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EXTENDED ABSTRACT

Techno-economic analysis for the decarbonization of an industrial mineral drying process in southern France

Summary

The SHIP4D project explores the integration of solar heat for the decarbonization of industrial process heat in the medium temperature range (100–400 °C). A hybrid energy system is modeled, including photovoltaics (PV), concentrated solar thermal (CST), electrical or thermal storage, power to heat (electric boiler or heat pump) and an auxiliary boiler (natural gas, biogas, or biomass). The CAIRN open-source optimization software minimizes Net Present Value (NPV) and Greenhouse Warming Potential (GWP) of the hybrid energy system. The analysis focuses on an industrial case study for a site producing industrial minerals in Southern France. The industrial process consists in grinding and drying calcium carbonate. Process heat is currently provided by a gas burner as a hot air stream. The analysis shows how this industrial process can be decarbonized economically by a combination of process electrification, demand response and hybridization with solar energy, including thermal energy and mineral storage.

Keywords: Solar energy, Hybrid energy system, Industrial Process Heat, Decarbonization

Field of application for the findings: Sustainable Heat for Industrial Process (SHIP)

Addressed audience: Industrial energy managers, renewable energy planners, research institutions

1. Introduction

According to the IEA (IEA,2026), the industrial sector represents 19% of France total final energy consumption and generates 15% of its CO2 emissions. More than 70% of this energy is consumed in the form of heat, while 50% of this heat requires a temperature below 400°C. Today, this thermal energy is mainly supplied by fossil fuels, particularly natural gas.

Several decarbonization pathways are considered in the sectoral transition plans presented by the French energy agency ADEME for 2050 (ADEME, 2026): i) energy efficiency and conservation, ii) process electrification, iii) smart integration of renewable energies and energy storage.

The SHIP4D project (SHIP4D, 2026), as part of the French research program for industry decarbonization (PEPR SPLEEN, 2026), studies the contribution of solar energy to the decarbonization of industrial processes, in particular for the medium temperature range (100-400°C). Preliminary results for a generic case study have been published in a project deliverable (Caron and Vuillerme, 2025). This paper follows a similar methodological approach tailored to a real industrial case study.

2. Case study

The industrial partner is an international producer of industrial minerals, mainly fillers and pigments derived from calcium carbonate and a worldwide distributor of specialty chemicals. The industrial site, located in Southern France, is ISO 50001 certified since 2018. The activities are mainly pre-grinding and drying of calcium carbonate, which require a significant amount of heat. The projected heat demand for 2030 is about 86 GWh of natural gas (HHV, high heating value).

The industrial partner aims to achieve net zero greenhouse gases (GHG) emissions and has already implemented several energy efficiency measures, such as waste heat recovery (WHR). These actions are in line with the objectives of the French Low Carbon Strategy (SNBC, 2025) and Energy and Climate Plan (NECP) (EU commission, 2024).

The industrial site is located in Orgon, France. The industrial partner has evaluated different options for this site, such as the integration of a biomass boiler, a hybrid gas-electric burner, process electrification and demand response, local production of renewable energy (solar PV, concentrated solar thermal CST). A roadmap has been defined to install a 8.4 MW_p PV park on site, phased in four stages, covering up to 17% of the site electrical consumption. There is also the potential to store calcium carbonate minerals on site (up to 30 ktons) to accommodate seasonal variations, while the power demand can be modulated (-3 MW demand response with a warning delay of 2 hours).

This case study focuses on the decarbonization of one drying process requiring a temperature of 300 °C, which represents approximately 30% of the site natural gas consumption. The objective of this case study is to optimize the energy infrastructure sizing and operation for this process, aiming at a hybrid system maximizing Net Present Value (NPV) and minimizing the Greenhouse Warming Potential (GWP).

3. Methodology

3.1. Hybrid energy system architecture

The hybrid energy system architecture is displayed in Figure 1. This system ca, supply heat and power for an arbitrary industrial site requiring process heat in the medium temperature range (100 – 400 °C). It integrates different technological components:

- Solar energy, (photovoltaics (PV) and Concentrated Solar Thermal (CST)),
- Energy storage (electrical EES or thermal TES)
- Power to heat (P2H) (electric burner)
- An auxiliary burner (natural gas/biogas or biomass)

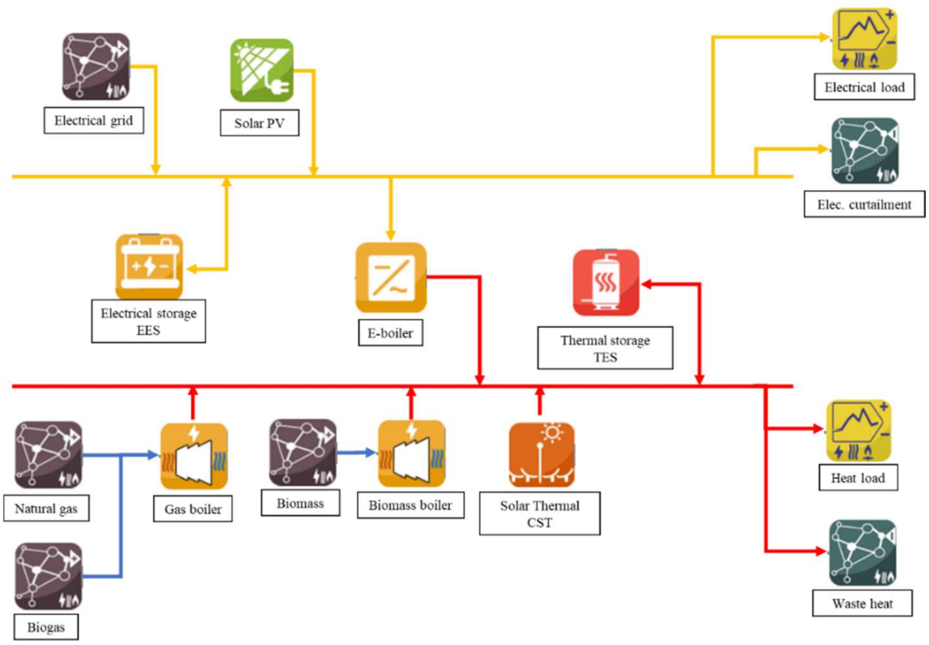

Fig. 1: Hybrid energy system architecture.

3.2. Optimization problem

The CAIRN open-source optimization software, (Ruby et al., CEA Liten, 2025) allows analyzing this hybrid system from a techno-economic and environmental perspective. The problem of optimizing the system design and control strategy is solved by applying Mixed-Integer Linear Programming (MILP). The cost function minimizes the system Net Present Value (NPV) of the system and can include various user-defined constraints, such as land or carbon footprint. This software requires input timeseries for the energy demand, as well as for solar energy yields. Typical Meteorological Year (TMY) data is retrieved from (Meteonorm 8, 2026) and processed with System Advisor Model (SAM, 2025) to compute solar energy yields. Optimization results are post-processed with Python and Excel.

3.3. Key performance indicators

A set of key performance indicators (KPI) is defined to analyze each hybrid system configuration. The Levelized Cost of Heat (LCOH), expressed in €/MWh, is derived by dividing the system NPV by the amount of useful energy produced.

Further indicators include:

- the CO_2 marginal abatement cost in €/$tCO_{2,eq\ (avoided)}$, which reflects the impact of an investment on the system carbon footprint (GWP)
- the auxiliary energy saving (%), which characterizes the amount of energy saved with respect to a reference system running exclusively on natural gas,
- the waste heat fraction (%), which characterizes the amount of excess heat that cannot be stored with Long Duration Energy Storage (LDES) to compensate inter-seasonal variations of solar energy,
- the solar multiple (SM), solar fraction (%), energy storage duration (hours), land footprint (m^2), etc.

4. Acknowledgements

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