hypster
Hydrogen Storage

Deliverable 1.1
H_2 production and consumption profiles

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Dissemination level: Public

2021

This project has received funding from the Fuel Cells and Hydrogen 2 Joint Undertaking under Grant Agreement No 101006751. This Joint Undertaking receives support from the European Union's Horizon 2020 Research and Innovation programme, Hydrogen Europe and Hydrogen Europe Research.

01

Introduction

Project context

HYPSTER is an FCH 2 JU funded project that aims to use **salt cavern storage to connect hydrogen production** by electrolysis to industrial and mobility uses.

This project is taking place at a Storengy underground gas storage site at **Étrez**, eastern France. It uses a salt cavern with a potential storage capacity of **44 tonnes of hydrogen**. On-site production of the green hydrogen will be carried out by a **1 MW electrolyser**, using the territory's renewable electricity sources.

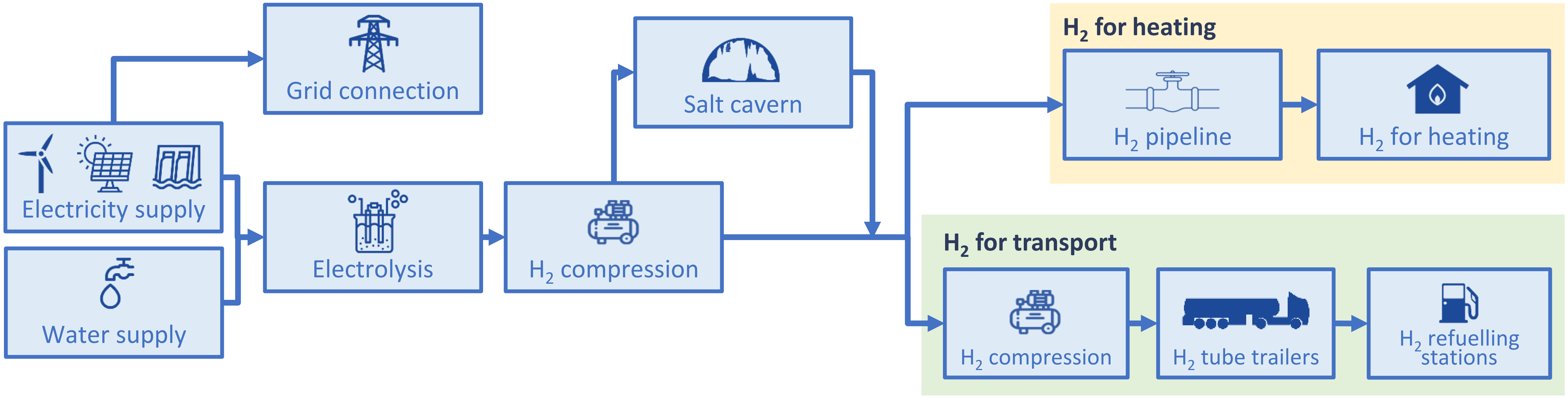
Currently in the study and design phase, the HYPSTER project will unfold in two phases:

- A first experimentation and demonstration phase between 2021 and 2023, with a parallel commercial development of hydrogen customer supply in 2023;
- A second phase for the commercialization of hydrogen storage services from 2024 onwards.

In partnership with **ESK GMBH**, **ARMINES**, **INERIS**, **AXELERA**, **Element Energy,** and **INOVYN**, this project is part of a dynamic region with increasing numbers of green hydrogen uses.

Example green hydrogen chain

The diagram below indicates the key processes involved in a chain of green hydrogen from production to consumption, which forms the basis of the modelling for this deliverable.



Task 1.1

Task 1.1 of HYPSTER looks to define scenarios for **hydrogen supply and consumption profiles** and the impact that this has on the design of the salt cavern operation.

The following sections provide an overview of different hydrogen production and consumption scenarios that can be used to test the cyclical operation of the salt cavern.

02

Hydrogen supply profiles

Green hydrogen production

This project focuses on hydrogen produced via **electrolysis** using **renewable electricity**, rather than electricity from the grid. Hydrogen produced from renewable electricity in this way is known as **green hydrogen**, because of the low emissions of the process compared to other hydrogen production technologies.

Given the **intermittent nature of renewables**, there may be periods where supply exceeds demand, resulting in **curtailment** of the renewable generation. By producing hydrogen during these periods of excess electricity supply, the electrolyser can provide a flexible demand source and reduce curtailment. As a flexible load, electrolysers can also provide **grid balancing services** to support the stability and security of the power grid.

However, use of renewable rather than grid electricity can result in a **variable hydrogen production profile**. The hydrogen produced may need to be stored to provide a buffer between fluctuations in seasonal and daily hydrogen production and demand. In HYPSTER, the use of **salt caverns** for **large-scale hydrogen storage** is being explored. It is important to demonstrate the salt cavern's ability to manage cyclical variation in the volume of H_2 stored.

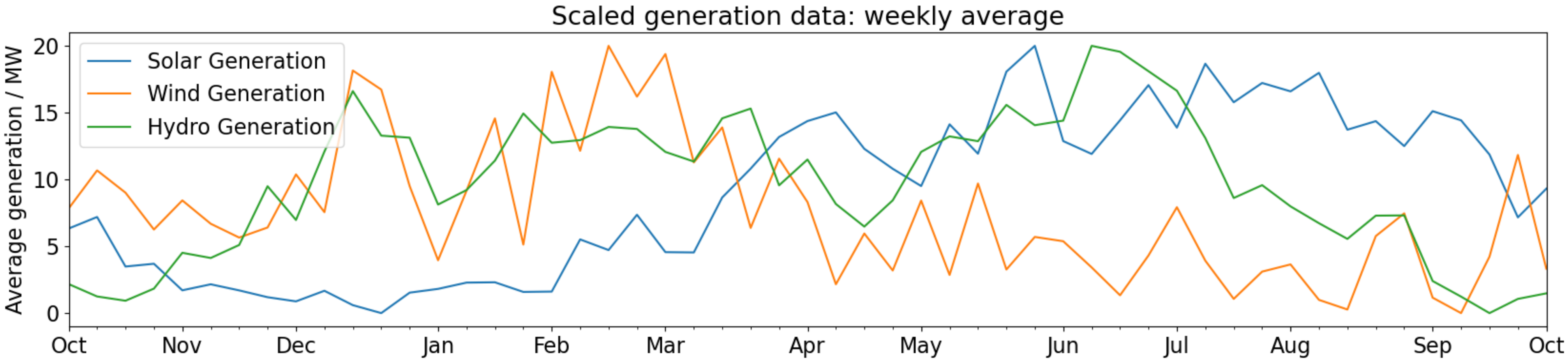
Connection between renewables and the electrolyser

Two approaches for the connection of the electrolyser directly to the renewable generation have been considered in this analysis:

- **Electrolyser priority**: This assumes that whenever there is sufficient renewable electricity generation to power the electrolyser, the electrolyser is operational. Different sizing of the electrolyser relative to the renewable generation capacity can increase the load factor of the electrolyser relative to the capacity factor of the renewables.
- **Grid priority**: This assumes that as well as supplying the electrolyser, the renewable electricity source supplies electricity to the grid. The electrolyser is only powered when renewable electricity in excess to a threshold grid export power is produced. The electrolyser therefore operates on a more intermittent basis.

Renewable generation profiles

The supply of hydrogen into the salt cavern is modelled based on **renewable energy generation profiles** for onshore wind and solar PV in France from 2019-20, and for hydroelectric generation in the Auvergne-Rhône-Alpes region from 2018-19. The profiles were scaled based on the project sizing, and are shown scaled to a 20 MW capacity in the graph below. It is evident that each of the profiles have some seasonal variation, which will affect the hydrogen stored in the salt cavern on a seasonal timescale.



The following slides include an overview of the different electrolyser sizing in relation to the capacity of renewable generation and the expected resulting profiles for hydrogen production.

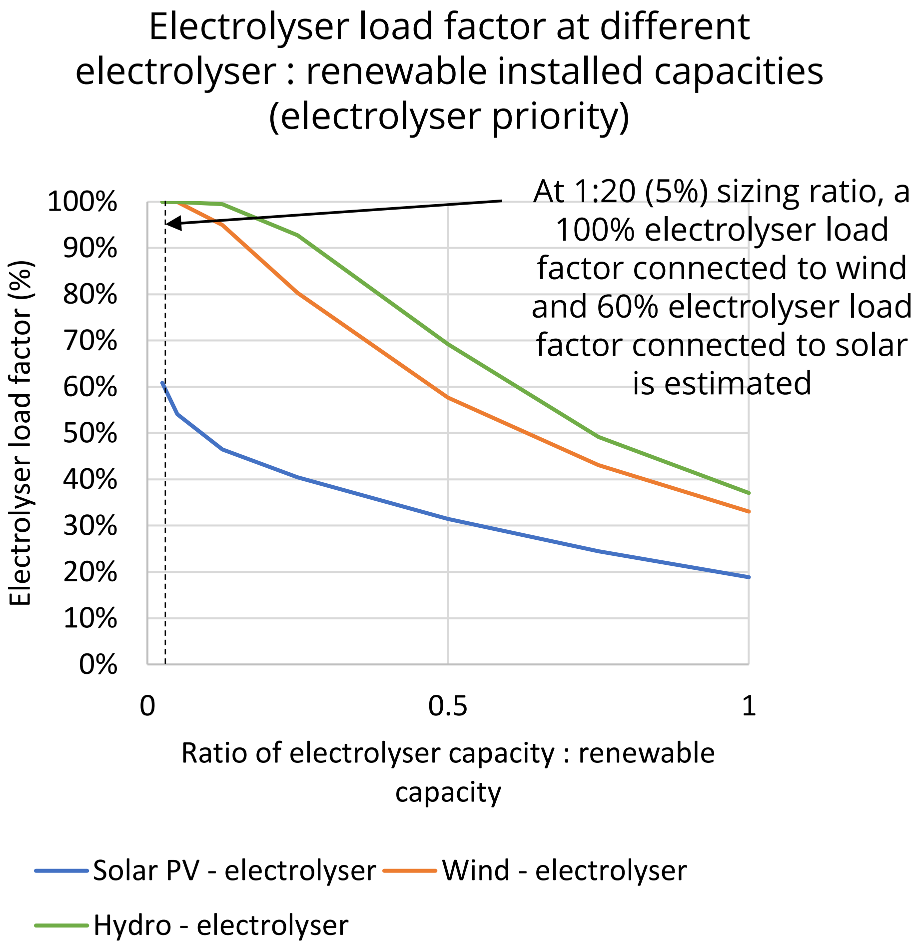
Wind and solar generation data from: https://transparency.entsoe.eu/dashboard/show
Hydroelectric generation data from: https://www.rte-france.com/eco2mix/telecharger-les-indicateurs

Electrolyser sizing

By selecting a different electrolyser capacity relative to the installed renewable capacity, higher load factors on the electrolyser can be achieved.

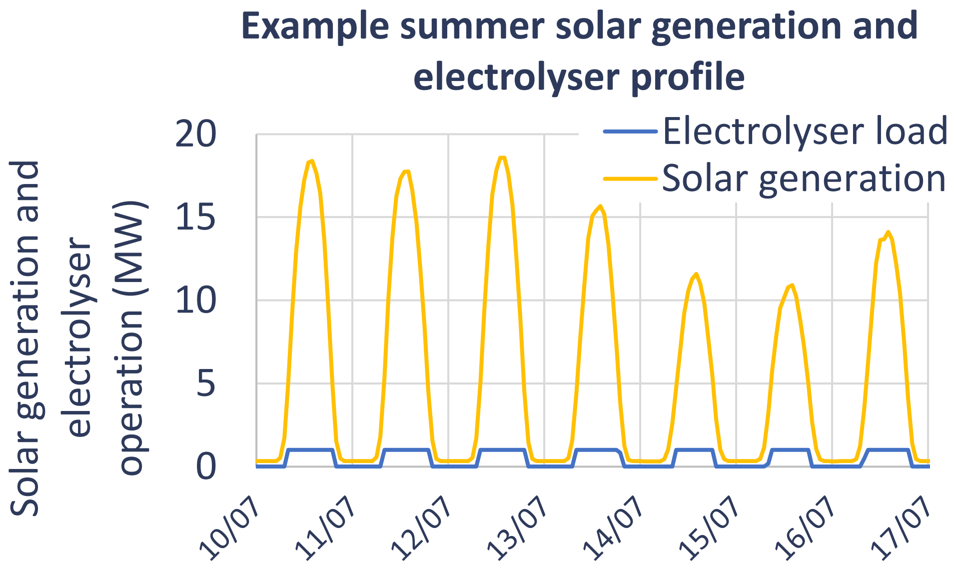
Higher load factors on the electrolyser increase the quantity of hydrogen produced and help reduce hydrogen production costs.

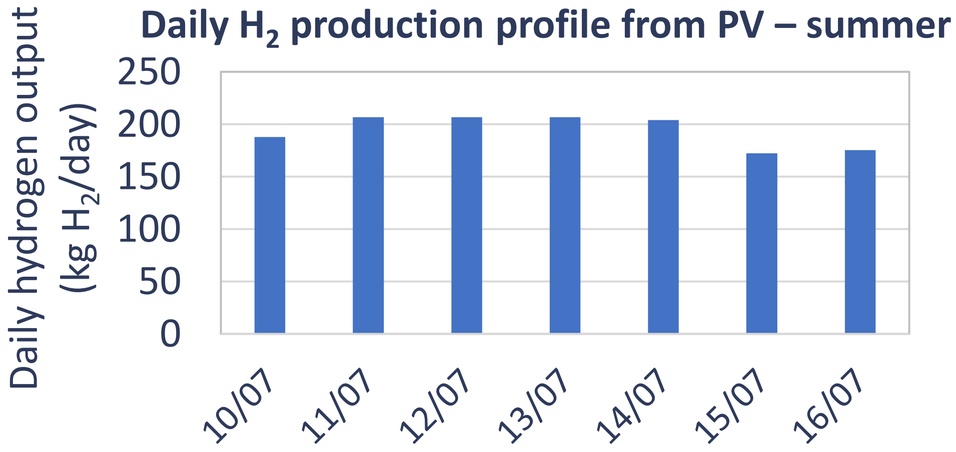
The electrolyser load factor for different electrolyser : renewable capacity ratios are shown to the right. At 1:20 ratio (electrolyser capacity is 5% of the renewable capacity) the electrolyser load factor is >60% when connected to solar PV and almost 100% when connected to onshore wind.



Direct connection to solar – summer

- The hydrogen production data has been based on modelled solar generation data and a relative sizing of the electrolyser to the installed solar capacity of 1:20 (i.e. for each 1 MW electrolyser installed, 20 MW solar capacity is installed). Ratios of 1:4, 1:2 and 1:1 were also considered.
- In the following example scenarios (slides 11 to 17), it is assumed that a baseline supply to the grid of 3 MW is prioritised before renewable energy is supplied for hydrogen production.
- Over the summer the solar generation (and hydrogen production) is relatively predictable, based on the daily solar generation profile shown over a typical summer week in July.

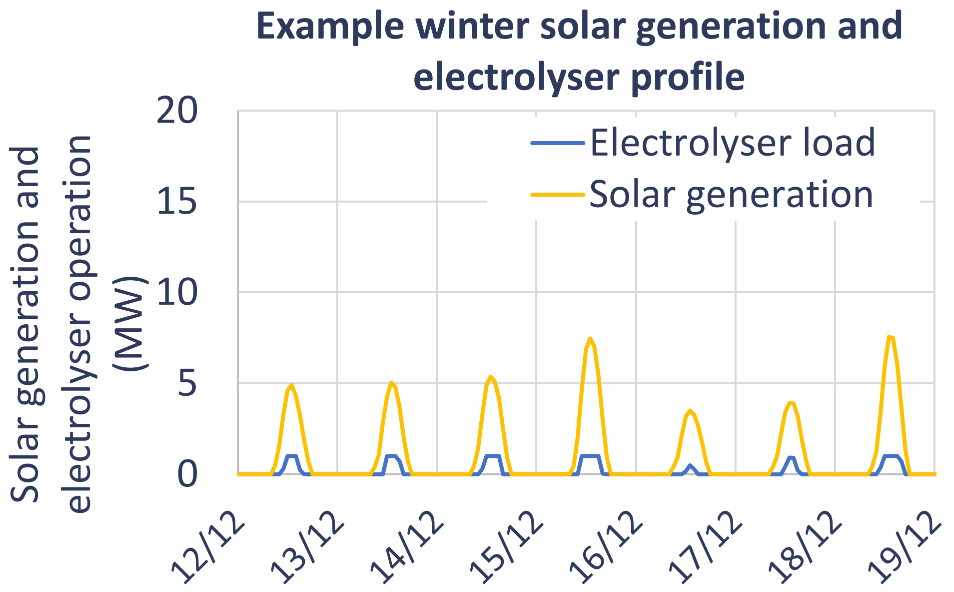


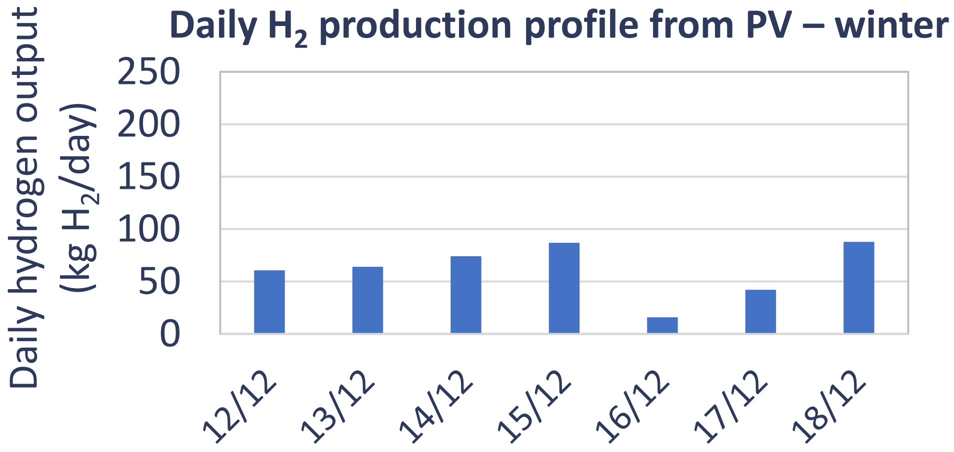


Direct connection to solar – winter

- Direct connection of an electrolyser to solar PV has a seasonal impact on production, with 25 – 50% less H_2 produced in winter months compared to summer months.
- Although narrower during the peak, the electrolyser operation profile is otherwise similar to the daily profile of solar generation.
- The narrower electrolyser peak profile is a result of the electrolyser's grid connection as well as the assumed minimum load of 100 kW for operation. The minimum turn-down ratio (i.e. the lowest load at which the electrolyser can operate relative to the full electrolyser capacity), varies depending on the technology supplier. Based on an average of 4% for PEM electrolysers and 15% for alkaline electrolysers[1], a middle value of 10% was chosen for the minimum turn-down ratio.

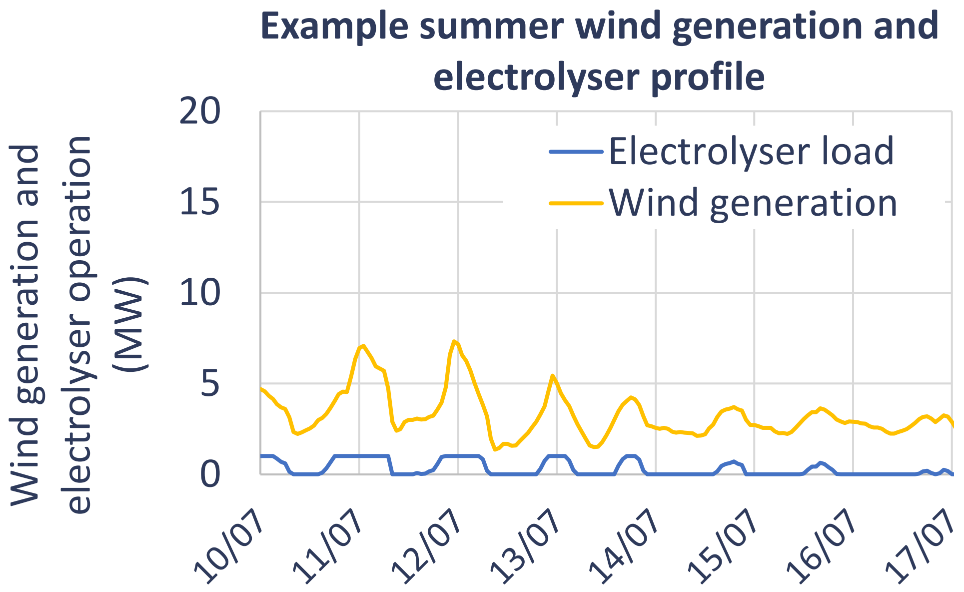
[1] Element Energy & E4Tech (2014) *Study on development of water electrolysis in the EU:* https://www.fch.europa.eu/sites/default/files/5%20APPENDIX%202B%20FCHJUElectrolysisStudy%20(ID%201329459).pdf

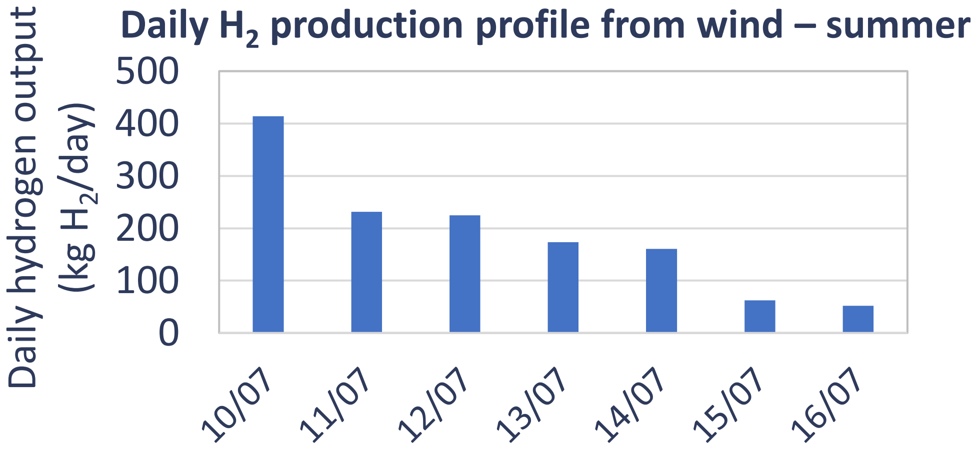




Direct connection to wind - summer

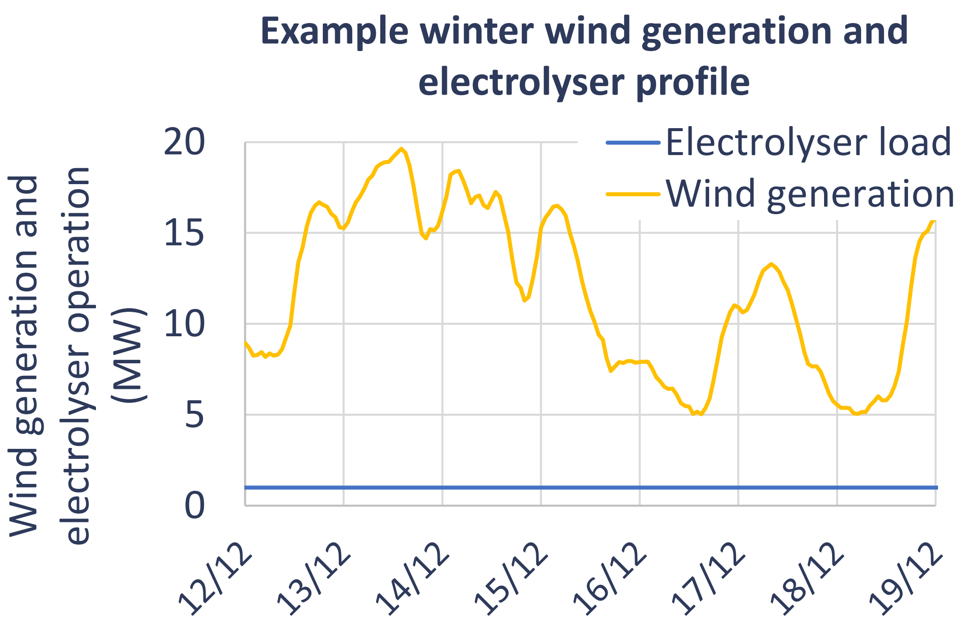
- Hydrogen production from an electrolyser connected to a wind farm was simulated based on modelled wind generation data.
- The profiles shown to the right are based on the same 1:20 electrolyser to wind capacity ratio.
- As wind generation is less consistent there are longer periods where the wind generation limits hydrogen production compared to connection to solar PV. These periods tend to be more frequent during summer months (i.e. the opposite profile to solar).

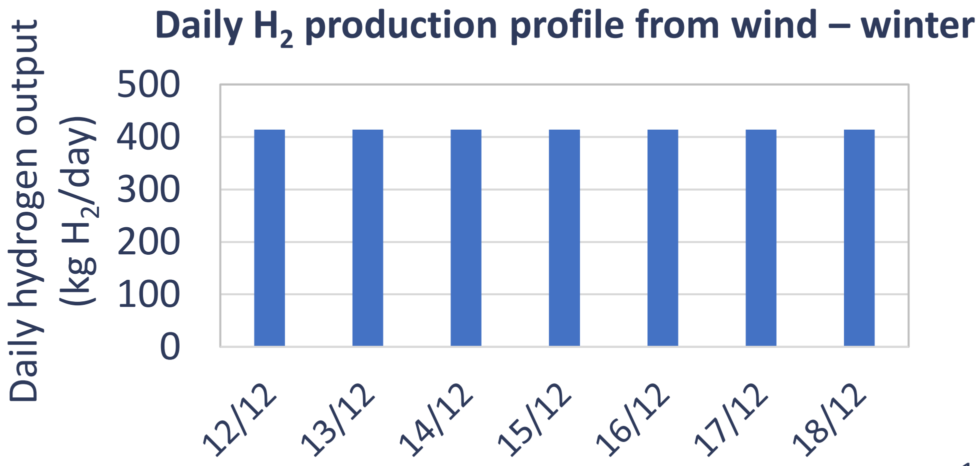




Direct connection to wind – winter

- Conversely, during the winter months there are periods when the electrolyser can operate at 100% load, provided that the electrolyser sizing is small enough relative to the wind farm capacity (a 1:20 electrolyser to wind capacity ratio is shown here).
- These conditions would influence the sizing of storage (or the electrolyser).
- This profile is of lesser concern when testing cyclical loading of salt cavern storage compared to the previous examples, given the steady hydrogen output.





Connection to hydroelectric generation

Hydroelectric run of river generation shows a seasonal variation in H_2 generation. In contrast with solar and wind profiles, which show the greatest difference between winter and summer generation, hydroelectric generation is highest in summer/winter and decreases significantly in autumn, as shown on slide 9. This difference is due to the rain-fall and snow melt that drive the riverflow.

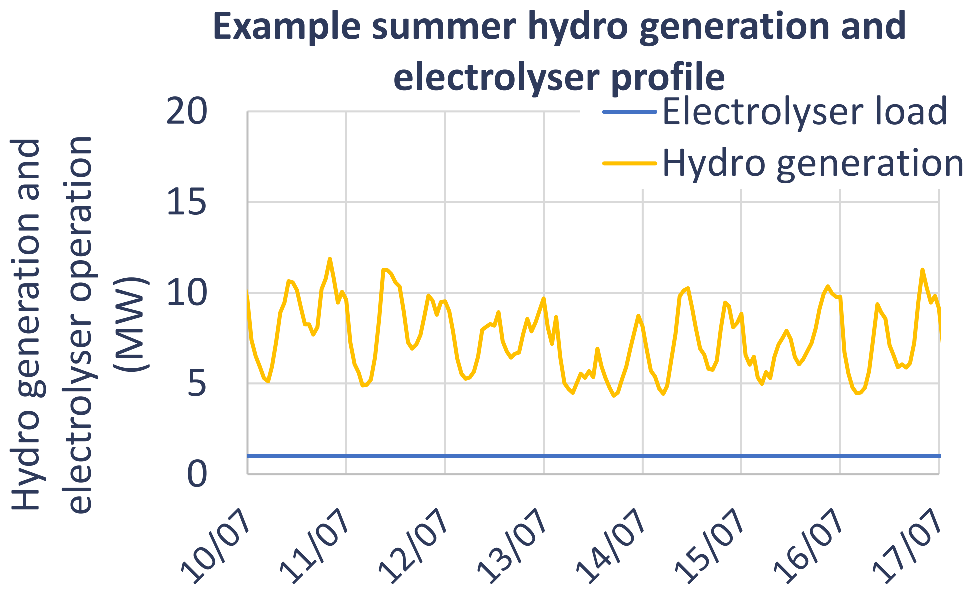
Salt cavern storage is unlikely to be produced using pumped hydroelectric storage, as pumped storage already provides energy storage and could provide dispatchable H_2 production. Whilst efforts were made to obtain data containing only run-of-river generation, the hourly profile of the data shown in the following slides suggests that there is a component of dispatchable hydro-electric generation: there are peaks in generation that in the morning and early evening that coincide with electricity demand peaks.

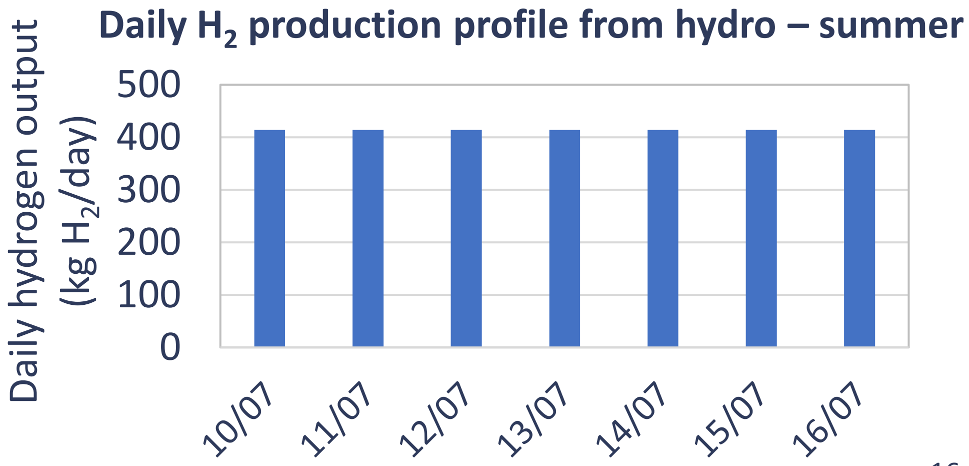
These daily peaks average out when looking at the daily average production of H_2 to assess the seasonal profiles of salt cavern use, and so this data is only used to consider the seasonal variation in H_2 production from hydroelectric generation.

The following two slides therefore contrast the peak production in summer and autumn hydrogen production using hydroelectric generation.

Direct connection to hydroelectric - summer

- Hydrogen production from an electrolyser connected to a hydroelectric generator was simulated based on local generation data from the Auvergne-Rhône-Alpes.
- The profiles shown to the right are based on the same 1:20 electrolyser to hydroelectric capacity ratio.
- In these peak months, the electrolyser can run at full capacity, producing the maximum amount of hydrogen per day for the electrolyser's 1 MW capacity.
- Given the high hydroelectric generation also seen through much of winter (as shown in the graph on slide 9), similar peak electrolyser and hydrogen production profiles would be seen.

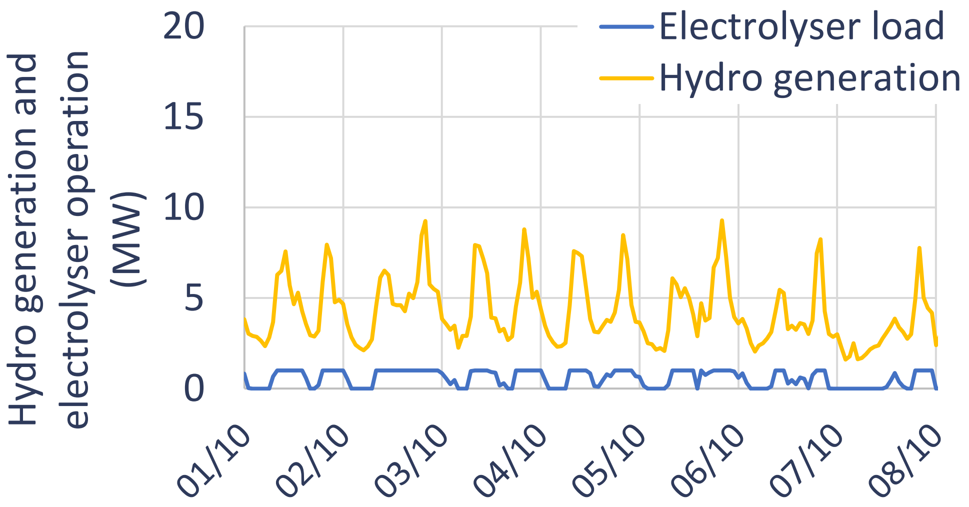




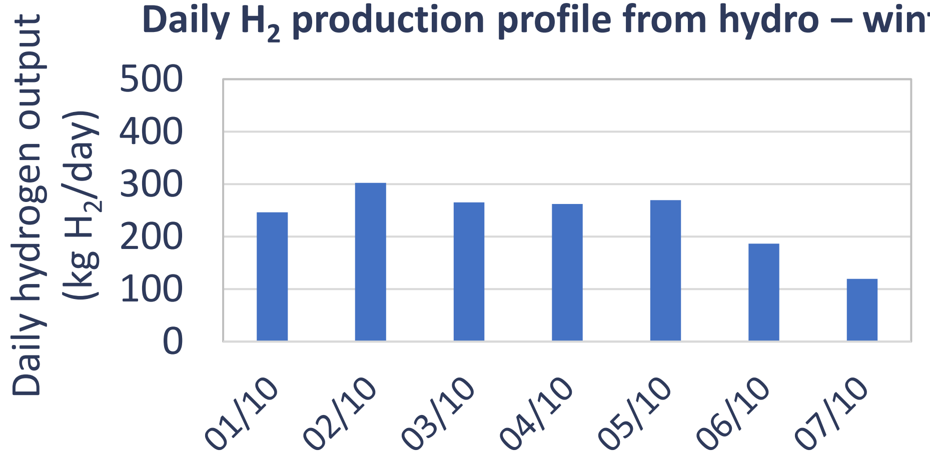
Direct connection to hydroelectric – autumn

- For solar and wind generation, the greatest contrast is seen between winter and summer generation. However, for hydroelectric generation electricity production is comparatively high in both summer and winter, with the most significant decrease in production in autumn, as shown in the graph on slide 9.
- Snow melt contributes to the high summer generation, whilst higher rainfall levels in the winter means that generation is also high during this period[1].
- The lower water levels in autumn results in more periods where the hydroelectric generation limits hydrogen production.

Example autumn hydro generation and electrolyser profile



Daily H_2 production profile from hydro – winter



[1] Pelto M.S. (2011) Hydropower: Hydroelectric Power Generation from Alpine Glacier Melt.

Supply sensitivities

- When a mixed solar and wind electricity supply is used, the hydrogen production profile is less variable on both a seasonal and daily timescale. In general, solar generation is higher in the summer and lower in the winter and vice versa for wind generation.
- Hydroelectric generation is higher in both summer and winter, but lower in the autumn. Combining hydroelectric generation with wind or solar therefore results in a more variable hydrogen production profile.
- It has been assumed that the electrolyser is able to operate at various load factors, and ramp up and down to match the renewable electricity supply. In reality, the electrolyser and compressor efficiency will vary as the load factor changes, although this would only have a small effect on the profiles presented.
- Other ratios of electrolyser capacity to renewable capacity were also explored. As the relative sizing of the electrolyser to the installed renewable capacity increases, the hydrogen production becomes more intermittent as the renewable electricity generated does not meet the full electrolyser capacity as frequently. This results in lower overall production of hydrogen. The electrolyser load for a ratio of 1:2 between the electrolyser capacity and renewable capacity is illustrated in the appendix.

03

Hydrogen demand

Hydrogen use cases

Hydrogen has a variety of end uses, including in **fuel cell vehicles**, for **heating**, or in **industry**.

Hydrogen is expected to play an important role in decarbonising some transport applications. An increasing range of hydrogen fuelled vehicles are becoming commercially available, with most major vehicle manufacturers developing hydrogen fuel cell vehicle options. Hydrogen demand from fuel cell cars and buses is considered in this analysis.

Current heating requirements are predominantly met by the natural gas grid. Alongside heat pumps, hydrogen could be used to decarbonise heating demand by blending it into the current natural gas network or by converting to a 100% hydrogen gas grid. Gas grid operators are currently exploring adaptations to the gas grid to enable compatibility with hydrogen, and boiler manufacturers are developing hydrogen-ready boilers.

Hydrogen is widely used in industry as a feedstock (including in ammonia production and in oil refineries), and is being introduced as a low carbon feedstock in other currently carbon-intensive industrial processes such as steel manufacturing. The industrial demands near Étrez are unlikely to be significant in the near-term, so have not been modelled in this analysis.

03

Hydrogen demand profiles

Transport demand profiles

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Hydrogen Storage

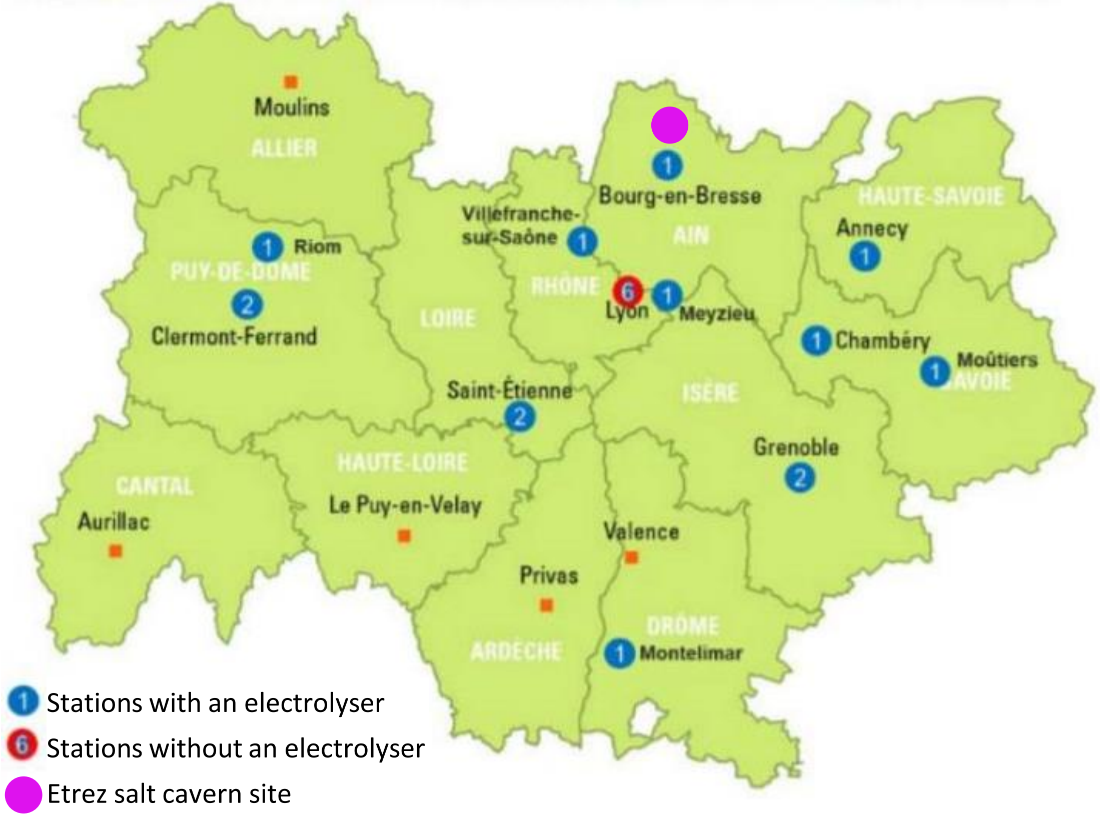
Transport demand in the Etrez region

The **Zero Emission Valley** (ZEV) project is a pioneering project in the Auvergne-Rhône-Alpes territory which plans to deploy 20 hydrogen refuelling stations (HRS) and 1,200 light duty vehicles, enabling the acceleration of the large-scale deployment of hydrogen as a clean energy carrier.

HYmpulsion is the commercial structure created by the partners of the Zero Emission Valley project: Engie, Michelin and the Auvergne-Rhône-Alpes region. It is responsible for the installation and operation of the stations, as well as the marketing of hydrogen energy.

This large-scale mobility project could provide demand for hydrogen in the Étrez region, which could be supplied from the salt cavern.

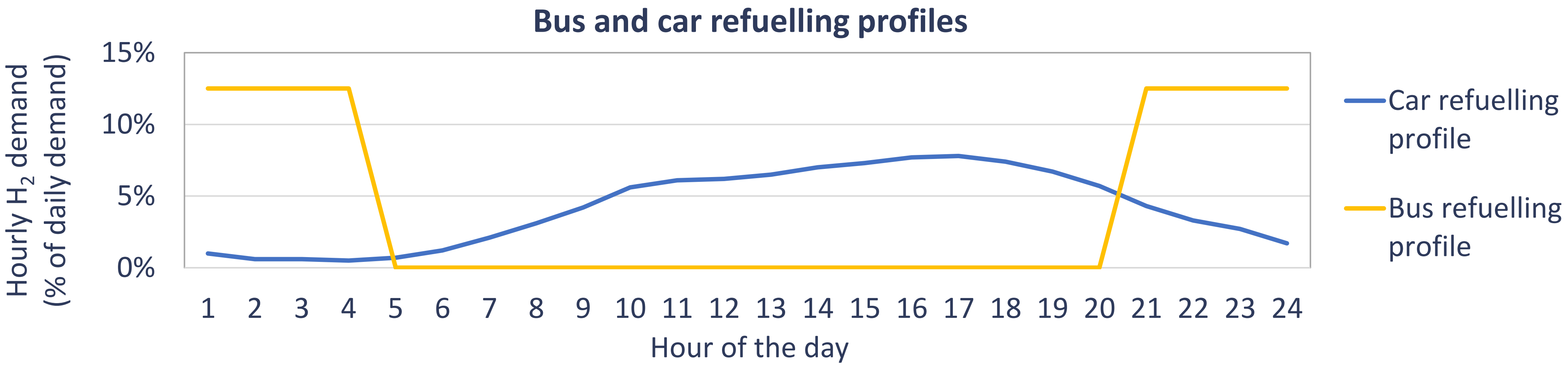
Indicative locations of the 20 ZEV HRS in the Auvergne-Rhône-Alpes territory



Map reference: H2-mobile

Bus and car refuelling profiles

- Hydrogen demand profiles were developed based on data collected from existing projects.
- Car refuelling profiles simulated below are based on data from Chevron for gasoline stations[1], and bus profiles based on information from the New Bus Refuelling for European Hydrogen Bus Depots project[2]. Bus refuelling occurs over the night, while car refuelling through the day is similar to conventional petrol / diesel refuelling stations.
- This data was used to inform tube trailer refilling profile from the salt cavern.



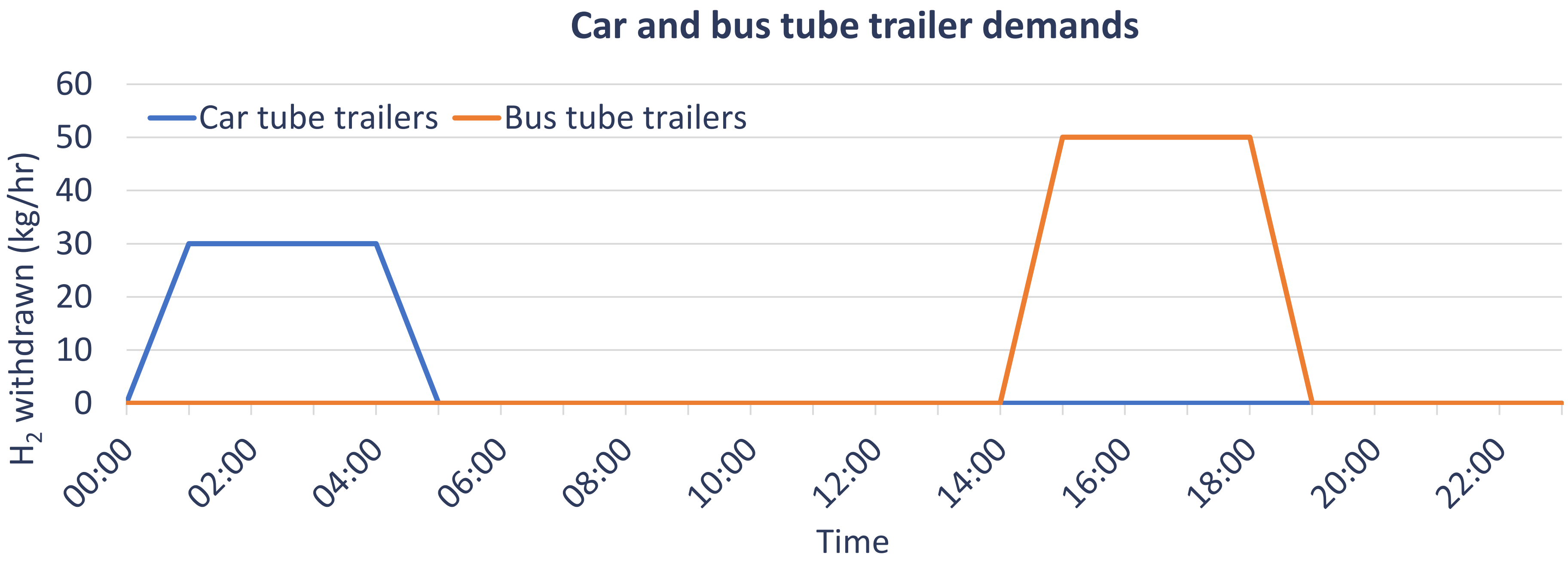
[1] https://www.energy.gov/sites/prod/files/2014/03/f11/delivery_infrastructure_analysis.pdf
[2] http://newbusfuel.eu/

Bus and car tube trailer refilling profiles

- It was assumed that hydrogen for transport will be delivered by tube trailers, which would be driven from the salt cavern to the HRS. The tube trailers would be connected to the HRS to supply the vehicles, then would be driven back to the salt cavern facility to be refilled as needed.
- The bus and car refuelling profiles were used to simulate indicative tube trailer refilling profiles from the salt cavern.
- It was assumed that the tube trailers refill at a constant rate over a period of 4 hours.
- The number of tube trailers needed to serve HRS in the region is based on data from the Zero Emission Valley (ZEV) and Hympulsion projects. This is then scaled down to serve a percentage of this total demand to match the hydrogen produced by the 1 MW electrolyser.
- It was also assumed that buses do not run on a Sunday.

Bus and car tube trailer refilling profiles – example case

In this case, a graph for 5% of the total ZEV HRS demand is shown, to match the 1 MW electrolyser capacity. This corresponds to 1 HRS serving approximately 60 cars and 10 buses. The graph shows the demand from tube trailers at the salt cavern site, allowing time for the tube trailers to be transported to the HRS in time for vehicle refuelling.



03

Hydrogen demand profiles

Hydrogen gas grid demand profiles

Hydrogen gas grid demand

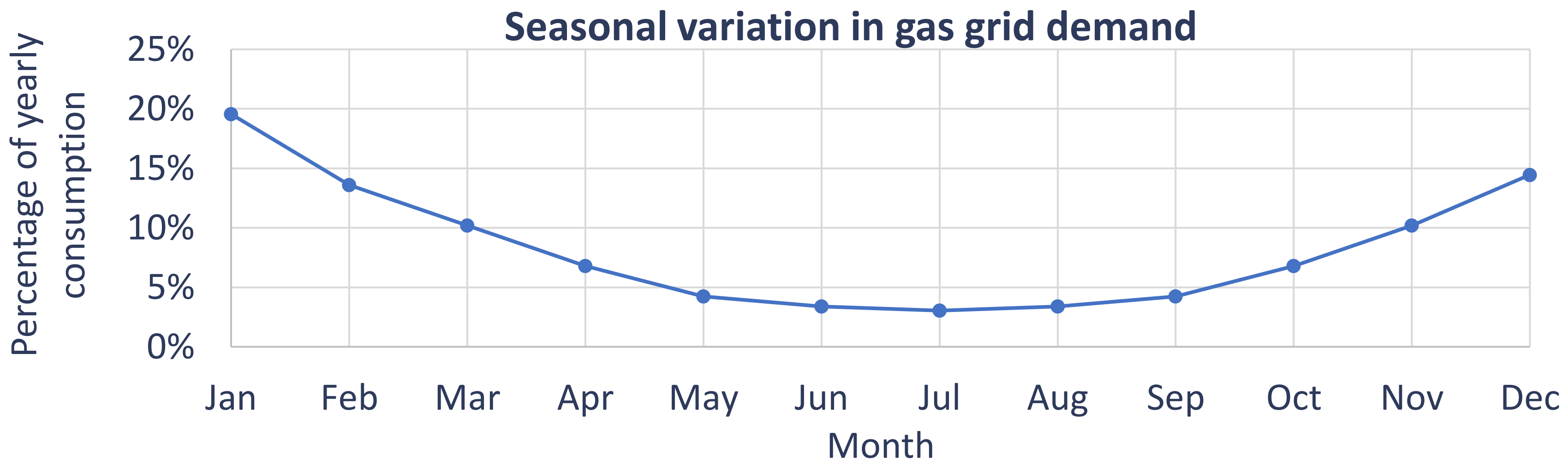
Whilst near-term hydrogen demands in the Étrez region are likely to be primarily associated with road transport applications, in the future hydrogen could be used for the decarbonisation of heating.

To facilitate the transition, hydrogen may be blended into the existing gas supply. Blends of up to 20% hydrogen are currently being tested. Whilst current green hydrogen production projects do not produce sufficient hydrogen to make the gas grid up to 20%, the gas grid could be a flexible demand source by varying the amount of hydrogen injected. In the longer term, the potential for the conversion of the gas network to 100% H_2 is being explored.

The gas grid demand profiles modelled in this section assume a 100% hydrogen gas grid has been deployed in the Étrez region. The gas grid demand was scaled by adjusting the yearly gas grid consumption.

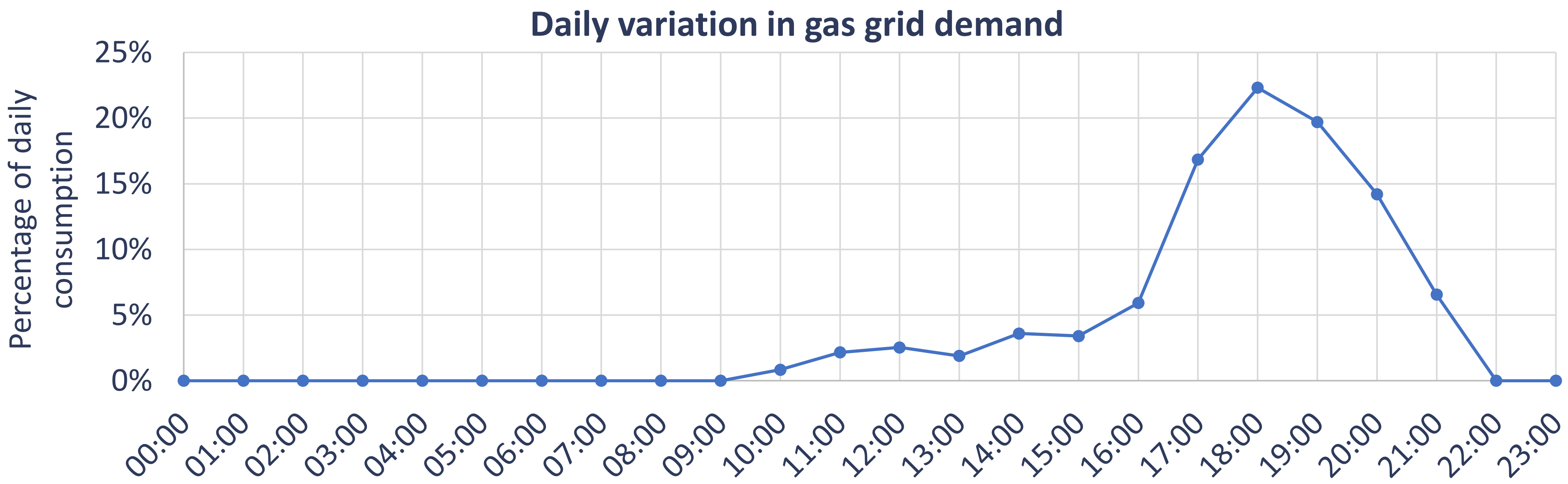
H_2 gas grid – seasonal variation

- The seasonal variation in hydrogen gas grid demand was approximated from natural gas grid demand profiles in areas with a similar seasonal temperature range.
- Gas consumption is higher in the winter months, as heating demand increases. This profile will vary depending on the ambient temperature (with lower heating demands in the winter but larger cooling demands in the summer for warmer regions). The profile will therefore vary across different regions in Europe.



H_2 gas grid – daily variation

- The daily variation in gas grid demand was approximated from natural gas grid profiles.
- Demand is higher in the evenings, aligning with activity and heating in the home.
- The daily variation was combined with the seasonal variation to give a year round hourly profile.



04

Salt Cavern Cycles

Salt cavern cycle profiles

In this section, several of examples of salt cavern hydrogen storage profiles are given. These profiles are based on the supply and demand profiles discussed in the previous sections. The example scenarios shown are:

- 1 MW electrolyser connected to a 20 MW wind farm, supplying HRS by tube trailer;
- 1 MW electrolyser connected to a 20 MW wind farm, suppling a H_2 gas grid;
- 1 MW electrolyser connected to a 20 MW solar farm, suppling a H_2 gas grid;
- 1 MW electrolyser connected to a 20 MW hydroelectric generator, suppling a H_2 gas grid.

Further scenarios were also modelled for the salt cavern testing, taking care to balance the supply and demand appropriately.

Salt cavern operating assumptions

The key parameters for the salt cavern are shown below.

Whilst the total cavern capacity is 80 tonnes of H_2, a certain amount of cushion gas is needed to ensure stability. The working gas capacity is therefore 44 tonnes of H_2.

Parameter	Unit	Value
Total cavern volume	m^3	8000
Total cavern capacity	tonnes H_2	80
Working gas capacity	tonnes H_2	44
Minimum working pressure	bar	60
Maximum working pressure	bar	160

Salt cavern cycle initial conditions

- To provide a baseline volume in the salt cavern, it was assumed that the cavern would be filled to 75% of the working gas capacity (i.e. 33 tonnes) in addition to the cushion gas, before beginning cyclical operation.
- This baseline volume is needed to allow for periods in which the H_2 stored is decreasing, i.e. when demand exceeds supply. As the salt cavern filling rate is limited by the electrolyser's 1 MW capacity, a larger baseline volume would result in a greater number of days required to fill the salt cavern before testing can begin (the maximum daily production from the 1 MW electrolyser is c.400 kg H_2/day).

Salt cavern storage supply assumptions

- The key supply assumptions for the salt cavern modelling are shown in the table to the right.
- A grid-priority scenario was assumed, in which a baseline supply to the grid of 3 MW is prioritised before renewable energy is supplied for hydrogen production.
- It was also assumed that the electrolyser will supply hydrogen to demand directly, supplemented by stored hydrogen from the salt cavern where necessary (if the demand exceeds the production rate at any given time).

Key supply assumptions for salt cavern example scenarios

Parameter	Units	Value
Renewable capacity	MW	20
Baseline grid requirement	MW	3
Electrolyser capacity	MW	1
Minimum electrolyser load	MW	0.1
Overall electrolyser system efficiency	kWh/kg	58

Salt cavern storage transport demand assumptions

- It was assumed that the salt cavern would serve 5% of the total ZEV HRS demand, to match the 1 MW electrolyser capacity in this demonstration project. This corresponds to 1 HRS serving approximately 60 cars and 10 buses (average c.300 kg H_2/day). It was also assumed that there were no buses running on Sundays.
- No significant seasonal variation in the transport demand was assumed.

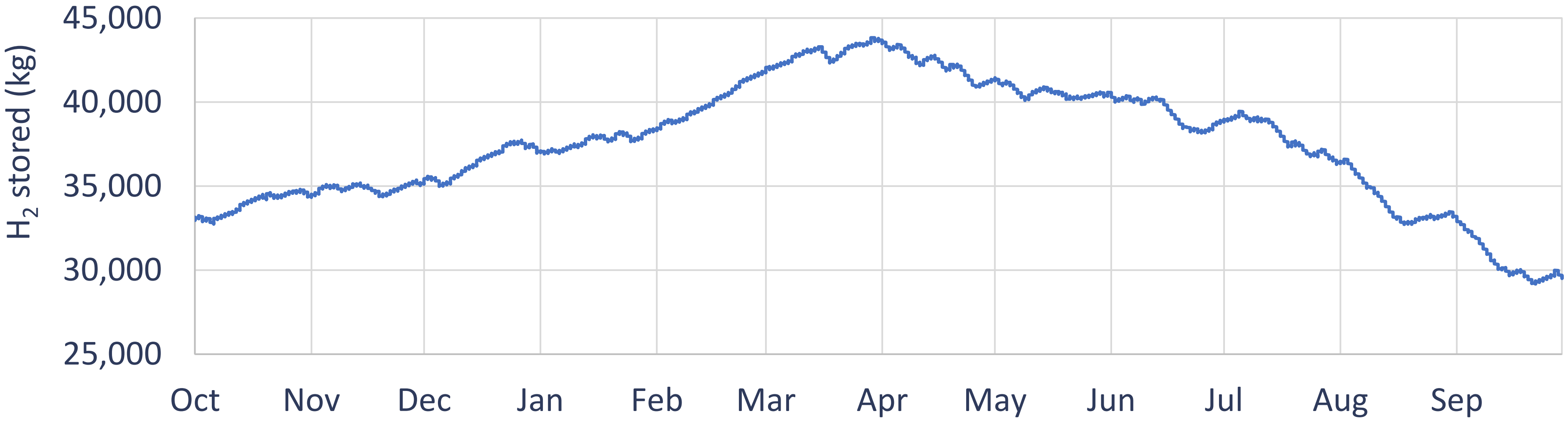
Key transport demand assumptions for salt cavern example scenarios

Parameter	Units	Value
Cars served	#	60
H_2 stored per car per day	kg	2
Buses served	#	10
H_2 stored per bus per day	kg	20

Salt cavern storage with wind generation for transport demand

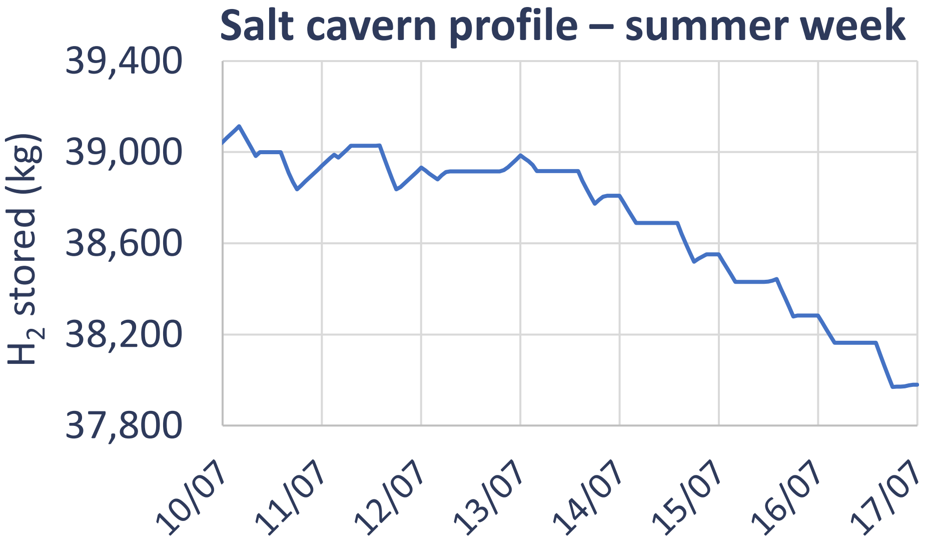
There is a large seasonal variation in the amount of hydrogen stored in the salt cavern, with the hydrogen stored in the cavern varying by around 15 tonnes (from c.29 – 44 tonnes, on top of the cushion gas) over the course of the year. The hydrogen demand from transport stays relatively constant throughout the year, and the fluctuation in total hydrogen storage quantity is driven by the seasonal variation in wind power.

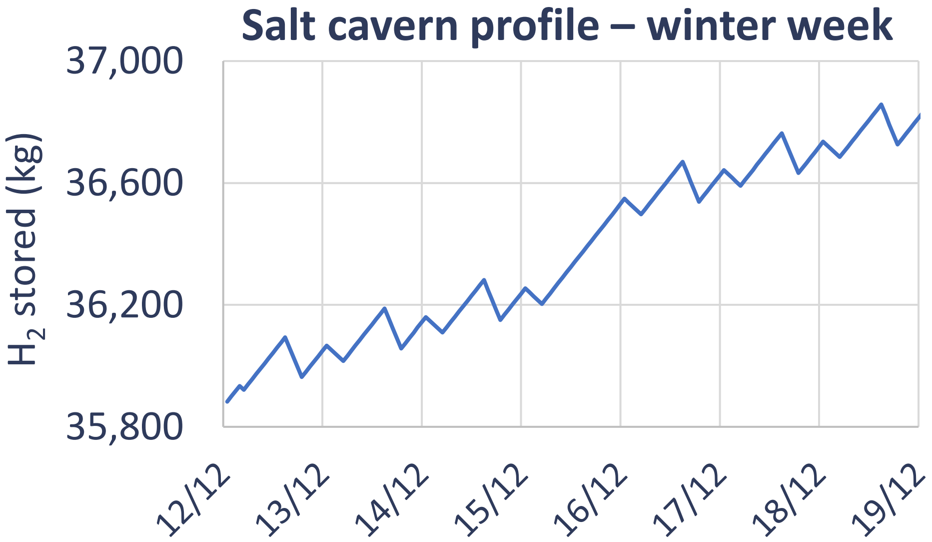
Yearly profile of H_2 stored in the salt cavern – wind generation, transport demand



Salt cavern storage with wind generation for transport demand – example weekly profiles

- Two example profiles are shown below, for a typical summer and winter week.
- In the summer, the H_2 stored can drop by over 200 kg H_2 of the total capacity over the course of the day.
- In the winter, the H_2 stored is increasing overall (with higher wind generation). On a daily scale, the H_2 stored increases to a peak around midday, and then decreases again into the night, with a fluctuation of c. 100 kg H_2 during this cycle. This is a result of the tube trailer fillings in the early morning and afternoon (see slide 25).





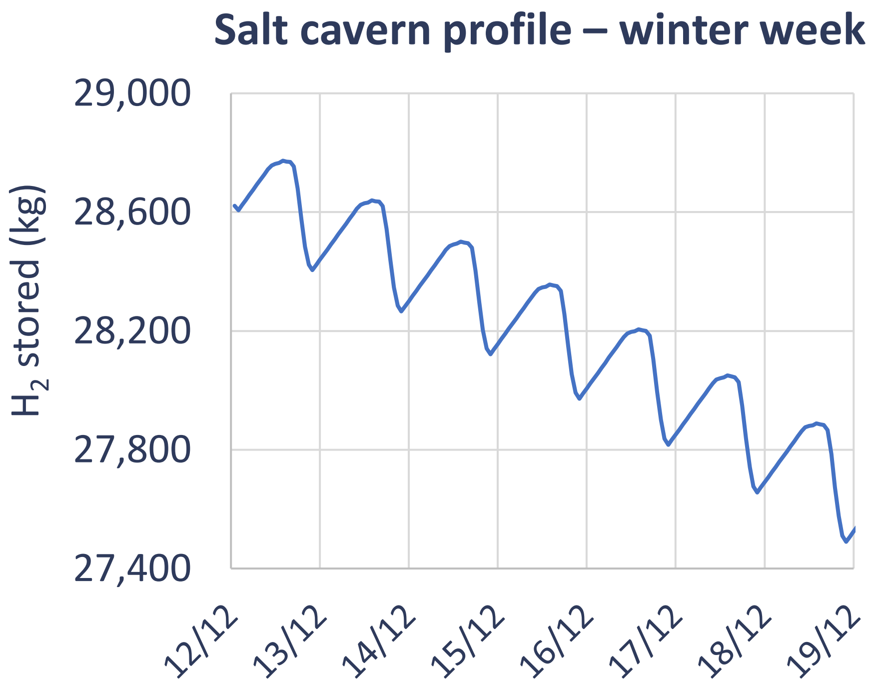
Salt cavern storage with wind generation for gas grid demand

- In the gas grid demand case, the seasonal pattern is reversed compared to the transport case. The H_2 stored in the salt cavern is highest in the summer, and lower in the winter. This is because the profile is dominated by the seasonal variation in gas grid demand (see slide 28).
- The gas grid demand was scaled to approximately match the H_2 produced over the course of the year by adjusting the total yearly gas grid consumption. To match the supply provided by the 1 MW electrolyser, a total annual H_2 consumption of 100 tonnes of H_2 was assumed.

Yearly profile of H_2 stored in the salt cavern – wind generation, 100 t/pa gas grid demand

Salt cavern storage with wind generation for gas grid demand – example winter week

- The magnitude of daily cyclical loading in the gas grid demand case is higher than for that of the transport case, with fluctuations of the order 300 kg over the course of a winter day.
- The H_2 stored drops rapidly from around midday to late evening, as a result of the evening demand peak (shown in slide 29).
- The H_2 stored then increases rapidly from late evening to midday, as the H_2 demand is very low during this hours.

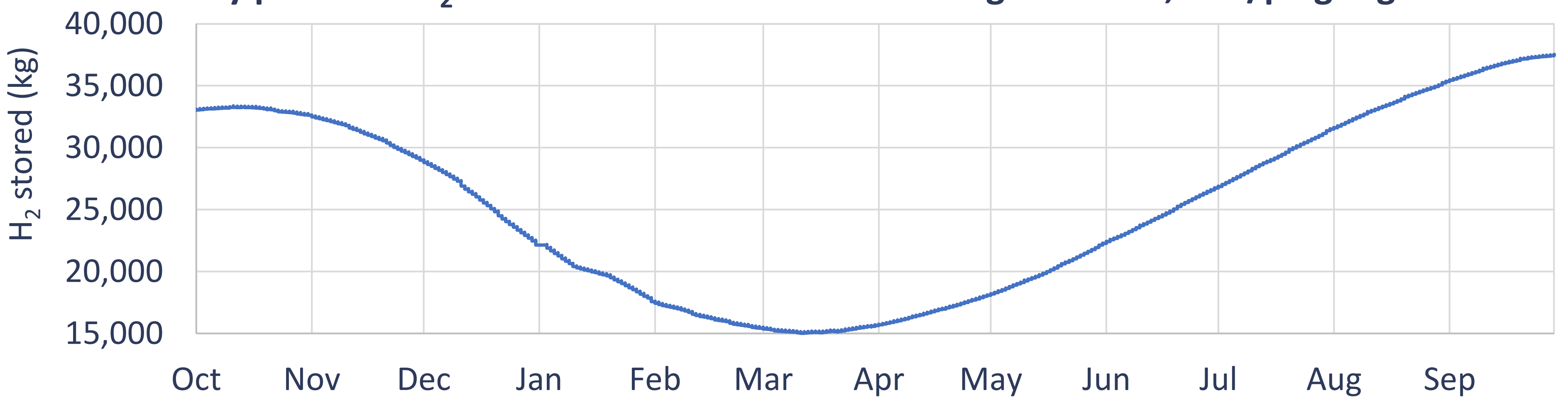


Salt cavern storage with solar generation

Solar PV has a lower capacity factor compared to wind in this region. Hence, for the same installed generation capacity, solar PV H_2 production meets a lower demand than wind production.

A 1 MW electrolyser connected to PV can produce enough hydrogen to meet an annual gas grid demand of 50 tonnes of hydrogen. This profile is displayed below. The salt cavern volume also limits the size of demand that can be met. In the summer, hydrogen production is high, whilst gas grid demand is low, meaning that there is a large change in the amount of H_2 stored.

Yearly profile of H_2 stored in the salt cavern – solar generation, 50 t/pa gas grid demand

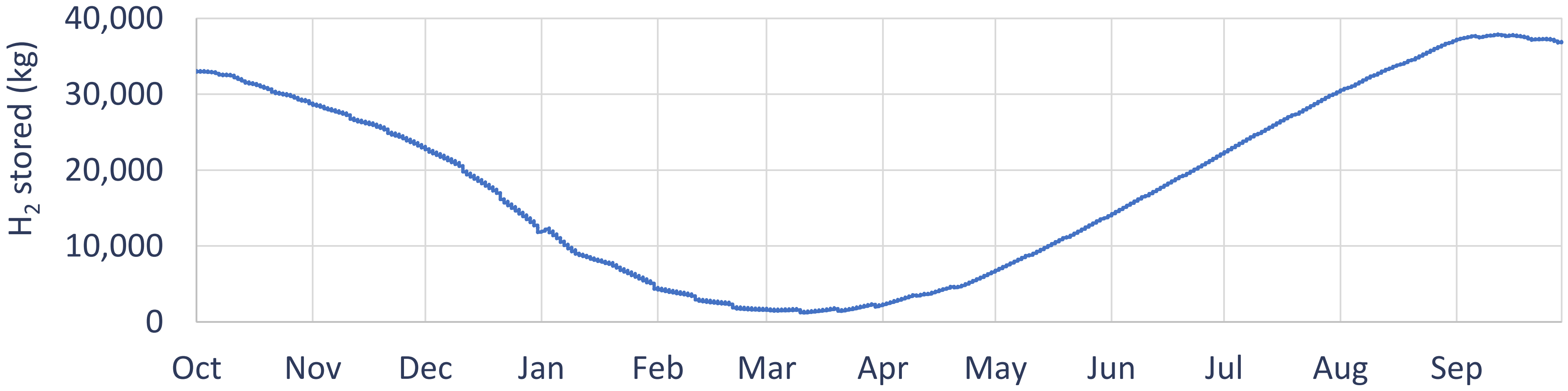


Salt cavern storage with hydroelectric generation

Hydroelectric generation has just a slightly higher capacity factor compared to wind in this region. However, the combined effect of the gas grid demand and hydroelectric generation seasonal fluctuations means that much larger variation is seen in the volume of hydrogen stored in the salt cavern. In the summer, hydrogen production is high, whilst gas grid demand is low. This means that the salt cavern storage size is the limiting factor in the size of demand that can be met.

The profile below shows the salt cavern profile for a gas grid demand of 125 tonnes and a 1 MW electrolyser. The salt cavern is almost entirely emptied by spring, but rapidly fills up to near full capacity by the autumn.

Yearly profile of H_2 stored in the salt cavern – hydroelectric generation, 125 t/pa gas grid demand



Application to other locations – supply

The hydrogen supply and demand profiles modelled may also be extended to other areas beyond the local focus on Étrez.

The general trends in the supply profiles are likely to remain similar. For solar generation, the seasonal trend of higher electricity generation and therefore hydrogen production in the summer will be consistent throughout Europe, as well as the lack of generation at night. However, the amount of electricity will vary depending on location because of varying insolation across Europe.

The higher wind generation in the winter would also be expected throughout Europe. However, the profiles may differ depending whether the electrolyser is supplied by onshore or offshore wind farms. The analysis presented here is based on onshore generation in France. In general, offshore wind farms operate at a higher load factor than onshore wind farms, which would result in a less variable supply profile (assuming the same electrolyser to wind farm capacity ratio).

The hydroelectric generation profiles are less replicable due to a dependence on regional snow melt and rainfall, which will vary with the local climate and geography.

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Application to other locations – demand

On the demand side, gas grid demand will vary with the location's ambient temperature, with greater heating demand associated with cooler regions. In the case of transport demand, local fleets of hydrogen fuel cell vehicles such as refuse trucks, material handling vehicles or trains could result in various transport demand profiles. Hydrogen fuelled trains, for example, would result in higher peaks in demand as a result of their large fuel consumption. Local vehicle fleets should therefore be taken into account when adapting these profiles for other locations.

The profile for most transport applications is relatively constant throughout the year, with daily or weekly variations dependent on bus and train timetables and driving habits of private users.

Hydrogen uses in industry could provide an additional demand case. This would result in an overall increase in the hydrogen demand. As industrial processes generally run continuously, no significant short-term nor seasonal variation is expected from industrial demand.

Application to other locations – scalability

The salt cavern profiles developed in this analysis could be scaled up to larger commercial salt caverns.

The rate of increase in the stored H_2 in the current salt cavern profiles is limited by the hydrogen production rate of the 1 MW electrolyser (the maximum daily production from the 1 MW electrolyser is c.400 kg H_2/day). The scale of the demand in these profiles was chosen so that the H_2 consumed approximately matched the H_2 produced over the course of the year. **There is scope to better match the electrolyser capacity and the demand with the scale of the salt cavern, to utilize the full range of the salt cavern capacity.**

Larger electrolyser capacity and demand would require a larger salt cavern capacity to accommodate annual fluctuations in stored H_2.

Summary and conclusions

This document provides example hydrogen supply and demand profiles for salt cavern storage in the Étrez region. These profiles included supply from solar, wind and hydroelectric generation, and transport and gas grid demand. The supply and demand profiles were combined to produce example salt cavern storage profiles. These profiles do not account for factors such as economic optimisation, but provide examples of what the salt cavern storage profile could look like in a number of possible scenarios. The example salt cavern storage profiles shown were based on wind, solar or hydroelectric generation connected to a 1 MW electrolyser producing hydrogen for either transport or a gas grid.

There is significant variation in the amount of hydrogen that would need to be stored in the salt cavern between the different renewable production methods. The large seasonal variation in both hydrogen production from renewables and hydrogen demand from a gas grid highlights the value of large-scale salt caverns in providing long-term energy storage.

Both solar and hydro-electric generation require a larger salt cavern store to meet gas demand than wind, due to the mis-match of the generation profile and gas network demand.

In the next stage of the project, the modelled profiles will be used to test the cyclical operation of the salt cavern.

Thanks !

Contact

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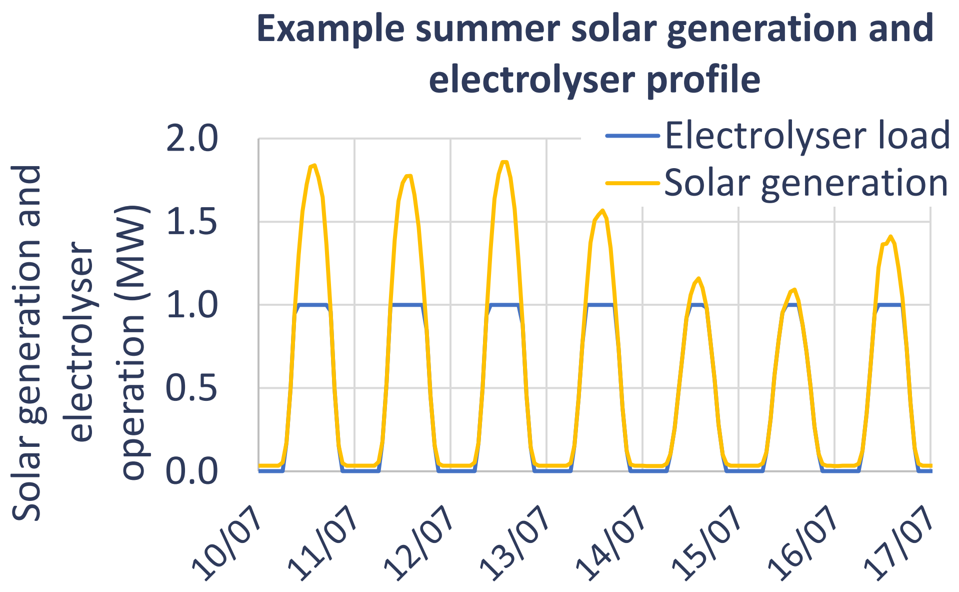
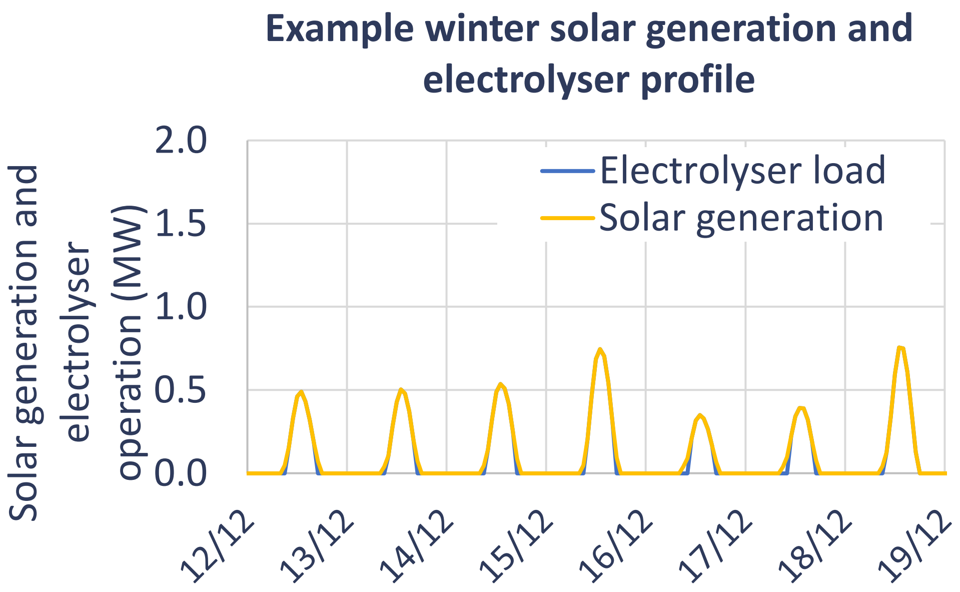
Appendix 1: Electronic filling identifier

Document Name and version	Deliverable 1.1 H_2 production and consumption profiles Version 1.0
Description	Deliverable 1.1 defines scenarios for hydrogen supply and consumption profiles to inform modelling of the salt cavern operation.
Location	WP1
Filing date	02/09/2021

Appendix 2A – higher ratio of electrolyser capacity to renewable capacity (solar)

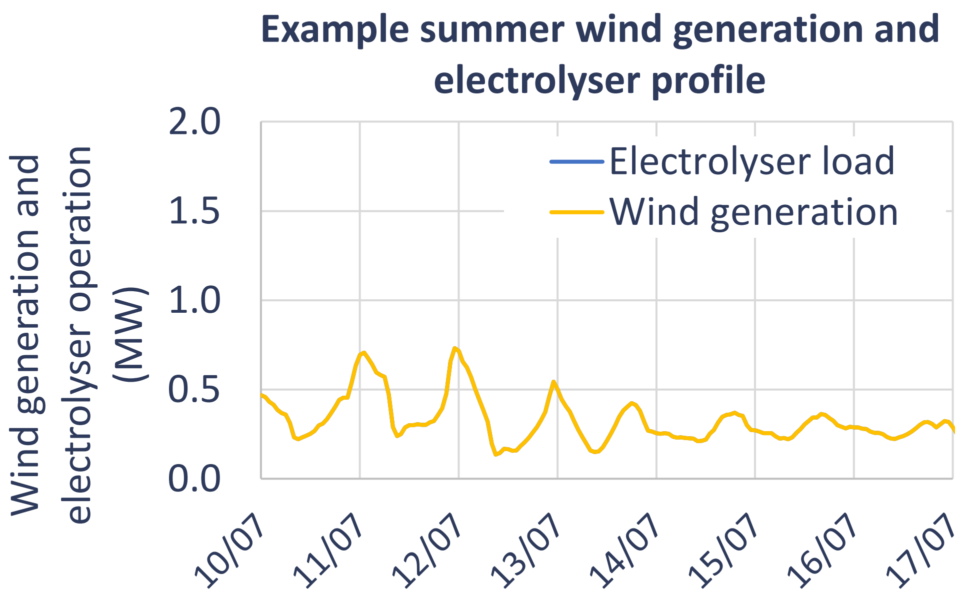
Example profiles for a 1:2 ratio of electrolyser capacity to solar capacity are shown below. Here, electrolyser priority rather than grid priority is assumed. The electrolyser profile closely follows the solar generation profile and reaches its full 1 MW capacity less frequently than in the profiles shown in slides 11 and 12.

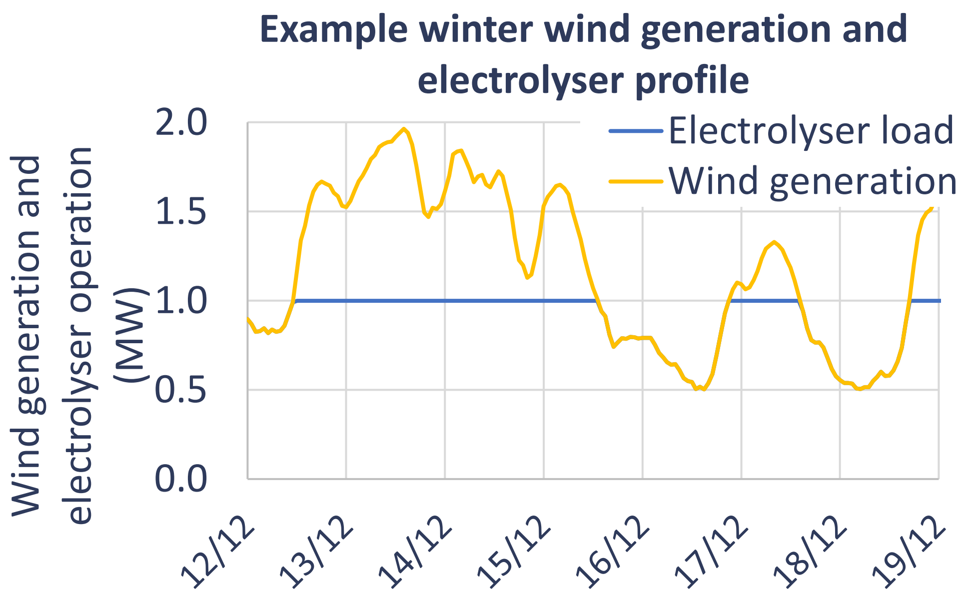




Appendix 2B – higher ratio of electrolyser capacity to renewable capacity (wind)

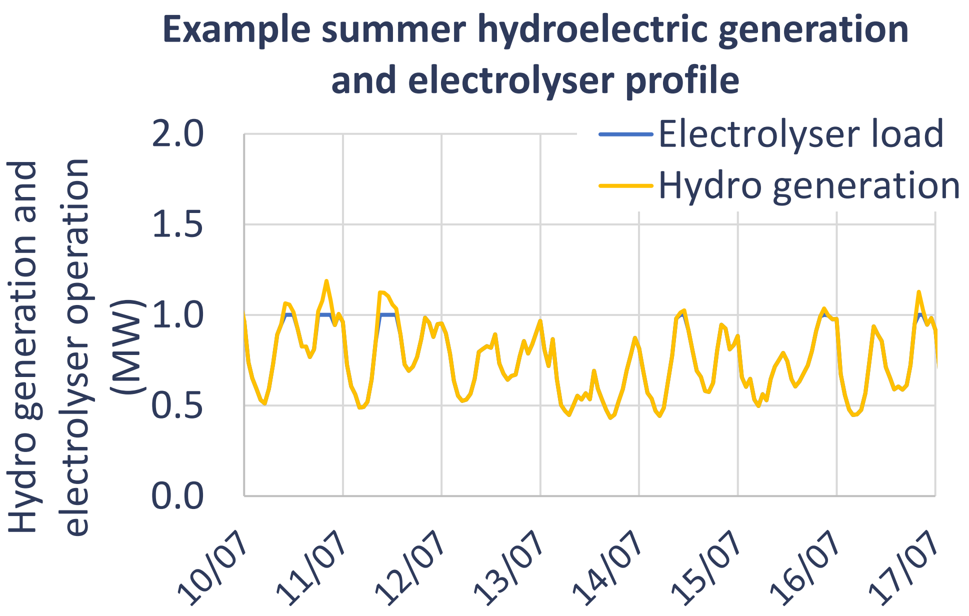
Example profiles for a 1:2 ratio of electrolyser capacity to wind capacity are shown below (assuming electrolyser priority). In the summer, the electrolyser profile follows the wind generation profile and does not reach its full 1 MW capacity. In the winter, the electrolyser sometimes operates at 1 MW, but has periods where the wind generation and therefore the electrolyser load decreases below 1 MW (unlike slide 14).

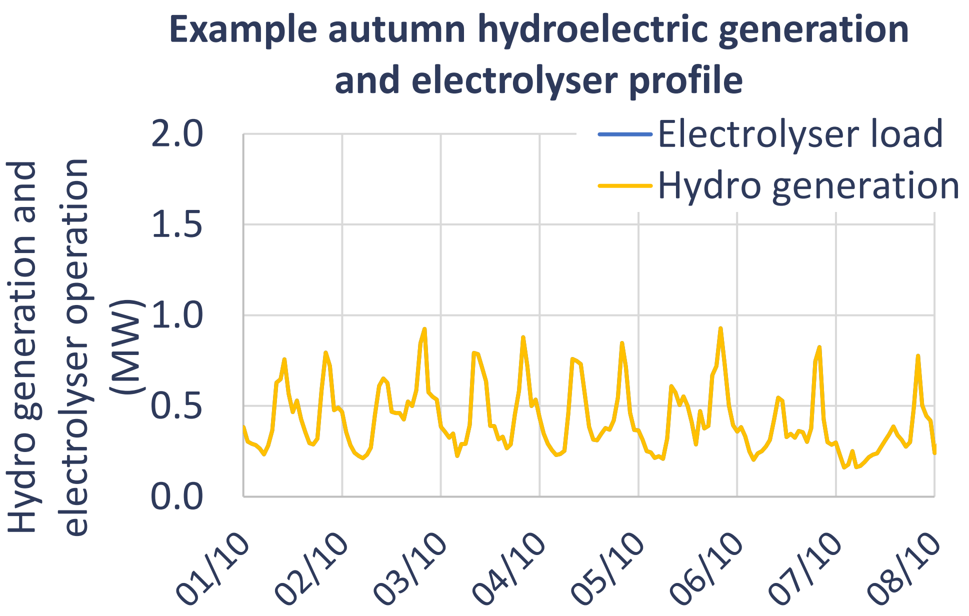




Appendix 2C – higher ratio of electrolyser capacity to renewable capacity (hydroelectric)

Example profiles for a 1:2 ratio of electrolyser capacity to hydroelectric capacity are shown below (assuming electrolyser priority). In the summer, the electrolyser profile largely follows the hydroelectric generation profile, occasionally operating at its full 1 MW capacity, unlike the steady operation at 1 MW in slide 16. In the autumn, the low hydroelectric generation means that electrolyser does not reach its full 1 MW at any point during the example week shown.

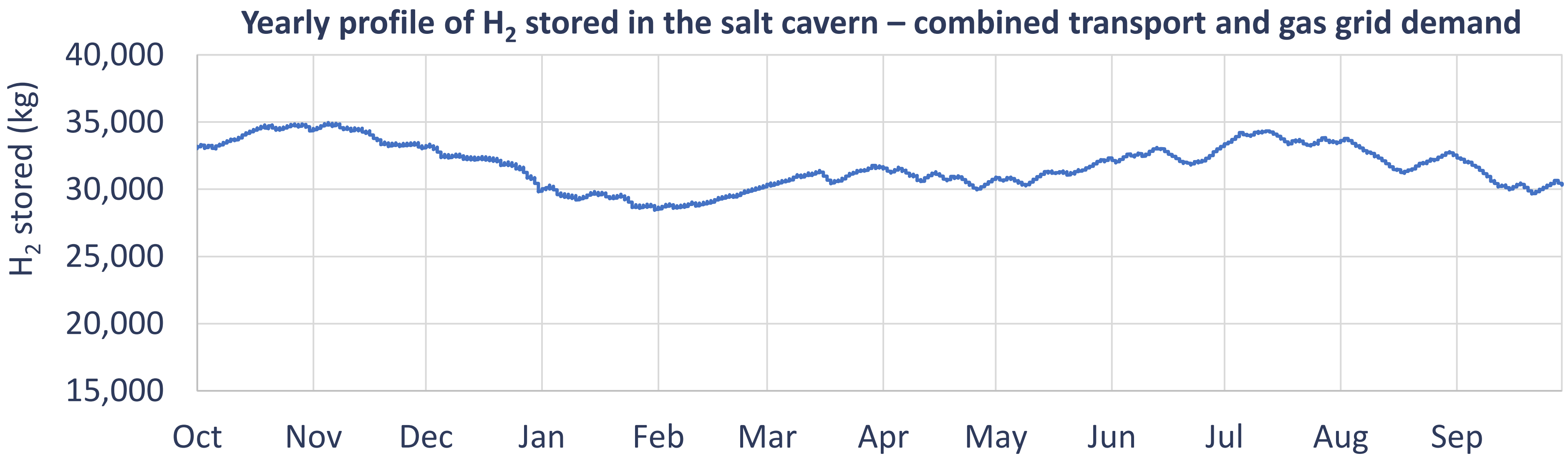




Appendix 2D – combined transport and gas grid demand

The profile below shows an example profile of the stored H_2 in the salt cavern for combined transport and gas grid demand. A 1 MW electrolyser and 20 MW wind farm was assumed, with 2.5% of the total ZEV HRS demand and 50 tonnes of yearly gas grid consumption. The ratio of transport demand to gas grid demand should be adjusted for different applications, with gas grid demand likely to become more significant as the hydrogen gas network develops.

The H_2 stored in this case remains relatively constant throughout the year.



ACKNOWLEDGMENT

This project has received funding from the Fuel Cells and Hydrogen 2 Joint Undertaking under Grant Agreement No 101006751. This Joint Undertaking receives support from the European Union's Horizon 2020 Research and Innovation programme, Hydrogen Europe, and Hydrogen Europe Research.