A potential for interconnecting district heating grids in the greater Zagreb region

Dominik Franjo Dominković*, DTU Compute

Ignacio Blanco, DTU Compute

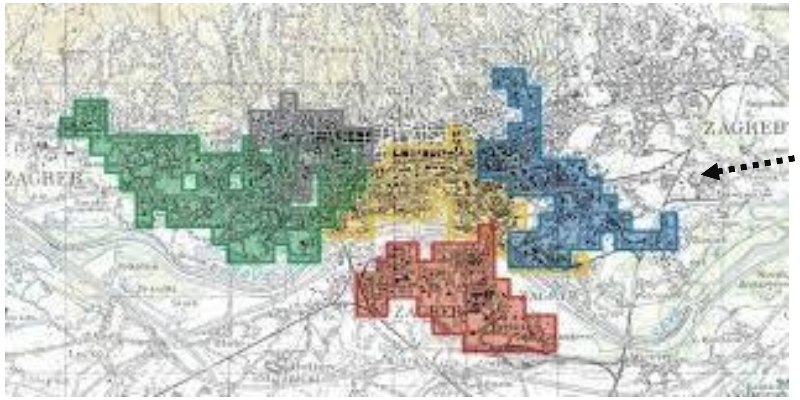
Tihomir Capan, FSB @ UNIZG

Goran Krajacic, FSB @ UNIZG

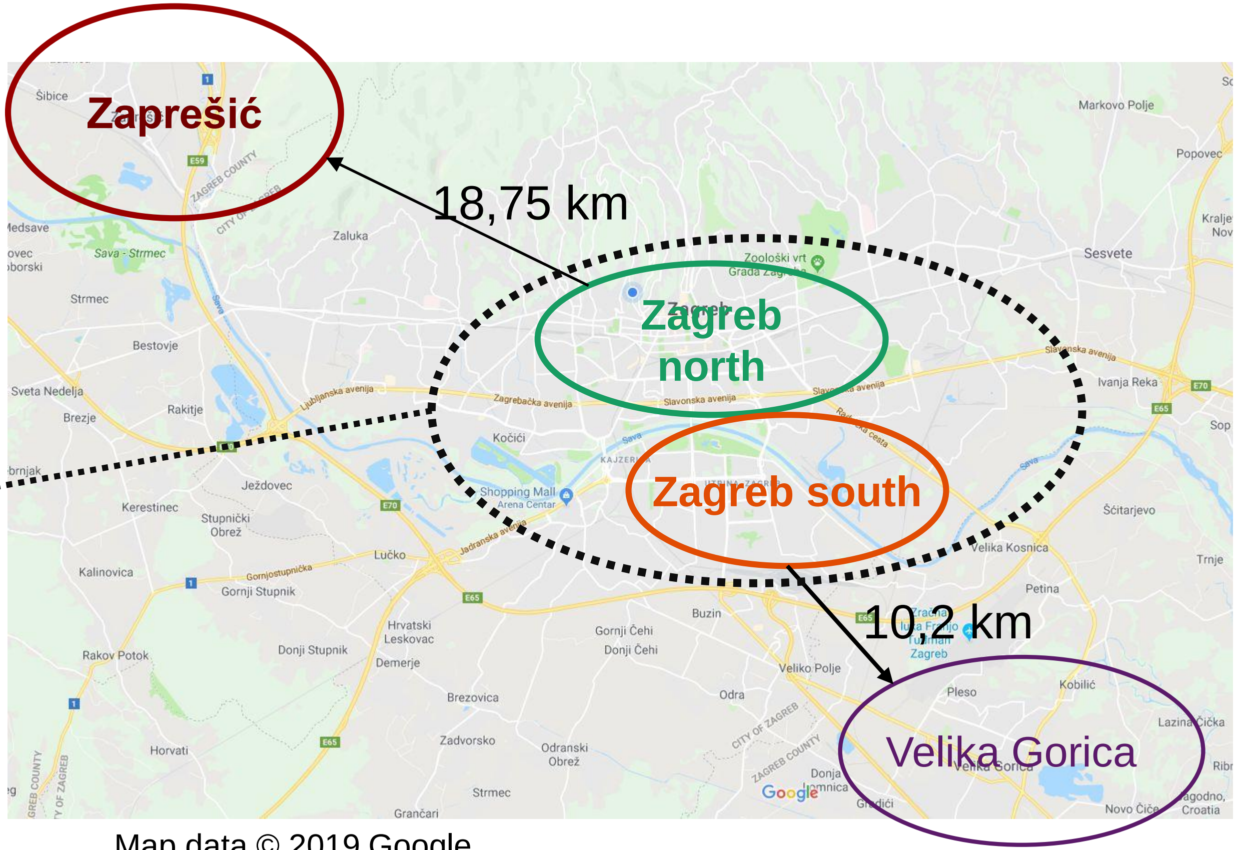
Outline

1) Regions considered
2) Optimization model used
3) Results
4) Sensitivity analyses
5) Outlook

Considered regions



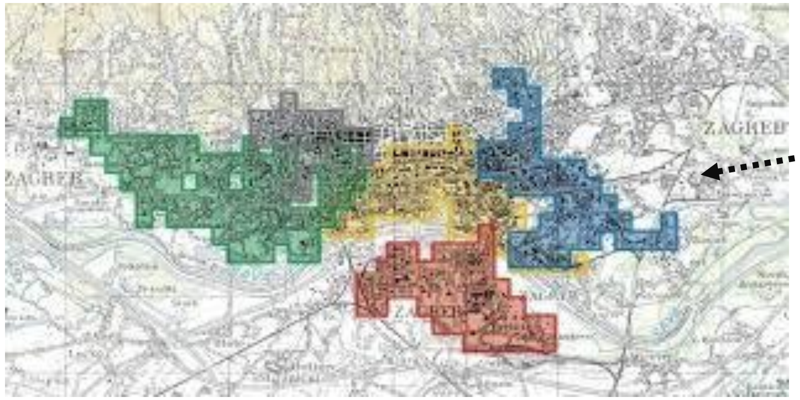
Source: Stratego project



Map data © 2019 Google

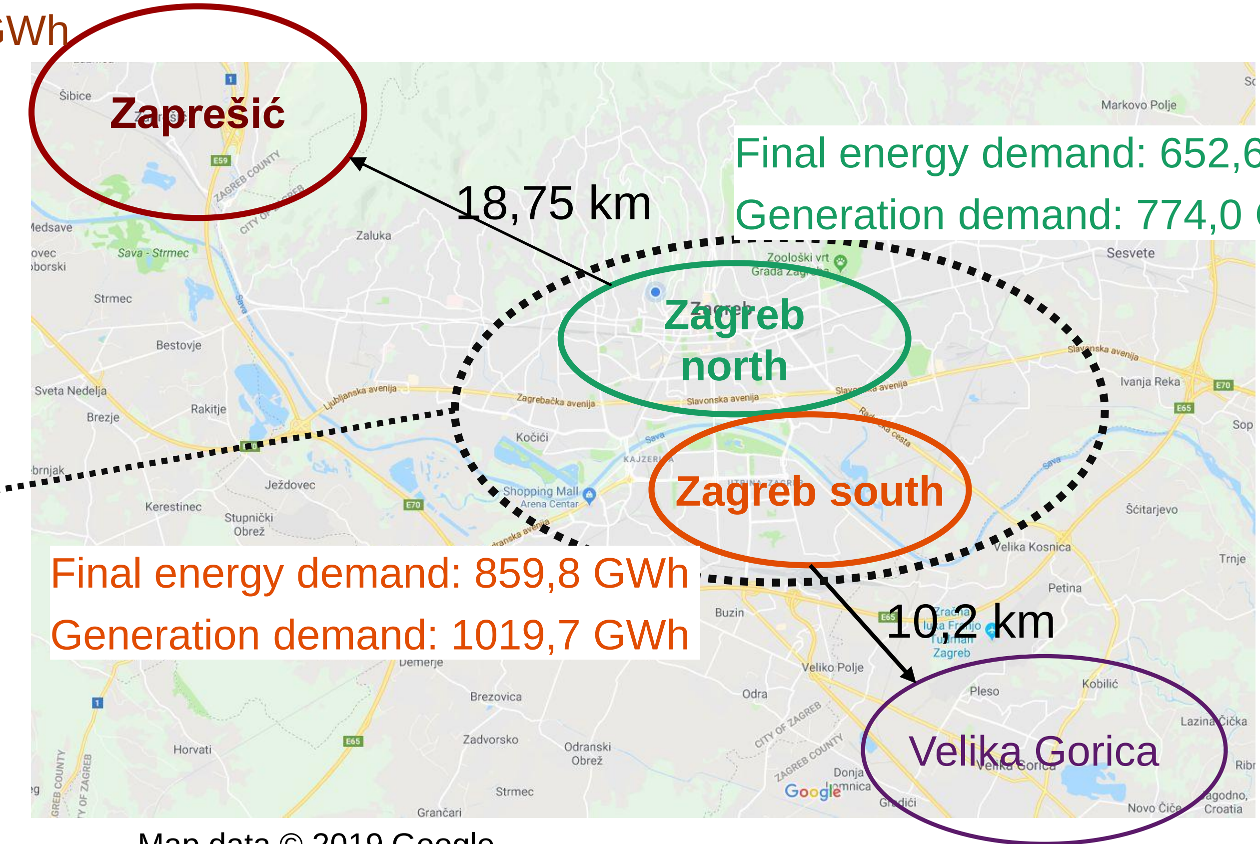
Considered regions – district heating demand

Average DH demand: 2013 - 2017



Source: Stratego project

Final energy demand: 16,2 GWh
Generation demand: 17,5 GWh



Map data © 2019 Google

Final energy demand: 652,6 GWh
Generation demand: 774,0 GWh

Final energy demand: 859,8 GWh
Generation demand: 1019,7 GWh

Final energy demand: 54,9 GWh
Generation demand: 61,0 GWh

Optimization model

- Objective function: to minimize the total socio-economic costs of the district heating system
  - » Considerations: annualized investment costs, O&M, fuel costs
  - » CHP operation (!!) – assigning fuel costs and income from electricity sales
  - » Sunk costs – already existing plants
- Variables:
  - » 1) hourly heat generation in each district heating system
  - » 2) capacities of plants – including new ones
  - » 3) storage operation
- Constraints:
  - » Meeting DH demand in each region – sufficient capacity of plants in the system
- Implementation: Python + Gurobi solver (free for academia)

Case study assumptions

- Connection piping price assumptions from: *Frederiksen, Werner: District Heating and Cooling* – adjusted for inflation and currency exchange

  - Piping cost:

	Start – up cost (M€)	Additional cost per capacity (M€/MW)
Zapresic	7,1	0,64
Velika Gorica	3,87	0,35

- Perfect foresight
- DH distribution losses modelled exogenously
- Transmission pipe loss: 5%
- Technology costs from: *Technology datasheet for energy plants* by Energinet and DEA
- CO2 price: 22€ / ton
- Electricity distribution and transmission fees: 40 €/MWh$_{ele}$ (in total)

Case study – investment options

- 1) Thermal energy storage
- 2) Electric boiler and/or heat pump
- 3) Connection pipe:
  - A) Zagreb north to Zapresic
  - B) Zagreb south to Velika Gorica

	Investment cost (EUR/ MW_{heat})	Annualized investment cost (EUR/(MW year))	Fixed cost (EUR/(MW year))	Variable cost (EUR/MWh)	Total efficiency	Lifetime (years)	Discount rate
Electric boiler	75,000	7,079	1,100	0.8	98%	20	7%
Heat pump	700,000	60,067	2,000	2	400% (COP)*	25	7%
Thermal storage (per MWh)	3,000	225	8.6	0.1	98%	40	7%

Techno - economic assessments

- Two different approaches
  - 1) socio-economic costs/benefits after the possible DH system interconnection
    - » No taxes considered (except CO_2)
    - » Electricity sales as an income – Cropex day-ahead for 2017
  - 2) prefeasibility study – ‘classical’ economic assessment of investment costs vs. newly available income stream
    - » Costs of proposed solutions
    - » Resulting capital costs per unit of heat sales
    - » Possible income to cover variable and fuel costs (compared to the best available alternative)

Best (cheapest) alternative heating option

	Efficiency / COP	Price per heat unit (€/MWh)
Gas boiler	98%	31.17
Solid biomass boiler	70%	42.86
Biomass – pellets	83%	48.19
Heat pump	320%*	31.88

Results (I)

Overall savings after the interconnection!

But highly sensitive to electricity and gas prices

	Zagreb south and north (base case)	Zagreb and Velika Gorica	Zagreb and Zaprešić	2 and 2 DH systems connected
Total system costs (M€)	4,37	3,29	-	3.97
Difference (€)	0	-1.09	-	-0.41

Expensive! DH Zaprešić should be handled separately

- Cropex day ahead weighted average price for 2017: 53.81 €/MWh (source: Cropex)
- DK1 and DK2 on Nordpool day ahead: 30.08 and 31.97 €/MWh (source: Nordpool)
- Gas price in 2017: 26 €/MWh for non-household consumers in Croatia (source: Eurostat)
- **!! Socio-economic costs sensitive to electricity prices > income from electricity sales – around 117 M€**

Results (II) – ‘classical’ techno-economic assessment

- Velika Gorica

- Optimal investment portfolio: 972 MWh thermal storage and 20.75 MW pipe capacity (peak final energy demand: 23.48 MW)

	Storage	Connection pipe
Investment cost (€)	2,916,000	11,127,275
Annuity (€ / year)	218,727	834,647
Total O&M (€ / year)	8,359	66,017
Total yearly costs (€/year)	1,127,750	

	€/MWh of heat sold
Capital price to recover investment	20.5
Calculated ‘room’ for DH heat price*	18.7

- ** compared to the best available alternative (gas and individual heat pump)*

Results (III) – DH Zaprešić

- Connection pipe to DH Zagreb north – cannot recover even the capital costs

- Optimal investment portfolio (peak capacity: 8.32 MW):
  - » Thermal storage: 98 MWh
  - » Electric boiler: 0.71 MW
  - » Heat pump: 3.82 MW (heating capacity)

Not profitable – not possible to recover variable costs (including electricity)

- Total DH system cost: 677,700 € / year ('classical' techno-economic assessment)

	Compared to the best available alternative	Compared to the current DH price
	€/MWh of heat sold	
Capital price to recover investment	41.8	41.8
Calculated 'room' for DH heat price	**-10.6**	7.3

Interconnections vs. optimal portfolios

Connected DH systems:	All heat supplied via interconnection System costs (M€/year)	Optimal portfolio (M€/year)	Difference
Velika Gorica and Zagreb	3,93	3,29	-16.3 %
Zaprešić and Zagreb	5,53	5,06	-8.5 %

Sensitivity analyses

- Electricity prices – Danish system (lower average and higher span)

Socio-economic system costs	Only DH Zagreb (south and north) (M€)	All 4 DH systems (M€)	Difference (M€)
Cropex ele. Prices (Croatia)	4,38	3,97	- 0.41
DK1 (western Denmark)	56,22	57,49	1.27

In total 1.68 M€

- Total annual costs for DH Velika Gorica and DH Zapresic (both inv. and running costs) ≈ 3.2 M€

- Gas prices

Gas price	Reference case - 26 €/MWh	41.9 €/MWh (2013 S2)	34.6 €/MWh (2015 S2)
DH case			
Only DH Zagreb (south and north) (M€)	4.38	23.92	15.01
All 4 DH systems (M€)	3.97	24.17	14.96

- Combination of high gas and electricity prices – total system costs (all 4 DH): 76.0 M€

Outlook

- Zaprešić – enlarging DH system or looking for efficient individual solutions (heat pumps)
- DH Zagreb extremely sensitive to gas prices (and CO2 price): diversification by installing electricity driven heat generators?
- Business-economic assessment
- Risk hedging possibilities
- Solar DH possibility
- Lowering DH temperatures (low hanging fruits)
- Offering down regulation on (future) regulation markets – calculating income stream
- Introducing demand response also on the demand side – medium term future

Acknowledgments

- Big thanks to **HEP Toplinarstvo** for providing data on Zagreb DH grid operation

- This work was financed by **CITIES** project No. DSF1305-00027B funded by the Danish Innovationsfonden (Ignacio and Dominik) and **KeepWarm** project that received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement no. 784966 (Goran and Tihomir)

- Thank you!