Planning of district heating networks

A Geographic Information-Based Mixed Integer Linear Programming Model

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Introduction

- Motivation:
  - Lack of methods and empirical numbers (for countries like Japan) for providing pre-feasibility planning and assessment of district heating systems for new target areas.
    - Cost viability, structure, trade-off analysis, etc.

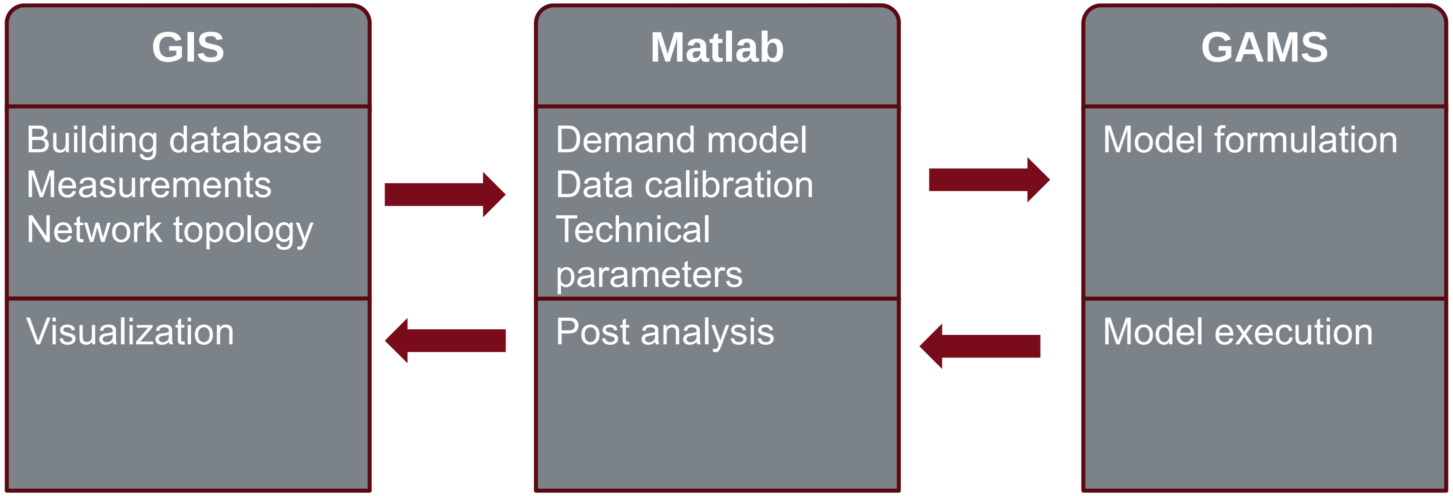
- Set up with developing/employing a district heating system design and operation optimization model.
  - Trade-off between system model accuracy and optimization solution robustness.
  - MILP is the dominant programming method for district/macro scale energy supply system optimization models.
    - Location; e.g. where to locate heat plants.
    - Scheduling; e.g. how to dispatch thermal sources and storages.
    - Network routing; e.g. to what extent to build the distribution network.

Introduction

- Lack of accurate geographical and operational characteristics of heat distribution networks.
  - Consumer aggregation, neglecting pipeline operational constraints, etc.

- Objective:
  - Develop a mixed integer deterministic optimization model for district heating system planning, taking into account geographical features.
    - Added focus on network geographical representation and operation.
  - … to employ the model on a case district for cost optimal design.

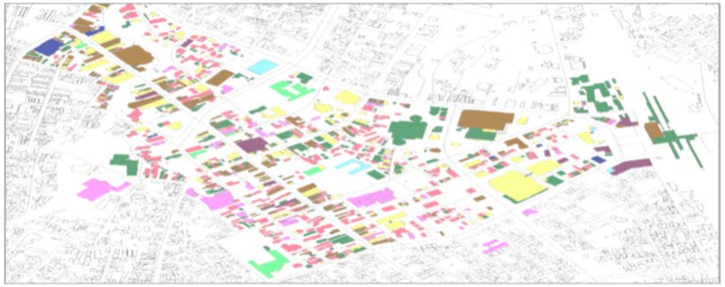
Model structure



Model data preparation

District calibration

- Buildings and street network adjusted as needed.



Topology generation

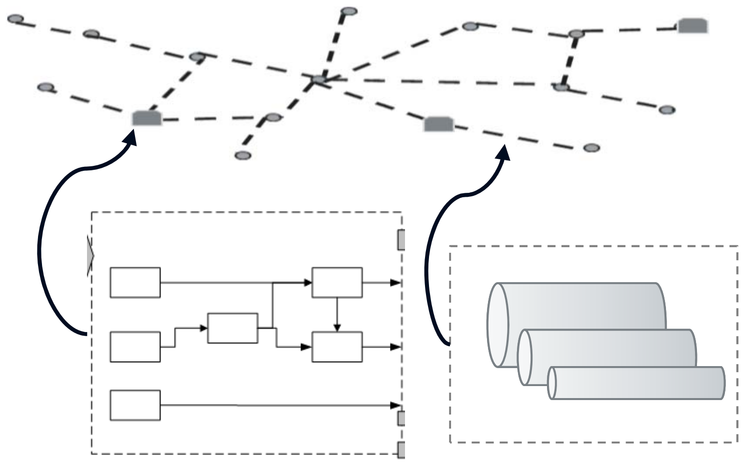
- Shortest path algorithm.
- Adjacency matrix.

Node definition

- Node: Junction, consumer and or supplier.

Super-structure

- Heat technology and other component options.



Model formulation

- MILP general formulation:

$$\min \sum_{j=1}^{n} c_j \cdot x_j$$

$$\sum_{j=1}^{n} a_{ij} \cdot x_j = b_i \qquad (i = 1,2, \dots, m)$$

$$x_j \geq 0 \qquad (j = 1,2, \dots, n)$$

$$x_j : integer \qquad (for\ some\ j = 1,2, \dots, n)$$

- Constraint groups:
  - Energy conservation.
  - Pipeline network structure.
  - Network operation.
  - Heat plant location, sizing and operation.

Model formulation

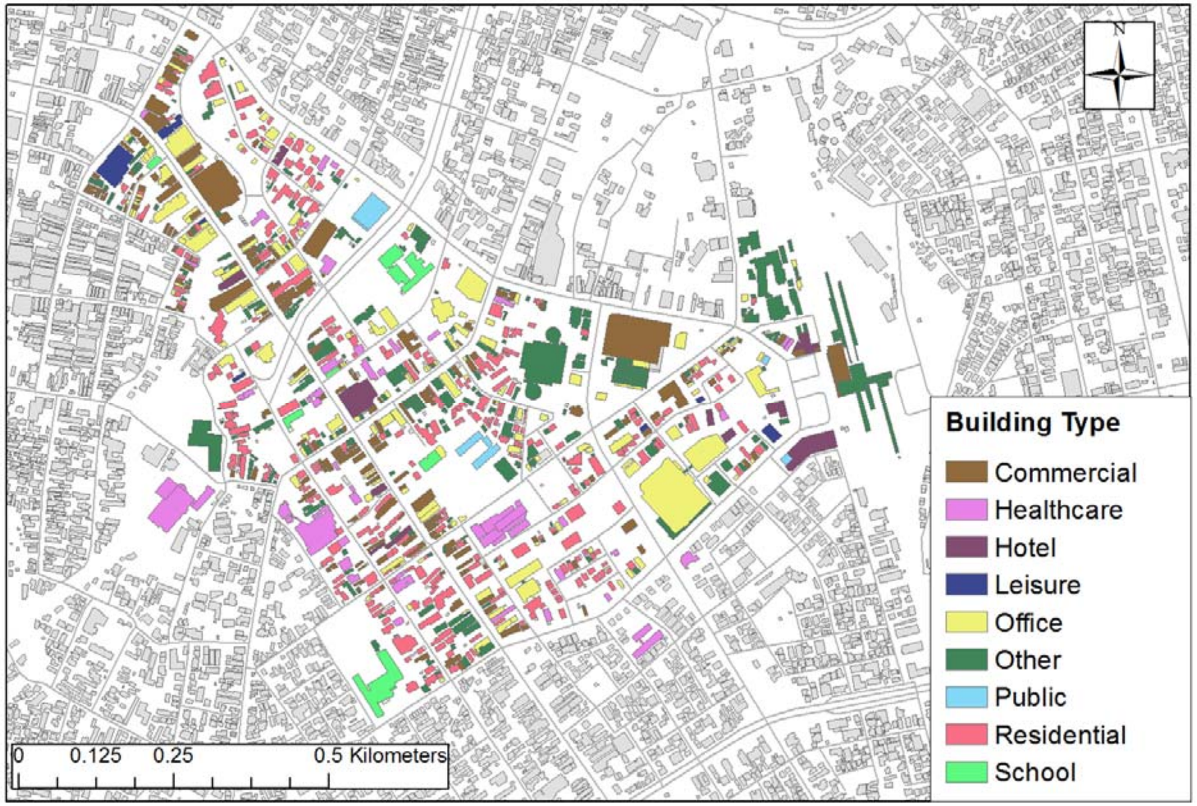
- Objective function:
  - Minimize the total annualized system cost.

$$\min Z = IC_{pipe} + IC_{plant} + OMC_{plant} + C_{fuel} + C_{pump} - C_{sell}^{Grid}$$

IC_{pipe}	Investment cost of pipeline network
IC_{plant}	Investment cost of heat plants
OMC_{pipe}	Operation & maintenance cost of plants
C_{fuel}	Total fuel cost
C_{pumpe}	Total pump cost
C_{sell}^{Grid}	Total electricity sold to the grid

Model application

- Project: Smart energy system design of Hirosaki city centre (North Japan)
- 1st design phase: Heat supply to strategically selected buidings (17 in total)



Model application

Heat plant candidates

- Biomass wood chips, municipal solid waste (MSW) and Geothermal heat available local resources.

Type	η_{th}	η_{el}	AF	Lower bound [MW]	Upper bound [MW]
Gas HOB[a]	0.97	-	0.98[d]	1	20
Gas CHP[a]	0.45	0.38	0.9	5	40
Biomass HOB[a]	1.08	-	0.96	1	17.6
Biomass CHP[a]	0.77	0.29	0.9	5	17.6
MSW HOB[a]	0.95	-	0.92	1	21
MSW CHP[a]	0.74	0.24	0.92	5	21
Geothermal[b]	1	-	0.95	0	28

[a]Parameters adopted from (Energinet.dk 2012)
[b]Adopted from (Baldvinsson and Nakata 2014)

Model application

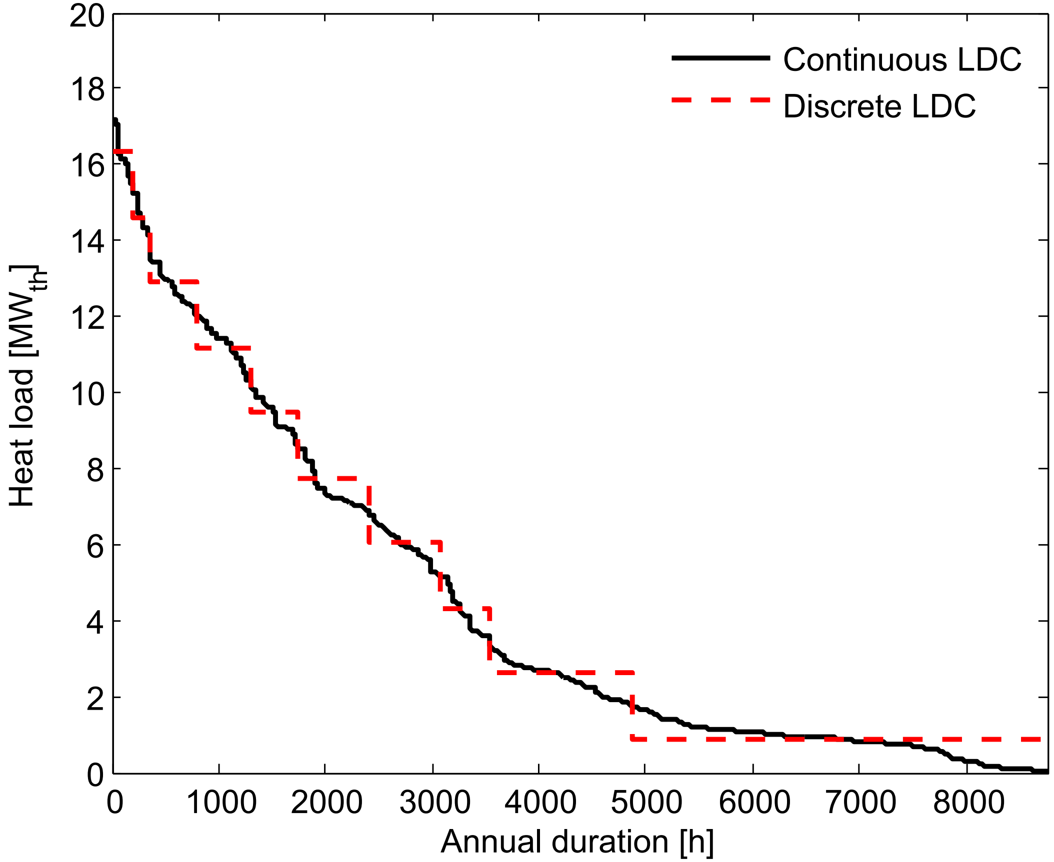
Pipeline candidates

- PEX type manufactured by MESCO.
- di: Inner diameter, ξ_{tot}: Total thermal resistance.

Pipe properties	Pipe type									
	30/118	40/118	50/152	65/152	75/176	100/210	125/228	150/272	200/311	250/362
d_i [m]	0.0347	0.0395	0.0504	0.0638	0.0748	0.0956	0.117	0.137	0.182	0.225
ξ_{tot} [mK/W]	5.819	5.055	5.276	3.898	3.838	3.453	2.735	2.800	1.966	1.617
Cost [JPY/m]	11,400	12,200	15,900	18,300	21,200	28,600	41,500	48,900	56,900	74,800

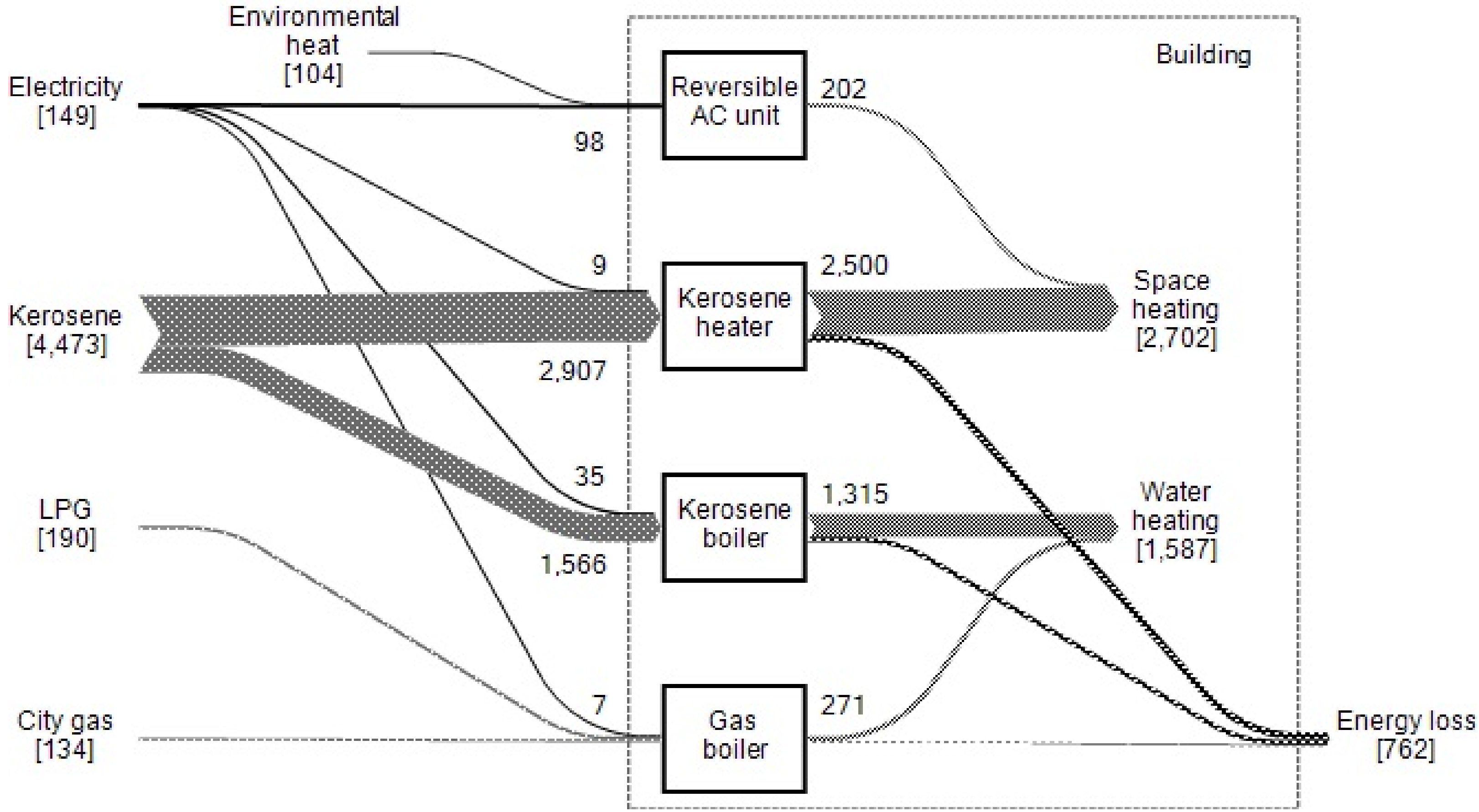
Model application

Heat load duration curve approximation



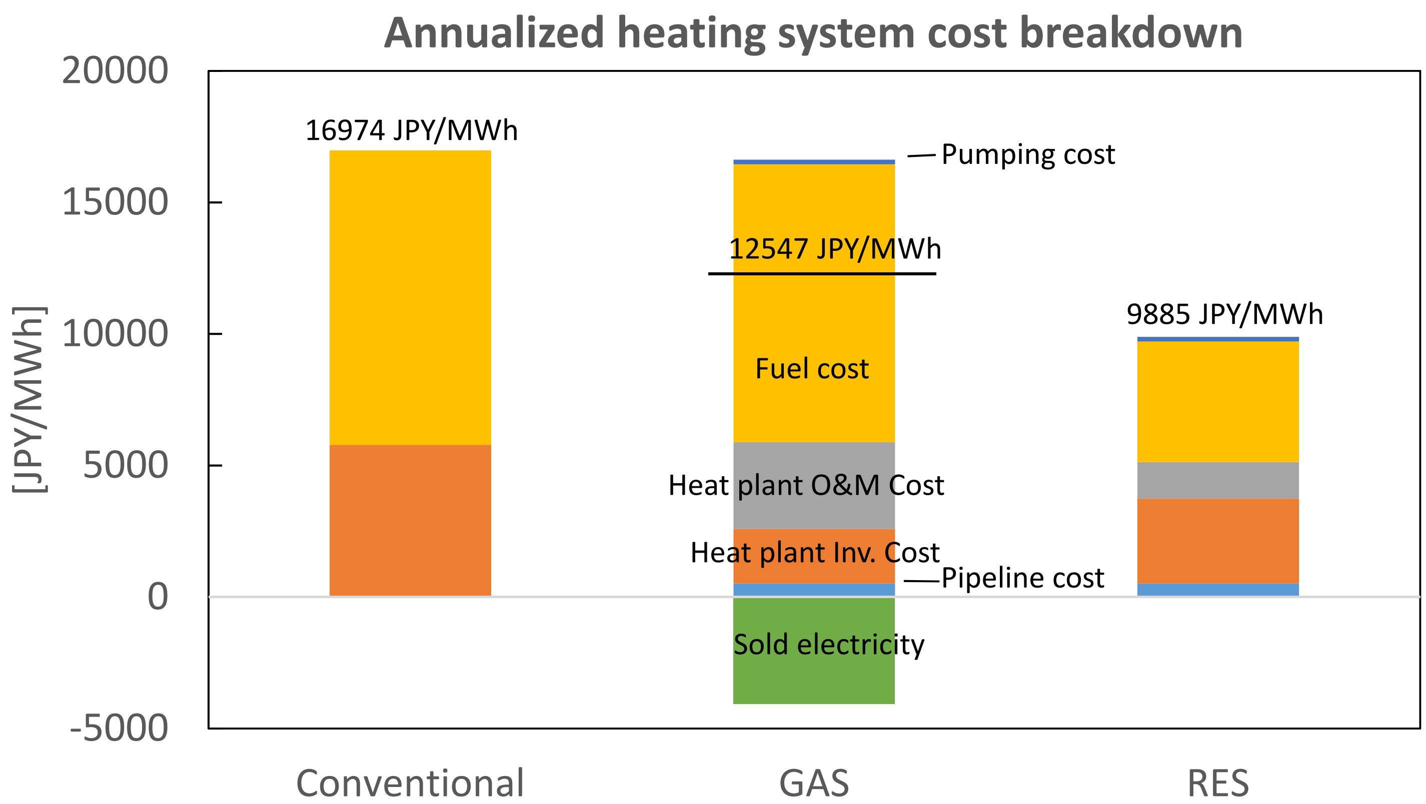
Model application

Reference system of Hirosaki city (Annual energy flow [TJ])



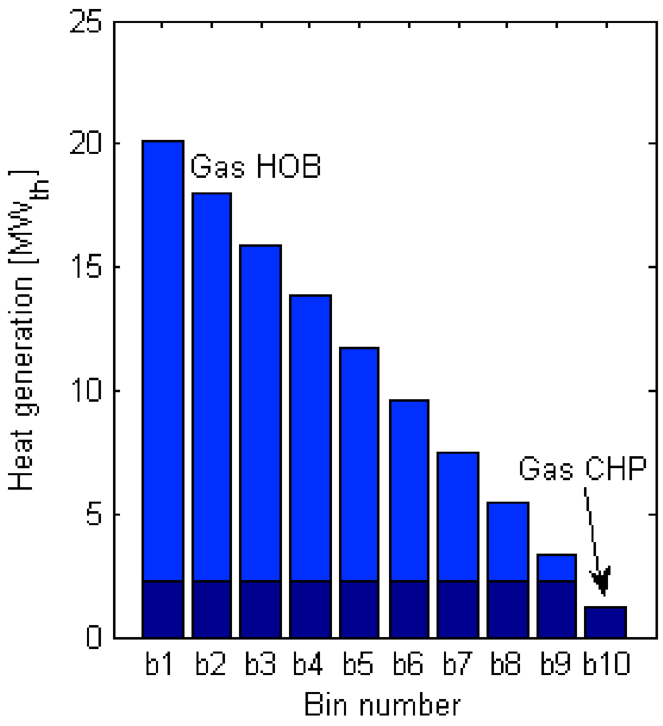
Optimization results

- Gas scenario: Gas technologies only considered.
- RES scenario: Local renewables also included.

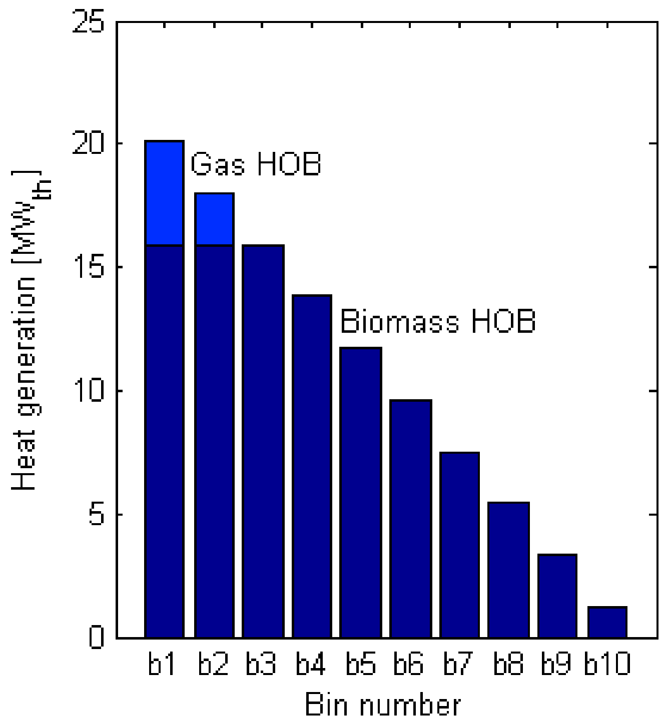


Optimization results

Optimal thermal power supply

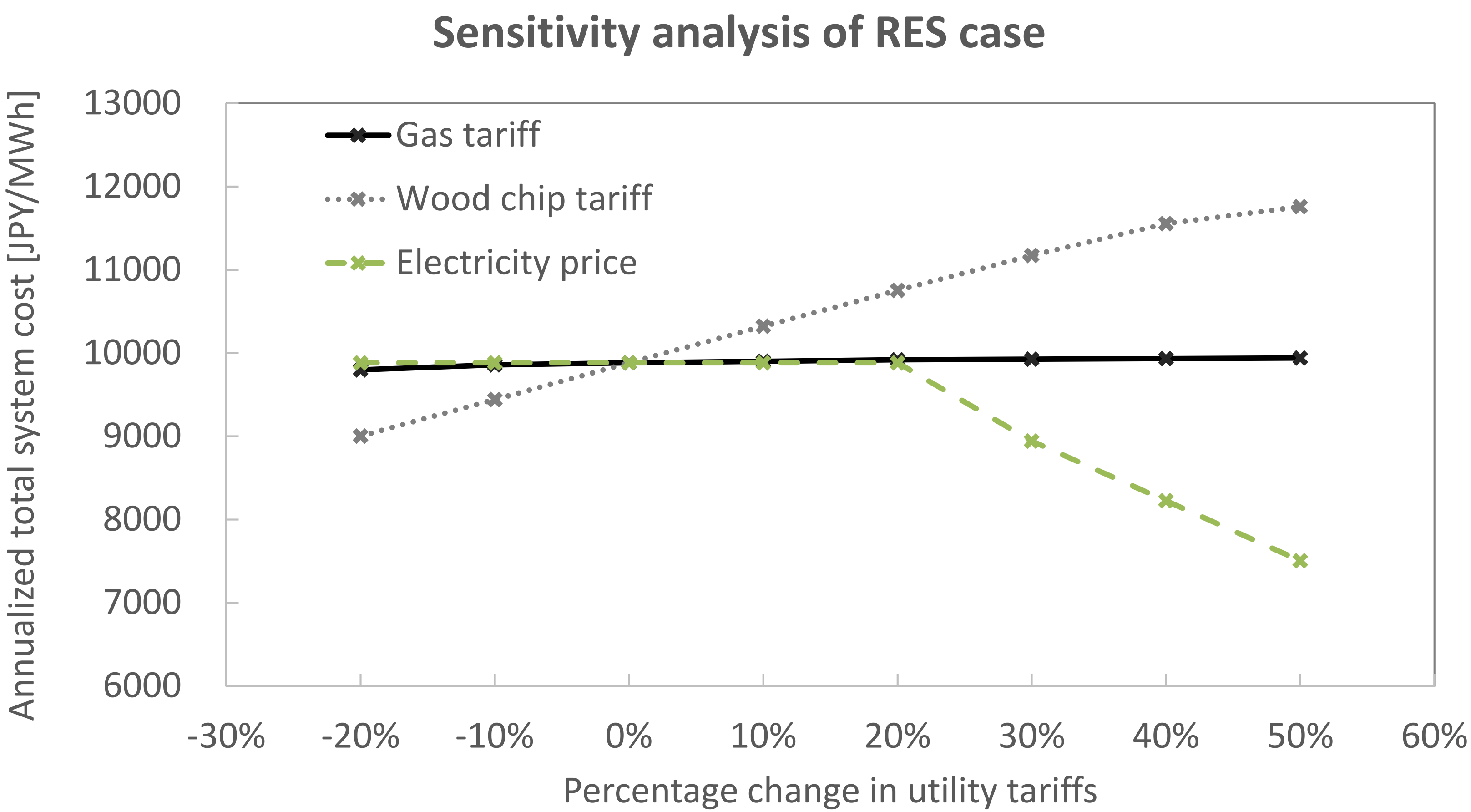


a) Gas case



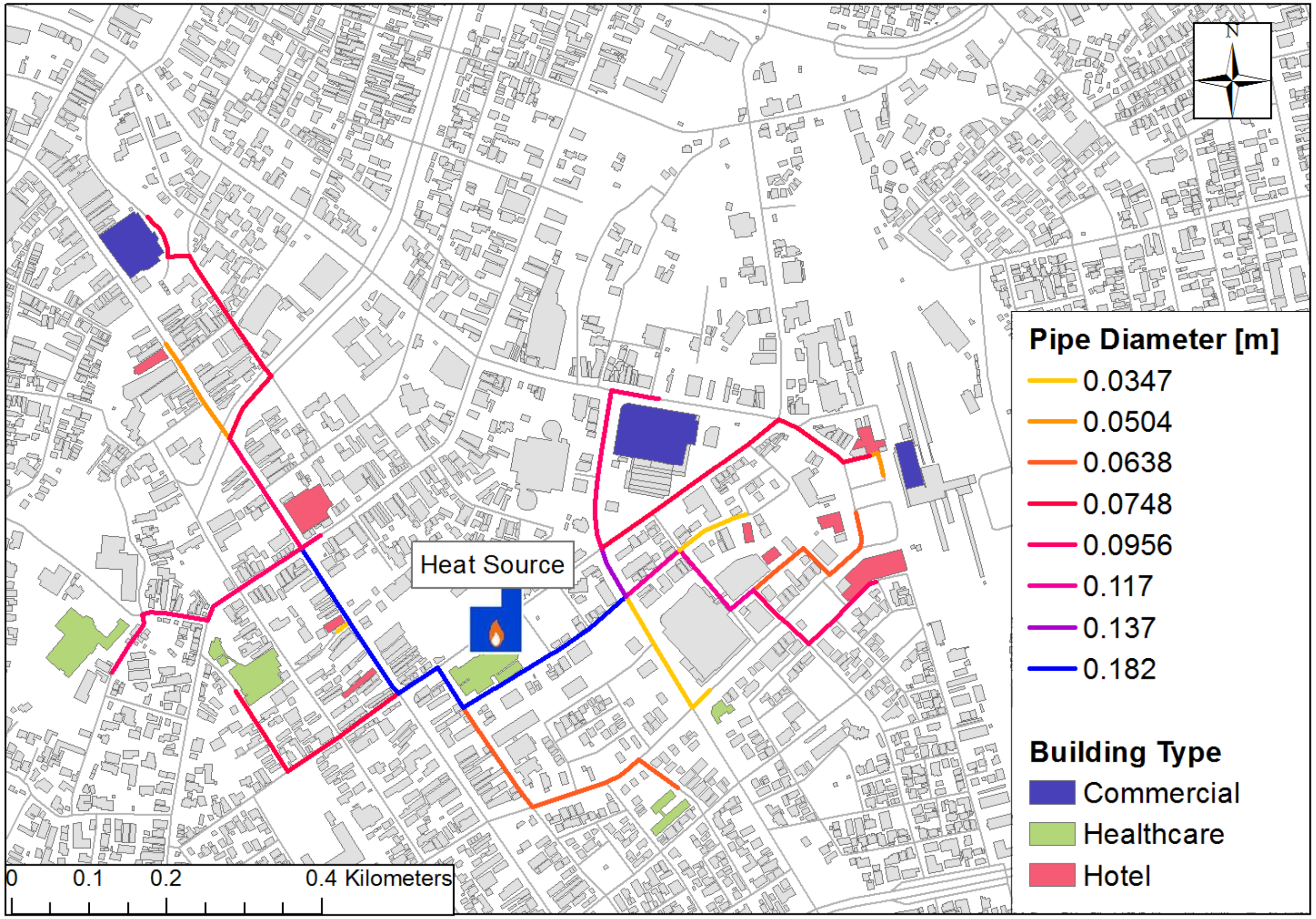
b) RES case

Optimization results



Optimization results

Optimal pipe network



Optimization results

Cost implication of network flow temperature

- LT: Low temperature mode; supply: 60° C, return: 30° C.
- MT: Medium temperature mode; supply: 80° C, return: 40° C.

Network heat loss and hydraulic energy demand comparison [MWh]

Operation mode	Period number										Total
	b1	b2	b3	b4	b5	b6	b7	b8	b9	b10	
Distribution network heat loss											
LT	29	21	59	61	56	78	74	48	129	265	819
MT	34	25	70	74	67	95	91	60	167	385	1069
Distribution network hydraulic energy from pump											
LT	34	23	59	57	45	53	41	20	37	38	408
MT	30	21	53	51	40	48	37	18	33	35	367

Optimization results

Cost implication of network flow temperature

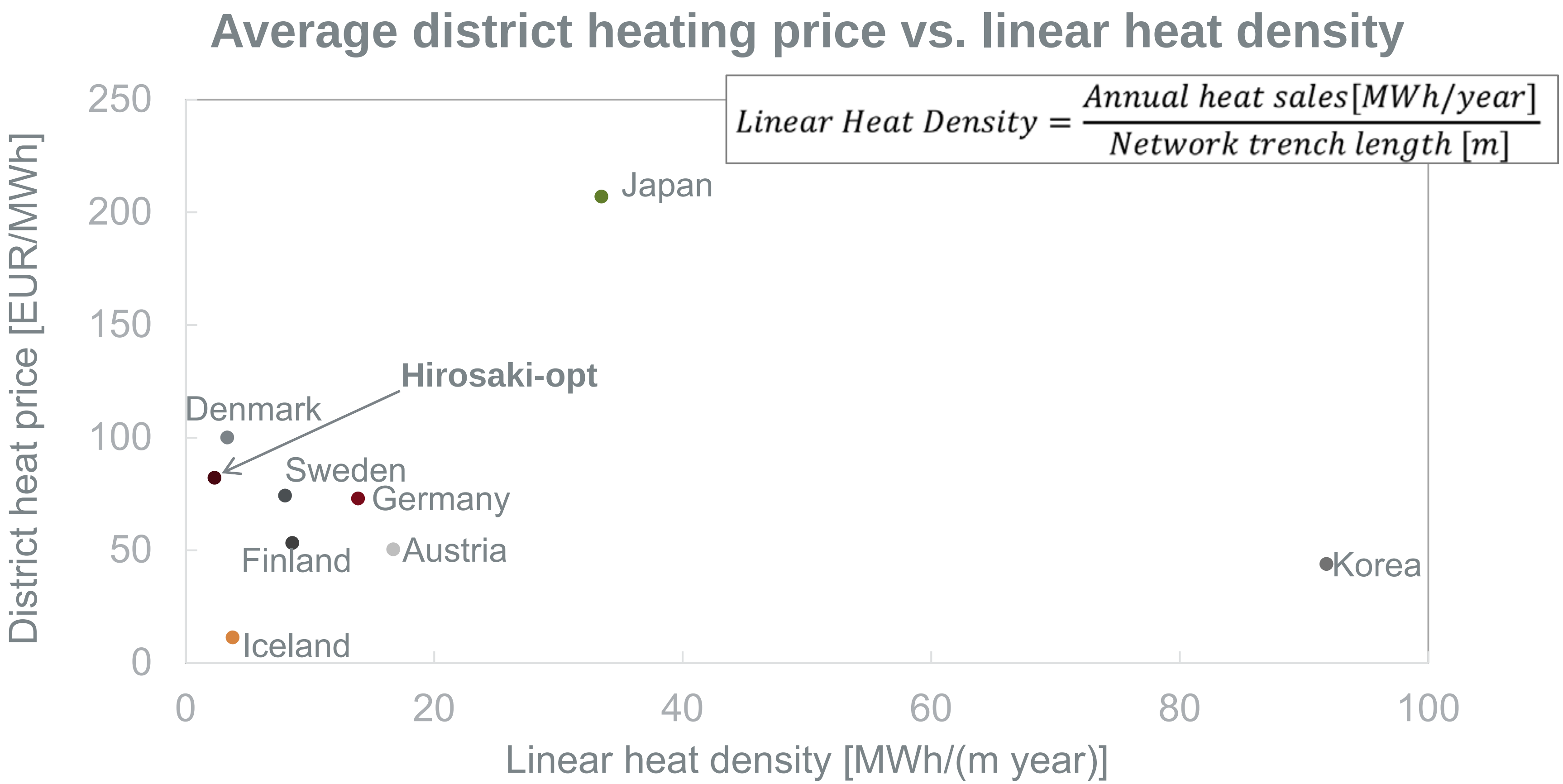
- Network equivalent diameter:
  - LT: 0.108 m
  - MT: 0.093 m

Cost comparison:

Cost type [10^6 JPY/year]	LT mode	MT mode
Network cost	24.8	20.7
Pumping cost	7.8	7.1
Fuel cost	183.8	184.7
Sum	216.4	212.5

Optimization results

Result comparison with empirical values



[Source: Euroheat and Power, District heating and cooling 2013 survey]

Conclusion

- A deterministic geographic-based district heating system MILP planning model was developed and shows promising results.
  - Network structure and operation accuracy.

- Despite district heating systems being few and far between in Japan, model results indicate socio-economic benefits of DHS over the existing system.
  - Less cost, primary energy consumption and GHG emissions.

- Fuel savings from low temperature operation are not sufficient to compensate the cost increase in pipe network.
  - Limits: Low operation impact on heating technologies not modeled, thus whole system effect not accounted for.

- Model is currently being further applied for a new development area in cooperation with Politecnico di Milano under the IEA-EBC Annex 64.

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your ingenious partner

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