EuroSun2026

FROM NATURAL GAS TO HYDROGEN: AN INTEGRATED ENERGY-HUB ANALYSIS FOR AN AUSTRIAN COFFEE ROASTERY

Summary

This work presents a decarbonization approach for small industrial sites by integrating hydrogen into an energy-hub system. Mathematical modelling of PV generation, electrolyzer operation, hydrogen storage, and thermal consumption is used to represent the system and also its energy flows. The model is implemented in MATLAB/Simulink to simulate renewable utilization and evaluate different hydrogen-based operation strategies. Applied to an Austrian coffee-roastery use case, the simulation demonstrates how hydrogen and renewable integration can support a transition from natural gas while improving system flexibility and efficiency.

Keywords: decarbonization, energy-hub, hydrogen, mathematical modelling, simulation.

Field of application for the findings: energy planning and system modeling, industrial decarbonization, hydrogen transition, multi-energy system integration.

Addressed audience: researchers and academics, industrial stakeholders, technology providers, network operators.

1. Introduction

The transition toward low-carbon industrial energy systems is increasingly driven by the integration of green gases, particularly renewable hydrogen, into multi-energy hubs. Hydrogen (H_2) provides seasonal and shorter storage flexibility, enables sector coupling, and enhances renewable energy utilization while also decreasing intermittency. Studies on PV-hydrogen integration show that directing a substantial share of renewable electricity toward hydrogen production significantly improves system efficiency and reduces fossil-fuel dependence, especially in small industrial facilities (Franco et al., 2025). Additionally, hydrogen is well known as a key vector in Europe's long-term decarbonization strategy due to its capacity to stabilize fluctuating renewable resources and support industrial thermal processes traditionally dependent on natural gas (Renau et al., 2025a).

Developing reliable system-level models is essential for designing and optimizing such energy hubs. Mathematical formulations usually present PV generation models based on irradiance dynamics, electrolyzer hydrogen-production equations based on conversion efficiencies and electrical input, as well as hydrogen-storage mass-balance equations describing inflow, outflow, and state-of-charge evolution. These modeling approaches are widely applied in integrated PV–electrolyzer systems, where the interaction between renewable supply, electrolyzer operation, and storage behavior must be accurately represented to predict system performance (Haidar et al., 2024). Moreover, optimization frameworks implemented in MATLAB/Simulink (The Mathworks Inc., 2026) allow for the evaluation of operational strategies that minimize grid dependence and improve renewable energy self-consumption (Wei et al., 2022).

To demonstrate the applicability of the developed energy hub model, the model is applied to the Austrian coffee-roastery use case. The system representation is implemented in MATLAB to simulate renewable electricity generation, hydrogen production, storage behavior, and thermal energy supply under realistic operational profiles. This simulation environment enables evaluation of hydrogen integration strategies and assessment of how renewable resources and system components interact to support a complete transition from natural gas to hydrogen.

2. Methodology

This work starts with the development of a mathematical framework capable of representing the energy flows within a multi-carrier industrial energy system. In this step, the energy-balance equations are formulated to capture interactions between electricity, hydrogen and thermal demand. These equations (Equation 1 – Equation (4)) ensuring that all physical constraints and conservation principles are respected (Haidar et al., 2024) and define the following quantities:

- Power input:

$$P_{pv} = \eta_{pv} A_{pv} G \tag{1}$$

Where η_{pv} is the photovoltaic (PV) module efficiency, A_{pv} is the PV area (m²) and G is the global solar irradiance (W/m²).

- Conversion efficiencies

$$\dot{m}_{H2} = \frac{\eta_{el} P_{el}}{HHV_{H2}} \tag{2}$$

Where η_{el} is the electrolyzer system efficiency, P_{el} the input electrical power (W), HHVH2=39.4 kWh/kg.

- Storage states (Wei et al., 2022)

$$\dot{m}_{storage} = \dot{m}_{in} - \dot{m}_{out} \tag{3}$$

$$SOC\ (t) = \frac{\dot{m}_{storage}(t)}{m_{max}}$$

Where, $\dot{m}_{storage}$ is the rate of change of hydrogen mass inside the storage system (kg/h), $\dot{m}_{in}$ is the mass flow of hydrogen entering the storage tank (kg/h), $\dot{m}_{out}$ is the mass flow of hydrogen exiting the storage tank (kg/h) and m_{max} is the maximum usable storage capacity

- and heat generation relationships (Renau et al., 2025b)

$$Q_{burner} = \eta_{burner} \dot{m}_{H2,burn} LHV_{H2} \tag{4}$$

Where η_{burner} is the burner efficiency, $\dot{m}_{H2,burn}$ the amount of consumed hydrogen (kg/h) and LHV_{H2} = 33.3 kWh/kg.

The system is composed of four key components, each presenting their own mathematical sub-models. First, the photovoltaic (PV) generation is modelled considering irradiance dependent power curves to simulate variable renewable electricity supply. Second, the electrolyzer model integrates hydrogen production efficiency, electrical power consumption, and also some additional conditions for compression before storage. Third, hydrogen storage dynamics are described using state-of-charge equations that consider charging, discharging and pressure constraints. Finally, the hydrogen burner is modeled to convert stored hydrogen into process heat, considering combustion efficiency and thermal load requirements. Figure 1 presents a general overview of the components that will be simulated in this study.

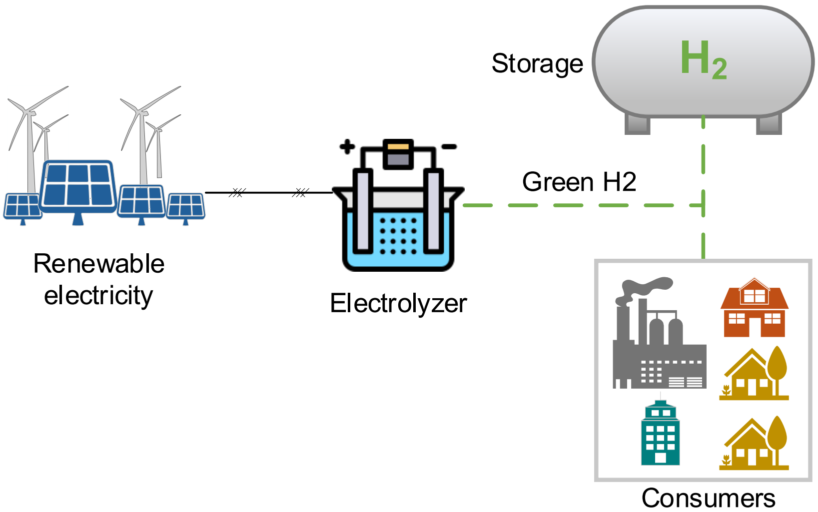

Figure 1: Overview of system components

Each of the component models will be further integrated into a unified system that describes the electrical and hydrogen energy flow across the whole facility. This integration will allow the model to capture interacting effects such as renewable variability, storage limitations, and heat-demand fluctuations. All the individual mathematical models combined form a flexible energy-hub model that can simulate multiple operating strategies and technological configurations.

All the system components as well as the complete model will be implemented in MATLAB/Simulink due to its ability to solve dynamic system equations and executing time-series simulations. To evaluate the practical applicability of the integrated energy-hub model, a real industrial use case of a coffee roastery in Austria will be then incorporated. The facility processes 50,000 kg of coffee per year, with roasting occurring two days per week (≈100 production days), resulting in a daily throughput of 500 kg. Based on a specific thermal demand of 0.5 kWh/kg, the roasting process requires approximately 250 kWh of thermal energy per day, equivalent to 71 m^3 of hydrogen or 6.5 kg H_2 per day. Roasting occurs in three batches per hour, each consisting of roughly 7 minutes of heating and 10 minutes for loading and unloading, producing an intermittent thermal-demand profile. In parallel, the facility has an electrical demand of 10kW, corresponding to 10 kWh/day, which is integrated into the electricity balance of the model.

The roastery hall is equipped with a 60 kWp PV system providing an annual yield of 54,000 kWh, forming the renewable backbone of the system. To supply hydrogen for the roasting burner, a small-scale electrolyzer with 5–10 kW capacity will be considered, enabling a hydrogen production rate of 1–2 m^3/h (approximately 0.1–0.2 kg/h) and a maximum daily generation of ≈5 kg H_2 per 24 h. Weekly hydrogen storage will be incorporated to buffer the mismatch between continuous hydrogen production and concentrated roasting days.

3. Outlook

For the final steps of this work, the resulting time-varying electricity generation, hydrogen production, combustion demand, and storage behavior will then be embedded into the MATLAB-based simulation, allowing optimization of electrolyzer operation and renewable utilization. This ensures that the model captures the real-world operational constraints and provides a quantitative basis for determining the feasibility of transitioning from natural gas to hydrogen in small industrial roasting applications.

4. References

Franco, A., Carcasci, C., Ademollo, A., Calabrese, M., Giovannini, C., 2025. Integrated Plant Design for Green Hydrogen Production and Power Generation in Photovoltaic Systems: Balancing Electrolyzer Sizing and Storage. Hydrogen 6, 7. https://doi.org/10.3390/hydrogen6010007

Haidar, F., Mrad, I., Dam, Q.T., 2024. Modeling and Simulation of Integrated Photovoltaic-Alkaline Electrolyzer System for Sustainable Hydrogen Production. eng.pers 4, 60–68. https://doi.org/10.29228/eng.pers.76380

Renau, J., García, V., Tejada, D., Isorna, F., Ridao, M.Á., Bordons, C., López, E., 2025b. Modelling Time-Variable Green Hydrogen Production with a PEM Electrolyser Coupled with Photovoltaic Energy, in: Belenguer, E., Beltran, H. (Eds.), ELECTRIMACS 2024, Lecture Notes in Electrical Engineering. Springer Nature Switzerland, Cham, pp. 577–588. https://doi.org/10.1007/978-3-031-73921-7_44

The Mathworks Inc., 2026. MATLAB.

Wei, D., Li, H., Ren, Y., Yao, X., Wang, L., Jin, K., 2022. Modeling of hydrogen production system for photovoltaic power generation and capacity optimization of energy storage system. Front. Energy Res. 10, 1004277. https://doi.org/10.3389/fenrg.2022.1004277