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ASSESSMENT OF HEAT PUMP INTEGRATION IN A LEGACY DISTRICT HEATING NETWORK IN CHILE

Summary

Electrifying existing district heating (DH) networks with large heat pumps can support decarbonisation, but outcomes depend on network losses, temperatures, and energy prices. This study evaluates heat pump integration in the COSSBO DH system in Santiago, Chile, a 3.13-km legacy tunnel-based network serving 26 buildings. Useful heat demand was reconstructed at 4.8 GWh_{th}/year, while an hourly pandapipes model indicates 6.7 GWh_{th}/year of plant generation, implying 1.9 GWh_{th}/year of distribution losses (~28%). Two retrofit options were assessed: a 1 MW_{th} base-load heat pump and a 5 MW_{th} near full-load case (SCOP ≈ 4.4). Electrification reduces variable heat cost from 30.8 to 22.7 USD/MWh_{th}, but simple payback remains 21.9 years for 1 MW_{th} and 42.6 years for 5 MW_{th}, with no discounted payback. Integration is therefore best limited to partial base-load electrification, as high network losses undermine the benefit of larger-scale deployment.

Keywords: district heating, heat pump, retrofit; network losses; techno-economic assessment

Field of application for the findings: Sustainable and Efficient Districts: Innovative District Heating and Cooling, Urban Planning of Districts, Simulations, Digitalization and AI

Addressed audience: District heating researchers, utility and municipal planners, heat pump integrators, and decision-makers involved in the decarbonization of existing urban energy systems

1. Introduction

Large-scale heat pumps are increasingly seen as an effective way to decarbonize district heating because they can integrate renewable and recovered heat sources. However, retrofitting older networks can be difficult, since many operate at high temperatures, are oversized for current demand, and suffer significant heat losses due to aging infrastructure. Chile offers a relevant context where large-scale DH remains uncommon, and the COSSBO system in Santiago constitutes a unique tunnel-based urban network, supplying space heating and domestic hot water to roughly 3,000 apartments through 26 buildings and 19 substations, currently dominated by biomass-based generation. As with many legacy assets, retrofit assessment is challenged by incomplete substation-level metering, limited temperature monitoring along the primary network, and the need to reconcile fuel-based production data with delivered heat—uncertainties that become critical when evaluating electrification under local electricity tariffs and capital constraints. Against this backdrop, this study reconstructs 2024 system operation and assesses the prefeasibility of integrating a central waste-heat heat pump by combining reconstructed demand profiles, thermo-hydraulic network modelling, and an incremental techno-economic framework to quantify the impact of distribution losses and compare alternative heat pump sizing strategies, with the goal of clarifying the structural conditions under which electrification of legacy DH systems becomes technically and economically viable.

2. Methodology

The assessment combines demand reconstruction with an hourly thermo-hydraulic model of the primary circuit to represent the coupled effects of mass flow, pressure drop, temperature evolution and heat losses. The network layout used in the model is shown in Figure 1 and was reconstructed in QGIS (geometry, pipe lengths and diameters) and then imported into Python/pandapipes to build the hydraulic–thermal representation of the primary network. Hydraulic variables (pressures and mass flows) were verified against reported and measured values to ensure model fidelity. This modelling layer provides the required plant heat generation over time and the corresponding operating envelopes, which are subsequently used for heat-pump sizing and incremental economic evaluation.

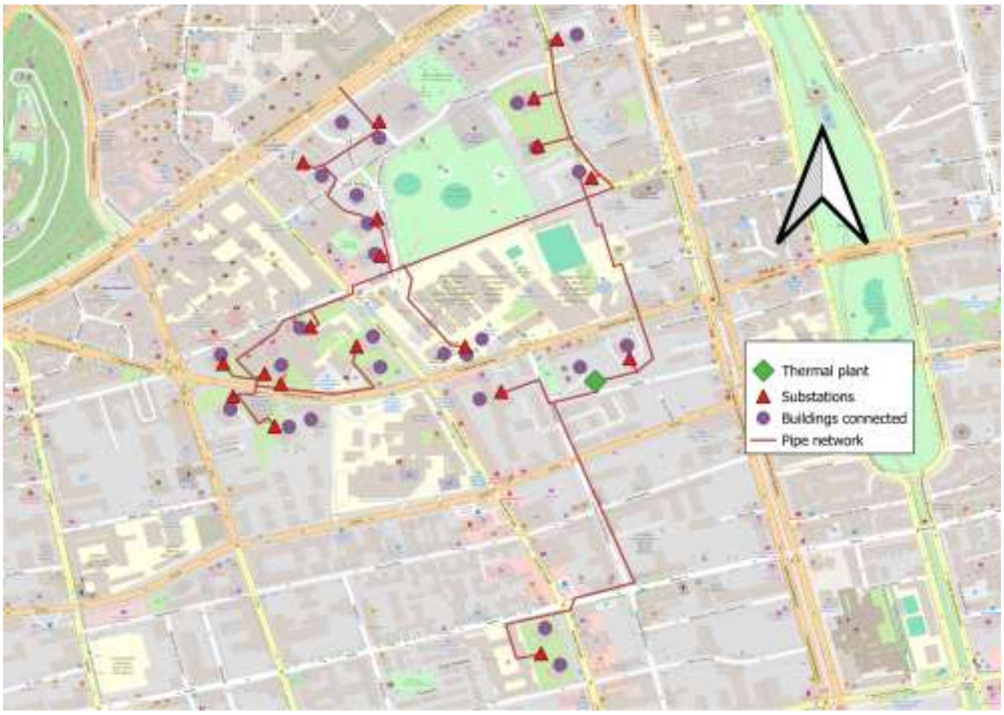

Figure 1: Routing of the COSSBO Primary District Heating Network

Heat demand was characterised using 2024 DHW data at building level, converting DHW volumes to thermal energy using standard thermophysical relationships. Space-heating demand was not directly metered and was therefore estimated indirectly for heating-connected buildings using proportionality with DHW consumption and an end-use split consistent with prior reference profiles (space heating vs. DHW). The resulting reconstructed useful heat delivered at substations is 2.6 $\mathrm{GWh_{th}}$/year (DHW) plus 2.2 $\mathrm{GWh_{th}}$/year (space heating), with winter peak loads of ~5.2 $\mathrm{MW_{th}}$. Hourly demand profiles were built using nationally derived space-heating and DHW reference profiles from previous Fraunhofer Chile studies then calibrated to reproduce reported 2024 DHW consumption and cross-checked against historical peak demand values.

A top-down annual energy balance was derived from measured fuel consumption using the fuel lower heating value (LHV) and an assumed boiler efficiency of ~90% informed by COSSBO, and then compared against the reconstructed useful heat delivered at substations. This comparison yields an apparent residual gap of ~57% of the fuel-derived annual production estimate, indicating that the available annual accounting alone is not sufficient to attribute losses unambiguously, but still suggesting substantial system inefficiencies and/or data limitations. Consequently, loss quantification for sizing and economic assessment was based on the calibrated hourly thermo-hydraulic simulation, which yields an annual distribution loss fraction of approximately 28% under the adopted network heat-loss parameters. The model was used to compute hourly mass flows, pressure drops and supply/return temperature evolution across the primary circuit, thereby closing the plant–network–substation heat balance and explicitly quantifying distribution losses. Pressure and flow results were further used to identify hydraulically critical sections and to confirm that the retrofit would operate within feasible pressure and circulation ranges, including an estimate of pumping requirements where relevant.

Two heat pump retrofit scenarios were evaluated, adopting a seasonal coefficient of performance of 4.4 based on contemporary planning guideline. The first scenario considered base-load coverage sized from the load duration curve (P80 ≈ 1 $\mathrm{MW_{th}}$), while the second assessed near full-load replacement with an installed capacity of approximately 5 $\mathrm{MW_{th}}$ as the closest commercially available rating to the required peak without excessive oversizing.

Economic feasibility was assessed through an incremental retrofit cost framework that isolates the costs and benefits directly attributable to adding a waste-heat heat pump to an existing DH system. CAPEX were estimated from prefeasibility cost correlations for the heat-pump package and dedicated auxiliaries (e.g., integration hydraulics/HEX, electrical works, controls), while OPEX were computed from hourly electricity tariffs and the avoided biomass fuel cost of the displaced boiler generation. This enabled a consistent estimation of the marginal operating-cost impact of electrification, expressed as annual incremental savings $\Delta C_y = (c_{\text{boiler}} - c_{\text{HP}})\, Q_{\text{HP},y}$, where the specific heat costs were calculated as $c = \frac{p}{\text{performance}}$ [USD/MWh$_{\text{th}}$] (with performance = η_{boiler} for boilers and COP/SCOP for the heat pump).

Performance was assessed using annual incremental savings and simple/discounted payback, which capture the retrofit's marginal operating-cost reduction and capital recovery under discounted cash flows. A full-system LCOH was not used as the primary metric because the distribution network CAPEX is a sunk cost in this retrofit context: the existing tunnel-based piping remains in service across all configurations and is therefore not avoidable by the heat-pump decision. Moreover, estimating a present-day replacement value for this 1970s legacy asset would introduce a large and highly uncertain cost term, making any LCOH-based benchmarking against other DH systems poorly comparable. The analysis therefore adopts an incremental payback/savings perspective, isolating the marginal CAPEX/OPEX attributable to the heat-pump retrofit while treating the network as a common/sunk asset.

3. Results

The calibrated hourly simulation indicates that the COSSBO network requires approximately 6.7 GWh$_{\text{th}}$/year of plant heat generation to deliver about 4.8 GWh$_{\text{th}}$/year at substations (2.6 GWh$_{\text{th}}$/y DHW + 2.2 GWh$_{\text{th}}$/year space heating), corresponding to roughly 1.9 GWh$_{\text{th}}$/year of distribution losses and an annual loss fraction of ~28%, with winter peak loads of about 5.2 MW$_{\text{th}}$. This performance is consistent with the extended tunnel-based primary circuit (≈3.13 km) and the adopted loss/operating assumptions, so a significant share of generated heat—regardless of the supply technology—must compensate distribution losses rather than serve useful demand.

Table 1: Main economic indicators of integration scenarios

Cost	Unit	Full load coverage	Partial load coverage
HP heat price	USD/ MWh$_{\text{th}}$	22.7	22.7
Boiler heat price	USD/ MWh$_{\text{th}}$	30.8	30.8
Simple payback	Years	42.6	21.9
Discounted payback	Years	Not reached	Not reached
HP Nominal Power	MW	5	1
CAPEX HP plant + Installation	MM USD	4.025	1.21

On the retrofit side, electrification reduces the variable heat cost from 30.8 to 22.7 USD/ MWh$_{\text{th}}$. Table 1 summarises the main indicators for the two sizing strategies (5 MW$_{\text{th}}$ near full-load vs 1 MW$_{\text{th}}$ base-load): simple payback is 42.6 years and 21.9 years, respectively, while discounted payback is not reached at r = 5% in either case. Overall, the results indicate that the integration of a central waste-heat heat pump is hydraulically feasible in the COSSBO network, but under current tariff and CAPEX assumptions it remains economically unattractive without prior loss reduction and operating-temperature optimisation.

4. References

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