Report

IEA TCP AFC

Deployment Use of Stationary Fuel Cells for Climate-neutral Districts and Neighbourhoods

2022–2024

Task 33
Fuel Cells for Stationary Applications

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IEA Technology Collaboration Programme
Advanced Fuel Cells

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Executive Summary

The development of the energy system towards the Austrian and European energy and environmental goals is characterised in particular by increasing decentralised electricity generation from renewable energy sources. Thanks to its wide range of possible applications, hydrogen as an energy carrier is a technological cornerstone for the decarbonisation of several key areas of the energy transition, such as buildings, mobility and industry. In this context, Austria took on a new subtask in the IEA Advanced Fuel Cell Technology Collaboration Programme (AFC TCP) in 2022, "Use of stationary fuel cells for climate-neutral districts and neighbourhoods". This subtask is investigating to what extent stationary fuel cells can be used in energy concepts based on renewable energy sources in energy communities or climate-neutral neighbourhoods.

The current project analyses the success factors of existing approaches at national and European level with the aim of identifying and demonstrating the prerequisites and potential benefits for replication in Austria. For this purpose, neighbourhoods and energy communities in which hydrogen-based energy systems have already been used or are planned were analysed in detail. The success factors and requirements as well as the remaining barriers for replicability in Austria were identified using a SWOT analysis (Strengths, Weaknesses, Opportunities, Threats) on the one hand and interviews with relevant Austrian stakeholders on the other.

In addition to the technological availability of the components, the modelling of energy flows plays a decisive role for the successful planning and implementation as well as the efficient operation of fuel cells in neighbourhoods. Therefore, alongside the identification of the components which are currently available (electrolyser, hydrogen storage, fuel cells), possible tools for modelling energy flows in neighbourhoods were also investigated and tested. Based on this, a method was developed to model and simulate three typical neighbourhoods in Austria with different scenarios. In addition, criteria were defined for a subsequent evaluation of the benefits that can be expected from the use of hydrogen technology in terms of climate neutrality.

The project results firstly underlined the already known crucial role of energy efficiency and the development of renewable energy sources in achieving climate neutrality. It also demonstrated the advantages of using hydrogen technology in neighbourhoods or energy communities in terms of grid serviceability. In this respect, a typical application is the absorption of surplus renewable electricity in summer and its time-delayed reconversion into electricity by fuel cells to support the power grid during possible winter supply shortages in rural areas. Self-sufficiency in electricity is not yet realistic, but waste heat from electrolysers or fuel cells can be used in local/district heating networks to cover the neighbourhood's heating demand. In neighbourhoods where buildings combine high energy efficiency standards with smart integration of heat pumps (using waste heat of the electrolyser and the fuel cell), complete decarbonisation of thermal energy demand can be expected. The study also shows a promising use of hydrogen technology for the decarbonisation of several applications in industrial areas (industrial heating, mobility, et cetera).

To summarise, typical applications were identified in Austria for which the technical components are already available. However, investment costs, space requirements and a lack of experience and suitable planning and modelling tools currently represent obstacles to widespread implementation.

The results of the study were published on the Webpage of the Austrian Energy Agency [1] and summarised in recommendations, which were presented to relevant stakeholders in Austria at a results workshop.

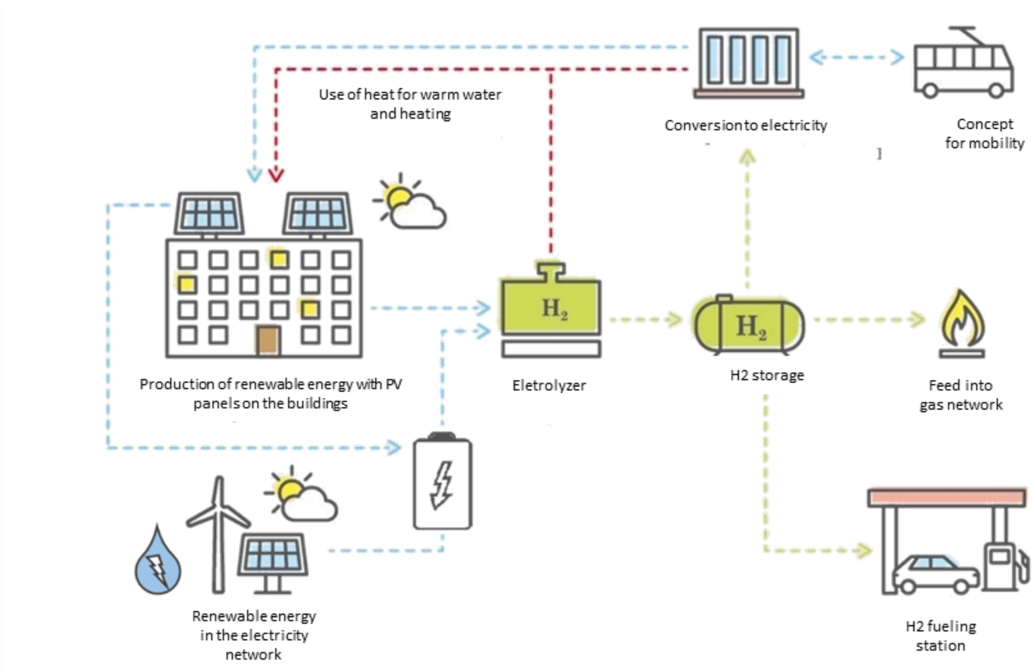
1. Introduction

The transition to sustainable energy systems in Austria and the European Union is driven by increasing decentralisation and a growing reliance on renewable energy sources. Hydrogen has emerged as a crucial energy carrier due to its versatility and potential for decarbonising key sectors such as buildings, mobility, and industry. Austria has actively contributed to the International Energy Agency (IEA) Advanced Fuel Cells TCP Task 33, which focuses on the application of stationary fuel cells within energy communities and climate-neutral districts.

In fact, the previous analyses in Task 33 have shown that the use of small stationary fuel cells, which, for example, have already led to commercial products in the power range of around 1 kW_{el} in the building sector in Japan (Ene-Farm systems), cannot be successfully implemented in the market in Austria (or Europe) due to entirely different framework conditions. However, based on the insights gained from the preliminary project, it could be demonstrated that the use of stationary fuel cell systems in larger applications has improved economic viability and can achieve high self-consumption rates [1]. By expanding to other applications such as electromobility, this aspect can be further strengthened. As a result, with appropriately designed storage systems, grids can be relieved in both winter and summer months, and the supply security and resilience of the energy system can be increased.

Thus, in the period from 2022 to 2024, it was agreed within Task 33 that Austria would address the new subtask: "Use of stationary fuel cells for climate-neutral districts and neighbourhoods."

Figure 1: Schematic view of the energy system in the district "Neue Stadt" in Esslingen, Germany. Source: Translated from German from: Projektträger Jülich | Forschungszentrum Jülich GmbH, 2024 [2]



As several examples in Europe already demonstrate, decentralised hydrogen concepts in combination with renewable energy sources can increase supply security, contribute to grid relief in both summer and winter months, enhance sector coupling and pave the way towards climate neutrality in neighbourhoods. This can also boost the social acceptance of renewable energy sources in society.

2. Project background and objectives

Pilot neighbourhoods in Europe, where hydrogen-based energy systems are already being used, indicate positive results, but they do not allow for direct conclusions about the general feasibility in Austria. The project in the task period 2022–2024 thus investigated the extent to which decentralised hydrogen-based energy systems using renewable energy sources can contribute to climate neutrality in energy communities.

Specifically, the following goals were pursued in the project:

- **Analysis of neighbourhoods** (primarily in Europe or in Task 33 member countries) in which energy systems already rely (partly or totally) on decentralised hydrogen solutions: Through the systematic investigation of success factors in these existing neighbourhoods and the exchange with a stakeholder group, insights into the expected benefits and the current barriers were analysed.
- A key motivation for the application of stationary fuel cells is the creation of a "climate-neutral neighbourhood," although there is currently no universally accepted definition for this. Compared to conventional plus-energy neighbourhoods, the choice of system boundaries, evaluation criteria, and energy balancing methods (especially the temporal resolution) is particularly relevant when hydrogen is used as an energy carrier (integration of sector coupling and long-term storage). The project aimed to **evaluate existing methods for the energy assessment of neighbourhoods** based on relevant assessment tools and to **propose recommendations for their use** and further development.
- During the project, the state of the art of hardware components (fuel cells, electrolysers, and hydrogen storage) was also surveyed. The **current state of available technologies** for the use of hydrogen technologies in neighbourhoods **was assessed**.
- Modelling energy flows in a neighbourhood (generation, storage, consumption, with different prioritisation rules and time resolution) is a crucial prerequisite for successful planning, implementation, and energy-efficient operation of the energy system. This is particularly important when using hydrogen technologies, which allow for seasonal storage and high sector coupling. Therefore, the project focused on currently available open-source tools. A range of tools was analysed, and three were tested. The goal was to **develop a modelling and simulation method** that can be used for further analysis of typical applications in Austria.

- Using the developed method, **three typical applications** for neighbourhoods were modelled and simulated. Specifically, simulations were conducted on three structurally different neighbourhoods (a commercial area, an urban neighbourhood, and a neighbourhood in a rural area) in order to make statements about **the most important requirements and primary benefits**.
- Eventually, dissemination and networking activities were organised to **inform and involve stakeholders** through publications, a workshop presenting the findings in a clear decision-making guide and participation in Annex 33 meetings.

3. Pilot neighbourhoods in Europe

3.1 Methodology

At the early phase of the project, an investigation was conducted to identify projects that have already been implemented or are still in the planning stages, in which hydrogen-based energy systems have been deployed in neighbourhoods. Projects that explicitly aim to reach climate neutrality (or energy autonomy), and which, due to their maturity (already carried out or in an advanced planning phase), show a high probability of implementation, were analysed in detail and summarised in the form of fact sheets (see following chapters). The components used in the implementation of these projects were also analysed and described.

Building on this, the studied neighbourhoods were classified into types, and for the applications relevant to this project, the success factors, limitations, and needs for replicability in Austria were identified through a SWOT analysis (strengths, weaknesses, opportunities, threats). As a result, typical potential applications of hydrogen in Austria could be identified (see Chapter 5.2).

3.2 "Neue Weststadt" in Esslingen am Neckar, Germany

In Esslingen am Neckar, a climate-neutral and grid-supportive urban district is being developed over an area of 120,000 m². This flagship project includes 450 apartments, office and commercial spaces, as well as the construction of a new university building. The electrolysis plant will be installed underground within the district.

More information: https://neue-weststadt.de/energiekonzept/

3.3 "H2-Revier" in Gütersloh, Germany

In Gütersloh, North Rhine-Westphalia, a climate-neutral urban district is being developed over an area of 32,000 m², including 3,000 m² dedicated to power generation facilities. The goal is to supply the entire district—comprising seven single-family homes, twelve multi-family buildings, a kindergarten, an office building, and a petrol station—with green hydrogen.

To enable local power generation, wind turbines, photovoltaic systems, and biogas plants will be installed around the district. The hydrogen produced will be supplied through a dedicated hydrogen network and converted back into electricity via fuel cells within the district.

More information (only German): https://www.tassikas-immobilien.com/h2-revier

3.4 "Energiezentrale der Zukunft" in Bochum-Weitmar, Germany

In Bochum-Weitmar, an existing urban district is partially transitioning to hydrogen supply. A total of 81 out of 1,541 apartments are expected to achieve a self-sufficiency rate of 60% using an electrolyser, brine-water heat pump, PV systems, as well as battery and hydrogen storage. The PV system supplies electricity to the apartments, with any surplus either used for hydrogen production or stored in a short-term battery storage system.

More information (only German): https://www.kup-ing.de/projekte/energiezentrale-der-zukunft-bochum/

3.5 Vårgårda, Sweden

In Vårgårda, six energy-renovated multi-family buildings (172 apartments) are self-sufficiently supplied with electricity and heat through a combination of solar panels, batteries, hydrogen, and fuel cells.

More information: https://www.sciencedirect.com/science/article/abs/pii/S1464285919300586

3.6 "Wasserstoff-Insel Öhringen" in Öhringen, Germany

In the northeast of Baden-Württemberg, the distribution network operator Netze BW 25 is working with households to create a "hydrogen island" in Öhringen. This project involves gradually increasing the hydrogen content in a section of the regular gas network, located on

Meisterhaussstraße, to 30%. The hydrogen required for this process will be produced on-site using an electrolyser.

More information (only German): https://www.netze-bw.de/unsernetz/netzinnovationen/wasserstoff-insel

3.7 MPreis in Völs, Austria

A facility to generate green hydrogen is being developed on the premises of the food retailer MPREIS headquarters in Völs near Innsbruck (Tyrol). This hydrogen will be produced using 100% renewable electricity from hydropower (grid serviceability) and used to refuel fuel cell trucks for the company's own fleet. Additionally, the hydrogen power a furnace in the on-site bakery, and the waste heat from hydrogen production will be utilised to heat the production facilities.

More information (only German): https://www.mpreis.at/wasserstoff?srsltid=AfmBOopXiNzMT1PNKjLOuyGUG36jFAIVYLII_0dlUnTA6K941q570ywh

3.8 SAN Group in Herzogenburg, Austria

By mid-2022, the first green hydrogen facility in Lower Austria was established at the SAN Group's company site in Herzogenburg, using the Fronius Solhub system. The facility is powered by solar electricity from the company's own PV installation. Hydrogen is produced on-site through electrolysis. The hydrogen is used for the company's fleet and is also available to external partner companies. A key factor in making the energy system largely self-sufficient was the hydrogen-powered emergency power supply for the site.

More information: https://www.san-group.com/news/san-group-builds-first-green-hydrogen-production-facility-in-lower-austria

3.9 "Energiegemeinschaft Almenland" in Gasen, Austria

As part of a demonstration project, a energy community for renewable energy was established in the municipality of Gasen (Styria) to optimise the consumption of locally generated renewable energy. Due to the relatively underdeveloped grid infrastructure in this rural area, residents and the mayor were highly motivated to create an energy community with a hydrogen-based system (ensuring supply security in case of a power outage) and take advantage of seasonal storage. The combination of technologies, including electrical short-term storage with a hydrogen storage system, as well as the integration of a biomass combined heat and power (CHP) system and an electric vehicle charging station, primarily serves to reduce the strain on the community's internal grid. The participants (ten buildings, including single-family homes, the town hall, elementary school, kindergarten, café/inn, and other mixed-use buildings) agree to forgo storage use for a few hours each year in exchange for the benefits.

More information (only German): https://www.gemeindeservice-stmk.at/projekt/energiegemeinschaften-almenland/

4. Technology report

Beside the study of the pilot project, the state of the art, the availability in Austria and the space requirements of electrolysers, hydrogen storage, and fuel cells were recorded and are presented in the table below.

4.1 Electrolysers

Table 1: Electrolysers available in Austria

Power range [MW]	0.1 to < 0.5	1.0	2.5 to ≤ 5.0
Manufacturer (model designation)	Elogen (E50) Hähn (EL20 – 80) H-TEC Systems (ME100/350) Kumatec (PEM-40-100)	Elogen (E200) Enapter (AEM Multicore) Green H2 Systems (Green Elektrolyzer 1 MW) H-TEC Systems (ME450/1400)	Elogen (E500) Elogen (E1000) Green H2 Systems (Green Elektrolyzer 2.5 MW to 5 MW) Hydrogenics (HyLyzer 1000)
Hydrogen production [kg/h]	2.0 to < 10.0	15.0 to < 20.0	≥ 40.0
Efficiency and operation data/typical specific power consumption [kWh/Nm³H2]	4.7	4.5	4.4
Electrolyser type	PEM	PEM and AEM (Enapter)	PEM
Space requirement [m²]	< 20.0	20.0 ≤ 30.0	≈ 30.0/MW

4.2 Storage

The following table lists demonstration projects that use a hydrogen storage system, including the amount of hydrogen stored in each case. The table provides an overview of demonstration districts and their hydrogen storage contents.

Table 2: Types of storage

Storage capacity [kg_{H2}]	up 50	50 to ≥ 500	500 to ≥ 1000
Projects	Neue Weststadt (Esslingen): 30 kg at 10 bar	H2-Revier (Gütersloh): 250 kg	MPREIS (Völs): 700 kg, 30 bar
Installation	Underground	On the ground	On the ground

4.3 Fuel cells

The following table presents a selection of fuel cells for decentralised and centralised applications in districts.

Table 3: Fuel cells available in Austria

Application	Decentral (in each building)	Central (in the district)
Power range [kW_{el}]	≤ 2.5	Depends on the application
Manufacturer	Buderus (Logapower FC10) SenerTec (Dachs InnoGen) Viessmann (Vitovolar 300-P) HEXIS (Leonardo) SOLIDpower (BlueGEN) SOLIDpower (EnGen-2500)	SOLIDpower EnGen-2500: connecting several units with each other Proton-Motor (HyScale) Modular: integration-ready multi-stack solution up to the megawatt range Ballard (FC Wave): from 200 kW to 1.2 MW electricity production
Fuel cell type	SOFC and PEMFC	SOFC and PEMFC
Generated electrical energy in kilowatt-hours per year [kWh/a]	15,000	75,000
Electrical efficiency [%]	30 to 70	30 to 70
Total efficiency [%]	80 to 90	80 to 90
Space requirement [m^2]	0.5 to 1.0	2.5 to 4.0
Height [m]	1.0 to 2.0	1.0 to 2.0

5. Methodology for modelling typical applications

5.1 Modelling and simulation methodology

To successfully plan and assess energy balance at district level, it is necessary to model and simulate the energy flows accurately. Within the framework of the project, energy balance simulation tools for districts available tools were gathered and compared using a multi-criteria analysis. The criteria for the selection of the tools were:

- Open-source or almost open-source availability
- Hourly (or quarterly) accounting
- The potential inclusion of storage, mobility, and hydrogen-based elements (electrolyser, fuel cell)

From the list of applications that were initially compiled, three tools were selected, which were developed in Germany, Switzerland, and Italy respectively:

- districtPH: published by Passivhaus Institut GmbH, Darmstadt [3]
- City Energy Analyst: published by the Institute of Technology in Architecture, ETH Zurich [4]
- MESS (Multi-Energy System Simulator): published by the Department of Industrial Engineering, University of Florence [5]

These three tools were subsequently tested using a sample neighbourhood in an urban area (see next paragraph). The neighbourhood was modelled with each of the three tools to assess how the input is processed and how the results are presented.

The following table summarises the results of the tests of the three tools.

Table 4: multi-criteria analysis of modelling tools

Criteria	**districtPH**	**City Energy Analyst**	**MESS**
Primary focus of the tool	**Building renovation in a district**	**Energy modelling of districts and cities**	**Simulation of multi-energy systems**
Licence	**Commercial**	**Open source**	**Open source**
User interface	**Excel (German)**	**GUI (English)**	**Phyton**
Inclusion of H2 components	No	No	Yes
Inclusion of energy storage	Limited	No	Yes

Criteria	districtPH	City Energy Analyst	MESS
Inclusion of mobility	Yes	Yes	Yes
Energy communities	No	No	Planned
Sector coupling	No	Yes	Yes

The results of the testing phase led to the development of a method that was then used for further simulation work. In this method, the first step is to define load profiles for the buildings and other consumers in the neighbourhood using the application districtPH. This allows for a precise specification of the energy efficiency of the buildings, and the heating and electricity loads for the entire neighbourhood can be derived. In a second step, the consumption profiles (electricity and heating) as well as the generation profiles from renewable energy sources are exported into the MESS application. There, the components (electrolyser, storage, fuel cells) are modelled, and priorities for the energy flows are defined. The simulation runs on an hourly basis, and the results can be presented, for example, in the form of bar charts displaying the energy balance for each month for clear visualisation.

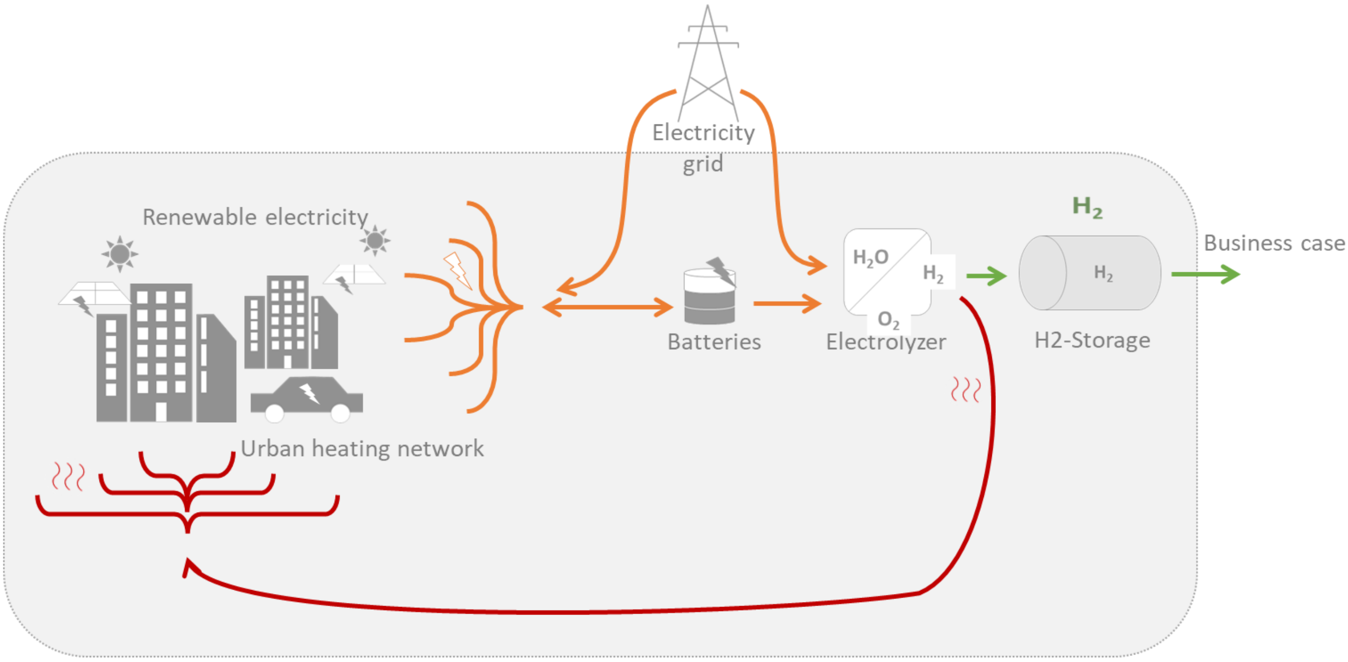
5.2 Definition of typical applications in Austria

To develop recommendations, three applications typical for Austria were modelled and simulated. Two of these neighbourhood types were selected to represent many forms of energy communities in Austria—one in an urban environment and the other in a rural environment. The third type represents an industrial area, focusing on examining how the use of hydrogen can support the decarbonisation of its applications. All three neighbourhoods are based on real-world examples, which are described in the fact sheets. For the study, the neighbourhoods had to be generalised or structurally simplified. The following section provides a brief description of the selected neighbourhood types and the scenarios used for the simulations.

- *District type 1: urban environment*

In a typical neighbourhood in an urban area, renewable electricity from PV (facades and roofs) is locally generated and directly consumed or briefly stored in batteries. However, when the PV generation capacity is expanded, there may be surpluses in the summer that are either fed into the grid in an uneconomical way or cannot be used at all. Additionally, the neighbourhood typically has a high consumption of fossil energy carriers for space heating (gas heating) and mobility. As an example for the simulation, the "Green Energy Center" neighbourhood in Innsbruck was used as a basis [6]. The neighbourhood consists of a mix of multi-storey residential buildings with office and supermarket spaces. Mobility (e-cars and charging stations, trams) was also included in the simulation. The characteristics of the neighbourhood were further simplified for the simulation. The following figure shows a schematic representation of the neighbourhood with the use of hydrogen technologies.

Figure 2: Schematic representation of district type 1 "urban environment". Source: Austrian Energy Agency



The simulation was conducted for three scenarios, corresponding to a step-by-step renovation of the neighbourhood with the use of hydrogen technology within the neighbourhood. The data for the scenarios are summarised in the following table.

Table 5: Scenarios for the simulations of district type 1 "urban environment"

	Scenario 1 "as existing"	Scenario 2 "mediocre renovation"	Scenario 3 "high quality renovation"
Building efficiency standard	Poor	Normal	High (passive house)
PV	500 kWp	1,000 kWp	2,000 kWp
Battery size	500 kWh	1,000 kWh	2,000 kWh
Electrolysis	-	**100 kW with at least 25% utilisation**	**100 kW with at least 25% utilisation**

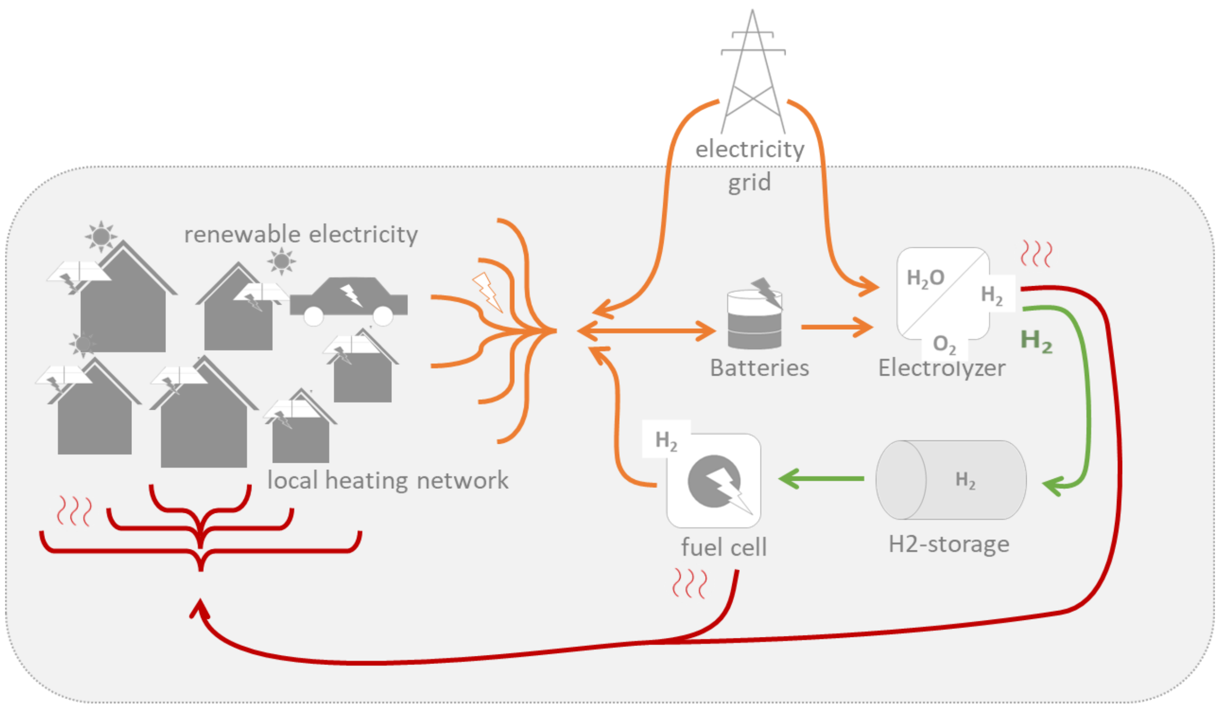
Further characteristics: 11,600 m^2 dwelling area, 800 m^2 office space, 2,000 m^2 supermarket, e-charging stations with demand from e-car sharing

The electrolysers should of course be operating as much as possible in full-capacity (100%), though when operating with renewable electricity, that cannot always be the case. For the simulation, the electrolyser was modelled and dimensioned in a way that it is at least operating in a part load of 25 %.

- *District type 2: rural environment*

District type 2 is a neighbourhood primarily consisting of single-family homes, with a small number of multi-family homes and service buildings in a rural environment. The distinctive feature of this area is the relatively poor connection to the power grid, which can lead to supply security issues in the winter. However, the area offers ample space for extensive local electricity generation from renewable energy sources. Additionally, as in the other neighbourhood, there is still a high demand for fossil-based energy carriers for space heating and mobility. As an example for the simulation, neighbourhood in Gasen (Almenland) was used as a basis [7]. The following figure shows a schematic representation of the neighbourhood with the use of hydrogen technologies.

Figure 3: Schematic view of district type 2 "rural area". Source: Austrian Energy Agency



Three scenarios were also designed and simulated for this neighbourhood. The scenarios are presented in the following table.

Table 6: Scenarios for the simulations of district type 2 "rural area"

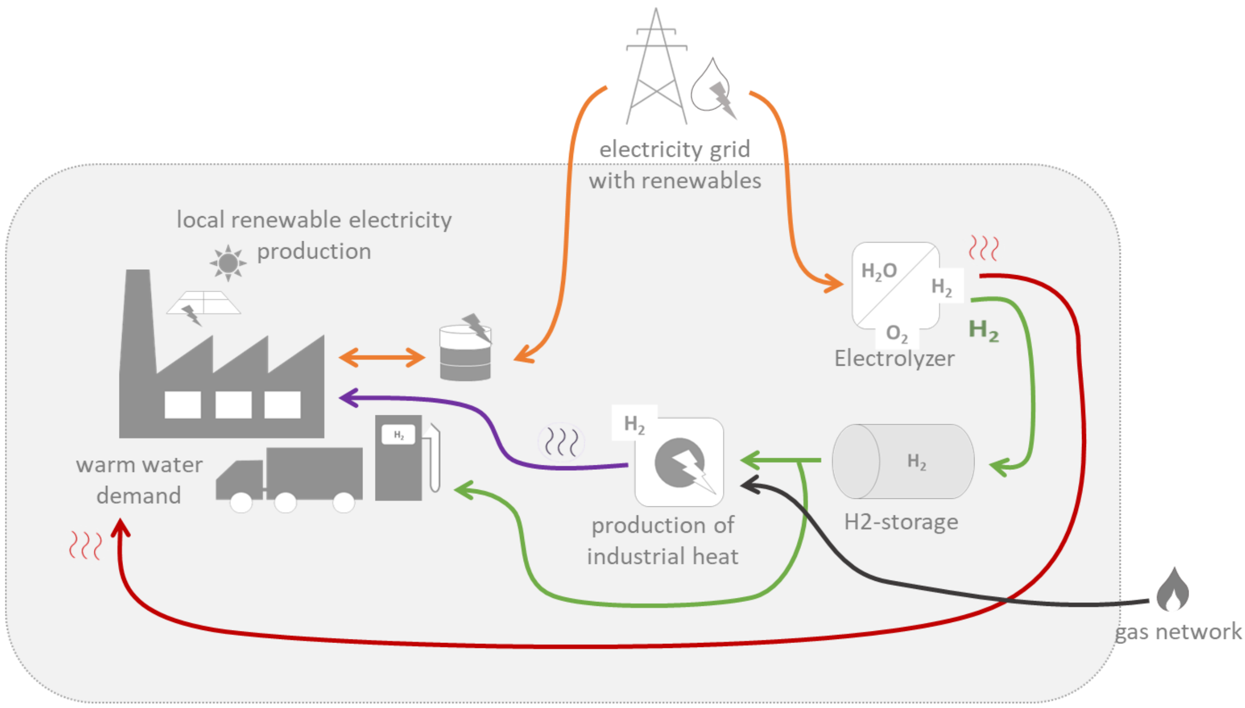
	Scenario 1 "as existing"	Scenario 2 "mediocre renovation"	Scenario 3 "high quality renovation"
Building efficiency standard	**Poor**	**Average**	**High (passive house)**
PV	**100 kWp**	**300 kWp**	**500 kWp**
Electrolysis	-	**100 kW (operation only in the summer)**	**100 kW (operation only in the summer)**
Fuel cell	-	**3 kW (operation only in the winter)**	**11 kW (operation only in the winter)**
H2 storage	-	**500 m³ at 30 bar**	**500 m³ at 30 bar**
Battery storage	-	**500 kWh**	**1,000 kWh**

Further characteristics of the neighbourhood: 3,800 m2 dwelling area, 3,200 m2 school and kindergarten, 450 m2 office space, 1,600 m2 restaurants and catering, e-charging station.

- *District type 3: Industrial area*

Energy consumers and producers can vary greatly in industrial areas. The application chosen here is based on a real example, the MPreis production facility in Völs, Tyrol, where hydrogen technology (electrolyser, H2 storage) is already in use [8]. For the simulation and analysis, the focus was placed on the generation of industrial heat and mobility (truck transport), as shown in the following diagram.

Figure 4: Schematic view of district type 3 "industrial area". Source: Austrian Energy Agency



The impact of a gradual increase in the share of renewable electricity used in the electrolyser on the decarbonisation of various consumers in the facility was simulated. The simulated characteristics of the neighbourhood are summarised in the following table.

Table 7: Scenario for the simulation of district type 3 "industrial area"

Components	Characteristics
Gas demand	12 GWh per year
PV	2 MWp
Mobility and logistics	**5 x H2 trucks / 73,000 kg H2 per year**
Fuel cell	**-**
Electrolysis	**3 MW**
H2 storage	**300 m^3 at 30 bar**

5.3 Assessment of climate neutrality

The terms "climate neutrality" and "climate-neutral neighbourhood/area" are currently not universally defined. In the analysis of the applicability of stationary fuel cells in integrated renewable energy concepts for climate-neutral neighbourhoods, the first step was to determine the current definitions of "climate-neutral neighbourhood" used both within and outside of Austria. The study also examined which evaluation methods and certification systems (national and international) are currently used for the assessment of climate-neutral neighbourhoods. Additionally, it was investigated how the most common evaluation methods differ in terms of the accounting boundaries of energy supply (temporal resolution of the accounting and spatial delineation), and how the energy consumption sectors (electricity and heating for buildings, public infrastructure, and e-mobility) are addressed. In particular, the relevant planning and evaluation methods in Austria (Future Neighbourhood Approach and klimaaktiv Standard for Settlements and Neighbourhoods) [9] were compared with the evaluation method of the German Energy Agency [10].

The goal is to assess the role of hydrogen technology in achieving climate neutrality for each of these three neighbourhood types. For this purpose, an evaluation based on the existing methods mentioned above was developed, using five criteria to assess the climate neutrality of the three neighbourhoods studied:

- Energy efficiency (heating, electricity, mobility)
- Share of renewable energy sources in final consumption (all sectors)
- Sector coupling (diversified use of energy carriers including the business case for selling electricity or hydrogen)
- Grid compatibility (storage capacity in summer and reduction of peak demand in winter)
- Overall lifecycle emissions

The neighbourhoods in the various scenarios were evaluated based on the simulations.

6. Results for the typical applications

6.2 Results for urban energy communities

The following figures illustrate electricity production and consumption regarding electricity for the simulated scenarios (“poor”, “normal” and “high” (see chapiter 5.2)) for a period of one year. It can be noted that increasing PV and battery size leads to significant decrease in the electricity taken from the grid, a slight increase in electricity given to the electrolyser and a significant share of PV surplus. Although the size of the electrolyser is maintained constant in each simulation, the effect of increasing PV and battery size is to increase the electrolyser’s capacity factor, and thus the hydrogen production. However, this also increases the amount of surplus electricity, which is given to the grid, as shown in the following figures and table.

Figure 5: Green Energy Center Europe electricity consumption and production in "poor", "normal", and "high" scenarios.

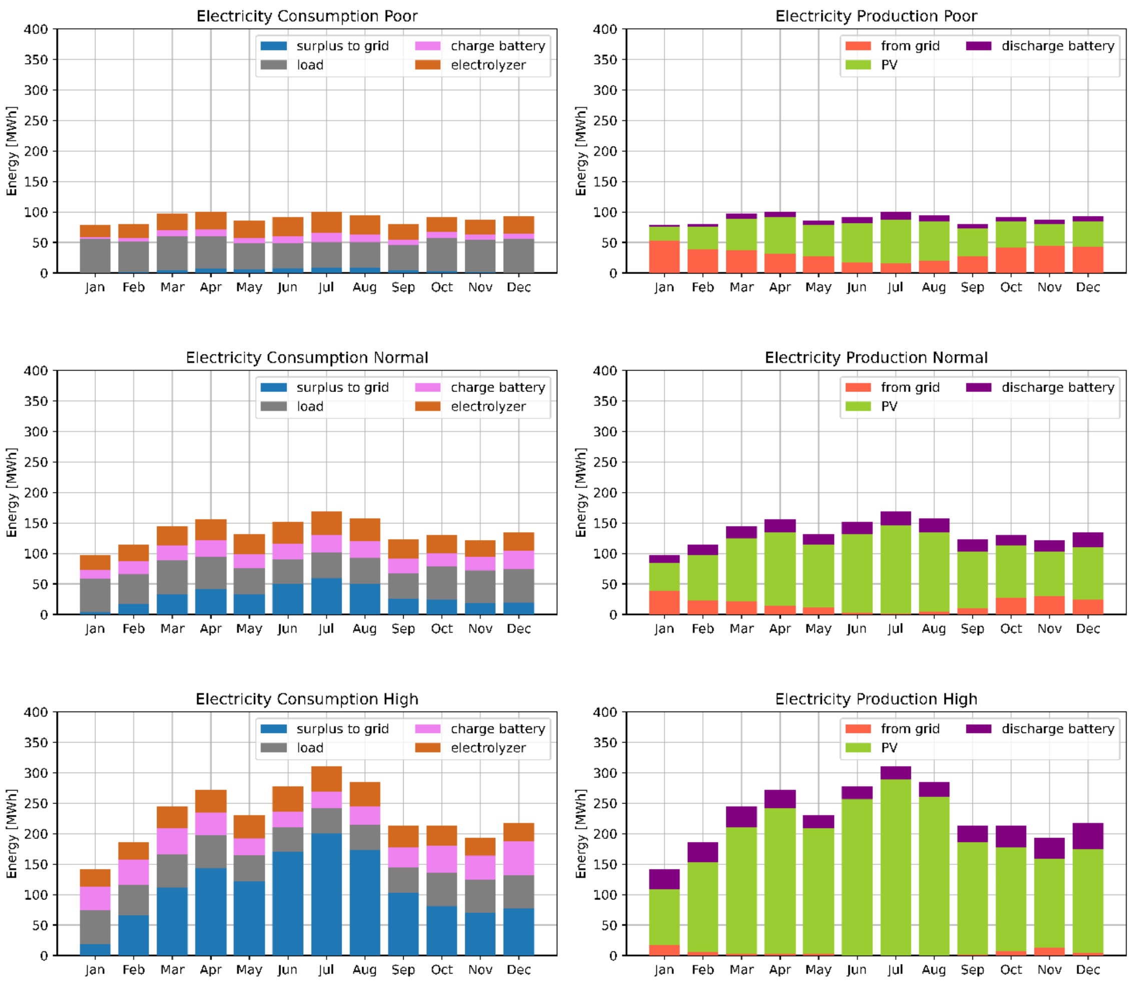
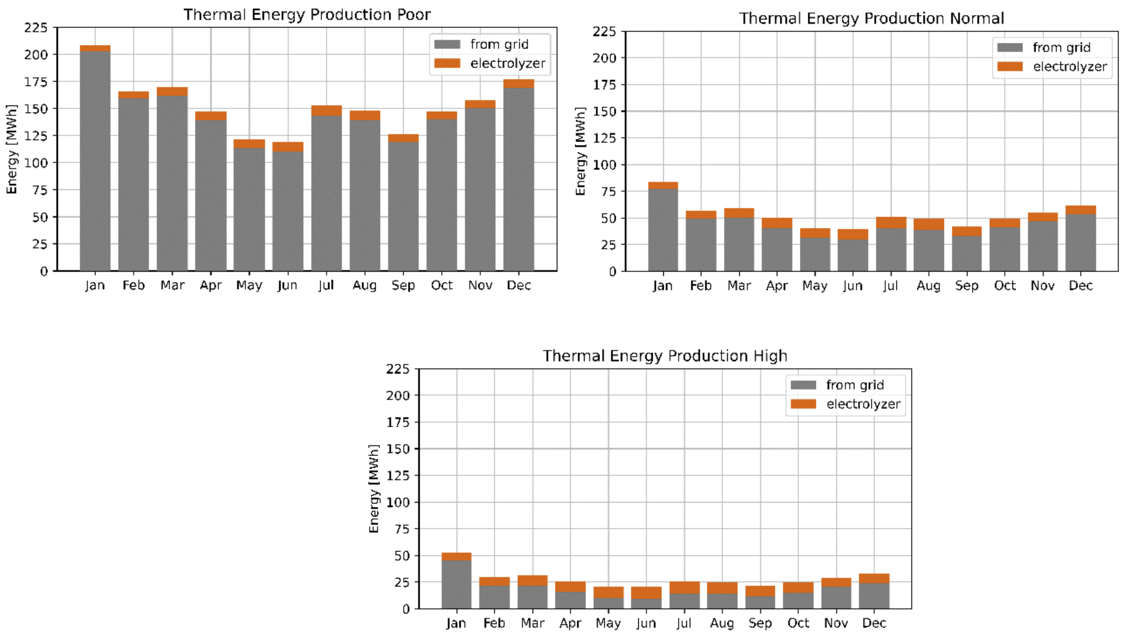


Table 8: Hydrogen production in simulated scenarios

Energy standard	Hydrogen production in kg	Capacity factor in %	Renewable share in %
poor	6,377	37.3	60.8
normal	7,457	43.5	69.3
high	8,256	48.1	74.5

The following figures represents the energy sources used to cover thermal demand. In the "poor" scenario, the majority of energy is taken from the grid (in this case, a district heating grid), and the electrolyser only covers a small portion of the demand. However, in the "high" scenario there is almost a 50 % coverage in the summer months attributed to the increased capacity factor of the electrolyser and, especially, to the strong decrease in the demand due to the high energy efficiency standard of the buildings.

Figure 6: Green Energy Center Europe thermal energy production in "poor", "normal", and "high" scenarios.



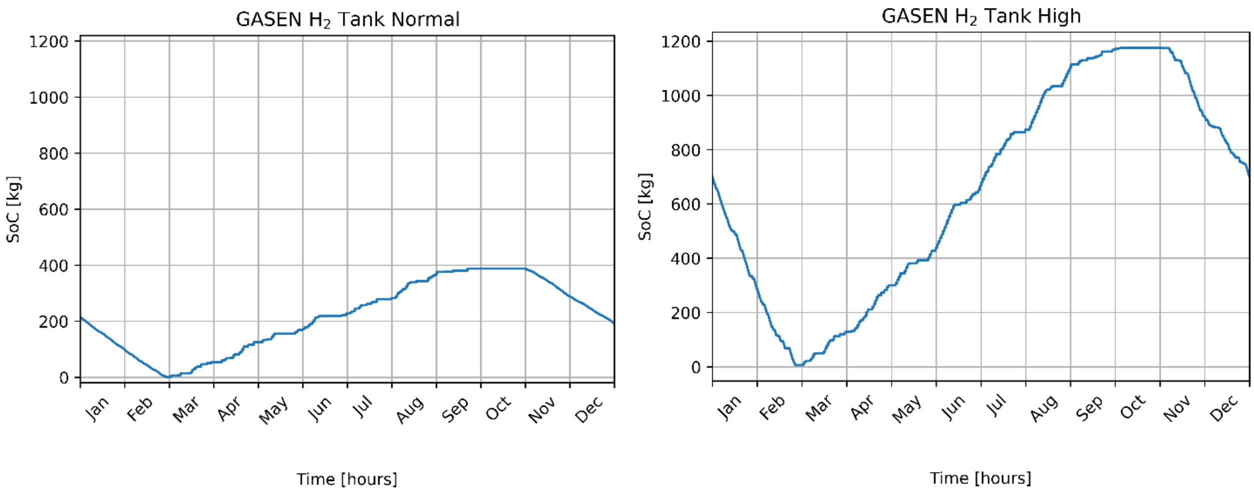
Urban energy communities present opportunities for hydrogen integration, due to their increasing reliance on renewable and intermittent energy generation. Especially, the utilisation of waste heat from electrolysers, which can be redirected to district heating networks, can improve the overall energy efficiency of urban communities. In this way, this pilot simulations show a pathway how hydrogen technologies can contribute to the reduction of carbon emissions from both electricity and heating systems.

However, economic and spatial constraints pose significant challenges to the widespread adoption of hydrogen in urban environments. The high investment costs associated with electrolysis infrastructure, storage systems, and fuel cell deployment limit market expansion. Additionally, the need for dedicated space and safety measures for hydrogen production and storage facilities can be restrictive in densely populated areas. Regulatory frameworks must be adapted to facilitate the safe and efficient integration of hydrogen systems within urban infrastructure, addressing permitting processes, safety protocols, and grid interconnection requirements.

6.3 Results for rural energy communities

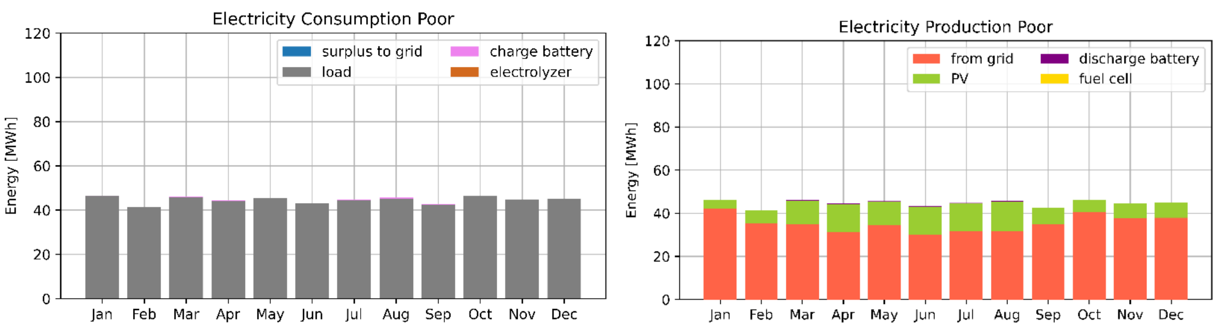
For the “normal” and the “high” scenarios, the electricity generated by PV, in addition to covering part of the demand, powers an electrolyser. The produced hydrogen is stored in a tank and is used during the winter months by a fuel cell to generate electricity. The electrolyser works only with renewable energy from March 1st to October 31st, while the fuel cell operates from November 1st to February 28th. The selected size for the fuel cell ensures that all the produced hydrogen is consumed during the operational period. The State of Charge (SoC) of the hydrogen tank is depicted in **Fehler! Verweisquelle konnte nicht gefunden werden.**, in combination with a fuel cell of 3 kW for the “normal” scenario and 11 kW for the “high” scenario.

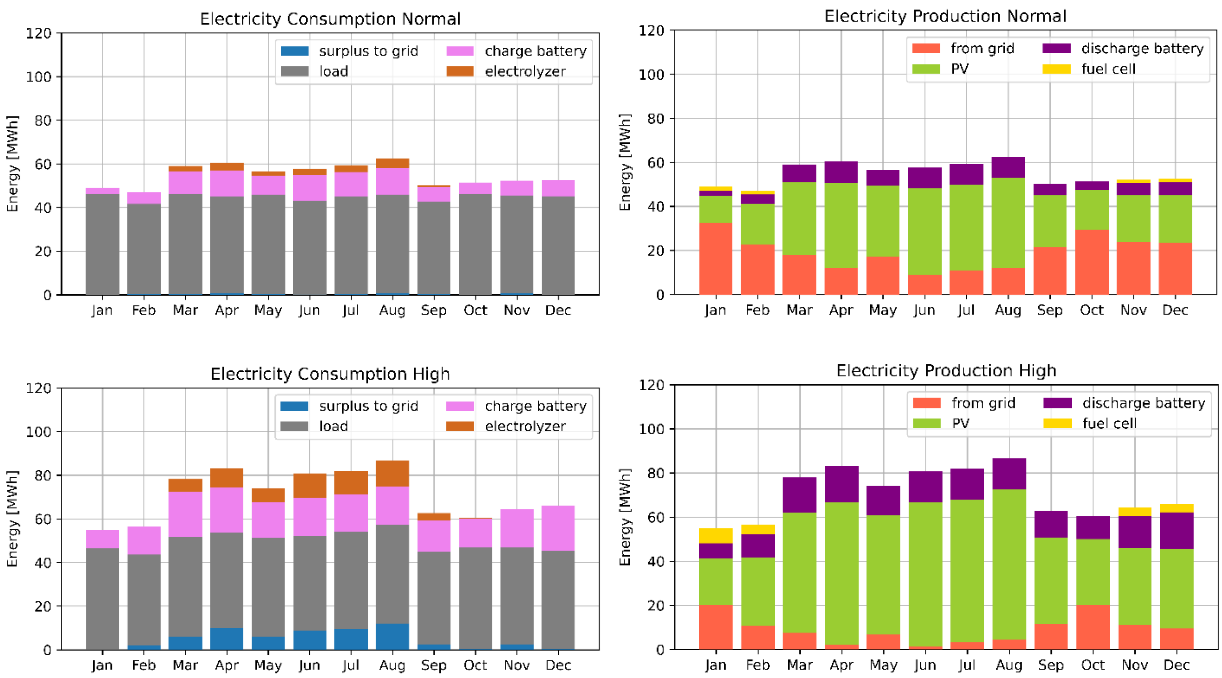
Figure 7 :state of charge of the hydrogene tank for the scenarios “normal” and “high”.



The electricity production and consumption is reported in the following figures for all three scenarios. We can observe that for the scenario “high” the grid independency is almost achieved in the summer, thanks to PV and battery self-consumption, and a share of electricity runs the electrolyser to produce 1,175 kg of hydrogen. Moreover, in the winter months the proportion of demand covered by grid electricity is reduced owing to PV, battery and the electricity produced by the fuel cell.

Figure 8: Electricity demand and electricity production for Gasen district for the three scenarios





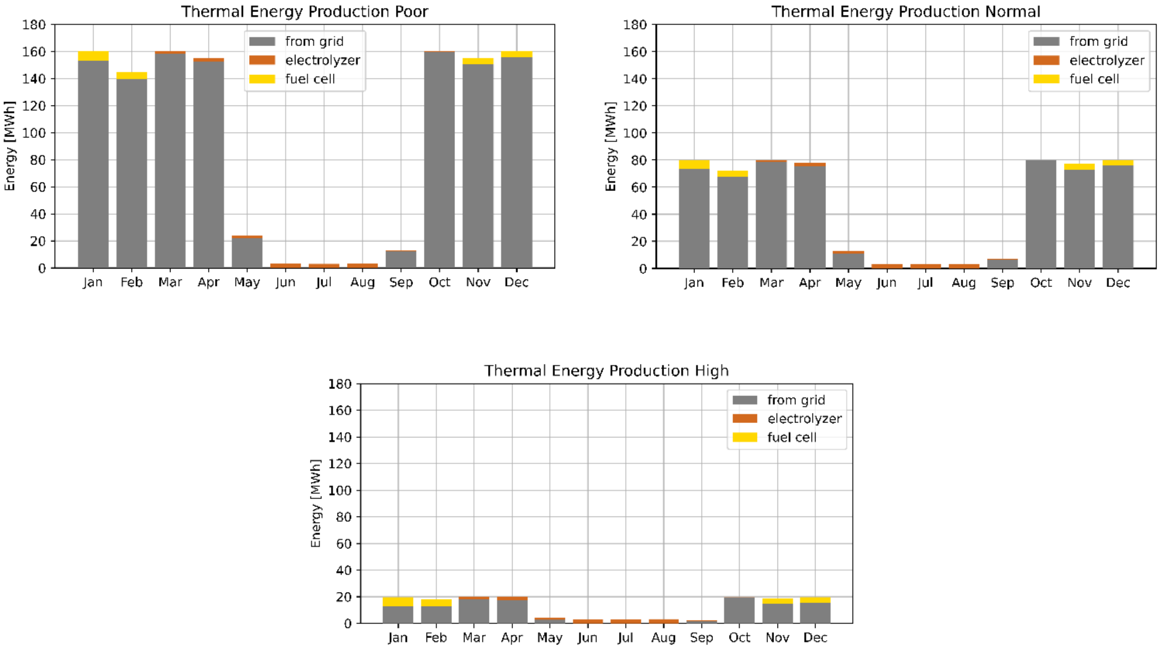
The following table summarizes the hydrogen production and the electricity supply needed from the grid for all three scenarios:

Table 9: hydrogen production and electricity supply from the grid for the three scenarios.

Scenario	Hydrogen production	Electricity supply from the grid
poor	-	422 MWh
normal	388 kg	233 MWh
high	1,175 kg	109 MWh

As far as thermal energy is concerned, we can see here also that the important decrease in the demand due to high efficiency of the buildings in scenario “high” almost leads to energy independency from the beginning of May to the end of September. Also in this scenario, the heat production of the fuel cell in the winter months covers approximately one third of the demand.

Figure 9: Gasen thermal energy demand coverage in “poor” (a), “normal” (b) and “high” (c) scenarios.



Combined with a heat pump (this has not been simulated here), it can be expected that in the scenario “high” energy independency would also be reached in the winter months.

6.4 Results for industrial applications

For these simulations, the electricity demand of the industrial site was not considered, only the demand for running the electrolyser. With an increase in PV size, there is a corresponding growth in hydrogen production and share of electricity taken from PV. With a 1.000 kW PV system, electrolyser produces 82 t of hydrogen in a year, with 28 % of electricity coming from PV. Scaling up to a 1.500 kW PV system, hydrogen production increases to 90 t with 39 % of electricity sourced from renewable energy. Finally, a 2.000 kW PV system, provides electricity to produce 99 t of hydrogen using 47 % of electricity coming from renewable sources.

Considering that the thermal energy demand is 12.000 MWh and hydrogen’s lower heating value (LHV) is 33,3 kWh/kg, the amount of hydrogen needed to completely decarbonise the industrial site would be about 360 t. This means that the electrolyser should produce 460 t of hydrogen, factoring in the burner efficiency and the hydrogen needed by the trucks. A 3 MW electrolyser could meet this demand by constantly operating at maximum load, however, in this case most of the electricity would be taken from the grid, unless a very high capacity of PV system is installed. For example, with a 50 MW PV system the share of renewable hydrogen would be about 40 %, with a very high quantity of electricity surplus.

Figure 10: MPREIS thermal energy demand coverage in “poor” (a), “normal” (b) and “high” (c) scenarios.

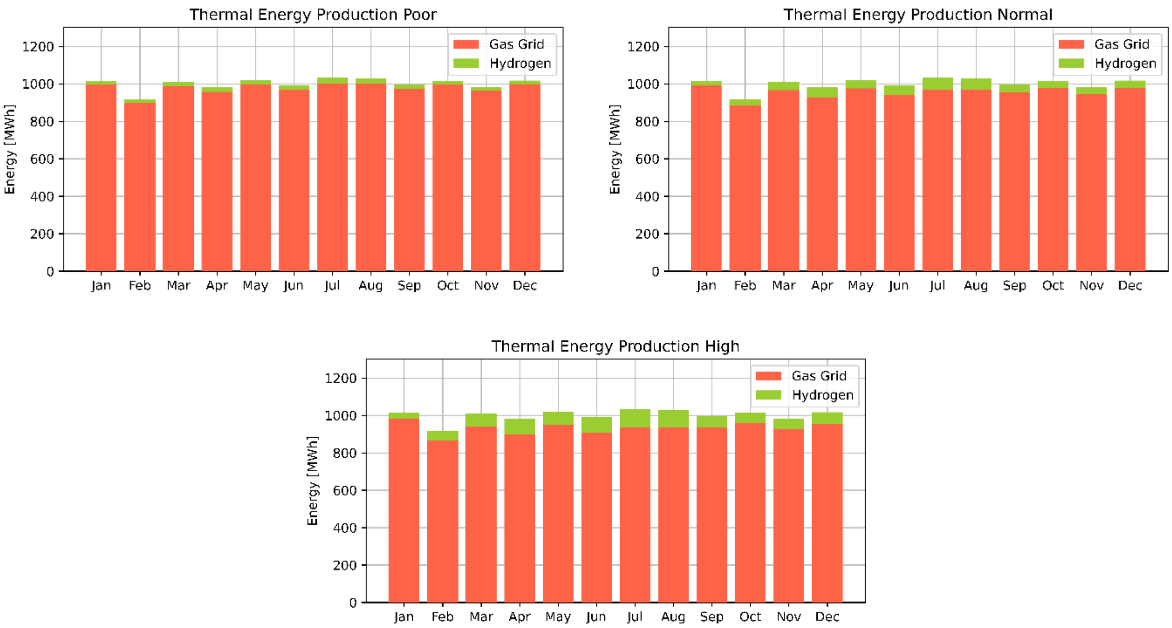
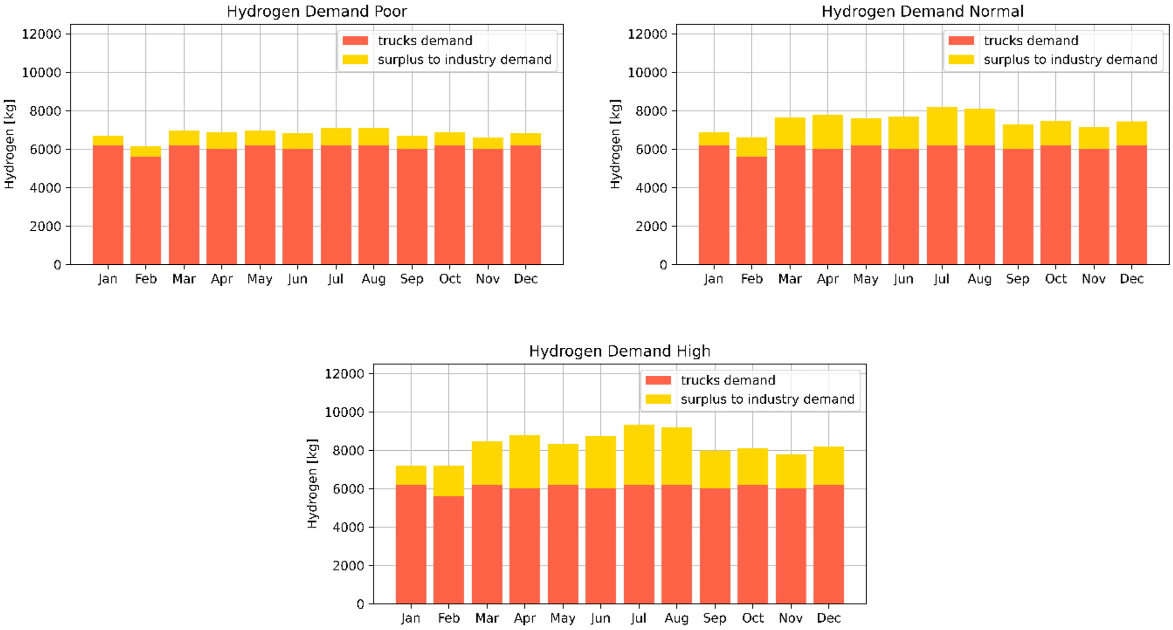


Figure 11: MPREIS Hydrogen demand coverage in "poor" (a), "normal" (b) and "high" (c) scenarios.



The simulation was made in a way that the refuelling of the fuel cell trucks has priority of the production of industrial heat. The results show that the demand for refuelling of the trucks is always met, however the percentage of thermal energy demand covered by hydrogen corresponds to the 2.2 % in the first scenario, to the 4.4 % with 1500 kW in the second scenario and to the 6.8 % with the 2000 kW PV in the third scenario.

7. Conclusion and recommendations

The findings of this study emphasise that hydrogen-based energy systems have significant potential to support Austria's climate neutrality objectives. High energy efficiency, expanded renewable energy capacity, and strategic sector coupling are essential for maximising the benefits of hydrogen integration.

One of the most promising areas for hydrogen deployment is rural energy communities, where hydrogen storage can help mitigate seasonal energy demand fluctuations and enhance energy self-sufficiency. The study demonstrates that hydrogen can effectively store surplus renewable electricity generated during summer months for use in winter, thereby reducing dependence on fossil fuels and improving energy security. This is particularly relevant for remote communities with limited grid access, where hydrogen-based solutions can enable an independent and resilient energy supply.

A key advantage of hydrogen in rural settings is its ability to support decentralised energy generation. By combining hydrogen production with local renewable resources such as wind and solar power, communities can achieve greater energy autonomy while minimising grid dependency. Additionally, integrating hydrogen fuel cells with heat pumps and combined heat and power (CHP) systems can enable the near-complete decarbonisation of residential heating demand.

Despite these benefits, several challenges remain. The high cost of hydrogen production and storage technologies presents a major barrier to large-scale adoption. Furthermore, effective policy incentives and funding mechanisms will be necessary to support the deployment of hydrogen infrastructure in rural communities. Ensuring the economic viability of hydrogen solutions in these areas requires coordinated efforts between government bodies, energy providers, and local stakeholders.

In urban settings, hydrogen technologies provide a solution for energy storage, backup power, and district heating applications. However, an important challenge is the cost-effectiveness of hydrogen in comparison to other energy storage technologies such as batteries. While hydrogen offers the advantage of long-term storage, its efficiency losses in conversion processes make it less attractive for short-term energy buffering. Therefore, hybrid solutions combining batteries for immediate load balancing with hydrogen for seasonal storage may be the most effective approach for urban applications. In this context, one promising application is the use of hydrogen-based fuel cells for backup power, particularly in high-density areas where energy consumption peaks create challenges for the existing grid infrastructure.

In an industrial context, hydrogen represents a viable alternative to fossil fuels in high-temperature processes and heavy transport. Scaling up industrial hydrogen use will require targeted policy interventions, infrastructure expansion, and increased research into cost reduction strategies. Hydrogen has strong potential to drive decarbonisation in industrial applications, particularly in energy-intensive sectors such as steel production, chemicals manufacturing, and heavy transport. The study highlights the role of hydrogen in replacing fossil fuels for high-temperature industrial processes, significantly reducing greenhouse gas emissions while using hydrogen-powered trucks and fuel cell electric vehicles to offer a viable alternative to diesel-powered fleets and contribute to cleaner transportation networks. Additionally, industrial sites with on-site hydrogen production capabilities can act as flexible energy consumers, adjusting their hydrogen production based on real-time electricity market conditions to optimise costs and improve grid stability.

However, large-scale industrial hydrogen adoption faces several hurdles, including the availability of cost-effective green hydrogen, the need for extensive infrastructure investments, and challenges related to hydrogen transportation and distribution. Expanding industrial hydrogen applications will require a combination of technological advancements, regulatory support, and financial incentives to make hydrogen a competitive alternative to conventional fuels.

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