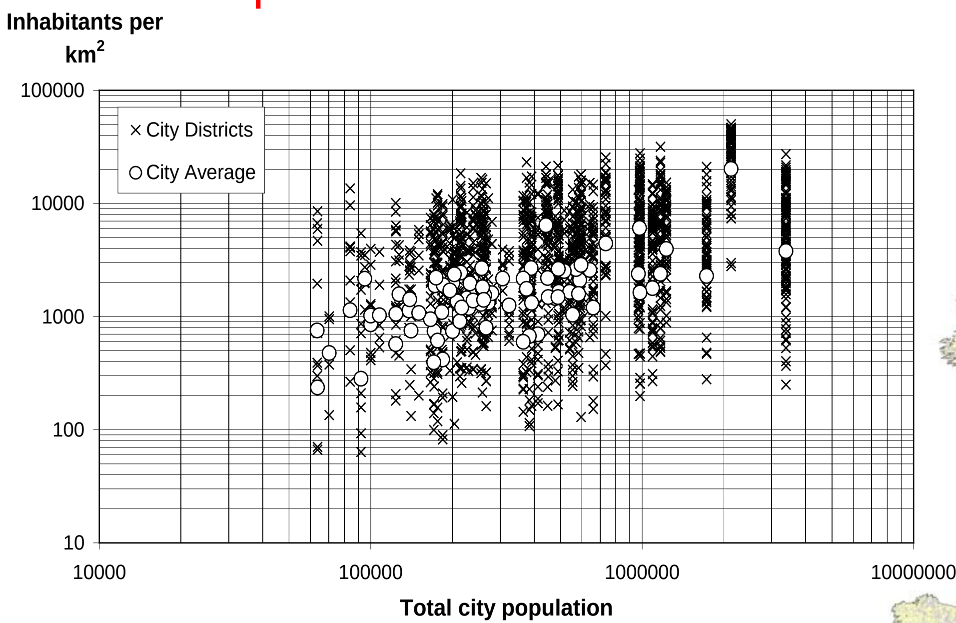
"Population statistics in themselves does not reveal where population and heat demand concentrations are located – how can feasible conditions for network heat distribution be identified in meta-planning"

Heat and cold demands

- Population and heat demand density



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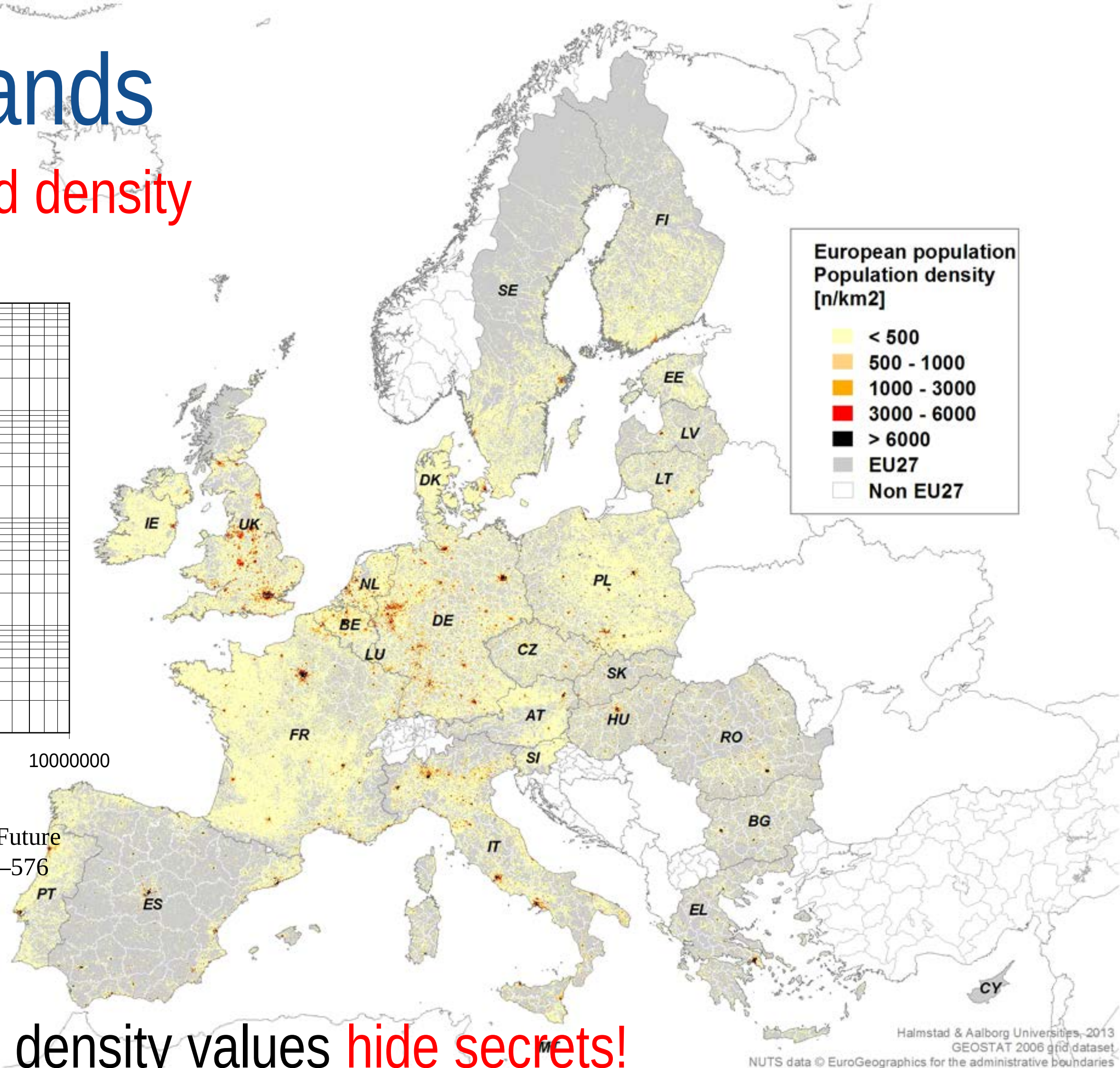

- City average population density values hide secrets!
- Competitive distribution conditions exist in high density sub-city districts – not detectable in city average values!

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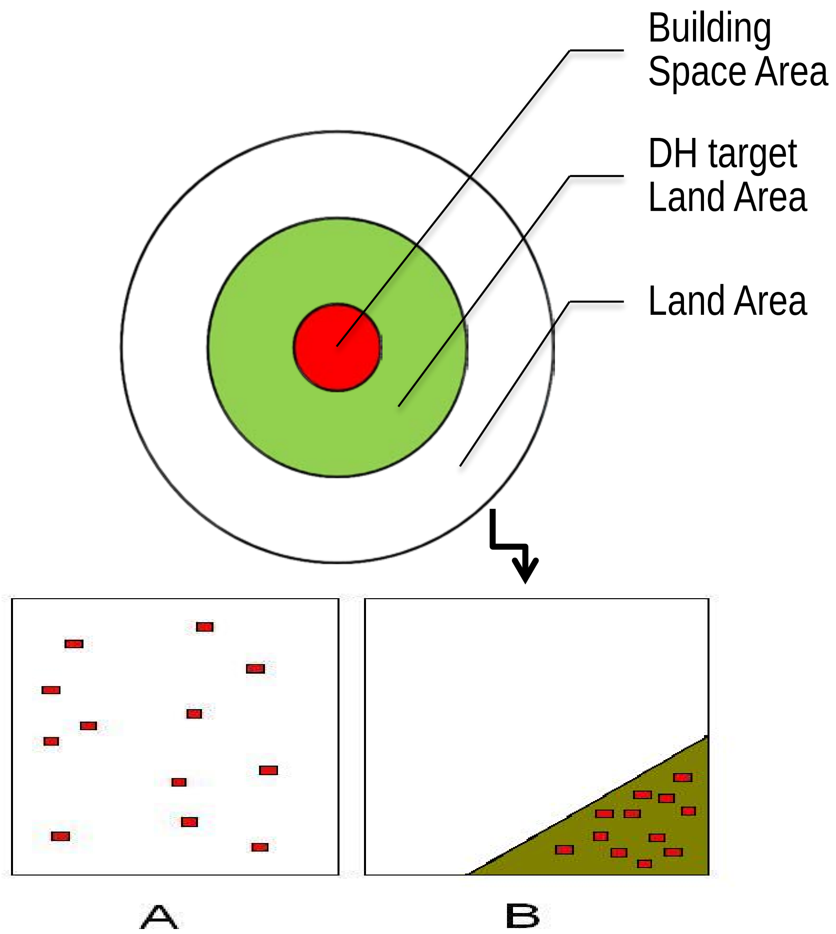
Heat and cold demands

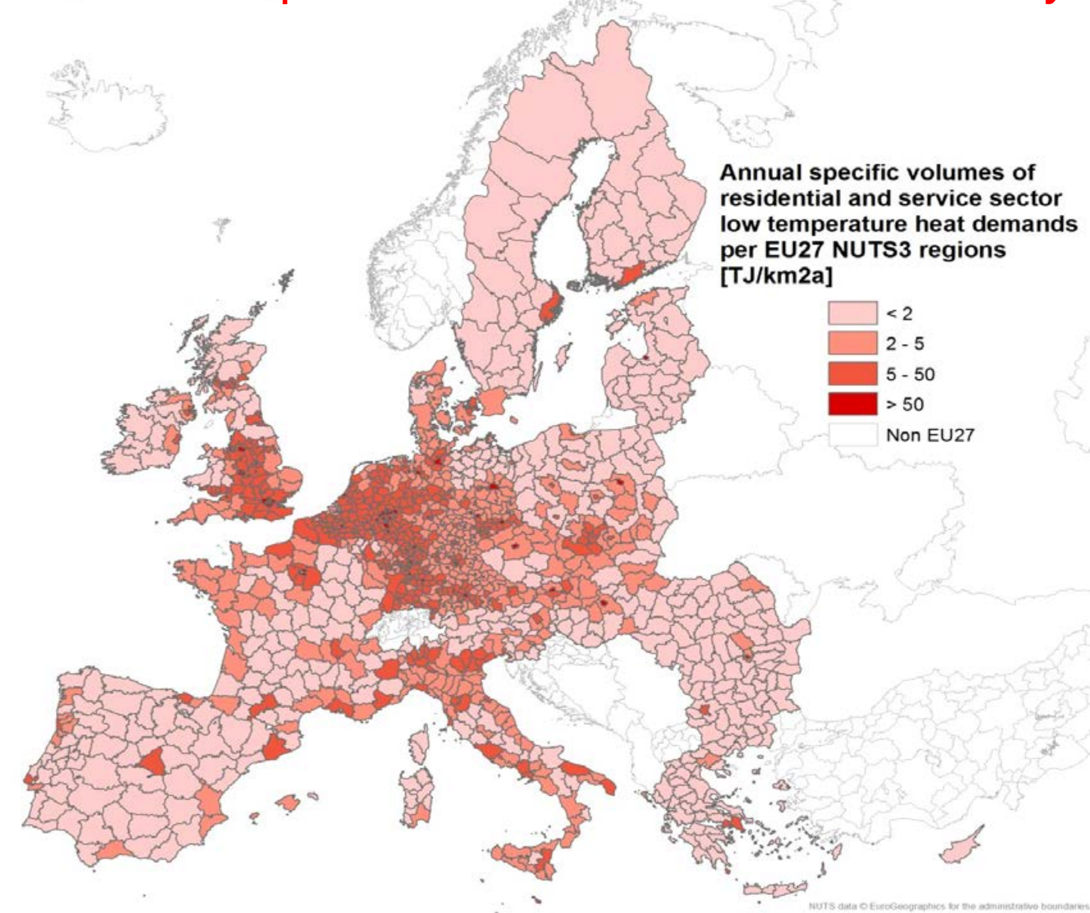
- Population and heat demand density
- Park area settlements (A) may prove unfeasible for DH expansions, due to insufficient Linear Heat Densities
- Depending on settlement structure, the Land Area may include territory not to be targeted by DH (B)
- A matter of resolution level in population data – 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

Heat and cold demands

- Population and heat demand density



	$Q_{Res\&serv}$ [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.

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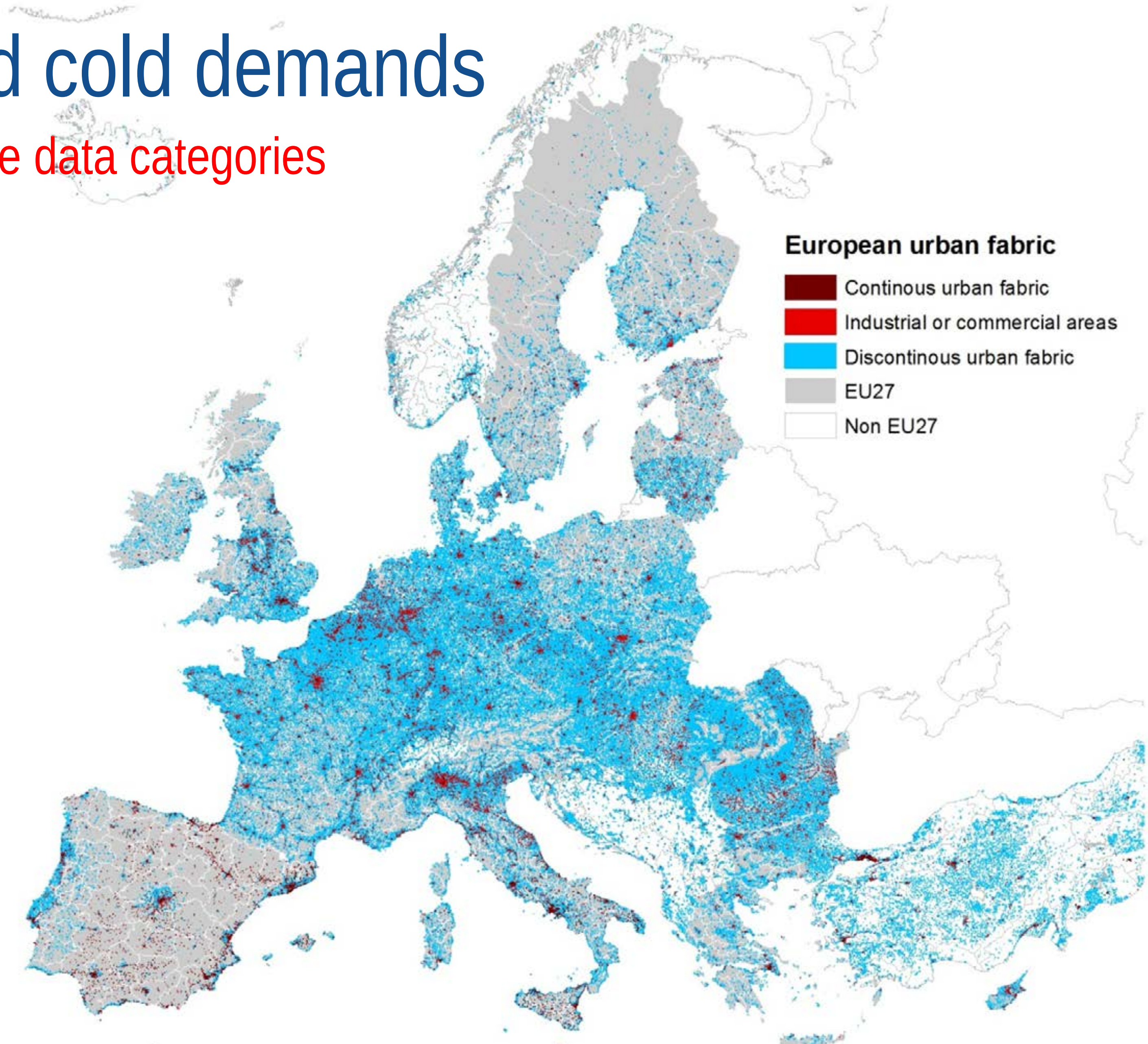
Heat and cold demands

- Land use data categories



Land use data from the CORINE 2000 Seamless vector database (EEA).

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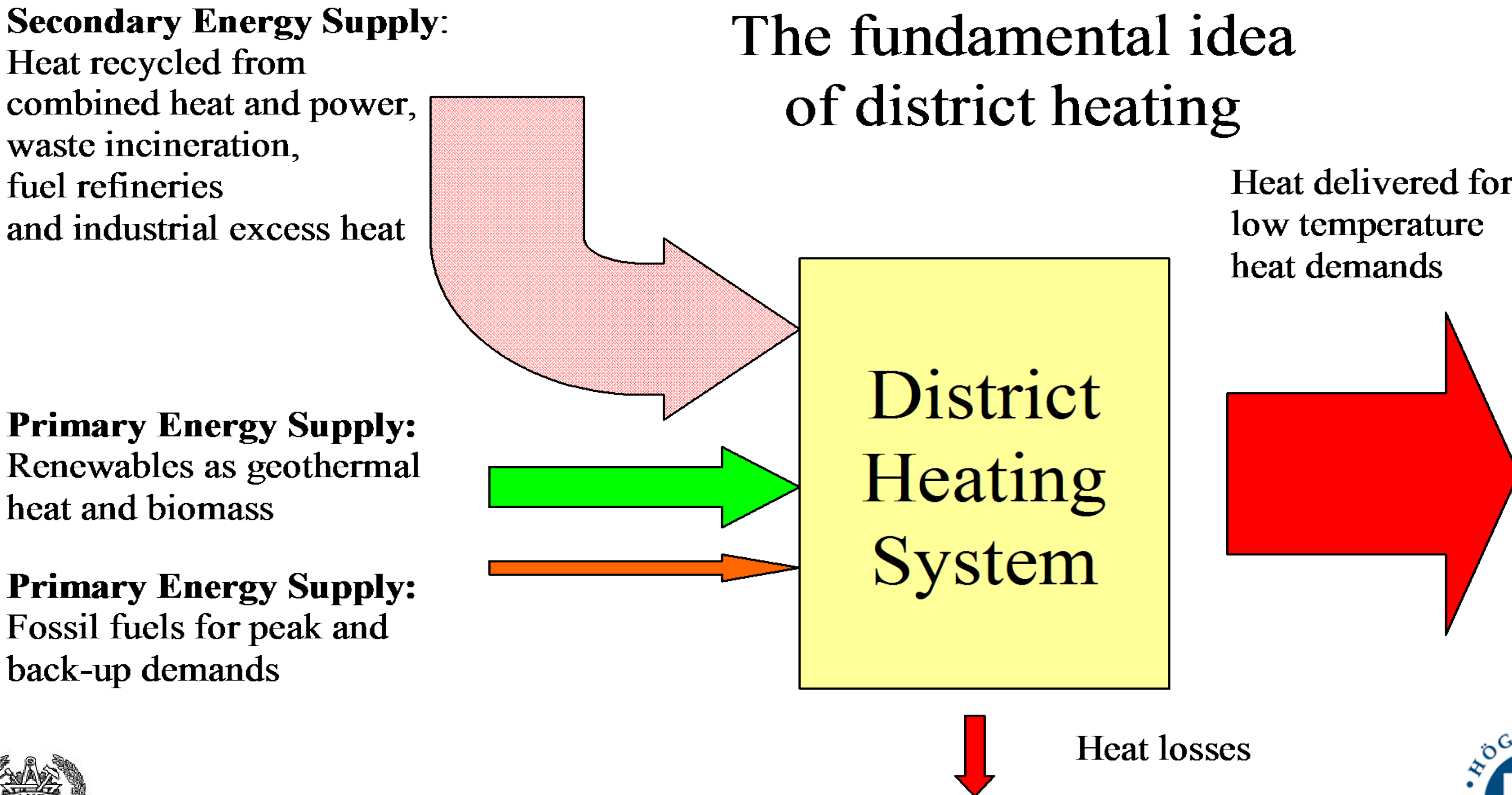
"In a sequential energy supply, excess heat recovery downstream primary energy conversions… reduces total primary energy demands by utilisation of low temperature heat that would otherwise be wasted"

Excess heat recovery

- Theory and concepts of excess heat recovery and utilisation



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

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Excess heat recovery

- Theory and concepts of excess heat recovery and utilisation

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

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

Excess heat recovery

- Theory and concepts of excess heat recovery and utilisation

Thermal generation by fuel – EU27	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 generation by fuel - Denmark	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

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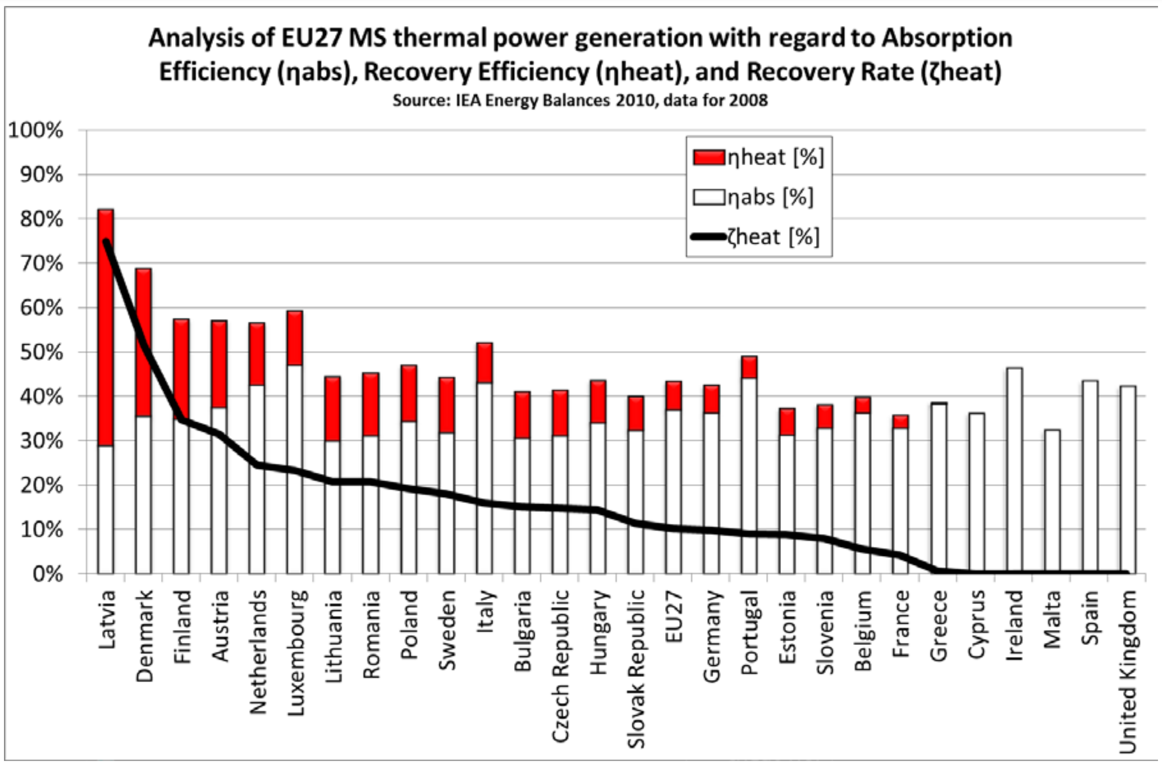
Excess heat recovery

- Theory and concepts of excess heat recovery and utilisation

Excess heat activity	*EU27* E_{prim} [EJ]	η_{heat} [%]	E_{heat} [EJ]	*Best MS* η_{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



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Excess heat recovery

- Theory and concepts of excess heat recovery and utilisation

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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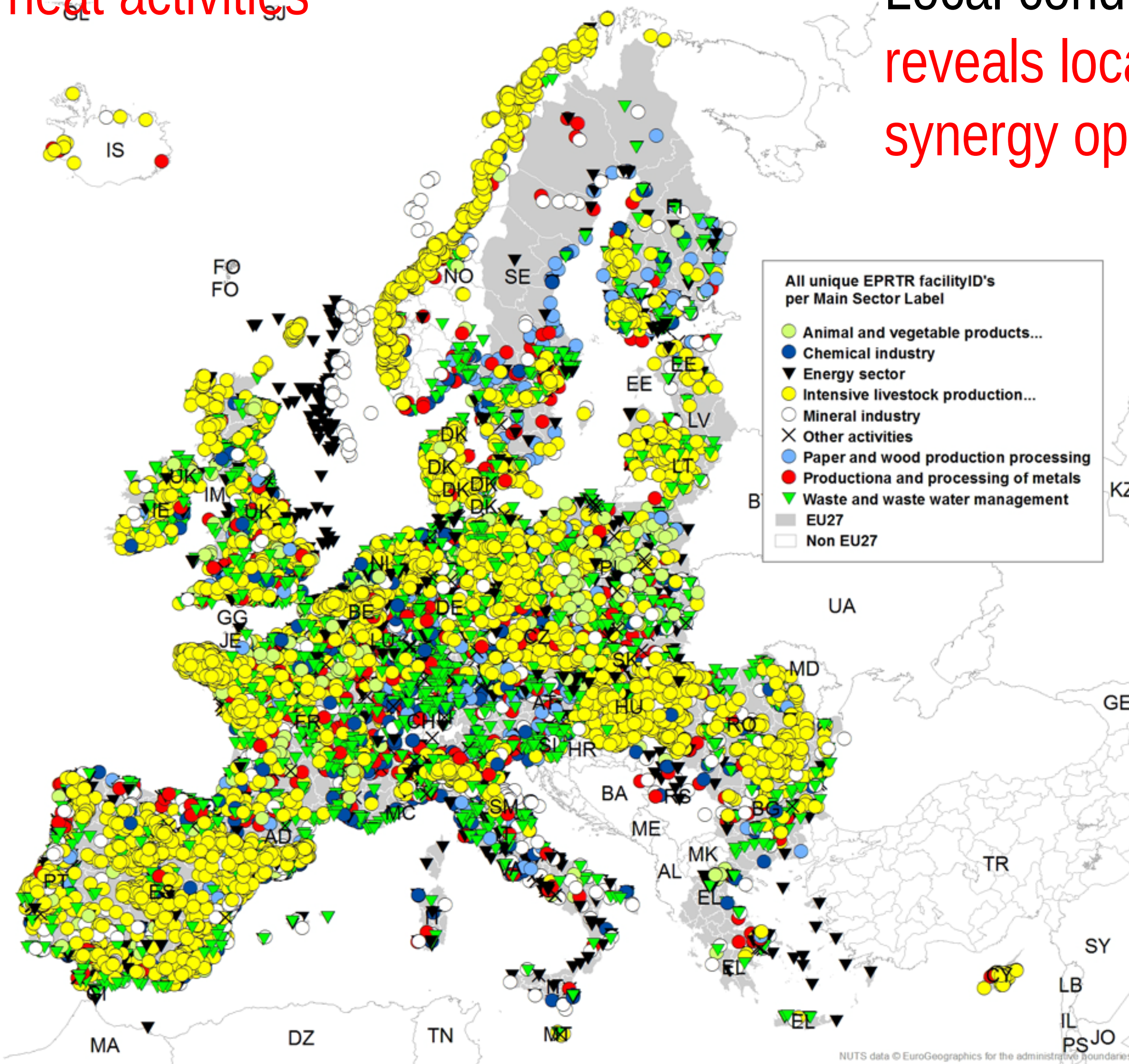
"Low temperature excess heat is a final product of many primary energy conversion processes that is poorly recognized and utilised as a resource in the industrialized world today… the fossil economy has shaped parallel supply structures, where each activity converts primary energy separately and often with only partial use of the fuel energy content"

Local heat resources

- Excess heat activities



- Main objective:
- Local condition analysis reveals local heat synergy opportunities!

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Local heat resources

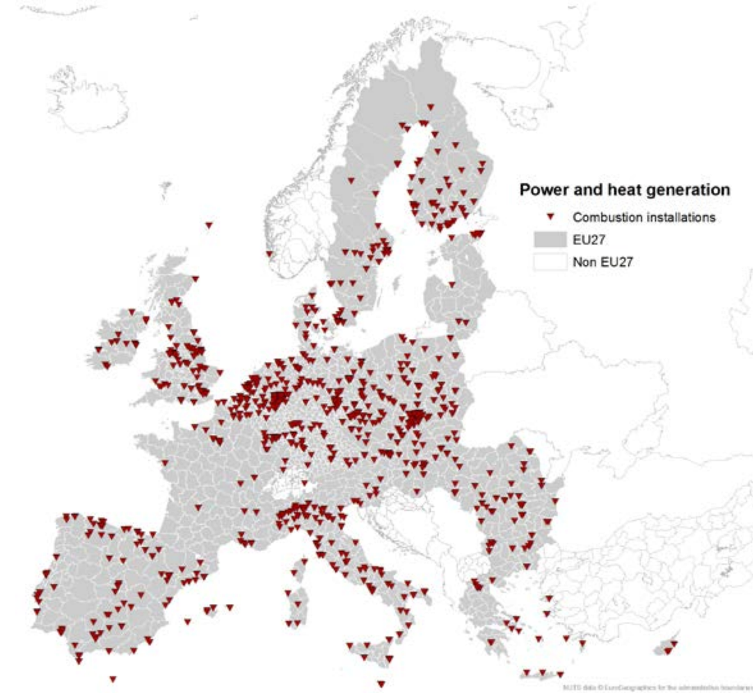
- Excess heat activities

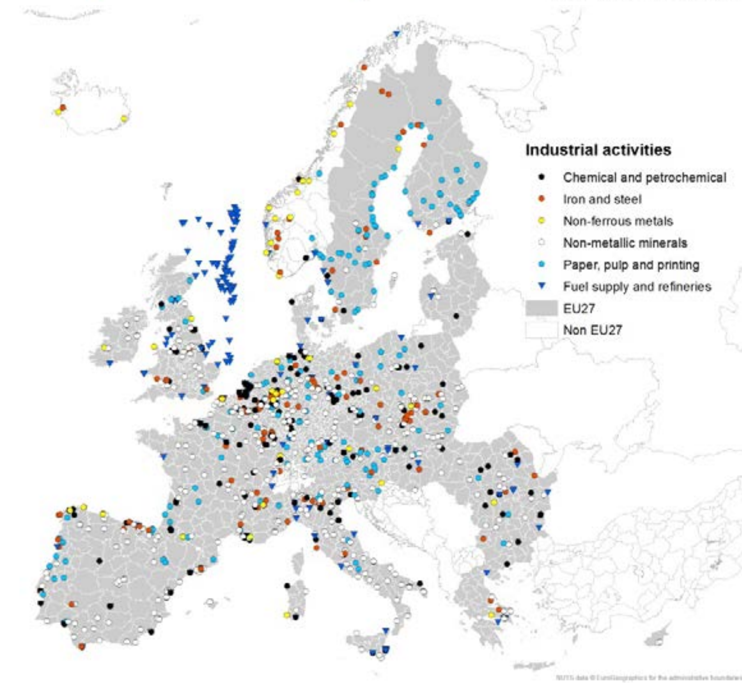
- Thermal power generation (~15 EJ/a)
  - ~1000 TPG plants > 50 MW
  - 407 Waste-to-Energy facilities

- Industrial activities (? EJ/a)
  - ~230 Chem. & petrochemical plants
  - ~140 Iron & steel works
  - ~30 Non-ferrous metal works
  - ~420 Non-metallic mineral facilities
  - ~170 Paper & pulp plants
  - ~190 fuel supply & refineries

- ~2400 European excess heat activities, given performed interpretations of data

  - Wide geographical distribution





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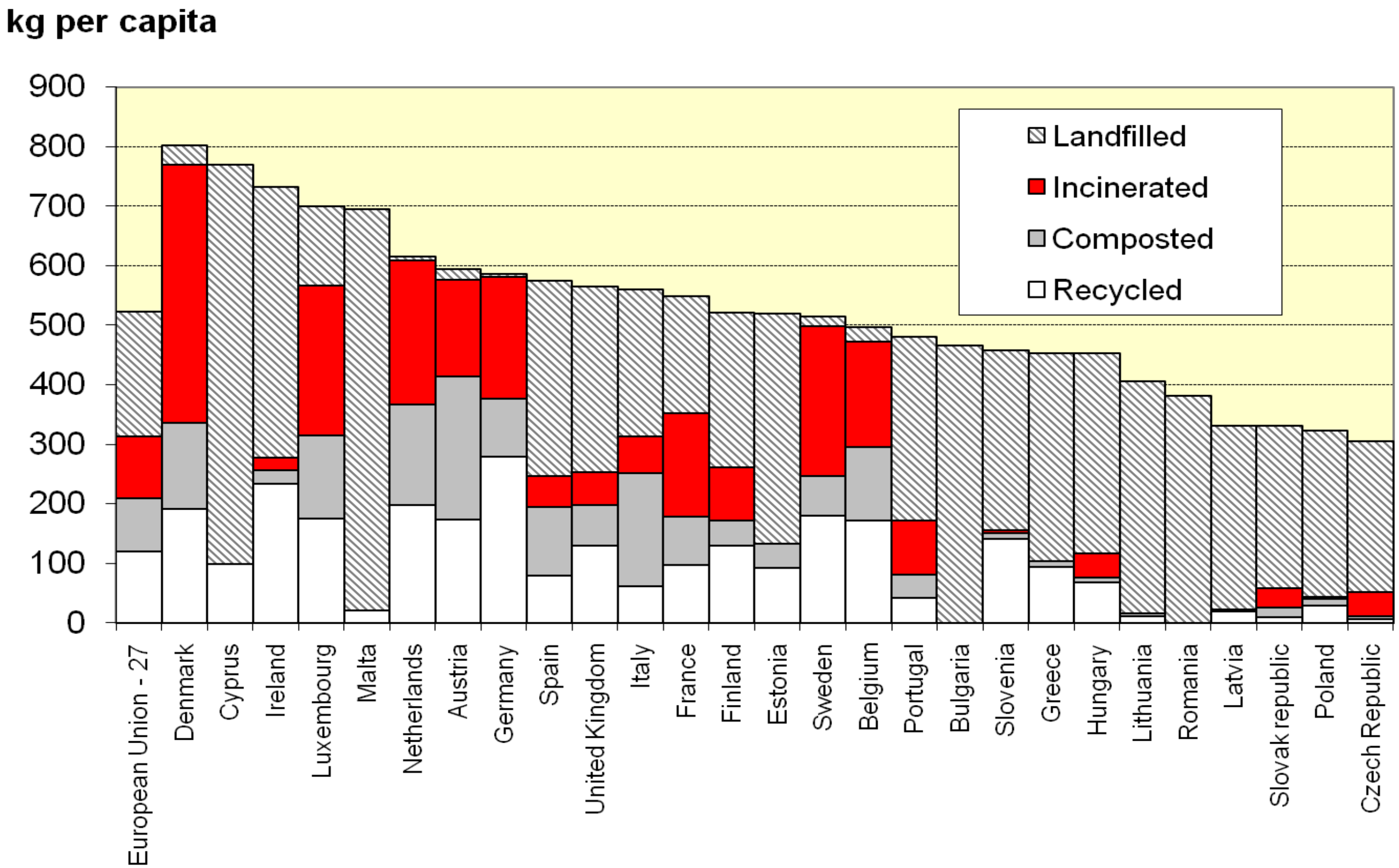
Local heat resources

- Excess heat activities



MSW management, EU27, 2008.

Persson & Werner 2012. District heating in sequential energy supply. Applied Energy 95 (2012) 123-131.

Source; Eurostat

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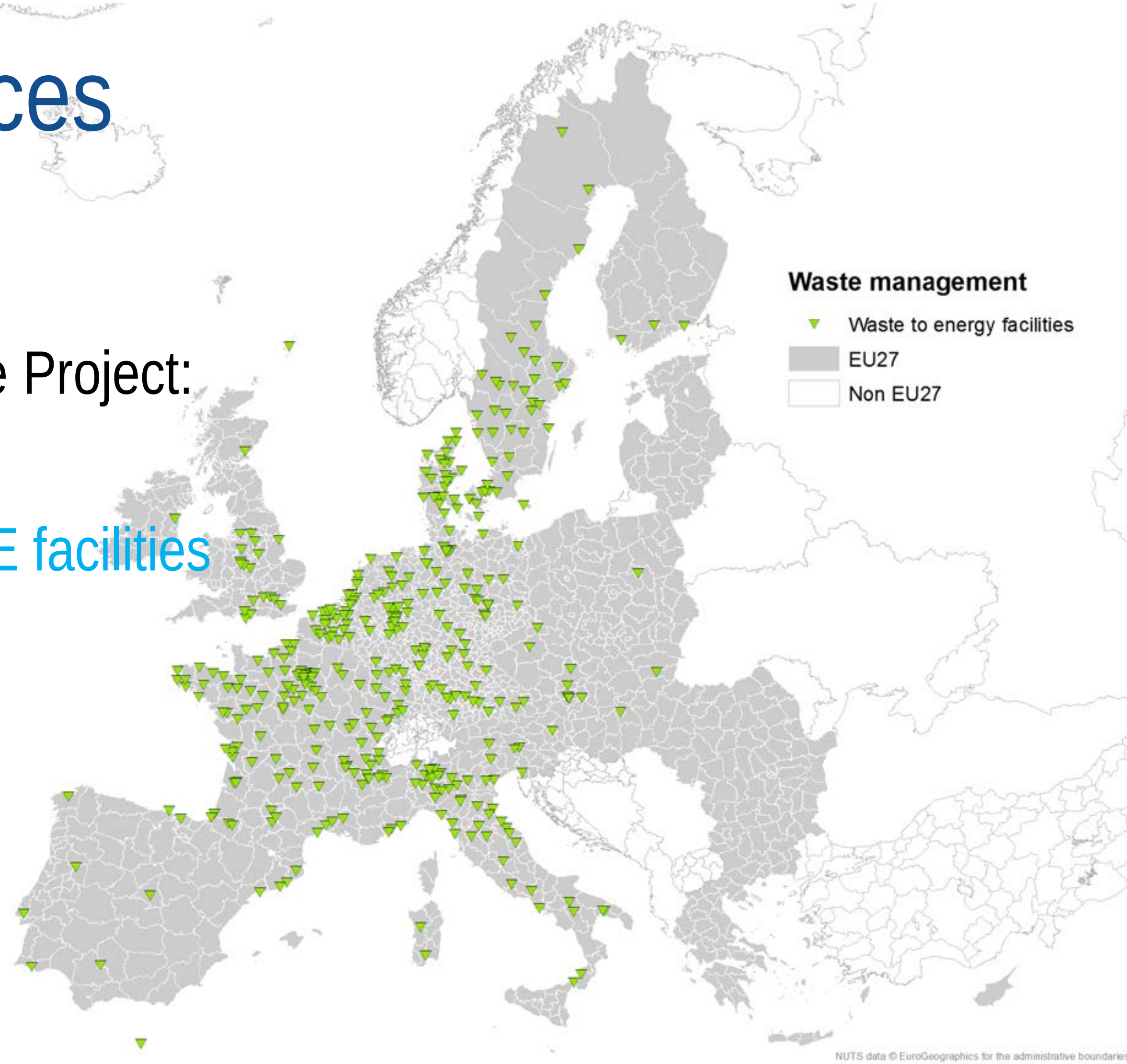
Local heat resources

- Excess heat activities
- In Heat Roadmap Europe Project:
- 407 identified EU27 W-t-E facilities
- Several data sources:
  - E-PRTR
  - ISWA
  - CEWEP
  - National registers



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Local heat resources

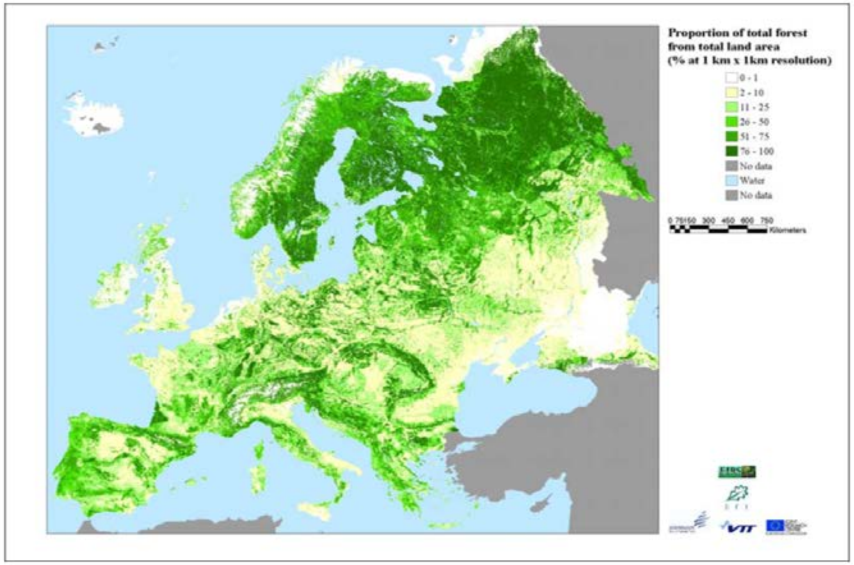
- Renewable heat sources

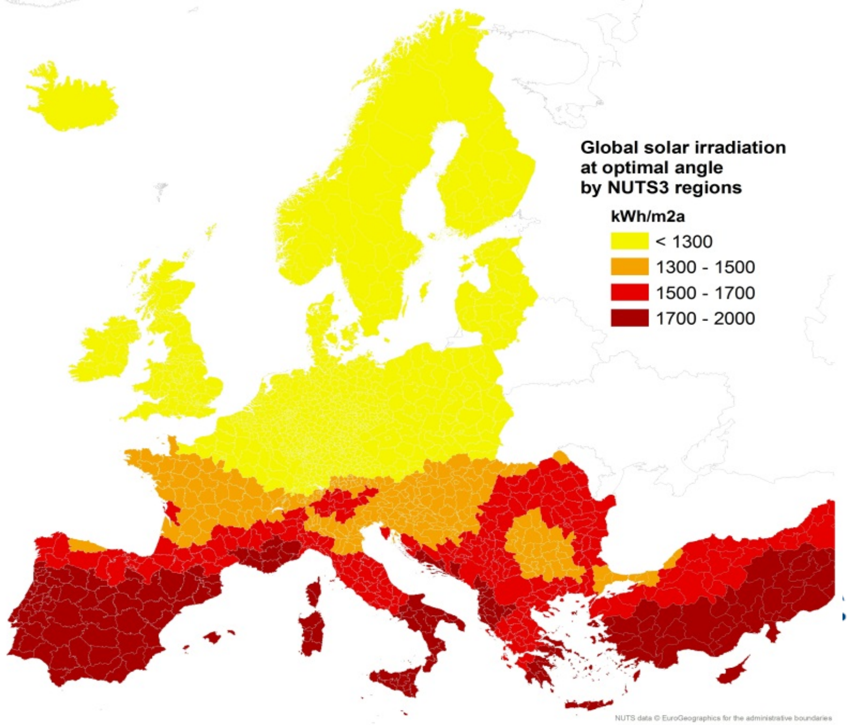
- Availability and magnitude of renewable heat streams heterogeneously spread:
  - Biomass (forestry propagation)
  - Solar (geographic location)
  - Geothermal (geology, ground composition)

- Biomass: ~240 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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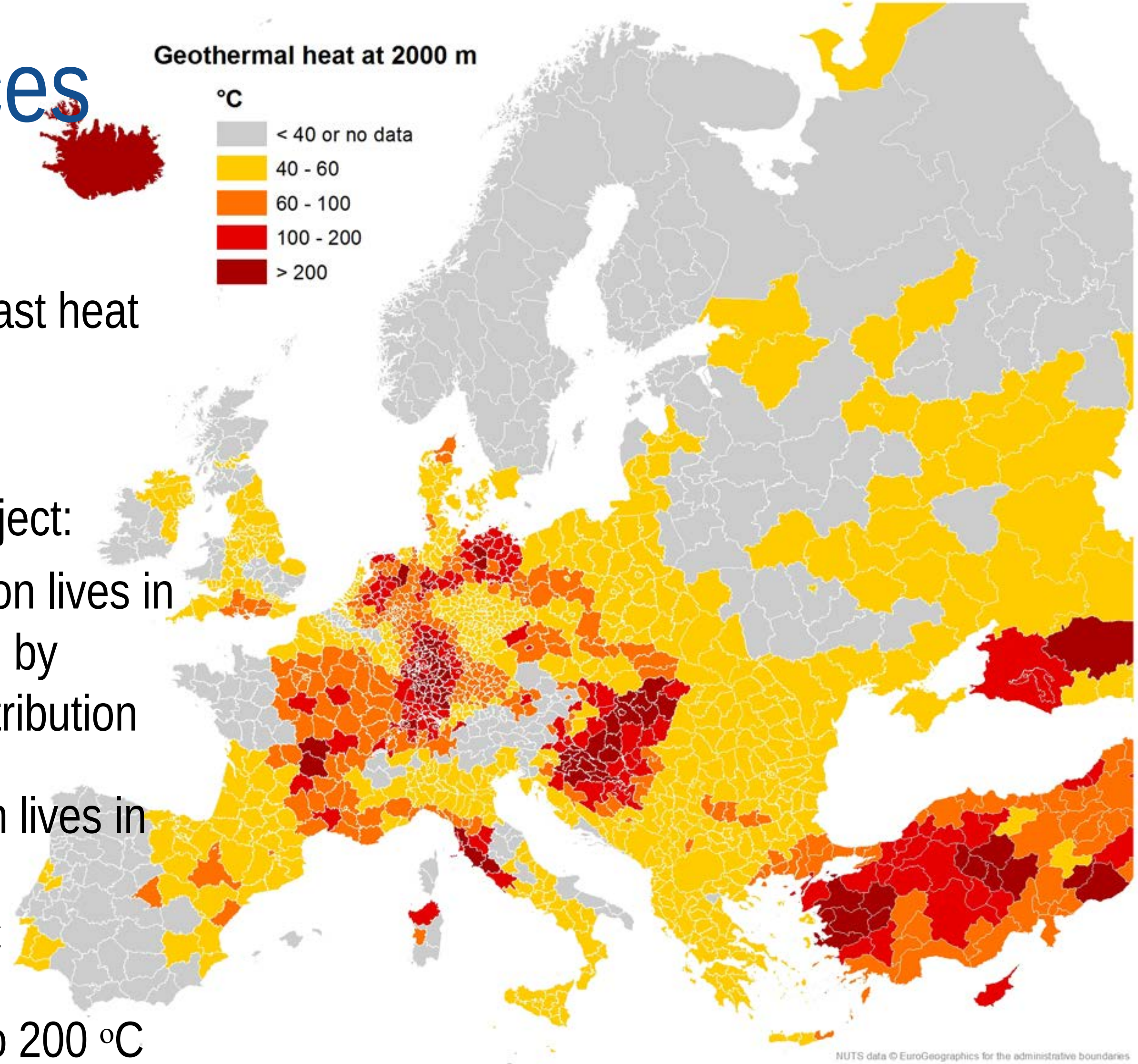
Local heat resources

- **Renewable heat sources**



- Geothermal assets represents vast heat resources in Europe!

- Estimated in Heat Roadmap Project:
- 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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Presentation outline

- Background
- District heating and cooling systems
  - District heating and cooling in Europe today
  - Basic economy of heat and cold distribution
- Heat and cold demands
  - Population and heat demand density
  - Land use data categories
- Excess heat recovery
  - Theory and concepts of excess heat recovery and utilisation
- Local heat resources
  - Excess heat activities
  - Renewable heat sources
- Spatial mapping
  - Geographic Information System (GIS)
  - Identifying excess heat hot spots
- Conclusions

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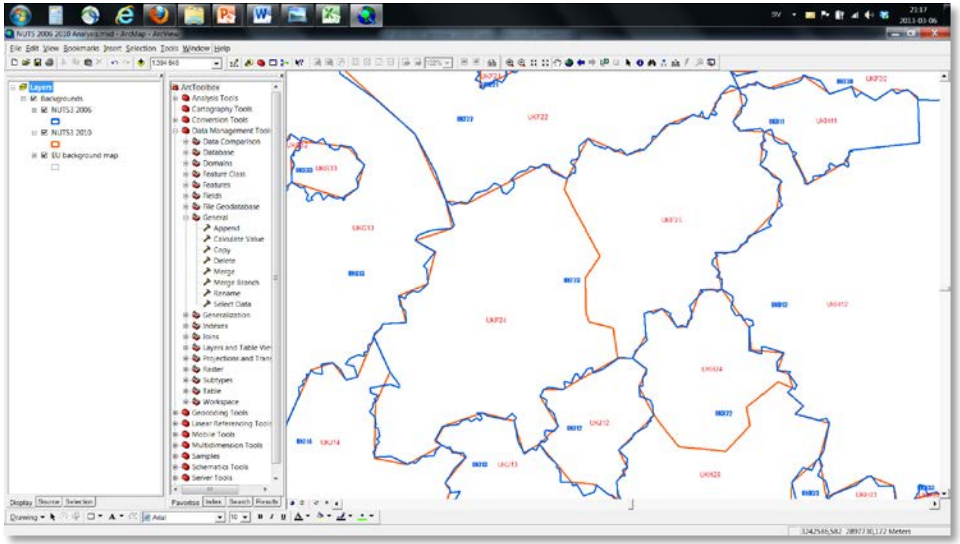
“A GIS interface is a powerful format for geographical and spatial studies, where all information is linked to a geo-reference… this enables unlimited association of additional data and statistics to any spatially defined location”

Spatial mapping

- Geographic Information System (GIS)
- Key features of GIS analysis:
  - Increased possibilities to integrate data and perform analysis in ways that exceed those of manual methods
  - Allows simoultaneous modelling, querying, and mapping, of large quantities of spatial information
  - Offers cartography as an optional output interface.



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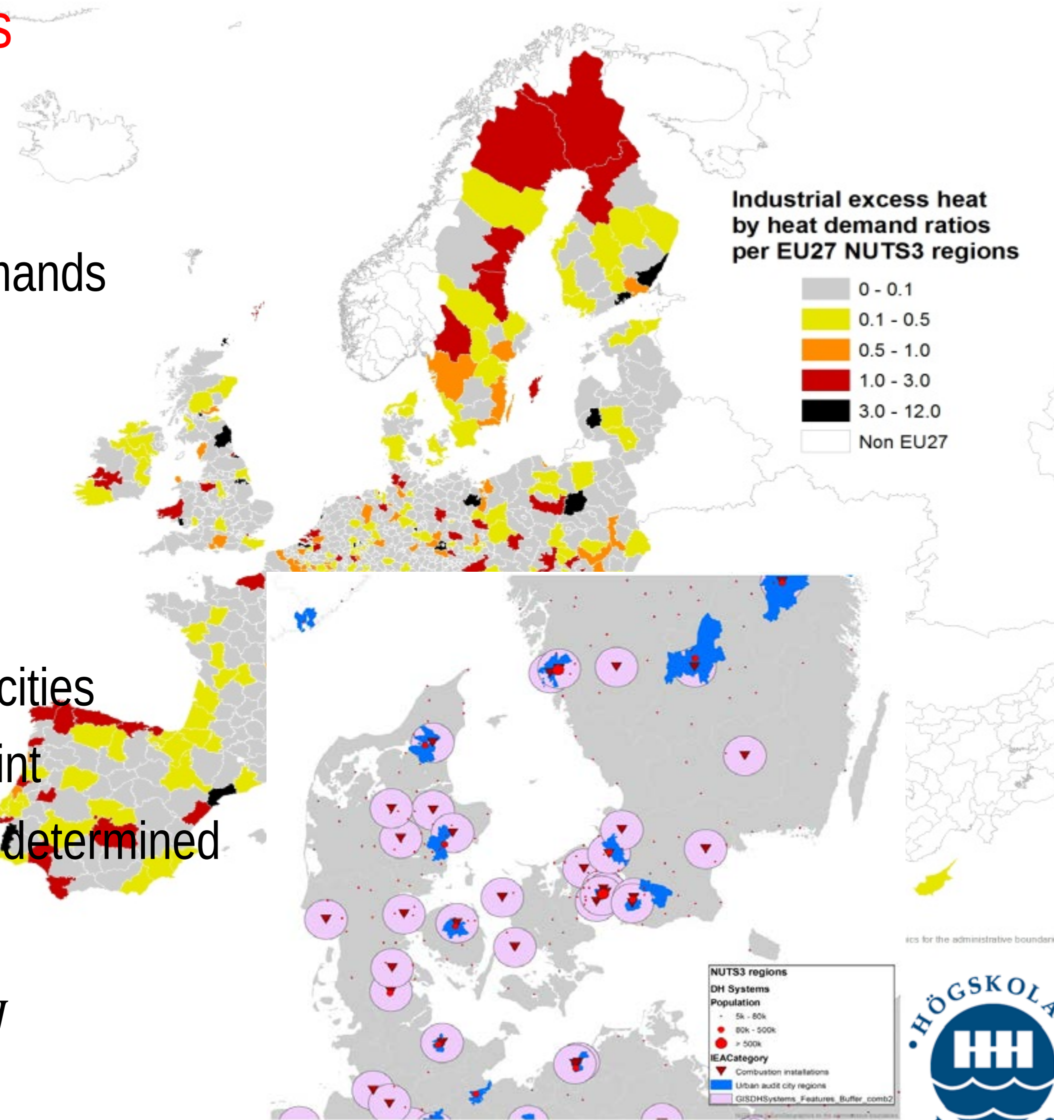
Spatial mapping

- Identifying excess heat hot spots
- 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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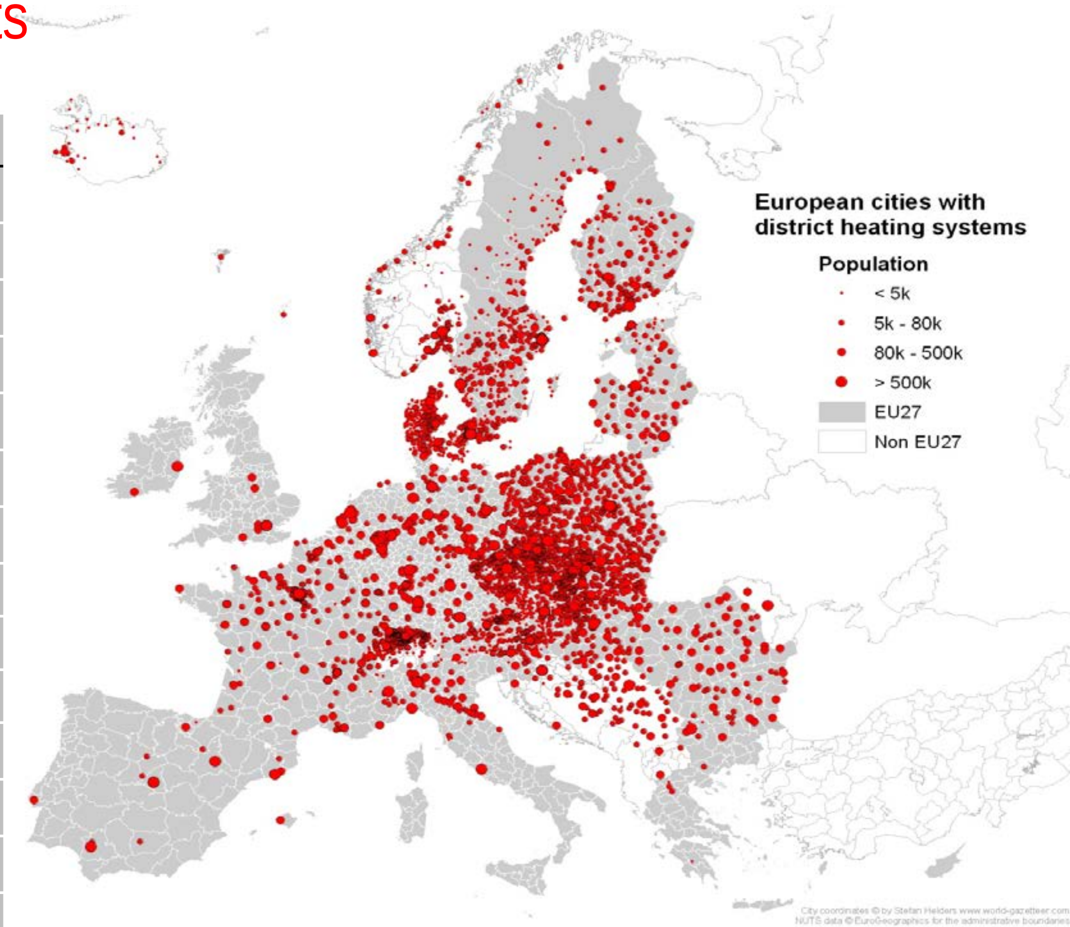
Spatial mapping

- Identifying excess heat hot spots

	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



General properties of assessed EU27 heat synergy opportunity zones (HSOZ) at max 30 km.
Source: Persson, Nillson, Möller & Werner (2012). Mapping Local European Heat Resources - a Spatial Approach to Identify Favourable Synergy Regions for District Heating.

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

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Spatial mapping

- Identifying excess heat hot spots

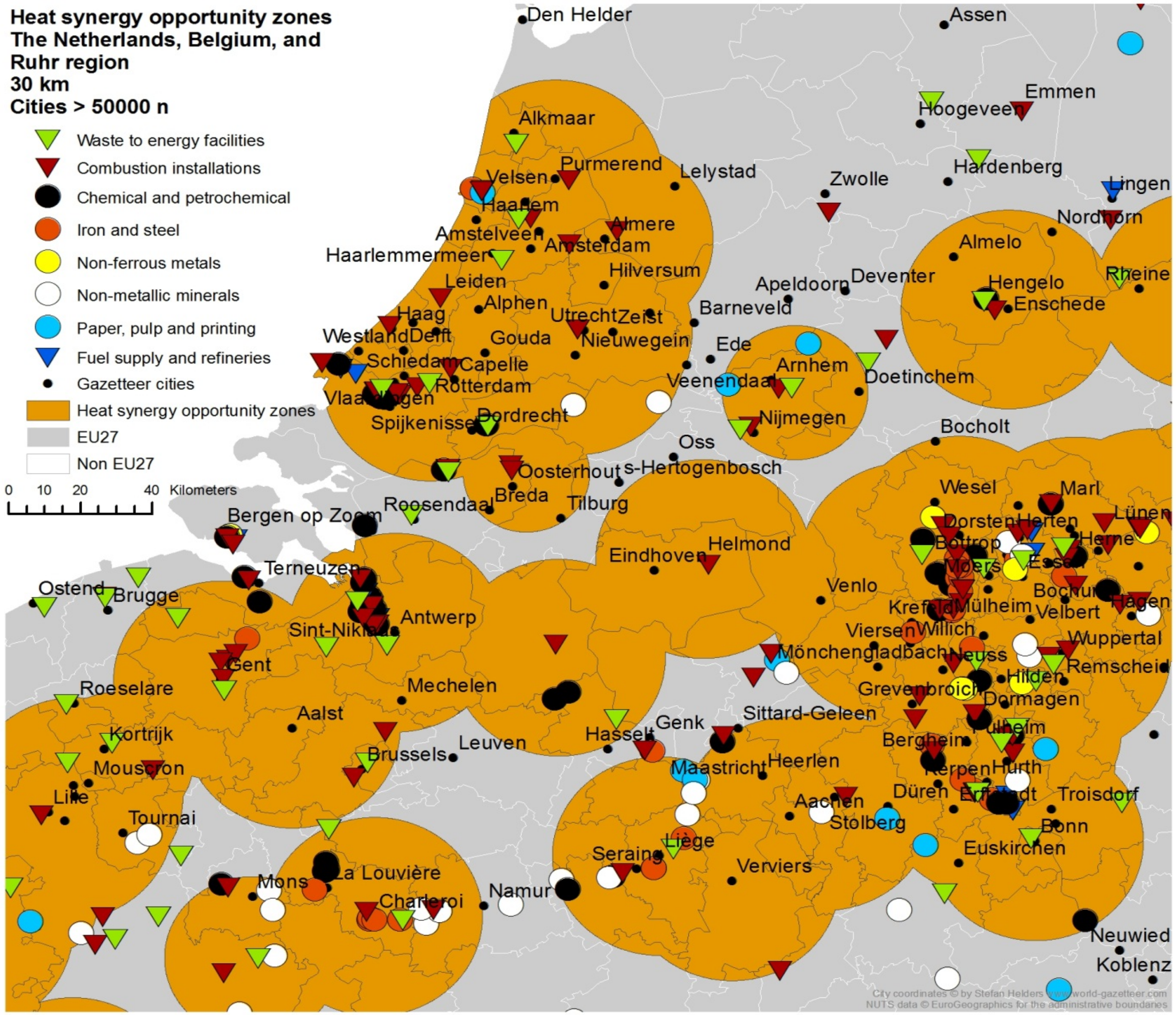
- Close-up:

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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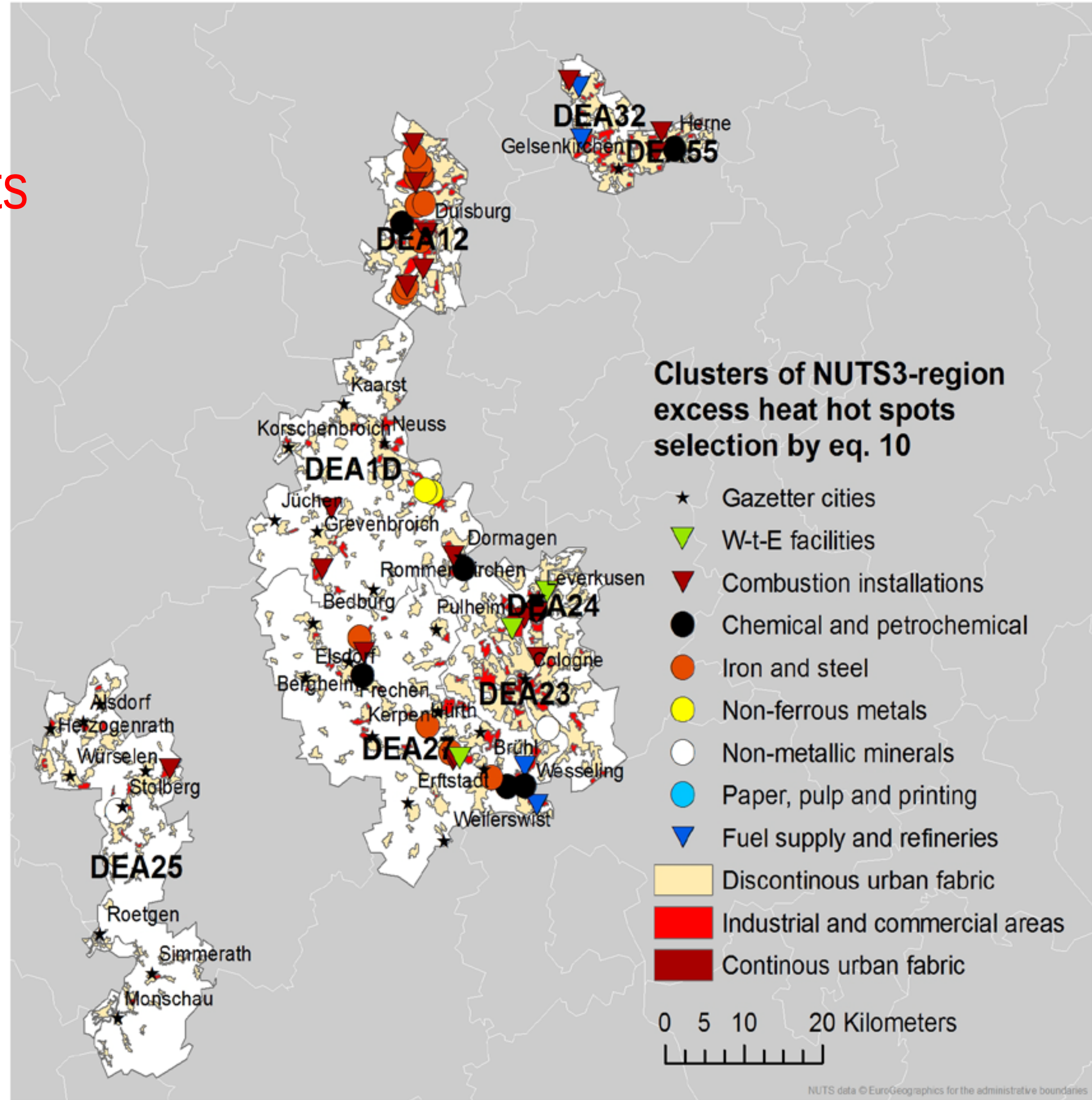
Spatial mapping

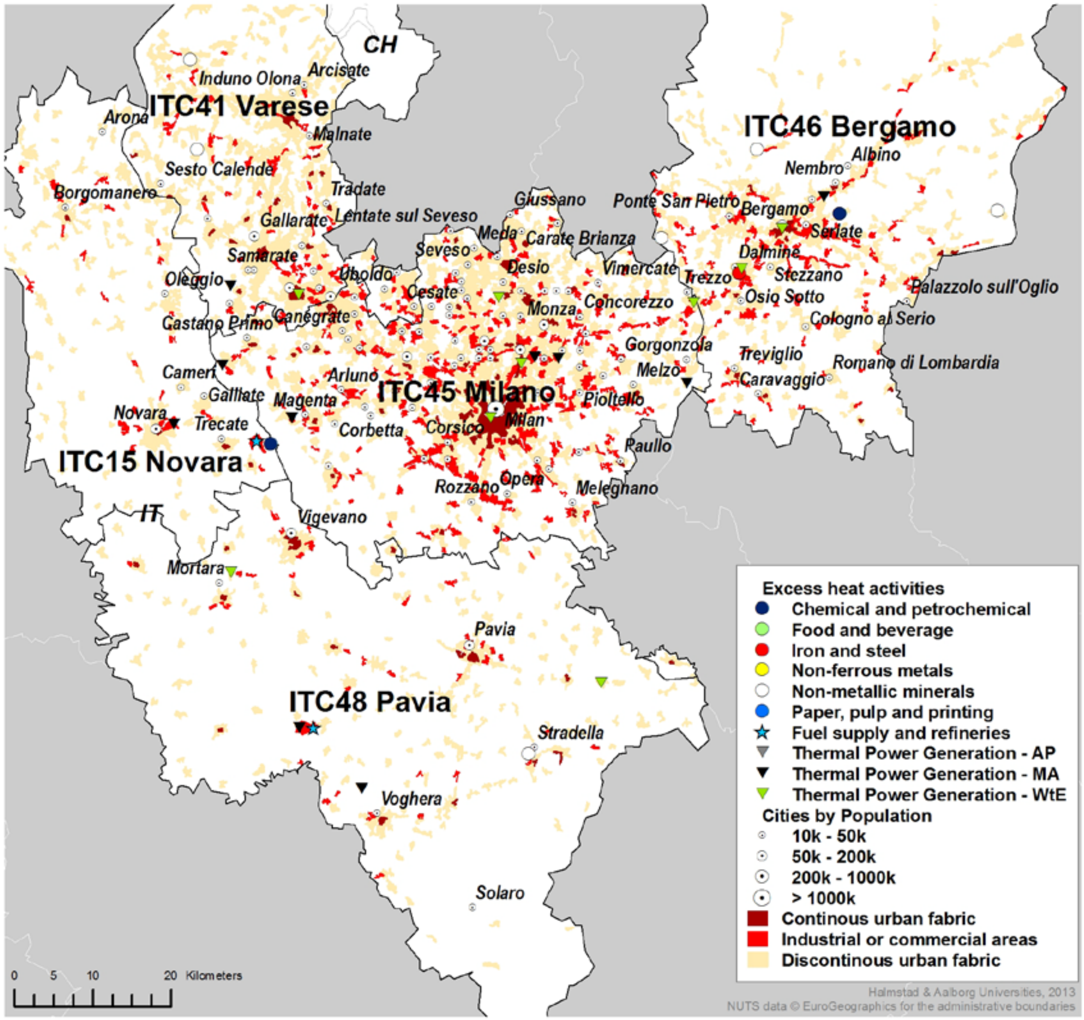
- Identifying excess heat hot spots
- In Heat Roadmap Europe:
- Assess total available NUTS3 region excess heat volumes
- Establish total NUTS3 region heat demands
- Calculate the Excess Heat Ratio (EHR) for any NUTS3 region



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

Spatial mapping

- Identifying excess heat 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

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

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Conclusions

- District heating and cooling systems
  - District heating and cooling in Europe today
    - ~12% district heating in EU27 today
    - Mature DH nations reach >50% of total heat markets
  - Basic economy of heat and cold distribution
    - Three-fold directly feasible expansion possibility in European urban areas
    - DH urban heat market shares of 60 % at anticipated Cd of 2,1 EUR/GJ
    - Indicative Plot Ratio Threshold; 0.15 – 0.20
    - Corresponding Heat Density; 90 TJ/km2 (~25 GWh/km2)
- Heat and cold demands
  - Population and heat demand density
    - City average population density values hide secrets!
    - Competitive distribution conditions exist in high density sub-city districts – not detectable in city average values!
    - DH opportunities may be depreciated by use of population mean values!

Conclusions

- Excess heat recovery
  - Theory and concepts of excess heat recovery and utilisation
    - By sequential energy supply, low temperature excess heat that would otherwise be wasted is recovered and utilised ➔ reduced primary energy demands!
    - Heat utilisation rates >40% are present in EU27 MS today (EU27 average ~9%)
    - Theroetical recovery potential: ~10 EJ/a (plausible recovery potential: ~5 EJ/a)
- Local heat resources
  - Excess heat activities ➔ Thermal power generation (incl. WTE) and energy intensive industry
  - Renewable heat sources ➔ Bioenergy, Solar thermal heat, and geothermal resources
- Spatial mapping
  - Geographic Information System (GIS)
  - Identifying excess heat hot spots
    - NUTS3 region characterization (1303 administrative regions in EU27) for local conditions
    - The excess heat ratio ➔ development of new theoretical concepts
    - National heat and cooling plans in line with EED 2012
    - The shapes of future cities – smart city planning in search of (heat) synergies

Main message:

District heating

principally in

European urban and suburban areas!

Availability of energy and industry sector excess heat
Availability of municipal and industrial waste
Availability of local renewable heat resources
High heat demand concentrations (incl. service sector)
Feasible conditions for network heat distribution

Individual heating alternatives

principally in

European rural areas

Strong incentive for local energy effciency measures
Low energy building technologies
Low availability of energy and industry sector excess heat
Non-feasible conditions for network heat distribution

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Thank You!

Questions?

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