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MINEWATER GEOEXCHANGE AND COMPUTATIONAL WASTE HEAT FOR FOOD AND BEVERAGE MANUFACTURING

Summary

A model of a novel industrial minewater thermal energy district was developed to investigate the optimal balance between data center waste heat reutilization, food and beverage manufacturing, and on-site controlled environment agriculture in a fourth-generation district thermal network (4GDTN) when connected to a flooded coal mine thermal reservoir via a fifth-generation district thermal network (5GDTN) that can also accommodate spaceheating via minewater geoexchange. Results indicate that less expensive and less carbon-intensive sources of heat could be coupled with the system to achieve impressive thermal network performance while positioning former mining towns as central hubs healthier industry in the age of AI.

Keywords: District Thermal Networks, Circular Economy, Data Center Waste Heat Reutilization, Industrial Ecology, Controlled Environment Agriculture, Food and Beverage Manufacturing, Minewater Geoexchange, Minewater Thermal , Sector Coupling

Field of application for the findings: Sustainable Heat for Industrial Processes

Addressed audience: Technical academic.

1. Background and case study description

Canada's industrial energy demand is currently only 20% electrified, highlighting the need for new low-carbon thermal solutions, for achieving the CO_2-reduction goals of 2050. This work investigates the use of an abandoned coal mine as the source of a fifth-generation district thermal network (5GDTN) supplying a new industrial park in British Columbia. The park, located above former mine workings, currently hosts only a yogurt factory and a small warehouse but offers the opportunity to design a carbon-free energy system from the outset. The long-term concept is to use waste heat from small, modular data centers (DCs) as the primary heat source for a fourth-generation district thermal network (4GDTN) supplying a greenhouse (GH) and the yogurt factory. Surplus heat is stored in the groundwater-flooded mine and later used through the 5GDTN. The mine water volume estimates range from 4.9 to 12.7 million cubic meters and are approximately 220 m below the industrial site. Fig 1a) gives an overview of the geological and geographical setup while Fig 1b) shows how the modeled system could be realized.

2. Materials and Methods

An energy-hub model of the industrial site was developed using the Python library *pyEHub*. The model consist of four nodes: the DCs with a gas boiler as the back up unit (1), the greenhouse (GH) (2), the yogurt factory (YF) (3) and the mine water thermal energy storage (MWTES) (4). The demand of the GH was modeled using the *Gewächshaus Energiekalkular* where the *Warmhaus* profile was selected. This profile most closely represents a GH used for fruits and berries [1]. The YF was modeled by monitored electricity consumption data from May 2024 to April 2025 and literature [2, 3, 4]. The space heating demand of the YF is estimated using the heating degree days. The DC's electricity consumption is taken from specifications borrowed from the DC operation at a local university. All these consumption and production profiles are given in hourly resolution for a whole year. The MWTES is assumed to act as a thermal source and sink. The temperature of the water estimated by the geothermal temperature gradient results in a temperature of 17 °C. Energy exchange between nodes occurs through links representing a omnidirectional 4GDTN and a bidirectional 5GDTN. The 4GDTN distributes waste heat from the DC to supply GH heating and industrial process heat. The MWTES stores surplus heat of the DC and supplies low-temperature heat and cold through the 5GDTN, where heat pumps and refrigeration systems provide space heating and cooling. Scenario families were generated by varying the number of DC from one to four. Within each family, additional scenarios were created by relaxing cost constraints and optimizing for emission reduction using epsilon-constraint method. In total, 24 scenarios were evaluated.

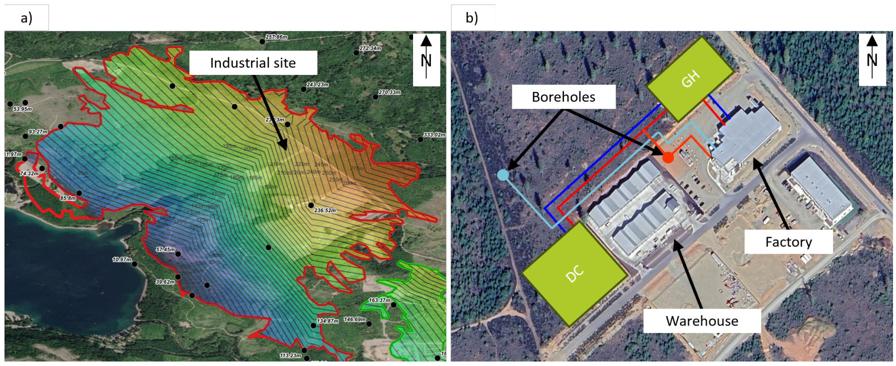

Fig. 1: a) Depth map of mine workings with the indstrial site indicated. b) Current industrial site with the modeled expansion highlighted.

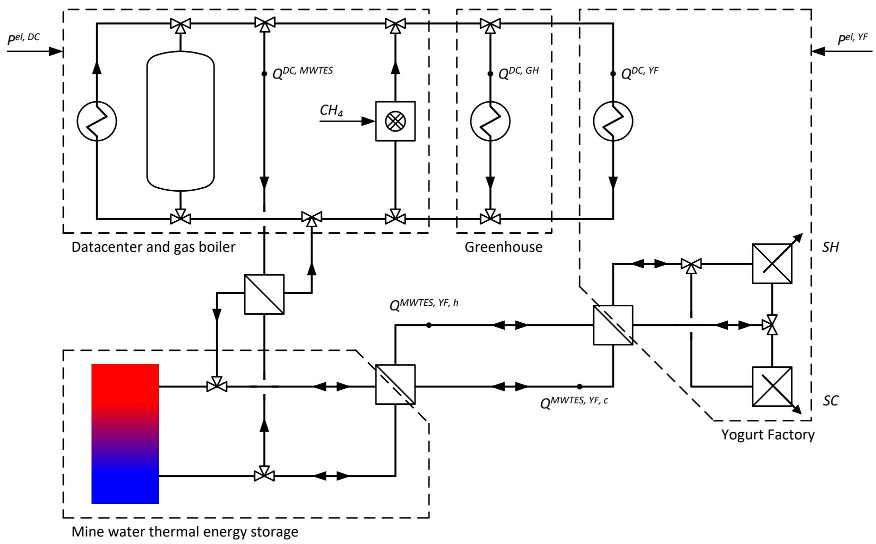

Fig. 2: Schematic overview of the modeled system. The arrows are indication to flow direction in the 4GDTN and the 5GDTN. The streams are labeled in an italic font, the nodes are labeled in the default font.

3. Results

The model produced physically consistent energy balances and operational behavior consistent with expectations for district thermal networks and thermal storage systems. The yearly view onto the scenario with two DCs and 10% cost relaxation looks as seen in Fig 3a). In this plot the energy flows of the DC node are visualized. This make the energy flows in the 4GDTN and the energy flow to the MWTES visible. It can be seen that the total exported energy is always the sum of each sub-stream leaving the node. The MWTES is charged as expected during summer times - with that the MWTES follows a seasonal pattern. As the MWTES was not suspect to the cycling constraint of default storage component in *pyEHub*, some imbalance was expected. In Fig 3b) in the right plot the imbalance is shown over the amount of storage discharge. Positive values on the y-axis implies a discharge dominated scenario, negative values implies charge dominated scenario. A scenario with balanced charging and discharging of the mine storage achieved specific emissions of approximately 15 kg CO_2/ MWh of thermal energy and associated thermal-energy costs of about 25.6 $/MWh. Increasing the number of data centers reduces emissions by increasing waste-heat availability but increases system costs due to larger infrastructure requirements. This is shown in Figure 3c).

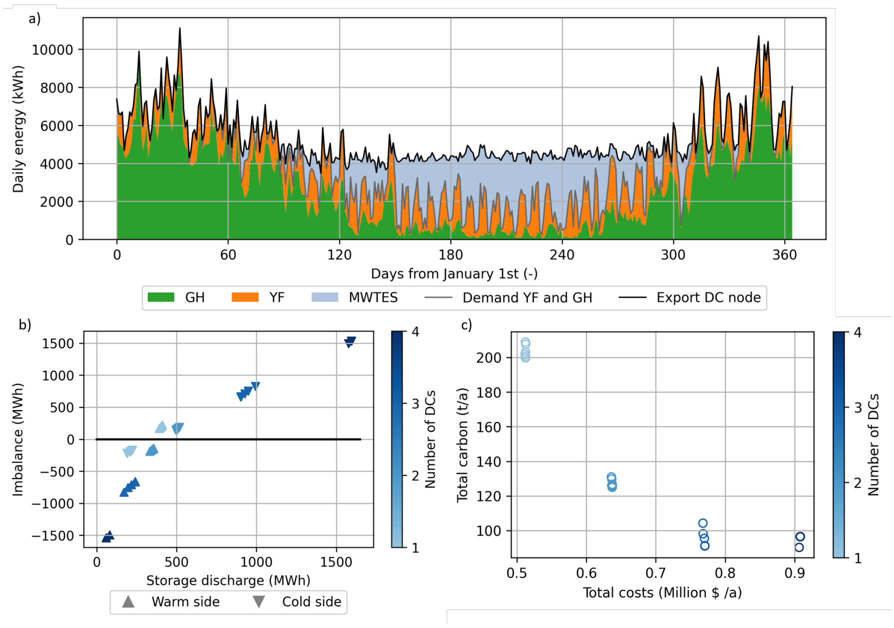

Fig. 3: In a) the time series solution of the DC node is shown. b) shows the imbalance of the MWTES and c) shows the carbon vs. cost plot.

4. Discussion

The results indicate that mine-water thermal energy storage can effectively support industrial heat supply when coupled with a continuous waste-heat source such as DCs. The cost estimates of 25.6 $/MWh are too low, as the costs of some equipment could not be included. The emissions on the other hand are realistic, but can be reduced even more by installing a less carbon intensive back-up unit. 74% of the emissions are caused by the gas boiler in the scenario with two DCs. Although the model cannot yet be validated, plausibility checks confirm that energy balances hold and that the operational behavior of storage, backup heating, and thermal networks is realistic.

5. Outlook

Drilling tests, uncertainty analysis, and development of a pilot installation are recommended to validate the modeling assumptions. Integrating electrical systems including photovoltaics (PV) and battery energy storage systems (BESS) into the model is identified as an important next step for reducing the net electrical consumption of the operation and improving the carbon footprint of the industrial site. The modeling framework developed in this study can support planning of other industrial sites located above abandoned mines and contribute to their importance as hubs in the decarbonization of industrial energy systems that can optimally utilize the waste heat generated by the rapid scaling of AI data center infrastructure.

References

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