Interreg
Co-funded by the European Union
Alpine Space

H2MA

Deliverable D.1.3.2

Evaluation analysis on optimal H2 mobility planning models and parameters

Activity 1.3

June 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	Evaluation analysis on optimal H2 mobility planning models and parameters
Version	V1
Author/s	
Organization/s responsible	PVF
Delivery period	1, 1-6

IMPRINT

This document is issued by the consortium formed for the implementation of the **H2MA** project, comprised by the following partners:

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

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- PP5 PVF (FR)

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SUMMARY

This report presents and analyses the results of the evaluation survey conducted within the context of H2MA Activity 1.3, titled 'Scoping and evaluation analysis of H2 mobility planning models to define optimal design parameters for the 'H2MA planning tool'. Project partners rated design specifications and criteria to optimally plan green hydrogen routes in partnership territories. The document elaborates on the findings that emerged through the evaluation process, to define the architecture, functionalities, and developmental steps of the H2MA tool, which will support H2 routes design (WP2) (to be developed during activity 1.5).

The report is structured as follows:

- Section 1 (introduction) provides an outline of the Activity and the purpose of this report.
- Section 2 describes the survey and the methodology used for data collection.
- Section 3 presents the rating of the proposed parameters on which the H2MA tool will be based, divided into five categories: a) hydrogen production, b) hydrogen transportation/distribution, c) Hydrogen Refuelling Stations (HRS), d) costs, e) optimisation/analysis criteria.
- Section 4 discusses the specifications deriving from the rating of parameters, and provides recommendations for the architecture, functionalities, and development steps to be followed for the design of the H2MA tool.

1. INTRODUCTION

1.1 The H2MA project

H2MA aims to increase the capacities of territorial public authorities and stakeholders to overcome existing barriers and collaboratively plan and pilot test transalpine zero-emission H2 routes through the joint development of cooperation mechanisms, strategies, tools, and resources. In particular, H2MA brings together 11 partners from all 5 Interreg Alpine Space EU countries (SI, IT, DE, FR, AT) in order to coordinate and accelerate the transnational rollout of green hydrogen (H2) infrastructure for transport and mobility in the Alpine region. In this context, H2MA aims to facilitate the creation of economies of scale (through the joint planning of H2 routes) in order to strengthen the commercial viability of green H2 mobility.

With the view to maximize the macro-regional impact of currently siloed initiatives, H2MA's integrated planning and implementation solutions for H2 mobility will enable the coordinated 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 addition, through the reduction of GHG emissions (as a result of the increased uptake of green H2 technologies), H2MA will help to mitigate climate change, lessen air and noise pollution, and encourage the expansion of Alpine space as a hub for sustainable transportation, all of which will greatly speed up the transition to low-carbon mobility.

In this context, H2MA will improve partners' and target groups' capacities to:

1. Streamline and coordinate territorial H2 rollout plans for both commercial/international and urban heavy-duty transportation.
2. Create policies that link the production of hydrogen for transportation with renewable energy sources to make it easier to plan HDV transalpine zero-emission routes.
3. Enhance territorial policy frameworks and support the development of complementarities and synergies between Alpine space initiatives on green mobility.

1.2 An overview of Deliverable 1.3.2

Employing the guidelines provided by Deliverable 1.3.1 of Activity 1.3, partners evaluated a number of parameters drawn from a pre-selected thematic pool of H2 mobility planning techniques and models, focusing on site selection and network design. Partners evaluated these parameters through an input form, selecting the most significant to be included in the H2MA tool to support H2 routes design. The analysis hereinafter is expected to define the architecture, functionalities and development steps of the H2MA tool.

2. SURVEY DESIGN AND METHODOLOGY

In order to narrow down the most crucial factors to serve as input for the design of the H2MA tool, a thorough research of parameters and criteria utilized in relevant studies pertaining to developing an effective and efficient fuel supply chain was carried out. Partners were asked to decide on the criticality of each parameter, based on own territorial experiences and needs, as well as future plans and priorities; to do so, they were provided with an input form (Annex II). Partners were also invited to make suggestions to enrich the list of parameters to be incorporated in the design of a green hydrogen supply chain and HRS networks.

PVF delivered the associated methodology and supporting tools in deliverable D1.3.1, which elaborated on applicable approaches and design specifications for planning green hydrogen heavy-duty transportation routes, including the following:

a) Mobility planning concepts related to green hydrogen.
b) The main approaches for designing a hydrogen supply chain and optimally placing the hydrogen refuelling stations (HRS), namely “spatial overlay analysis conducted in geographical information systems (GIS)” and “spatial optimisation models”.
c) Proposed methodological steps for designing green hydrogen routes in the Alpine Space.

Each parameter provided in the input form was ranked on a scale of 1 (redundant) to 5 (essential). The total score of each parameter (i.e., the average of all partners’ evaluations) is used to rank it in terms of significance to be included in the H2MA tool for hydrogen mobility planning in the Alpine area.

3. SURVEY DATA AND RESULTS

All but two[1] of the H2MA partners contributed with evaluations of the most critical parameters to be included in the H2MA tool; this section provides a presentation of the data gathered. Two of the partners[2] provided more than one input forms, filled-in by additional partner staff and external experts; hence, there were 12 completed evaluation forms from 9 partners. The forms provided the list of all parameters to be assessed, employing a 5-point Likert scale ranging from 1 (redundant) to 5 (essential). The following graphs offer a visualization of the overall findings, indicating the ranking of the parameters as an average of all available partner's evaluations.

In this analysis, the average score of 3 will be used as the threshold to eliminate parameters (the initial suggestion was 2.5). Partners tend to disagree on the importance or criticality of the parameter if the score is less than 3, whereas a score of 3 or more implies agreement on the parameter's inclusion in the tool.

3.1 Hydrogen demand

The first set of parameters pertained to hydrogen demand, which is a fundamental concept since its fluctuation affects all other significant parameters in the supply chain. More specifically, the parameters under partners' consideration were:

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

The level and spatial dispersion of hydrogen demand have a significant impact on costs and the choice of hydrogen production technologies and distribution mechanisms.

Figure 1 illustrates the averaged score for each parameter according to partner's responses. The findings show that all partners believe **it is very critical to add predictions of future hydrogen demand into the tool** (both for the mid-term of 2030

[1] PP3 EMS, Eurometropole de Strasbourg (FR) AND PP4 FLA, Lombardy Foundation for the Environment (IT)

[2] PP2 BSC, Business Support Centre, Ltd, Kranj (SI) and PP8 4ward Energy Research Ltd (AT)

and the long-term of 2050). It is also imperative that **the spatial distribution of hydrogen demand** is included in the tool. In contrast, current hydrogen demand is not seen as critical, receiving the lowest score 2.67 and therefore according to the partners should is suggested to be excluded from the tool. The latter is likely due to the fact that the hydrogen market is developing but not yet well established, and current hydrogen demand is insignificant for the construction of hydrogen routes that aim to meet the predicted increased future hydrogen demands. However, it is recommended to not omit the current demand, as it seems necessary for the development of the tool.

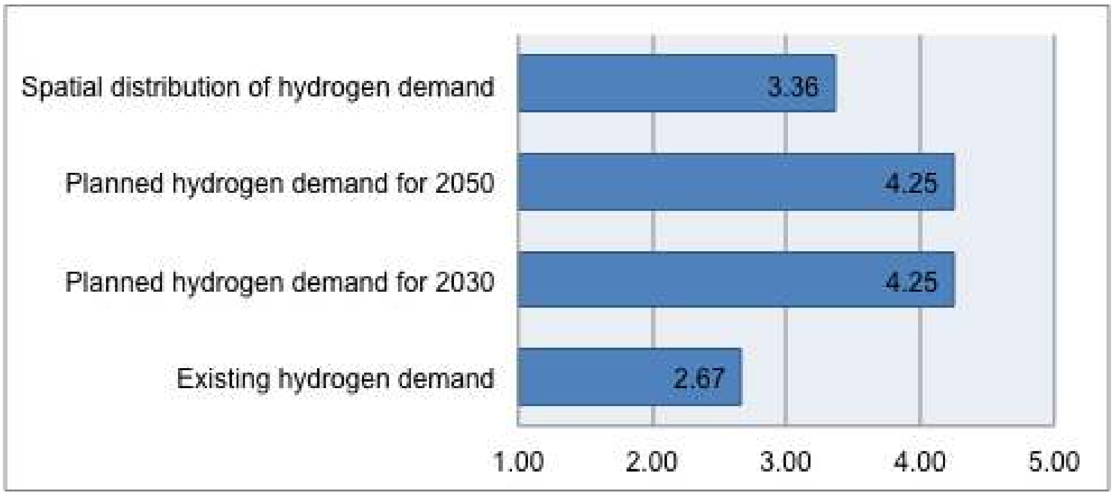

Figure 1 Ranking of averaged score for each parameter of Hydrogen demand on a scale from 1 (redundant) to 5 (essential)

In addition, partners suggested two extra parameters:

- The estimated hydrogen demand on TEN-T corridors.
- The ratio between hydrogen industry and hydrogen mobility.

The developers of the tool, in conjunction with the rest of the partners, will further assess whether these extra parameters will be included in the tool.

3.2 Hydrogen production

To figure out which parameters are the most important for the design of the hydrogen mobility infrastructure, partners were requested to evaluate the following parameters regarding hydrogen production:

- Off-site production: locations and capacity

- On-site production/electrolysis: locations and capacity
- Gaseous hydrogen production (CGH2) or liquid hydrogen production (LH2) for either off-site or on-site

In comparison to the other criteria related to hydrogen production, partners agreed that the **location of the production sites** (whether off-site or on-site) is the most significant aspect to include in the tool. The **capacity of the production sites** was the second most essential issue, whether for on-site or off-site production. The type of hydrogen production, whether gaseous (CGH2) or liquid (LH2), was rated as the least relevant, with both ratings below 3, and hence will not be included in the tool.

The parameters of the on-site production sites have ranked higher than the one of the off-site sites. 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[3]. **Partners favour on-site production sites**, likely attributable to the fact that eliminating on-road transit enhances public safety, reduces greenhouse gas emissions, and contributes to the cost-competitiveness of point-of-use hydrogen production with conventional fuels.

Figure 2 showcases partners' responses for each parameter regarding Hydrogen production category.

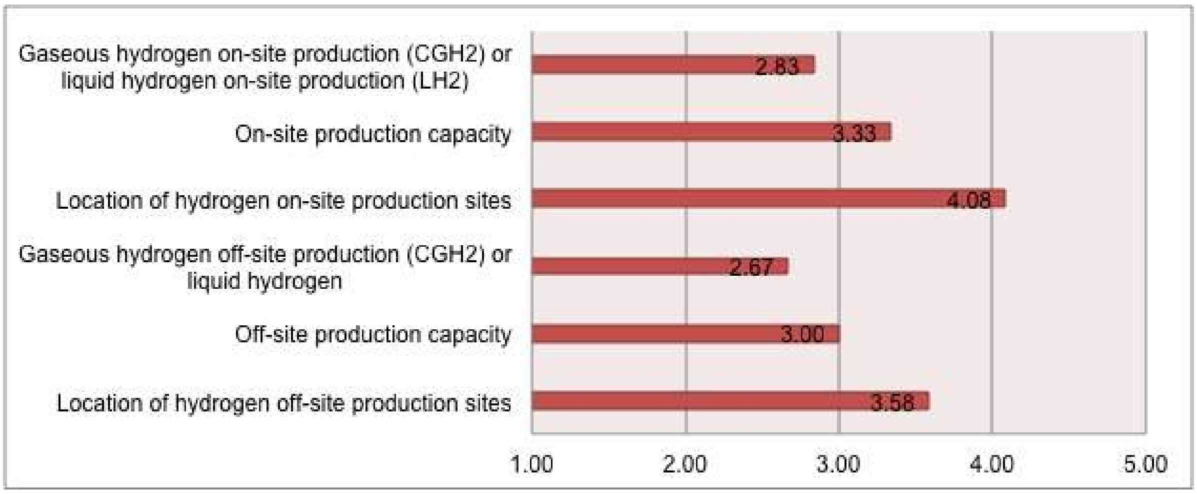

Figure 2 Ranking of averaged score for each parameter for Hydrogen production on a scale from 1 (redundant) to 5 (essential)

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

One of the partners suggested that the carbon footprint per type of hydrogen is also a crucial parameter to include in the tool. Nonetheless, because the carbon footprint of each stage in the hydrogen supply process falls within the suggested analysis/optimisation criteria, it is already deemed to be included in the tool.

3.3 Hydrogen transportation/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 and pipelines for distribution.

In terms of hydrogen transportation/distribution, the parameters under consideration by partners for inclusion in the tool were:

- The fleet size of the CGH2 road tankers/trailers
- The fleet size of the LH2 road tankers/trailers
- The type, the location and the routes of the pipelines (CGH2)

In their evaluation, partners decided that the most important data that must be represented in the tool is the **type, location, and routes of the pipelines (CGH2)**. This indicates that according to partners' view it is more likely that the hydrogen will be in gas form rather than liquid. A probable reason for this is that a compressed hydrogen gas storage system allows end-users to rapidly refuel their vehicles, which is essentially the main advantage of gas hydrogen. With a high-pressure gas storage system, refuelling can be achieved in minutes, while liquid storage refuelling protocols and processes are not yet available. Furthermore, both the fleet size and the travel routes of the road tankers (either CGH2 or LH2) were considered as important parameters for the tool.

The **distance between the station and the manufacturing site** is an additional piece of information that should be included in the tool, per the advice of partners. It is indeed a crucial variable, because it has a big impact on the distribution costs. Therefore, the developers of the tool should take that into account.

Figure 3 depicts the ranking of each parameter's averaged score per partners' assessment.

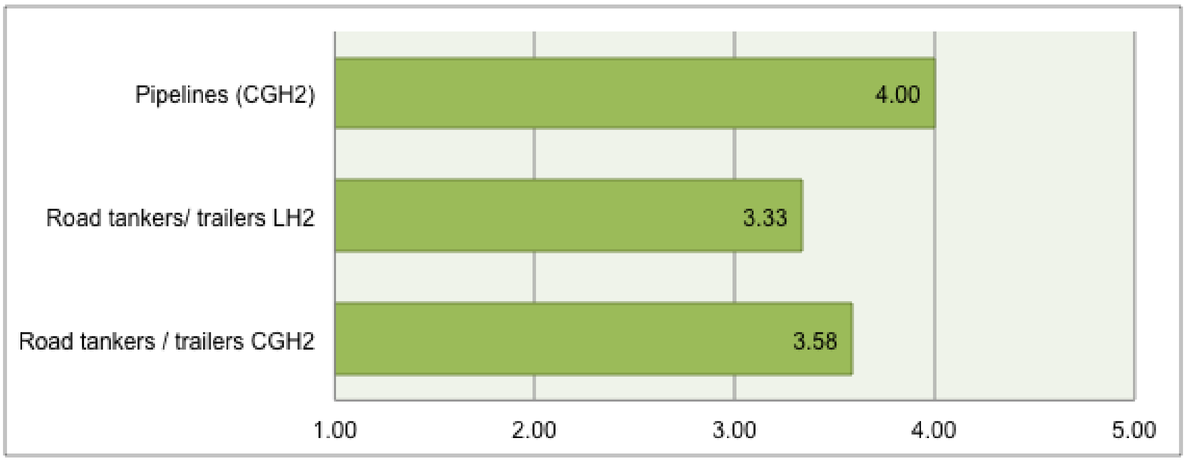

Figure 3 Ranking of averaged score for each parameter for Hydrogen distribution/transportation on a scale from 1 (redundant) to 5 (essential)

3.4 Hydrogen refuelling stations (HRS)

The set of parameters regarding the Hydrogen Refuelling Stations category were:

- The number, location, size (how many and what kind of vehicles it can accommodate) and type (liquid or gas) of existing HRS
- The number, location, size and type of planned HRS
- The HRS storage capacity

The **storage capacity per HRS** is the most crucial for the tool according to partners' evaluations. In terms of the number, location, size, and type of an HRS, **information about future HRSs is placed higher than information about present ones**. The second most essential factor for the tool in HRS category, and hence the construction of the Hydrogen transalpine network, was the **location of the HRSs**, while the type was deemed as non-critical (average scores below 3), and thus it will not be included in the tool.

Figure 4 depicts the ranking of each parameter's averaged score regarding HRSs.

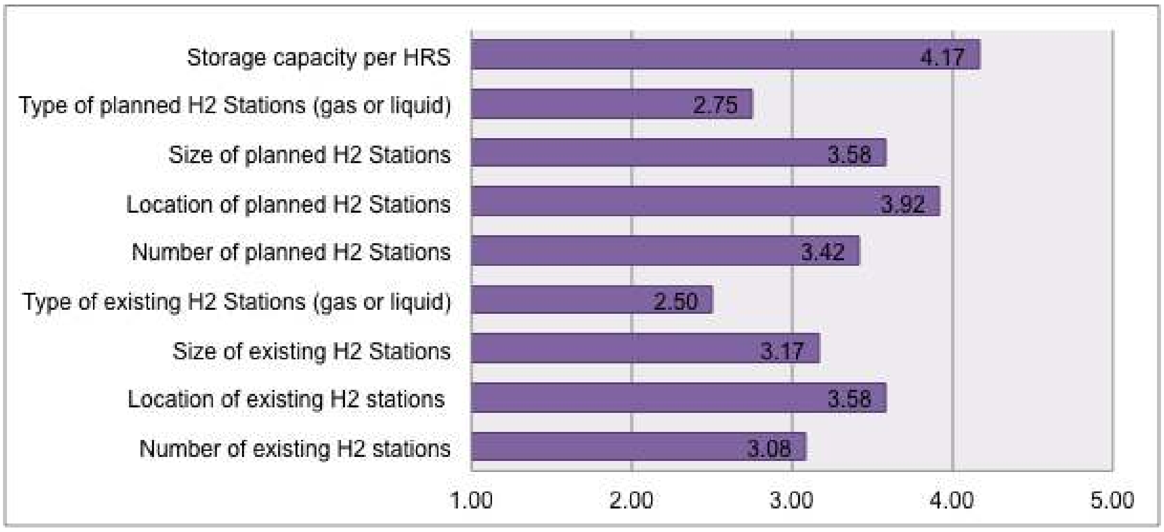

Figure 4 Ranking of averaged score for each parameter for HRSs on a scale from 1 (redundant) to 5 (essential)

The additional critical parameters that partners suggested were:

- The long-term storage capacity
- The daily storage capacity
- The availability of a dual pressure HRS: 350 bar for heavy duty vehicles and 700 bar for medium and light-duty vehicles.

The storage capacity per HRS, which was regarded as the most important parameter in this category, comprises two of the suggested parameters: **long-term and daily storage capacity**, which both will be included in the tool. Furthermore, whether the parameter of the availability of a dual pressure refuelling station should be investigated further for the development of the H2MA tool.

3.5 Costs

There are several criteria that must be considered when determining the best location for an HRS; keeping the capital, operational and infrastructure costs as low as possible is one of the most important. The set of parameters regarding costs were:

- Operational expenditures (OPEX) (maintenance, repair, stock loss, energy consumption)
- Capital expenditures (CAPEX) (i.e. compressor, cryo-pump, piping, storage, cooling unit, civil works, power connection) for hydrogen production, distribution, and refuelling infrastructure

- H2 transportation costs
- H2 production costs

The results show that estimations of the costs related to the hydrogen supply chain are important as an input for the tool to determine the best location of HRS in the Alpine region. **Production costs and CAPEX** (capital expenditures) per station are considered slightly more critical than the transportation/distribution costs and the OPEX (operational expenditures) per station. An additional parameter suggested by one of the partners was the cost for the customer (hydrogen pricing) at the refuelling station.

Figure 5 shows the ranking of each parameter's averaged score regarding the relevant costs.

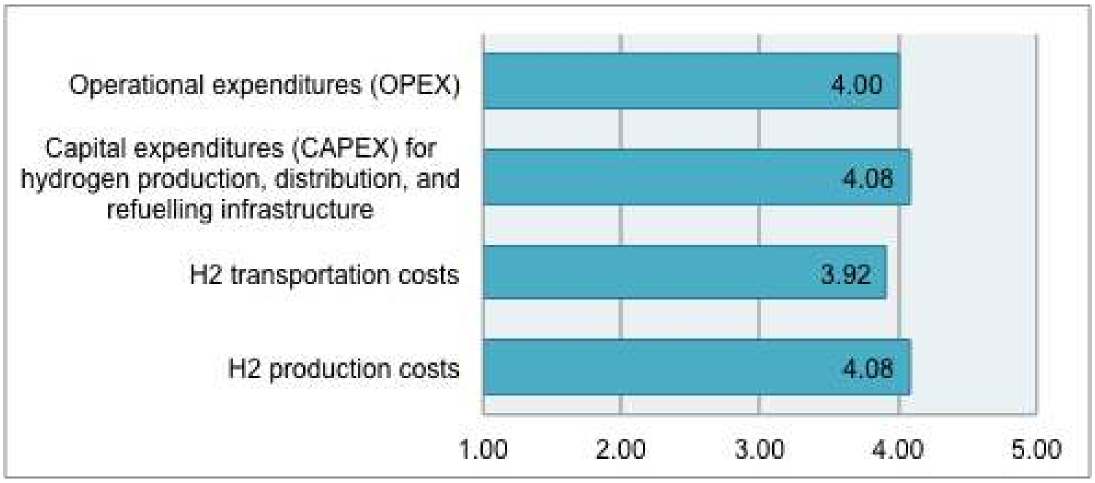

Figure 5 Ranking of averaged score for each parameter for the costs on a scale from 1 (redundant) to 5 (essential)

3.6 Optimisation/ analysis criteria

All parameters presented above will be essentially used as input information by end-users within the H2MA tool, while this section is focused on parameters relevant to analysis and optimization procedures. These methods will be built into the tool to provide the best potential results, by taking into consideration the input information provided each time and combining and comparing the possible outcomes, to facilitate the determination of the best possible design for the Hydrogen supply chain in the Alpine region.

The optimisation/analysis criteria that were selected and given to partners for evaluation were the following:

- Distance between HRSs
- Carbon footprint / total greenhouse gas (GHG) emissions from the H2 supply chain per km
- Supply and demand matching in the developed network
- Total capital network costs
- Total operational network costs

Partners deemed the **distance between HRSs** to be the most crucial of all the aforementioned criteria for the analysis, while the carbon footprint / total greenhouse gas (GHG) emissions to be the least critical, but nevertheless important for the tool.

Figure 6 shows the ranking of each parameter's averaged score regarding each optimisation/analysis criterion.

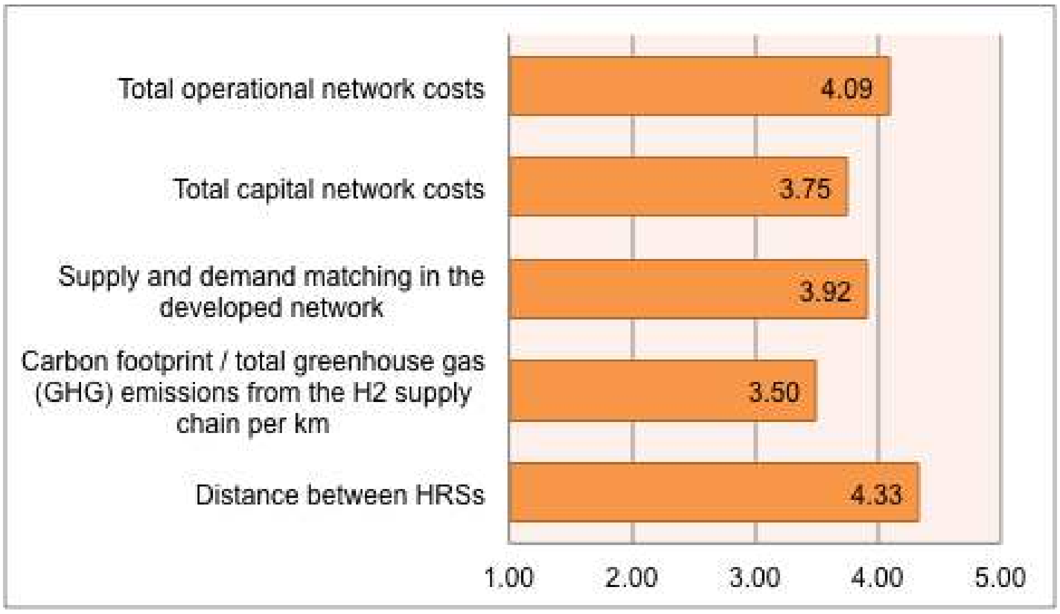

Figure 6 Ranking of averaged score for each parameter on a scale from 1 (redundant) to 5 (essential)

4. SPECIFICATIONS FOR THE DEVELOPMENT OF THE H2MA TOOL

4.1 H2MA tool's proposed approach

The proposed approach is to develop the planning support tool (A1.5) using Geographical Information Systems (GIS) as a basis, which it is essential for spatial planning, as well as selected elements from spatial optimization models to support the optimisation of the network design. The focus of the parameters in the H2MA tool will be on site selection and network design.

More specifically, regarding *site selection*, GIS can be used to find and pick appropriate locations for facilities that produce and store hydrogen, as well as fuelling stations for H2 land vehicles (such as large trucks or trains). GIS data can be used to analyse elements including population density, land-use patterns, accessibility to renewable energy sources, and transportation infrastructure. Regarding *network design*, GIS can be used to plan the hydrogen distribution system, including the placement of hydrogen storage tanks and the path of hydrogen pipelines. For the network to have the least amount of financial and environmental impact, GIS can be used to analyse variables like distance, geography, and land-use patterns.

One of the key advantages of Geographical Information Systems (GIS) is its ability to model complex systems and simulate different scenarios. For example, GIS can be used to estimate the potential output of a solar or wind farm, which can then be used to determine the optimal size and location of a hydrogen production facility. GIS can also be used to model the transport and storage of hydrogen, which can help to identify potential bottlenecks and optimize the design of the infrastructure.

GIS can also be used to monitor and manage the production, distribution, and consumption of green hydrogen. By integrating real-time data from sensors and other sources, GIS can provide a detailed picture of the current status of the system and enable operators to make informed decisions in real-time. For example, GIS can be used to monitor the performance of individual hydrogen production units, track the movement of hydrogen along pipelines, and predict demand based on weather and other factors.

In addition to its technical benefits, GIS can also provide valuable insights into the social and environmental impacts of green hydrogen. GIS can be used, for example, to identify regions where the building of hydrogen infrastructure may have a negative influence on local communities or ecosystems, as well as potential conflicts between diverse land uses. To summarize, widespread use of green hydrogen requires efficient and effective planning, management, and monitoring of this new energy carrier's production, distribution, and consumption. GIS is a strong technology that can provide significant insights into these processes and aid in the optimization of hydrogen infrastructure design and operation.

4.2 Architecture and functionalities

4.2.1 An introduction

A tool's architecture is determined by the functions it must have. The main idea for the H2MA 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. To this end, the first step is to define the data that the tool receives from the user as input parameters, since these parameters are necessary for the tool to work. Changing the value of an input parameter produces a different result; section 4.2.2 contains the list of the parameters chosen by the partners. The selection and definition of these parameters to be used in the tool has been completed through the entire evaluation process that took place in the activity 3.1 (Deliverable 1.3.1, Evaluation from the partners through the input forms and results). Within this step, the data sources for the variables required by the tool to achieve its aim should be researched and their values determined; a data variable (such as population or mileage statistics) is a characteristic that can be measured and can take on various values.

The next step is to set up the processes that the tool will use to accomplish its goal. These processes will process the data and return an outcome/result. To evaluate the outcome, some optimisation/analysis criteria need to be in place.

4.2.2 Input parameters

The input parameters are the information that the users will be entering to the tool. For the H2MA tool the proposed input parameters according to partners' assessment are the following:

1. **Planned hydrogen demand (mid-term 2030 and long-term 2050)**
2. **Spatial distribution of hydrogen demand**

Hydrogen demand: 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. The data variables needed to calculate these first two parameters might include 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. The data sources for the aforementioned information might include the official national census data from each Alpine country and the Departments/Ministries of Transportation or Energy.

3. **Off-site production: locations and capacity**
4. **On-site production/electrolysis: locations and capacity**

Hydrogen production: Since this is a geospatial analysis, once the main hubs of hydrogen production in Europe that make up the current annual production are located, then the relevant data for the Alpine area can be highlighted and extracted. Data sources for this kind of information can be derived, for example, from the Hydrogen Roadmap Europe 2019[4], the Chemical industry database[5] and the International Energy Agency (IEA)[6] statistics.

5. **The fleet size of the CGH2 road tankers/trailers**
6. **The fleet size of the LH2 road tankers/trailers**
7. **The type, the location and the routes of the pipelines (CGH2)**

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[4] Fuel Cells and Hydrogen 2 Joint Undertaking, *Hydrogen roadmap Europe – A sustainable pathway for the European energy transition*, Publications Office, 2019, https://data.europa.eu/doi/10.2843/341510

[5] Boulamanti A, Moya J. Energy efficiency and GHG emissions: Prospective scenarios for the Chemical and Petrochemical Industry. Luxembourg; 2017. doi:10.2760/20486.

[6] IEA International Energy Agency. World Energy Outlook 2019. Paris: OECD/IEA; 2019.

Hydrogen transportation/distribution: Currently hydrogen is mostly produced and consumed in the same location, without the need for transport infrastructure[7]. However, demand is increasing and about 2 000 km of hydrogen pipelines are in operation in Europe, mainly owned by private companies, utilised to connect industrial users. Several countries are developing plans for new hydrogen infrastructure. The European Hydrogen Backbone initiative groups together 31 gas infrastructure operators with the aim of establishing a pan-European hydrogen infrastructure. Another data source is the Fuel Cells and Hydrogen Observatory (https://www.fchobservatory.eu/observatory/technology-and-market/hydrogen-pipelines). Users must investigate all available sources to collect and give appropriate data for the Alpine region to the tool.

8. **The number, location, size (how many and what kind of vehicles it can accommodate) of existing HRS**
9. **The number, location, size of planned HRS**
10. **The HRS storage capacity**

Hydrogen refuelling stations: A list of the existing HRSs in Europe, their operator, locations and availability of 350 or 700 bar can be found in https://h2-map.eu/. The ones corresponding to the Alpine area can be easily extracted. Information on whether the hydrogen is green as well as on the size and storage capacity of each HRS needs further investigation. Another interactive map, which shows the number of truck-specific hydrogen refuelling, stations required in Europe (the 27 EU member states plus the UK) by 2025 and 2030 for each country can be found here: https://www.acea.auto/figure/interactive-map-truck-hydrogen-refuelling-stations-needed-in-europe-by-2025-and-2030-per-country/.

To estimate future HRS storage capacity, parameters such as the future hydrogen demand, the distance between the HRSs, and the number of hydrogen vehicles should be taken into account.

11. **Operational expenditures (OPEX) (maintenance, repair, stock loss, energy consumption)**

[7] https://www.iea.org/reports/hydrogen-supply

12. **Capital expenditures (CAPEX) (i.e. compressor, cryo-pump, piping, storage, cooling unit, civil works, power connection) for hydrogen production, distribution, and refuelling infrastructure**
13. **H2 transportation costs**
14. **H2 production costs**

Hydrogen costs: Renewable hydrogen (or green hydrogen) is produced through electrolysis using renewable energy sources (RES) and it is a near-zero carbon production route[8] with its cost at $6.00 (€5.09) per kilogram in 2020[9] It is projected to cost $2.50 (€2.12) per kilogram in 2030 under average European wind energy productivity. Electrolyser CAPEX, the utilisation factor (operating hours) and electricity price are the main parameters determining the cost of producing green hydrogen[10]. Electrolyser costs are projected to halve by 2050, from $840 per kilowatt in 2019, while renewable electricity costs will continue to fall as well. In parallel, Europe, and more specifically the Fuel Cells and Hydrogen Joint Undertaking (FCH JU), already funds a pioneering electrolysis project of 20 MW[11], and R&D has led to notable technological and cost reduction achievements[12] Calculations of the individual expenses of each link in the hydrogen supply chain should be made in order to determine the total cost. Techno-economic assessments and other economic analyses are needed to determine each cost related to the hydrogen supply chain and infrastructure.

Moreover, the **additional parameters** that were suggested by the partners and the tools' developers should consider are:

1. The estimated hydrogen demand on TEN-T corridors.
2. The ratio between hydrogen industry and hydrogen mobility.
3. The distance between the station and the manufacturing site
4. The availability of a dual pressure HRS: 350 bar for heavy duty vehicles or 700 bar for medium and light-duty vehicles.

[8] IRENA. Hydrogen: A renewable energy perspective. Abu Dhabi, UAE; 2020
[9] Hydrogen Council. Path to hydrogen competitiveness. A cost perspective. Oslo, Norway; 2020
[10] G. Kakoulaki, I. Kougias, N. Taylor, F. Dolci, J. Moya, A. Jäger-Waldau, Green hydrogen in Europe – A regional assessment: Substituting existing production with electrolysis powered by renewables, Energy Conversion and Management, Volume 228, 2021, 113649
[11] Fuel Cells and Hydrogen Joint Undertaking. FCH JU funds pioneering green hydrogen project. Media Release 2020. https://www.fch.europa.eu/news/fch-ju-funds-pioneering-green-hydrogen-project.
[12] G. Glenk, S. Reichelstein, Economics of converting renewable power to hydrogen, Nat Energy, 4 (2019)

5. The cost for the customer (hydrogen pricing) at the refuelling station.

The Hydrogen Infrastructure Map (https://www.h2inframap.eu/#keys), which showcases concrete European hydrogen infrastructure projects and possibilities for transport routes and corridors, is a good example of data needed and their sources. The interactive map includes hydrogen infrastructure projects and shows the development of projects in 2030, 2040 and 2050. The projects are split into 5 categories, including transmission pipelines, distribution pipelines, terminals and ports, storages, as well as demand and production projects. This map could be used as a background layer to assist on choosing Hydrogen refuelling locations for the Alpine network.

4.2.3 Criteria for analysis/optimisation and outputs

The selected criteria (output variables) are the limits that the user will set for the tool to optimise the calculations accordingly.

1. **Distance between HRSs**: this parameter aims to ensure that the targets according to European strategies are met such as minimum distance between the HRSs (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).
2. **Carbon footprint / total greenhouse gas (GHG) emissions** from the H2 supply chain per km: the aim is that the carbon footprint from the trucks or the construction of the infrastructure (plants, stations, pipelines) is minimised (if not eliminated).
3. **Supply and demand matching** in the developed network: ensuring that the supply will match demand according to EU strategies and projections.
4. **Total capital network costs**: keeping the costs as minimum as possible.
5. **Total operational network costs**: keeping the costs as minimum as possible.

End-users of the H2MA tool are expected to provide values for the parameters, with the tool performing calculations to determine the output. For example, if the input parameters are hydrogen demand for 2050, number of planned HRSs and production capacity, then the tool can perform calculations and determine whether the supply meets the demand (output variable). The main objective of the tool is to find the most appropriate location sites for the HRSs, under (desired) conditions that will be provided through the parameters/queries by the users. Additionally, the tool could perform geographic queries and analysis, searching for relationships between some given parameters.

To summarize, the tool's principal output will essentially be the **optimal cost-benefit design of the Alpine hydrogen network.**

5. ANNEX I – EVALUATIONS' RESULTS TABLES

PARAMETERS	PP1 KSSENA	PP2 (a) BSC - ELES	PP2 (b) BSC - SIGR	PP3 EMS	PP4 FLA	PP5 PVF	PP6 CMT	PP7 KPO	PP8 4ER	PP8 4ER - ATE	PP8 4ER - Carinthia	PP9 RL	PP10 COD	PP11 ITALCAM	Average
HYDROGEN DEMAND															
Existing hydrogen demand	3	1	1			4	1	5	2	4	3	1	2	5	2.67
Planned hydrogen demand for 2030	4	3	3			5	4	5	5	5	4	3	5	5	4.25
Planned hydrogen demand for 2050	5	5	3			2	5	5	4	4	5	4	4	5	4.25
Spatial distribution of hydrogen demand	4	3	1			4	3	4	4	3	-	4	4	3	3.36
Other: Hydrogen demand on TEN-T corridors	5														

Other: Ratio between industry and mobility (regarding the choice of station)	4										

PARAMETERS	PP1 KSSENA	PP2 (a) BSC - ELES	PP2 (b) BSC - SIGR	PP3 EMS	PP4 FLA	PP5 PVF	PP6 CMT	PP7 KPO	PP8 4ER	PP8 4ER - ATE	PP8 4ER - Carinthia	PP9 RL	PP10 COD	PP11 ITALCAM	Average
HYDROGEN PRODUCTION															
Location of hydrogen off-site production sites	4	2	1			5	4	5	4	2	4	4	4	4	3.58
Off-site production capacity	3	1	1			5	1	4	5	2	4	1	5	4	3.00
Gaseous hydrogen off-site production (CGH2) or liquid hydrogen	3	3	1			1	1	4	4	2	4	1	4	4	2.67
Location of hydrogen on-site production sites	5	4	1			5	4	5	5	4	3	4	5	4	4.08
On-site production capacity	3	3	1			5	1	5	5	4	3	1	5	4	3.33

Gaseous hydrogen on-site production (CGH2) or liquid hydrogen on-site production (LH2)	3	3	1			1	1	4	5	4	3	1	5	3	2.83
Other: Carbon footprint (type of hydrogen produced)						5									

PARAMETERS	PP1 KSSENA	PP2 (a) BSC - ELES	PP2 (b) BSC - SIGR	PP3 EMS	PP4 FLA	PP5 PVF	PP6 CMT	PP7 KPO	PP8 4ER	PP8 4ER - ATE	PP8 4ER - Carinthia	PP9 RL	PP10 COD	PP11 ITALCAM	Average
HYDROGEN TRANSPORTATION/ DISTRIBUTION															
Road tankers / trailers CGH2	3	4	1			4	3	5	4	3	4	4	4	4	3.58
Road tankers/ trailers LH2	3	4	1			2	3	5	4	3	3	4	4	4	3.33
Pipelines (CGH2)	2	4	1			4	4	5	5	5	4	5	5	4	4.00
Other: Distance between the station and the production site						5									

PARAMETERS	PP1 KSSENA	PP2 (a) BSC - ELES	PP2 (b) BSC - SIGR	PP3 EMS	PP4 FLA	PP5 PVF	PP6 CMT	PP7 KPO	PP8 4ER	PP8 4ER - ATE	PP8 4ER - Carinthia	PP9 RL	PP10 COD	PP11 ITALCAM	Average
HYDROGEN REFUELLING STATIONS (HRS)															
Number of existing H2 stations	5	1	1			2	1	5	5	5	1	2	5	4	3.08
Location of existing H2 stations	5	1	1			5	1	5	5	5	1	5	5	4	3.58
Size of existing H2 Stations	4	1	1			4	1	4	5	5	1	3	5	4	3.17
Type of existing H2 Stations (gas or liquid)	2	1	1			2	1	4	3	5	1	3	3	4	2.50
Number of planned H2 Stations	3	3	2			3	3	5	5	3	3	2	5	4	3.42
Location of planned H2 Stations	3	4	2			5	3	5	5	3	3	5	5	4	3.92

Size of planned H2 Stations	2	4	2			4	3	4	5	3	3	4	5	4	3.58
Type of planned H2 Stations (gas or liquid)	1	4	2			2	2	4	3	3	3	2	3	4	2.75
Storage capacity per HRS	5	5	2			4	3	5	4	5	4	5	4	4	4.17
Other: Long term storage capacity (t/a)	5														
Other: Daily storage capacity (t/day)	4														
Other: Availability 350 or 700 bar						4									

PARAMETERS	PP1 KSSENA	PP2 (a) BSC - ELES	PP2 (b) BSC - SIGR	PP3 EMS	PP4 FLA	PP5 PVF	PP6 CMT	PP7 KPO	PP8 4ER	PP8 4ER - ATE	PP8 4ER - Carinthia	PP9 RL	PP10 COD	PP11 ITALCAM	Average
COSTS															
H2 production costs	5	5	3			5	3	4	4	4	4	4	4	4	4.08
H2 transportation costs	4	5	3			4	3	4	4	4	4	4	4	4	3.92
Capital expenditures (CAPEX) for hydrogen production, distribution, and refuelling infrastructure	5	5	3			4	4	4	4	4	4	4	4	4	4.08
Operational expenditures (OPEX)	3	5	3			4	3	4	5	4	4		5	4	4.00
Other: Price for the customer (at the refuelling station)						5									

PARAMETERS	PP1 KSSENA	PP2 (a) BSC - ELES	PP2 (b) BSC - SIGR	PP3 EMS	PP4 FLA	PP5 PVF	PP6 CMT	PP7 KPO	PP8 4ER	PP8 4ER - ATE	PP8 4ER - Carinthia	PP9 RL	PP10 COD	PP11 ITALCAM	Average
OPTIMISATION / ANALYSIS CRITERIA															
Distance between HRSs	5	4	3			4	5	4	5	5	3	5	5	4	4.33
Carbon footprint / total greenhouse gas (GHG) emissions from the H2 supply chain per km	1	4	3			4	3	3	4	4	5	4	4	3	3.50
Supply and demand matching in the developed network	4	5	3			4	3	4	4	4	4	4	4	4	3.92
Total capital network costs	3	4	2			4	4	4	4	3	4	5	4	4	3.75
Total operational network costs	3	5	3			5	-	4	4	4	4	5	4	4	4.09

6. ANNEX II - EVALUATION FORM

Name:	
Organisation:	
Please evaluate the parameters by rating on a 1 (redundant) to 5 (essential) scale	
Input Parameter/ Layer	Rating
I. Hydrogen demand	**Critical 1 (redundant) to 5 (essential)**
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 Click here to enter	1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐
Other Click here to enter	1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐
Other Click here to enter	1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐

II. Hydrogen Production	Critical 1 (redundant) to 5 (essential)
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 Click here to enter	1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐
Other Click here to enter	1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐
Other Click here to enter	1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐

III. Hydrogen transportation/ distribution	Critical 1 (redundant) to 5 (essential)
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 Click here to enter	1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐
Other Click here to enter	1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐
Other Click here to enter	1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐
Input Parameter/ Layer	Critical 1 (redundant) to 5 (essential)
IV. Hydrogen Refuelling Stations (HRS)	
Number of existing H2 Stations	1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐
Location of existing H2 Stations	1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐
Size of existing H2 Stations	1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐
Type of existing H2 Stations (gas or liquid)	1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐
Number of planned H2 Stations	1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐
Location of planned H2 Stations	1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐
Size of planned H2 Stations	1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐
Type of planned H2 Stations (gas or liquid)	1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐
Storage capacity per HRS	1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐

(For reference, the EU target for heavy trucks is for an HRS to have a minimum daily capacity of at least six tonnes of H2, with at least two dispensers per stations)	
Other Click here to enter	1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐
Other Click here to enter	1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐
Other Click here to enter	1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐
V. Costs	Critical 1 (redundant) to 5 (essential)
Costs of production per H2 kg	1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐
Costs of transportation per unit H2 per km	1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐
Capital costs of production infrastructure	1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐
Capital costs of transportation infrastructure	1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐
Costs of the refuelling infrastructure *(Pipelines, liquefaction plants, storage facilities, compressors, and dispensers involved in the process of delivering fuel)*	1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐
Capital expenditures (CAPEX) *(Maintenance, repair, stock loss, energy consumption)*	1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐
Operational expenditures (OPEX) *(The sum of all direct costs incurred in the production of goods or services)*	1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐
Other Click here to enter	1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐

Other	Click here to enter	1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐
Other	Click here to enter	1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐

Optimisation/analysis criteria	Critical 1 (redundant) to 5 (essential)
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[13]/ 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 according to the EU strategies)*	1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐
Total capital network costs *(Calculate and optimise the cost configurations i.e. between on-site or off-site, different configurations)*	1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐
Total operational network costs	1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐
Other Click here to enter	1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐
Other Click here to enter	1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐

[13] A carbon footprint is the total greenhouse gas (GHG) emissions caused directly and indirectly by an individual, organization, event or product."[1] 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).

Other	Click here to enter	1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐