GIS-based development of anergy networks using mine water geothermal energy for cross-sectoral heating and cooling supply of municipal quarters

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Abstract

The structural change within the communities in the former Ore mountains mining region in Eastern Germany requires aftercare measures. The local authorities must handle an eternal task and develop strategies for dealing with the accumulating water in the former mine shafts and tunnels. However, the accessible mining waters reach temperature levels which can be used for grid-based energy supply purposes – especially in low temperature residential and non-residential anergy networks. Due to the year-round and weather-independent availability the energy represents a base-load source for heating and cooling. Many prior analyses show the local amount of thermal power is very high at various points (several MW) which makes an individual energy supply no longer appropriate. Thus, the case study *GEoQart* is investigating possibilities to combine aftercare measures in former mining regions with a grid-based renewable heating and cooling supply using anergy networks for feasible quarters.

The novelty is a grid-based energy distribution analysis from the energy source to various consumers using algorithmic and spatial planning methods. Innovative, grid-connected supply concepts are examined to distribute the energy from the mine to various nearby consumers – mainly residential and non-residential buildings in suitable quarters. Furthermore, a *GIS-based method using 3D LOD-2 geodata* is developed to localize suitable building-specific heat sinks and cooling requirements for a feasible quarter analysis and routing simulation.

The project results in a tool that considers the underground site parameters and surface conditions. It should be operable by any user (e.g. municipality, company) to locate suitable supply quarters and establish business models. The results combine underground potentials with above-ground requirements in an ecologically and economically appropriate way. Even though the analyses are not fully completed yet, they already show that the implementation of an energy usage concept for former mining regions is highly feasible. This yields a notable degree of grid-connected customers considering their heating and cooling demands simultaneously.

The project contributes to innovative energy supply concepts in the Ore mountains mining region in Germany dealing with aftercare measures simultaneously. The tool will simplify the site acquisition for municipalities and companies regardless of their location. Using the *GEoQart* approach creates economic and ecological benefits from providing buildings with sustainable mine water heating and cooling. The project is already supported by a total of seven associated partners including local authorities, energy suppliers and plant engineering manufactures. Based on the findings, first land-use plans are adopted by local authorities.

Keywords: Grid-based energy supply, anergy networks, building sector, mine water geothermal energy, geoinformation system

Introduction

The building sector in Germany is a key lever to achieve the federal climate protection targets. But at present, natural gas and oil are still predominantly used to ensure its heat supply. The share of renewables is stagnating at 15%. To enrich the renewable share in the future, geothermal energy can be an alternative to the current fossil fuel dominated heat supply due to its seasonally independent availability. Especially the energy from mine water is an innovative, base load-capable and renewable energy source that can be utilized in the building sector using anergy networks (cold heating networks) with mine water geothermal energy as the primary energy source. As mining was widespread in Germany and other countries, many areas are theoretically suitable for a grid-based and mine water powered energy concept. In any case, aftercare measures in old mines can be utilized positively to transform the cost-intensive task of in-perpetuity management into an opportunity to supply buildings with renewable energy. This might generate a future economic value, but as this has not yet been evaluated in the form of realization concepts there are still obstacles to realizations. The core objective of the *GEoQart* project is the analysis of technical and economic feasibility supply networks for heating and cooling buildings using mine water geothermal energy and other renewable energy sources for representative districts in the Ore mountains mining region. To do so, it is necessary to identify regions and quarters where a lucrative and medium-term feasible operation of anergy heating networks is possible. Further, the project's final public output will be a user-friendly analysis-tool that drafts individual pilot concepts for mine water-based districts. This should be possible to use by any stakeholder to lower the investment barriers as a basic feasibility can be pre-checked for any suitable location.

Building-specific simulation of heating demands using 3D geospatial data

To guarantee location specific concepts the utilization of geographic information systems (GIS) and spatial simulation tools is essential. To raise the energy demand calculations for large amounts of data automatically to a new level of detail, a complete new algorithmic methodology must be developed. Currently, specific parameters (e.g. heat demand per square meter of floor space, per inhabitant) are commonly used for calculations to simulate heat requirements. However, as those values often do not suit the building, which is being simulated, the project sets the goal of developing a methodology that no longer requires any of those specific parameters. The aim is to run an efficient simulation based solely on 3D-geometry files (Level of Detail 2 (LOD2)) [The Level of Detail 2 (LOD2) 3D model consists of the building envelope with roof structures and, if applicable, simple texturing of the outer envelope as well as dormers or balconies (BKG 2023)], land use data and climate data - theoretically for an unlimited number of buildings irrespective of specific characteristic values. Also, most of the input data used should be open data and not proprietary to make the final project tool usable for the public and shareholders. The energy calculation for an individual building forms the basis for developing the methodology. In Germany, energy performance certificates for individual buildings are drawn up in accordance with the DIN V 18599 standard (DIN 2018). So, the calculation will be based on DIN V 18599 and will be applied to each single geometric file to be simulated. This means for each building the heat sinks and heat sources will be balanced using following formula:

$$Q_{h,b} = Q_{sink} - \eta \cdot Q_{source} - \Delta Q_{c,b}$$

$Q_{h,b}$ heating demand in the building zone

Q_{sink} the sum of the heat sinks in the building zone under the respective boundary conditions

Q_{source} the sum of the heat sources in the building zone under the respective boundary conditions

$\Delta Q_{c,b}$ Storage heat in the external building components

η the monthly degree of utilization of the heat sources (for heating purposes)

The sum of the heat sinks in the building zone consists of all transmission and ventilation heat sinks as well as heat sinks due to radiation. The heat sources are similar even though the solar radiation plays an important role especially in the summer. The sources also consider all the internal heat sources inside the building such as electrical supplier. To simulate the heating demands, the LOD2-data will be used as they describe each house with roof shapes, building height (absolute, roof and eaves) and footprint size. Prior to enriching the data with energy related values, the floor areas, roof areas and wall areas should be calculated including their exact orientation angles. Also, the total building volume (roof volume and void volume) should be calculated to know the amount of volume to be heated. Additionally, an estimation of areas for windows, chimneys etc. should be calculated for each different roof and wall. Based on the complete 3D-data it is possible to estimate structural parameters for each building using climatic influences. The building shape and orientation for example enables estimations about the loss of transmission heat to the environment and the heat gains through solar radiation through windows and the roof. Also, each part of the building can be enriched by specific building material properties to use different heat transfer coefficients as necessary. In total there are more than 100 different influences which can be considered in the simulation of the building energy demand. Even estimations about people's behaviour (e.g. ventilation, air exchange rates, electric device using) or the comfort temperature inside the house can be considered house specific. Fig. 1 below shows the locally simulated heating demands based on 3D-geodata.

Development of a geospatial heating network routing tool with GIS

The results from the previous 3D-object based simulation using the LOD2 geospatial data will be used to develop a heating network routing tool, which will be able to intelligently grow feasible heating network structures along suitable infrastructure, such as roads or pathways. The objective is to develop a geospatial algorithm which works with a high amount of heat consumers simultaneously to evaluate various energy supply concepts

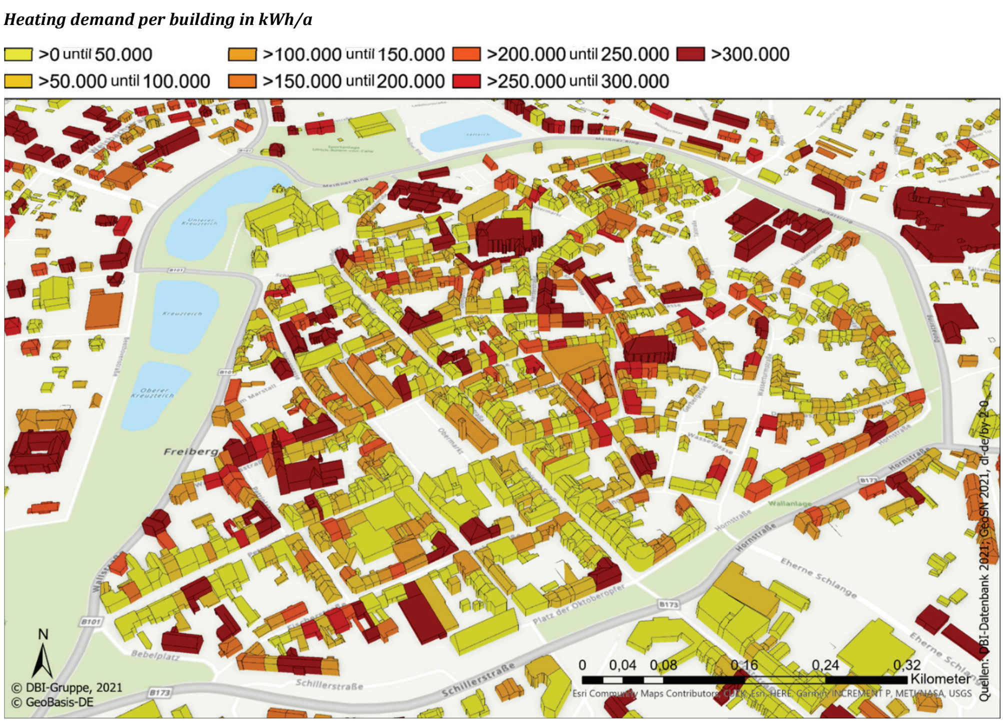

Figure 1 simulated heating demands per building based on 3D-geodata and use as much mine water geothermal energy in the anergy networks as possible. Beforehand, the 3D data will first be converted into point-data, which are then used to carry out the routing as it is not necessary to know the building's geometry anymore for the subsequent steps. To guarantee an efficient tool and enable the transition in the whole project's workflow, the algorithm development takes part in two steps.

Algorithm step 1: Allocation of customers to nearby infrastructure

First, a GIS analysis is used to create an address-specific relationship between the buildings in the municipalities and the nearby road network as energy distribution infrastructures like heating networks, but also gas distribution networks, are often installed alongside public roads. Both, the type of road and road sections that lead over bridges and through tunnels, are also considered for the subsequent network routing calculation. The whole road network which consists of motorways, federal highways, regional and state roads, municipal roads, local roads, and service roads is available in the internal DBI geodatabase (DBI 2023). Fig. 2 illustrates the step-by-step linking of the heat consumer address points with the road network resulting in lucrative streets.

The first step (left picture) shows the allocation of all buildings and other relevant parameters (e.g. number of individual consumers, residential buildings/non-residential buildings.) to the nearby road network. The heating requirements are based on the simulated (3D-data) and, if available, recorded values (e.g. hot water, heating) beforehand. In the second step (middle picture), those parts of the road network which contains at least one building in the immediate vicinity will be selected. Roads away from residential and commercial areas are therefore excluded from the following considerations to save simulation running time. Step three (right picture) shows the selection of lucrative network sections according to a defined amount of heat that can be sold per meter of route length. The amount of heat distribution for a network section per year and meter of pipeline is named as heat utilization. It is calculated automatically by the algorithm for each street or lucrative network section as follows:

$$\text{heat utilization}\left(\frac{\text{kWh}}{\text{a}\times\text{m}}\right)=\frac{\text{distributed heat alongside the selected lucrative street (kWh)}}{\text{year (a)}\times\text{length of the selected lucrative street (m)}}$$

Algorithm step 2: Heat network modelling for lucrative network sections and area clustering

Based on the lucrative network sections identified, a heating network routing can be simulated. The minimum heat utilization is a measure of the potential economic efficiency of the supply network (ifeu 2017). The lower the heat utilization, the greater the heat losses in relation to the amount of heat transported in the heating network – even though for anergy networks the losses are not as high

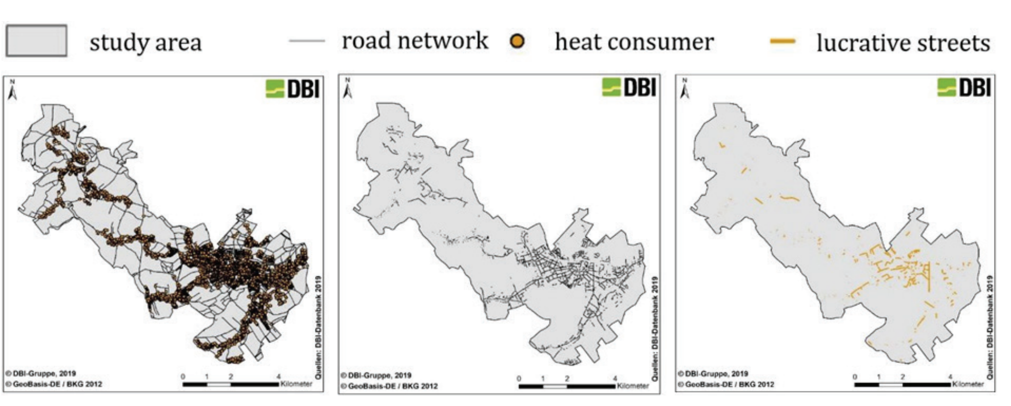

Figure 2 *Allocation of heat consumers (points) to existing infrastructure (roads) to identify lucrative streets*

as for conventional grids due to the lower temperature level in the grid. The stricter the minimal heat utilization will be set, the more lucrative the network sections become as the efficiency of the heating network increases with a larger amount of heat distributed per meter of pipe. In the project, a various amount of heat utilization values will be modeled and compared to each other. To accomplish this task, a GIS analysis tool, the *DBI-GridAnalyst*, has been developed. The tool automatically creates routes of heating network paths and identifies the most lucrative heating networks iteratively considering also possible mine water extraction points based on land use data. The calculation of the grid pathway is based on four main conditions. *First*, the network should only follow public roads and infrastructure excluding not suitable roads. *Second*, the grid length should include the flow and return pipes. *Third*, the network route should be as short as possible, so loops or meshes will be checked and systematically avoided by the algorithm. *Last*, cost-intensive sections such as motorways, major traffic light junctions, bridges and tunnels should be avoided unless there is no other option. To model the heating networks the algorithm's methodological approach starts at the most lucrative street (maximum heat utilization). After that, every lucrative street that matches the minimum chosen heat utilization will be checked for a possible connection. Further, the heat utilization for each possible connection will be calculated and the option with the highest value will be connected to the network. After that, the available connections nearby will be checked again. The simulation process will stop when all eligible lucrative streets are connected. As can be seen from Fig. 3, the supply area becomes more and more restricted as the minimum heat utilisation increases. So, it becomes clear which potential network sections are the most suitable. However, the economic parameters of the heating network always change based on the modelled network route. This means that the parameters of the entire heating network change with each iteration step. This will affect the optimal network length, the number of connected buildings and thus the amount of heat that can be distributed to supply the buildings.

Next steps to finalize the simulation

The algorithm for the heating network simulation will be optimized to gradually approach the best solution using economic values in an implicit mathematic optimization process. For example, a previously non-

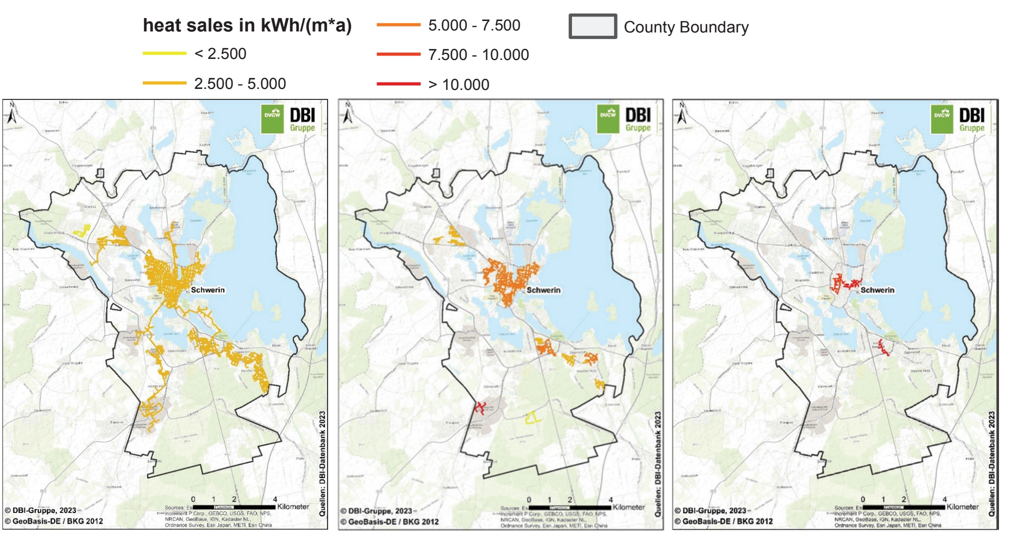

Figure 3 Modeled heat networks in an example county depending on different min. heat utilizations (left: 1.500 kWh/(m × a), middle: 3.000 kWh/(m × a), right: 6.000 kWh/(m × a))

lucrative network section can be connected to the already modelled heating network which was not possible an iteration loop before. This also means that other potential buildings which could not be identified as lucrative can also be connected if they are in the immediate vicinity of the network and the heat utilization does not fall below the minimum set value. To validate the optimization results, economic values must be incorporated, such as:

- *Specific net length*: < 50 m per connection (Kaspers et al. 2019)
- *Average power density:* > 15 kW thermal power per network (Kaspers. et al. 2019)
- *Heat utilization density:* > 1.500 kWh/(m × a) for conventional district heating (ifeu 2017)

→ for high shares of renewables: > 500 kWh/(m × a), < 800 kWh/(m × a) (KfW 2022)

In the end, all the results will be transferred into the project's analysis-tool that will be published after the project is finished to draft individual pilot concepts for mine water-based districts.

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- Eins Energie in Sachsen GmbH & Co. KG (grid operator and energy supplier in Germany)
- Tranter Inc. (American based global manufacturer of heat exchangers)
- City of Brand-Erbisdorf
- City of Freiberg
- City of Ehrenfriedersdorf

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