COMBINING SOLAR THERMAL ENERGY AND HIGH-TEMPERATURE HEAT PUMPS FOR EFFICIENT AND SUSTAINABLE PROCESS HEAT IN THE FOOD INDUSTRY

Summary

To meet the EU's 2050 climate-neutrality target, decarbonizing industrial process heat is critical. The industrial sector is currently responsible for 24.5% of Europe's final energy (2024 data) and is primarily driven by fossil fuels. High-Temperature heat pumps (HTHP), recognized as a net-zero technology, offer high efficiency (COP 2–3) but face adoption barriers due to limited standardization, awareness and low-cost sustainable heat source. This study investigates the integration of solar thermal collectors with HTHPs to supply high-temperature process heat (120°C), using thermal energy storage (TES) to address solar intermittency. A dynamic TRNSYS18 model simulates a system combining vacuum flat plate collectors, a heat pump, and TES across three European climates. Performance metrics—solar coverage, TES utilisation, system sizing, and efficiency—are analysed to evaluate feasibility and climate suitability. Results highlight the system's potential to enhance industrial heat decarbonization, while identifying challenges for scalability and the need for backup solutions.

Keywords: Industrial application, process heat, synergies, solar thermal, high-temperature heat pump

Field of application for the findings: Industrial processes

Addressed audience: Industrial stakeholders, energy auditors, researchers

1. Introduction

The EU has set the goal to become climate-neutral in 2050 to reduce the environmental load and limit the global warming. This requires equal effort in all fields, including mobility, building energy demand, green electricity, but also industrial process heat and cold. Industrial process heat responsible for 24.5% of European final energy consumption and is predominantly powered by fossil fuel, more than 30% from natural gas only (eurostat, 2026). The industrial sector to become climate neutral, also called net-zero, substantial and structural changes and developments are required. This includes technologies and activities such as hydrogen, synthetic fuels, but also electrification of processes via direct electric heating and industrial heat pumps.

While direct electric heating has an efficiency of ≤ 1, industrial heat pumps operate much more efficient with COPs of 2 – 3. Industrial heat pumps are identified as a net-zero technology following the European Net-Zero Industry Act (NZIA) ("Net-Zero Industry Act - European Commission," 2026). Operated by electricity from renewable energy sources such as solar PV or wind power, industrial heat pumps are a key instrument to decarbonize the industrial sector. However, their market roll-out faces multiple challenges. Decision makers in the manufacturing industry often lack awareness and individual integration schemes make replication difficult and costly. The EU-funded LIFE project EXQUISHEAT addresses this challenge and will develop standardized integration schemes for industrial heat pumps in four selected processes in the food and beverage industry (European Climate, Infrastructure and Environment Executive Agency, 2026). This will facilitate the integration of industrial heat pumps in the processes of hot water generation, pasteurization, evaporation and refrigeration. Another challenge, especially for High-Temperature Heat Pumps (HTHP) is having a low-cost heat source at a sufficient temperature. The higher the heat source temperature is, the lower is the temperature lift the heat pump needs to achieve and the more efficient it can operate. Yet industrial heat pumps are most feasible if untapped industrial waste heat can be used of when there is a simultaneous demand of heat and cold, creating promising conditions for HTHPs. However, this will likely not be enough heat source to fully decarbonize the total industrial sector. Additional heat sources are needed.

This is where solar thermal heat comes into action. Solar thermal is a well proven, efficient and sustainable source of heat. To cover times of no sufficient solar radiation, thermal energy storages (TES) are required to be integrated such a solar thermal heat pump system for industrial process heat. This study investigates coupling the two net-zero technologies of solar thermal collectors and industrial heat pumps to provide high temperature heat for industrial processes.

2. Method

First, an industrial process concept and heat demand schedule based on realistic data will be characterized and developed. This process concept is to present not a unique system, but a more generic set-up to underline the replicabilities of the results. The investigation is performed in the dynamic simulation software TRNSYS18, allowing the authors to operate with proven and customizable components and to model industrial systems in detail. The thermal demand of the developed process concept is pictured in the system and is the heat demand to cover.

The total system consists of solar thermal collector field providing heat which is then upgraded to a higher temperature to supply the heat at high temperature to the process equipment. High quality vacuum flat plate collectors are selected to provide heat at 80 – 90 °C to the heat pump. The heat pump lifts the temperature to reach temperatures of 120 °C in the second loop of pressurized water. A simplified scheme of that system is shown in Figure 1. Additionally, the influence of TES located in the solar hot water loop will be investigated. TES must be considered to increase the hours of solar coverage, bridge times of low solar radiation and save solar heat during hours of no process operation.

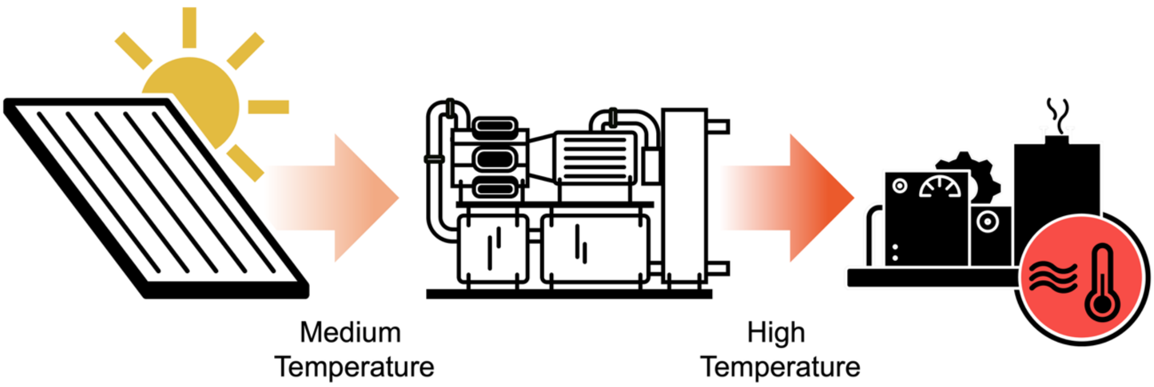

Figure 1: Graphical presentation of the study concept, lifting solar thermal heat via industrial heat pumps to promising temperature level for industrial processes

The system is applied for three different climates across Europe to investigate its performance in different environment with different levels of solar radiation. The simulation time step is set to be ≤ 1 hour maximum to model the solar availability and the cycles in the process heat demand as detailed as possible.

3. Results

The results show the performance of the system, indicated by the key factors such as hours solar operation, energy charged to and discharged from the TES, size of solar thermal collector and volume of TES as well as the efficiency of the industrial heat pump. Daily and seasonal fluctuations and performances will be analysed to identify strengths and challenges of the system and the potential need of back-up systems. The system energy performance in the three different climates will be assessed to elaborated to assess the most promising climates and locations for the system.

The overall objective is to evaluate the feasibility of the system as a total and its added value and limitations in industrial application field.

4. References

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