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Clustering of heat demand in district heating areas & estimation of transmission line costs

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Energy Economics Group

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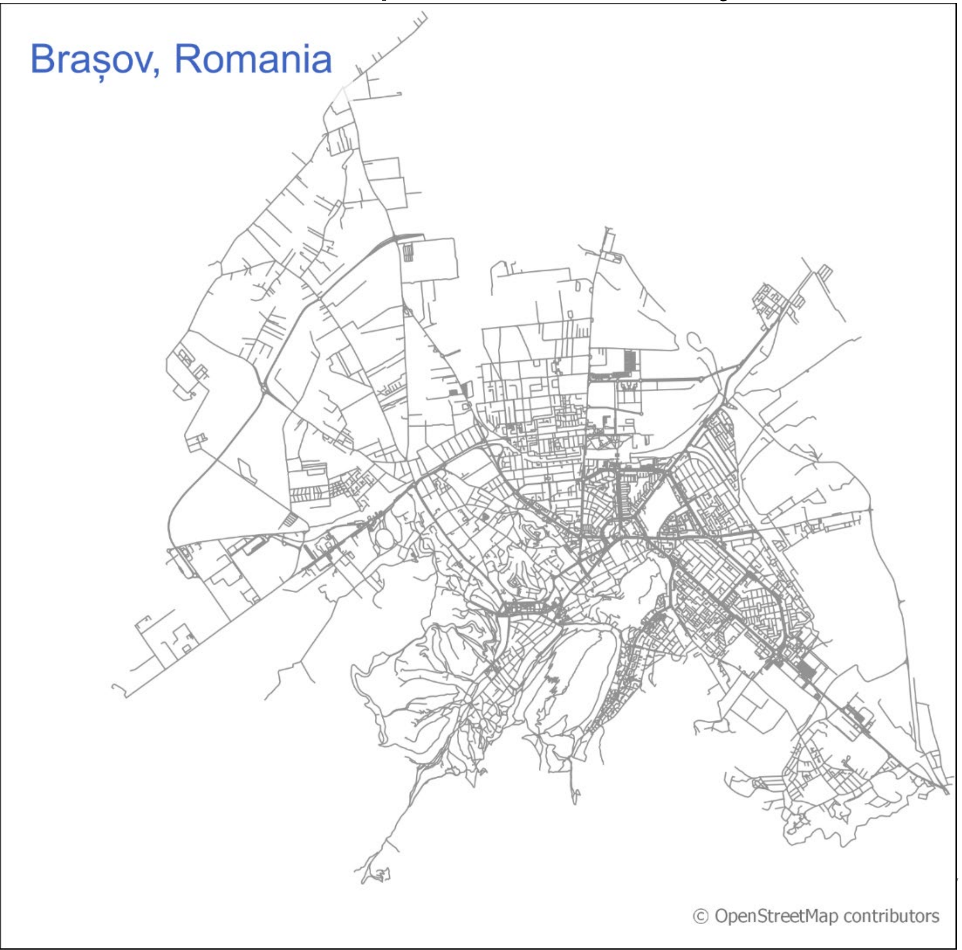
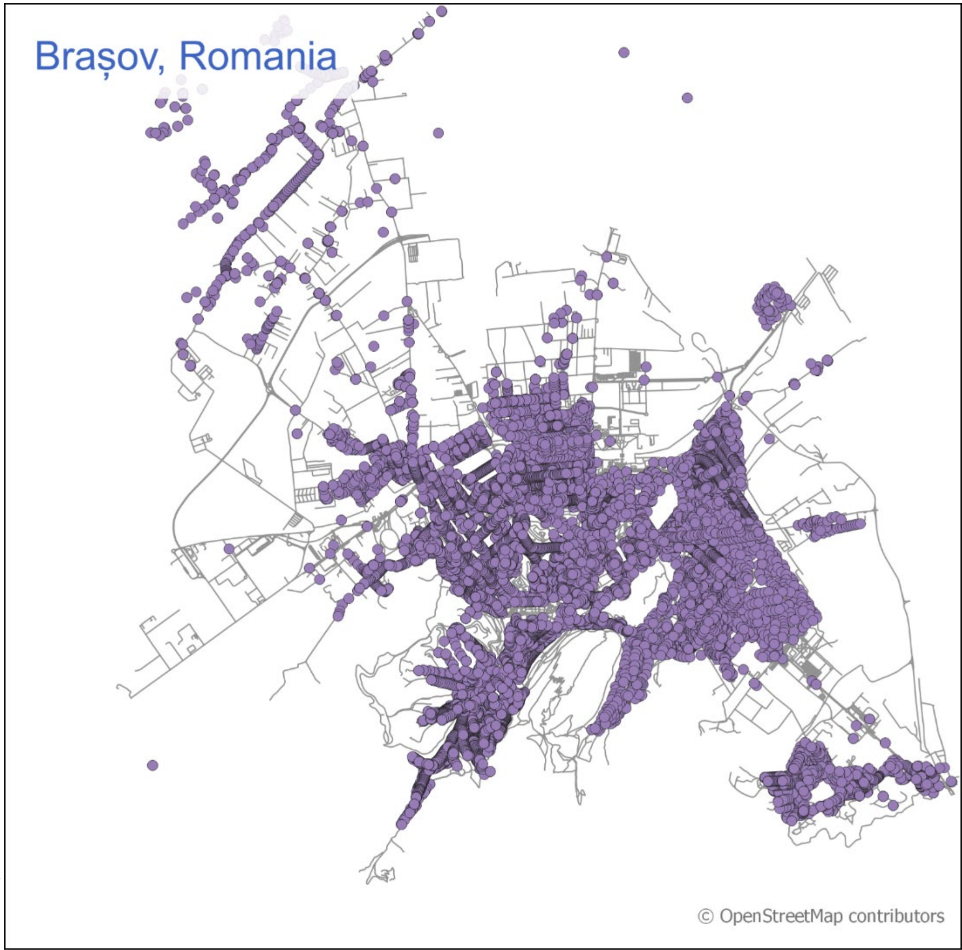
Start planning for DH system

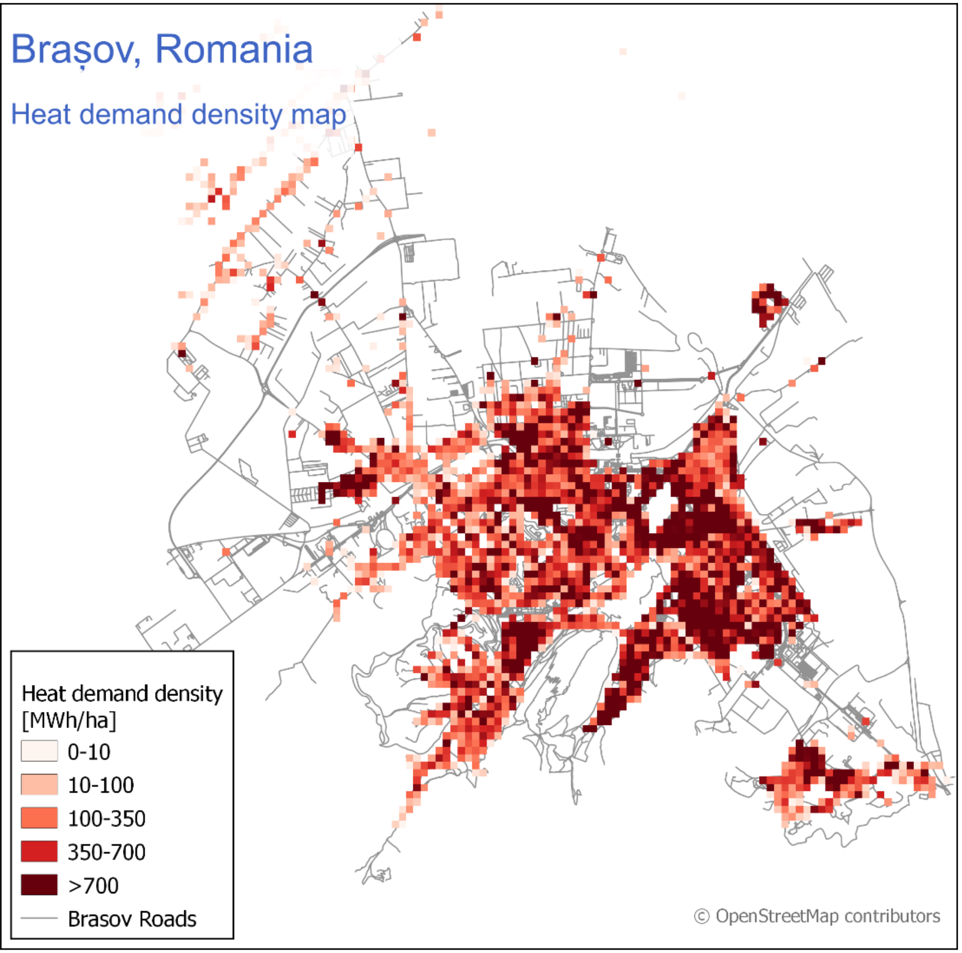
- For planning DH system, we should have a perspective to the urban areas and distribution of heat consumers.

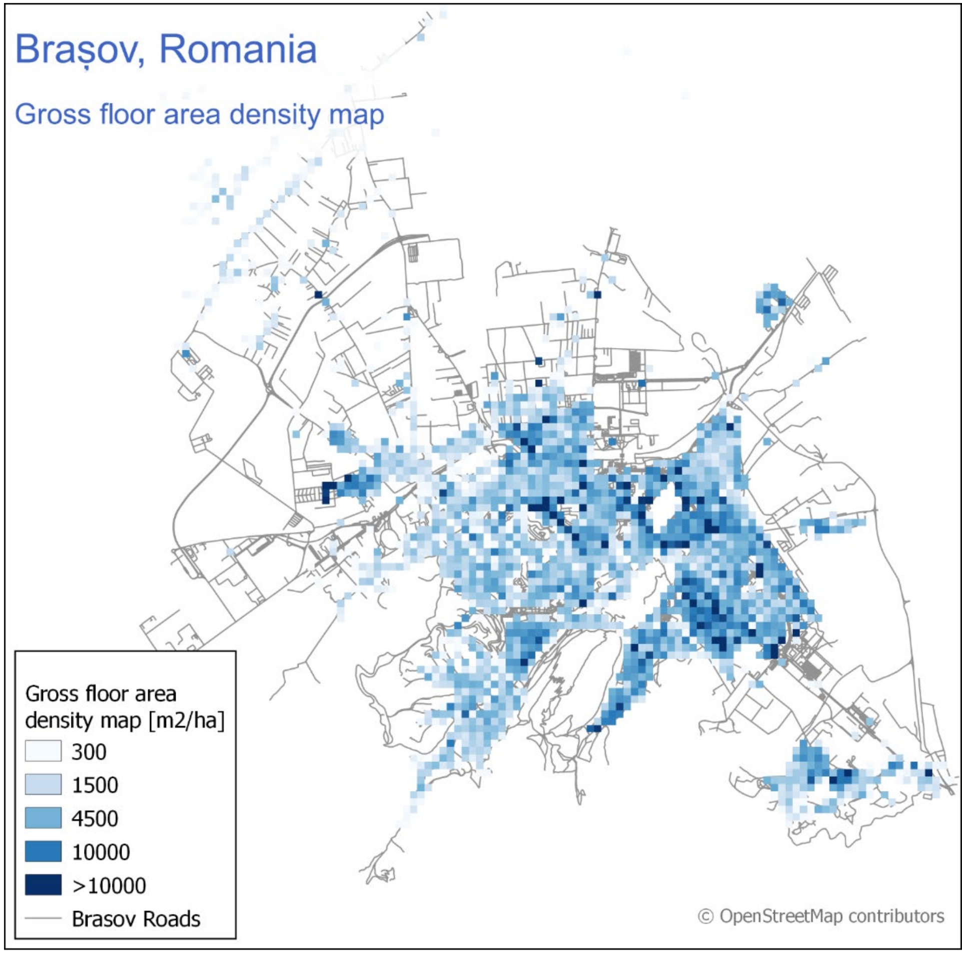
- Roads and points do not say much!





Heat & gross floor area density maps

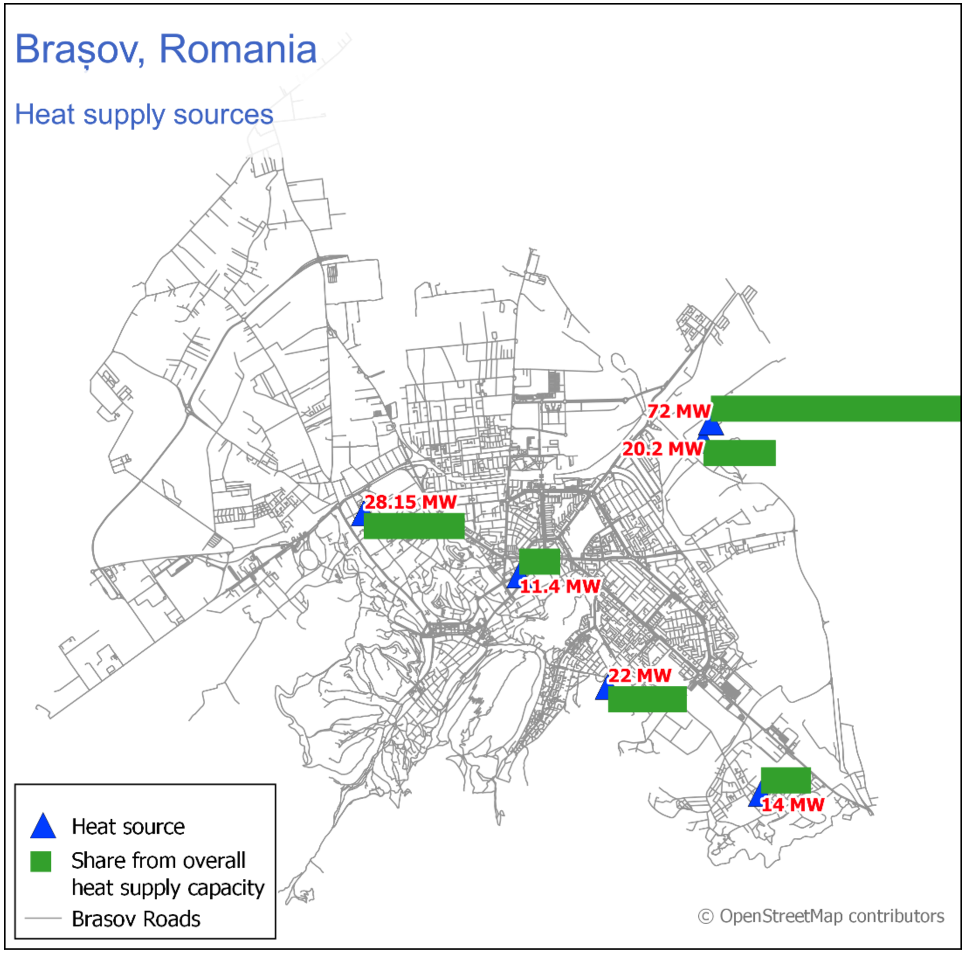




Persson U, Wiechers E, Möller B, Werner S. Heat Roadmap Europe: Heat distribution costs. Energy 2019;176:604–22. doi:10.1016/j.energy.2019.03.189.

$$Inv = \propto * \frac{C_1 + C_2 * d_a}{Q/L}$$

We should also know about heat sources!

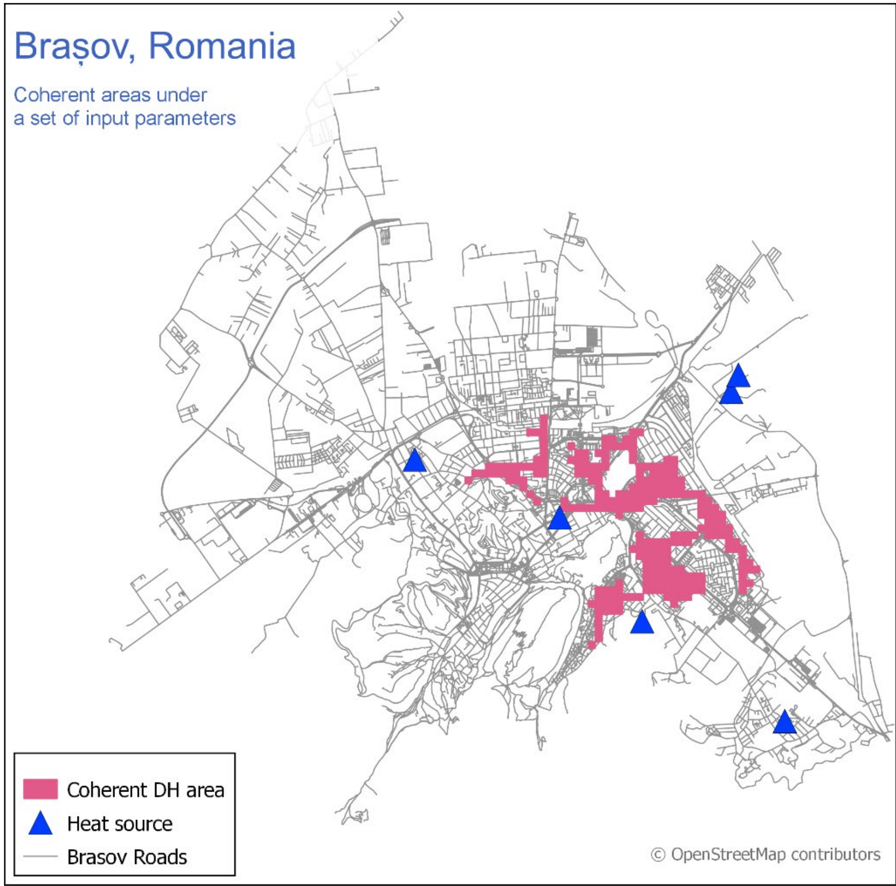


For each heat source, a simple cost function is defined:

Costs = fix_costs + Oper_costs

Determine potential DH areas (coherent DH areas)

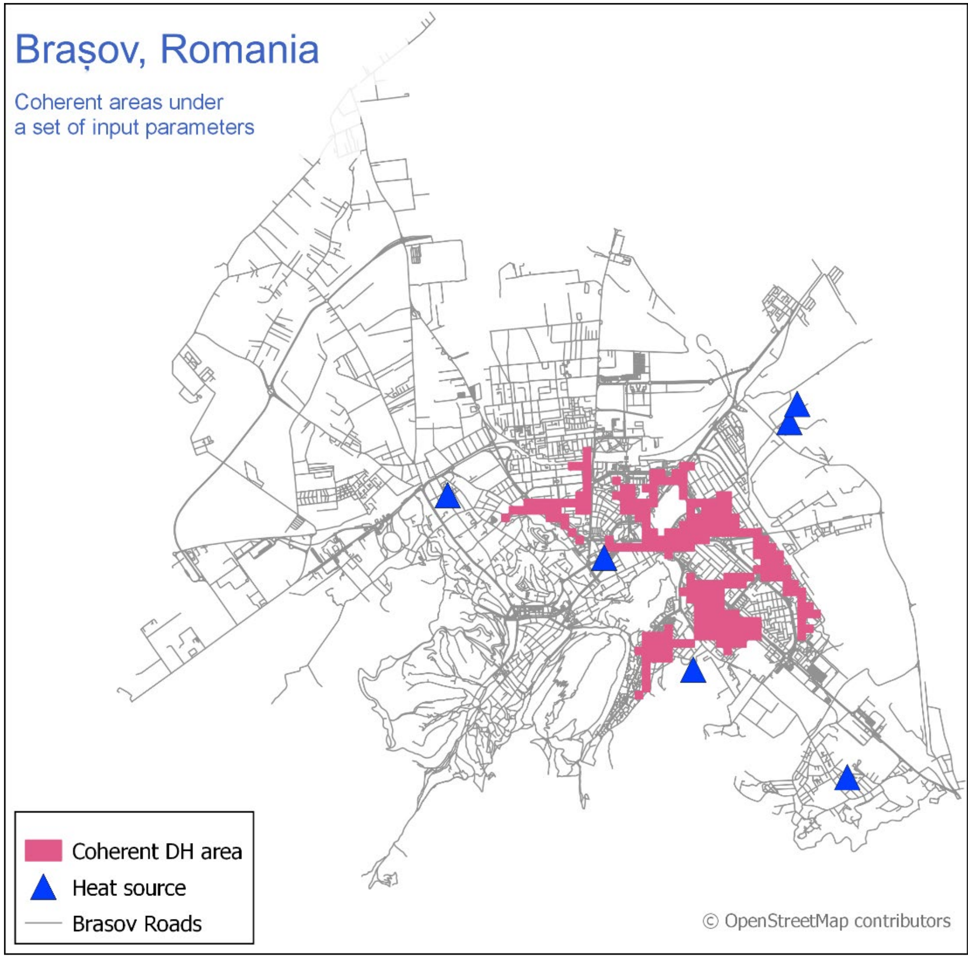
- Annualized specific investment cost per unit of delivered heat in each pixel: according to Persson et al.*.
- **Economic parameters**: available capital for investment, interest rate, investment period, grid cost ceiling, construction cost constant & coefficient
- **Other parameters**: connection rate, energy saving, heat demand, plot ratio
- Priority of coherent areas with higher heat demand.
- Conditions:
  - Distribution grid cost ceiling (EUR/MWh),
  - Available capital for investment in **<u>grid</u>** (Million EUR),
  - Available heat to supply.



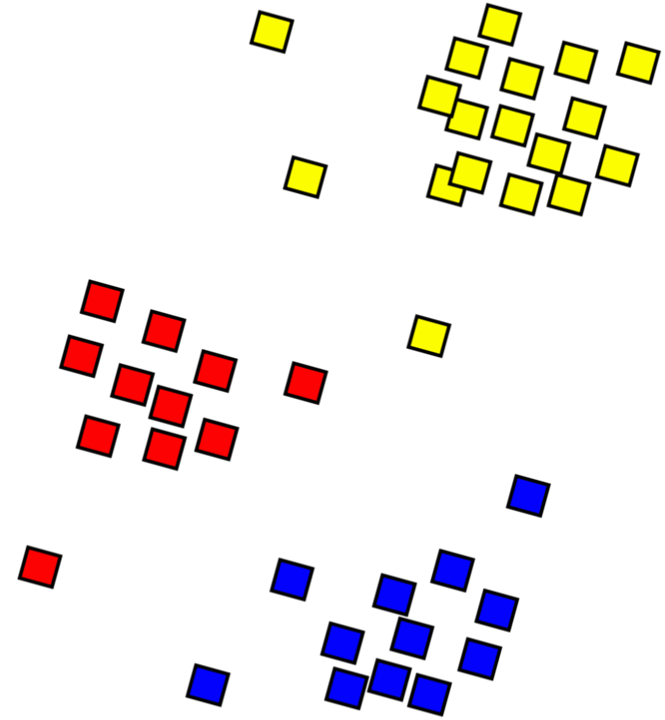
* Persson U, Wiechers E, Möller B, Werner S. Heat Roadmap Europe: Heat distribution costs. Energy 2019;176:604–22. doi:10.1016/j.energy.2019.03.189.

Research questions

- Is implementation of DH in all potential DH areas economically viable?
- How good is the estimation for the distribution grid?
- Which one of the available heat sources should be use?
- Which routes should be used to supply heat to DH areas?
- How much of their capacity is used?
- Which routes and capacities should be used for transmission lines? How much do they cost?



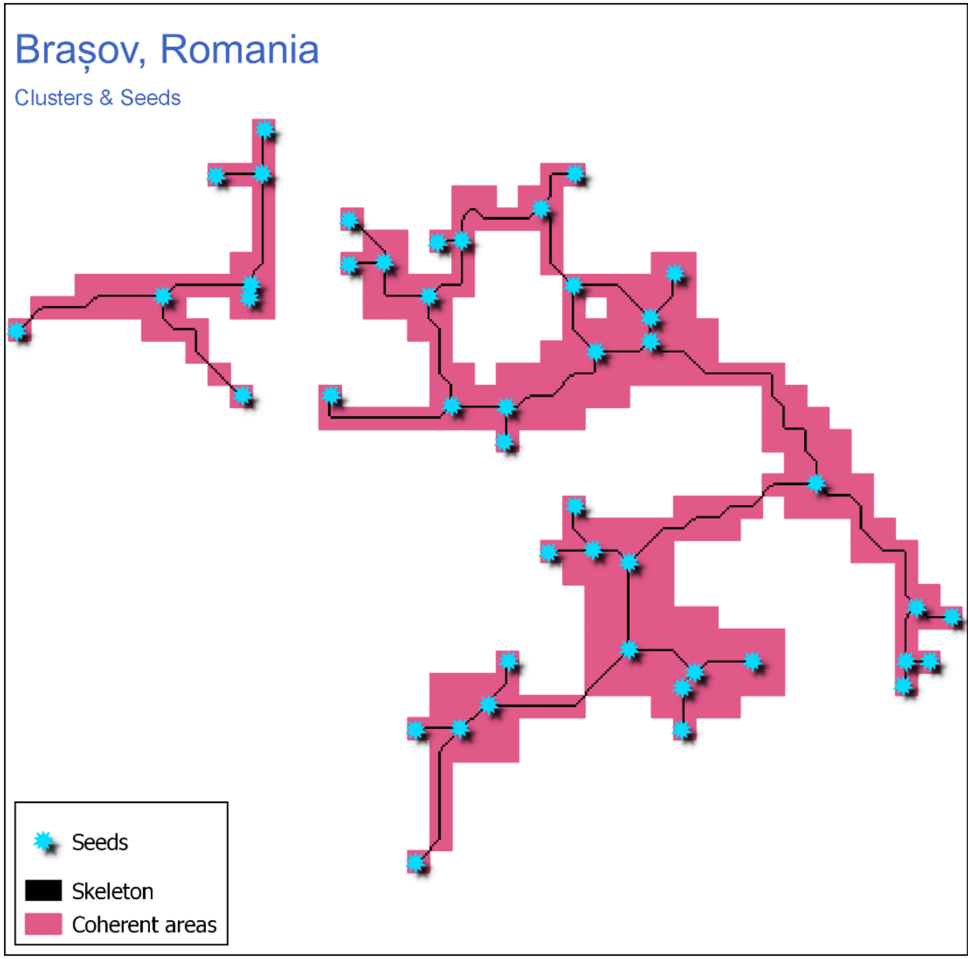
Clustering in coherent areas for answering to research questions



- Optimization-based clustering approach contributes in **reducing model complexity** and **increasing tangibility**,
  - We can plan transmission and distribution grids separately,
  - Distribution grid can be optimized and planned in each cluster → reduced complexity.
- Better control over development of DH system in each phase of implementation,
  - **Long-term** and **step-wised** planning of the expansion/extension of DH system,
  - Determination of profitable areas for starting the implementation,
  - Exclusion of non-profitable areas,
  - Estimation of costs and required capital in each phase,

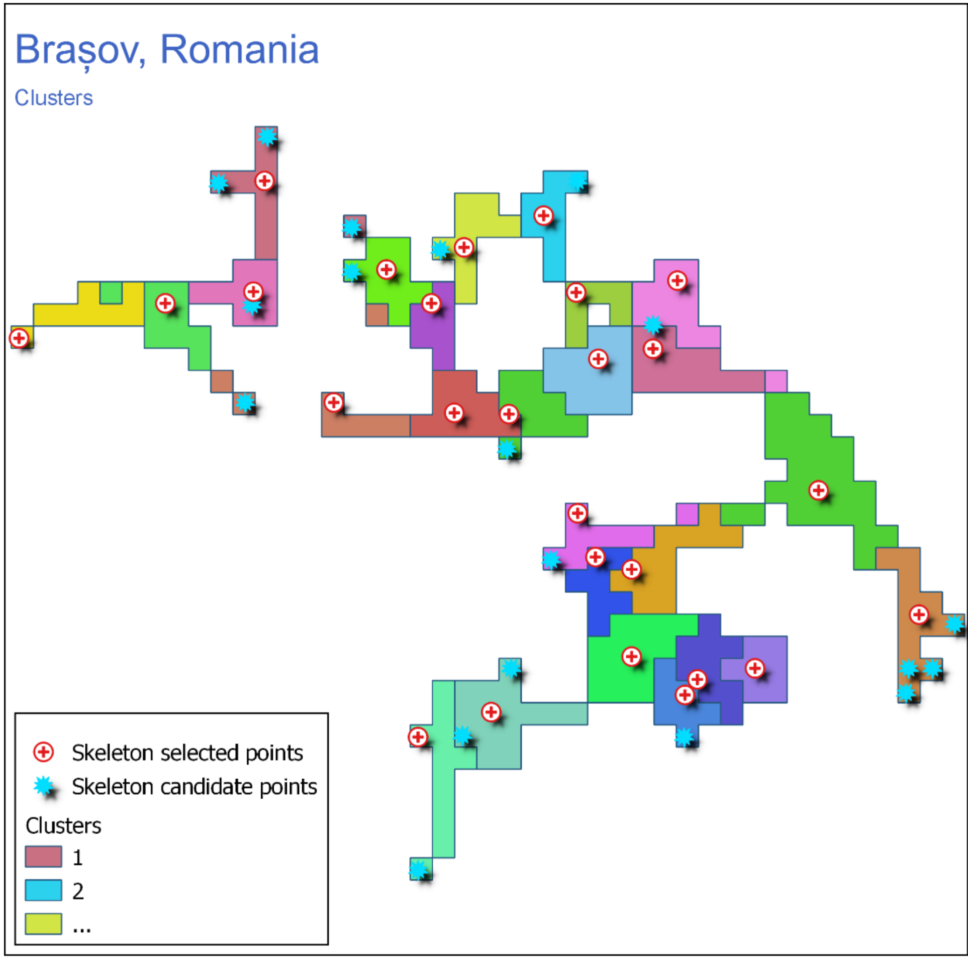
Clustering

- For clustering, the number and location of center points of clusters are important.
- A skeleton of the DH areas is calculated and all cross-sections and end-points are considered candidate seeds for constituting clusters.
- In a clustering model, best seeds and consequently, clusters are determined with **conditions on heat demand of clusters**.
- Transmission lines transfer heat from sources to the center of clusters. Subsequently, the heat is distributed within the clusters via distribution grids.



Clustering model

- Criteria:
  - Sum of the heat supplied by DH in a cluster must be:
    - **greater than** user-defined lower band (here, 6.3 GWh/a),
    - **lower than** user-defined upper band (here, 17 GWh/a, For dense areas).
    - To have a uniform set of clusters.
    - Decided based on connection rate and local conditions.
  - Each pixel must belong to **only one cluster**.
- Objective:
  - Sum of distances of all pixels from their cluster center should be minimized



Optimization model – Inputs

- Distance matrix
  - The distance between all pairs of **cluster centroids** and **sources** are calculated using **Open Street Map** routes (all routes except private ones).
- Cost function of heat sources
- Distribution grid costs (currently the values come from Persson et al. method)
- Heat sale price
- Available pipeline dimensions and heat volume that can be transferred by them
- Heat loss level in the grid
- Peak load factor

Optimization model – Objective & expected outputs

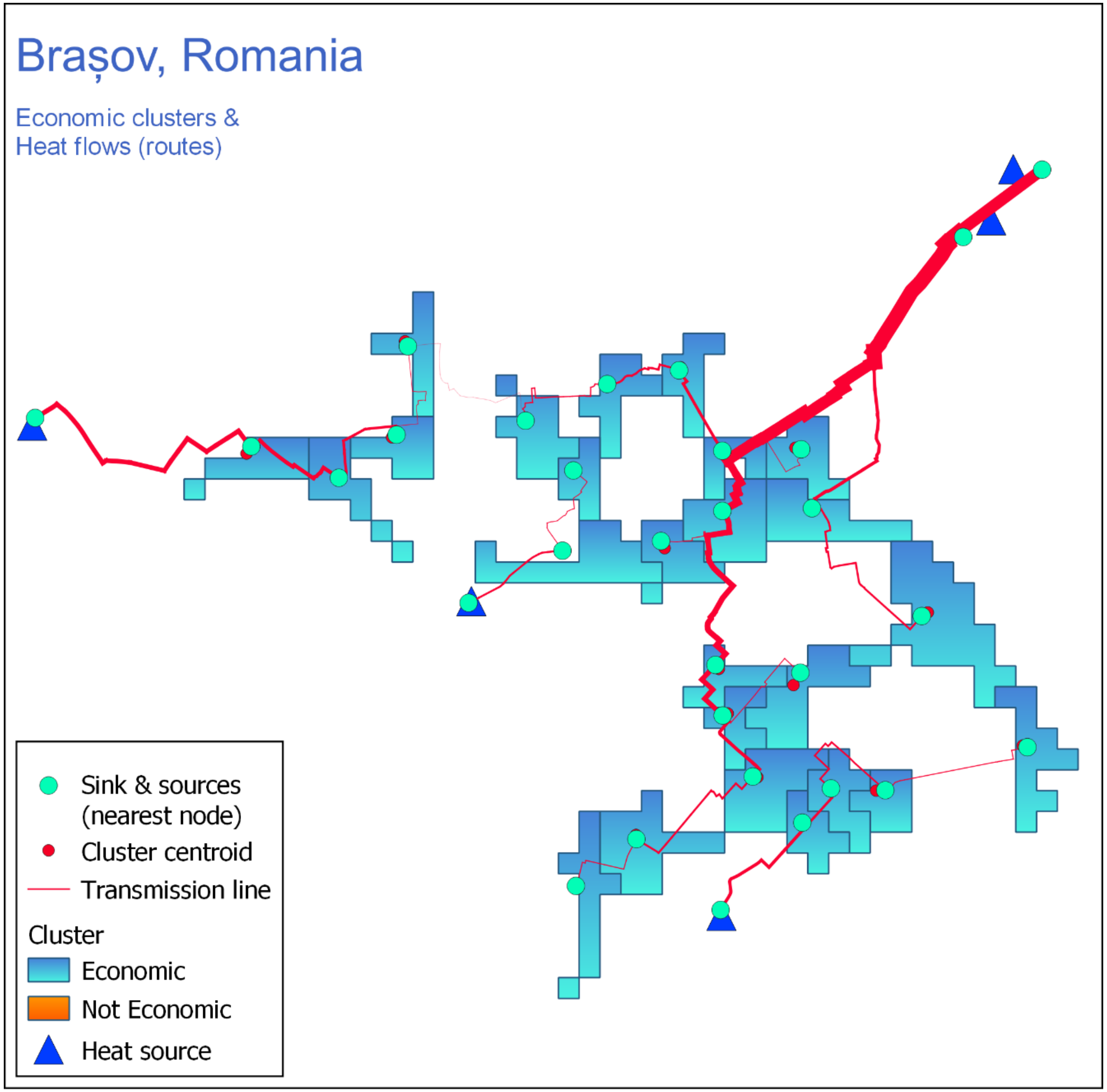
- MILP optimization
- The objective of the MILP optimization model is:

Maximising the heat sale profit

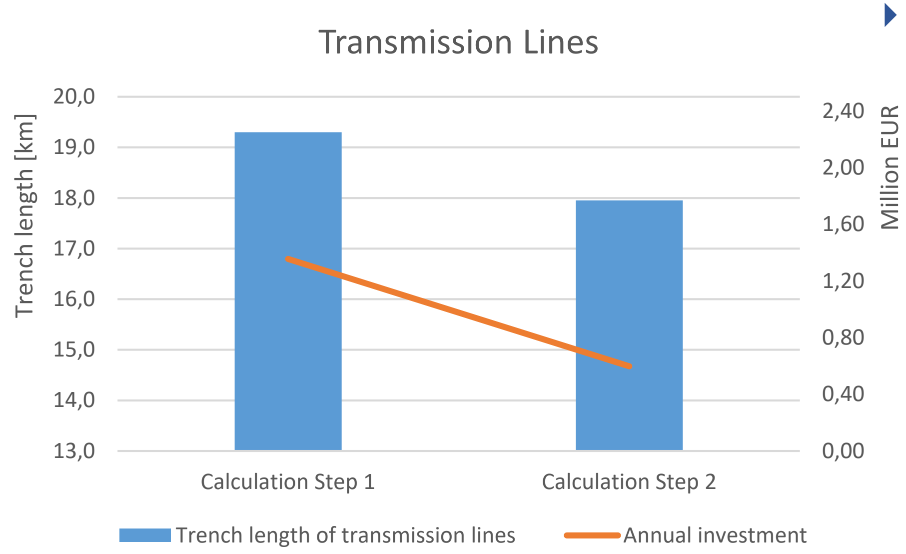
$$Max\ Profit = R_{HeatSale} - C_{HeatGen} - C_{Grid}$$

- Find economic clusters
- Determine the required sources
- Determine the transmission lines routes
- Determine the transmission lines dimensions

Economic clusters, heat flow direction & capacities



Summary of results & limitations



- Under defined conditions for this case study:

$$\frac{Trans.\,grid\ costs}{Total\ grid\ investment} * 100 \cong 17\%$$

- Current limitations:
  - It is assumed that grids operate at the same temperature level.
  - Heat losses are not function of pipe length and dimension.
  - Line costs are aggregation of field work, pipe work, materials, and digging. Therefore, in case of common routes for two pipes, digging costs are calculated twice.
  - Also distance matrix used in model considers distances between cluster centers. → over-estimation in model
    - Is recalculated after model calculation

Conclusions

- Transmission lines constitute moderate share of grid investment; however, have **great impact on profits & avoided costs** (avoided heat losses).

- The proposed method:
  - Leads to reduced model complexity and increased tangibility by:
    - introduction of DH coherent areas,
    - optimization-based clustering,
  - Enables us for:
    - Step-wised planning for extension and expansion of the DH grid,
    - Determination of profitable areas for starting the implementation,
    - Excluding non-profitable areas,
    - Estimation of costs and required capital in each phase,

- To reflect a better cost estimation, the limitations should be removed in the next updates.

Thank you for your attention!

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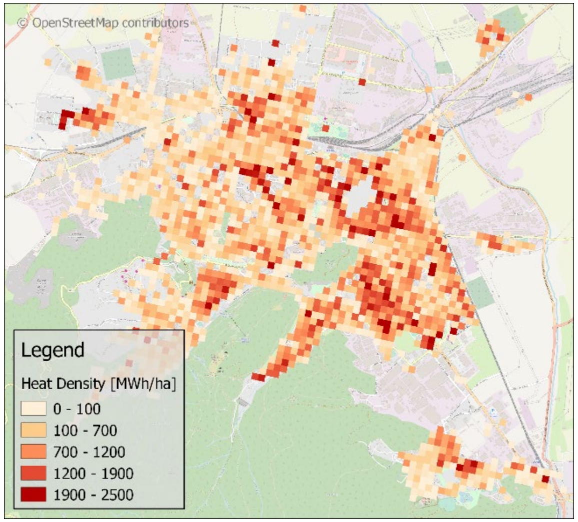
Orig. Photo: Patrick Stargardt

Approach

DH Distribution Costs



- Input GIS layers:
  - Heat demand density map (HDM) – 1ha resolution
  - Plot ratio map – 1ha resolution

- For each pixel of HDM in each year within the investment period, the followings should be calculated:
  - Annual heat demand (D_t) based on the expected accumulated energy saving (S),
  - Annual heat supply via DH system (Q_t) depending on the market shares (MS_0 & MS_m),
  - Annualized specific investment cost per unit of delivered heat: according to Persson & Werner** (audit were performed in 83 cities in DE, NL, FR, BE on over 1700 networks.

$$D_t = D_0 \cdot \sqrt[m]{(1-S)^t}$$

$$0 \le S \le 1 \quad ; \quad t \in \{0,1,2,\ldots,m\}$$

$$Q_t = D_t \cdot \left[MS_0 + t \cdot \frac{MS_m - MS_0}{m} \right]$$

$$L = 1/w = 1/\left(61.8 \cdot e^{-0.15}\right) \quad [\text{m}]$$

$$d_a = 0.0486 \cdot \ln\left(Q_t / L\right) + 0.0007 \quad [\text{m}]$$

$$Inv_T = \frac{C_{1,T} + C_{2,T} \cdot d_a}{\left(\sum_{t=0}^{m} \frac{Q_{T+t}}{(1+r)^t} + \sum_{t=m+1}^{n} \frac{Q_{T+m}}{(1+r)^t} \right) / L} \quad [€/\text{GJ}]$$

$$Inv = \propto * \frac{C_1 + C_2 * d_a}{Q/L}$$

* www.progressheat.eu

** Persson U, Wiechers E, Möller B, Werner S. Heat Roadmap Europe: Heat distribution costs. Energy 2019;176:604–22. doi:10.1016/j.energy.2019.03.189.

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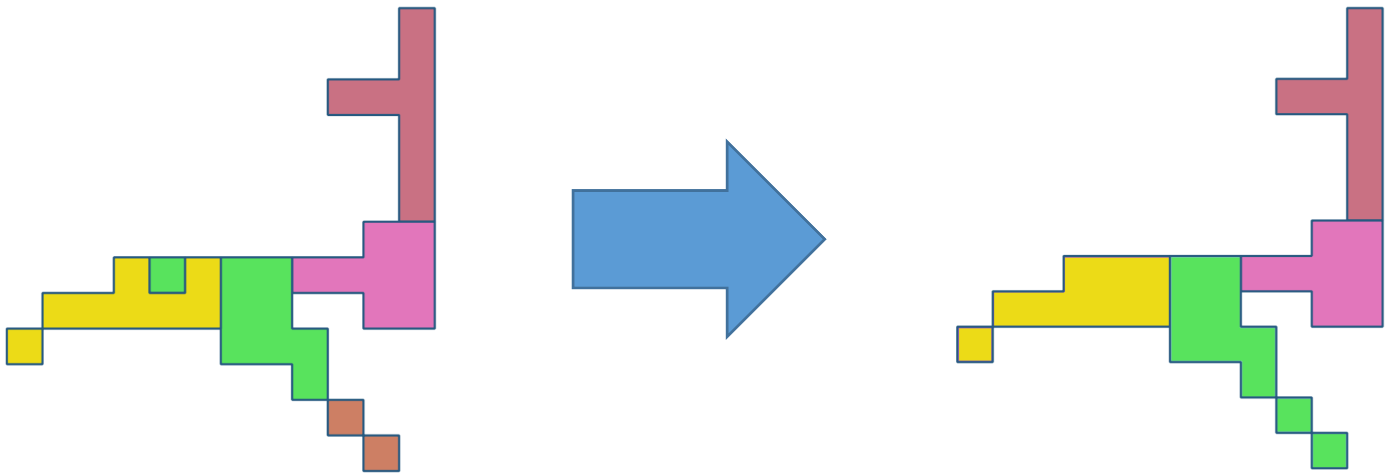
Revised clusters

- Assign disconnected pixels to their neighbors



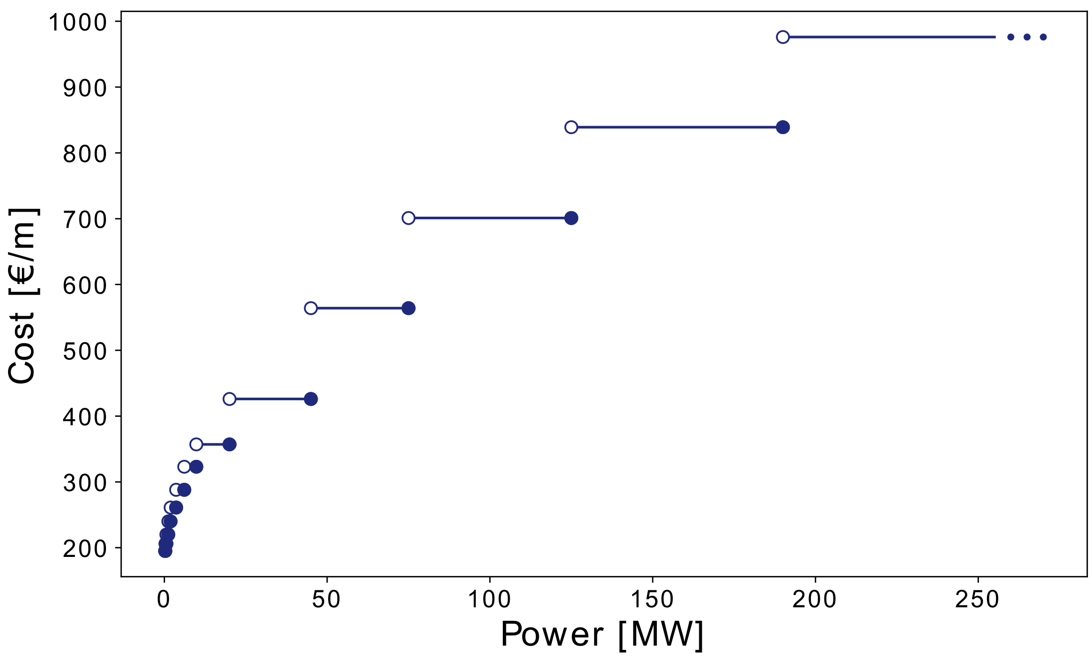
- Calculate center of polygons and consider as cluster center (Substations)

- Find closest point of the OpenStreetMap graph to the cluster centers
  - For route calculations

Transmission Line Dimensions

- Total cost of transmission pipes including projecting, field work, pipe work, materials, and digging with 55°C temperature difference*.

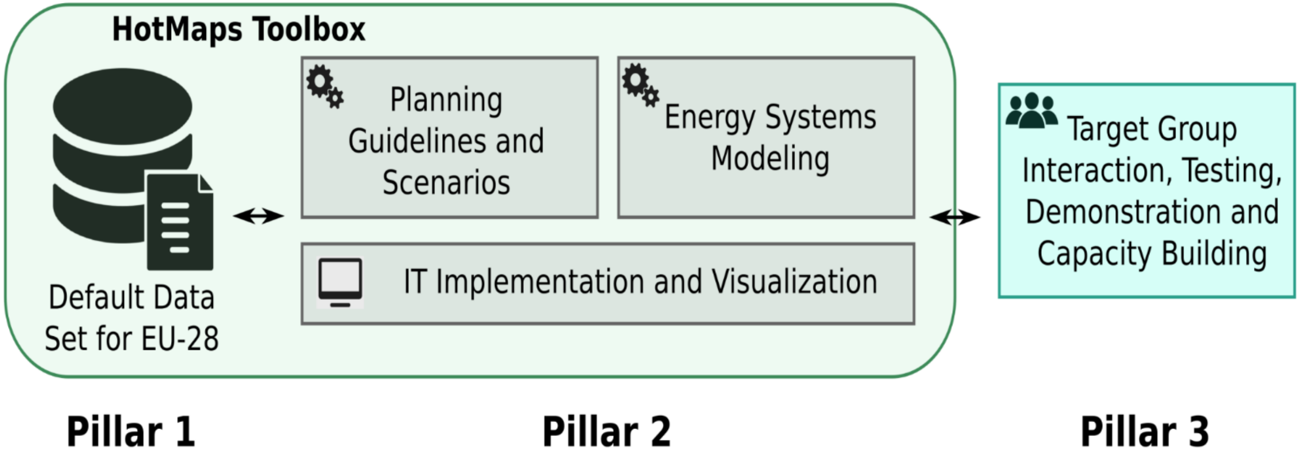
Step (C)	Dimension DN	Water flow (m/s)	Capacity [MW] (PowStep)	Specific Cost [EUR/m] (SPCTL)
0	32	0.9	0.2	195
1	40	1	0.3	206
2	50	1.2	0.6	220
3	65	1.4	1.2	240
4	80	1.6	1.9	261
5	100	1.8	3.6	288
6	125	2	6.1	323
7	150	2.2	9.8	357
8	200	2.5	20	426
9	300	2.7	45	564
10	400	2.8	75	701
11	500	2.9	125	839
12	600	3	190	976



* Nielsen S, Möller B. GIS based analysis of future district heating potential in Denmark. Energy 2013;57:458–68. doi:10.1016/j.energy.2013.05.041.

Hotmaps Project

Hotmaps will develop, demonstrate and disseminate **a toolbox to support public authorities, energy agencies and planners in strategic heating and cooling planning** at local, regional and national levels, and in line with EU policies.



- **User-driven**: developed in collaboration with 7 pilot areas
- **Open source**: will run without requiring any commercial software
- **EU-28 compatible**: applicable for cities and areas in EU-28