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Building aggregation to estimate the potential for shared energy generation with heat pumps

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Abstract:

Switzerland uses a total of 50.2 TWh to heat buildings and produces warm water in 2019, corresponding to around 80% of the energy consumption in Swiss households. Fossil heat generators account for 65% of heating energy in buildings and 53% of warm water generation (Kemmler 2020). This corresponds to 31.4 TWh per year and causes 7.5 million tons per year of CO2 emissions, with a share of 61% oil heating and 39% gas heating. With the “Energy Strategy 2050+” Switzerland commits to becoming climate neutral by 2050 (Bundesrat 2020) with the goal to no emit no more greenhouse gas, than are compensated (net zero target). One target to reach this goal is to replace fossil-based heat generators in existing buildings with heat generators based on renewable energy. In urban areas, gas networks are unlikely to be renewed and likely be shut down. However, this means that buildings previously supplied with gas will have to switch to another heat generator. If the gas network is not replaced by district heating, heat must be generated locally at the buildings. As a result, each building will have to look for its own new heat generation. Since larger heat generators are more efficient and economical than individual small heat generators, it makes sense to combine adjacent buildings into a thermal micro-grid, e.g. semi-detached houses are supplied by one heat generator. Thermal micro-grids are therefore more sustainable than individual solutions.

These thermal micro-grids should comprise about two to eight buildings to make the implementation less complex (owners, space conditions, pipe lengths, etc.). For this purpose, buildings in regions where there are gas grids must be evaluated. As a rule, thermal micro-grids of buildings with the same utilisation and degree of expansion are to be preferred, as this is usually technically easier to implement.

Studies show the benefit in energy and financial savings and avoided CO2 emissions for district heating (Pompei et al. 2022, Geyer et al. 2017, Möller and Lund, 2010). Hence, building aggregation to denote clusters for thermal micro-grids and district heating differ in the desired cluster sizes. Unternährer et al. (2017) in a similar graph-based approach denote for the city of Lausanne in Switzerland that the profitability of district heating integration is strongly affected by the spatial density of the heating demand in urban areas. Their approach is based on K-Means, Delaunay triangulation, Johnson's routing algorithm and Kruskal's algorithm to establish the clusters, searches for larger building clusters typical for district heating and is less suited for estimating for clustering micro-grids in urban city blocks. Schlüter et al (2016) identify thermal micro-grids applying fuzzy logic and cost-benefit analysis with pairwise comparison of suitable buildings and agglomerating connected buildings to thermal micro grids in a case study in Zernez Switzerland.

For the energy development or transformation of cities, it is therefore useful to have a mapping model showing the potential for thermal micro-grids. In the map, the different types of thermal micro-grids are represented and symbolised, as well as different variants for the individual thermal micro-grid sizes in terms of heat load. This map can be incorporated into the corresponding geoportal and offers, for example, the municipality, the individual owners, but also energy suppliers or energy consultants, an overview of sensible grid layouts.

Based on publicly available national building geodata including construction year, heat generation type, energy reference area and location, this work describes a building aggregation method for estimating the potential of thermal micro-grids in urban areas.

The method derives based on urban building blocks clusters of candidate thermal micro-grids in the study region delineating is the canton of Basel-Stadt in Switzerland. The approach derives for each building the heating capacity [kW] based on the construction year and the energy reference area (Aksoezen 2015, EnergieSchweiz 2020).

The proposed method starts by generating the topology of the buildings with a Delaunay triangulation based on each centroid of the building for each city block. Additionally, the edges between the buildings that are directly adjacent

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based on the building footprint are annotated. Then the method generates a Minimum Spanning Tree (MST) per city block with modified weights for attached houses to favour edges of adjacent buildings (Figure 1). The MST minimising the distance to travel between a sequence of buildings favouring those that are directly adjacent lays the base to find building cluster for thermal micro-grids. Starting at a leaf node of the MST, the traversal of the MST, then clusters buildings to thermal micro-grids based on a set of constraints. The constraints to cluster buildings to form a thermal micro-grid are, an upper limit of total heat load [kW] of the grid, the maximum length of an edge for non-attached houses and same building type. This work analysed for various upper heat load limits (30, 40, 50, 100 kW) thermal micro-grids for residential buildings with gas heating.

Figure 1. Generation of micro-grids with a maximum heat load of 100 kW for two city blocks, a) inner city block b) suburban city block denoting the Delaunay triangulation of building centroid and the weighted MST applied to form the micro-grids.

Figure 1 exemplifies the approach for two city blocks with different building layouts. It illustrates the MST based on the Delaunay triangulation, the resulting MST, and the proposed thermal micro-grids (in light green) with a maximum heat load of 100kW. Buildings that were excluded from the grid generation are denoted in grey (not residential or no gas supply for heating) and in white are candidate buildings that, according to the upper heat load limit or distance constraint, could not form a microgrid that fulfilled the constraints.

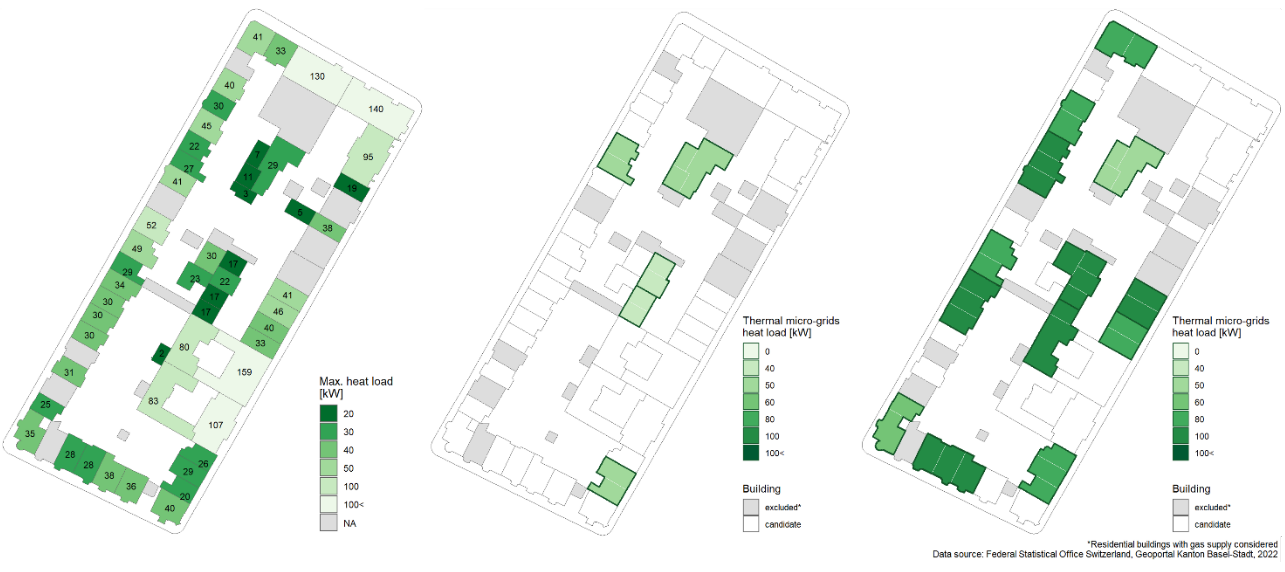

Figure 2. Building heat loads of multi-family terraced houses with the estimated heat load denoted within the building footprint (a) and possible thermal micro-grids with heat load limits of 50 kW (b) and 100 kW (c).

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Early results show potential for city blocks with terraced houses and small building footprints. Figure 2 shows the distribution of the potential of thermal micro-grids (max. 50 kW and 100 kW) in the canton of Basel-Stadt and highlights a detailed city block with a high potential for thermal micro-grids.

Figure 3 illustrates on a city block level for a heat load limit of 50kW the spatial distribution of the potential for thermal micro-grids in the Canton of Basel-Stadt. The graph below shows the number of networks and the total heat loads for different heat load limits for the study region. This work provides decision makers with an overview of where building owners have opportunities to invest in alternative heating and which buildings groups are suited for thermal micro-grids as similar building types exist in their immediate neighbourhood that provide the opportunity to form such thermal micro-grids.

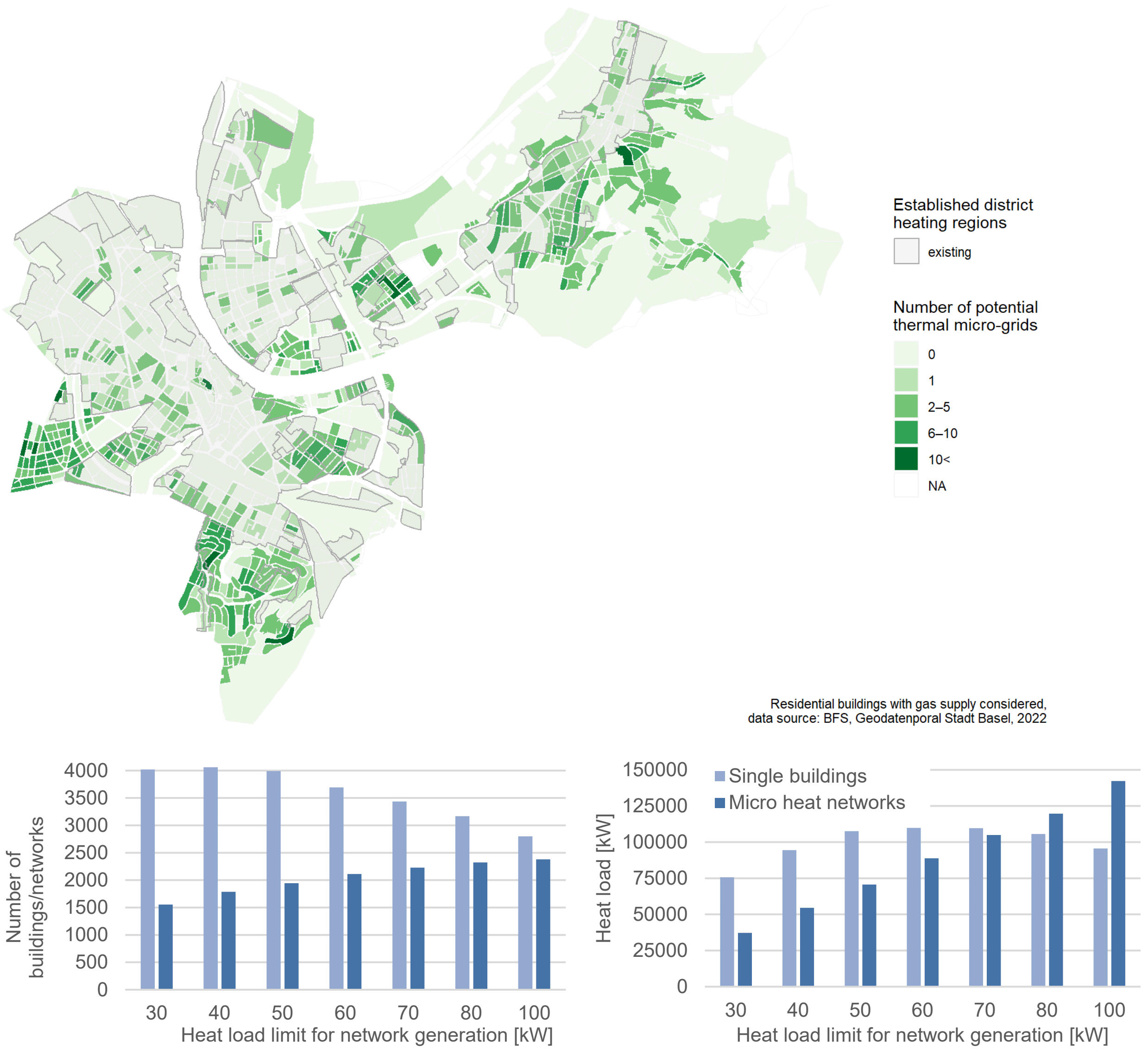

Figure 3. top: Potential of thermal micro-grids per urban city block in the canton of Basel-Stadt Switzerland with a heating capacity limit of 50kW, bottom left: number of buildings forming a micro-grid versus number of single buildings that cannot join a grid, bottom right: total heat load of thermal micro-grids and single buildings.

Next steps encompass deepened spatial and analytical geo-visualisation. Future work would be an analysis how to inform building owners about the possibility and advantages of thermal micro-grids and give planning and law support. Thermal micro-grids are a contribution to the net zero target of Switzerland.

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