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

4DH
4th Generation District Heating Technologies and Systems

reINVEST

3RD INTERNATIONAL CONFERENCE ON

SMART ENERGY SYSTEMS AND 4TH GENERATION DISTRICT HEATING

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AALBORG UNIVERSITY
DENMARK

DE LA RECHERCHE À L'INDUSTRIE

COST-BENEFIT ANALYSIS OF DISTRICT HEATING SYSTEMS USING HEAT FROM NUCLEAR THERMAL PLANTS IN EUROPE

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Background (1)

- Urgent need to decarbonize space & water heating in the residential & tertiary sectors

  ≈ 29% of EU greenhouse gases (GHG) emissions (IEA, 2014)

- Compromise between GHG emissions and heating cost is important

  The correlation between GDP and primary energy consumption is LM6-70% (60% average) (Safa, 2017; Giraud, 2014)

  It is crucial to prioritize least-cost alternatives when decarbonising energy systems

  If not, the transition towards sustainable energy systems could negatively affect GDP growth; which may in turn lead to lower public acceptance for capitalistic energy projects

LM6 Most classic economists consider that the correlation between GDP and primary energy consumption ≈ 10%

This results from the assumption that energy markets are perfect equilibrium

While in reality there are many market failures (e.g. business consortium, speculation)

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Background (2)

- DH can be competitive, especially in dense urban areas
- DH has allowed the use of renewable energies and the recycling of heat sources that would otherwise have been wasted

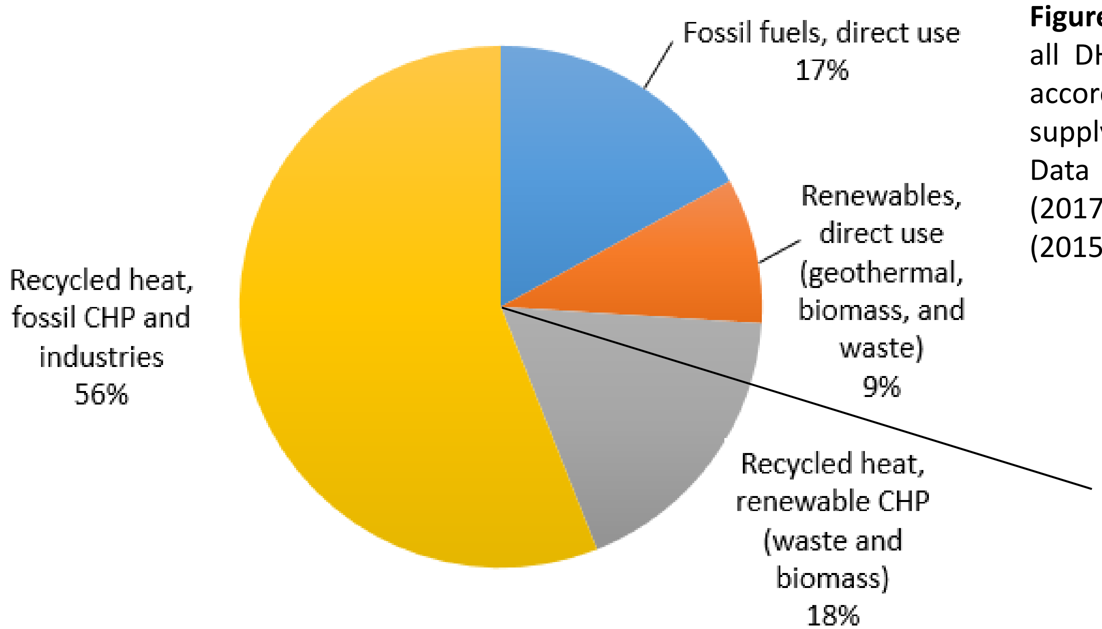

Figure: Heat supplied into all DH systems in the EU according to four heat supply methods, 2014. Data source: Werner (2017), referring to IEA (2015)

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Slide 4

LM3 Brief comment about why:
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LM4 There are many explanations for this low market share of NCHP across the EU such as the often long distance between nuclear sites and urban areas, local governance, economic feasibility, institutional structures, and the historical development of the different national energy systems
LEURENT Martin, 9/1/2017

LM5 Tiny share also because lot of nuclear-sourced DH experiences are in Russia - transition with the next map. If we include Russia it would be 0.3%, but still not significant right?
LEURENT Martin, 9/1/2017

LM11 Yet there are increasing interest from policy makers and stakeholders. International groups I had the chance to be involved in comprise the OECD and the IAEA; but there are many others studies being led at company, national or international levels
LEURENT Martin, 9/1/2017

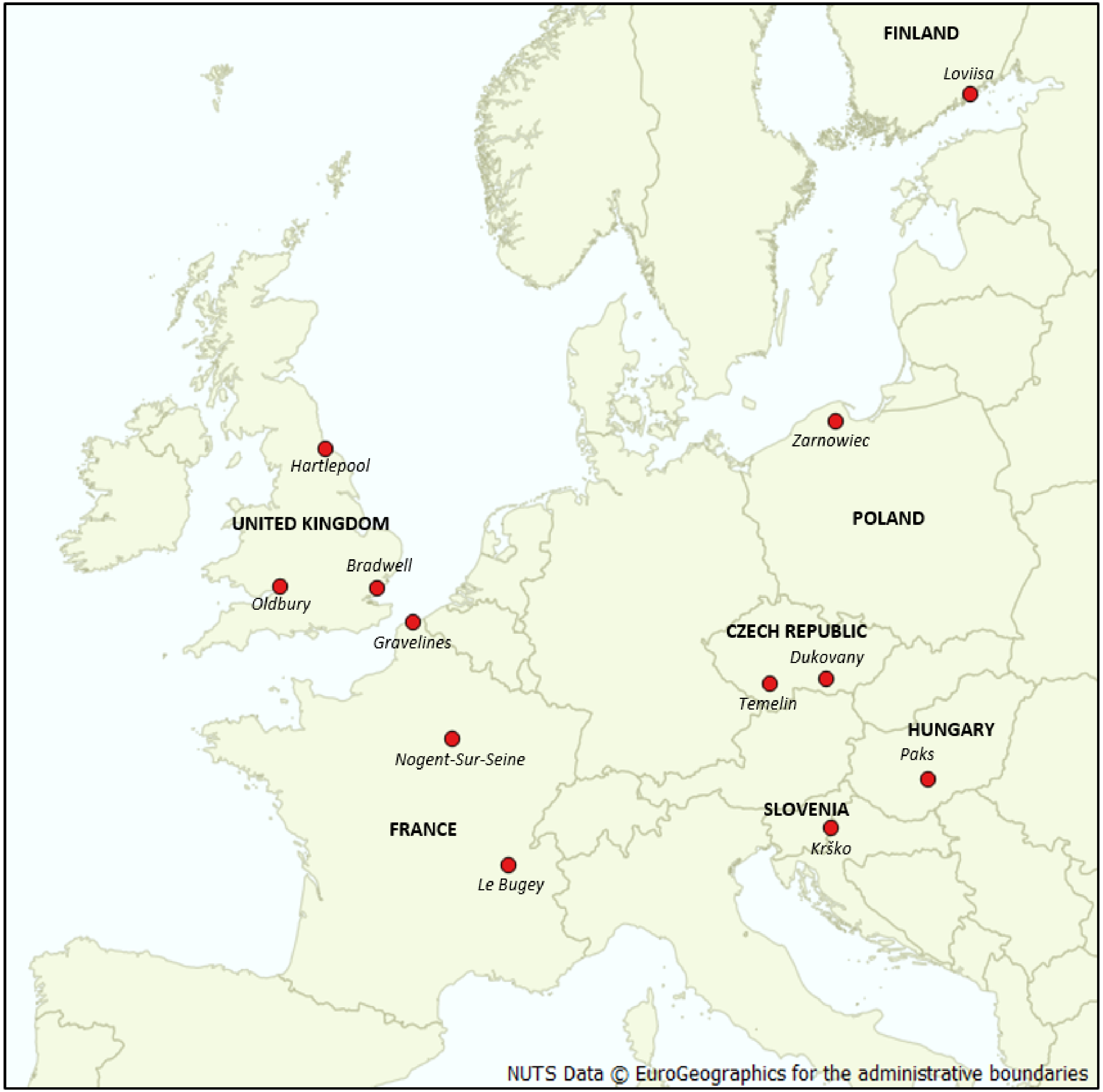

Figure: DH+NCHP systems which have recently been considered by national stakeholders

Interest for DH+NCHP in Europe

Country	Interest for DH+NCHP projects from	Metropolitan area	Plant location	Length of the heat transport line (km)
Czech Republic (CR)	Policy makers, researchers and energy company (CEZ Group)	České Budějovice	Temeline	25
		Brno	Dukovany	35
Finland	Energy company (Fortum) and researchers	Helsinki	Loviisa	80
France	Researchers	Dunkerque	Gravelines	15
		Lyon	Le Bugey	30
		Paris	Nog.-S.-Seine	90
Hungary	Researchers and energy company (MVM Group)	Paks	Szekszard	30
Poland	Policy makers and researchers	Weljherowo	Zarnowiec	18
		Gdynia + Wel.		40
		Gdansk + Gdy.+ Wel.		85
Slovenia	Energy company	Krško	Krško	2.3
		Brežice + Krško		7
UK	Researchers	Bristol	Oldbury	20
		Newcastle	Hartlepool	40
		London	Bradwell	70

Research questions

- What would be the heat density of DH systems in areas where no DH network is implemented?

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- What are the costs and benefits of DH+NCHP systems?

- What are the uncertainties at stake?

LM12 very simple RQ;
LEURENT Martin, 9/1/2017

LM13 but still no one has yet answered it in a proper way
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LM14 eg no clear comparison of diverse DH+NCHP systems
LEURENT Martin, 9/1/2017

LM15 This will be our modest contribution
LEURENT Martin, 9/1/2017

Methodology

- Cost-Benefit Analysis (CBA) following EU guidelines (EC, 2014)

EC (2014) recommends to apply:

Discount rate = 3.5%

Technical lifetime = 40 years (longest lifetime of the system components)

Contruction period: 2020-2030

Operation period: 2030-2070

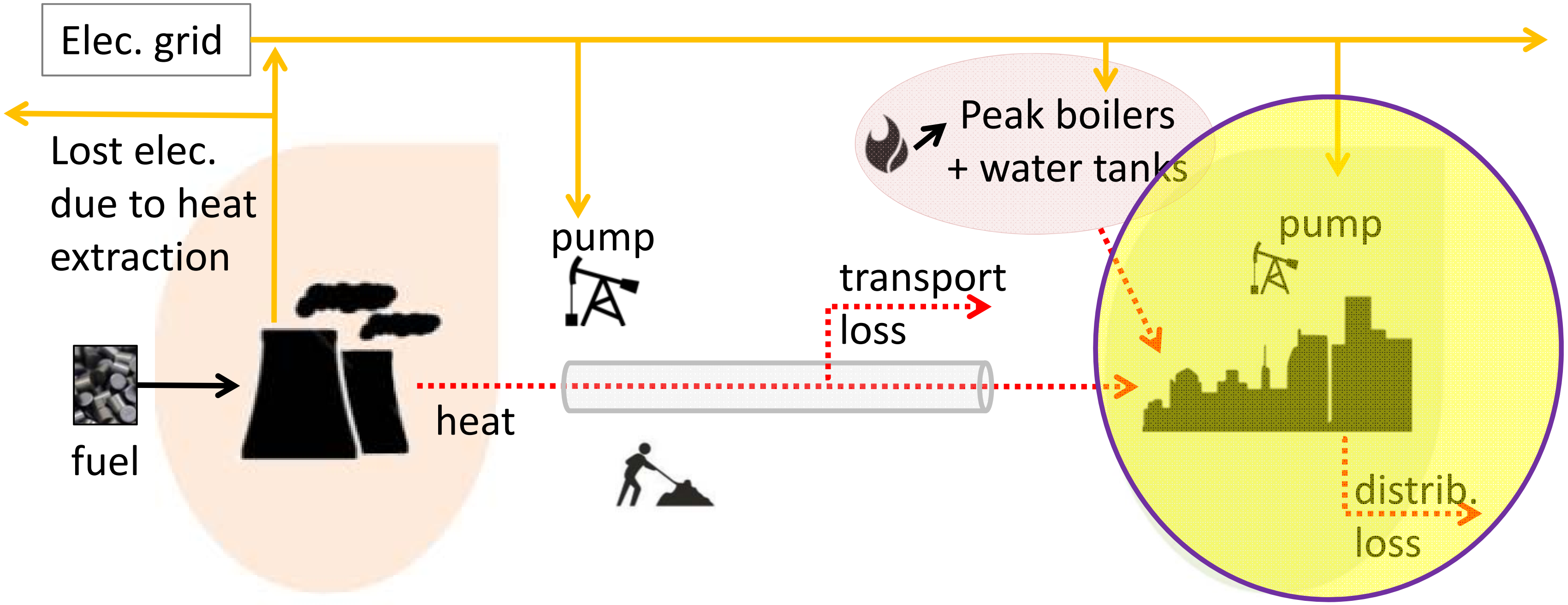
Levelised cost of the heat (LCOH), Net Present Value (NPV), Payback period

Direct and lifecycle GHG emissions from operating DH+NCHP systems

NB: DH operational stages ≈ 95% of total GHG emissions (Bartholozzi et al., 2017)

GHG abatment cost (€/t eCO2)

Techno-economic modelling



How to model the heat distribution network? (1)

- From effective width to linear heat density

W, the effective width of a DH network is expressed as:

$$w = A_L/L = 61{,}8 \cdot a^{-0{,}15} (m), \text{ where } a = \frac{A_B}{A_L}$$

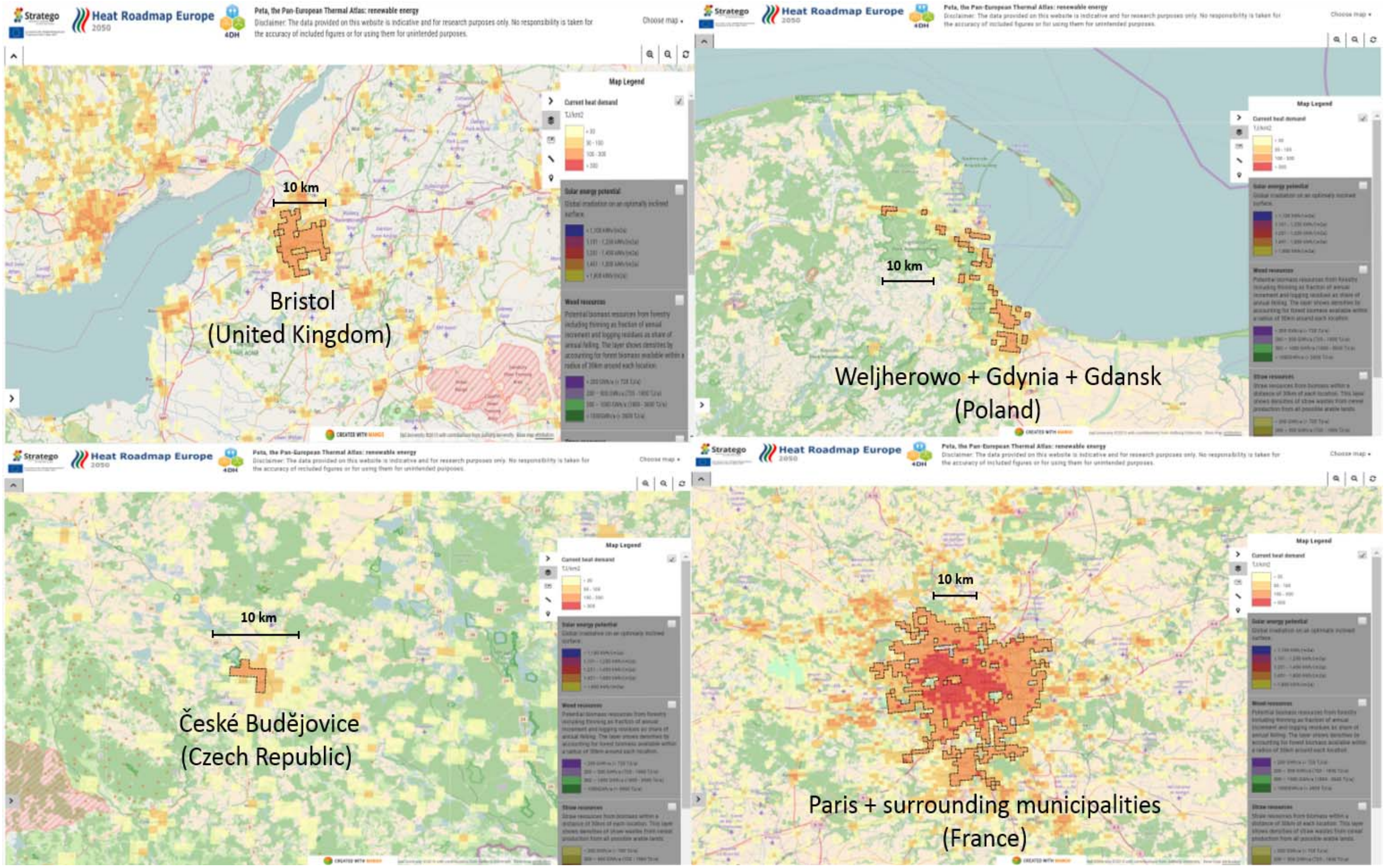
Empirical results from Persson and Werner (2011) based on 83 European networks
In line with Nielsen (2013)

Heat Roadmap Europe (2015) provides annual space and water heating consumption ($GWh_{th}/km^2 an$) in 2015. We projected it towards 2030 to account for expected decrease in heat demand

- A_L : *Land surface area* (m^2)
- A_B : *Buidling surface area* (m^2)
- L : *DH network length* (m)

$$= \frac{\text{Heat consumption of the area}(KWh_{th}/\text{year})}{\text{Av.buildings consumption } (KWh_{th}/\text{m}^2 year)}$$

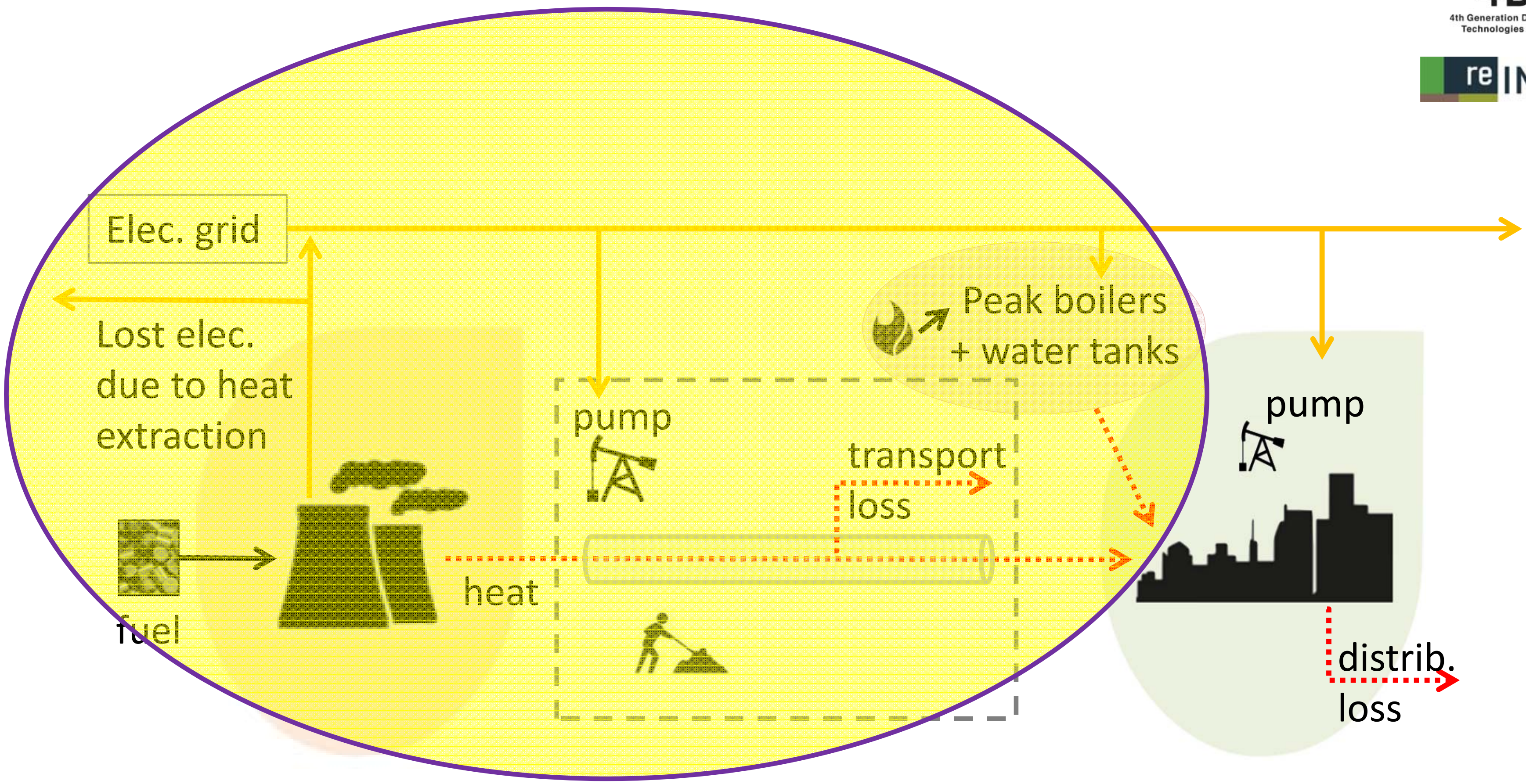
How to model the heat distribution network? (2)



Results for the Modelled DH networks

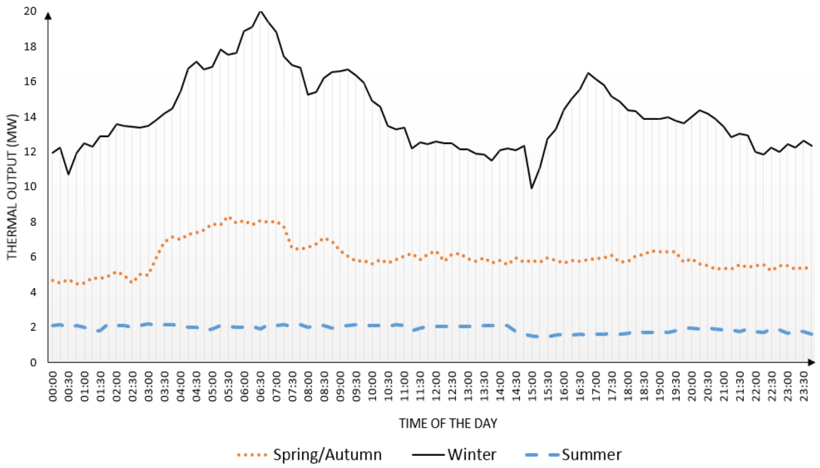
Country	GHG emission factor of space & water heating $(t\ eCO_2/GWh_{th})$, country average	Urban area	Population supplied with the modelled DH network (k capita)	Average linear heat density in 2030 (MWh/ma)	Length of the modelled DH networks (km)	Length of the existing DH networks (km)
Czech Republic	453	České Budějovice	48.3	3.1	91.7	101.9
		Brno	167.2	3.0	454.4	1349
Finland	288	Helsinki	639.9	3.9	2198.2	2750
France	332	Dunkerque	101.9	2.9	252.2	40
		Lyon	788.8	3.9	1443.3	185.4
		Paris	7913.9	5.2	9602.7	1239.9
Hungary	347	Paks	20.5	1.3	91.0	85.5
Poland	510	Weljherowo	31.1	2.5	62.9	42
		Gdynia + Wel.	188.3	2.7	357.0	331
		Gdansk + Gdynia + Wel.	452.5	2.8	800.4	816
Slovenia	256	Krško	6.4	0.9	42.4	61.4
		Brežice + Krško	8.9	0.9	53.8	78
UK	428	Bristol	241	2.9	858.6	10-13 *(estimated)*
		Newcastle	451	2.5	1841.9	18-23 *(estimated)*
		London	3784	3.2	12241.3	400-600 *(estimated)*

Techno-economic modelling



How to model heat generation?

1



Q_{MAX} (MW), the maximum thermal power required, is calculated in order to be able to supply 80% of annual heat loads with the NCHP

The remaining 20% are supplied with natural gas heat-only boilers

2

Capital cost attributable to heat generation with NCHP ≈ 0.1 Q_{MAX} (M€)
(see ETI, 2016, for PWR)

3

Reduction in power generation ≈ *1/6 of heat extracted (100°C)*
(see IAEA, 2016)

How to model heat transportation?

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1

G_s (kg/s), the water flow

$$G_s = \frac{Q_{MAX}\,10^6}{C_p\,\Delta_T}$$

C_p: sp. Water heat cp. (Ws/kgK)
$\Delta_T = T_{supply} - T_{return}$

2

$\mathring{v}\ (m^3/s)$, the volumetric flow rate

$$\mathring{v} = \frac{G_s}{\rho}$$

ρ : water density (kg/m^3)

3

D (m), the pipe diameter

$$D = \sqrt{\frac{4\,\mathring{v}}{\pi\,v}}$$

v : flow velocity (m/s) = 3 m/s
(see e.g. Safa, 2012)

4

C_{HTS} (€/m), the capital cost

$$C_{HTS} = 3000\,D^2 + 4000\,D + 1500$$

Burried pipelines (s ch et al., 2016; ETI, 2016
LM18 LM19

5

P_{PM} (W_e), the pumping power

$$P_{PM} = \frac{g\ G_s\ H}{\eta_p}$$

g: gravitational acc. (m/s^2)
η_p: pump efficiency ratio (0.75)
H : lifting height (m), calculated referring to the Darcy–Weisbach equation

Slide 15

LM18 we have assumed based on results from eg Hirsch or safa that heat losses are equal to 2%. this is possible with 200-300mm insulation layer, and is included in the cost of the line.

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LM19 eg 1m=7.5millions (e); it is in line with empirical cost of burried pipelines

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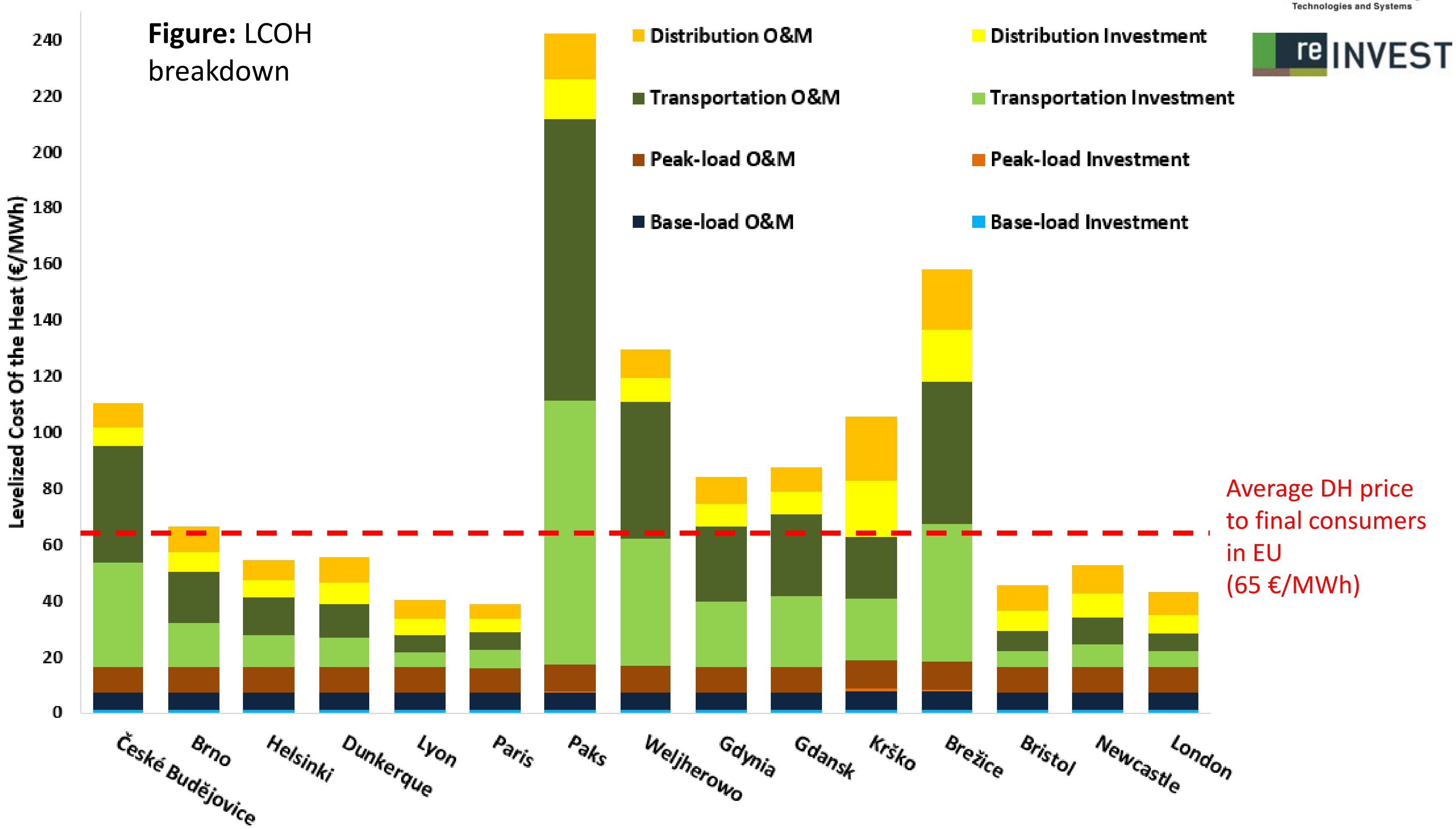
CBA for a 25% connexion rate (1)



CBA for a 25% connexion rate (2)

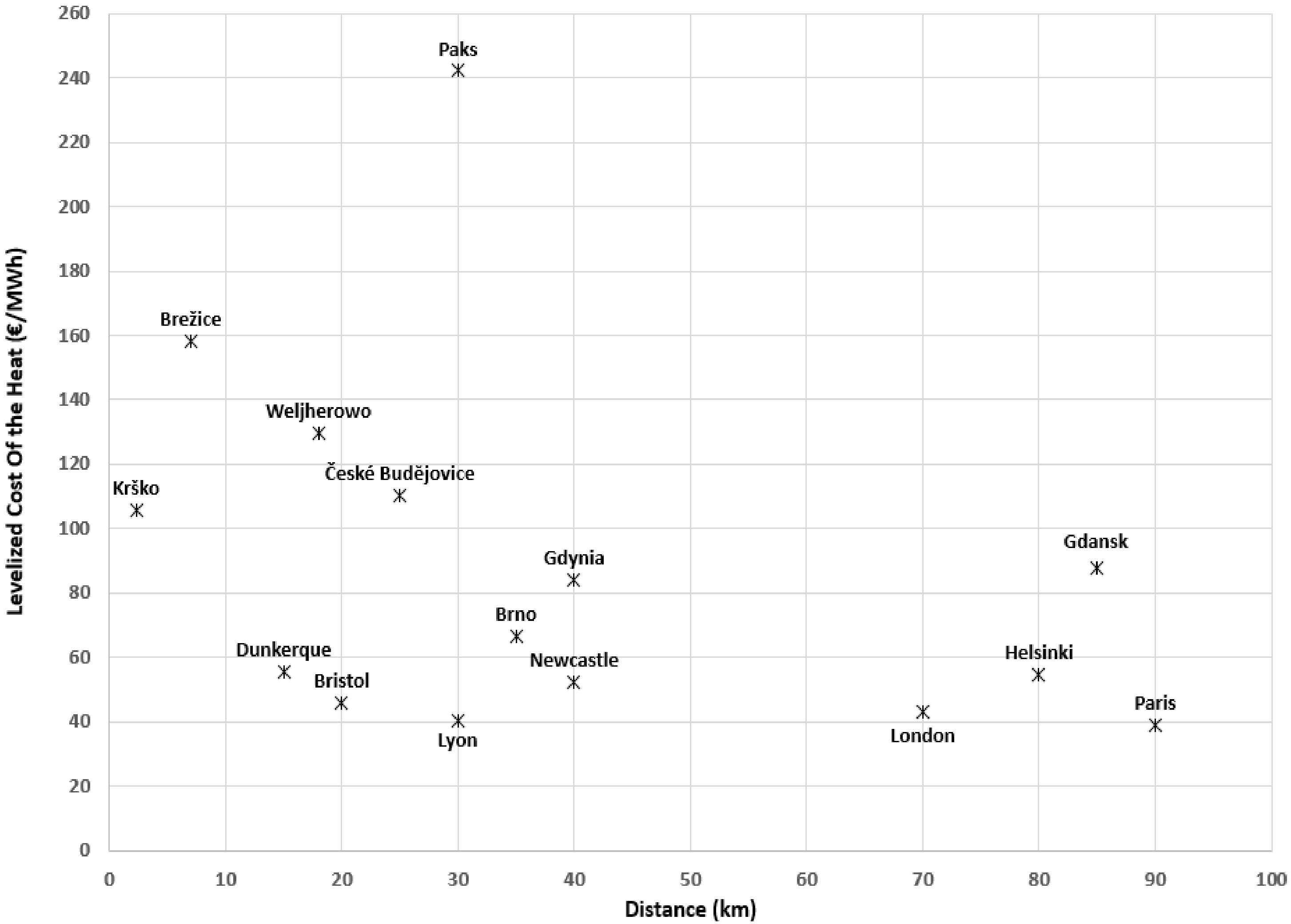


Figure: LCOH as a function of distances from NCHP to cities

CBA with varying connexion rates (1)

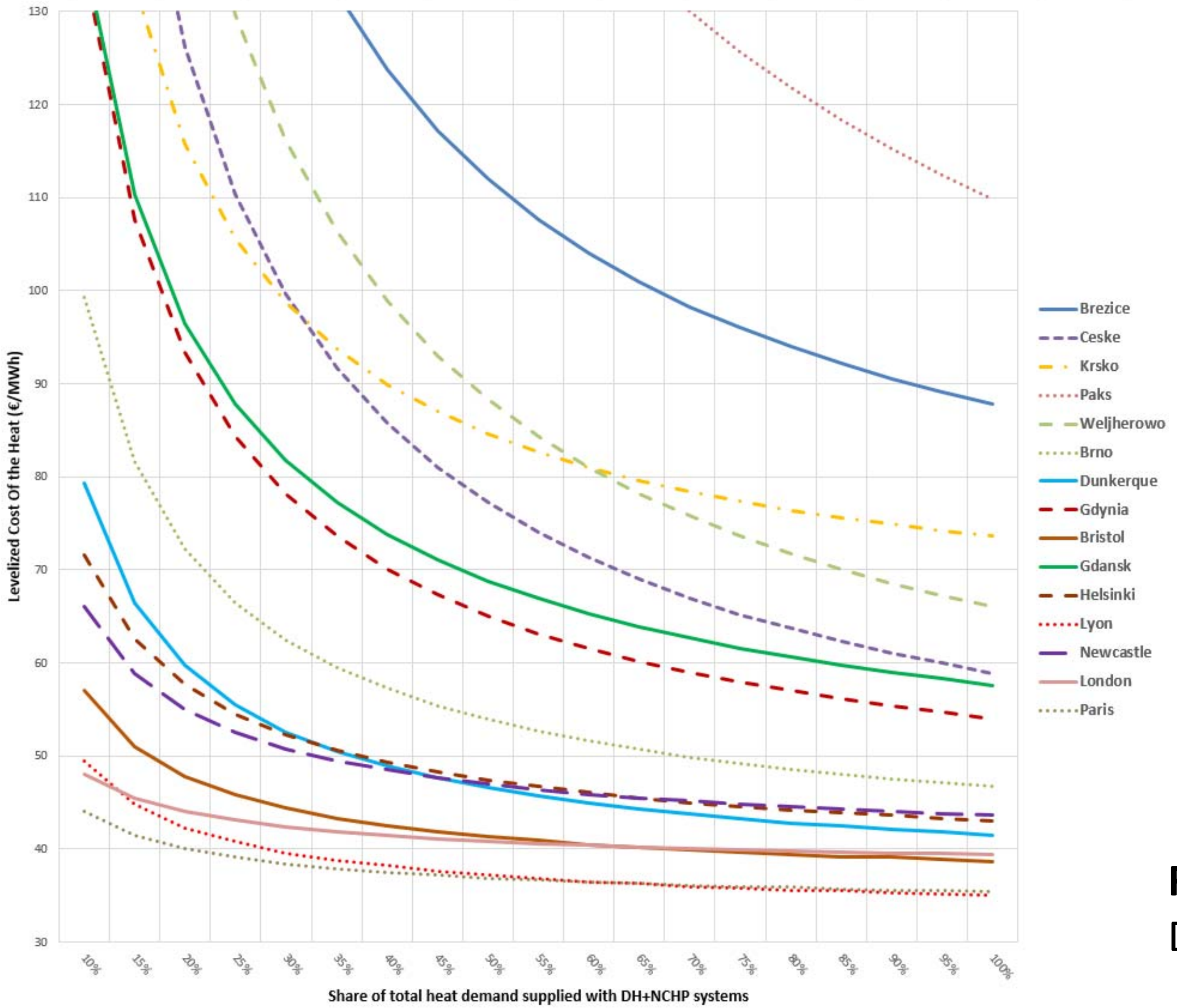
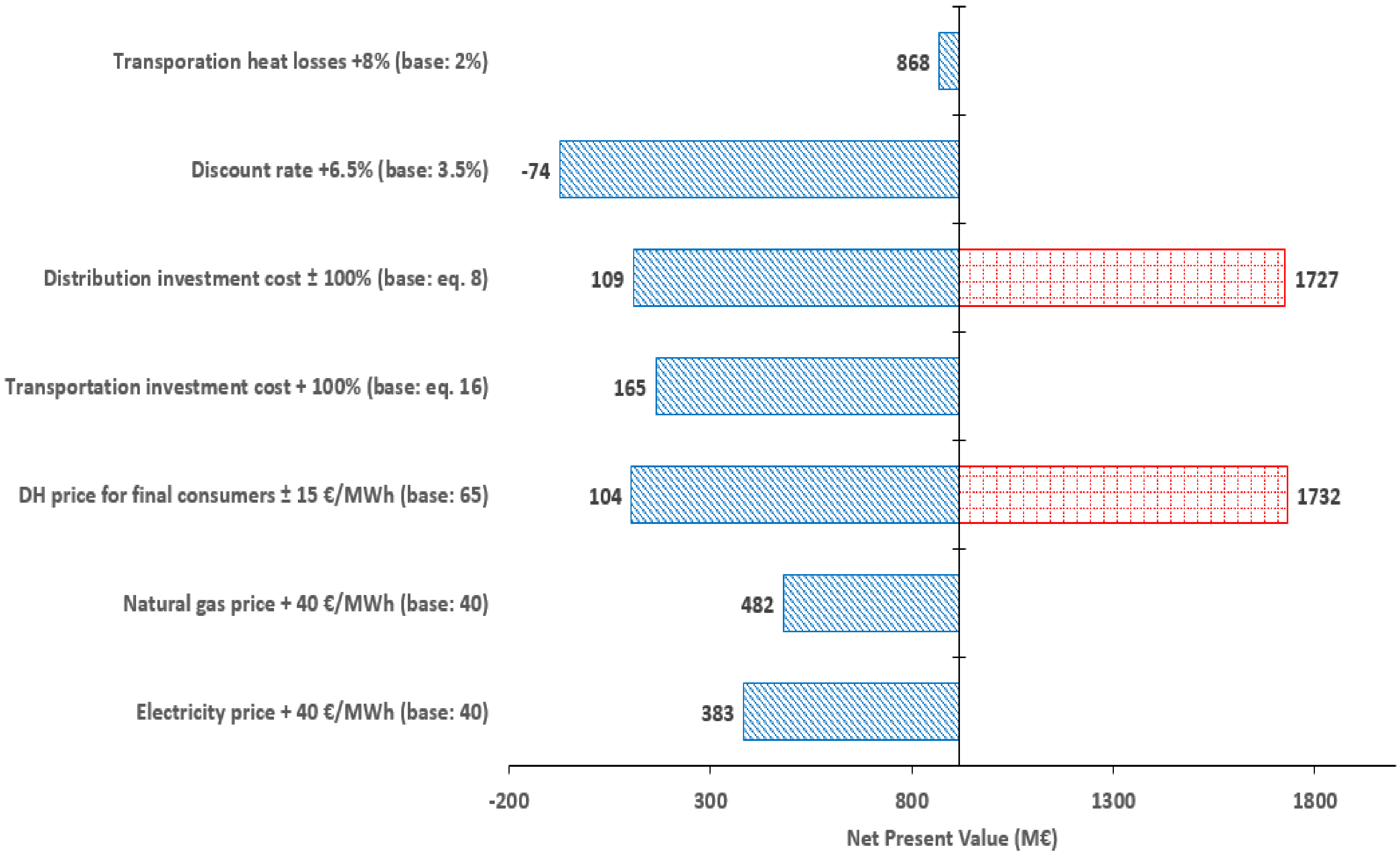


Figure: LCOH with varying DH+NCHP connexion rates

Sensitivity analysis for the London DH+NCHP system

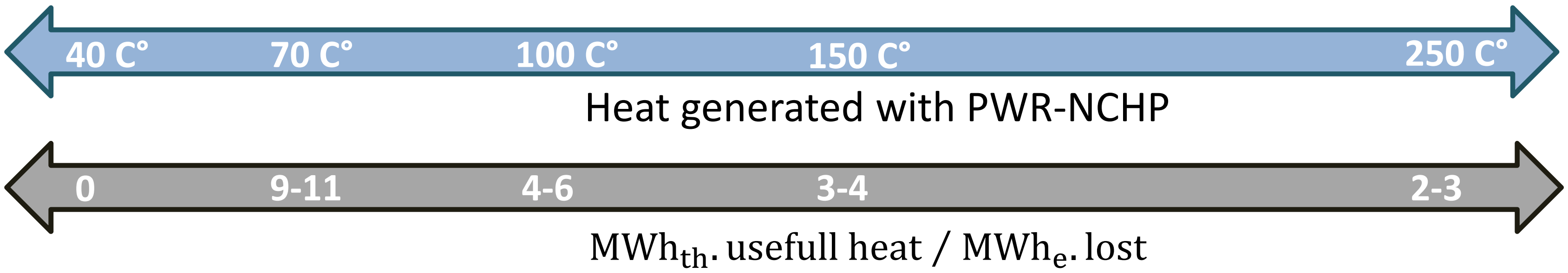
(25% connexion rate, 10 TWh/yr, 80km heat transportation, DH price = 65 €/MWh)



Impact of 4DH Generation

Better insulation of buildings means comfort will be achieved by lower supply temperatures

For NCHP, this means lower electrical losses per unit of heat generated (compare to similar plant producing electricity only)
This accounts for 5-10% of the LCOH for 100°C heat generation



However, other CHP and renewable technologies would also benefit from 4GDH
The competitiveness of NCHP with these sources remains to be studied

Limitations & future research

- Limitations of the heat distribution model
  - Buildings without central heating systems are included
  - Spatial resolution of the data used (GWh/ km2)
  - Neglecting the industrial process heat demand
  - we assumed that the geographic properties of areas with the same heat density level was similar

- Caution is needed when applying these results
  - Significant uncertainty is at stake. For implementation in real planning, these results should be checked experimentally in the next step, using parameter values specific to each local context

- Major stakes for future research
  - Comparison of DH+NCHP systems with other low carbon heating systems
  - Evaluation of DH+NCHP systems combined with improved building performance (4DH context)
  - Stakeholder's interaction and public opinion issues

Conclusions

- There is unexploited DH potential
  - DH networks with heat density >2.5 MWh/m.a could be deployed so that the total length of DH pipelines would represent approximately 7, 20 and 70 times the length of existing networks in French cities, London and Newcastle/Bristol, respectively
- Cost-effectiveness in 7 to 11 cases, depending on the connexion rate
  - For a 25% connexion rate, 7 projects (out of 15) have a positive NPV when the DH price to final consumers is 65 €/MWh
  - Implementing these projects would reduce GHG emissions by about 10 Mt eCO2/year
- When considering the marginal GHG abatement cost (€/t eCO_2 avoided), the relative attractiveness of DH+NCHP systems is changed
  - The attractiveness of Polish and Czech DH+NCHP projects is relatively higher.
  - This is because their heating sector is more dependent on fossil-fuels
  - A carbon taxation > 50 €/t eCO2 could be a game changer for DH+NCHP projects

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Appendix A

Metropolitan area	NPV profitability threshold (connexion rate from which NPV > 0)	Rankings of payback periods (ascending order)	Rankings of LCOH (ascending order)	Rankings of GHG abatement cost (ascending order)
České Budějovice	75%	6	9	5
Brno	27%	4	6	3
Helsinki	13%	3	5	5
Dunkerque	16%	3	5	4
Lyon	5%	1	2	2
Paris	2%	1	1	2
Paks	NPV < 0	> 40 years	11	7
Weljherowo	NPV < 0	7	9	5
+ Gdynia	51%	4	7	4
+ Gdansk	61%	5	8	4
Krško	NPV < 0	8	9	6
+ Brežice	NPV < 0	> 40 years	10	7
Bristol	7%	2	4	1
Newcastle	11%	3	5	2
London	3%	2	3	1

Appendix B: How to calculate GHG emissions savings?

	Direct emissions ($t\ eCO_2/GWh_{th}$), IPCC (2006)	Lifecycle emissions, EU27 average ($t\ eCO_2/GWh_{th}$), Ecoinvent (2005)
Biomass	0	0
Fuel oil	264,8	317,2
Natural gas	202,2	221,8
Coal	347,7	385,2
Electricity	Country average Data for 2009 (EEA, 2011) are extrapolated towards 2030 considering that the average GHG content of electricity will be decreased by 35%, following results from EC (2013; EU average)	

$E_{DH+NCHP}$, specific GHG emissions of DH+NCHP

E_{BAU}, specific GHG emissions generated using conventional heating systems (ref: ENTRANZE, 2014)

Cm_{GHG} (€/tCO2), the marginal GHG abatement cost

$$Cm_{GHG} = \frac{LCOH\ \ Q_{DH}}{EF_{BAU}\ - E_{DH+NCHP}}$$

$LCOH$ (€/MWh)
Q_{DH}: annual DH delivery ($MWh/year$)