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Stratego
ENHANCED HEATING
& COOLING PLANS

# Quantifying the Potential for District Heating and Cooling in EU Member States

***Work Package 2***

***Background Report 6***

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# 1. Potential for district heating and cooling and their corresponding distribution costs

## 1.1. Objectives

For the five Stratego target countries: CZ, HR, IT, RO and UK the prospective DH areas are to be delineated and their properties are to be mapped. The costs of establishing district heating and cooling grids are to be calculated on the basis of empirical, analytical cost models. Using the mapped potentials for district heating and cooling in combination with the cost mapping and the properties of prospective district heating and cooling grids, cost-supply analysis is to be carried out, which yields tabular results for export to energy systems analysis as well as a graphical representation of the economic constraints of utilizing the potential to develop district energy systems.

## 1.2. Potentials for district heat development

Potentials for the development of district heating are assessed initially using heat demand density as a single criterion. Where ever heat demand is falling into categories of 0 – 30, 30 – 100, 100 – 300 or above 300 TJ/km$^2$, it is being summarized for a whole country. This first assessment of potentials leaves out the connectedness of systems, the size of operations and its location relative to renewable energy sources. What can be seen in Table 1 is how the potentials are distributed for the five countries. With current district heating technology, which may require heat demand densities above 100 TJ/km$^2$, the potential is highest in the UK, in relative and absolute terms. A country like Croatia however has just 12% of is present heat demand located in sufficiently dense areas, and size and location of the country in a warmer climate also mean that the absolute heat market is very small. With advanced 4$^{th}$ generation district heating systems (4DH), the required heat demand densities are lower, increasing the shares of heat demand likely to be covered with 4DH systems to 57 to 86%.

**Table 1: Heat demand by heat demand density classes, which explain the suitability for developing district heating, in PJ and in %.**

| Member State | CZ | HR | IT | RO | UK |
|---|---|---|---|---|---|
| Heat demand density 0 - 30 TJ/km$^2$ (PJ) | 28 | 13 | 46 | 60 | 46 |
| Heat demand density 30 - 100 TJ/km$^2$ (PJ) | 95 | 28 | 321 | 91 | 306 |
| Heat demand density 100 - 300 TJ/km$^2$ (PJ) | 110 | 8 | 664 | 95 | 1,075 |
| Heat demand density > 300 TJ/km$^2$ (PJ) | 24 | 0 | 954 | 2 | 118 |
| Heat demand in built-up areas, sum (PJ) | 256 | 48 | 1,124 | 248 | 1,545 |
| Heat demand, total (PJ) | 290 | 63 | 1,344 | 290 | 1,738 |
| Heat demand in rural areas (PJ) | 34 | 14 | 219 | 42 | 192 |
| Heat demand in rural areas, % | 12% | 23% | 16% | 14% | 11% |
| DH Almost Impossible (0 - 30 TJ/km$^2$) | 10% | 20% | 3% | 21% | 3% |
| Potential for 4DH (30 - 100 TJ/km$^2$) | 33% | 44% | 24% | 31% | 18% |
| DH Currently Possible (100 - 300 TJ/km$^2$) | 38% | 12% | 49% | 33% | 62% |
| DH Highly Feasible (>300 TJ/km$^2$) | 8% | 0% | 7% | 1% | 7% |
| Cumulative Above 30 TJ/km$^2$ | 79% | 57% | 80% | 65% | 86% |
| Cumulative Above 100 TJ/km$^2$ | 46% | 13% | 56% | 34% | 69% |

## 1.3. Identification of potential district heating systems

In order to find coherent areas with heat demands, which could comprise prospective district heating areas, a clustering process is required. By means of contingency mapping, connected cells are grouped to individual heat supply areas, see Figure 1. A threshold of 1 km is used to interconnect neighbouring areas. The result is a clustering of heat demand into larger, coherent areas, which may comprise prospective district heating systems, depending on their demand densities and the resulting costs of district heat supply.

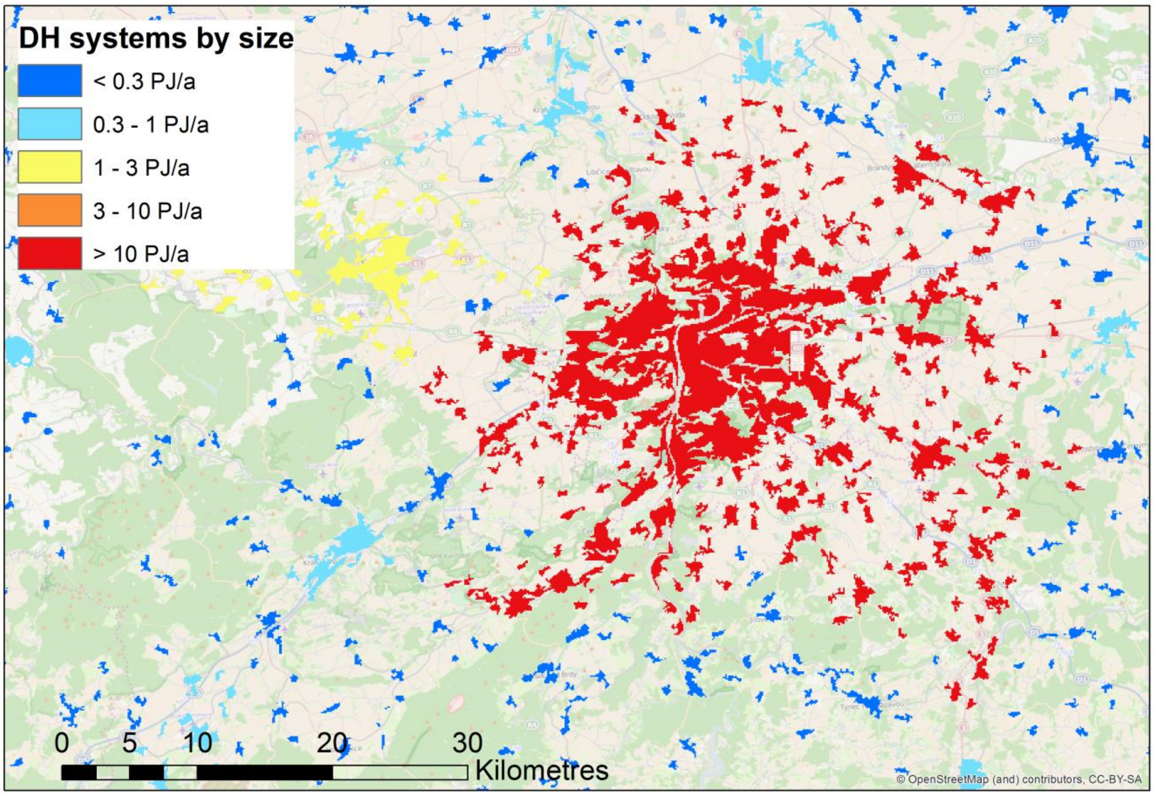


**Figure 1: Prospective DH systems by size (sum of gross annual heat demand) around the city of Prague, Czech Republic. This mapping allows for a quantification of potentials and costs by several system variables, one of which is the size of a system, which may be related to the heat production technologies used. Furthermore, systems located less than 1 km apart are considered coherent, i.e. they could be connected to agglomerated systems.**

For each of these areas a number of attributes can be derived from the map, or attached from other map layers using spatial analysis. By means of zonal statistics by district heat supply area, the sum of heat demand, the area and the average heat demand densities are fused to the heat supply area layer. The attributes are then used in the cost-supply areas in order to establish relationships of potentials and costs by various system properties, such as system size in terms of area or heat demand, as well as access to renewable energy sources etc.

Table 2 shows the heat demand of the five targeted countries by prospective DH system size, which is the sum of heat demand within each individual, coherent area. While very large systems above 10 PJ/a comprise about 20% of the non-rural heat demand in the Czech Republic, in the UK this is more than half. Romania is predominantly rural, which means that about half of the heat demand is located in areas, which have less than 0.3 PJ annual heat demand. Systems in the size of 3 to 10

PJ/a are underrepresented in all countries, where only about 10% of the heat demand is located in cities with a cumulative heat demand of this magnitude.

**Table 2: Heat demand by district heating system size for the 5 Stratego countries, in PJ.**

| Heat demand by DH system size, PJ | CZ | HR | IT | RO | UK |
|---|---|---|---|---|---|
| **< 0.3 PJ** | 87 | 20 | 283 | 116 | 155 |
| **0.3 - 1 PJ** | 51 | 8 | 152 | 38 | 138 |
| **1 - 3 PJ** | 38 | 8 | 140 | 36 | 176 |
| **3 - 10 PJ** | 25 | - | 99 | 30 | 196 |
| **> 10 PJ** | 55 | 12 | 451 | 28 | 881 |
| **Sum (excl. rural)** | 256 | 48 | 1,125 | 248 | 1,546 |

## 1.4. Potentials for district cooling development

District cooling is much less developed in Europe and also the potentials for developing district cooling systems are much lower, in general. From Table 3 it follows that Croatia and the UK have significant potentials for district cooling under current conditions, while with the advent of advanced district cooling systems by far the most cooling demand could be covered by these systems. Please observe that the threshold levels for possibility are different than for district heating.

**Table 3: Cooling demand by cooling demand density as a means to identify potential district cooling areas, in PJ and in %.**

| Member State | CZ | HR | IT | RO | UK |
|---|---|---|---|---|---|
| **Cooling Demand (PJ) by Cooling Density, < 30 TJ/km²** | 1.41 | 0.19 | 0.83 | 0.01 | 0 |
| **Cooling Demand (PJ) by Cooling Density 30 - 100 TJ/km²** | 18.65 | 0.26 | 23.27 | 12.21 | 8.70 |
| **Cooling Demand (PJ) by Cooling Density 100-300 TJ/km²** | 0.53 | 9.16 | 133.58 | 0.03 | 42.28 |
| **Cooling Demand (PJ) by Cooling Density >300 TJ/km²** | 0.00 | 2.00 | 1.93 | 0 | 18.64 |
| **Cooling Demand (PJ) by Cooling Density, sum** | 20.60 | 11.60 | 159.60 | 12.25 | 69.62 |
| **Cooling demand, rural areas (< 30 TJ/km²)** | 7% | 2% | 1% | 0% | 0% |
| **DC Almost Impossible (30 - 100 TJ/km²)** | 91% | 2% | 15% | 100% | 12% |
| **Potential for advanced DC (100 - 300 TJ/km²)** | 3% | 79% | 84% | 0% | 61% |
| **DC Currently Possible (> 300 TJ/km²)** | 0% | 17% | 1% | 0% | 27% |
| **Cumulative Above 30 TJ/km²** | 93% | 98% | 99% | 100% | 100% |
| **Cumulative Above 100 TJ/km²** | 3% | 96% | 85% | 0% | 88% |

# 2. Assessment of investment costs for heat and cold distribution

## 2.1. Background

The assignment is to estimate the average investment costs for heat and cold distribution as a function of the heat and cold densities for modelling and planning purposes. This aim is achieved by elaborating the basic theory of heat and cold distribution costs presented in section 11.4 of the international textbook of (Frederiksen & Werner, 2013).

## 2.2. Method

The expected output from this estimation analysis is to obtain the specific investment cost for heat and cold distribution as a function of heat and cold densities. This output is achieved in five steps:

- Estimation of the investment cost per metre of trench length by pipe dimension and ground conditions.
- Estimation of the average investment cost with respect to typical ground conditions.
- Estimation of the average pipe dimension from the linear heat density
- Estimation of the average investment cost from the average pipe dimension as a function of the land area density as heat or cold demand per land area
- Final estimation of the specific investment cost per heat and cold sold as a function of the heat and cold densities.

## 2.3. Intermediate estimations

The two first two steps are presented in Figure 2, showing the investment cost for district heating pipes per trench length. The information is based on the Swedish cost level of 2007. Hereby, the cost level includes also a learning process for putting the pipes efficiently into the ground as achieved in mature district heating countries. Small pipes are normally used in areas with single family areas, with a high proportion of green areas. Wider pipes are normally used in inner city areas with higher building densities and higher construction costs, as presented in Figure 2. These ground conditions are considered when creating the average cost line by using the marked dots in Figure 2. This estimated linear average cost line will have the following composition:

*Average investment cost = 130 + 2858*(average pipe diameter in m)*  [EUR/m]

The third step will utilize the experienced relation between the linear heat densities and the average pipe dimensions in 134 Swedish heat distribution networks or parts of networks as presented in Figure 11.8 in (Frederiksen & Werner, 2013). The linear heat density is the heat sold annually divided by the corresponding trench length. This relation can be written as

*Average pipe dimension = 0.0486 * LN (linear heat density in MWh/m) + 0.063*  [m]

The fourth step is obtained by combining the average cost line in Figure 2, the relation above for the average pipe dimension, and an effective width of 65 m. The latter assumption for the effective width is based on Figure 11.10 in (Frederiksen & Werner, 2013) showing that the effective width is almost constant at that level for plot ratios above 0.4. The effective width is needed since the linear densities are equal to the product of the effective width and the land area densities. The intermediate result from the fourth step is presented in Figure 3.

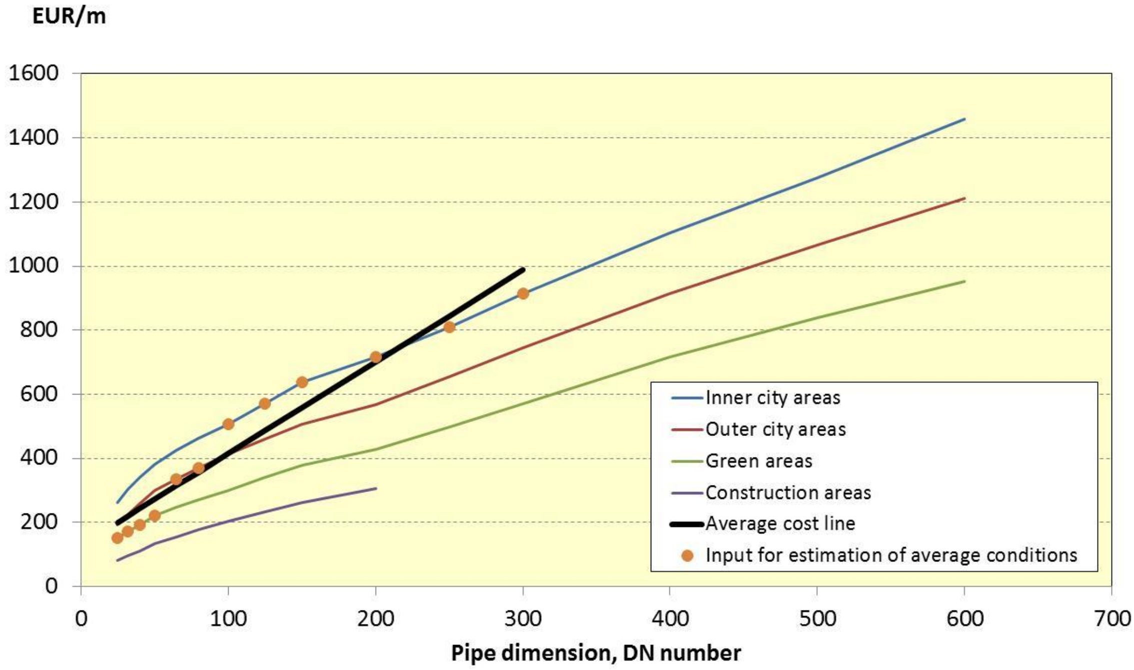


**Figure 2: The investment cost for distribution pipes per trench length by pipe dimension and ground conditions based on Swedish experiences for the 2007 cost level.**

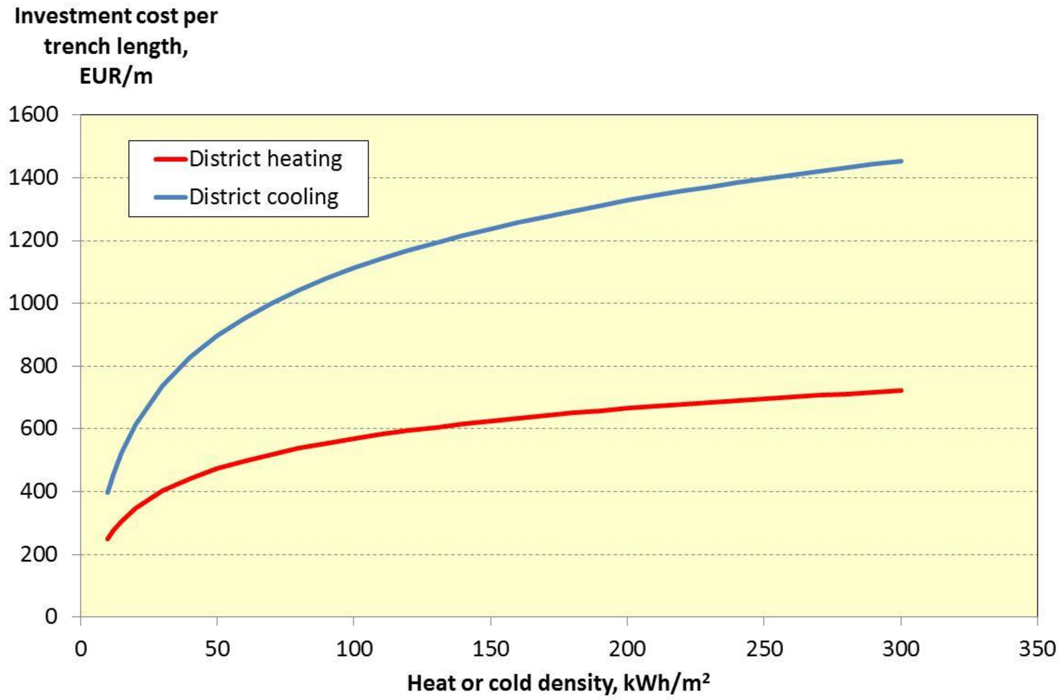


**Figure 3: The estimated average distribution costs for district heating and district cooling as a function of the heat and cold densities, respectively.**

The average cost line for district cooling was estimated with pipe dimensions that are wider than the corresponding pipe dimension for district heating. The used upscaling factor was the square root of five, since the flows in district cooling networks are about five times higher than in district heating networks at same demand levels. This higher flow level appear since the temperature differences in district cooling networks are about one fifth of the temperature differences in district heating networks.

## 2.4. Result

The final fifth and resulting step in the estimation is presented in Figure 3. The specific average investment costs were estimated by dividing the average investment costs in Figure 2 by the corresponding linear densities as defined in (Frederiksen & Werner, 2013). The linear densities were again estimated by the product of the land area densities with the assumed constant effective width of 65 m.

These specific average investment costs are consequentially being used within the STRATEGO project for overall assessments and feasibility studies for new or extended district heating and district cooling networks.

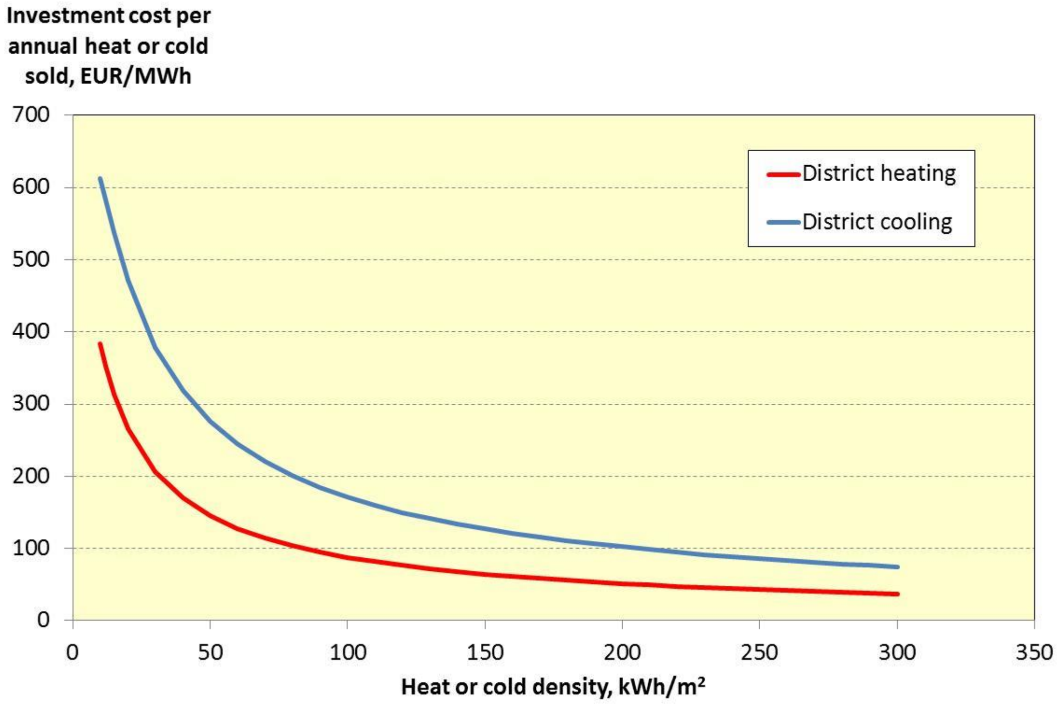


**Figure 4. The specific investment cost per heat or cold annually sold as function of the heat and cold densities, both related to the corresponding land area.**

From Figure 4 it follows that district cooling systems are more expensive to install for the same amount of energy delivered. The highest sensitivity to energy density is in the low density areas at the threshold to economic feasibility. It can be expected that the geographical boundaries between collective and individual heating or cooling systems are subject to high cost sensitivity also, as the cost curves suggest.

## 2.5. Cost-supply analysis

In cost-supply analysis, the marginal costs of cumulative utilization of a potential are given. A cost-supply curve establishes a mathematical relation between the amount of a given resource (in this case heating or cooling demand) and their costs (here the annualized investment costs to utilize the resource). The basic assumption is that the most economical portions of a resource are used first, to be followed by marginally less attractive, in economic terms. Cost-supply curves of district heating and cooling therefor allow for establishing the costs of supply especially for supply, whose cost highly depends on the potentials used. Because the potentials of district energy highly depend on the location, distribution and distance to sources, it is obvious to use GIS-based cost-supply modelling. The inputs to this are a) the quantification of costs, b) the quantification of supply available at these costs, and c) several other attributes to be used to further specify the cost-supply relations, such as member state, size of system, or the availability of renewable energy sources. All these data can be retrieved from the Heating and Cooling Atlas.

Investment costs have been annualized using a technical lifetime of 30 years and a socio-economic interest rate of 3%.

Figure 5 shows the cost-supply curves for the five countries participating in work package 2 of the Stratego-project as per cent of total urban heat demand. In the UK, the Czech Republic and in Italy about 25% of the total demand in villages, towns and cities can be supplied at less than 1.5 €/GJ annual heat demand. At a threshold of 2 €/GJ the share rises to 50 – 70% in these countries, which is well consistent with Persson and Werner (2011). For Romania the costs are on a higher level because of the low demand densities, while in Croatia the cost-supply curve in Figure 5 is very steep initially and the costs are generally very high, while the economic potential is very small for both countries. Generally, the steeper the cost curves, the higher i the cost sensitivity to geographical factors. It has to be added that the feasibility also depends on the costs of heat supply, and that the specific investment costs are here assumed to be the same for all countries despite different levels of labour costs etc.

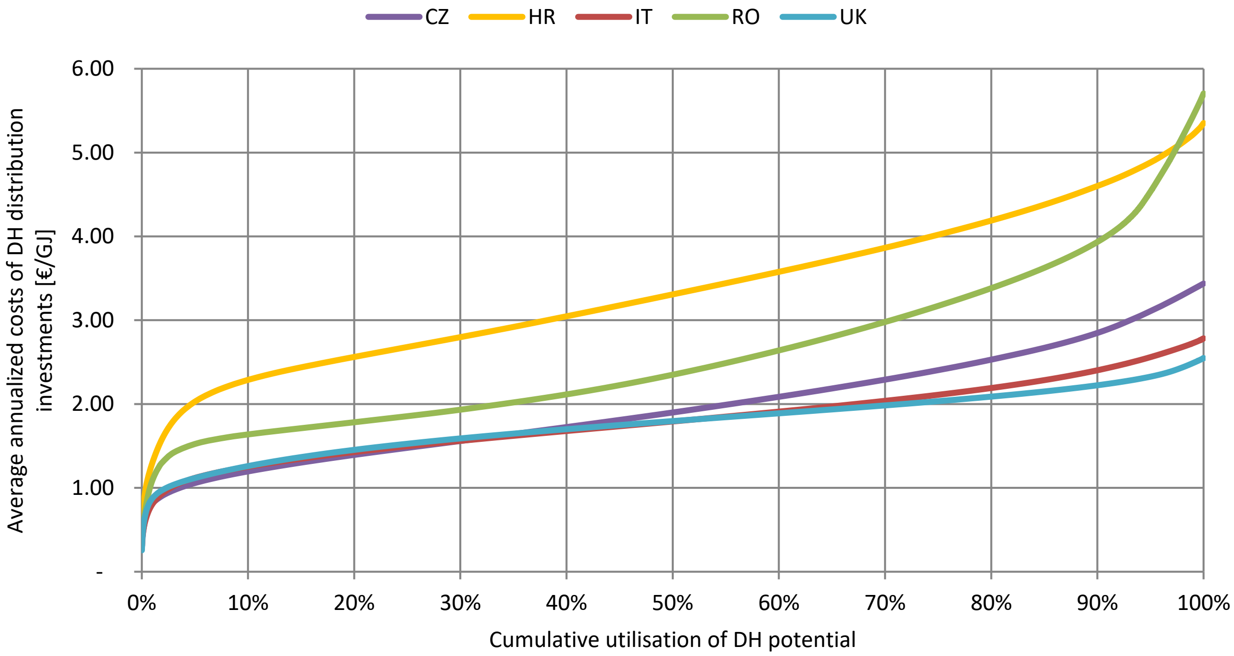


**Figure 5: Cost-supply curves for district heat distribution for the 5 STRATEGO countries showing the average, annualized costs of developing district heating distribution infrastructure.**

Costs of distributing district cooling are generally higher, partly because the higher specific costs but also because of generally lower cooling demand densities; see Figure 6. At a threshold of 2€/GJ (annualized) the UK may have 22% of its potential cooling demand covered with district cooling, while Croatia may just be at 3% and the other Stratego countries are left with minute potentials at this level. At 2.5 €/GJ, Italy reaches 4%, Croatia 44%, and the UK 56%. Italy reaches 42% at 3€/GJ, while the economic potential remains zero in the Czech Republic and in Romania. However, one great uncertainty is the degree of connectedness of the cooling demand in towns and cities, which along with the fact that all above figures relate to the potential cooling demand, makes any results uncertain and indicative only.

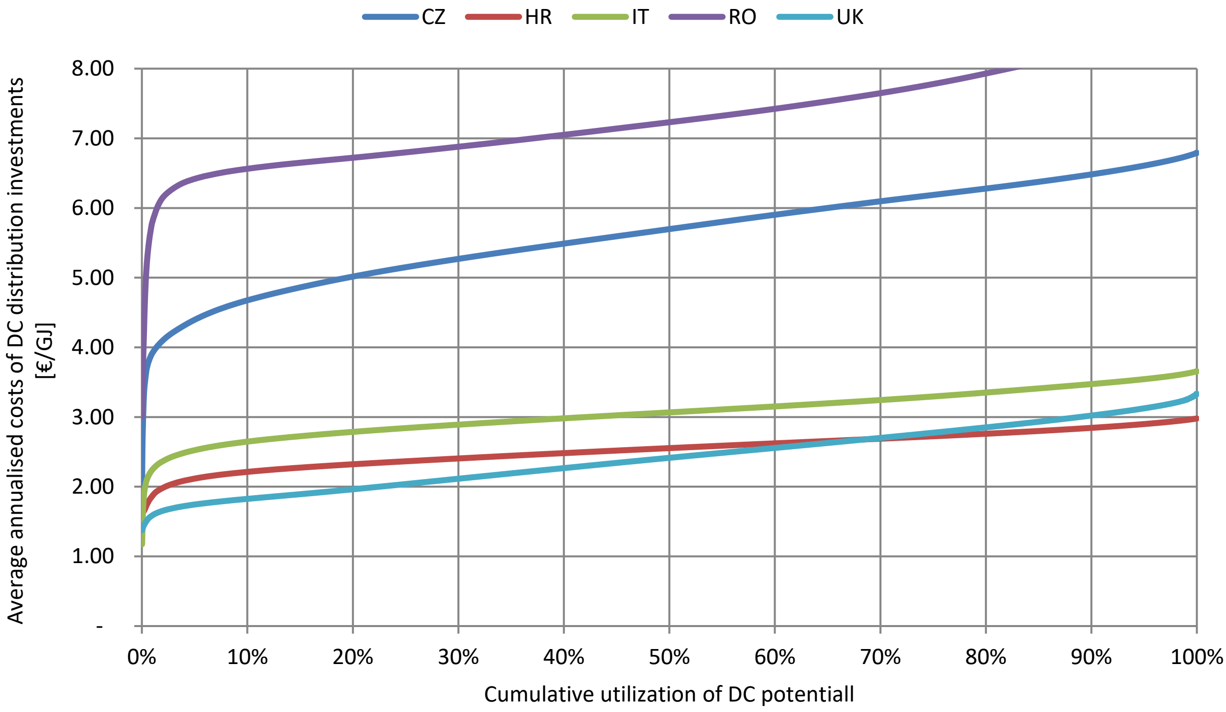


**Figure 6: Cost-supply analysis of district cooling grids showing average annualised costs of establishing DC grids in the five Stratego countries.**

## DH potential by size of system

Using the prospective supply system properties, cost-supply curves can be produced for different system types as well. Accordingly, Figure 7 presents a cost-supply curve for the Czech Republic by prospective district heating system size. Each curve features a more or less distinct turn at which costs increase disproportionally. This indicates a point where the economic (under most optimistic conditions) and the total potential can be separated. Usually the economic potential, it follows from this example, is about half of the total. Depending on the threshold for economic feasibility, which is subject to an overall economic assessment, because other cost factors, such as the production costs of district heat, need to be included, the economic potential for a given location and system size can be derived for systems of different size. It can be seen that larger systems, because they are usually located in denser urban areas of bigger towns and cities, have lower distribution costs than smaller systems. It shows that in the Czech Republic systems > 10PJ/a have a heat supply market of 38PJ/a at an annualized distribution cost of 1.5€/GJ, while another 10PJ/a can be found in systems of 1-3 and 3-10 PJ/a, respectively. For smaller systems the steeper curves furthermore indicate greater uncertainties in the economic potentials.

The economic potentials for district heating in Croatia require generally higher investments in distribution grid infrastructure. Assuming cost thresholds of 2.5 €/GJ, the biggest systems may realize 5PJ/a, while another 3PJ is available in smaller systems, see Figure 8.

Italy shows good economic potentials for the development of district heating systems, see Figure 9. At 2 €/GJ, almost all of the heat demand in the largest cities can be covered, while the share is 50-70% for systems between 0.5 and 10 PJ. Even the smallest systems < 0.3 PJ/a may represent a potential market.

Romania, because it is predominantly rural, has a rather small district heating potential. However, almost all of the heat demand in the biggest city of Bucharest can be covered by district heating, as well as the major part in systems between 1 and 10 PJ annual demand, see Figure 10.

Finally, the heat market of the UK is greatly dominated by large cities, which comprise 80% of the economic potential at 1.5 €/GJ annualized costs, see Figure 11.

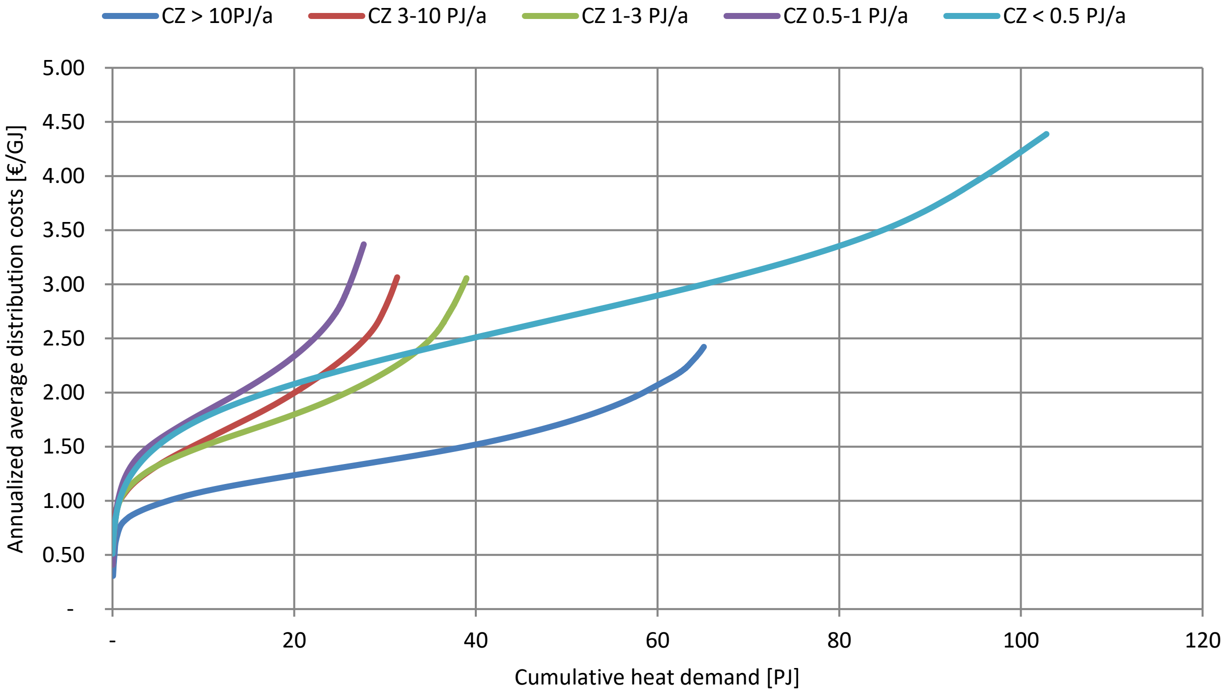


**Figure 7: The cost-supply curve for district heating potentials in the Czech Republic by prospective district heating system size.**

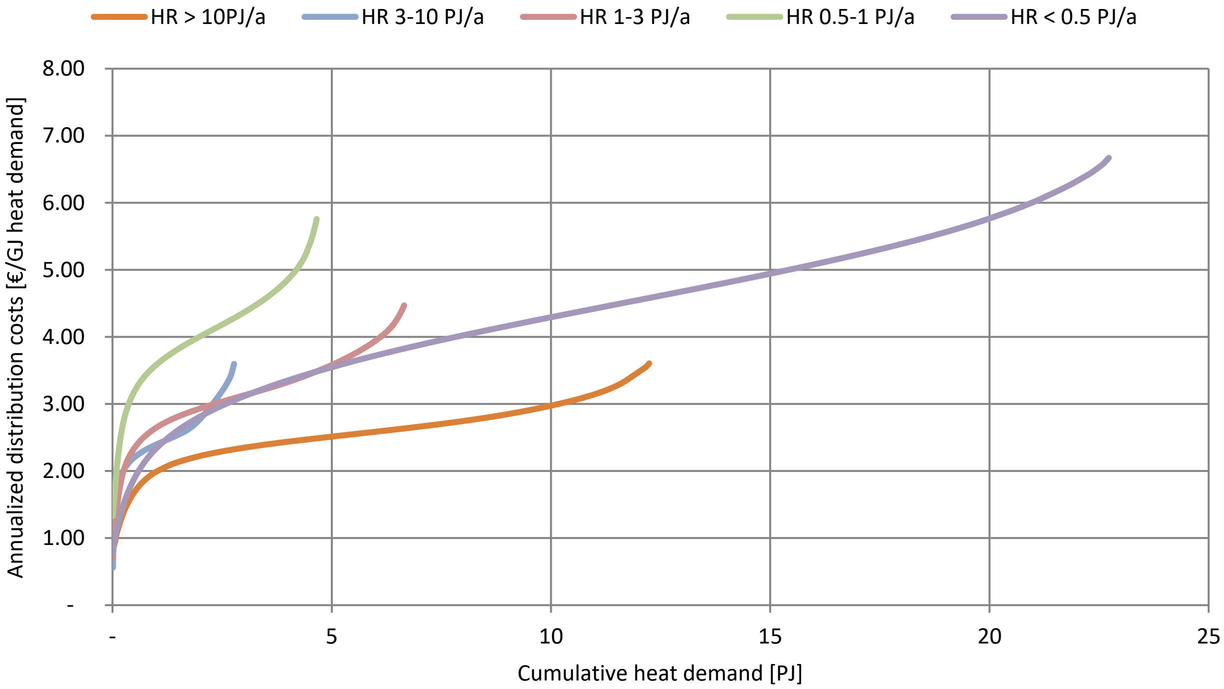


**Figure 8: Cost-supply curve for district hearting potentials in Croatia by prospective district heating system size.**

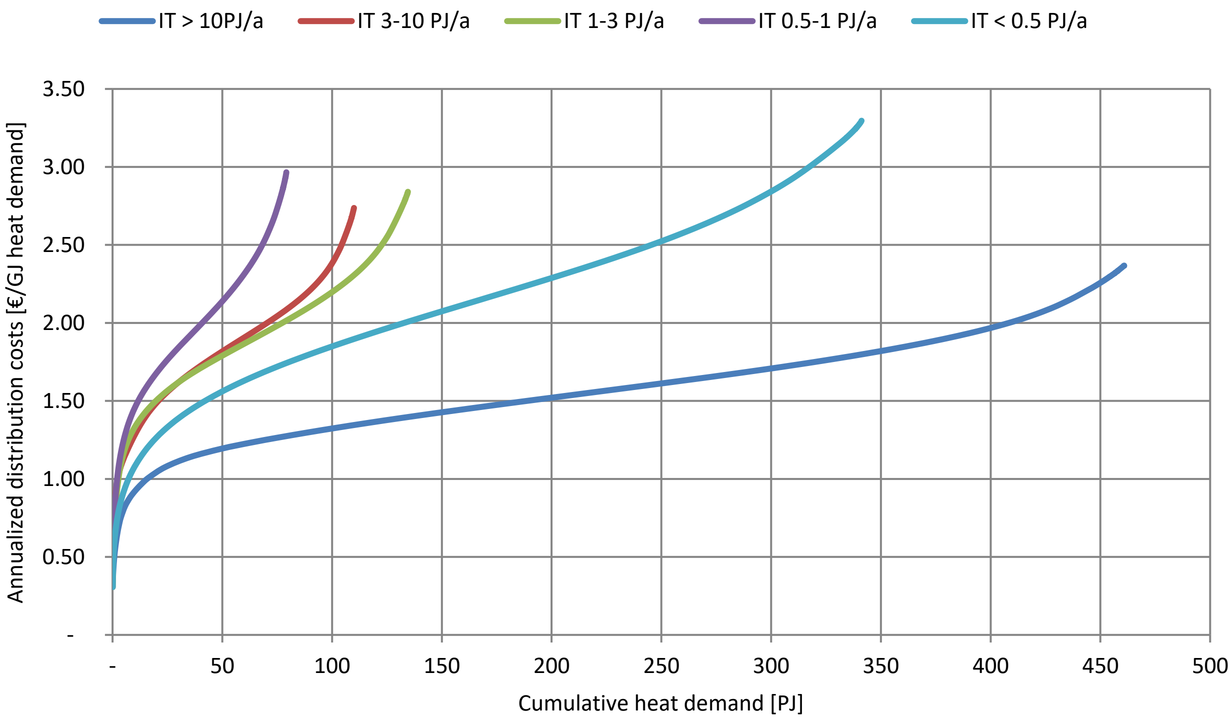


**Figure 9: Cost-supply curves for district heating potentials in Italy by prospective district heating system size.**

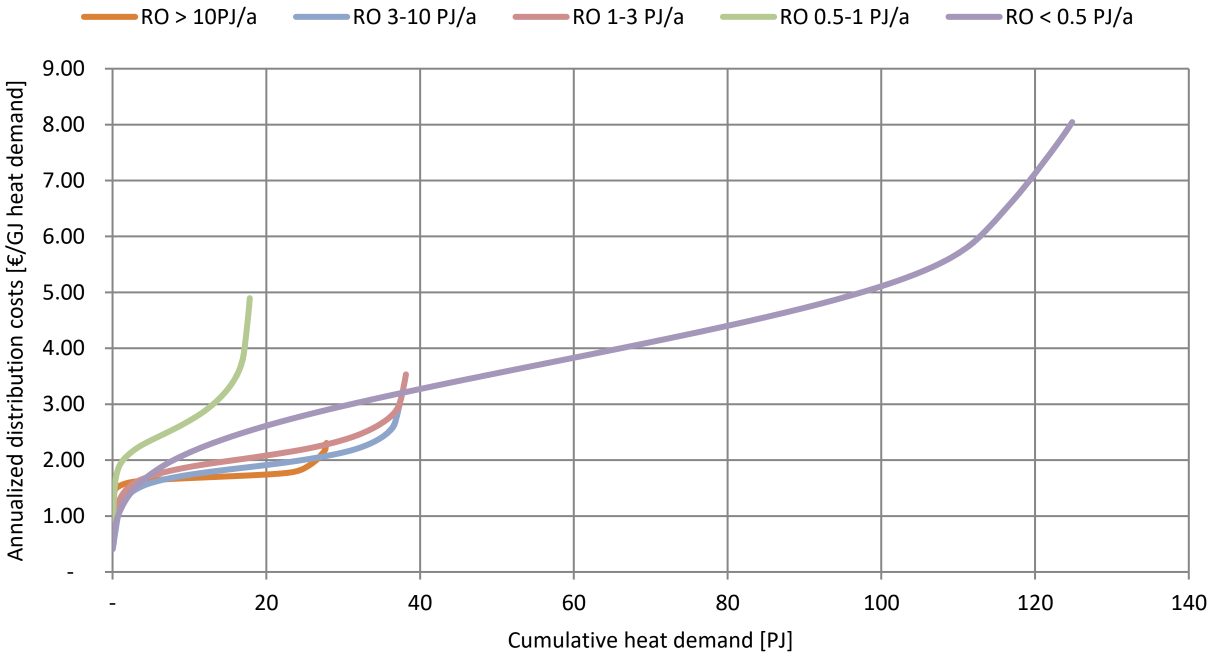


**Figure 10: Cost-supply curves for district heating potentials in Romania by prospective district heating system size.**

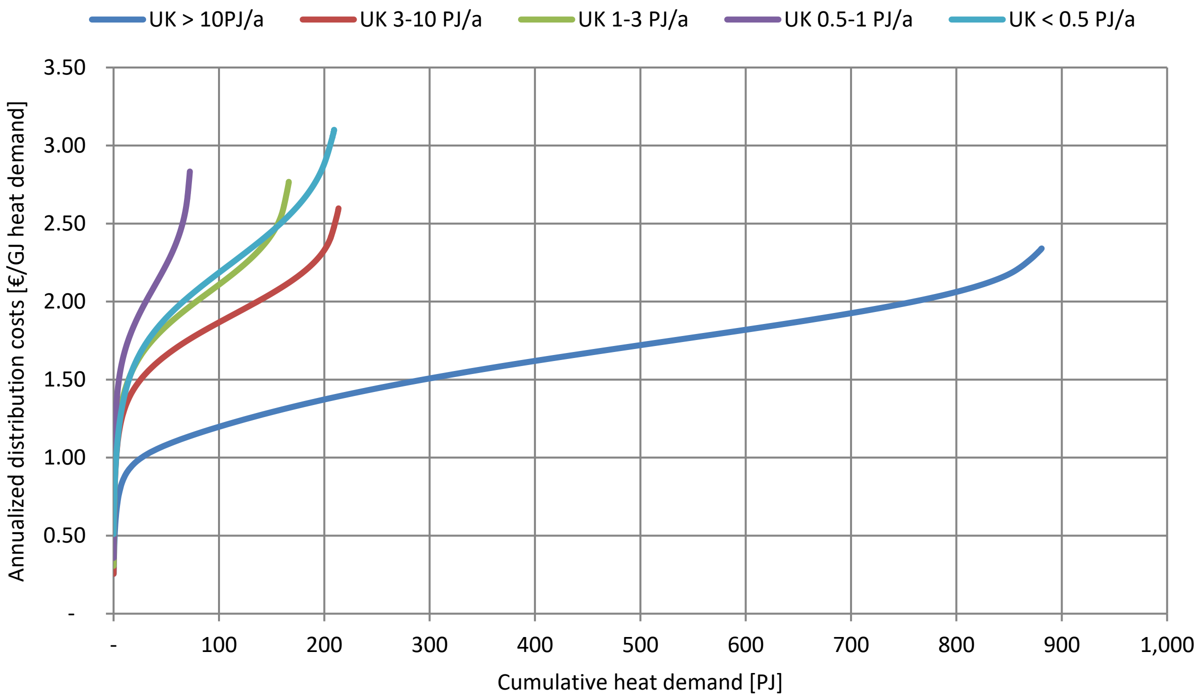


**Figure 11: Cost-supply curves for district heating potentials in the United Kingdom by prospective district heating system size.**

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