Interreg
Co-funded by the European Union
Alpine Space

Pôle Véhicule du Futur
Solutions pour véhicules & mobilités du futur

H2MA

Deliverable D.1.3.1

Methodology and tools for identifying H_2 mobility planning models and parameters

Activity 1.3

March 2023

DOCUMENT CONTROL SHEET

Project reference

Project title	Green Hydrogen Mobility for Alpine Region Transportation
Acronym	H2MA
Programme priority	Carbon neutral and resource sensitive Alpine region
Specific objective	SO 2.1: Promoting energy efficiency and reducing greenhouse gas emissions
Duration	01.11.2022 – 31.10.2025
Project website	https://www.alpine-space.eu/project/h2ma/
Lead partner	KSSENA

Short description

H2MA brings together 11 partners from all 5 Interreg Alpine Space EU countries (SI, IT, DE, FR, AT), to coordinate and accelerate the transnational roll-out of green hydrogen (H2) infrastructure for transport and mobility in the Alpine region. Through the joint development of cooperation mechanisms, strategies, tools, and resources, H2MA will increase the capacities of territorial public authorities and stakeholders to overcome existing barriers and collaboratively plan and pilot test transalpine zero-emission H2 routes.

Document details

Full document's title	Methodology and tools for identifying H_2 mobility planning models and parameters
Version	V1.0
Author/s	
Organization/s responsible	Pole Vehicule du Futur (PVF)
Delivery period	1

IMPRINT

This document is issued by the consortium of the **H2MA** project, consisting of the following partners:

- PP1 (LP) KSSENA, Energy Agency of Savinjska, Saleska and Koroska Region (SI)
- PP2 BSC, Business Support Centre, Ltd, Kranj (SI)
- PP3 EMS, EUROMETROPOLE DE STRASBOURG (FR)
- PP4 FLA, Lombardy Foundation for the Environment (IT)
- PP5 PVF, Cluster Pole Vehicule du Futur (FR)
- PP6 CMT, Turin Metropolitan City (IT)
- PP7 KPO, Climate Partner Upper Rhine Valley (DE)
- PP8 4ER, 4ward Energy Research Ltd (AT)
- PP9 RL, Lombardy Region (IT)
- PP10 COD, Codognotto Austria (AT)
- PP11 ITALCAM, Italian German Chamber of Commerce Munich-Stuttgart (DE)

Responsible Partner/s for the compilation of this document

- PP5 PVF, Cluster Pole Vehicule du Futur (FR)

CONTENT

1. EXECUTIVE SUMMARY

This document, prepared by Cluster Pole Vehicule du Futur (PVF), provides the methodology and tools for project partners to elaborate on applicable approaches and design specifications for planning green hydrogen heavy-duty transportation routes. Specifically:

- Mobility planning concepts related to green hydrogen are described in Section 3.
- The two main approaches for designing a hydrogen (H_2) supply chain and optimally locating the refuelling stations (HRS), namely “spatial overlay analysis conducted in geographical information systems (GIS)” and “spatial optimisation models”, are presented in Section 4.
- The proposed methodological steps for designing green hydrogen routes in the Alpine Space are provided in Section 5.
- Lastly, since partners are expected to evaluate a number of parameters related to designing a hydrogen supply chain, the process is analysed in Section 6.

2. INTRODUCTION

2.1 H2MA: an overview

H2MA brings together 11 partners from all 5 Interreg Alpine Space EU countries (SI, IT, DE, FR, AT), to coordinate and accelerate the transnational rollout of green hydrogen (H_2) infrastructure for transport and mobility in the Alpine region and facilitate the integration of transnational infrastructure planning with urban installations for trucks and trains (already existing in DE, FR, AT, IT participating territories), thus creating economies of scale and strengthening the commercial viability of green H_2 mobility. Through the joint development of cooperation mechanisms, strategies, tools, and resources, H2MA will increase the capacities of territorial public authorities and stakeholders to overcome existing barriers and collaboratively plan and pilot test transalpine zero-emission H_2 routes.

H2MA's integrated planning and implementation solutions for H_2 mobility will enable the synchronised deployment of transnational infrastructure for freight and passenger transport (heavy-duty trucks and railway in the short-term, maritime and aviation in the long-term), in tandem with urban mobility planning (buses), amplifying the macro-regional impact of currently siloed initiatives. As a result, H2MA will contribute to climate change mitigation (by curbing GHG emissions), reduce air and noise pollution, and further support the growth of Alpine space as a sustainable transportation hub, significantly advancing the shift to low-carbon mobility.

The **objectives** of H2MA are to:

1. Improve the governance of green H_2 mobility in the Alpine region, as over 20 policy authorities and 80 stakeholders will use and upscale project outputs (resources, tools, strategies), **optimising territorial mobility plans**.
2. Boost the uptake of green H_2 for heavy-duty transportation across the Alpine space by supporting infrastructure development for **at least 2,000** H_2 **-powered vehicles, thus contributing to saving approximately 240 thousand CO_2 tons (per year) by 2030.**
3. Unlock **green financing** and improve the cooperation framework between public authorities and businesses involved in green H_2 mobility in the Alpine region, by deepening public-private synergies and harmonising policy planning with automotive and green H_2 production and distribution value chains.

H2MA will enhance partners and target groups' capacities to:

1. Streamline and coordinate territorial H_2 rollout plans for both commercial/transnational and urban **heavy-duty transportation**, to promote an integrated approach to supply and distribution planning and build a critical mass for further business development.
2. Design measures to connect H_2 production for **mobility with renewables**, to facilitate the planning of transalpine zero-emission routes for HDVs.
3. Propose areas of **harmonisation** between Alpine space strategies on green mobility, to improve existing **policy frameworks**.

2.2 Activity 1.3.1: Description and goals

In the context of the H2MA Activity 1.3 (WP1), partners will survey a pre-selected thematic pool of H_2 mobility planning approaches and models provided in this document, to evaluate the design parameters and set the course for adaptations that will be needed to develop the 'H2MA planning tool' (Activity 1.5) to support H_2 routes design (WP2). PVF will collect partners' evaluations, and deliver a specifications report (Activity 1.3.2) defining the architecture, functionalities and development steps of the H2MA tool.

The proposed methodology consists of two sections:

A. Thematic background:
   1. Introduction of the concepts related to "H_2 mobility planning".
   2. Identification and provision of indicative examples of H_2 mobility planning approaches and models.

B. Guidelines for the evaluation process:
   1. Provision of a step-by-step description of the evaluation process.
   2. Definition of assessment rationale for evaluating the parameters identified in the thematic section.
   3. Provision of input forms to ensure accuracy and consistency in partners' input.

3. BACKGROUND

Heavy-duty transportation is a major contributor to Alpine GHG emissions, causing negative externalities such as air and noise pollution. Green Hydrogen (H_2) represents a particularly promising decarbonisation pathway for hard-to-electrify vehicles (e.g., trucks and buses). Operationally, hydrogen trucks exhibit a sufficiently long range (up to 480 km)[1], have a short refuelling time (~5 minutes), their range is not affected by the weather, produce low noise pollution when in use, and have zero emissions since only water vapour is released.

Accordingly, public authorities and stakeholders across Alpine long-distance and urban road networks share the need to curtail the carbon footprint of heavy-duty transportation, and address common barriers to achieving economies of scale in order to ensure the financial viability of H_2 mobility ecosystems. To that end, the joint development of H_2 strategies and infrastructure for transnational zero emissions routes and urban mobility can play a key role in avoiding redundancies and creating a critical mass for the further development of H_2 ecosystems.

Nonetheless, the design of a hydrogen supply chain network in the transportation sector is a complex system. It includes various components, from feedstock supply sites to hydrogen fuelling stations. The selection of feedstock, production and fuelling technology, locations of hydrogen facilities, and other decisions leave open the possibility for multiple design pathways, each of which leads to a different network configuration. This makes the development of H_2 infrastructure and ensuring its economic viability particularly challenging, requiring planning and decision-making tools not usually available to public authorities and stakeholders (to be) involved.

3.1 EU Hydrogen policies and initiatives

The European Union (EU) views hydrogen as an important pathway towards ensuring energy security and effecting the energy transition. In 2003, the 25 EU nations launched the European Research Area (ERA) project, which included the building of the European hydrogen and fuel cell technology research and development platform, focusing on key technologies in the hydrogen and fuel cell industries. In 2008, the EU established a public private partnership, namely the Fuel Cells and Hydrogen Joint Undertaking[2] (FCHJU), which played a vital role in the development and deployment of hydrogen and fuel cell technologies in Europe. In February 2019, FCHJU released the “Hydrogen Roadmap Europe: A sustainable pathway for the European Energy Transition”, which proposed a roadmap for hydrogen energy development towards 2030 and 2050, paving the way for the large-scale

---

[1] https://hydrogen-central.com/possible-haul-50-tons-fuel-cell-powered-trucks/

[2] FCH2JU, Who we are. Available from: https://www.fch.europa.eu/page/who-we-are

deployment of hydrogen technologies in Europe[3]. The two main recommendations included in the roadmap were the following:

- Regulators and industry should jointly set out clear, long-term and realistic decarbonisation pathways for all sectors and segments.
- The European industry should invest in hydrogen and fuel cell technologies to remain competitive and well positioned to capture emerging opportunities.

The roadmap also proposed the following concrete milestones across the following sectors:

- In terms of **transportation**, a fleet of 3.7 million fuel cell passenger vehicles, 500,000 fuel cell light commercial vehicles (LCVs), 45,000 fuel cell trucks and buses are projected to be on the road by 2030. Fuel cell trains could also replace roughly 570 diesel trains by 2030.
- In terms of infrastructure for fuel cell vehicles, about 3,700 large refuelling stations are expected by 2030.
- In terms of heating, hydrogen could replace an estimated 7% of natural gas (by volume) by 2030, and 32% by 2040, and would cover the heating demand of about 2.5 million and more than 11.0 million households in 2030 and 2040.
- In terms of industrial applications, a transition to one-third ultra-low carbon hydrogen production by 2030 could be achieved in all applications, including refineries and ammonia production.
- In terms of power generation, the at-scale conversion of “surplus” renewables into hydrogen, large-scale demonstrations of power generation from hydrogen, and renewable-hydrogen generation plants could also take place by 2030.

The European Union’s Green Deal aims to make Europe the first climate-neutral continent by 2050 and is betting on the development of three alternatives that will contribute to its decarbonisation: electricity, eco-fuels and hydrogen. The European Commission will allocate up to 29,660 million euros to hydrogen over the next ten years[4].

---

[3] FCH, Hydrogen Roadmap Europe: A sustainable pathway for the European Energy Transition. Available from: https://www.fch.europa.eu/news/hydrogenroadmap-europe-sustainable-pathway-european-energy-transition

[4] https://www.bbva.ch/en/news/hydrogen-mobility-an-emerging-sector/

3.2 Green hydrogen: benefits and considerations

Hydrogen is an environmentally friendly alternative to fossil fuels and can be used to provide flexible and high-density power and propulsion for a wide range of modes of transportation. Although hydrogen (H_2) can be produced in a variety of ways, e.g. from natural gas, nuclear power, or biomass, zero emission H_2 is produced through electrolysis of water, powered from renewables like solar and wind.

Electrolysis (a highly energy-consuming process) using renewable energy sources is currently a **high cost** option, which only accounts for around 5% of total H_2 production. Presently, the vast majority of global hydrogen production is based on fossil fuel sources (methane gas reforming). The cost for a unit of power from hydrogen fuel cells is currently greater than other energy sources, including solar panels. This is expected to change as the technology matures, making more efficient and cost-effective electrolysers available and reducing the green H_2 production cost. Nevertheless, this current high production costs currently constitute a major barrier to the widespread use of hydrogen. An added benefit, though, is that because this method uses electricity, it also offers the potential to divert any excess electricity – which is hard to store (for example from surplus wind power) – to water electrolysis, using it to create hydrogen gas that can be stored for future energy needs.

Other considerations include the lower energy density relative to liquid hydrocarbon fuels, relatively high costs of transport, storage and dispensing in compressed or liquefied form, and the lack of infrastructure. Hydrogen also faces the usual challenges of novel technologies: lack of economies of scale, lack of diversity in vehicle choices, public misperceptions and lack of awareness, and the need to establish an appropriate institutional infrastructure.

Despite the challenges in the realisation the full potential of hydrogen as a key enabler for a future decarbonised energy system, hydrogen can provide a fully **renewable and clean** power source for stationary and mobile applications in the near future due to the **storability and transportability** of hydrogen. To that end, there is the need to scale up decarbonised hydrogen production and fuel cell manufacture, and develop the required regulatory framework to clearly define commercial deployment models. Further technological advances to lower the associated costs of extraction, storage and transportation are required, along with further investment in the infrastructure to support it.

3.3 Decarbonising transportation

The transportation industry is under pressure to rapidly decarbonise. Regulatory changes, as well as customers' demands for greener transportation value chains, are prompting the industry to adapt. In short-haul freight, battery electric vehicles (BEVs) are already reaching total cost of ownership (TCO) parity with conventional vehicles in the first use cases, helping to simplify the transition for fleets. This is enabled by both rapidly declining battery costs and the launch of new vehicles.

However, the picture is quite different for heavy-duty vehicles (HDV). Long distances, unpredictable routes, high uptime requirements, strict driving-time regulations, and the importance of high payloads have made this sector particularly hard to decarbonise. With current energy densities, batteries are too heavy, charging speeds are too slow, and infrastructure is not yet available to directly electrify trucks on particularly challenging routes.

In this context, hydrogen-powered vehicles are attractive for two reasons. For one, faster refuelling and greater range can increase the uptime potential for HDVs; furthermore, their lower weight compared with batteries can increase payload capacity for trucks. Together, these factors improve hydrogen HDVs total cost of ownership (TCO), which is a key performance indicator (KPI) for the transportation sector.

3.4 Basics of hydrogen mobility

Hydrogen fuel cells use hydrogen as a fuel in an electrochemical process that combines hydrogen and oxygen to produce electrical energy and water. **Fuel cell electric vehicles** (FCEVs), as battery electric vehicles (BEVs), are powered by electricity but produce it from fuel cells instead of utilising batteries. FCEVs are a necessary complement to BEVs, as the former have longer ranges and fast fuelling times. This makes hydrogen ideal for heavy-duty tractor-trailers and public transit buses, which travel hundreds of miles at a time. As already mentioned, FCEVs can also provide potentially very low carbon emissions[5] (zero emissions if the production of hydrogen is done by water electrolysis using power from RES).

In terms of cost per mile, FCEVs will require subsidisation to be competitive with conventional cars and other types of alternative fuel vehicles during the early stages of commercial implementation[6]. However, significant cost reduction can be realised by scaling up manufacturing of FCEVs, hydrogen production and hydrogen fuelling infrastructures to supply trucks, buses, and cars[7]. In order to produce a secure, resilient and decarbonised energy system, production and bulk storage of hydrogen will play an important role in balancing intermittent supply of energy from renewable energy sources with end-user demands (i.e. fuel for transportation).

---

[5] https://www.iea.org/reports/the-future-of-hydrogen

[6] https://www.nrel.gov/docs/fy11osti/49231.pdf. doi:10.4271/2011-01-1345

[7] https://www.mckinsey.com/capabilities/operations/our-insights/global-infrastructure-initiative/voices/unlocking-hydrogens-power-for-long-haul-freight-transport

3.5 Renewable (green) hydrogen supply chain (HSC)

A Hydrogen Supply Chain (HSC) consists of various stages (production, storage, transportation and distribution, fuelling stations, vehicle fleet) with strong interdependencies, which further increases complexity. More specifically **designing a network for green hydrogen mobility** involves the following key elements:

Hydrogen production:

The first step in designing a network for green hydrogen mobility is to ensure that the hydrogen is produced in a way that does not generate CO_2. To avoid GHG emissions during the production, hydrogen should be produced through water electrolysis, which only consumes electricity and water to produce hydrogen and oxygen. This reaction takes place in a unit called an electrolyser. Electrolysers can range in size from small, appliance-size equipment that is well-suited for small-scale distributed hydrogen production to large-scale, central production facilities that could be tied directly to renewable or other non-greenhouse-gas-emitting forms of electricity production. Furthermore, to produce green hydrogen and ensure zero emissions in the entire hydrogen supply chain, the electricity should be generated from renewable sources such as solar, wind, biomass, hydro, tidal, or geothermal energy.. In addition, the process provides a way to store energy from electrical power in the form of hydrogen. Hydrogen can be produced with or without a direct connection to the electricity grid. In the latter case, supply disruption is common. Thus, hydrogen production without an electricity grid needs to manage the uncertainty of feedstock availability, but its advantage lies in more easily transitioning to 100% RES-based production.

Hydrogen storage, transportation and distribution:

Once hydrogen is produced, it needs to be stored and transported to the various points of use, such as fuelling stations for vehicles. This can be done using a combination of on-site storage at hydrogen production facilities, as well as large-scale storage tanks. Transportation requires either the use of specialized trucks that can transport (liquid or gas) hydrogen or the use of pipelines. The latter option is expected to be financially preferable in the long-term (assuming an extended utilization of hydrogen as a fuel and energy storage medium).

Hydrogen fuelling stations:

There are two types of refuelling station, off-site and on-site depending on the hydrogen supply method. Off-site refuelling stations operate with hydrogen produced in a large-scale hydrogen-producing facility, whereas on-site refuelling stations operate with hydrogen produced in the refuelling station using electrolysis. As a result, an **off-site** station is supplied through a pipeline or tube trailers. Since hydrogen distribution can be costly, off-site stations are more appropriate for areas close to hydrogen supply sources. On the other hand, **on-site** stations produce the hydrogen they need. Consequently, hydrogen can be produced according to the refuelling demand of each refuelling station and does not require hydrogen distribution infrastructure, such as a pipeline network. However, on-site stations require hydrogen production and refining facilities, resulting in a higher construction cost than for off-site stations. A typical on-site station has a hydrogen supply capacity of 100–300 Nm^3 /h[8]. This corresponds to a capacity for refuelling five HFCVs or fewer per hour.

Besides infrastructure, it is significant to have the following elements taken into account, as prerequisites when planning hydrogen supply chain:

Government policies:

Government policies and regulations play a critical role in the design and implementation of a green hydrogen mobility network. This includes regulations on the production, storage, distribution, and use of hydrogen fuel, as well as incentives for the adoption of hydrogen vehicles.

Public awareness and education:

Building public awareness and educating people about the benefits and safety of hydrogen fuel is essential for the success of green hydrogen mobility. This includes providing information to the general public, as well as training for hydrogen fuel station attendants and vehicle operators. The development of training courses across a wide range of hydrogen-related topic areas could also become critical for the development of the hydrogen sector in any particular region. This should include university undergraduate and postgraduate modules and programmes, college courses for technical staff, and shorter industry courses. Additionally, a significant effort should be made to engage local agencies, industry, and other stakeholders in the opportunities presented by hydrogen and to engage the wider public.

Monitoring and evaluation:

Lastly, it is important to monitor and evaluate the performance of the network, including the production and consumption of hydrogen, the performance of the vehicles, and the economic and environmental impacts of the network.

Eventually, planning of an HSC also depends on the status of **hydrogen adoption and market development, and on how mature the associated technologies are**, and both factors are characterised by high uncertainties.

---

[8] Bae, S.; Lee, E.; Han, J. Multi-Period Planning of Hydrogen Supply Network for Refuelling Hydrogen Fuel Cell Vehicles in Urban Areas. *Sustainability* **2020**, *12*, 4114. https://doi.org/10.3390/su12104114

3.6 Planning elements of an HSC for transportation

The structure of an HSC for transportation includes the following elements: feedstock, production, type of product, transportation, type of terminal, distribution and refuelling station, as depicted in Figure 2. In a renewable HSC, various renewable sources as solar, wind, hydro and geothermal ones, are converted into electricity used for water electrolysis.

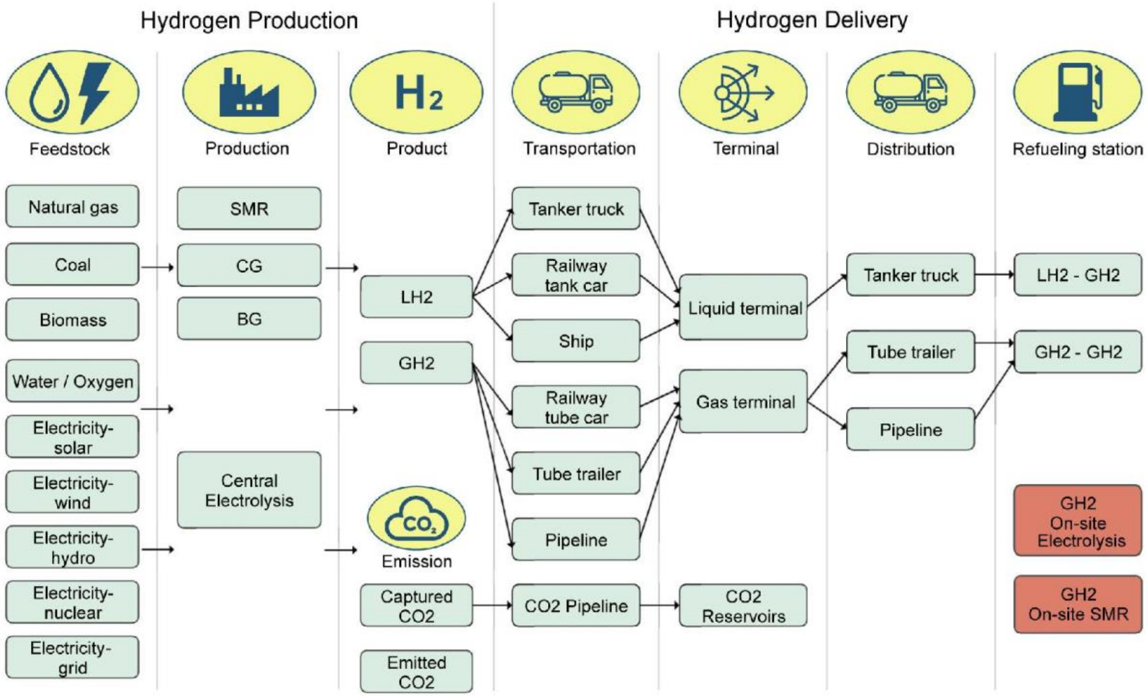


Figure 1 Structure of HSCN in the transportation sector[9]

To satisfy the demand for hydrogen, the renewable HSC needs to be configured with a proper distribution network, to transport hydrogen from the production sites to the points of use. A commonly used framework in supply chain management to describe the main planning problems and corresponding tasks is the supply chain-planning matrix (Stadtler et al., 2015). This matrix categorises the planning problems and tasks in accordance with two dimensions:

(i) The ***supply chain processes*** of procurement, production, distribution, and sales, and

(ii) The ***planning horizons***, namely long-term and mid-/short-term.

More specifically, the unique supply chain processes are matched with the supply chain stages: the feedstock, production, storage, distribution, and application stages correspond

---

[9] Lei Li, Hervé Manier, Marie-Ange Manier (2019) Hydrogen supply chain network design: An optimisation-oriented review, Renewable and Sustainable Energy Reviews, Volume 103, Pages 342-360, ISSN 1364-0321, https://doi.org/10.1016/j.rser.2018.12.060.

to sourcing, production, storage, distribution, and market and sales processes, respectively. However, due to the unique operational characteristics of renewable HSCs and their adoption and market development, the planning matrix for traditional supply chains is inadequate to represent and summarise the different renewable HSC-related planning problems and tasks. Therefore, a new planning matrix should be developed specifically for renewable HSCs as shown in Figure 3.

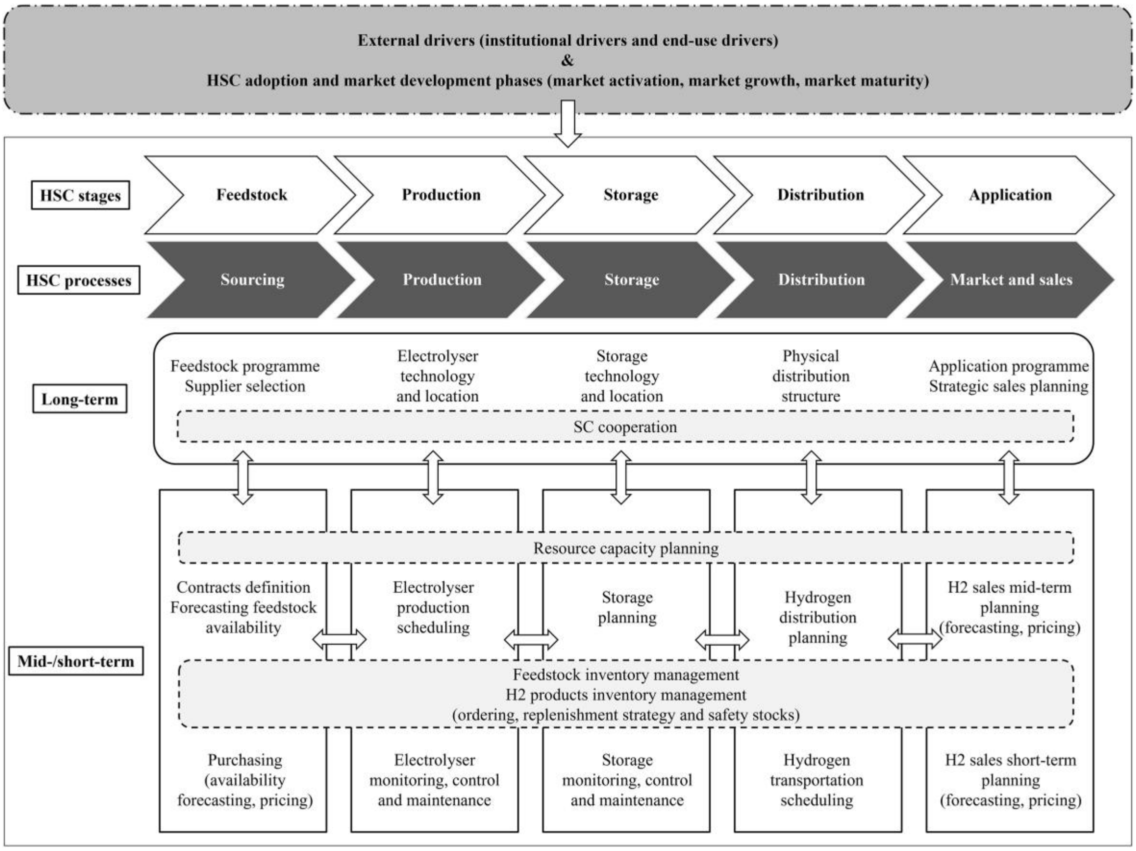


Figure 2 Planning matrix for renewable HSCs

The planning tasks are reported with respect to two planning horizons (namely long-term and mid-/short-term), and the different planning processes in renewable HSC (sourcing, production, storage, distribution, and market and sales). From the analysis of planning tasks Li et al (2019) it emerges that:

- **(i)** **It is important to *jointly* consider all planning tasks related to the different processes, since these are interconnected, and**
- **(ii)** **The *adoption* of renewable HSCs and market development are important factors, which impact the definition of planning tasks.**

To sum up, in order to design a hydrogen supply chain (HSC), each step of the following aspects needs to be carefully taken into account:

1) Energy source, production, transportation, storage, refuelling stations
2) Different time (short, mid, long term) and geographical scales (regional, national)
3) Geographic constraints (highways, buildings, mountains, water bodies).

4. HYDROGEN SUPPLY CHAIN PLANNING APPROACHES

The usual approaches to planning a network of facilities in a given region are: a) optimisation models, b) spatial overlay analysis conducted in Geographical Information Systems (GIS), and c) a combination of both, since significant overlap exists between the two[10]. The literature includes models originally developed for other kinds of facilities or fuel stations, adapted to HRS siting, as well as models originally designed for HRSs.

The proposed approach is to develop the planning support tool (Activity 1.5) using GIS as a basis, since it is essential for spatial planning, and selected elements from spatial optimisation models on top of that to support the network design. The selected parameters (see section 4.4) to be used in the approach will be evaluated from the partners before serving as input in the development of the tool in Activity 1.5, using the form provided in this document (see section 6.2).

4.1 Optimisation models

Optimisation[11] (mathematical) models describe the technological and spatial interactions that exist between the different parts of a network. Several models for hydrogen networks have been developed, and they typically fall into one of the following two categories Li et al. (2019):

- **Hydrogen supply chain network design (HSCND) models**: these models include multiple components such as feedstock, production, storage, and transportation. They focus on long-term planning and usually run on a national scale.
- **Hydrogen fuelling station-planning (HFSP) models**: these models determine the optimal location of hydrogen fuelling stations. They focus on the initial development of infrastructures and are generally applied at a city or regional level.

However, a combined approach of the two categories is needed to have a **model that can cover all types of infrastructures within a hydrogen supply network**. In addition, the **time** horizon and **geographic** scale should also be considered.

To date, significant attention has been given to the role of optimisation techniques in designing and operating a (future) HSC network. The main objective of the optimisation frameworks is to *compare and evaluate different alternatives of the hydrogen pathways and then integrate them within the existing energy supply chain*s. According to literature, the linear programming and mixed-integer linear programming (LP/MILP) models are mostly

---

[10] Church, R.; Murray, A. Location Covering Models: History, Applications and Advancements; Advances in Spatial Science; Springer International Publishing: Berlin/Heidelberg, Germany, 2018; ISBN 978-3-319-99845-9.

[11] Optimization models are **mathematical models that include functions that represent goals or objectives for the system being modeled**. Optimization models can be an- alyzed to explore system trade-offs in order to find solutions that optimize system objectives.

used, and only few studies adopted the dynamic programming (DP) models. A large portion of the studies tackled the multi-echelon problem; this is because one of the significant advantages of the LP/MILP model is accounting for the complex interactions among different echelons.

A multi-echelon supply chain features **complex supply chain networks with many distribution points from the point-of-origin to the endpoint, the consumer**. In a multi-echelon supply chain, each distribution level is treated simultaneously to recognize a level's impact on another. Other approaches include life cycle costing (LCC) methodology and the life cycle assessment (LCA) approach, and the maximal covering location problem (MCLP).

Most models for spatially optimising refuelling station locations represent demand by using one of three approaches[12]: **points** on a network, **arcs** on a network, or **trips / paths** between origins and destinations. Point-based models represent demand as nodes with demand weights (e.g., population, maximum distance or travel time for covering a demand). Arc-Based Models is another approach, developed specifically for locating fuel stations, views traffic on network arcs showing the demand for fuel stations (e.g. demand as arcs with annual average daily traffic). Trip-Based Models is the third general approach that defines demand as origin-destination (O-D) trip volumes on their shortest/fastest paths. The flow-capturing location model maximizes the number of O-D trips that can be intercepted by any facility located on their shortest path.

It is beyond the scope of this deliverable to further expand on how to develop a mathematical model for an HSC network since the project approach will focus on employing a visualised tool (such as GIS, further explained in section 4) to incorporate the parameters needed for designing an Alpine hydrogen supply chain and refuelling stations. However, optimisation models could also be developed externally to generate networks of HRSs in Alpine region and add them as map layers in the GIS tool.

4.2 Geospatial approach

Mobility is a geospatial phenomenon that typically comprises a high degree of variability in both space and time. Coupling geographical information systems (GIS) with energy system modelling has been already applied in the field of hydrogen supply, demand and infrastructure. An example is the cited approach that links energy systems and GIS models to investigate spatial hydrogen infrastructure development in a low-carbon UK energy

---

[12] Lopez Jaramillo, O.; Rinebold, J.; Kuby, M.; Kelley, S.; Ruddell, D.; Stotts, R.; Krafft, A.; Wentz, E. Hydrogen Station Location Planning via Geodesign in Connecticut: Comparing Optimisation Models and Structured Stakeholder Collaboration. Energies 2021, 14, 7747. https://doi.org/ 10.3390/en14227747

system (Strachan et al[13]). Furthermore, for the German hydrogen economy, Ball et al.[14] introduce an optimisation approach for accessing the geographic and temporal aspects of a hydrogen transport infrastructure configuration. The outcomes of both studies reveal that the use of GIS is crucial when exploring the impact of the geospatial dimension of hydrogen networks and the increasing changes in energy generation mix on future energy system infrastructures and supply chains.

A Geographic Information System (GIS) can be used to design a green hydrogen mobility network for heavy-duty transport in several ways, as described below. Since the aim of this deliverable is to find parameters to support Hydrogen routes design, the focus will be on **site selection** and **network design**:

Primary focus

Site selection: GIS can be used to identify and select suitable locations for hydrogen production and storage facilities, as well as fuelling stations for heavy-duty vehicles. GIS data can be used to analyse factors such as proximity to renewable energy sources, transportation infrastructure, population density, and land-use patterns.

Network design: GIS can be used to design the hydrogen distribution network, including the routing of hydrogen pipelines and the placement of hydrogen storage tanks. GIS can be used to analyse factors such as distance, terrain, and land-use patterns to minimize the costs and environmental impacts of the network.

Fleet management: GIS can be used to track the location and status of heavy-duty vehicles that are part of the hydrogen mobility network in order to optimise the routing and scheduling of vehicles, as well as to monitor their performance.

Environmental Impact Analysis: GIS can be used to assess the environmental impacts of the hydrogen mobility network, including the potential impacts on air quality, water resources, and wildlife habitats.

Public engagement: GIS can be used to create interactive maps and visualisations that can be used to engage the public and stakeholders in the planning and design of the hydrogen mobility network.

---

[13] Neil Strachan, Nazmiye Balta-Ozkan, David Joffe, Kate McGeevor, Nick Hughes (2009) Soft-linking energy systems and GIS models to investigate spatial hydrogen infrastructure development in a low-carbon UK energy system, International Journal of Hydrogen Energy, Volume 34, Issue 2, Pages 642-657,

[14] Michael Ball, Martin Wietschel, Otto Rentz (2007) Integration of a hydrogen economy into the German energy system: an optimising modelling approach, International Journal of Hydrogen Energy, Volume 32, Issues 10–11, Pages 1355-1368, ISSN 0360-3199, https://doi.org/10.1016/j.ijhydene.2006.10.016.

Monitoring and evaluation: GIS can be used to monitor and evaluate the performance of the hydrogen mobility network over time. This includes monitoring the production and consumption of hydrogen, the performance of heavy-duty vehicles, as well as the economic and environmental impacts of the network.

The GIS approach creates, collects, and analyses spatial data to develop a spatial plan for facility locations. The process varies depending on team members, methods, data, resources available, and project goals. Some commonalities include using multiple layers of georeferenced data that represent particular geographic phenomena important to understanding a study area's spatial context, combining and superimposing those layers to help identify locations suitable to site location, stepwise site selection, and using maps to visualize and communicate spatial information and outputs. Optimisation models could also be developed externally to generate networks of HRSs in metropolitan Alpine region and add them as map layers.

Key takeaway

The main idea for the tool (A1.5) in terms of functionality is for each partner to add or delete stations with a simple point-and-click operation, view and overlay different map layers, compute performance metrics, and compare their designs to those of other partners. By using these sources of information and their own expert local knowledge, partners are expected to recommend possible locations for hydrogen refuelling stations and routes.

4.3 Geospatial approach: Indicative examples

Example 1: The importance of economies of scale, transport costs and demand patterns in optimising hydrogen-fuelling infrastructure: An exploration with SHIPMod (Spatial hydrogen infrastructure planning model)[15]

This study focuses on the importance of assumptions regarding hydrogen demand. It draws on socio-economic data to develop a spatially detailed scenario of possible hydrogen demand. The paper then shows that assumptions about the level and spatial dispersion of

---

[15] Agnolucci, Paolo & Akgul, Ozlem & Mcdowall, William & Papageorgiou, Lazaros. (2013). The importance of economies of scale, transport costs and demand patterns in optimising hydrogen fuelling infrastructure: An exploration with SHIPMod (Spatial hydrogen infrastructure planning model). International Journal of Hydrogen Energy. 38. 11189–11201. 10.1016/j.ijhydene.2013.06.071.

hydrogen demand have a significant impact on costs and the choice of hydrogen production technologies and distribution mechanisms. For more information click: here.

Example 2: Deployment of a hydrogen supply chain by multi-objective/multi-period optimisation at regional and national scales

Almaraz et al (2015)[16] study focuses on the development of a methodological framework for the design of a five-echelon hydrogen supply chain (HSC) (energy source, production, storage, transportation and fuelling station), considering the geographic level of implementation. The formulation based on mixed integer linear programming involves a multi-criteria approach where three objectives have to be optimised simultaneously, i.e., cost, global warming potential and safety risk.

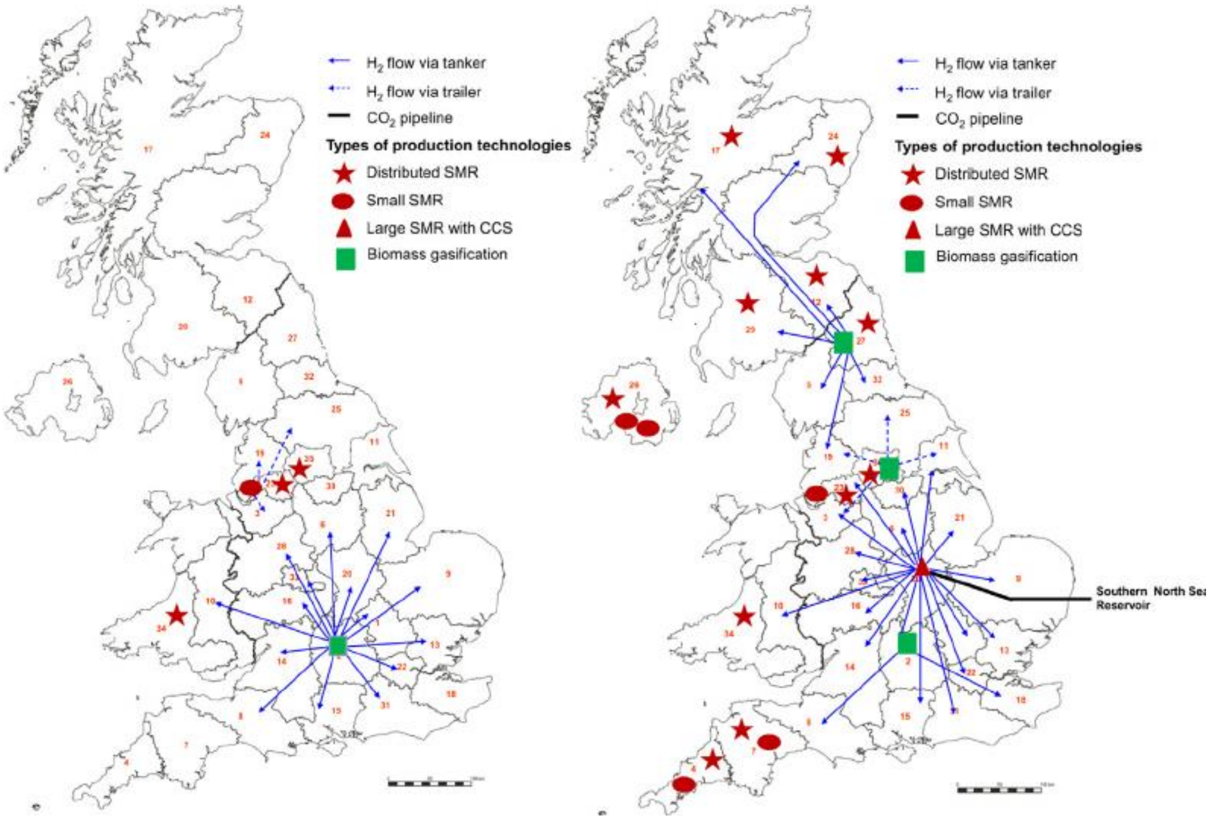
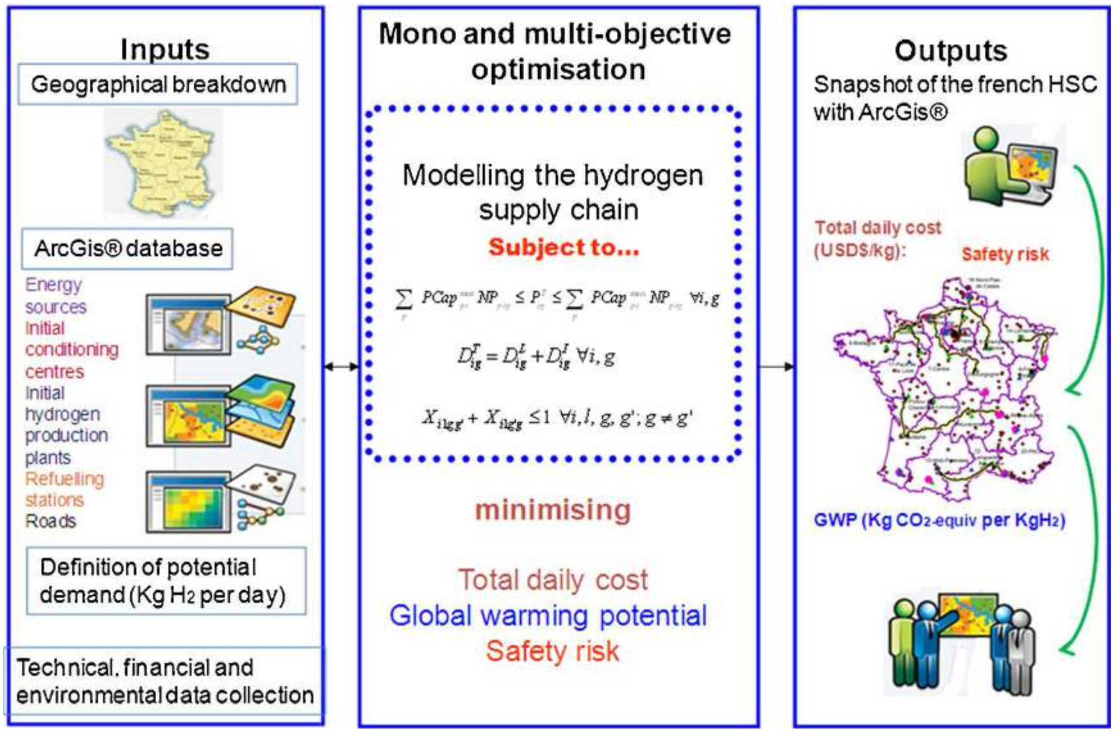


Figure 3 Evolution of supply in a multi-period case scenario (Example 1)

---

[16] Sofía De-León Almaraz, Catherine Azzaro-Pantel, Ludovic Montastruc, Marianne Boix, Deployment of a hydrogen supply chain by multi-objective/multi-period optimisation at regional and national scales, Chemical Engineering Research and Design, Volume 104, 2015, Pages 11-31, ISSN 0263-8762,http://dx.doi.org/10.1016/j.cherd.2015.07.005



$$\sum_p PCap_{pi}^{min} NP_{pig} \le P_{ig}^{T} \le \sum_p PCap_{pi}^{max} NP_{pig} \quad \forall i, g$$

$$D_{ig}^{T} = D_{ig}^{L} + D_{ig}^{I} \quad \forall i, g$$

$$X_{ilgg'} + X_{ilg'g} \le 1 \quad \forall i, l, g, g'; g \ne g'$$

Figure 4 Methodology framework for the French case study (Example 2)

4.4 Parameters, Indicators, and Layers

Following the literature review of all approaches mentioned in the previous chapters, a number of parameters (each representing a layer in a GIS tool) are listed hereinafter. As mentioned before, these parameters focus on site selection and network design. The partners will evaluate these parameters through the input forms (provided in 6.2) and assess how critical they consider them to be in order to include them in the tool to support H_2 routes design.

Hydrogen demand

- Existing hydrogen demand
- Planned hydrogen demand (mid-term 2030 and long-term 2050)
- Spatial distribution of hydrogen demand

Hydrogen Production

- Off-site production: locations and capacity
- On-site production/electrolysis: locations and capacity
- Gaseous hydrogen production (CGH2) or liquid hydrogen production (LH2)

Hydrogen transportation/distribution

- Road tankers/trailers CGH2 – fleet size
- Road tankers/trailers LH2 – fleet size
- Pipelines (CGH2): type and location, routes

Hydrogen Refuelling Stations (HRS)

- Number, location, size and type of existing HRS
- Number, location, size and type of planned HRS
- HRS storage capacity

Costs

- Costs of production per H2 Watt
- Costs of transportation per unit H2 per km
- Capital costs of production infrastructure
- Capital costs of transportation infrastructure
- Costs of the refuelling infrastructure
- Capital expenditures (CAPEX) (i.e. compressor, cryo pump, piping, storage, cooling unit, civil works, power connection)
- Operational expenditures (OPEX) (maintenance, repair, stock loss, energy consumption)

Optimisation/analysis criteria

- Total number of HRSs
- Distance between HRSs
- Carbon footprint / total greenhouse gas (GHG) emissions from the trucks per km
- Carbon footprint/ total greenhouse gas (GHG) emissions from pipelines and other infrastructure' construction
- Supply and demand matching in the developed network
- Cost comparisons
- Total operational network costs

5. METHODOLOGICAL STEPS FOR DESIGNING AN ALPINE HYDROGEN ROUTE

As discussed in the previous sections, the aim of this document is to support the development of a tool to design an effective supply network for green hydrogen refuelling infrastructure for heavy-duty transportation. The proposed approach is to integrate the relevant data in a geo-information system (GIS), and use selected elements from spatial optimisation models on top of that to support the network design, employing the following steps:

5.1 Mapping the location of hydrogen production facilities

Regarding the design of hydrogen infrastructure, one must consider the spatial planning and the geographic positioning of production facilities in relation to demand. A state-of-the-art review of hydrogen supply chain models reveals that there are important trade-offs between centralised production, with more extensive delivery infrastructure, and decentralised production, which has lower distribution costs but higher production costs[17].

On-site production means flexible, on-purpose production with low or no transportation cost. In contrast, centralised hydrogen production refers to large-scale systems connected to a hydrogen delivery/distribution network transporting the H_2 to the point of use in gaseous or liquid state via pipeline or truck. Centralised large facilities are usually the result of efforts to decrease specific production cost by increasing the unit size (economy of scale).

HSC designers therefore are likely to face a choice between:

- Constructing centralised production facilities that produce the hydrogen more efficiently and at lower cost, but require more extensive delivery infrastructure (i.e., more vehicle deliveries or a more extensive pipeline network). Centralisation allows for a secure and stable supply.
- Decentralised production, where production costs per unit of hydrogen are higher, but delivery infrastructure costs are lower because the production facilities are closer to demand outlets or are even collocated together.

Using renewable resources from remote locations would require additional investment in the transport infrastructure, from pipelines to conversion and liquefaction units, as well as storage, which increases the initial investment needed. It is thus important to: i) determine the state –of-play of the hydrogen **infrastructure** in the Alpine region and ii) estimate and record the current and planned hydrogen **demand** in the area. Within the framework of this

---

[17] https://doi.org/10.1016/B978-1-78242-362-1.00014-6

process, the construction and expansion of pipelines in the area should also be examined. Pipelines for using electrolysers to produce hydrogen from renewable electricity have increased in recent years, with projects at various stages of development. This momentum is expected to increase renewable energy capacity needs. In this context, stand-alone or cluster solutions could also be included to increase the production capacities of green hydrogen.

Once the energy sources have been determined and the hydrogen demand estimated, it is important to know the location and other characteristics of the hydrogen production facilities. For instance, the existing petroleum infrastructure in terms of production, distribution, and storage could be taken into account, since studies have shown that a future HSC network could be somewhat similar to it. The main difference is that the future hydrogen supply has the benefit of using distributed forecourt production of hydrogen at local fuelling stations via several production technologies. For land transport, hydrogen pipelines are the most cost-efficient option.

Example: The planning of an alpine regional infrastructure to supply hydrogen begins with the estimation of hydrogen demand potential in the future for the Alpine area. To quantify the spatial distribution and size of hydrogen demand projections for the future at each hydrogen vehicle market penetration level, a model developed in GIS systems can be used, for instance, which should be based upon spatial characteristics, namely: population, projections for daily/weekly/monthly hydrogen use per vehicle, and market penetration levels, vehicle fleet (current and potential), mileage statistics for each vehicle category, vehicle density in each area.

5.2 Determination of hydrogen transport facilities

Providing the required amount of hydrogen is challenging; H_2 needs to be stored at high density in order to contain enough fuel (within a feasible space) for mobile applications like a truck or a train. The two most accessible ways of achieving this are: storing the H2 as a highly compressed gas, or as a cryogenic liquid. There are pros and cons of both approaches. Due to its significantly reduced volume, liquid storage can work better when vast quantities are being transported. However, experts claim that this option does not offer an adaptable solution for the modern variety of ways in which hydrogen can be used. Instead high-pressure gas, stored in strong, light carbon fibre type IV pressure vessels has more potential[18]. In any case, the choice between the two is to be considered by a network designer since it is a parameter that can alter the total cost.

Depending on the refuelling technology, the hydrogen can be delivered to the HRS in either gaseous (CGH2) or liquid form (LH2). For commercial use, supply by trailer (CGH2 or LH2 trailer) or pipeline (CGH2) can be considered. Depending on the material used, the weight-to-volume ratio of the storage vessels varies significantly. Recent changes in safety regulations make it possible for storage vessels to become lighter and more cost-effective in the future, making it possible for the same tank configurations to handle higher-pressure levels. A higher trailer supply pressure allows for more efficient gaseous refuelling concepts. However, in order to reach higher trailer pressures longer filling times and more compressor power at the filling plants are required.

Another alternative are liquid hydrogen (LH2) supply trailers with vacuum-insulated cryo-tanks. Due to the particularly high storage density, such a trailer can transport significantly more hydrogen than a CGH2 tube trailer. Therefore, when supplying a HRS, fewer trailers would be used and fewer delivery cycles would be needed. This could reduce logistics costs.

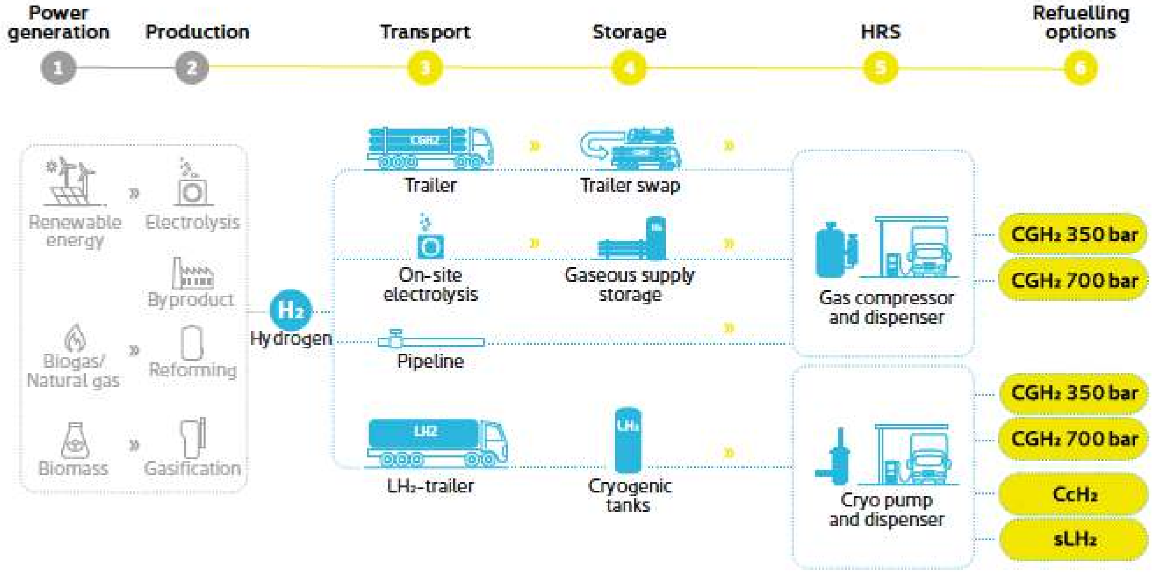


Figure 5 Hydrogen HDV supply chain[19]

Another option is to supply gaseous hydrogen via pipeline. Currently, the process of using existing natural gas pipeline infrastructure to transport future hydrogen throughout Europe

---

[18] https://www.nproxx.com/why-high-pressure-gas-storage-beats-liquid-hydrogen/

[19] Overview Hydrogen Refuelling For Heavy Duty Vehicles https://h2-mobility.de › uploads › sites › 2021/08

(European Hydrogen Backbone) is being explored[20]. Specifically, the process of integrating and connecting the pipeline and HRS network is being studied and investigated. To ensure that the quality of hydrogen is sufficient for mobility, a hydrogen purifier will likely be required at off take locations (e.g. the HRS).

5.3 Identification of locations and time scales of potential hydrogen refuelling stations

Studies[21] show that hydrogen-refuelling stations for heavy-duty vehicles are very different in size compared with passenger car stations. The main concern when identifying the best location for an HRS is to accommodate as many trucks as possible with the minimum costs. There are a number of criteria that need to be taken into account for the analysis for the optimal location of an HRS such as to ensure that:

- The capital, operational and infrastructure costs will be the minimum possible;
- The supply will meet the expected demand;
- The targets according to European strategies are met (i.e. availability of at least one HRS every 200km by 2030 - EU target for heavy trucks for the TEN-T core network by 2030);
- The Carbon footprint from the trucks or the construction of the infrastructure (plants, stations, pipelines) is minimised (if not eliminated).

Research results[22] on the optimal location of hydrogen refuelling stations have been published along with several review papers. One approach is the optimisation models for the facility location problems of most alternative fuel stations, including hydrogen stations, which can be divided into node-based and path-based models as mentioned in section 4.1. For the node-based models, the refuelling demands are represented as points in space. On a highway network, for example, nodes can be referred to as highway entries, exits or intersections. A geographic information system can be used to synthesise different information to assess possible station sites. In the path-based model, demand is defined as the amount of traffic that passes through the path between the origin and the destination nodes.

On-site or off-site hydrogen refuelling station

---

[20] Overview Hydrogen Refuelling For Heavy Duty Vehicles https://h2-mobility.de › uploads › sites › 2021/08

[21] a) Agnolucci, P.; McDowall,W. Designing future hydrogen infrastructure: Insights from analysis at different spatial scales. Int. J. Hydrog. Energy 2013, 38, 5181–5191.
b) Alazemi, J.; Andrews, J. Automotive hydrogen fuelling stations: An international review. Renew. Sustain. Energy Rev. 2015, 48, 483–499.
Ko, J.; Gim, T.H.T.; Guensler, R. Locating refuelling stations for alternative fuel vehicles: A review on models and applications. Transp. Rev. 2017, 37, 551–570.

[22] Ko, J.; Gim, T.H.T.; Guensler, R. Locating refuelling stations for alternative fuel vehicles: A review on models and applications. Transp. Rev. 2017, 37, 551–570.

The large-scale hydrogen refuelling infrastructure for heavy-duty vehicles and its potential to reduce its costs by coupling flexible hydrogen production with the electricity system needs careful consideration. There are different parameters to be considered such as whether the hydrogen refuelling station will be on-site or off-site. In general, an **off-site** station is supplied with a large amount of hydrogen produced in nearby production plant through a pipeline or tube trailers, and therefore the costs of transporting the hydrogen are to be considered. **On-site** stations do not need hydrogen transport infrastructure but they require hydrogen reforming and refining facilities, resulting in a higher construction cost than for off-site stations.

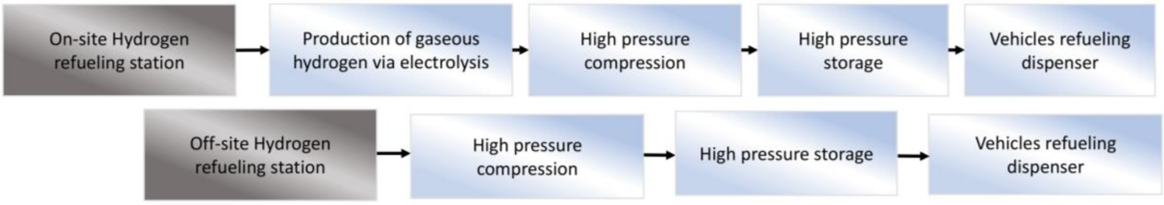


Figure 6 General components of HRS[23]

GIS, as already mentioned in previous sections, can assist in identifying the potential locations and showcase it in a map like the one below, which is depicting the current availability of H_2 fuelling options in Europe.

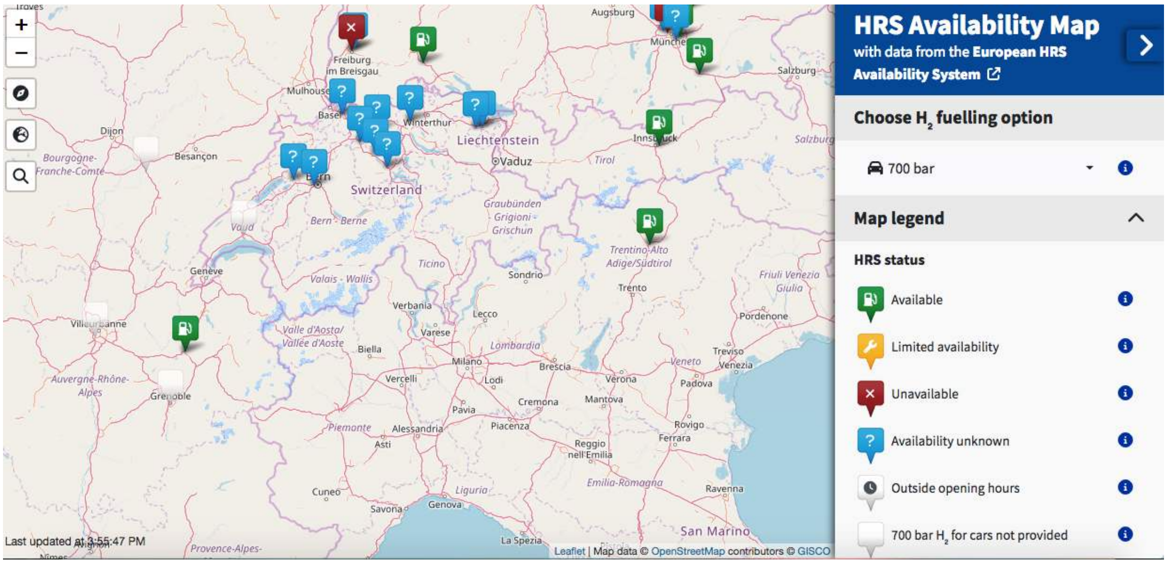


Figure 7 European HRS availability map[24]

---

[23] Deployment of a Hydrogen Supply Chain. Hanane Dagdougui, ... Ahmed Ouammi, in Hydrogen Infrastructure for Energy Applications, 2018

[24] https://h2-map.eu/

5.4 Identifying infrastructure costs

When assessing the optimal design for a hydrogen supply chain, costs are an important factor to be considered. One of the main challenges to scaling-up a circular hydrogen economy and ensuring economic sustainability includes the cost management challenges. Capital Expenditures (CAPEX) (i.e. compressor, cryo pump, piping, storage, cooling unit, civil works, and power connection), and the Operational Expenditures (OPEX) (maintenance, repair, stock loss, and energy consumption) should be evaluated across all refuelling options, and a cost comparison between the different configurations should take place within the analysis.

6. GUIDELINES FOR THE EVALUATION PROCESS

6.1 Description of the evaluation process/ Assessment rationale

In this section, partners are provided with guidelines on how to conduct the evaluation of the H_2 mobility planning parameters identified in this document. Specifically, partners will jointly fine-tune the suggested geospatial (GIS) approach by identifying the parameters most critical for the design of an Alpine hydrogen route for heavy-duty vehicles (HDVs), in order to develop the tool specifications for Activity 1.5. The assessment will be based on the current and future plans and priorities of partners' own territories and the most important parameters will be used as input in the tool. Partners are also invited to make suggestions to enrich the list of parameters for the (optimal) design of a green hydrogen supply chain and the location of HRSs.

6.2 Input forms

Each parameter provided in the input form will be ranked on a scale of 1 (redundant) to 5 (essential). The total score of each parameter (i.e. by taking into account all evaluations from the partners) will be used to rank it in terms of importance for hydrogen mobility planning in the Alpine area. The threshold value (i.e. score) for a parameter to be included in the tool (A1.5) is 2.5; in addition, to avoid skewing, values of ± 2 standard deviations from the mean will be treated as outliers.

EVALUATION FORM

Name:	
Organisation:	
Input Parameter/ Layer	**Rating** (*Please evaluate the parameters by rating on a 1 (redundant) to 5 (essential) scale*)
I. HYDROGEN DEMAND	
Existing hydrogen demand	1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐
Planned hydrogen demand for 2030	1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐
Planned hydrogen demand for 2050	1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐
Spatial distribution of hydrogen demand *(i.e. based on exogenously-derived population data and market penetration rates)*	1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐
Other	1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐
Other	1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐
Other	1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐

II. HYDROGEN PRODUCTION	
Location (coordinates) of hydrogen off-site production sites	1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐
Off-site production capacity	1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐
Gaseous hydrogen off-site production (CGH2) or liquid hydrogen off-site production (LH2)	1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐
Location (coordinates) of hydrogen on-site production sites	1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐
On-site Production capacity	1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐
Gaseous hydrogen on-site production (CGH2) or liquid hydrogen on-site production (LH2)	1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐
Other	1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐
Other	1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐
Other	1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐
III. HYDROGEN TRANSPORTATION/ DISTRIBUTION	
Road tankers/trailers CGH2	1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐
Road tankers/trailers LH2	1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐

Pipelines (CGH2)	1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐
Other	1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐
Other	1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐
Other	1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐
IV. HYDROGEN REFUELLING STATIONS (HRS)	
Number of existing H_2 Stations	1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐
Location of existing H_2 Stations	1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐
Size of existing H_2 Stations	1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐
Type of existing H_2 Stations (gas or liquid)	1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐
Number of planned H_2 Stations	1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐
Location of planned H_2 Stations	1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐
Size of planned H_2 Stations	1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐
Type of planned H_2 Stations (gas or liquid)	1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐

Storage capacity per HRS (*For reference, the EU target for heavy trucks is for an HRS to have a minimum daily capacity of at least six tonnes of H_2, with at least two dispensers per stations*)	1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐
Other	1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐
Other	1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐
Other	1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐
V. COSTS	
H2 production costs	1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐
H_2 transportation costs	1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐
Capital expenditures (CAPEX) for hydrogen production, distribution and refuelling infrastructure	1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐
Operational expenditures (OPEX)	1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐
Other	1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐
Other	1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐
Other	1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐

OPTIMISATION/ANALYSIS CRITERIA	
Distance between HRSs *(For reference, the EU target for heavy trucks for the TEN-T core network by 2030 is the availability of at least one HRS every 200km by 2030)*	1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐
Carbon footprint[25]/ total greenhouse gas (GHG) emissions from the H2 supply chain per km	1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐
Supply and demand matching in the developed network *(Ensuring whether supply will match demand foreseen by EU/national strategies and)*	1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐
Total capital network costs *(Calculate and optimise the cost of different configurations e.g. between on-site or off-site, different configurations)*	1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐
Total operational network costs	1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐
Other	1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐
Other	1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐
Other	1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐

---

[25] A carbon footprint is the total greenhouse gas (GHG) emissions caused directly and indirectly by an individual, organization, event or product. It is calculated by summing the emissions resulting from every stage of a product or service's lifetime (material production, manufacturing, use, and end-of-life).