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Integrated District Heating and Cooling: combining Thermal Networks with on-site PV-Production

Summary

Current approaches of planning districts mostly only consider one energy sectors such as electrical or thermal. When considering future energy systems, heating and cooling is often covered via electrical energy (i.e. heat pumps and chillers) and therefore a sector-coupling is inevitable. This submission outlines an approach combining electrical and thermal site planning focussing on thermal networks. It incorporates bottom-up modelling of building-level heating and cooling demands, at hourly resolution, accounting for both the quantity and quality of energy. Based on the network temperatures, substation configurations, and the network is calculated. The addition of on-site photovoltaic production to cover on-site electrical creates a holistic system model. A preliminary case study in Switzerland illustrates the methodology's applicability. The findings emphasize the value of integrating thermal and electrical energy models early in the planning process.

Keywords: district heating and cooling, PV, sector coupling, self-consumption

Field of application for the findings: early-stage design and techno-economic assessment of district-scale heating/cooling concepts with electrified conversion and local renewable electricity

Addressed audience: urban energy planners, utilities and network operators, and researchers in district energy and sector coupling

1. Background

Thermal networks that use ambient and renewable sources are increasingly important in the Swiss energy transition, particularly when combined with heat pumps that can provide heating and supply cooling networks while recovering waste heat (Bundesamt für Energie (BFE), 2026a). Coupling a District Heating and Cooling Network (DHCN) with site-level photovoltaics (PV) is beneficial because in totally or partially electrified PV-backed electricity can cover the electrical consumption caused by the thermal demands and therefore, improving grid-flexibility and increasing local self-consumption in a coupled electricity-thermal system (Buffa et al., 2019; Quirosa et al., 2022). In Switzerland, this integrated concept aligns with the *Energy Strategy 2050*, which targets reduced building energy consumption and supports a shift toward efficient, low-carbon supply options including electrification and thermal networks (Bundesamt für Energie (BFE), 2023), it is further strengthened by recently enacted *Federal act on a secure electricity supply*, which allows localized sharing of PV-production and consumption (Bundesamt für Energie (BFE), 2026b). Additionally, the Swiss confederation provides open-source datasets both on buildings (Bundesamt für Statistik, 2022) and solar potential (Bundesamt für Energie (BFE), 2026c), which are a highly valuable baseline for energy analysis. Together, these policy and the data-availability motivate and facilitate integrated district-energy planning that explicitly integrate thermal and electrical considerations.

2. Materials and Methods

The proposed methodology combines the calculation of DHCNs and adds another layer in the PV-production and usage for the coverage of thermal demands. The framework combines multiple datasets and models thermal demands on a building level with hourly-resolved quantity and quality of thermal energy flows. The thermal network is structured (s. Figure 1) as a system of interconnected prosumers (buildings) linked to a central energy station (ES) through a distribution system (DIS). Each building (B) contains multiple heating and/or cooling demands and is connected to either a warm or cold pipe. Heating demands extract heat from the network $(\dot{Q}_h^{net})$, while cooling demands supply heat back into it $(\dot{Q}_c^{net})$. Additionally, thermal losses $(\dot{Q}_l)$ occur due to heat dissipation caused by temperature differences between the pipes and their surroundings. Any resulting thermal imbalance - whether a deficit or surplus - is compensated either by the TES $(\dot{Q}_{TES})$ or by a heat pump/chiller (HP/CH) at the ES $(\dot{Q}_{ES})$, leading to the formulation of the network-wide thermal energy balance.

$$-\sum_{b\in B}\dot{Q}_{h,b}^{net}+\sum_{b\in B}\dot{Q}_{c,b}^{net}+\sum_{e\in E}\dot{Q}_{l,e}+\dot{Q}_{TES}+\dot{Q}_{ES}=0 \qquad \text{(eq. 1)}$$

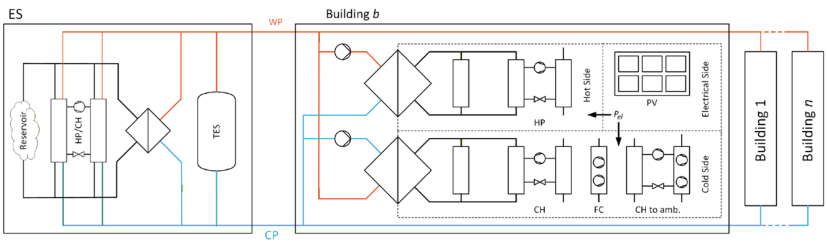

Figure 1: Superstructure of the DHCN with detailed representation of the ES and one detailed building b.

At the building level, substations equipped with heat exchangers and optional process units (PU), such as heat pumps (HP) or chillers (CH), enable the required temperature adjustments. Depending on the PU both heat extraction and rejection are possible. For heating, this may involve direct heat exchange or the use of a HP to raise the temperature, while cooling can be achieved through direct cooling, CH, or free cooling options. The choice of PU is driven by the network temperature and determines both the energy exchanged with the network and the associated electricity consumption. To facilitate highly integrated districts the provision of the electricity via PV would be beneficial. Therefore, each building includes hourly photovoltaic production, where production is used to cover the PU electrical demands. For the current iteration of the model, it is assumed that all the site participants are part of a shared energy infrastructure, i.e., can freely share electricity between them. Leading to an overall electrical energy balance for the total site as follows:

$$P_{ext}=\sum_{b\in B}P_{b,h}+P_{b,C}+P_{Pump}-\sum_{b\in B}P_{b,PV} \qquad \text{(eq. 2)}$$

To economically qualify the viability of the site the levelized costs for heating and cooling ($LCoHC$) can be calculated, thereby the total costs are composed of all annualized investment costs (CAPEX) and required operating costs (OPEX). Compared to when solely looking at the thermal side of DHCN the proposed approach extends the costs by the CAPEX for the PV system and reduces OPEX in times of concurrent electrical demand and production. Outside of self-consumption, electricity can be freely bought or sold to the grid, the selling creates a revenue which can reduce the $LCoHC$:

$$LCoHC=\frac{CAPEX+OPEX-C_{rev,PV}}{Q_{TOT}}=\frac{C_{TOT}-C_{rev,PV}}{\sum Q_H+\sum Q_C} \qquad \text{(eq. 3)}$$

3. Case Study and preliminary Results

The proposed framework is applied to a district in Switzerland. The district is located adjacent to a lake, which serves as a thermal reservoir. The case study comprises 60 buildings. The total annual heating demand is 9.15 GWh/a, and the annual cooling demand is 4.61 GWh/a. As a warm pipe temperature of 10°C and as cold pipe temperature of 5°C are selected, this leads to a DHCN with direct cooling and heating via HPs at the substations. To cover all the heating and cooling demands the systems consumes 3.35 GWh/a of electricity annually. PV-installation is considered for all roofs with at least 1’000 kWh/m^{2}a irradiance and a total usage of 60% of the available roof is selected. Leading to a total PV harvesting potential of 1.67 GWh/a. As in the current model no electrical storage is included, the produced electricity is either consumed to cover the thermal demands or rejected to the electrical grid. The split between direct usage (30%) and grid rejection (70%) is mainly caused by the variance in production and consumption (summer vs. winter). Economically, PV integration increases annualised CAPEX by 25% and reduces OPEX by 32% via reduced grid electricity purchases and revenue generated. This change is reflected in a reduction of the $LCoHC$ of 4%, which indicates that the PV-inclusion is a net positive.

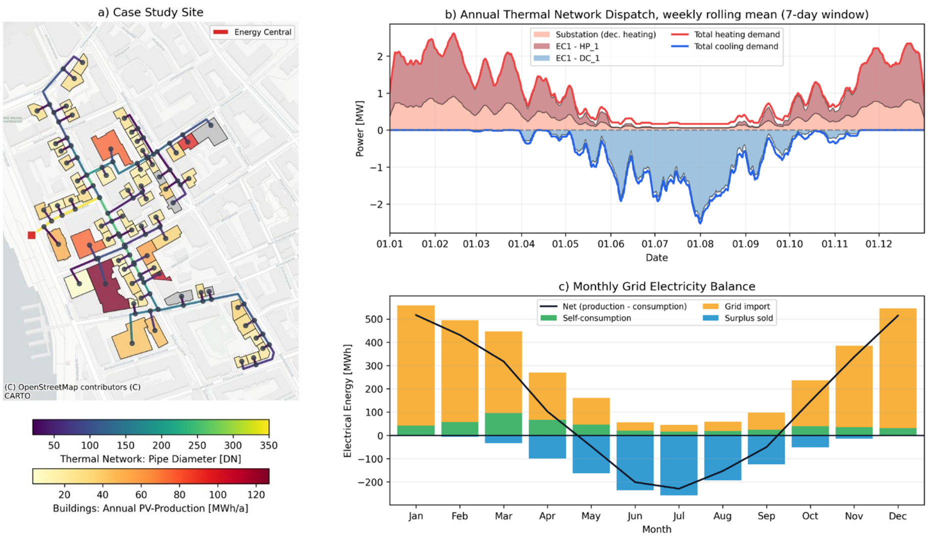

Figure 2: Preliminary Case Stuy:
a) Site with DHCN diameters and annual PV-production per building;
b) Annual thermal energy dispatch per technology
c) Monthly electrical energy balance between production and consumption

4. Discussion and Outlook

The framework provides a first step for integrated design of DHCNs with PV-coupling and supports early-stage evaluation of temperature levels, conversion placement, and resulting impacts on efficiency and cost. The used data-sources facilitate and easy and fast application to any site in Switzerland. Ongoing work targets the inclusion of seasonal thermal storage and electrical storage, as well as a more detailed representation of non-thermal electricity demands and electricity-grid interactions, to better quantify flexibility value and boundary conditions for PV utilisation under Swiss regulation.

5. References

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