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Prospective life-cycle assessment of geothermal district heating and cooling networks

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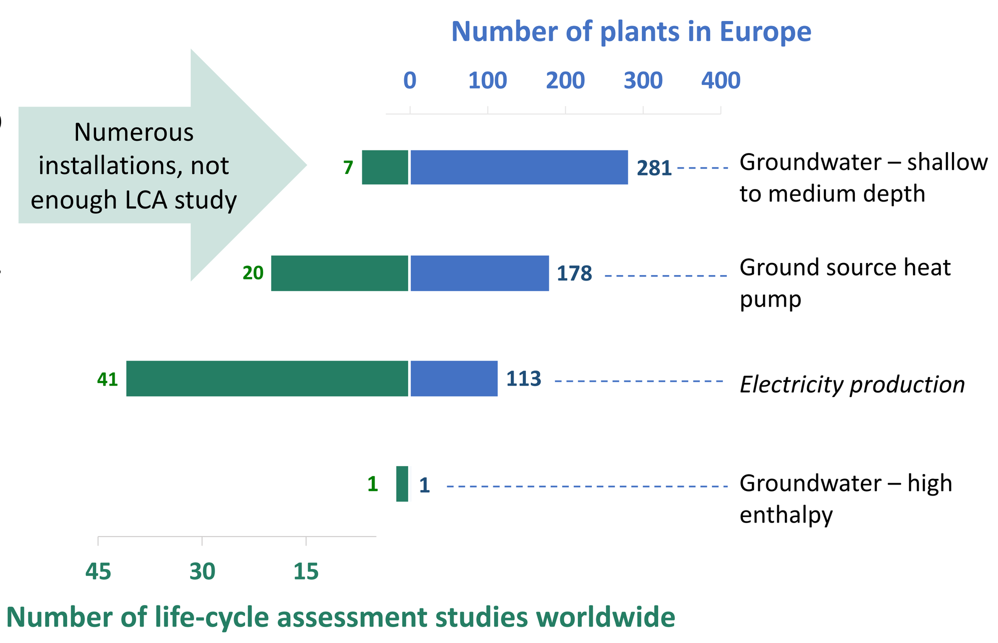
Background

As part of the strategy to reduce greenhouse gas emissions by 60% by 2035, the Canton of Geneva in Switzerland aims to increase the share of renewable energy in the heating and cooling mix, where geothermal energy from shallow to medium depth and district heating play an important role [1].

Life-cycle assessment studies for geothermal energy in the literature rarely covered geothermal heating from shallow to medium depth despite of the popularity of such systems in Europe, leaving their environmental impacts unknown [2].



Research objectives

- Quantifying the life-cycle environmental impacts of the **future six key configurations** of **shallow to medium-depth geothermal heating and cooling networks** in the State of Geneva, including considering their **uncertainties**.
- Comparing the environmental performance of shallow to medium-depth geothermal heating and cooling networks to that of other heating and cooling sources used in the State of Geneva.

Methods

Define six key configurations to supply heat and cooling at 75°C and 14°C resp. and **build parameterized model**

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Analyze uncertainty using bounding analysis, evaluating **eight scenarios** for each configuration

Quantify eight environmental impacts per MWh of delivered energy (heating and cooling)

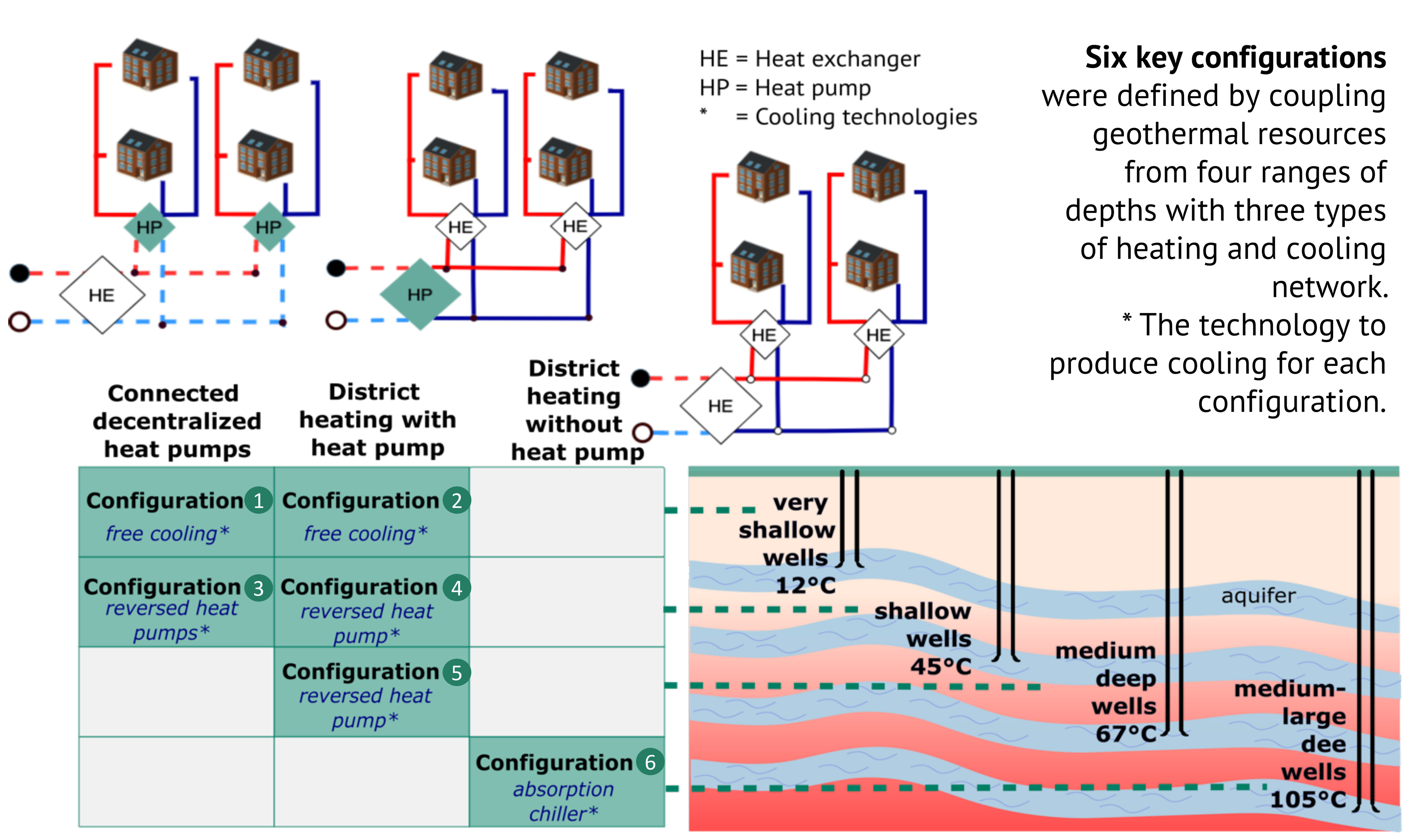
Collect life cycle inventory from several installations and define **parameters' values for reference configurations**

ecoinvent

ReCiPe

Compare their environmental impacts with those of other technologies

Global warming | Land use | Water consumption | Mineral resource scarcity | Particulate matter formation | Terrestrial acidification | Fossil resource scarcity | Total energy demand



Six key configurations were defined by coupling geothermal resources from four ranges of depths with three types of heating and cooling network.

* The technology to produce cooling for each configuration.

Findings

Only four out of eight environmental impacts are presented

Reference configurations

heating

Global warming ($kg\ CO_{2\ eq}/MWh$)

(1) 16.1	(2) 18.1	
(3) 9.8	(4) 14.9	
	(5) 18.9	
		(6) 17.3

Land use ($m^2 \cdot year\ crop_{eq}/MWh$)

0.41	0.44	
0.20	0.30	
	0.35	
		0.25

Mineral resource scarcity ($g\ Cu_{eq}/MWh$)

409	492	
256	456	
	450	
		304

Particulate matter ($g\ PM_{2.5\ eq}/MWh$)

42.9	47.1	
24.6	35.0	
	47.3	
		40.3

1. For a given depth, reference configurations with connected decentralized heat pumps (1 and 3) have lower environmental impacts than the ones with centralized district heating systems (2 and 4), because the latter require steel-based pipes, while the former plastic-based pipes. This trend is confirmed by the uncertainty analysis (see reference #3).
2. For a given network, reference configurations with shallow wells have lower environmental impacts (3 and 4) than the ones with very shallow wells (1 and 2), because the former requires less energy to drill the wells and less electricity to operate the heat pumps than the latter. This trend is also confirmed by the uncertainty analysis (see reference #3).
3. Obtaining heat from deeper depth will reduce most of environmental impacts only when heat pumps are no more required during the operation phase (configuration 6) .

cooling

exergy allocation

Global warming ($kg\ CO_{2\ eq}/MWh$)

(1) 5.8	(2) 6.3	
(3) 6.6	(4) 7.5	
	(5) 10.2	
		(6) 7.8

Land use ($m^2 \cdot year\ crop_{eq}/MWh$)

0.11	0.12	
0.19	0.20	
	0.27	
		0.12

Mineral resource scarcity ($g\ Cu_{eq}/MWh$)

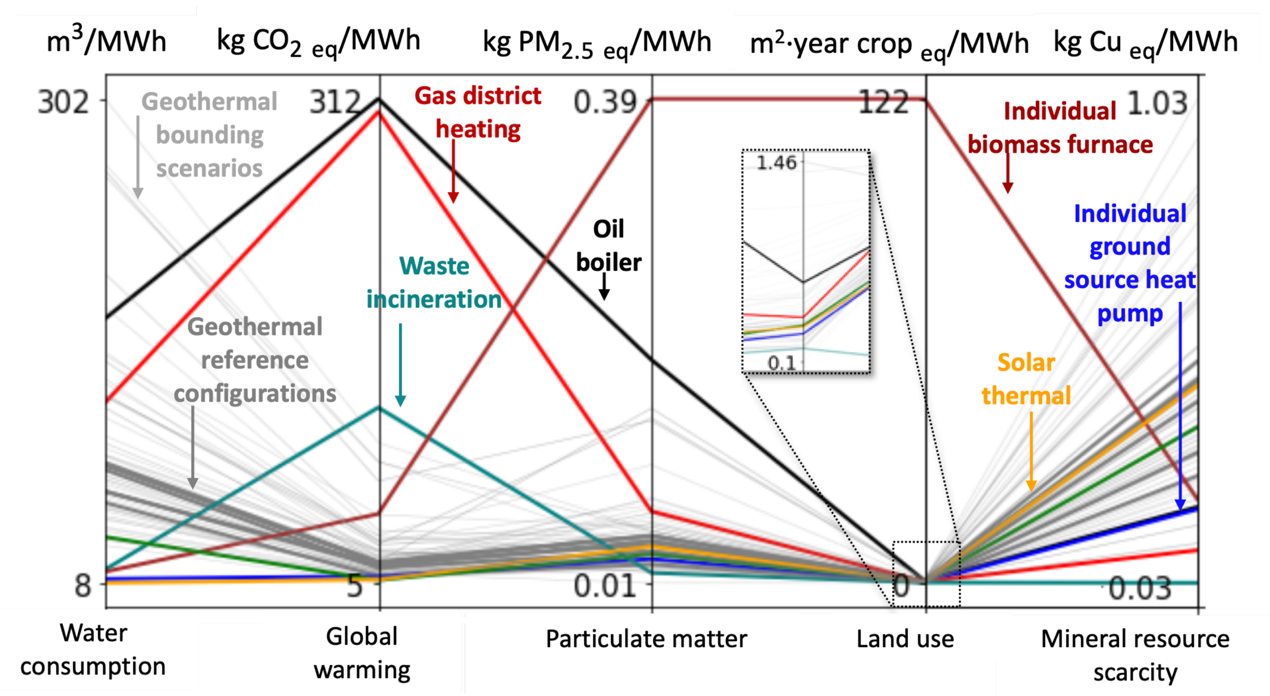
115	129	
218	246	
	286	
		141

Particulate matter ($g\ PM_{2.5\ eq}/MWh$)

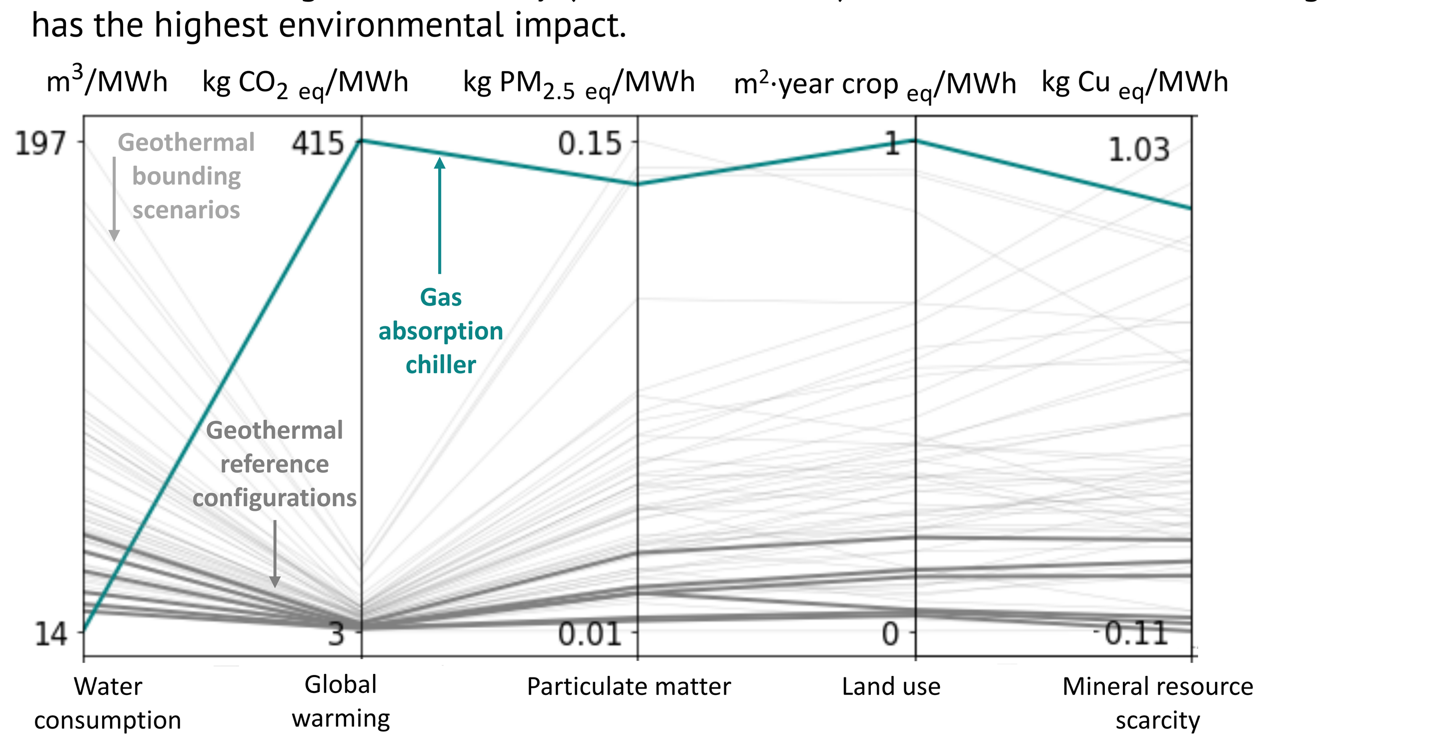
13.0	13.9	
20.6	22.4	
	32.0	
		20.8

1. Reference configurations with free cooling (1 and 2) have the lowest environmental impacts, thanks to low electricity. However, the uncertainty analysis shows that in worst cases (e.g., when the extracted geothermal energy is very small and the equipment is highly material intensive), such configurations could have much higher impacts (see reference #3).
2. Supplying cooling using a decentralized network (1 and 3) leads to slightly lower impacts as no additional set of network pipes is required to allow a simultaneous supply of heating and cooling, unlike the centralized district heating systems (2 and 4) . This trend is confirmed by the uncertainty analysis (see reference #3).
3. The reference configuration with absorption chiller has moderate environmental impacts but it has the largest uncertainty (see reference #3). In its worst case, this configuration has the highest environmental impact.

Comparison



The environmental impacts of geothermal heating configurations are at a lower range, except for mineral resource scarcity (similar to solar thermal, electric heating and ground source heat pumps). Some geothermal bounding scenarios that analyze uncertainty (marked in grey lines) have higher particulate matter impacts as compared to gas district heating, but their global warming impacts remain lower.



Geothermal cooling have much lower environmental impacts than gas absorption chiller except for water consumption. Some geothermal bounding scenarios that analyze uncertainty (marked in grey lines) have high particulate matter impacts, implying the importance of careful design.

Conclusions

1. Geothermal heating and cooling have lower environmental impacts compared to fossil-fuel heating. Their low climate change impacts confirm that they are suitable for decarbonization, but the impacts of mineral resource scarcity need to be managed.
2. For a given geothermal resources, configurations with decentralized connected heat pumps have lower environmental impacts both for heating and cooling applications.
3. The uncertainty analysis using bounding scenarios shows system designs significantly influence environmental impacts.

References

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3. Pratiwi AS, Trutnevyte E. Life-cycle assessment of shallow to medium-depth geothermal heating and cooling networks in the State of Geneva. Geothermics 2021;90:101988. https://doi.org/10.1016/j.geothermics.2020.101988.

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