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District heating grid planning

a mathematical optimization approach

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- Distribution gird planning
- Determination of economic clusters & transmission grids
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Introduction

Why DH grid planning is important?

Why DH grid planning is important?

- Decarbonizing heating sector is crucial.
- District heating can have a considerable role in integrating local renewable sources, sector coupling and CO2 reductions.
- Lack of knowledge in municipalities:
  - Where to start? How to start?
  - DH is investment intensive
- Computer-based approach is less time consuming and less risk prone
  - Required especially in the pre-feasibility phases
- Having basic data on H&C, a Computer-based approach can be of a great use if it:
  - Has good performance in large scale problems.
  - Can be applied to the whole Europe.

Steps to be taken before grid planning

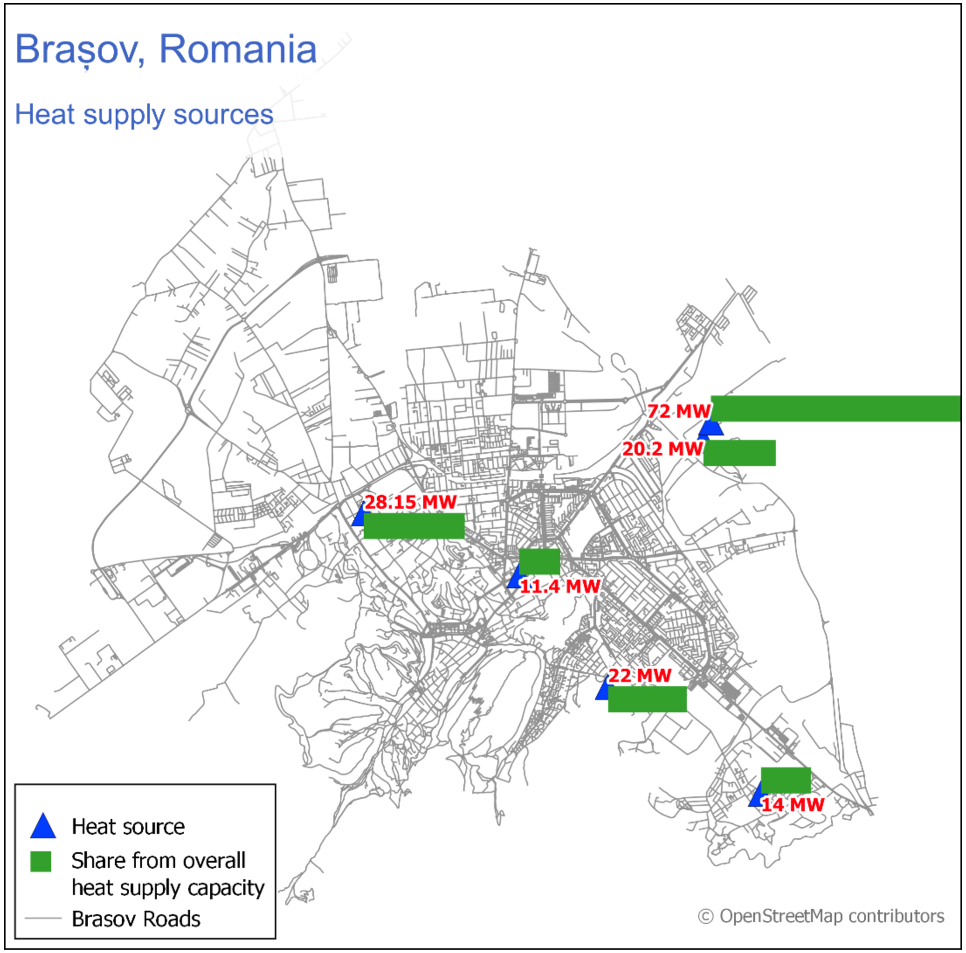
We should know about available heat sources!

Where are the heat sources?

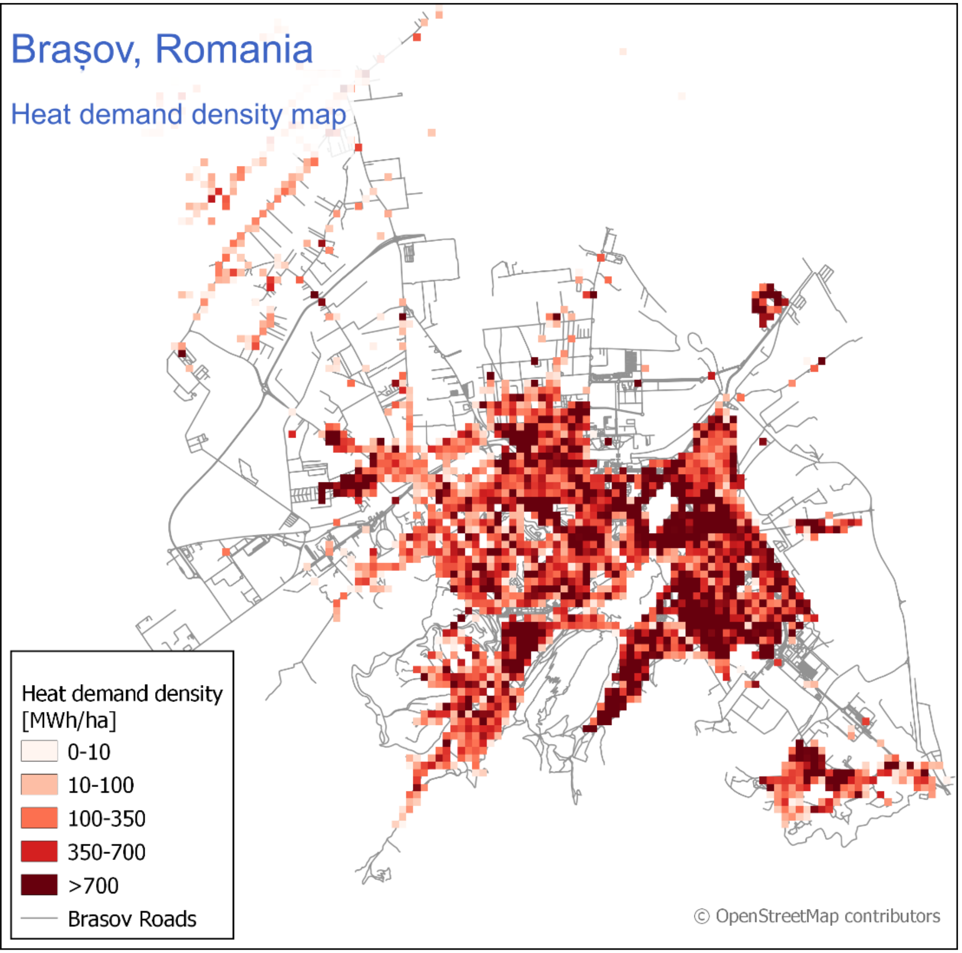
When are they available?

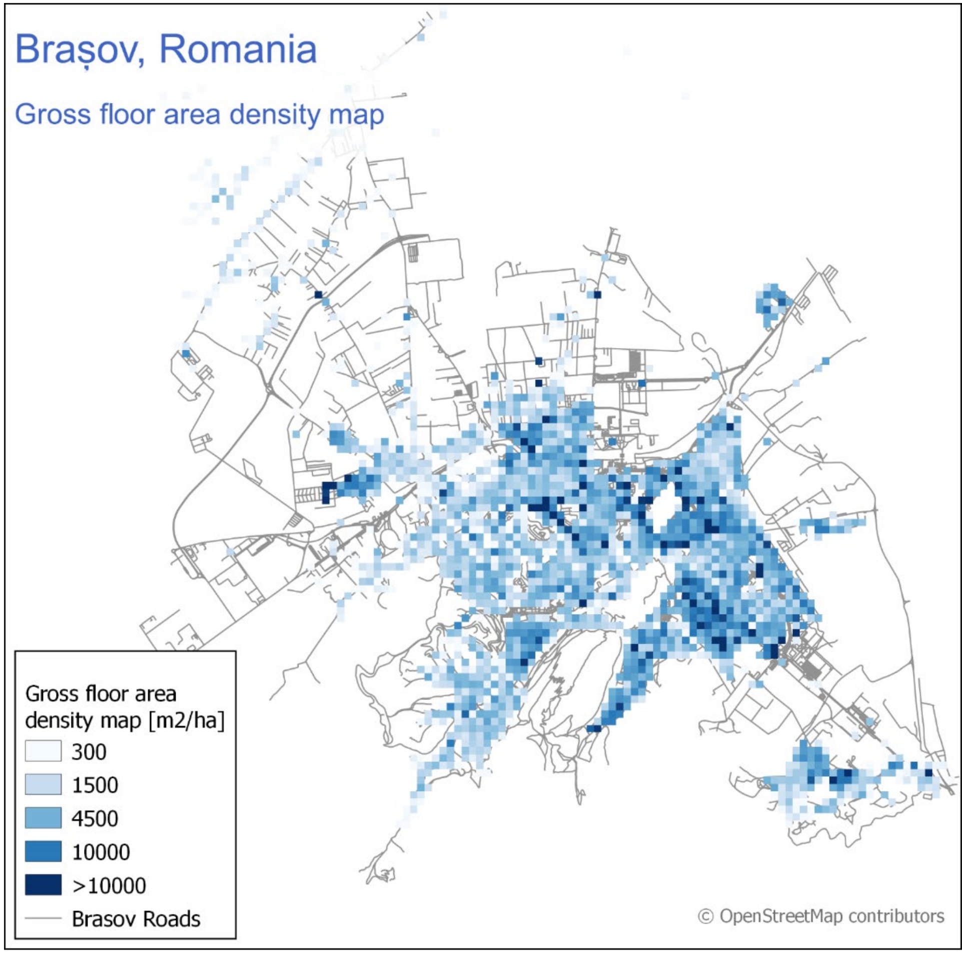
How much the cost?

Costs = fix_costs + Oper_costs



Heat & gross floor area density maps



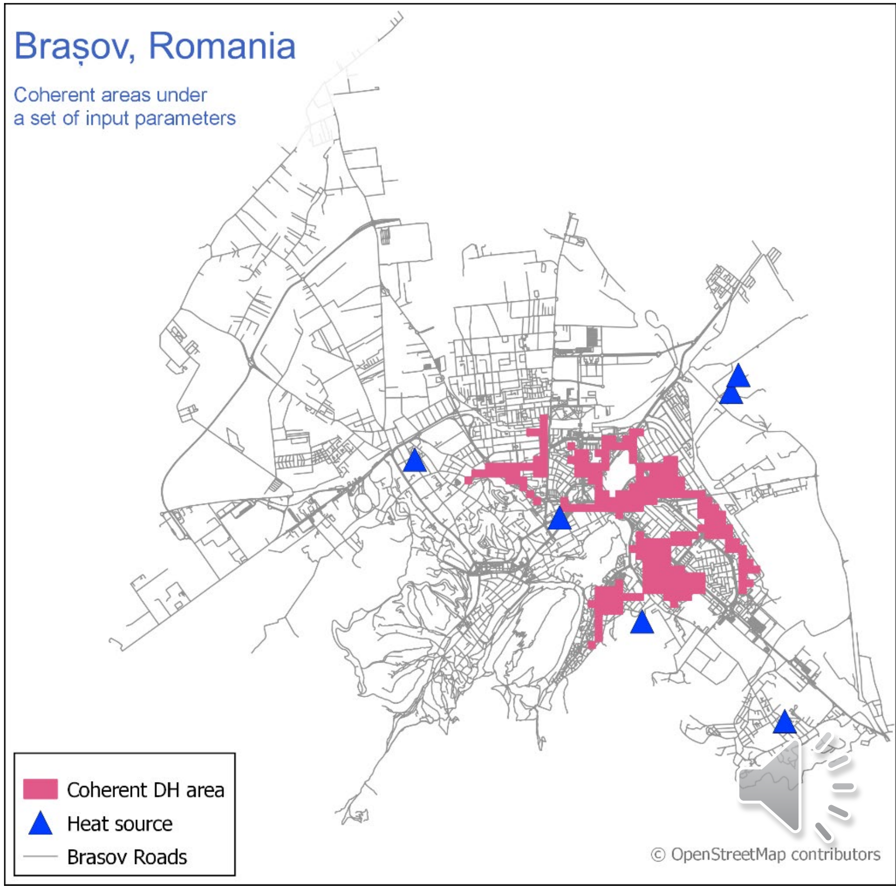


Persson U, Wiechers E, Möller B, Werner S. Heat Roadmap Europe: Heat distribution costs. Energy 2019;176:604–22. doi:10.1016/j.energy.2019.03.189.

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

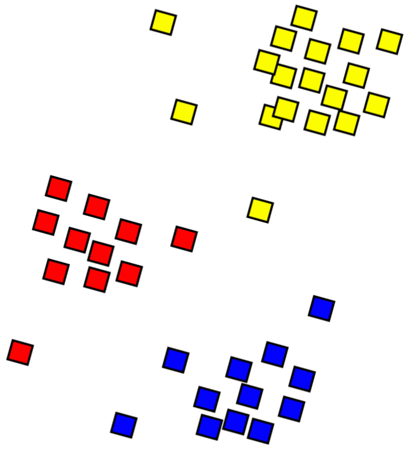
Determine potential DH areas (coherent DH areas)

- 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 **grid** (Million EUR),
  - Available heat to supply.

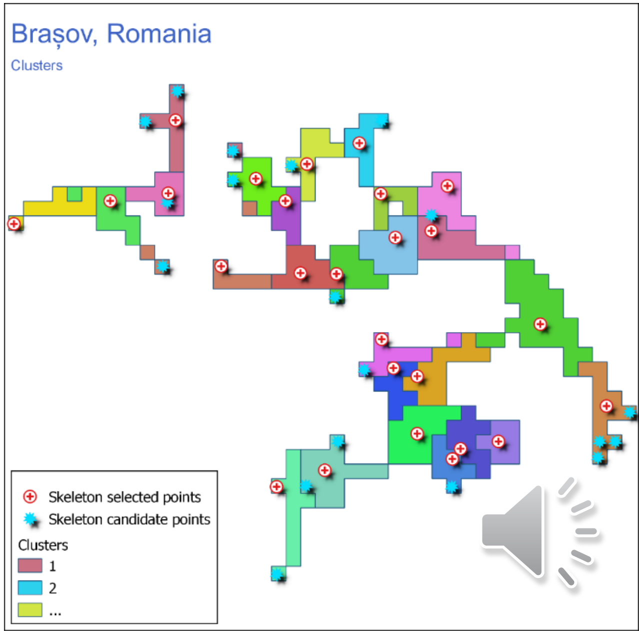


* Persson U, Wiechers E, Möller B, Werner S. Heat Roadmap Europe: Heat distribution costs. Energy 2019;176:604–22. doi:10.1016/j.energy.2019.03.189.

Clustering model to break coherent areas to smaller pieces



- Reduce model complexity and increase tangibility **by clustering**,
  - Plan transmission & distribution grids separately,
  - Optimize distribution grid for 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



Distribution grid planning

Distribution Grid in clusters

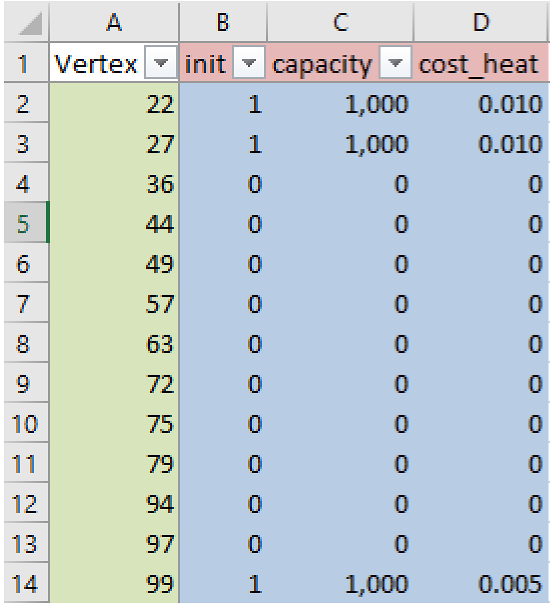
DHMIN Model

- For the distribution grid, the DHMIN model is used.

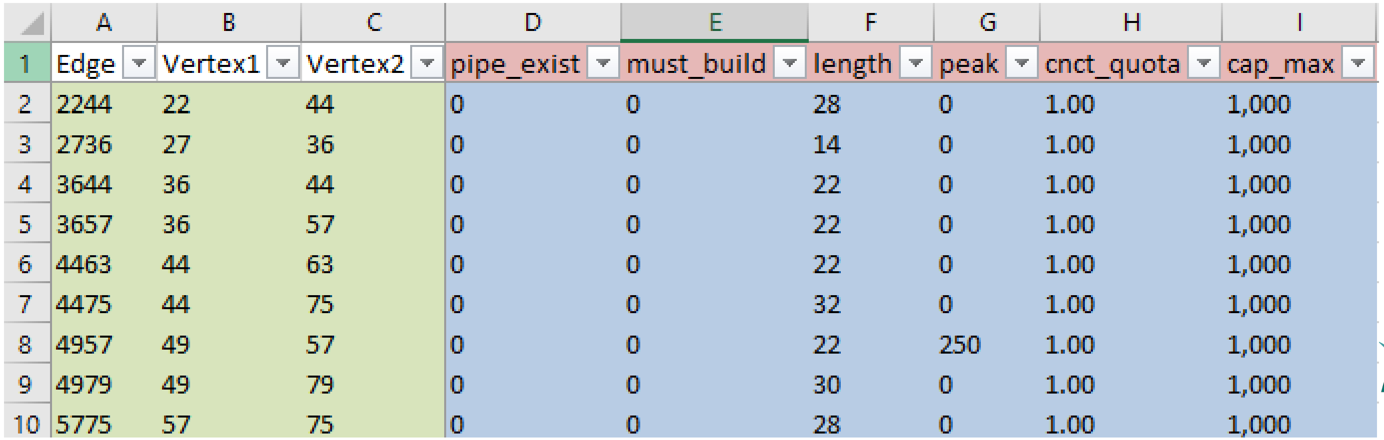
- DHMIN:
  - MILP model for single-commodity energy infrastructure network systems
  - It finds maximum revenue tradeoff for the size of network
  - Main features:
    - Model peak loads (short duration) and typical loads (long duration),
    - Model heat source availability (redundancy study),
    - Model existing pipelines,
    - Oblige pipe construction on certain route,
    - Simple heat loss modeling,
    - Simple pipe cost modeling (linear cost model),

Input parameters

- Pipeline cost function, heat loss function, interest rate
- Peak load heat demand on street edges
- Time steps: to model seasonality (full load hours, summer-winter hours)
- Heat source vertex, its capacity and heat costs
- Heat sale price

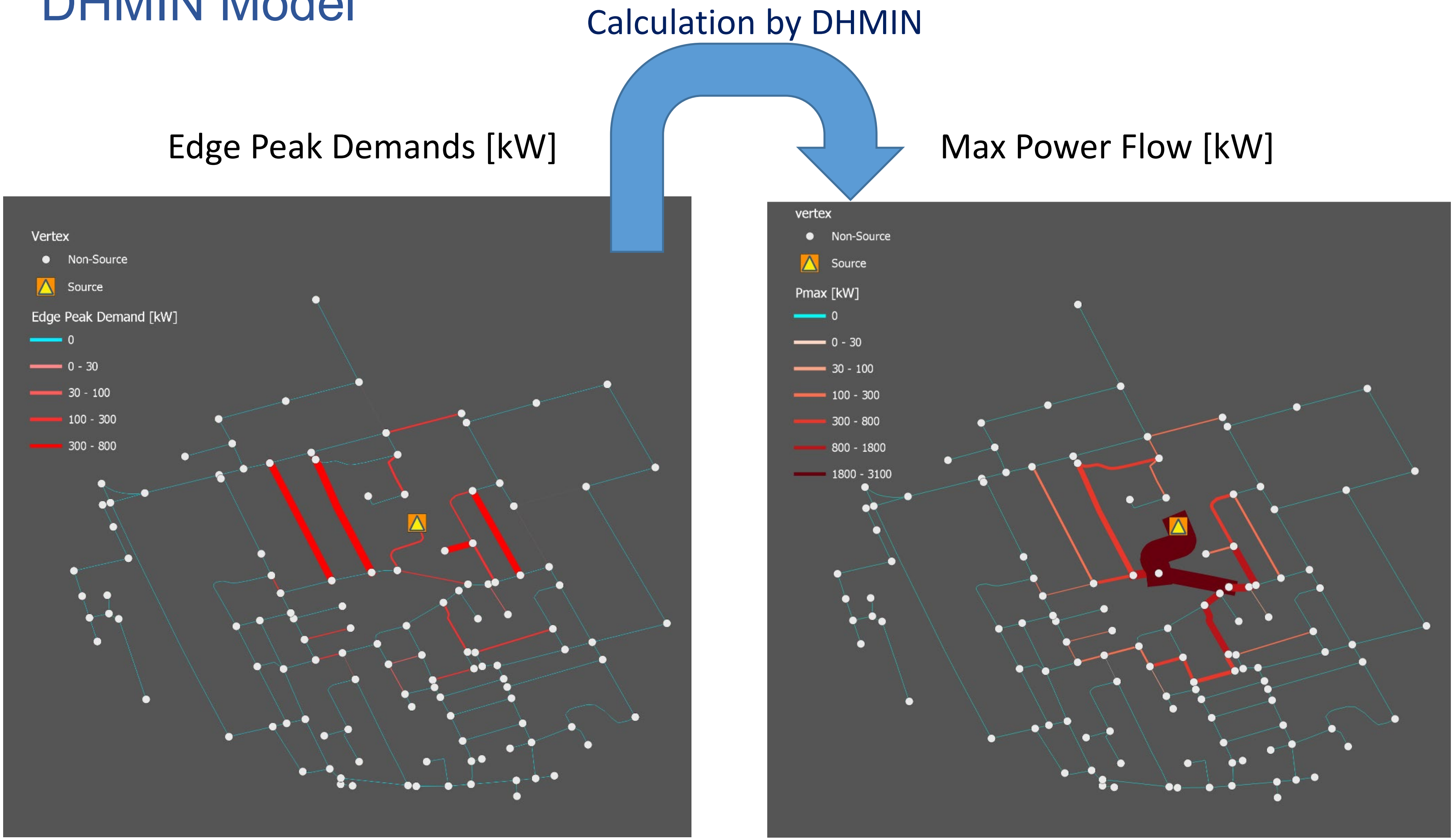


	A	B	C	D
1	Vertex	init	capacity	cost_heat
2	22	1	1,000	0.010
3	27	1	1,000	0.010
4	36	0	0	0
5	44	0	0	0
6	49	0	0	0
7	57	0	0	0
8	63	0	0	0
9	72	0	0	0
10	75	0	0	0
11	79	0	0	0
12	94	0	0	0
13	97	0	0	0
14	99	1	1,000	0.005



	A	B	C	D	E	F	G	H	I
1	Edge	Vertex1	Vertex2	pipe_exist	must_build	length	peak	cnct_quota	cap_max
2	2244	22	44	0	0	28	0	1.00	1,000
3	2736	27	36	0	0	14	0	1.00	1,000
4	3644	36	44	0	0	22	0	1.00	1,000
5	3657	36	57	0	0	22	0	1.00	1,000
6	4463	44	63	0	0	22	0	1.00	1,000
7	4475	44	75	0	0	32	0	1.00	1,000
8	4957	49	57	0	0	22	250	1.00	1,000
9	4979	49	79	0	0	30	0	1.00	1,000
10	5775	57	75	0	0	28	0	1.00	1,000

DHMIN Model



Calculation by DHMIN

Edge Peak Demands [kW]

Max Power Flow [kW]

What are the model results?

- Beside the network topology, the following indicators are obtained for each cluster:
  - Heat sale [MWh]
    - final energy demand := supply in substation – heat losses in dist. Grid
  - Revenue that can be made via heat sale [EUR]
    - FED * heat_sale_price
  - Distribution grid investment (annuity) [EUR]

Determination of economic clusters & Transmission grids

Optimization model – Inputs

- **Open Street Map** routes, **cluster centroids’** (substations) and **sources’** locations.
- Cost function of heat sources
- Distribution grid related indicators
- Potential revenues in each cluster

Obtained from the last step

- Available range of pipeline dimensions and their costs;
- Under given supply and return temperatures:
  - heat that can be transferred by each pipe size
  - Heat loss level in the transmission grid
- Peak load factor

Optimization model – Objective & expected outputs

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

Maximising the heat sale profit

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

R := Revenue
C := Cost

- Find economic clusters
- Determine the **utilized sources** and **generation costs**
- Determine the transmission lines **routes**, **dimensions**, and their **associated costs**

Results

Case of Brasov, Romania
Impacts from redundancy constraints

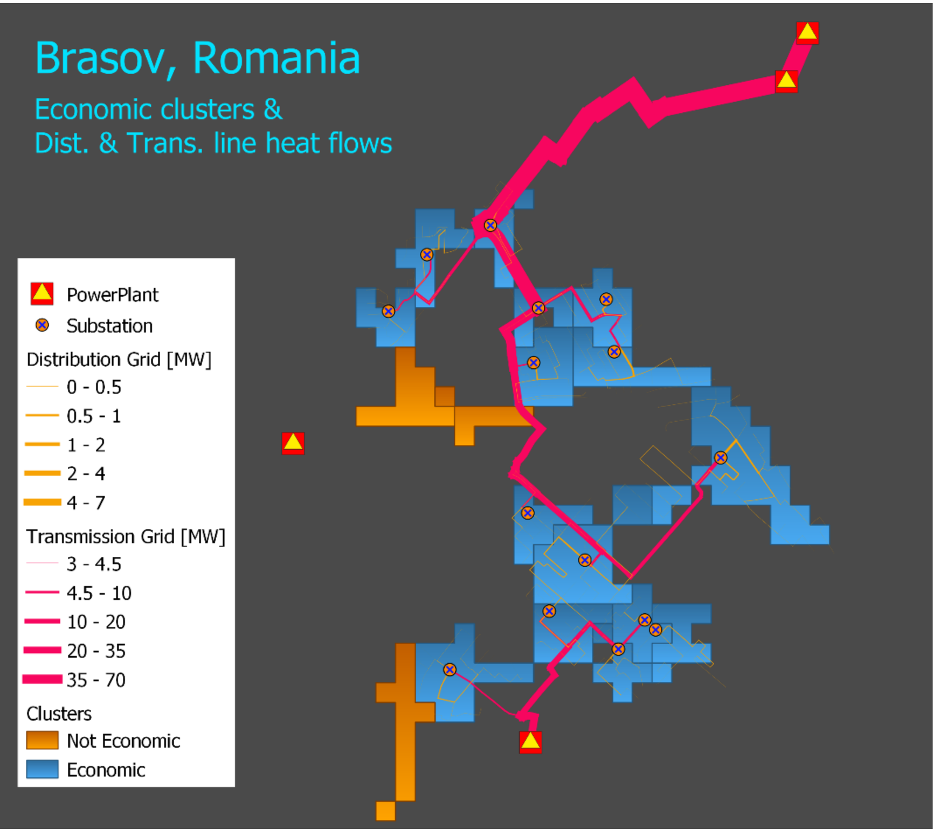
Results

Economic clusters & heat flow direction

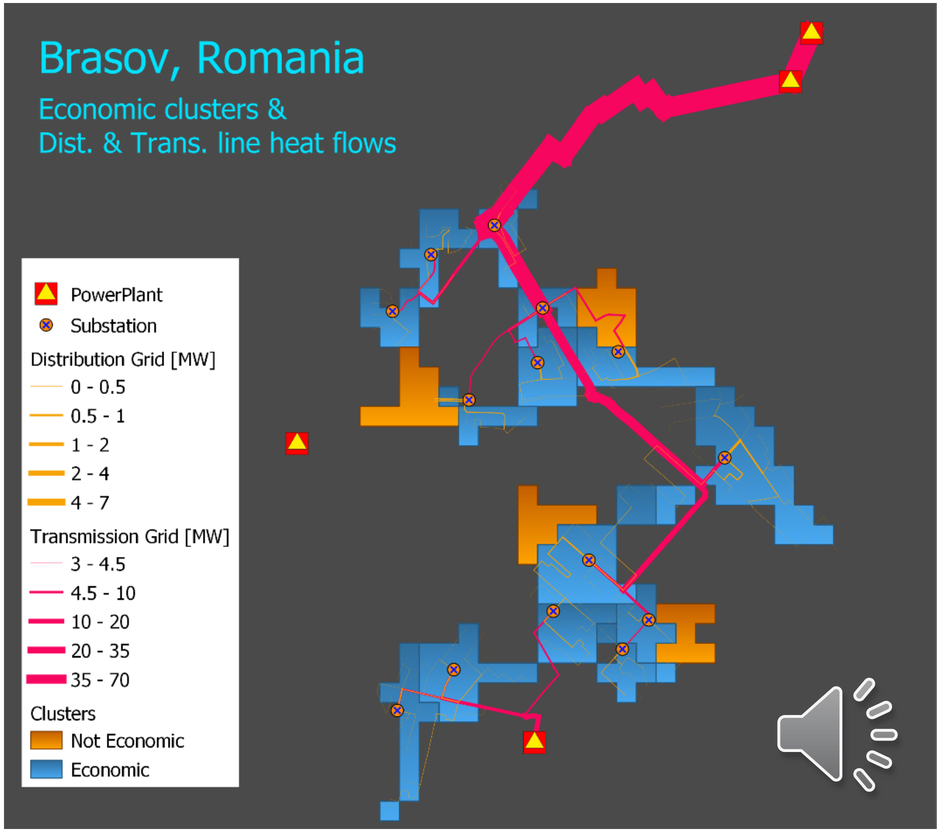
With and without redundancy constraints

- **N-1 security in network planning**:
  - for each source we consider factor which demonstrates the capacity that is not available at certain time

No
redundancy constraint



With
redundancy constraint

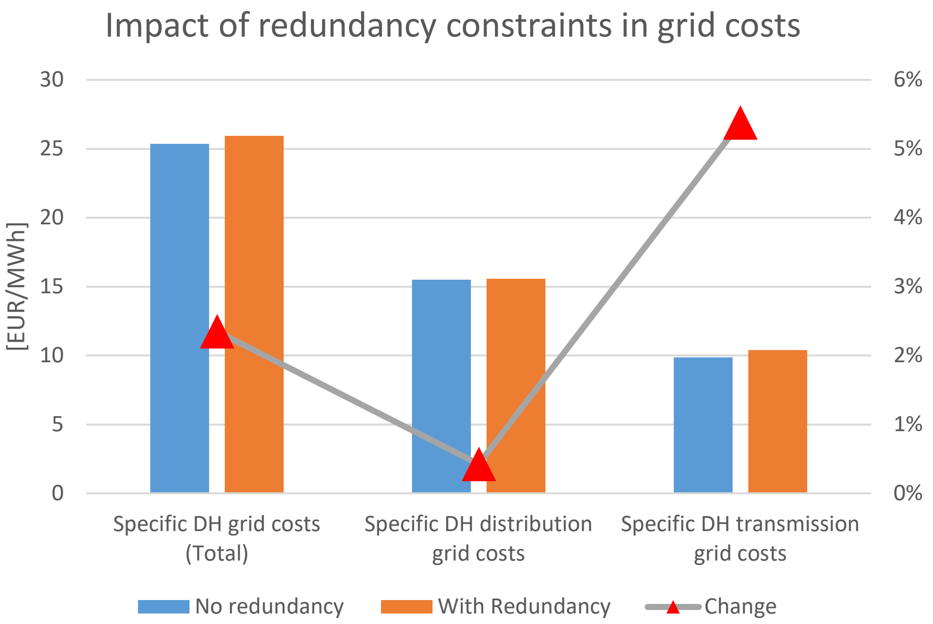


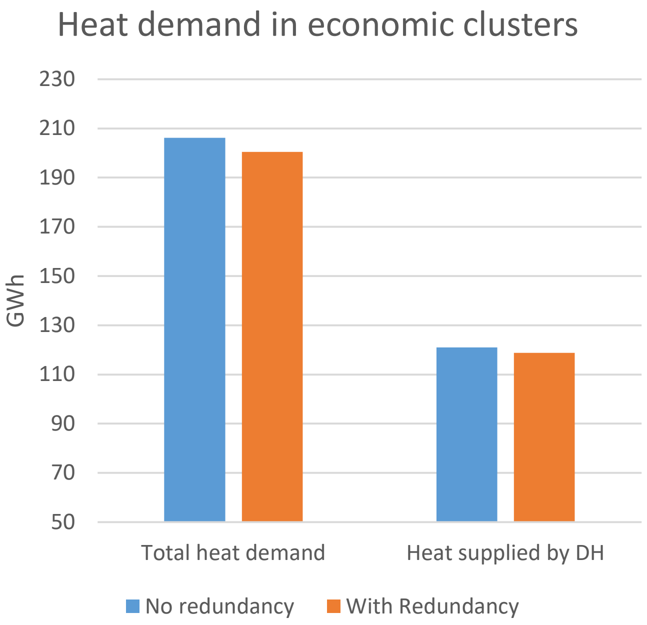
Indicators

- Impact on distribution grid is low, since redundancy in distribution grid were not studied. (the difference is due to having different clusters).

Market share

Target: 62%
No redundancy: 58.72%
With redundancy: 59.24%





Conclusions

Conclusions

- Important Notes:
  - To get a good quality results, enough attention should be paid to input parameters.
  - The calculation may need to be run for various scenarios

- The proposed method:
  - Requires 1-2 hours of calculation for a large case study,
  - Leads to reduced model complexity and increased tangibility by:
    - introduction of DH coherent areas,
    - optimization-based clustering,
  - Enables us for:
    - Systematic planning (roll out phases) for extension and expansion of the DH grid,
    - Determination of profitable areas for starting the implementation,
    - Performing redundancy calculations,
    - Estimation of costs and required capital in each phase.

Thank you for your attention!

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Orig. Photo: Patrick Stargardt

Input parameters

Parameters	Value	Unit
Available capital for investment in the DH grids	39,485,460	EUR
Capital increase factor to select areas of interests	1.2	-
Investment period	16	years
Market share at the start of the investment	0.0	%
Expected market share at the end of investment period	62	%
Depreciation time of grids	25.0	years
Heat sale price	90	EUR/MWh
Peak load factor	0.0	-
interest rate	6	%

Sources	S1	S2	S3	S4	S5	S6
Source installed power [MW]	22	14	20.2	72	28.15	11.4
Source availability factor for the redundancy calculations	0.73	0.72	0.75	0.8	0.75	0.74
Source fix costs (annuity) [EUR/year]	162500	162500	162500	162500	162500	162500
Source operating costs [EUR/MWh]	43	43	43	43	43	43

Used parameters for the transmission & distribution grids

Transmission Lines Values for Temperature difference of 40°C

Pipeline	Capacity [MW]	Pipe Cost [EUR/m]	Digging Cost [EUR/m]	heat loss rate [W/m]
DN20	0.05	273	180	57.48
DN25	0.14	279	180	67.71
DN32	0.27	311	180	73.79
DN40	0.40	329	180	83.10
DN50	0.74	354	222	93.09
DN65	1.40	405	222	104.65
DN80	2.18	455	262	110.01
DN100	3.87	610	282	114.77
DN125	6.24	775	302	131.93
DN150	11.41	957	340	149.12
DN200	25.87	1161	384	157.47
DN250	47.91	1649	430	158.47
DN300	67.74	1979	470	174.77
DN350	82.16	2343	546	175.77
DN400	107.43	2547	590	176.77

Distribution Grid Parameters

Parameter	Value
fixed pipe investment [€/m]	600
variable pipe investment [€/kW/m]	0.02
operation & maintenance [€/m]	5
retail price for heat [€/kWh]	0.09
fixed thermal losses [kW/m]	0.02
variable thermal losses [kW/kW/m]	0.00
concurrence effect [%]	1