EuroSun2026

Power-to-Heat in industry – An economic and ecological analysis including balancing energy market

Summary

There are a variety of options for decarbonizing the industrial sector. One of these options is the use of power-to-heat, where electrical energy is converted into thermal energy. However, the transition from conventional powered processes to power-to-heat technologies typically involves system modification and is usually coupled with high investment costs. Since power-to-heat applications normally use electricity from the public power grid, the economic and ecological operation of these systems highly depends on the prevailing electricity prices and electricity mix. Therefore, this work investigates and analyses several power-to-heat applications in industrial processes, regarding their economic operation and ecological behavior. For this purpose, different systems are modeled and examined regarding their investment and operational costs as well as their CO_2 emissions. By integrating the balancing energy market into the analysis, additional insights regarding the use of surplus electricity from renewable sources can be derived.

Keywords: power to heat, economic viability, process modeling, balancing energy market, ecological behavior

Field of application for the findings: Sustainable heat for industrial processes, Sector coupling

Addressed audience: Researchers, Industrial stakeholders

---

1. Introduction

One major challenge for a sustainable energy system involves the decarbonization of the industrial sector, as this sector is responsible for about 25% (European Commission, 2025) of the final energy consumption in the European Union (EU). Keeping in mind that still about 50% of the industrial final energy consumption in the EU is covered by fossil fuels (Eurostat, 2025) there is a huge potential for decarbonizing the industrial sector and consequently the whole energy system. Therefore, various technologies are currently under research and development. One of these options is power-to-heat (P2H), where (renewable) electricity is converted into thermal energy, thus enabling the substitution of fossil fuels used in thermal processes. This conversion can be done in several ways, for example by using electrode boilers, electric resistance heaters or heat pumps (Maruf et al., 2022).

However, in most cases the adaptation of fossil fuel powered processes to a P2H based process cannot be done without modification of the system or process redesign and is consequently associated with high investment costs. Furthermore, the economic operation of P2H systems significantly depends on the electricity prices. On the other hand, the potential for reducing CO_2 emissions directly corresponds to the composition of the electricity mix and therefore depends on the amount of electricity, which is produced by renewable energy sources like solar or wind power.

One option for the economic and ecological operation of P2H systems might be the participation in the balancing energy market. During periods of a surplus of renewable electricity, P2H systems can use this surplus to fully produce renewable and cheap process heat. However, the question arises, what conditions must be met and to what extent the participation in the balancing energy market can contribute to ensure an economic and ecological operation of P2H systems.

The aim of this work is therefore to analyze different P2H applications in industrial processes, focusing on economic and ecological aspects. The analysis is based on numerical simulation of different representative industrial processes. By changing several parameters like electricity prices, composition of the electricity mix, demand and load profiles, investment costs as well as costs for CO_2 emissions, the impact on the economic and ecological behavior of P2H systems can be evaluated.

2. Methodology

The study is carried out in three essential steps, namely the numerical modeling of the systems, the calculation of economic and ecological indicators and finally a parameter variation. Each of these steps is carried out twice, once for the fossil fuel powered process and once for the P2H process, see Fig. 1.

Initially, a numerical model of the industrial process which is currently powered by fossil fuels like oil or natural gas is developed, to identify the relevant energy and power flows for the ecological and economic evaluation. The simulation task is carried out on an annual, seasonal or load-profile-relevant time scale basis using MATLAB (The MathWorks Inc., 2025a) and MATLAB Simulink (The MathWorks Inc., 2025b). Based on the simulation result, the economic and ecological indicators for the fossil fuel powered system are calculated. As ecological indicators, both the CO_2 emissions and the non-renewable primary energy demand are selected.

For the economic evaluation, the "Levelized Cost of Heat" (LCoH) are used for describing the overall economic behavior of the systems. By taking depreciation and residual value into account, the different technologies can be compared, since each of them has a distinct lifespan. In course of this work, the LCoH formula of IEA SHC task 54 (IEA, 2018), which was originally designed for economic calculations of solar thermal systems, is applied in an alternative manner to evaluate the economic performance of the different systems. The LCoH can be calculated as follows (Louvet et al. 2019):

$$LCoH = \frac{I_0 - S_0 + \sum_{t=1}^{T} \frac{C_t \cdot (1 - TR) - DEP_t \cdot TR}{(1+r)^t} - \frac{RV}{(1+r)^T}}{\sum_{t=1}^{T} \frac{E_t}{(1+r)^T}} \qquad \text{eq. 1}$$

Where $LCoH$ are the levelized cost of heat (€/kWh), I_0 and S_0 are investment cost (€) and subsidies (€), C_t are the operating costs (€/a), TR and DEP_t are corporate tax (%) and depreciation (€/a), RV describes the residual value (€) and finally E_t is the provided energy (kWh). Furthermore, r and T stand for the discount rate (%) and the analysis period (a)

After calculating the CO_2 emissions, the non-renewable primary energy demand as well as the LCoH of the fossil fuel powered system, relevant parameters, like fuel prices or costs for CO_2 emissions, are varied and the calculation of the economic and ecological indicators is repeated. Following the parameter variation, the model is extended to include various P2H technologies, such as electrode boilers, continuous-flow water heaters as well as heat pumps, with the aim of partially or completely replacing the required fossil fuels. Again, all critical energy and power flows are calculated and the corresponding economic and ecological indicators are derived. Similar to the fossil fuel powered system, relevant parameters of the P2H system are varied and the resulting impact on the economic and ecological indicators is examined.

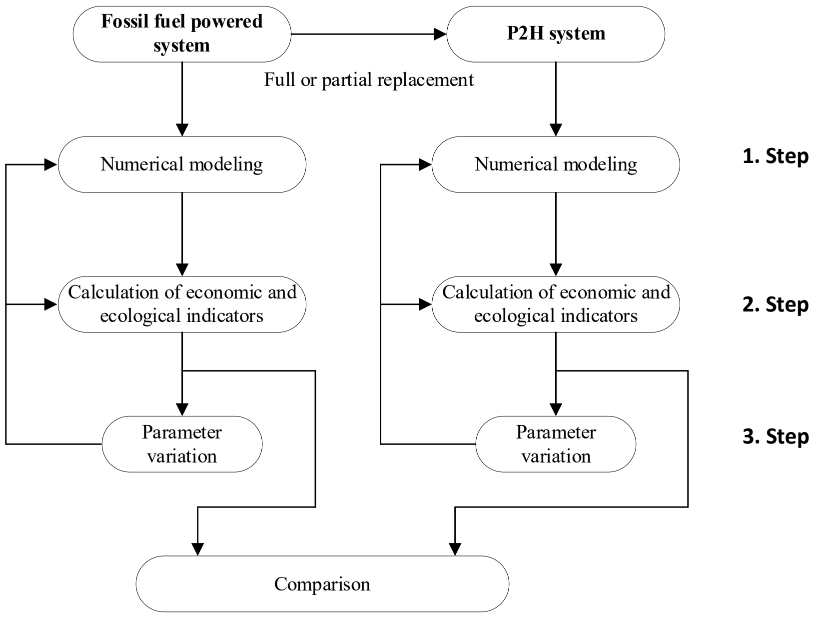

Fig. 1: Structure of the proposed work

As a significant proportion of the operating costs results from the electricity required for the P2H process, participation in the balancing power market is also considered. This allows an examination of the economic and ecological performance under fluctuating electricity prices, taking into account the dynamics of the balancing energy market, including negative market prices caused by a surplus of renewable electricity generation. To conduct a comprehensive analysis, the following parameters are varied across different scenarios:

- Investment costs of P2H applications
- Composition of electricity mix
- Electricity and fossil fuel prices
- Costs for CO_2 emissions
- Demand load profiles
- Residual load curve of the balancing energy market

3. Expected results

Based on the modeling activities and the calculation of the economic and ecological indicators, both types of systems as well as the individual scenarios are compared to each other. As a result of the parameter variation, those parameters that have the highest influence on both economic performance and ecological impact are identified. Furthermore, the following questions, including but not limited to, are answered:

- What boundary conditions must be met (electricity prices, investment costs, electricity mix, …) that P2H is more economic and ecological than conventionally powered systems
- To what extent does participation in the balancing energy market contribute to economic viability?
- How much CO_2 emissions and primary energy can be saved in industrial processes by replacing fossil fuel powered processes with P2H

4. Outlook

Since this work focuses directly on P2H applications and technologies directly, next steps include the implementation of different types of energy storage (thermal and electrical) combined with P2H technologies. Energy storage can serve as a buffer and thus offers more flexible use of P2H on a larger scale. Nevertheless, the implementation of storage systems is associated with investment costs and therefore also requires a detailed economic assessment.

5. References

European Commission, Directorate-General for Energy, 2025. EU energy in figures – Statistical pocketbook 2025. DOI: 10.2833/6042969.

Eurostat, 2025. Final energy consumption in industry - detailed statistics. https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Final_energy_consumption_in_industry_-_detailed_statistics

IEA, 2018. IEA-SHC Task 54 - Price Reduction of solar Thermal Systems. 2015-2018. https://task54.iea-shc.org/

Louvet, Y., Fischer, S., Furbo, S., Giovanetti, F., Köhl, M., Mauthner, F., et al., 2019. Guideline for levelized cost of heat (LCoH) calculations for solar thermal applications. IEA Task 54. https://task54.iea-shc.org/.

Maruf, M., Nasimul I., Morales-España, G., Sijm, J., Helistö, N., Kiviluoma, J., 2022. Classification, potential role, and modeling of power-to-heat and thermal energy storage in energy systems: A review. In: *Sustainable Energy Technologies and Assessments* 53, S. 102553. DOI: 10.1016/j.seta.2022.102553.

The MathWorks Inc. 2025a. MATLAB. Version R2025b https://www.mathworks.com/products/matlab.html,

The MathWorks Inc. 2025b. MATLAB Simulink. Version R2025b https://www.mathworks.com/products/simulink.html