Data package: **Scenarios of technical and useful ground-source heat pump potential for building heating and cooling in Western Switzerland**

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This data package is a supplement to the following research article:

Walch, Alina, Xiang Li, Jonathan Chambers, Nahid Mohajeri, Selin Yilmaz, Martin Patel, and Jean-Louis Scartezzini (2022). 'Shallow Geothermal Energy Potential for Heating and Cooling of Buildings with Regeneration under Climate Change Scenarios'. *Energy*, 123086. https://doi.org/10.1016/j.energy.2021.123086.

Introduction

This data package contains an estimation of the useful and technical potential of shallow ground-source heat pumps (GSHPs) for Western Switzerland, at a spatial resolution of 400 x 400 m^2. The **technical potential** is hereby defined as the maximum energy that could be extracted from GSHP systems in case of their dense deployment, such as to *avoid the over-exploitation* of the heat capacity of the ground. We consider GSHPs with *vertical closed-loop borehole heat exchangers* (BHE) installed at depths of 50 - 200 m. The **useful potential** is defined as the potential that could be delivered to building heating and cooling systems via a water-to-water heat pump.

The dataset contains future scenarios of heating and cooling demand, space cooling equipment deployment (service sector only) and climate change models and considers the potential use of DHC. The dataset covers around 80,000 property units (parcels) in the Swiss Cantons of Vaud and Geneva, excluding only the areas of the Alps and the Jura mountains.

The data package contains information on the available area for GSHP systems, the heating and cooling demand as well as the resulting technical and useful potentials for all simulated scenarios of future cooling demand (for 2,000 Monte Carlo runs), for the case of **direct heat supply** (per pixel of 400 x 400 m^2) as well as for **district heating and cooling** (DHC). In scenarios without DHC (direct heat supply), the results are summarized by pixel. In scenarios with DHC, the results of potentials *within* DHCs are summarized by DHC (see *_in_dhc.csv*) while potentials *outside* of DHCs are summarized by pixel (see *_outside_dhc.csv*).

For details on the methodology applied to obtain the results provided in the data package, please refer to the above-mentioned research articles. A description of all files is provided below, and metadata is provided in *Datapackage.json.* Further technical notes are provided at the end of the document.

File overview

The data package contains the following files:

- *Datapackage.json:* Metadata description
- *pixel_info.csv*: Descriptive characteristics of pixels (400 x 400 m^2)
- *dhc_info.csv*: Descriptive characteristics of potential DHC zones
- *dhc_zones.gpkg*: Geometries of DHC zones
- *NC-ND.csv*: Results for scenario NC-ND (no cooling, no DHC)
- *NC-D_in_dhc.csv, NC-D_outside_dhc.csv:* Results for scenario NC-D (no cooling, with DHC), including the results within DHC zones and in pixels without DHC
- *PC-ND-[26/45/85].csv:* Results for scenario PC-ND (partial cooling, no DHC), for three climate change scenarios (RCP 2.6, 4.5, 8.5)
- *PC-D-[26/45/85]_[in/outside]_dhc.csv:* Scenario PC-D (in analogy to above)
- *FC-ND-[26/45/85].csv:* Scenario FC-ND (full cooling, no DHC)
- *FC-D-[26/45/85]_[in/outside]_dhc.csv:* Scenario FC-D (in analogy to above)

File structure:

The data files have the following attributes:

pixel_info.csv

`x, y`	coordinates of pixel centroid in CRS EPSG 2056
`Canton`	GE: pixel located in canton of Geneva; VD: canton of Vaud
`Heat_demand`	Projected heat demand (2050) of buildings within pixel [kWh/y]
`Heat_demand_outside_dhc`	Projected heat demand (2050) of buildings within pixel and outside of potential DHC zones (scenarios D) [kWh/y]
`GSHP_area`	Available area for borehole installation for GSHP systems attributed to the pixel (note: can exceed the pixel area!) [m2]
`Restriction_type`	Known restrictions for GSHP installation; see article for interpretation
`T_surface`	Average ground surface temperature, derived from Assouline et al. (2019) [°C]

dhc_info.csv

`dhc_id`	ID of DHC zones
`Canton`	GE: pixel located in canton of Geneva; VD: canton of Vaud
`Heat_demand`	Projected heat demand (2050) of buildings within pixel [kWh/y]
`DHC_area`	Area of the potential DHC zone [m2]
`GSHP_area`	Available area for borehole installation for GSHP systems attributed to the dhc zone (note: often exceeds the dhc area!) [m2]
`Restriction_type`	Known restrictions for GSHP installation; see article for interpretation

[PC/FC]-ND-[26/45/85].csv

`Statistics`	Statistics of the results across all Monte Carlo runs: mean, standard deviation (STD), sample run
`x, y`	coordinates of pixel centroid in CRS EPSG 2056
`Q_injected`	The technical heat injection potential [kWh/y]
`Q_extracted`	The technical heat extraction potential [kWh/y]
`Q_usable_heat`	Useful potential to supply building heat demand [kWh/y]
`Q_usable_cool`	Useful potential to supply building cooling demand [kWh/y]
`Q_cool_demand`	Total cooling demand of pixel [kWh/y]

NC-ND.csv

In analogy to above (*[PC/FC]-ND-[26/45/85].csv*), but no column `Statistics` is provided (as Monte Carlo runs are only performed for cooling demand, and NC is the "no cooling" scenario). Consequently, the following columns are not applicable: `Q_injected, Q_usable_cool, Q_cool_demand`

[PC/FC]-D-[26/45/85] _in_dhc.csv

`Statistics`	Statistics of the results across all Monte Carlo runs: mean, standard deviation (STD), sample run
`dhc_id`	ID of DHC zones (geospatial reference in *dhc_zones.gpkg*)
`Q_injected`	The technical heat injection potential [kWh/y]
`Q_extracted`	The technical heat extraction potential [kWh/y]
`Q_usable_heat_supply`	Useful heating potential based on where the thermal energy is **extracted** [kWh/y]
`Q_usable_heat_demand`	Useful heating potential based on where the thermal energy is **used** (following spatial allocation procedure) [kWh/y]
`Q_usable_cool`	Useful potential to supply building cooling demand [kWh/y]
`Q_cool_demand`	Total cooling demand of DHC zone [kWh/y]

NC-D_in_dhc.csv

In analogy to the above, but no column `Statistics` is provided (as Monte Carlo runs are only performed for cooling demand, and NC is the "no cooling" scenario). Consequently, the following columns are not applicable: `Q_injected,Q_usable_cool,Q_cool_demand`

[PC/FC]-D-[26/45/85] _outside_dhc.csv

`Statistics`	Statistics of the results across all Monte Carlo runs: mean, standard deviation (STD), sample run
`x, y`	coordinates of pixel centroid in CRS EPSG 2056
`Q_injected`	The technical heat injection potential [kWh/y]
`Q_extracted`	The technical heat extraction potential [kWh/y]
`Q_usable_heat_supply`	Useful heating potential based on where the thermal energy is **extracted** [kWh/y]
`Q_usable_heat_demand`	Useful heating potential based on where the thermal energy is **used** (following spatial allocation procedure) [kWh/y]
`Q_usable_cool`	Useful potential to supply building cooling demand [kWh/y]
`Q_cool_demand`	Total cooling demand of pixel outside of DHC zones [kWh/y]

NC-D_outside_dhc.csv

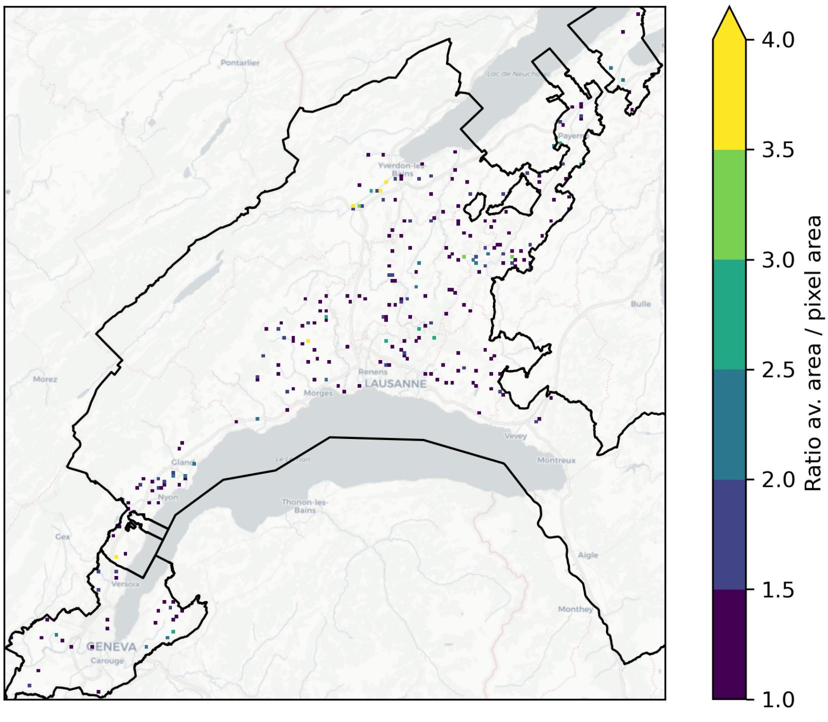
In analogy to the above, but no column `Statistics` is provided (as Monte Carlo runs are only performed for cooling demand, and NC is the "no cooling" scenario). Consequently, the following columns are not applicable: `Q_injected,Q_usable_cool,Q_cool_demand`

Technical notes

As indicated in the first two tables in the above section, the GSHP area may exceed the pixel area of 16 hectares (see *pixel_info.csv*) as well as the DHC area (see *dhc_info.csv*). The former (i.e. GSHP area > pixel area) is the case in 5% of the pixels, whereby in 1% of the pixels the GSHP area exceeds 1.5 times the pixel area (i.e. 24 hectares). The latter (i.e. GSHP area > dhc area) is the case for most of the (small) potential DHC zones. As this may seem counter-intuitive, in the following we provide a justification for this finding, as well as some relevant considerations for the interpretation of the results.

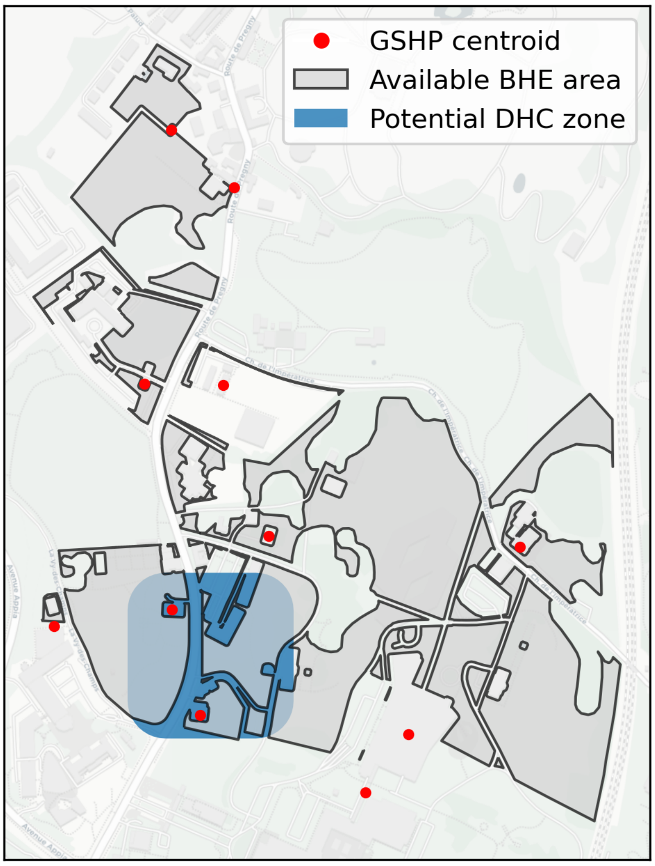
The first reason for GSHP areas exceeding pixel or DHC areas – and the primary reason in the case of direct heat supply (i.e. pixel-scale results) – is that the mapping from *parcels* to *pixels* is done by **centroid**, rather than by dividing each parcel in multiple pieces attributed to different pixels. As mentioned above, this simplifying assumption holds for most pixels, particularly in urban areas. This approach is justified by the fact that each *parcel* is connected to a *building* (where the demand arises), so matching by centroid is more realistic for the evaluation of the useful potential. However, in the cases where the available area exceeds the pixel area, the energy density plotted in Fig. 5 in the research article must be interpreted with caution.

The below figure shows the location of the pixels with a GSHP area larger than the pixel area (whereby the color scale represents the ratio of GSHP area to pixel area (16 hectares)):



Another reason why GSHP areas are larger than DHC areas in most cases (primarily small potential heating networks) is that GSHPs are assumed to supply DHCs of up to **1000 m** in their proximity. These GSHPs (see figure for example) are assumed to be connected to the DHC, such that the heating demand these generate is accounted to the DHC and the cooling demand from this DHC may be discharged into these GSHPs. Note that this is different from the spatial allocation process, whereby the connection of DHC to *building heat demand* is performed. These two steps are decoupled in the present methodology.

The following figure visualises this aspect for an example DHC zone:



<u>References</u>:

Assouline, Dan, Nahid Mohajeri, Agust Gudmundsson, and Jean-Louis Scartezzini. 'A Machine Learning Approach for Mapping the Very Shallow Theoretical Geothermal Potential'. *Geothermal Energy* 7, no. 1 (December 2019): 19. https://doi.org/10.1186/s40517-019-0135-6.