energies

Article

A Flow-Based Approach for the Optimal Location and Sizing of Hydrogen Refueling Stations Along a Highway Corridor

Salvatore Micari [1,*], Antonino Salvatore Scardino [1], Giuseppe Napoli [1], Luciano Costanzo [1], Orlando Marco Belcore [2] and Antonio Polimeni [2]

[1] National Research Council of Italy Institute of Advanced Technologies for Energy, 98126 Messina, Italy; antoninosalvatorescardino@cnr.it (A.S.S.); giuseppe.napoli@cnr.it (G.N.); lucianocostanzo@cnr.it (L.C.)
[2] Department of Engineering, University of Messina, 98158 Messina, Italy; obelcore@unime.it (O.M.B.); antonio.polimeni1@unime.it (A.P.)
* Correspondence: salvatore.micari@cnr.it

Abstract

The development of hydrogen refueling infrastructure plays a strategic role in enabling the decarbonization of the transport sector, especially along major freight and passenger corridors such as the Trans-European Transport Network (TEN-T). Despite the growing interest in hydrogen mobility, existing methodologies for the optimal location of hydrogen refueling stations (HRS) remain fragmented and often overlook operational dynamics. Following a review of the existing literature on HRS location models and approaches, this study highlights key methodological gaps that hinder effective infrastructure planning. In response, a two-stage framework is proposed, combining a flow-based location model with a stochastic queueing approach to determine both the optimal placement of HRS and the number of dispensers required at each site. The method is applied to a real segment of the TEN-T network in Northern Italy. The results demonstrate the flexibility of the model in accommodating different hydrogen vehicle penetration scenarios and its utility as a decision-support tool for public authorities and infrastructure planners.

Keywords: hydrogen refueling stations; flow-based location model; fuel cell electric vehicles; TEN-T corridor; hydrogen mobility planning

check for updates

Academic Editors: Jin Lin, Kai Song, Jinhai Jiang and Fulin Fan

Received: 19 August 2025
Revised: 23 September 2025
Accepted: 7 October 2025
Published: 9 October 2025

Citation: Micari, S.; Scardino, A.S.; Napoli, G.; Costanzo, L.; Belcore, O.M.; Polimeni, A. A Flow-Based Approach for the Optimal Location and Sizing of Hydrogen Refueling Stations Along a Highway Corridor. *Energies* **2025**, *18*, 5322. https://doi.org/10.3390/en18195322

Copyright: © 2025 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https://creativecommons.org/licenses/by/4.0/).

1. Introduction

Hydrogen is recognized as a key pillar in the decarbonization of the transport sector, particularly in segments that are hard-to-abate. Therefore, the deployment of dedicated refueling networks is essential to support the uptake of fuel cell electric vehicles (FCEVs) and to facilitate the transition toward more sustainable mobility systems. In this context, several countries have launched large-scale programs aimed at expanding the hydrogen supply chain. HRS play a crucial role in supporting hydrogen-based mobility adoption and are increasingly being designed to serve a wide range of transport applications, including both passenger and freight vehicles [1,2].

In Asia, hydrogen has been positioned by several countries as a strategic pillar of long-term decarbonization efforts, with particular emphasis on applications in heavy-duty transport, industrial corridors, and port logistics. China currently leads the implementation of the hydrogen infrastructure, actively promoting the adoption of FCEVs through coordinated national and provincial subsidy programs [3,4]. Likewise, Japan and South Korea have launched ambitious investment strategies, aiming to deploy more than 1000 HRS each

by 2030 to support commercial fleets and public transport. These countries are promoting integrated hydrogen ecosystems that encompass production, distribution, and refueling, underpinned by long-term industrial policies and strong public–private collaboration [5]. In North America, the United States have adopted a national-scale approach through the National Clean Hydrogen Strategy and Roadmap, reinforced by large-scale investments under the Infrastructure Investment and Jobs Act. This includes the creation of Hydrogen Hubs (H2Hubs) and a clear focus on enabling hydrogen for freight and logistics corridors, with coordinated deployment of production, distribution, and refueling assets [6,7]. In Europe, hydrogen plays a central role in the Green Deal and the REPowerEU initiative, which emphasizes the need to reduce fossil fuel dependence and increase renewable energy integration. The Alternative Fuels Infrastructure Regulation (AFIR), adopted in 2023, requires the installation of publicly accessible HRS for heavy-duty vehicles every 200 km along the TEN-T by 2030, with minimum requirements for capacity, safety, and interoperability [8–10]. Several European countries have already incorporated these objectives into their national strategies. Germany, France, Spain, and the Netherlands have combined regulatory frameworks with financial instruments to accelerate deployment. In Italy, the National Hydrogen Strategy [11] and the National Recovery and Resilience Plan (PNRR) have planned the construction of 40–48 HRS along key TEN-T corridors. The ongoing projects in Verona, Trento, and Sadobre reflect this momentum and aim to support both domestic and cross-border freight mobility with scalable, dual-pressure stations.

Despite the rapid growth of policy support and infrastructure deployment, significant challenges remain regarding the spatial planning and technical dimensioning of HRS networks. Most of the existing studies in HRS literature focus on the location optimization using simplified representations of transport networks or abstract demand approximations. These approaches often fail to account for real-world traffic dynamics, temporal variability in vehicle flows, and the stochastic nature of the process, which are critical factors in infrastructure planning. Furthermore, sizing aspects, such as the number of dispensers required at each station and the expected service level, are typically addressed separately if at all. Existing stations, when present, are rarely integrated as fixed nodes within the optimization process, despite their impact on future infrastructure configurations.

This study addresses these gaps by proposing a two-stage methodological framework for the optimal location and sizing of HRS within real transport networks, with a test application to a portion of the Italian segment of the TEN-T corridor. The procedure is sequential: before the stations are located on the network and after they are sized as a function of the potential vehicular flows by using the stochastic queueing theory. The position of (eventual) existing stations is considered fixed; only their size is recalculated. The findings of this paper may be useful to decision makers in planning the network of refueling stations, both in terms of location and the number of pumps to be activated.

Although the scientific community has produced a wide range of contributions on the problem of HRS planning, several weaknesses remain evident. Traditional p-median and set-covering formulations provide valuable insights for facility location but usually assume homogeneous demand distributions and static operating conditions, thus overlooking the variability of real traffic flows and temporal demand peaks. Flow-based approaches, on the other hand, capture the role of vehicle routes and origin–destination flows, but are often limited to theoretical formulations or simplified network structures that do not reflect the constraints and heterogeneity of actual transport corridors. Furthermore, the majority of studies treat the sizing of stations as a separate problem, addressing capacity, number of dispensers, or service levels independently from the location model. This separation reduces the applicability of the results in real-world contexts, where the interaction between the geographical placement of a station and its operational performance is decisive. An-

other limitation concerns the treatment of existing infrastructure: in many cases, available or planned HRS are not explicitly integrated as fixed nodes in the optimization, even though their presence can significantly influence future network configurations. These gaps highlight the need for methodological frameworks able to integrate spatial location and capacity sizing within a single, coherent decision-support process. The innovative contribution of the present study lies precisely in this integration: a two-stage model that first applies a flow-based location approach and then incorporates a stochastic queueing procedure for dispenser allocation. In this way, the method not only identifies optimal sites along a real highway corridor but also provides quantitative indications on the number of pumps required to guarantee predefined service levels under different penetration scenarios of hydrogen vehicles. By addressing location and sizing simultaneously, while considering existing stations as fixed elements, the proposed approach improves robustness and transferability compared to previous models and offers infrastructure planners a more realistic and operationally relevant tool.

The structure is as follows: Section 2 provides a review of the main modeling approaches for HRS location, with a focus on flow-based, p-median, and set-covering models. Section 3 discusses the technological and policy context for HRS deployment with particular reference to recent Italian and European initiatives. Section 4 describes the methodological framework adopted in this study, which combines a location model with a queueing-based sizing procedure. Section 5 illustrates the application of the proposed model to a segment of the Italian TEN-T network, analyzing the results under different traffic and planning scenarios. Section 6 presents a discussion of the findings and their implications. Finally, Section 7 concludes the paper and outlines directions for future research.

2. Literature Review

The location problem for refueling/charging stations has been formulated and solved by several scholars, with different models and approaches. In general, the location science consists of determining the best location for one or several facilities or equipment [12] with the aim of satisfying the demand of a set of users. This topic is widely studied in the literature and it is related to different sectors (e.g., industry [13,14], transportation [15,16], sensors placement [17]). Several classifications of location problems can be made, in relation to the objective to be optimized and the constraints to be respected [18]. The following groups of problems should be considered: *p*-median problems (aimed at minimizing the sum of the cost between each customer and the nearest facility), set-covering problems (aimed at locating the minimum number of facilities by covering all the customers), and flow-based approaches (aimed at maximizing the flows intercepted by the stations). Other methods are available in the literature, such as *p*-center models, but these models are rarely used for the positioning of HRS (as an example, see Lin and Lin [19] who proposed a *p*-center model with the objective of minimizing the percentage of deviation from the shortest path by users who need to reach the refueling station).

Itaoka et al. [20] proposed a *p*-median model where the time is weighted with respect to the demand level and the objective is the minimization of the total average time of the users. The approach (a combination of heuristic algorithms) is designed to take into account the presence of existing HRS. Upchurch and Kuby [21] compared the results obtained using a *p*-median model and a flow-based model, concluding that the flow-based model performs better than the *p*-median one. A similar comparison is reported in Homna and Kuby [22] who highlight how flow-based models allow users to reduce the time spent to reach the stations. Kim et al. [23] applied a sequential approach (set that covers *p*-median models) to solve the problem. Starting from the minimum number of required stations, the location problem and the assignment of the demand to the stations are solved

sequentially. Gündüz et al. [24] used a set-covering model that incorporates information on population density to locate HRS within a city. The problem is formulated considering different time periods and is solved by means of heuristic procedures. Mirhassani and Ebrazi [25] proposed a path-based approach to locate refueling stations on a road network, the aim being to minimize the costs of station construction. The authors also formulated a modification of the problem to transform it into a flow-based model, the goal of which is to maximize the covered demand. Gallo [18] formulated a flow-based problem aimed at maximizing demand served, also providing a variant of the problem formulated as maximization of the origin–destination pairs covered. The solution procedure is a greedy algorithm. Similarly, in [26], the flow-based model was coupled with a model capable of simulating the diffusion of FCEVs. Kim and Kuby [27] proposed a flow-based model that could take into account the deviation of the user from the shortest path to reach the refueling station. The objective is to maximize the demand covered by guaranteeing an established number of refueling stations. Nicholas et al. [28] proposed an approach based on a geographic information system to locate stations within a city with the aim of minimizing the travel time of the user who needs to refuel. While these contributions provide valuable insights into HRS planning, they also share important limitations. Many formulations adopt simplified demand assumptions or static network representations that do not capture the variability of real traffic flows. Others focus exclusively on the spatial location of facilities, postponing or neglecting the sizing of stations, which in practice strongly affects service levels and user acceptance. In addition, the role of existing or planned stations is rarely considered explicitly, even though their presence can substantially shape the optimal configuration of future networks. These aspects limit the transferability of results to real transport corridors and reduce the usefulness of models for infrastructure planners. The framework proposed in this study seeks to address these deficiencies by integrating a flow-based approach with a stochastic queueing model for dispenser allocation, thus combining location and sizing within a single, coherent procedure.

3. Technological and Policy Context

The widespread deployment of HRS is a key enabler for the large-scale adoption of hydrogen-based mobility. This process depends not only on strategic planning and infrastructure design, but also on the availability of mature and reliable technologies, as well as on the presence of clear and consistent policy frameworks at national and international level. From a technological standpoint, HRS can be classified according to the hydrogen supply mode. Stations may be equipped with on-site production systems, typically based on water electrolysis, or rely on off-site hydrogen delivery, which can include high pressure gaseous hydrogen transported through tube trailers, liquid hydrogen (LH_2) delivered by cryogenic trucks, or, in some contexts, pipeline connections. The choice between on-site generation and external supply has direct implications for compression, storage, and dispensing subsystems, as well as for operational flexibility and integration with renewable energy sources. Hydrogen stations are highly diversified and must be tailored to the specific operational context in which they are installed. Key parameters include refueling capacity, delivery pressure (commonly 350 or 700 bar), and storage technology (compressed gas, liquid, or cryo-compressed hydrogen), focusing solely on the class of light-duty vehicles with typical refueling times on the order of 5 min [29–32].

3.1. Technological Configuration of HRS

The HRS can operate by either receiving hydrogen from external sources or producing it on-site. In the case of external supply, the infrastructure must accommodate unloading, intermediate storage, compression, and dispensing systems compatible with the delivered

form and pressure. On the contrary, stations equipped with on-site production systems, such as electrolysis, require the integration of electrolyzers, water purification units, power electronics, and thermal management components, as well as coordinated interaction with compression and storage subsystems. Each configuration has specific design and operational requirements that affect capital costs, station layout, and integration with the energy supply system. Among electrolysis technologies, the alkaline (ALK) and proton exchange membrane (PEM) systems are the most commercially mature. Alkaline electrolyzers offer high durability and are cost-effective for base-load operation, whereas PEM electrolyzers provide faster dynamic response and compactness, making them well-suited for coupling with variable renewable energy sources. Emerging systems such as an anion exchange membrane (AEM) and solid oxide electrolyzers (SO) are under investigation. AEM technology combines the structural simplicity of alkaline systems with the dynamic capabilities of PEM, while SO operates at high temperatures and allows for improved energy efficiency by recovering industrial heat. However, both still face technical challenges regarding stability, cost, and commercial scalability. Integration of electrolysis in HRS affects the entire station architecture, particularly in terms of compression stages, storage dimensioning, pre-cooling requirements, and electrical supply systems. A comparative overview of the main electrolysis technologies is presented in Table 1, highlighting differences in operating conditions, durability, purity, and costs.

Table 1. Electrolyzer Comparison.

Technology	Temperature (°C)	Pressure (Bar)	Durability (Hours)	Purity H_2 (%)	Costs [USD/kW]	References
ALK	60–80	2–35	10,000–40,000	99.3–99.9	2.36–6.98	[1,33–35]
PEM	50–80	15–40	10,000–40,000	99.9999	2.5–6.8	[33,36]
AEM	60–80	1–30	<3000	99.99	3–7	[34,35]
SO	500–1000	1–10	< 20,000	>99.5	2.99–7.02	[33,37]

Hydrogen compression is a critical subsystem in the refueling station architecture, allowing the pressurization of hydrogen gas up to 700 bar for on-site storage and vehicle dispensing. The selection of compression technology directly affects the efficiency of the system, the purity of the gas, the energy consumption, and the maintenance requirements [38–40]. Mechanical compression remains the most widely used solution in HRS. Reciprocating piston compressors are widely adopted because of their ability to deliver high outlet pressures. However, they involve moving parts subject to wear and require frequent maintenance and gas purification stages to mitigate the risks of lubricant contamination [41,42]. Diaphragm compressors represent a well-established alternative, particularly in applications requiring high-purity hydrogen. These systems utilize a flexible membrane actuated hydraulically. This design isolates the gas from mechanical elements, eliminating oil contamination and ensuring high-purity output [40]. Recent developments include ionic liquid compressors, which replace pistons with ionic fluids to reduce mechanical wear and maintain purity, although scalability and fluid stability remain challenging [43]. Non-mechanical compression technologies are also under exploration. Cryogenic hydrogen systems employ pumps to pressurize liquid hydrogen before vaporization, achieving high flow rates with reduced mechanical complexity. Adsorption-based and metal hydride compressors rely on thermally driven phase transfer processes, whereas electrochemical compressors, based on proton exchange membranes, enable oil-free compression in compact, modular formats, suitable for decentralized or small-scale applications. Despite their advantages, these systems still face constraints in flow rate and thermal control [44]. Hydrogen storage and distribution systems are equally crucial for station safety and performance.

Compressed gaseous hydrogen (CGH_2) at 350–700 bar is the most common storage method, typically using Type IV composite tanks with thermal control. Although it allows rapid refueling, its low volumetric energy density (~5.6 MJ/L) necessitates significant infrastructure [45]. For high-capacity applications, cryogenic liquid hydrogen (LH_2) offers a higher energy density (~8.5 MJ/L). However, it involves boil-off losses and energy-intensive liquefaction, which can consume up to 30% of the usable hydrogen energy content [46]. Cryo-compressed hydrogen (CcH_2) offers an intermediate solution, which combines moderate pressures with cryogenic conditions to improve storage density and reduce losses. Alternative chemical storage methods, such as metal hydrides and liquid organic hydrogen carriers (LOHCs), support ambient storage but are constrained by kinetics and thermal requirements [47]. Ammonia-based configurations have shown competitive costs (6.28–6.89 €/kg at 450 kg/day), while photovoltaic-powered electrolysis remains costlier (~7.92 €/kg) due to high capital expenditure [48]. Hydrogen distribution is commonly based on cascade systems, which employ sequential storage banks at descending pressures to optimize refueling dynamics while complying with SAE J2601 standards [49]. Pre-cooling systems (−40 °C) are standard for minimizing thermal effects during fast fills, although they can contribute 4% to overall station energy consumption. Subcooled liquid hydrogen (sLH_2), stored at ~−245 °C and 16–25 bar, is emerging as a high-density alternative for heavy-duty vehicle applications [50,51].

3.2. Policy Framework and National Funding Programs in Italy

The policy framework plays a crucial role in enabling the deployment of hydrogen refueling infrastructure. National and European strategies have established a combination of regulatory targets and funding mechanisms to support the expansion of the hydrogen economy, particularly in the transport sector. In Italy, these policies have taken shape through measures included in the National Hydrogen Strategy, the PNRR, and the AFIR, which collectively aim to promote the deployment of public HRS along strategic corridors. Several funding measures have already been launched to support hydrogen production, logistics, and end-use applications (see Table 2), and additional programs are expected to be activated in the near future.

Table 2. Overview of national funding programs in Italy for hydrogen refueling infrastructure.

Call/Funding Program	Objective	Key Requirements	Results	References
PNRR M2C2 Investment 3.3	Hydrogen experimentation for road transport	TEN-T corridors, certified green hydrogen, public–private partnerships	40–48 HRS	[52]
CEF Transport Alternative Fuels Infrastructure Facility (AFIF)	Support alternative fuels infrastructure	Public–private co-financing, priority TEN-T corridors, intermodality	Deployment of hydrogen refueling stations on TEN-T network	[53]

Under PNRR M2C2—Investment 3.3, a total of 48 HRS projects were initially funded, although subsequent withdrawals have reduced the number to 30 [52]. Additionally, two more stations are supported through CEF funding [53]. Four HRS projects in Italy, located at Paganella Est, Paganella Ovest, Verona, and Sadobre, have entered the executive design or construction phase as part of the National Hydrogen Strategy and PNRR (Investment 3.3). Table 3 provides a summary of the technical specifications of HRS in Italy, encompassing both operational sites and those currently under construction. Daily capacities range from 500 to 3500 kg of hydrogen, with dual-pressure dispensing at 350 and 700 bar to serve

both light-duty and heavy-duty vehicles. Stations typically include 6 to 8 dispensing points, precooling systems to −40 °C, and multistage compression systems. Refueling times remain less than 5 min for LDV. All facilities comply with relevant EU and national standards, such as ISO 14687 [54] and SAE J2601.

Table 3. Comparison of Design and Performance Parameters for Italian HRS Projects.

Italian HRS Projects	Average Daily H_2 Requirement [kg]	Number of Daily Refueled LDV	Delivery Pressures [bar]	Number of Dispensing Columns	Refueling Time [kg]	Total H_2 Storage [kg]	References
Paganella Ovest	500	46	700	2	10 ≤ 5 min	~2350	[55]
Paganella Est	500	46	700	2	10 ≤ 5 min	~2350	[56]
Verona Nord (CSA)	3500	270	700	1	10 ≤ 5 min	2000 @ 350 bar 1000 @ 500 bar 500 @ 940 bar	[57]
Sadobre	1700	16	700	2	—	1180 @ 350 bar 380 @ 500 bar 140 @ 900 bar	[58]
Carugate Est	1000	—	350/700 (1)	3	—	333 @ 500 bar 115 @ 930 bar	[59,60]

(1) Multiple refueling modes: 700 bar for light-duty vehicles, 350 bar for both light- and heavy-duty vehicles, and 350 bar high-flow for heavy-duty applications.

4. Methodology

The methodology aims to obtain a network of HRS in a highway and consists of two main parts: a location procedure which outputs a potential position for the station in relation to the road classification, and a sizing procedure, which outputs the number of dispensers in relation to the vehicular flow.

The location procedure is designed to identify the points where to locate the hydrogen stations, taking into account a threshold value d_{max} for the distance between two successive stations and the type of road link. The presence of existing stations is also considered in the procedure, representing the road by means of a graph $G(N, L)$, where N is the set of nodes and L is the set of links; the existing station set E is a subset of N ($E \subseteq N$), and the set L consists of two disjoint subsets: L_1 contains links where the stations could be located, and L_2 contains links where the location is not possible (e.g., a bridge, a tunnel, a motorway junction). The set N can also be divided into two subsets: N_1 containing road nodes (e.g., a motorway junction) and N_2 containing other nodes (e.g., existing stations).

The developed procedure allows us to quickly obtain the position of the stations, postponing their sizing to the next phase. In the first step, the road macro-sections between two successive nodes belonging to N_1 are identified (e.g., the section between nodes 1 and 2 in Figure 1). If the macro-link contains existing stations, it is further divided into links (1–s_1 and s_1–2 in Figure 1). Taking existing stations into account allows (1) (possibly) optimizing their size and (2) including as input to the problem the location of traditional fueling stations for which it has been established (a priori) that it is possible to allocate a hydrogen refueling plant, while also considering the regulatory constraints of each country regarding the safety distances required for hydrogen installations.

Then, the distance d_{ij} between two successive nodes i and j is calculated, and the ideal number of stations n to put is as follows:

$$n = \left\lceil \frac{d_{ij}}{d_{\max}} \right\rceil \quad (1)$$

The distance between the stations is:

$$d_{mod} = \left\lfloor \frac{d_{ij}}{n} \right\rfloor \tag{2}$$

Repetition of the procedure for all pairs of nodes ensures that the stations are placed throughout the analyzed road network.

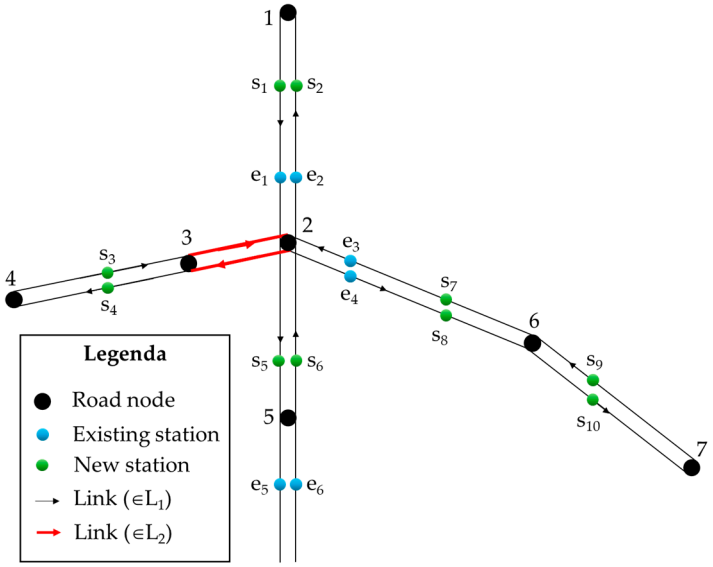


Figure 1. Positioning the stations.

After the location of the stations, it is required to define their size as a function of the number of users (per unit of time) that require to use them. To solve this problem, an approach based on stochastic queues is used [61]. In particular, the system is simulated with a multi-server M/M/s queue model [62] with a service discipline type FIFO (First In First Out). Assuming that the arrival of vehicles [63] is a Poisson distribution with parameter λ, it is possible to size each station in terms of the number of servers (two nozzles for each dispenser) s so that the probability of waiting in the queue (intended as a measure of the level of service of the system) is less than a threshold value. Since each dispenser contains two nozzles, the model outputs the number of nozzles used in relation to the level of service established. Let the service rate be the same for all servers, the value $s\mu$ represent the maximum service rate, and $\rho = (1/s\mu)$ be the traffic intensity. With this symbology, the average service time t_s is equal to $1/\mu$. When a system is represented in this way, the probability P_w that a user experiences a delay is given by the following:

$$P_w = \frac{\alpha^s}{s!\left(1 - \frac{\alpha}{s}\right)} \cdot p_0 \tag{3}$$

where

- $\alpha = \lambda/\mu$;
- s is the number of servers;
- $p_0 = \left[\sum_{r=0}^{s-1} \frac{\alpha^r}{s!} + \frac{\alpha^s}{s!} \cdot \left(1 - \frac{\alpha}{s}\right)^{-1}\right]^{-1}$ is the probability of having no vehicles in the system.

The goal is to set the value of s in order for $P_w \leq p_{lim}$, where p_{lim} is a parameter that indicates a probability value that must not be exceeded (this guarantees the desired level of service). Once the value of s has been identified, other indicators can be calculated to analyze the system's performance:

- $L_q = \frac{\rho\alpha^s}{s!(1-\rho)^2} \cdot p_0$, the queue length;
- $L = L_q + \alpha$, the number of vehicles in the system;
- $W_q = \frac{\alpha^s}{s!s\mu(1-\rho)^2} \cdot p_0$, the average waiting time in queue;
- $W = W_q + \frac{1}{\mu}$, the average time spent in the system.

Figure 2 shows the sizing procedure used to determine the number of dispensers at each station.

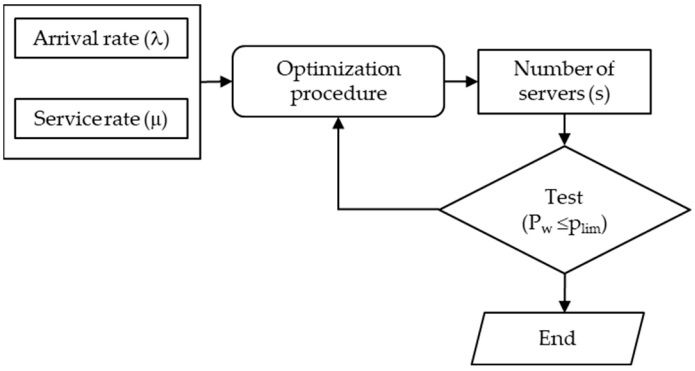


Figure 2. Sizing the stations.

5. Application

The application focuses on a portion of an Italian highway A22, located in Northern Italy, between Brenner (on the Italian border) and Verona (Figure 3). This highway is part of the TEN-T for the Scandinavian–Mediterranean corridor [64]. The road portion considered is 225.64 km long in the north–south direction and 227.03 km long in the south–north direction, and crosses two different administrative regions (Trentino and Veneto) with a total population of approximately 6 million. In the direction of north–south, there are 40.94 (18.14%) kilometers where the stations cannot be located; in the opposite direction, the unusable road links amount to 39.61 (17.45%) kilometers.

To date, in Italy, only one hydrogen charging station is available and another is in development (Figure 4). Other stations are foreseen in future years (both by upgrading existing stations and by building new ones). However, the penetration scenarios of FCEVs are highly uncertain due to the limited number of hydrogen vehicles currently registered in Italy. The Italian National Hydrogen Mobility Plan for 2019 provided indicative projections of around 27,000 vehicles by 2025 (~0.1% of the national fleet), 290,000 by 2030 (~0.7%), and 8.5 million by 2050 (~20%) [63]. Although the most recent Italian National Hydrogen Strategy (2024) reports that the actual number of FCEVs in circulation remains extremely low, 65 units in 2023 and only 368 vehicles sold in Italy between 2014 and 2024, it is expected that the momentum generated by the European Green Deal and the investments in the hydrogen sector within the National Recovery and Resilience Plan (PNRR) could accelerate hydrogen production, storage, and distribution for the automotive sector, as well as the deployment and use of fuel cell vehicles in addition to battery electric ones [11,65–67]. To this end, a wide range of scenarios has been considered, including penetration coefficients up to twice those estimated in [68]. Therefore, the adopted approach is parametric considering the number of FCEVs as a rate of vehicles on the road. The first four scenarios (labeled from A to D) were developed based on the optimistic projections reported in [68], assuming a penetration coefficient r between 5% and 20%. As an additional exercise, subsequent post-2050 projections were evaluated, considering higher values of r in the range of 25% to 40% (labeled from E to H).

To set the arrival rate and in order to maintain the generality of the procedure, it is assumed that the level of hydrogen in the tank follows a normal distribution; then, the contents of the tank can vary between a minimum and a maximum following the normal distribution; vehicles stopping to refuel have a quantity of hydrogen below a threshold value (similarly to what is done for electric vehicles, [69]).

The analysis considers exclusively hydrogen LDV, which are typically equipped with 700 bar (70 MPa) high-pressure-type IV tanks, in accordance with the SAE J2601 standard. This configuration reflects the specifications of currently available vehicles on the market, such as the Toyota Mirai [29] and Hyundai NEXO. Furthermore, according to the scientific literature [70,71], the time required for full refueling of these vehicles generally ranges between 2.6 and 6.7 min, depending on the initial pressure of the tank and ambient temperature. However, since vehicles typically do not arrive with an empty tank, this study adopts a realistic refueling time between 2 and 6 min.

In summary (Table 4), for each scenario, a percentage r of vehicular flow consists of hydrogen cars and, among these, those with a quantity of hydrogen below a threshold stop to refuel. The value of the refueling time t_s (linked to the parameter m) is different for each scenario. When solving the problem, the position of the two available stations in the area is considered fixed, while the position of the others is obtained following the procedure described in the previous section. The size of the stations (number of hydrogen pumps to allocate) is obtained by setting a value of 10% for the parameter p_{lim} and a value of 50 km for d_{max}.

Table 4. The parameters of the problem.

Scenario	r (Rate of FCEVs) [%]	t_s (Average Service Time) [min]	p_{lim} [%]	d_{max} [km]
A	5	6	10	50
B	10	6		
C	15	5		
D	20	5		
E	25	4		
F	30	3		
G	35	2		
H	40	2		

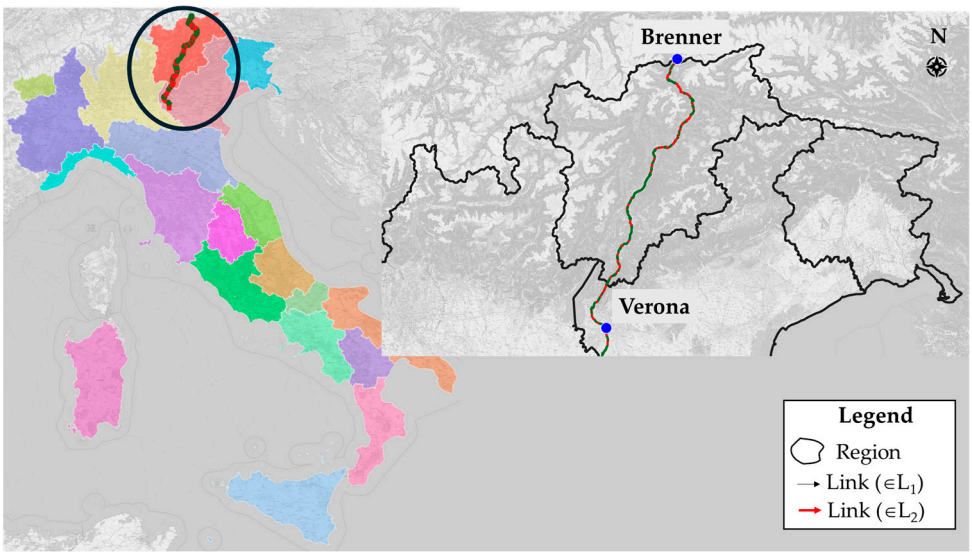


Figure 3. The study area: motorway from Brenner to Verona (background map: OpenStreetMap).

The application takes as input a portion of a highway, but the methodology is applicable to networks of any size both in relation to the positioning of the hydrogen stations and their sizing.

6. Discussion

In this section, the results of the location and sizing of the stations are reported. On the road selected for the test problem, the two points (Figure 4) where the stations are already located are considered fixed. Figure 4 is a schematic representation of the stretch of highway under consideration. Following such a figure, consider the North–South direction:

- The link 1–s_2 has a length less than d_{max}, so on this link, positioning a station is not needed;
- For the link s_2–s_4, the approach gives as output 2 stations to be located on the link: one of the two is the existing one, and the second will be placed at a distance of 34.41 km from the first;
- For the link s_4–3, the approach gives as output 3 stations, the first of which is s_4.

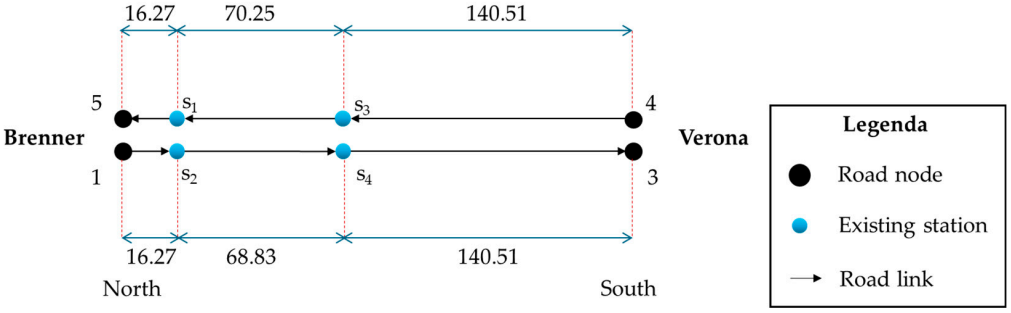


Figure 4. Schematic representation of the highway (length in kilometers).

Table 5 reports the position of the stations in terms of location (coordinates) and direction (if positioned in the north–south axis or in the opposite direction). Also, it is indicated whether the station exists or not and the distance to travel to reach the next one. Figure 5 shows the position of the stations along the highway; it can be noted that the position for North–South and vice versa is quite symmetrical (this symmetry is not perfect because of the different length of the two directions and the constraint on feasible links).

Table 5. The position of the stations.

Station ID	Coordinates	Direction	Existent	Distance Interval [km] *
1	(11.436275, 46.884503)	North-South	Yes	34.41
2	(11.611089, 46.663272)	North-South	No	34.41
3	(11.318711, 46.477766)	North-South	Yes	46.85
4	(11.086679, 46.117956)	North-South	No	46.85
5	(10.986084, 45.748814)	North-South	No	46.85
6	(10.907998, 45.430118)	North-South	No	-
7	(10.908106, 45.430072)	South-North	No	46.84
8	(10.986198, 45.748719)	South-North	No	46.84
9	(11.086875, 46.117795)	South-North	No	35.13
10	(11.318717, 46.477577)	South-North	Yes	35.13
11	(11.605555, 46.658260)	South-North	No	35.13
12	(11.436609, 46.884690)	South-North	Yes	-

* to the next station.

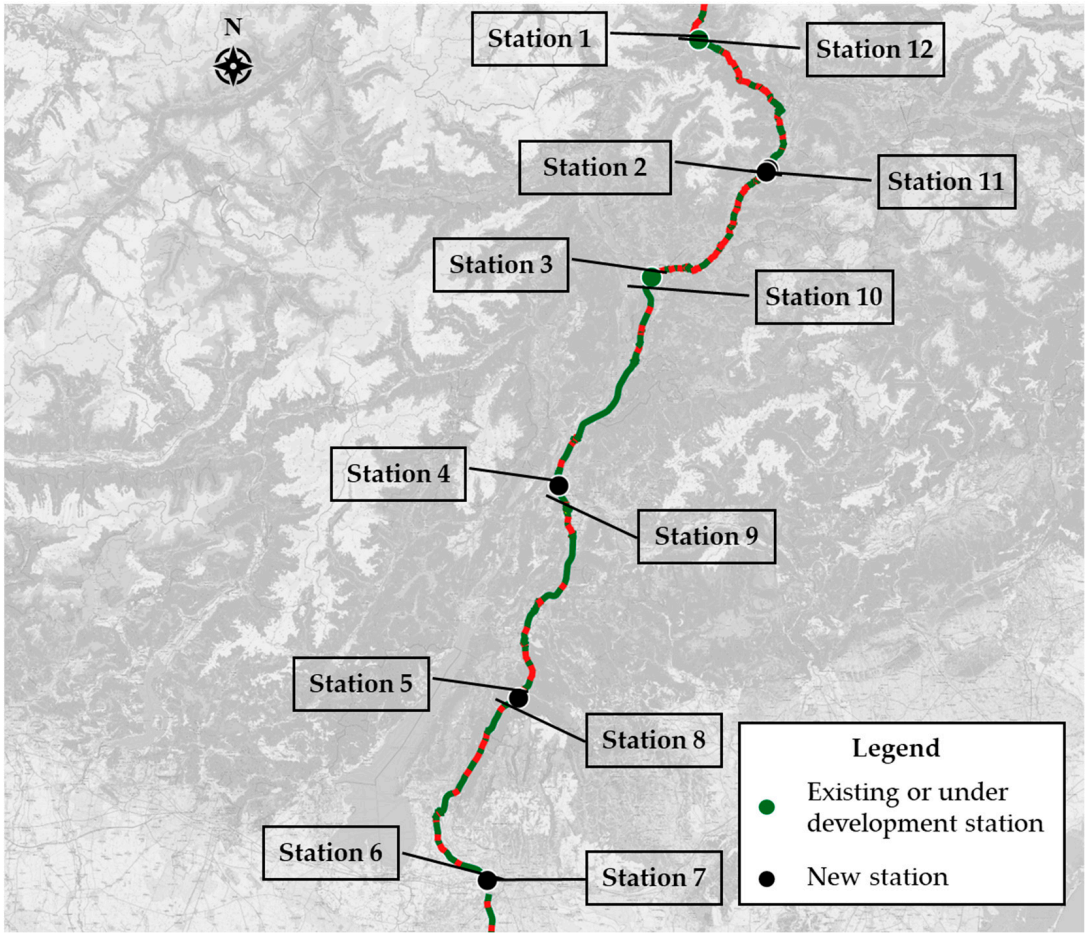


Figure 5. Stations on the selected highway (background map: OpenStreetMap).

Figure 6 shows the results of the sizing problem for each station and each scenario. The minimum number of pumps needed is 2, while the maximum is 8. Similarly, Figure 7 reports the results in terms of P_w, whose value ranges from 10% (the maximum admitted) to about 3%.

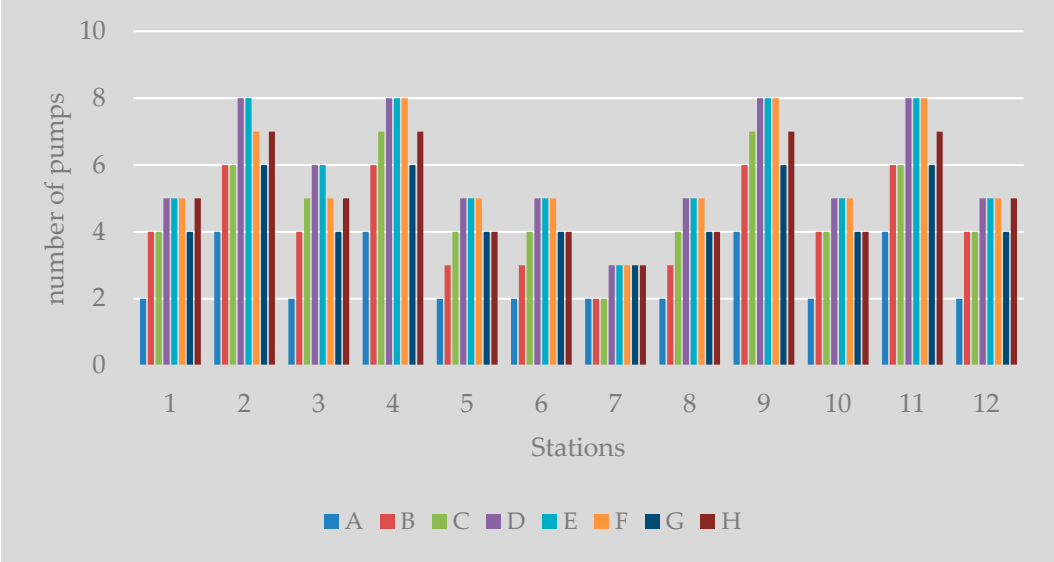


Figure 6. Number of pumps per station and scenario.

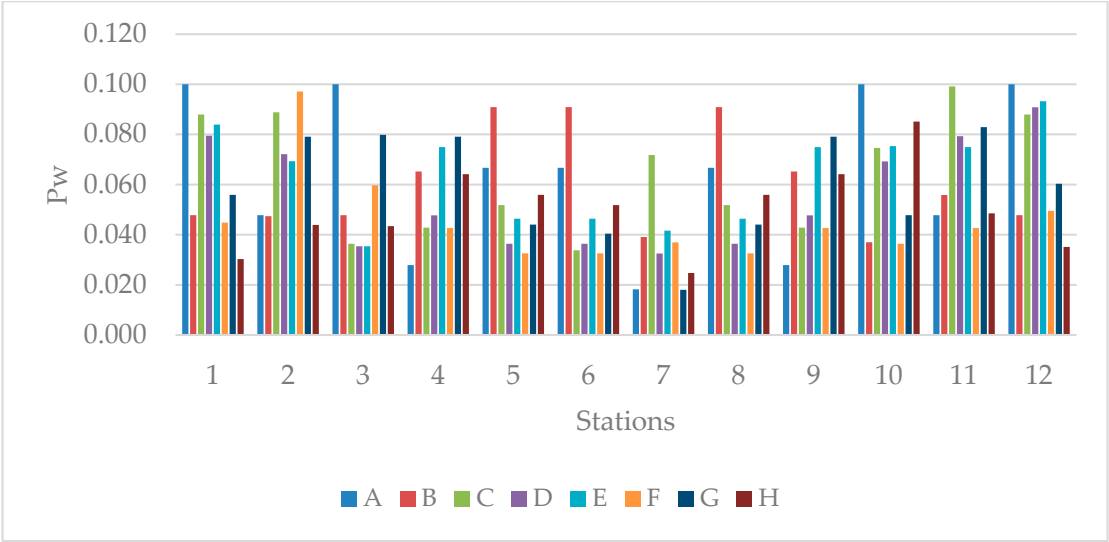


Figure 7. Delay probability P_w per station and scenario.

The other queue indicators (L_q, L, W_q and W) reported in Figures 8 and 9 give further information on how the system is functioning. In the case test reported here to illustrate the functioning of the procedure, no critical aspects emerged. We noted a maximum number of 4 vehicles in the system; the most disadvantaged user remained in the system for 6 min. Although these are the results of a test, the procedure can be applied to any other case and provides quantitative indicators to assess the functioning of the system. In addition, it can be used to size the system and assess future scenarios.

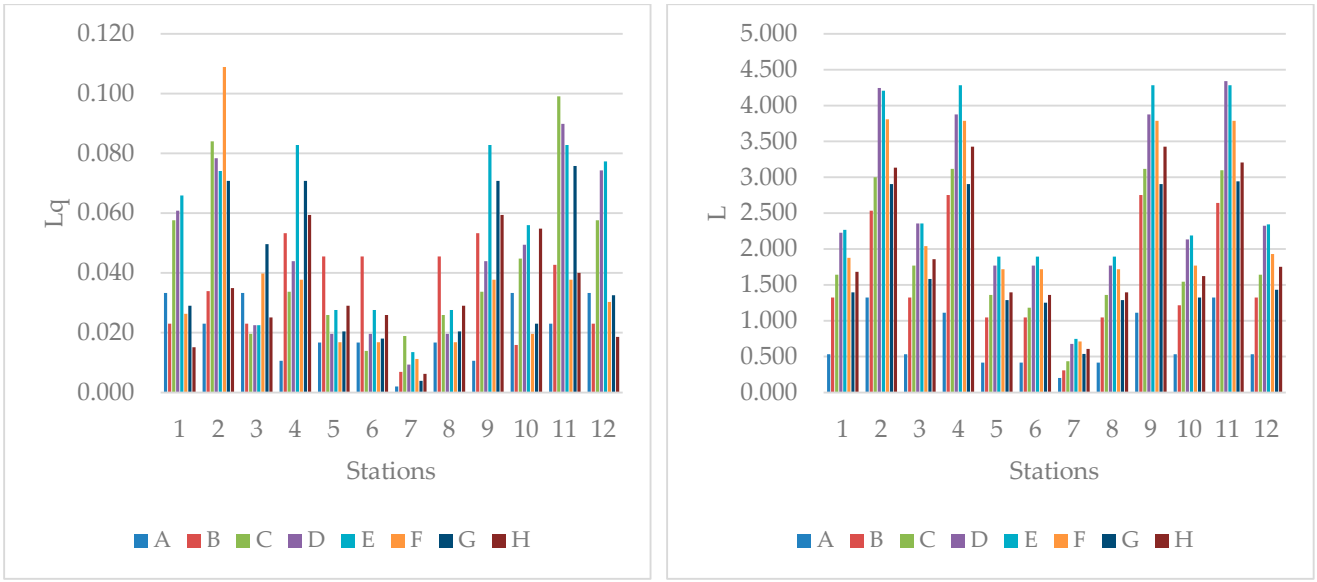


Figure 8. Indicators: queue length (L_q) and number of vehicles in the system (L).

Furthermore, a comprehensive global sensitivity analysis (GSA) would be required to fully assess the robustness of the proposed framework with respect to its main input parameters. This task goes beyond the scope of the present work and will be addressed in future research. However, to provide the reader with a reference for possible methodological extensions, we highlight that similar GSA approaches have been successfully applied in other engineering domains to capture the influence of multiple interacting factors, for example, in the study of hot-mix asphalt dynamic modulus parameters [72] and in the seismic performance of reinforced concrete shear walls [73]. A complete techno-economic

evaluation was not included, since HRS costs (CAPEX and OPEX) strongly depend on technology maturity (TRL < 9), geographical location, supply chain configuration, and station size. Nevertheless, recent European studies provide indicative benchmarks for green hydrogen refueling based on electrolysis technologies. Reported values include CAPEX in the range of 1600–2000 €/kW for Alkaline and PEM electrolyzers, with annual OPEX of 40–65 €/kW, while the average levelized cost of hydrogen (LCOH) in 2023 varies between ~6.6 €/kg for renewable-based electrolysis and ~7.9 €/kg for grid-connected electrolysis, with significant country-specific differences (Table 6). These values, together with indicative energy consumption for compression, storage, and dispensing, offer useful references for planners while acknowledging the current uncertainty [39,48,73–75].

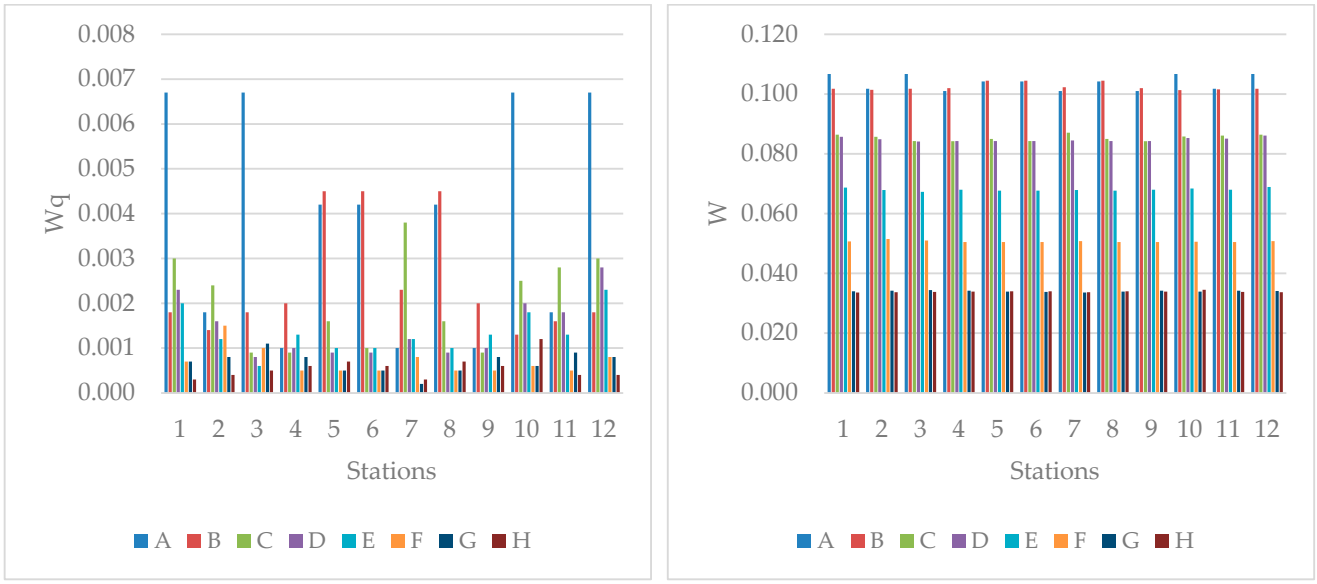


Figure 9. Indicators: waiting time in queue (W_q) and waiting spent in the system (W).

Table 6. Indicative CAPEX, OPEX and LCOH benchmarks for hydrogen production and refueling in Europe (2023) [75].

Technology /Component	CAPEX	OPEX	LCOH/Cost Indicator	Notes
Alkaline electrolyzer	1666 €/kW	43 €/kW/yr	-	Stack 408 €/kW, BoP 686 €/kW, EPC 572 €/kW
PEM electrolyzer	1970 €/kW	64 €/kW/yr	-	Stack 732 €/kW, BoP 464 €/kW, EPC 774 €/kW
Grid-connected electrolysis (EU)	2.76 €/kg	5.18 €/kg	7.94 €/kg H_2	Cyprus 17.36 €/kg, Italy 10.10 €/kg, Sweden 3.43 €/kg
Renewable-based electrolysis (EU)	3.79 €/kg	2.82 €/kg	6.61 €/kg H_2	Norway 4.28 €/kg, Ireland 4.13 €/kg, Luxembourg 9.30 €/kg
Compressor, storage & dispenser	–	–	Energy consumption: 2.43 kWh/kg H_2 (GH_2 HRS); 0.37 kWh/kg H_2 (LH_2 HRS)	Compressor is the main OPEX driver

7. Conclusions

This paper presents a two-stage methodological framework for the optimal location and size of HRS within a real-world road network, with application to a segment of the

TEN-T corridor in Northern Italy. The model integrates a flow-based location approach with a stochastic queueing system for station sizing, enabling flexible scenario analysis under different infrastructural and demand constraints. The results highlight the potential of the proposed method as a decision-support tool for public authorities and stakeholders involved in the planning and rollout of hydrogen-based mobility systems. The approach, representing the supply by means of graph theory, can potentially be applied to highway networks of any size. However, this work represents an initial step toward a more comprehensive planning framework. Future developments will include the integration of projections for FCEV adoption in the Italian market. Vehicle-specific parameters, such as the real driving range and refueling time provided by the manufacturers, will be incorporated into the model. Additional parameters related to station operation will also be considered, including the hydrogen supply method (on-site production or external delivery). Furthermore, the model will introduce cost assessments for different hydrogen supply chains, improving its techno-economic evaluation capabilities. These enhancements will strengthen the analytical basis for HRS network optimization and long-term infrastructure planning. In particular, the model is expected to support the strategic alignment of hydrogen refueling deployment with evolving regional and national decarbonization goals, including the integration of emerging Hydrogen Valleys, local ecosystems where hydrogen production, distribution, and consumption are co-located, as key hubs within the broader TEN-T transport corridors.

Author Contributions: Conceptualization, S.M., G.N. and A.P.; methodology, S.M. and A.P.; software, A.P.; validation, S.M., A.S.S., G.N. and A.P.; formal analysis, S.M. and A.P.; investigation, S.M., A.S.S., L.C. and A.P.; resources, G.N., A.S.S. and L.C.; data curation, S.M., A.S.S., A.P. and O.M.B.; writing—original draft preparation, S.M., A.S.S. and A.P. writing—review and editing, S.M., G.N., A.P. and O.M.B.; visualization, S.M., A.S.S., G.N., L.C., A.P. and O.M.B.; supervision, S.M., G.N. and A.P. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: The data presented in this study are available on request from the corresponding author due to institutional restrictions and ongoing research activities.

Conflicts of Interest: The authors declare no conflicts of interest.

Abbreviations

The following abbreviations are used in this manuscript:

AEM	Anion Exchange Membrane
AFIR	Alternative Fuels Infrastructure Regulation
ALK	Alkaline
CcH_2	Cryo-compressed Hydrogen
CGH_2	Compressed Gaseous Hydrogen
FCEV	Fuel Cell Electric Vehicle
HRS	Hydrogen Refueling Stations
LH_2	Cryogenic Liquid Hydrogen
LOHC	Liquid Organic Hydrogen Carriers
PEM	Proton Exchange Membrane
PNRR	National Recovery and Resilience Plan
sLH_2	Subcooled Liquid Hydrogen
SO	Solid Oxide
TEN-T	Trans-European Transport Network

References

1. IEA. Global Hydrogen Review 2024. Available online: https://www.iea.org/reports/global-hydrogen-review-2024 (accessed on 24 June 2025).
2. H2-Stations. Available online: https://www.h2stations.org/ (accessed on 24 June 2025).
3. General Office of the State Council Development Plan for the New Energy Vehicle Industry (2021–2035). Available online: https://www.gov.cn/zhengce/content/2020-11/02/content_5556716.htm (accessed on 30 June 2025).
4. Planning Department Development Plan for New Energy Vehicle Industry (2021–2035). Available online: https://www.ndrc.gov.cn/fggz/fzzlgh/gjjzxgh/202111/t20211101_1302487.html (accessed on 20 September 2025).
5. Pak, S.B.; Lee, Y. Common but Differentiated? Policymakers' Priorities of Social Acceptance for Expanding Hydrogen Refueling Stations in Japan and Korea. *Int. J. Hydrogen Energy* **2024**, *89*, 799–809. [CrossRef]
6. Regional Clean Hydrogen Hubs. Available online: https://www.energy.gov/oced/regional-clean-hydrogen-hubs-0 (accessed on 30 June 2025).
7. U.S. National Hydrogen Strategy and Roadmap | Hydrogen Program. Available online: https://www.hydrogen.energy.gov/library/roadmaps-vision/clean-hydrogen-strategy-roadmap (accessed on 30 June 2025).
8. Alternative Fuels Infrastructure—European Commission. Available online: https://transport.ec.europa.eu/transport-themes/clean-transport/alternative-fuels-sustainable-mobility-europe/alternative-fuels-infrastructure_en (accessed on 27 July 2025).
9. Il Green Deal Europeo—Commissione Europea. Available online: https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal_it (accessed on 27 July 2025).
10. REPowerEU: La Politica Energetica nei Piani per la Ripresa e la Resilienza dei Paesi UE. Available online: https://www.consilium.europa.eu/it/policies/repowereu/ (accessed on 27 July 2025).
11. Idrogeno: Presentata la Strategia Nazionale, Più Scenari per la Sua Diffusione. Available online: https://www.mase.gov.it/portale/-/idrogeno-presentata-la-strategia-nazionale-piu-scenari-per-la-sua-diffusione (accessed on 3 July 2025).
12. Laporte, G.; Nickel, S.; da Gama, F.S. (Eds.) Introduction to Location Science. In *Location Science*; Springer International Publishing: Cham, Switzerland, 2015; pp. 1–18. ISBN 978-3-319-13111-5.
13. Conceição, S.V.; Pedrosa, L.H.P.; Neto, A.S.C.; Vinagre, M.; Wolff, E. The Facility Location Problem in the Steel Industry: A Case Study in Latin America. *Prod. Plan. Control.* **2012**, *23*, 26–46. [CrossRef]
14. Nambiar, J.M.; Gelders, L.F.; Van Wassenhove, L.N. A Large Scale Location-Allocation Problem in the Natural Rubber Industry. *Eur. J. Oper. Res.* **1981**, *6*, 183–189. [CrossRef]
15. Musolino, G.; Rindone, C.; Polimeni, A.; Vitetta, A. Planning Urban Distribution Center Location with Variable Restocking Demand Scenarios: General Methodology and Testing in a Medium-Size Town. *Transp. Policy* **2019**, *80*, 157–166. [CrossRef]
16. Çakmak, E.; Önden, İ.; Acar, A.Z.; Eldemir, F. Analyzing the Location of City Logistics Centers in Istanbul by Integrating Geographic Information Systems with Binary Particle Swarm Optimization Algorithm. *Case Stud. Transp. Policy* **2021**, *9*, 59–67. [CrossRef]
17. Owais, M. Traffic Sensor Location Problem: Three Decades of Research. *Expert Syst. Appl.* **2022**, *208*, 118134. [CrossRef]
18. Gallo, M. Optimisation Models for the Location of Refuelling Stations for Fuel Cell Electric Freight Vehicles in Italy: Preliminary Tests. In Proceedings of the 2024 IEEE International Conference on Electrical Systems for Aircraft, Railway, Ship Propulsion and Road Vehicles & International Transportation Electrification Conference (ESARS-ITEC), Naples, Italy, 26–29 November 2024; pp. 1–5.
19. Lin, C.C.; Lin, C.C. The *p*-Center Flow-Refueling Facility Location Problem. *Transp. Res. Part B Methodol.* **2018**, *118*, 124–142. [CrossRef]
20. Itaoka, K.; Kimura, S.; Hirose, K. Methodology Development to Locate Hydrogen Stations for the Initial Deployment Stage. *E3S Web Conf.* **2019**, *83*, 01014. [CrossRef]
21. Upchurch, C.; Kuby, M. Comparing the *p*-Median and Flow-Refueling Models for Locating Alternative-Fuel Stations. *J. Transp. Geogr.* **2010**, *18*, 750–758. [CrossRef]
22. Honma, Y.; Kuby, M. Node-Based vs. Path-Based Location Models for Urban Hydrogen Refueling Stations: Comparing Convenience and Coverage Abilities. *Int. J. Hydrogen Energy* **2019**, *44*, 15246–15261. [CrossRef]
23. Kim, H.; Eom, M.; Kim, B.-I. Development of Strategic Hydrogen Refueling Station Deployment Plan for Korea. *Int. J. Hydrogen Energy* **2020**, *45*, 19900–19911. [CrossRef]
24. Gündüz, S.B.; Geçici, E.; Güler, M.G. Locating Hydrogen Fuel Stations: A Comparative Study for Istanbul. *Int. J. Hydrogen Energy* **2024**, *52*, 1234–1246. [CrossRef]
25. MirHassani, S.A.; Ebrazi, R. A Flexible Reformulation of the Refueling Station Location Problem. *Transp. Sci.* **2013**, *47*, 617–628. [CrossRef]
26. Li, Y.; Cui, F.; Li, L. An Integrated Optimization Model for the Location of Hydrogen Refueling Stations. *Int. J. Hydrogen Energy* **2018**, *43*, 19636–19649. [CrossRef]

27. Kim, J.-G.; Kuby, M. The Deviation-Flow Refueling Location Model for Optimizing a Network of Refueling Stations. *Int. J. Hydrogen Energy* **2012**, *37*, 5406–5420. [CrossRef]
28. Nicholas, M.A.; Handy, S.L.; Sperling, D. Using Geographic Information Systems to Evaluate Siting and Networks of Hydrogen Stations. *Transp. Res. Rec.* **2004**, *1880*, 126–134. [CrossRef]
29. Toyota Hydrogen, Guida a Zero Emissioni, Solo Gocce D'acqua | Toyota. Available online: https://www.toyota.it/electrified/fuel-cell (accessed on 19 September 2025).
30. Caratteristiche. Available online: https://www.hyundai.com/it/it/models/nexo/caratteristiche.html (accessed on 1 August 2025).
31. Opel Movano HYDROGEN. Available online: https://www.media.stellantis.com/it-it/opel/press/opel-movano-hydrogen-per-un-offerta-ancora-piu-forte (accessed on 19 September 2025).
32. Light-Duty Vehicles—European Commission. Available online: https://climate.ec.europa.eu/eu-action/transport-decarbonisation/road-transport/light-duty-vehicles_en (accessed on 22 September 2025).
33. Franco, A.; Giovannini, C. Recent and Future Advances in Water Electrolysis for Green Hydrogen Generation: Critical Analysis and Perspectives. *Sustainability* **2023**, *15*, 16917. [CrossRef]
34. Vincent, I.; Bessarabov, D. Low Cost Hydrogen Production by Anion Exchange Membrane Electrolysis: A Review. *Renew. Sustain. Energy Rev.* **2018**, *81*, 1690–1704. [CrossRef]
35. Mulk, W.U.; Aziz, A.R.A.; Ismael, M.A.; Ghoto, A.A.; Ali, S.A.; Younas, M.; Gallucci, F. Electrochemical Hydrogen Production through Anion Exchange Membrane Water Electrolysis (AEMWE): Recent Progress and Associated Challenges in Hydrogen Production. *Int. J. Hydrogen Energy* **2024**, *94*, 1174–1211. [CrossRef]
36. Millet, P.; Grigoriev, S. Chapter 2—Water Electrolysis Technologies. In *Renewable Hydrogen Technologies*; Gandía, L.M., Arzamendi, G., Diéguez, P.M., Eds.; Elsevier: Amsterdam, The Netherlands, 2013; pp. 19–41. ISBN 978-0-444-56352-1.
37. Wang, T.; Cao, X.; Jiao, L. PEM Water Electrolysis for Hydrogen Production: Fundamentals, Advances, and Prospects. *Carb Neutrality* **2022**, *1*, 21. [CrossRef]
38. Zou, J.; Han, N.; Yan, J.; Feng, Q.; Wang, Y.; Zhao, Z.; Fan, J.; Zeng, L.; Li, H.; Wang, H. Electrochemical Compression Technologies for High-Pressure Hydrogen: Current Status, Challenges and Perspective. *Electrochem. Energ. Rev.* **2020**, *3*, 690–729. [CrossRef]
39. Genovese, M.; Fragiacomo, P. Hydrogen Refueling Station: Overview of the Technological Status and Research Enhancement. *J. Energy Storage* **2023**, *61*, 106758. [CrossRef]
40. Giuffrida, A.; Colbertaldo, P. Overview of Diaphragm Compressors for Hydrogen Service: Capacity, Discharge Pressure and Operational Challenges. *J. Energy Storage* **2025**, *129*, 117286. [CrossRef]
41. Arjomand Kermani, N.; Petrushina, I.; Rokni, M.M. Evaluation of Ionic Liquids as Replacements for the Solid Piston in Conventional Hydrogen Reciprocating Compressors: A Review. *Int. J. Hydrogen Energy* **2020**, *45*, 16337–16354. [CrossRef]
42. Cui, W.; Fu, X.; Hong, X.; Wang, D.; Liu, D.; Cao, X. Review of Suction Valve Capacity Regulation Technology in Reciprocating Compressor. *Renew. Sustain. Energy Rev.* **2025**, *213*, 115435. [CrossRef]
43. Zhou, H.; Zhou, S.; Sun, H.; Yang, X.; Dong, P.; Zhao, S. Development and Experimental Research of an Integrated Dynamic Simulation Platform for an Ionic Liquid Hydrogen Compressor Utilized in Hydrogen Refueling Stations. *Renew. Energy* **2025**, *252*, 123565. [CrossRef]
44. Parida, A.; Muthukumar, P.; Dalal, A. A Review on Non-Mechanical Hydrogen Compressors for Hydrogen Refuelling Stations. *Int. J. Hydrogen Energy* **2025**, *145*, 292–321. [CrossRef]
45. Mekonnin, A.S.; Wacławiak, K.; Humayun, M.; Zhang, S.; Ullah, H. Hydrogen Storage Technology, and Its Challenges: A Review. *Catalysts* **2025**, *15*, 260. [CrossRef]
46. Hassan, Q.; Algburi, S.; Sameen, A.Z.; Jaszczur, M.; Salman, H.M. Hydrogen as an Energy Carrier: Properties, Storage Methods, Challenges, and Future Implications. *Env. Syst Decis* **2024**, *44*, 327–350. [CrossRef]
47. Patel, S.K.S.; Gupta, R.K.; Rohit, M.V.; Lee, J.-K. Recent Developments in Hydrogen Production, Storage, and Transportation: Challenges, Opportunities, and Perspectives. *Fire* **2024**, *7*, 233. [CrossRef]
48. Perna, A.; Minutillo, M.; Di Micco, S.; Jannelli, E. Design and Costs Analysis of Hydrogen Refuelling Stations Based on Different Hydrogen Sources and Plant Configurations. *Energies* **2022**, *15*, 541. [CrossRef]
49. *J2601_202005*; Fueling Protocols for Light Duty Gaseous Hydrogen Surface Vehicles. Fuel Cell Standards[M1] Committee SAE International: Warrendale, PA, USA, 2020. [CrossRef]
50. Pizzutilo, E.; Acher, T.; Reuter, B.; Will, C.; Schäfer, S. Subcooled Liquid Hydrogen Technology for Heavy-Duty Trucks. *World Electr. Veh. J.* **2024**, *15*, 22. [CrossRef]
51. Alipour Bonab, S.; Yazdani-Asrami, M. Investigation on the Heat Transfer Estimation of Subcooled Liquid Hydrogen for Transportation Applications Using Intelligent Technique. *Int. J. Hydrogen Energy* **2024**, *84*, 468–479. [CrossRef]
52. Ministero Affari Europei, PNRR e Politiche di Coesione Sesta Relazione al Parlamento Sullo Stato di Attuazione del Piano Nazionale di Ripresa e Resilienza (Sezione I e II). Available online: http://www.strutturapnrr.gov.it/it/documenti/relazioni-al-parlamento/sesta-relazione-al-parlamento-sullo-stato-di-attuazione-del-pnrr/ (accessed on 7 July 2025).

53. CEF Transport Alternative Fuels Infrastructure Facility (AFIF) Call for Proposal—European Commission. Available online: https://cinea.ec.europa.eu/funding-opportunities/calls-proposals/cef-transport-alternative-fuels-infrastructure-facility-afif-call-proposal_en (accessed on 7 July 2025).
54. ISO 14687:2025. Available online: https://www.iso.org/standard/82660.html (accessed on 11 July 2025).
55. PFTE—Paganella Ovest. Available online: https://autobrennero.acquistitelematici.it/tender/3566 (accessed on 11 July 2025).
56. PFTE—Paganella Est. Available online: https://autobrennero.acquistitelematici.it/tender/2591 (accessed on 11 July 2025).
57. PFTE—Verona. Available online: https://autobrennero.acquistitelematici.it/tender/1969 (accessed on 11 July 2025).
58. PFTE—Sadobre. Available online: https://autobrennero.acquistitelematici.it/tender/3687 (accessed on 11 July 2025).
59. Milano Serravalle. Available online: https://www.serravalle.it/index.php/pagine/load/serraH2valle (accessed on 11 July 2025).
60. Bottino, F. Pronta la Prima Stazione di Rifornimento di Idrogeno Realizzata da FNM Sulla Tangenziale di Milano. *HydroNews*. 30 June 2025. Available online: https://hydronews.it/pronta-la-prima-stazione-di-rifornimento-di-idrogeno-realizzata-da-fnm-sulla-tangenziale-di-milano/ (accessed on 11 July 2025).
61. Bhat, U.N. *An Introduction to Queueing Theory: Modeling and Analysis in Applications*; Statistics for Industry and Technology; Birkhäuser: Boston, MA, USA, 2015; ISBN 978-0-8176-8420-4.
62. Zheng, J.; Zhao, L.; Ou, K.; Guo, J.; Xu, P.; Zhao, Y.; Zhang, L. Queuing-Based Approach for Optimal Dispenser Allocation to Hydrogen Refueling Stations. *Int. J. Hydrogen Energy* **2014**, *39*, 8055–8062. [CrossRef]
63. Breiman, L. The Poisson Tendency in Traffic Distribution. *Ann. Math. Stat.* **1963**, *34*, 308–311. [CrossRef]
64. European Commission Scandinavian—Mediterranean Corridor. Available online: https://transport.ec.europa.eu/transport-themes/infrastructure-and-investment/trans-european-transport-network-ten-t/scandinavian-mediterranean-corridor_en (accessed on 9 July 2025).
65. Piano-Nazionale_Mobilita-Idrogeno_integrale2019.Pdf. Available online: https://docs.google.com/viewerng/viewer?url=https://www.h2it.it/wp-content/uploads/2020/03/Piano-Nazionale_Mobilita-Idrogeno_integrale2019.pdf&hl (accessed on 18 September 2025).
66. Global EV Data Explorer—Data Tools. Available online: https://www.iea.org/data-and-statistics/data-tools/global-ev-data-explorer (accessed on 29 July 2025).
67. EU Hydrogen Strategy Under the EU Green Deal | European Hydrogen Observatory. Available online: https://observatory.clean-hydrogen.europa.eu/eu-policy/eu-hydrogen-strategy-under-eu-green-deal (accessed on 23 September 2025).
68. Hydrogen. Available online: https://energy.ec.europa.eu/topics/eus-energy-system/hydrogen_en (accessed on 23 September 2025).
69. Franke, T.; Krems, J.F. Interacting with Limited Mobility Resources: Psychological Range Levels in Electric Vehicle Use. *Transp. Res. Part A Policy Pract.* **2013**, *48*, 109–122. [CrossRef]
70. Galanido, R.J.; Sebastian, L.J.; Asante, D.O.; Kim, D.S.; Chun, N.-J.; Cho, J. Fuel Filling Time Estimation for Hydrogen-Powered Fuel Cell Electric Vehicle at Different Initial Conditions Using Dynamic Simulation. *Korean J. Chem. Eng.* **2022**, *39*, 853–864. [CrossRef]
71. Sahin, H. Hydrogen Refueling of a Fuel Cell Electric Vehicle. *Int. J. Hydrogen Energy* **2024**, *75*, 604–612. [CrossRef]
72. Owais, M.; Moussa, G.S. Global Sensitivity Analysis for Studying Hot-Mix Asphalt Dynamic Modulus Parameters. *Constr. Build. Mater.* **2024**, *413*, 134775. [CrossRef]
73. Idriss, L.K.; Owais, M. Global Sensitivity Analysis for Seismic Performance of Shear Wall with High-Strength Steel Bars and Recycled Aggregate Concrete. *Constr. Build. Mater.* **2024**, *411*, 134498. [CrossRef]
74. Hydrogen as an Energy Carrier: Properties, Storage Methods, Challenges, and Future Implications | Environment Systems and Decisions. Available online: https://link.springer.com/article/10.1007/s10669-023-09932-z (accessed on 18 September 2025).
75. European Hydrogen Observatory The European Hydrogen Market Landscape. November 2024. Available online: https://observatory.clean-hydrogen.europa.eu/sites/default/files/2024-11/The%20European%20hydrogen%20market%20landscape_November%202024.pdf (accessed on 23 September 2025).

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.