3\textsuperscript{RD} INTERNATIONAL CONFERENCE ON

SMART ENERGY SYSTEMS AND

4\textsuperscript{TH} GENERATION DISTRICT HEATING

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

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Da Costa, P., Rämä, M., Urban, P., Jasserand, F.
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 ≈ 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
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)
Brief comment about why:
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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
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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

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

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

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3rd international conference on SMART ENERGY SYSTEMS AND 4TH GENERATION DISTRICT HEATING Copenhagen, 12-13 September 2017

[www.4dh.eu](http://www.4dh.eu)  [www.reinvestproject.eu](http://www.reinvestproject.eu)  [www.heatroadmap.eu](http://www.heatroadmap.eu)
Research questions

- What would be the heat density of DH systems in areas where no DH network is implemented?
- What are the costs and benefits of DH+NCHP systems?
- What are the uncertainties at stake?
very simple RQ;
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but still no one has yet answered it in a proper way
LEURENT Martin, 9/1/2017

eg no clear comparison of diverse DH+NCHP systems
LEURENT Martin, 9/1/2017

This will be our modest contribution
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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)
- Construction 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 abatement cost (€/t eCO2)
Techno-economic modelling

- Elec. grid
- Lost elec. due to heat extraction
- fuel
- pump
- transport loss
- Peak boilers + water tanks
- pump
- distrib. loss
How to model the heat distribution network? (1)

- From effective width to linear heat density

\[ w = \frac{A_L}{L} = 61.8 \cdot a^{-0.15} \text{ (m)}, \text{ where } a = \frac{A_B}{A_L} \]

- \( A_L \): Land surface area (m\(^2\))

- \( A_B \): Building surface area (m\(^2\))

- \( L \): DH network length (m)


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

Heat consumption of the area (\( KWh_{th} / \text{year} \))

\[ \frac{\text{Av. buildings consumption (KWh}_{th}/m^2 \text{ year)}}{} \]
How to model the heat distribution network? (2)
Results for the Modelled DH networks

<table>
<thead>
<tr>
<th>Country</th>
<th>GHG emission factor of space &amp; water heating (t eCO₂/GWhₜₕ), country average</th>
<th>Urban area</th>
<th>Population supplied with the modelled DH network (k capita)</th>
<th>Average linear heat density in 2030 (MWh/ma)</th>
<th>Length of the modelled DH networks (km)</th>
<th>Length of the existing DH networks (km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Czech Republic</td>
<td>453</td>
<td>České Budějovice</td>
<td>48.3</td>
<td>3.1</td>
<td>91.7</td>
<td>101.9</td>
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<tr>
<td></td>
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<td>Brno</td>
<td>167.2</td>
<td>3.0</td>
<td>454.4</td>
<td>1349</td>
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<tr>
<td>Finland</td>
<td>288</td>
<td>Helsinki</td>
<td>639.9</td>
<td>3.9</td>
<td>2198.2</td>
<td>2750</td>
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<td>France</td>
<td>332</td>
<td>Dunkerque</td>
<td>101.9</td>
<td>2.9</td>
<td>252.2</td>
<td>40</td>
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<tr>
<td></td>
<td>Lyon</td>
<td>788.8</td>
<td>3.9</td>
<td>1443.3</td>
<td>185.4</td>
<td></td>
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<tr>
<td></td>
<td>Paris</td>
<td>7913.9</td>
<td>5.2</td>
<td>9602.7</td>
<td>1239.9</td>
<td></td>
</tr>
<tr>
<td>Hungary</td>
<td>347</td>
<td>Paks</td>
<td>20.5</td>
<td>1.3</td>
<td>91.0</td>
<td>85.5</td>
</tr>
<tr>
<td>Poland</td>
<td>510</td>
<td>Welżherowo</td>
<td>31.1</td>
<td>2.5</td>
<td>62.9</td>
<td>42</td>
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<tr>
<td></td>
<td>Gdynia + Wel.</td>
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<td>2.7</td>
<td>357.0</td>
<td>331</td>
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<tr>
<td></td>
<td>Gdansk + Gdynia + Wel.</td>
<td>452.5</td>
<td>2.8</td>
<td>800.4</td>
<td>816</td>
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<tr>
<td>Slovenia</td>
<td>256</td>
<td>Krško</td>
<td>6.4</td>
<td>0.9</td>
<td>42.4</td>
<td>61.4</td>
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<tr>
<td></td>
<td>Brežice + Krško</td>
<td>8.9</td>
<td>0.9</td>
<td>53.8</td>
<td>78</td>
<td></td>
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<tr>
<td>UK</td>
<td>428</td>
<td>Bristol</td>
<td>241</td>
<td>2.9</td>
<td>858.6</td>
<td>10-13 (estimated)</td>
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<tr>
<td></td>
<td>Newcastle</td>
<td>451</td>
<td>2.5</td>
<td>1841.9</td>
<td>18-23 (estimated)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>London</td>
<td>3784</td>
<td>3.2</td>
<td>12241.3</td>
<td>400-600 (estimated)</td>
<td></td>
</tr>
</tbody>
</table>
Techno-economic modelling

Elec. grid

Lost elec. due to heat extraction

fuel

Peak boilers + water tanks

pump

transport loss

heat

pump
distrib. loss
**How to model heat generation?**

1. **Capital cost attributable to heat generation with NCHP**: $\approx 0.1 \times Q_{MAX} \ (\text{M€})$
   (see ETI, 2016, for PWR)

2. **Reduction in power generation**: $\approx 1/6 \text{ of heat extracted (100°C)}$
   (see IAEA, 2016)

$Q_{MAX}$ (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.
How to model heat transportation?

1. \(G_S\) (kg/s), the water flow

\[
G_S = \frac{Q_{\text{MAX}} \times 10^6}{C_p \Delta T}
\]

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

2. \(\dot{V}\) (m³/s), the volumetric flow rate

\[
\dot{V} = \frac{G_S}{\rho}
\]

\(\rho\): water density (kg/m³)
\(\nu\): flow velocity (m/s)

3. \(D\) (m), the pipe diameter

\[
D = \sqrt[4]{\frac{4 \dot{V}}{\pi \nu}}
\]

4. \(C_{HTS}\) (€/m), the capital cost

\[
C_{HTS} = 3000 D^2 + 4000 D + 1500
\]

\(\text{Buried pipelines (see Hirsch et al., 2016; ETI, 2016)}\)

5. \(P_{PM}\) (Wₑ), the pumping power

\[
P_{PM} = \frac{g \frac{G_S H}{\eta_p}}
\]

\(g\): gravitational acc. (m/s²)
\(\eta_p\): pump efficiency ratio (0.75)
\(H\): lifting height (m), calculated referring to the Darcy–Weisbach equation
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.

eg $1m=7.5$millions (e); it is in line with empirical cost of buried pipelines
CBA for a 25% connexion rate (1)

Figure: LCOH breakdown

Average DH price to final consumers in EU (65 €/MWh)
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)

Transportation heat losses ±8% (base: 2%) 868
Discount rate ±6.5% (base: 3.5%) -74
Distribution investment cost ±100% (base: eq. 8) 109
Transportation investment cost ±100% (base: eq. 16) 165
DH price for final consumers ±15 €/MWh (base: 65) 104
Natural gas price +40 €/MWh (base: 40) 482
Electricity price +40 €/MWh (base: 40) 383

Net Present Value (M€)
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 eCO2 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.
References


### Appendix A

<table>
<thead>
<tr>
<th>Metropolitan area</th>
<th>NPV profitability threshold (connexion rate from which NPV &gt; 0)</th>
<th>Rankings of payback periods (ascending order)</th>
<th>Rankings of LCOH (ascending order)</th>
<th>Rankings of GHG abatement cost (ascending order)</th>
</tr>
</thead>
<tbody>
<tr>
<td>České Budějovice</td>
<td>75%</td>
<td>6</td>
<td>9</td>
<td>5</td>
</tr>
<tr>
<td>Brno</td>
<td>27%</td>
<td>4</td>
<td>6</td>
<td>3</td>
</tr>
<tr>
<td>Helsinki</td>
<td>13%</td>
<td>3</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Dunkerque</td>
<td>16%</td>
<td>3</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>Lyon</td>
<td>5%</td>
<td>1</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Paris</td>
<td>2%</td>
<td>1</td>
<td>1</td>
<td>2</td>
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<tr>
<td>Paks</td>
<td>NPV &lt; 0</td>
<td>&gt; 40 years</td>
<td>11</td>
<td>7</td>
</tr>
<tr>
<td>Weljherowo</td>
<td>NPV &lt; 0</td>
<td>7</td>
<td>9</td>
<td>5</td>
</tr>
<tr>
<td>+ Gdynia</td>
<td>51%</td>
<td>4</td>
<td>7</td>
<td>4</td>
</tr>
<tr>
<td>+ Gdansk</td>
<td>61%</td>
<td>5</td>
<td>8</td>
<td>4</td>
</tr>
<tr>
<td>Krško</td>
<td>NPV &lt; 0</td>
<td>8</td>
<td>9</td>
<td>6</td>
</tr>
<tr>
<td>+ Brežice</td>
<td>NPV &lt; 0</td>
<td>&gt; 40 years</td>
<td>10</td>
<td>7</td>
</tr>
<tr>
<td>Bristol</td>
<td>7%</td>
<td>2</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>Newcastle</td>
<td>11%</td>
<td>3</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>London</td>
<td>3%</td>
<td>2</td>
<td>3</td>
<td>1</td>
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</table>
Appendix B: How to calculate GHG emissions savings?

<table>
<thead>
<tr>
<th>Direct emissions (t eCO₂/GWhₜₜ), IPCC (2006)</th>
<th>Lifecycle emissions, EU27 average (t eCO₂/GWhₜₜ), Ecoinvent (2005)</th>
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</thead>
<tbody>
<tr>
<td>Biomass</td>
<td>0</td>
</tr>
<tr>
<td>Fuel oil</td>
<td>264,8</td>
</tr>
<tr>
<td>Natural gas</td>
<td>202,2</td>
</tr>
<tr>
<td>Coal</td>
<td>347,7</td>
</tr>
<tr>
<td>Electricity</td>
<td><strong>Country average</strong> 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)</td>
</tr>
</tbody>
</table>

\[
Cm_{GHG} (\text{€/tCO}_2), \text{ the marginal GHG abatement cost} = \frac{LCOH \cdot Q_{DH}}{EF_{BAU} - E_{DH+NCHP}}
\]

\[
E_{DH+NCHP}, \text{ specific GHG emissions of DH+NCHP}
\]

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

\[
LCOH (\text{€/MWh}) \quad Q_{DH}: \text{ annual DH delivery (MWh/year)}
\]