HEAT PUMPS FOR INDUSTRIAL PROCESS HEAT IN CHILE: NATIONAL PRE-FEASIBILITY AND GRAPE JUICE CASE STUDY

Summary

This work evaluates High-Temperature Heat Pumps (HTHPs) using a dual-scale approach: a national database of all industrial fossil-boiler users, detailing representative processes and temperature ranges, and a process-resolved simulation of a grape-juice plant. National technical coverage is quantified by matching process temperatures against commercially available HTHPs (TRL 7–9). The case study process is driven by steam, and the HTHP upgrades waste heat and delivers thermal energy to an indirect steam generator. Across three operational scenarios (seasonal, corrected, and intensive), the system delivers 1.57 to 3.89 GWh_{th}/year (COP 3.1 to 3.3), avoiding 223 to 565 tCO_2/year. In the representative 'corrected' case, the LCOH (57.4 USD/MWh) presents a moderate cost increase of 11% over the fossil baseline (51.6 USD/MWh), confirming HTHPs as a viable decarbonization technology based on actual site-specific fuel and electricity costs.

Keywords: High-temperature heat pumps (HTHP), industrial process heat, waste-heat recovery

Field of application for the findings: Decarbonization of industrial process heat through HTHP integration and waste-heat valorization; techno-economic evaluation for steam agro-industrial processes.

Addressed audience: Industrial energy managers and plant engineers; heat pump technology providers

1. Introduction

Process heat dominates industrial energy demand (accounting 74% of the sector's direct energy use in 2021) (REN21, 2024). In Chile, heating and cooling represent at least 37% of primary energy consumption and are still largely fossil-based, making process-heat decarbonization a strategic priority (Ministerio de Energía, 2021). Policy targets reinforce the need for scalable solutions, driven by 2030 emission caps and renewable mandates, alongside 2050 carbon-neutrality goals (Ministerio del Medio Ambiente, 2020; Ministerio de Energía, 2021). However, investment is constrained by limited temperature-resolved evidence on where high-temperature heat pumps (HTHPs) can replace fossil boilers, and on their techno-economic competitiveness when coupled to recoverable waste heat. This work addresses this gap by combining a national, facility-level screening with a process-resolved industrial case study.

2. Methodology

A dual-scale approach combined a national screening with a process-resolved case study.

2.1 National Screening

Useful thermal demand from fossil-fuel boilers was calculated from updated public emission records (Ministerio del Medio Ambiente, 2026) by applying the validated national industrial heat framework (Naranjo et al., 2025). Technical pre-feasibility was assessed case by case, matching the specific temperature range of each individual process against a commercial TRL 7–9 HTHP catalogue (Zühlsdorf, 2023) via an automated Python screening. Conservative pinch constraints were applied (10 K for processes ≤100 °C; 40 K for >100 °C treated as steam) to reflect practical integration requirements. Results were aggregated at the subsector level to determine coverage and technology options.

2.2 Case Study: Grape Juice Production

Validation was conducted in a grape juice plant by modelling each thermal device using mass and energy balances in TRNSYS. Waste heat streams were characterized through evaporator boundary conditions. Operational uncertainty was assessed via three scenarios: seasonal load patterns, a 'corrected' case calibrated against actual annual fuel consumption, and intensive continuous operation. A techno-economic assessment was performed to report delivered heat, avoided CO_2, and LCOH at both process and plant levels. Actual site-specific electricity tariffs and fuel prices provided by the operator were utilized to reflect real world peak charges and operational costs rather than average market rates.

3. Results

Fig. 1 summarizes the national HTHP feasibility screening. Fig. 1A relates TRL 7–9 supplier availability to required supply temperature, and Fig. 1B shows the Top-90% industrial thermal demand by sub-sector with representative maximum process temperatures.

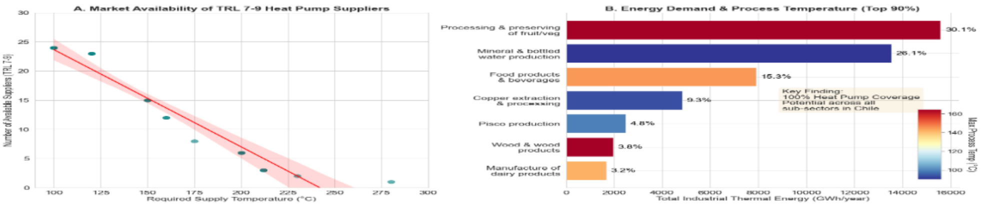

Fig. 1: 1A (left) Market availability of heat pump suppliers; 1B (right) Industrial demand by process temperature

The supplier database was obtained from the Annex 58 Task 1 catalogue (Zühlsdorf, 2023), covering maximum supply temperatures of 100–280 °C. The data show a negative relationship between required temperature and number of suppliers, with lower availability as thermal requirements increase. Cross-matching with industrial demand was performed at facility level by assigning process temperatures by sub-sector and applying conservative approaches (processes <100 °C, 10 K supply–process difference; processes ≥100 °C, 40 K difference, treated as steam). Under these criteria, the assessed HTHPs can operate across 100% of the sub-sectors in the Top-90% demand, while demand remains concentrated, with 80% of energy in four sub-rubrics.

Fig. 2 presents the plant-level case study results, integrating thermal system simulation with process-unit steam demand estimation.

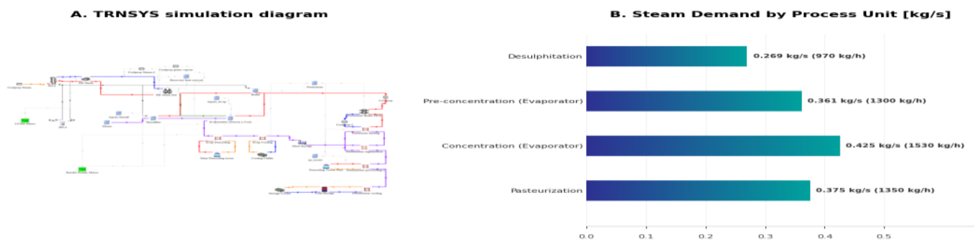

Fig. 2: A: TRNSYS simulation diagram; B: Steam demand by process

As shown, Fig. 2A illustrates the dynamic TRNSYS model (mass and energy balances and process-level HTHP integration), while Fig. 2B details the specific unit steam demands, peaking at 0.27– 0.42 kg/s (970 – 1530 kg/h). The model reproduces steam production and energy use with <10% error over a representative intensive production period, validating the baseline for the proposed scenarios.

Fig. 3 presents the economic and environmental results of HTHP integration in the case study, comparing process-level and plant-wide scenarios.

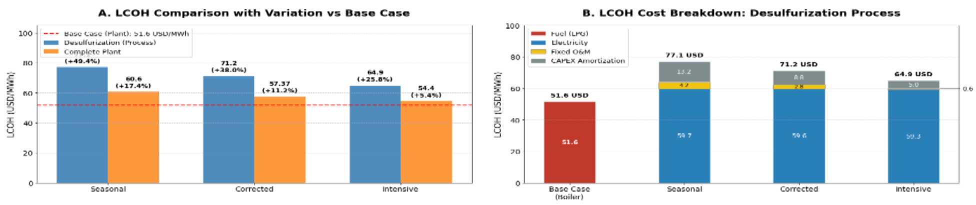

Fig. 3: A: LCOH Comparison against the fossil baseline; B: LCOH Cost Breakdown for the Desulfurization Process

Fig. 3A shows that while process-level integration (Desulfurization) raises LCOH to 64.9–77.1 USD/MWh against the 51.6 USD/MWh baseline, the plant-wide blended LCOH demonstrates a much more moderate impact due to cost dilution. In the representative 'corrected' scenario, the plant-wide LCOH is 57.4 USD/MWh (+11.2%), sitting between the intensive (+5.4%) and seasonal (+17.4%) extremes. Fig. 3B presents the LCOH cost breakdown specifically for the Desulfurization process, highlighting that the cost structure is mainly driven by electricity (approx. 59 USD/MWh), which replaces fuel costs. CAPEX amortization varies significantly with utilization, reaching 13.2 USD/MWh in the seasonal case.

Environmentally, this integration translates into significant decarbonization, avoiding between 223 to 565 tCO_2/year depending on the operational scenario.

4. Conclusions

This study confirms the hypothesis that HTHPs can be deployed as a technically feasible solution with significant potential for industrial process heat in Chile. The national screening demonstrates that, under conservative thermal criteria, commercial HTHP technologies can technically cover most of the fossil-based thermal demand across key industrial sectors.

However, economic competitiveness is strongly stratified by operational profiles. The analysis reveals a clear divergence between sectors with continuous baseload demand versus those with seasonal variability. While continuous processes benefit from high utilization rates that offset capital costs and minimize the Levelized Cost of Heat (LCOH), seasonal sectors face higher economic barriers due to lower capacity factors.

Regarding investment viability, although direct replacement of functional fossil assets may currently result in a higher LCOH compared to the fossil baseline, the study identifies clear pathways to profitability. The results suggest that HTHPs become economically attractive particularly in greenfield scenarios (where integration is optimized at the design phase) or when supported by carbon pricing mechanisms that monetize CO_2 reductions, thereby bridging the cost gap with established fossil technologies.

5. References

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