CHALMERS
UNIVERSITY OF TECHNOLOGY

How much H_2 in 2030 – where, to whom and with what probability?

Quantifying hydrogen production in Sweden under different scenarios

Master's thesis in Industrial Ecology

EBBA BJÖRSTRAND

TOVA JACOBSSON

DEPARTMENT OF MECHANICS AND MARITIME SCIENCES
CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2026
www.chalmers.se

Master's thesis 2026

How much H_2 in 2030 – where, to whom and with what probability?

Quantifying hydrogen production in Sweden under different scenarios

EBBA BJÖRSTRAND
TOVA JACOBSSON

Department of Mechanics and Maritime Sciences
Chalmers University of Technology
Gothenburg, Sweden 2026

How much H_2 in 2030 – where, to whom and with what probability?
Quantifying hydrogen production in Sweden under different scenarios
EBBA BJÖRSTRAND, TOVA JACOBSSON

Industry supervisors:
Monica Johansson, Volvo TTI
Magnus Karlström, Lindholmen Science Park
Ulrika Colpier, Lindholmen Science Park

Academic supervisor and Examiner:
Maria Grahn, Department of Mechanics and Maritime Sciences

Master's Thesis 2026
Department of Mechanics and Maritime Sciences
Chalmers University of Technology
SE-412 96 Gothenburg
Telephone +46 31 772 1000

Typeset in LaTeX
Printed by Chalmers Reproservice
Gothenburg, Sweden 2026

How much H_2 in 2030 – where, to whom and with what probability?
Quantifying hydrogen production in Sweden under different scenarios
EBBA BJÖRSTRAND
TOVA JACOBSSON
Department of Mechanics and Maritime Sciences
Chalmers University of Technology

Abstract

Hydrogen is widely regarded as a key enabler of decarbonization in hard-to-abate sectors, yet its market development remains highly uncertain. This thesis investigates the potential scale and conditions for green hydrogen production in Sweden toward 2030 by combining project mapping, stakeholder interviews, and scenario-based modeling. The study aims to quantify future hydrogen production, identify key demand sectors, and analyze the main drivers and barriers influencing market development.

The results indicate that potential production outcomes vary significantly depending on realization conditions. While an upper-bound estimate suggests a possible production capacity of approximately 660,000 tonnes of hydrogen per year, the most probable outcome is substantially lower under current conditions. The analysis identifies a limited number of large-scale industrial projects as system anchors that largely determine overall production volumes.

A total of 43 hydrogen production projects were assessed using a probabilistic framework based on four core factors: project status, electricity bidding zone, public funding, and sector readiness. These were evaluated under three socio-economic scenarios (SSP1, SSP2, SSP3), complemented by Monte Carlo simulations to capture uncertainty in project realization.

Key barriers include high production costs, uncertain demand, infrastructure limitations, and persistent coordination challenges between producers and consumers. The study concludes that hydrogen market development in Sweden is highly interdependent, relying on progress across both the hydrogen value chain and the regulatory landscape, and remains embedded within a broader global system. Achieving large-scale deployment therefore requires coordinated action, including strengthened and coherent policy frameworks, demand-side support mechanisms, and improved alignment between supply and demand.

Keywords: Green Hydrogen, Hydrogen Production, Scenario Analysis, H2Ignite, Market Analysis, Policy Landscape, Energy Systems, Decarbonization, Energy Transition

Acknowledgements

We would first like to express our genuine gratitude to our supervisor and examiner, Maria Grahn at the Department of Mechanics and Maritime Sciences at Chalmers University of Technology, for your continuous support throughout this thesis. Your guidance and constructive feedback have truly been invaluable in shaping both the direction and the quality of this work. We highly appreciate your engagement and the time you have dedicated to helping us navigate this research process.

We would also like to extend our sincerest thanks to Monica Johansson at Volvo, as well as Magnus Karlström and Ulrika Colpier at Lindholmen Science Park, for making this thesis possible within the context of the H2Ignite initiative. Your involvement has been essential, and your insights, encouragement, and perspectives on the hydrogen landscape have greatly contributed to both the scope and development of this study. We are grateful for your continuous engagement throughout the process and your openness in sharing your knowledge and perspectives, which has greatly deepened our understanding of the subject.

Furthermore, we would like to express our appreciation to Volvo and Lindholmen Science Park, partners in H2Ignite, for providing us with the opportunity to conduct this thesis project. Being able to carry out our work within this collaborative initiative has been both rewarding and motivating, and has provided us with valuable insight into an emerging and highly relevant field.

Finally, we would like to thank all interview participants who generously took the time to contribute to this study. We are grateful for the willingness with which you shared your experiences, reflections, and expertise. The knowledge and perspectives you have provided have been essential for our analysis and have significantly enriched the quality of this research. Without your contributions, this thesis would not have been possible.

Ebba Björstrand & Tova Jacobsson, Gothenburg, June 2026

H2ignite
Interreg
North Sea
Co-funded by
the European Union

List of Acronyms

ALK	Alkaline
AFIR	Alternative Fuels Infrastructure Regulation
CAPEX	Capital Expenditure
CBAM	Carbon Border Adjustment Mechanism
CCS	Carbon Capture and Storage
CGH_2	Compressed Gas Hydrogen
CHP	Combined Heat and Power
CO_2	Carbon Dioxide
E-fuel	Electro-fuel
EU ETS	European Union Emissions Trading System
FEED	Front End Engineering Design
FID	Final Investment Decision
GDPR	General Data Protection Regulation
GHG	Greenhouse Gases
GROT	Grenar och Toppar (Forest residue; Branches and Tops)
H_2	Hydrogen
IMO	International Maritime Organization
LH_2	Liquid Hydrogen
OPEX	Operational Expenditure
PEM	Proton Exchange Membrane
RED III	Renewable Energy Directive III
RFNBO	Renewable Fuels of Non-Biological Origin
SMR	Steam Methane Reforming
SOP	Start of Production
SSP	Shared Socioeconomic Pathways
STIP	Sustainable Transport Investment Plan

Contents

Appendices

1

Introduction

Climate change is an urgent challenge for our generation that requires both societal transformation and technological advancement. Since the combustion of fossil fuels is a major driver of greenhouse gas (GHG) emissions, addressing climate change requires transitioning from fossil-based systems [1].

Given society's dependence on fossil fuels, decarbonization requires coordinated climate policy, technological innovation, and structural transformation across energy systems and markets [2]. Renewable energy sources are central to this transition. In this context, hydrogen has gained importance as a potential enabler of decarbonization, when produced by sustainable energy sources. Hydrogen can serve as an energy carrier and feedstock, enabling emission reductions in sectors that are difficult to electrify directly, such as industry, heavy transport, and long-term energy storage [3].

Hydrogen is recognized as a key component of the European Union's strategy for sustainable development and decarbonization. As part of its 2030 climate ambitions, the EU has set a target of producing 10 million tonnes of renewable hydrogen annually by 2030 [4].

Several Nordic countries have developed national hydrogen strategies and targets to contribute to this broader European vision. Finland, for example, has established a target of producing 1 million tonnes of hydrogen annually, while Denmark and Norway have also introduced national hydrogen strategies to support the transition towards a low-carbon economy [5].

However, unlike neighboring countries, Sweden currently lacks an official national hydrogen strategy with a defined production target. Nevertheless, Hydrogen Sweden, a national industry organization, has formulated its own operational objective of creating the conditions necessary for Sweden to enable production capacity corresponding to 1 million tonnes of hydrogen annually. This is not an official governmental target, but rather an industry-driven ambition intended to support and align with the broader European hydrogen vision [6].

Hydrogen can be produced through various methods, often referred to by color classifications that indicate the energy source and associated emissions. Most of the hydrogen used globally as well as nationally in Sweden is fossil-based, which does not contribute to emission reductions and constitutes a gap between ambition and reality. In contrast, hydrogen produced from renewable energy (referred to as green hydrogen) has the potential to decrease emissions [7].

Green hydrogen has become a current focus with many projects aimed at producing green hydrogen as part of a transition away from fossil-based hydrogen. The projects are strongly dependent on market conditions and policy support and several planned projects have been postponed or canceled due to economic, political, and technological uncertainties [5, 8, 9, 10].

The future availability and the role of renewable hydrogen will differ depending on how the world develops, creating a range of potential scenarios. Current hydrogen projects vary considerably in terms of maturity, level of commitment, and likelihood of realization [11]. The outcomes are still uncertain and will depend on how successfully technical, economic, and regulatory challenges are addressed, possibly leading to substantially different development trajectories. At the same time, demand for hydrogen is not yet firmly established and is expected to evolve in response to changing policies, the economic situation, and market conditions [5]. In order for the industry to determine its strategic direction, it is crucial to understand the potential availability of renewable hydrogen under different development pathways.

Since both hydrogen supply and demand are still developing and strongly interdependent, there is a need for updated and comprehensive assessments of the current situation. Existing figures may quickly become outdated as projects progress, are delayed, or canceled. This creates a knowledge gap regarding the realistic scale of hydrogen production in the near-to-medium term.

In this context, scenario analysis provides a valuable tool for exploring plausible futures under conditions of uncertainty. It allows researchers and policymakers to consider how different assumptions about technology, policy, and market development may affect outcomes, while also making clear both the value and the limitations of such an approach [12]. By systematically mapping potential pathways, scenario analysis helps create a foundation for strategic planning and decision-making in the rapidly evolving hydrogen sector.

To enable further analysis of hydrogen production scale-up and future opportunities, a solid foundation based on up-to-date data is required. This includes an assessment of the current status of hydrogen projects as well as an analysis of the key factors influencing their development. By mapping the current situation and exploring possible future scenarios, this study contributes to a more robust understanding of how renewable hydrogen production may evolve towards 2030 and beyond.

1.1 Aim

The aim of this thesis is to estimate green hydrogen production in Sweden towards 2030 and beyond.

The study aims to map the Swedish hydrogen market by identifying current and prospective hydrogen producers, as well as actors interested in hydrogen consumption. Based on this mapping, the thesis will quantify projected hydrogen production and demand until 2030.

Furthermore, the thesis also aims to identify and analyze the main drivers and barriers influencing hydrogen production, distribution, and consumption. The study will conduct a scenario analysis to explore how different assumptions, drivers, and barriers affect future green hydrogen deployment.

1.2 Research Questions

This thesis investigates the following research questions:

- Where and in what quantities is green hydrogen estimated to be produced in Sweden 2030 and beyond?
- Which sectors are expected to generate demand?
- What drivers and barriers can be identified for the green hydrogen market?
- Which factors most significantly influence the development of this market?
- What realization outcomes can be expected for planned green hydrogen projects in Sweden, according to scenario-based modelling?

1.3 Delimitations

To narrow the scope of the study and ensure analytical focus, some limitations are applied:

The spatial scope of this study is limited to hydrogen production within Sweden. This delimitation allows for a detailed assessment of domestic market developments, while excluding imports.

The primary temporal scope of the study is from the present up until 2030, although this thesis also extends to analyze possible developments in a near future after 2030. This time horizon is chosen to align with key milestones in both EU and Swedish climate and energy strategies, which emphasize significant emission reductions by 2030.

The mapping of the Swedish hydrogen market focuses exclusively on green hydrogen. Other hydrogen production technologies will not be included in this study.

2

Theory

This chapter presents the theoretical framework that underpins the study, focusing on key concepts related to hydrogen production, applications, and system integration. It also outlines relevant perspectives on technological development and system dynamics, which are essential for understanding the opportunities and challenges associated with scaling green hydrogen.

2.1 Green Hydrogen

This section outlines the fundamental concepts, production pathways, and applications of green hydrogen, providing the theoretical basis necessary to understand its role within future energy infrastructures.

2.1.1 Classification and Definition of Green Hydrogen

Hydrogen is commonly categorized using a color-based classification system that reflects the energy sources and production processes used. The most widely used categories are grey, blue, pink, and green hydrogen [13]. This classification helps to distinguish between hydrogen production methods based on the associated carbon emissions and their primary energy inputs. Regardless of production pathway, hydrogen is chemically identical and can therefore be used in the same end-use applications [14].

Grey hydrogen is produced from fossil fuel feedstock, mostly natural gas or methane. The typical production method is steam methane reforming (SMR), a process that results in significant carbon dioxide (CO_2) emissions released into the atmosphere [15].

Blue hydrogen is also produced from fossil resources using similar processes to grey hydrogen, such as SMR. However, in this case, carbon capture and storage (CCS) technologies are used to capture the CO_2 generated during production, thereby reducing the amount of emissions released [15]. Despite this, the overall climate performance of blue hydrogen remains subject to debate. Capture rates are not always complete, and residual emissions can still be significant depending on the efficiency of the CCS system.

Pink hydrogen refers to hydrogen produced using nuclear energy. Since nuclear power does not emit CO_2 during operation, pink hydrogen is considered a low-emission option. However, it still relies on fissile feedstock such as uranium, which is a finite resource [16].

Green hydrogen, defined within the EU regulatory framework as RFNBO (Renewable Fuels of Non-Biological Origin), is produced using strictly renewable energy sources such as wind or solar power [17]. As a result, its production process does not generate greenhouse gas emissions. Some definitions also include hydrogen produced from biomass, but typically only when combined with CCS technologies [16, 18].

Within the context of sustainable energy systems, green hydrogen is therefore defined as hydrogen produced from renewable energy sources with minimal or no associated greenhouse gas emissions, distinguishing it from other hydrogen production pathways that rely on fossil fuels or finite energy resources [18]. In the Swedish context, the electricity mix is largely composed of renewable sources such as hydropower, solar and wind power, which means that hydrogen produced through electrolysis using the Swedish energy system can generally be considered green [19].

2.1.2 Production Processes of Green Hydrogen

Several technological processes exist for producing hydrogen using renewable energy sources. Among these, three commonly referenced mature renewable hydrogen production technologies include water electrolysis, biogas steam reforming and biomass gasification [15].

2.1.2.1 Electrolysis

Water electrolysis is one of the most widely discussed methods for producing green hydrogen. This process splits water molecules into hydrogen and oxygen by applying electrical energy. In electrolysis, water undergoes an electrochemical reaction in which it is decomposed into hydrogen gas and oxygen gas when an electric current passes through the system [20]. When the electricity used in this process originates from renewable sources such as wind or solar power, the resulting hydrogen is considered green hydrogen [18].

Electrolysis systems are based on electrolyzers, and the main technologies can be distinguished on the basis of the type of electrolyte used in the electrolysis cell. Two of the most prominent technologies are alkaline (ALK) electrolysis cells and proton exchange membrane (PEM) electrolysis cells [18].

ALK electrolysis cells are the most established and widely used technology for water electrolysis. These systems use an alkaline solution as the electrolyte and are capable of operating at relatively high temperatures and pressures. On the one hand, ALK systems are considered technically mature and are associated with relatively low capital costs, which has made them widely applied in hydrogen production. On the other hand, they generally have lower operational flexibility and slower dynamic response, making them less well-suited for integration with variable renewable energy sources [18].

PEM electrolysis is a relatively recent technological development that employs a solid polymer membrane as the electrolyte, which separates the electrodes and enables proton transport within the cell. On the one hand, PEM technology offers advantages in terms of scalability, higher current densities, and system flexibility, making it well suited for integration with intermittent renewable electricity generation. On the other hand, PEM systems are associated with higher capital costs and rely on scarce and expensive noble metal catalysts, such as platinum and iridium, which raises concerns regarding both economic feasibility and material availability [21].

Compared with ALK systems, PEM electrolysis cells generally operate at lower temperatures and pressures while offering higher efficiency. However, these advantages come at the cost of increased material requirements and system complexity, illustrating the trade-offs between technological maturity, cost, and performance across different electrolysis technologies.

2.1.2.2 Biogas Steam Reforming

Another pathway for renewable hydrogen production is biogas steam reforming. In this process, biogas (from e.g. anaerobic digestion of household waste) as the feedstock in a reforming reaction similar to the conventional steam reforming of methane. The methane component of the biogas reacts with steam at high temperatures to produce hydrogen and carbon monoxide, which can be further processed through a water–gas shift reaction to increase hydrogen yield. When biogas originates from renewable biomass sources, this pathway can provide a renewable route for hydrogen production [15].

2.1.2.3 Biomass Gasification

Biomass gasification provides a pathway for syngas production from solid biomass. The biomass is dried and pretreated to enhance performance as a feedstock, and is then converted into syngas, containing hydrogen, carbon monoxide, carbon dioxide and methane. The syngas goes through a water-gas shift reaction which increases hydrogen yields.

The syngas may be used directly as a process gas for industrial applications due to its hydrogen content, or it can be further processed to produce hydrogen. Both this method and Biogas Steam Reforming can be considered a carbon-negative route for hydrogen production when coupled with CCS [22].

2.2 Roles and Applications of Hydrogen

Hydrogen has the potential to play a versatile role as an energy carrier in various fields and branches of applications. When produced sustainably (green hydrogen), it supports decarbonization across sectors where direct electrification is difficult or currently not feasible.

2.2.1 Transport Sector

One of the most prominent applications of hydrogen is in the transport sector. Hydrogen can be used as a fuel in fuel cell vehicles, where it is converted into electricity to power electric motors, or in hydrogen combustion engines. These technologies can be applied across several transport modes, including road transport, maritime transport, rail, and aviation. In addition to direct hydrogen use, hydrogen can also be used as a feedstock for the production of electro-fuels (e-fuels), which can then be used in conventional combustion engines (with no or minor modifications) in sectors where electrification is more difficult [18, 23].

2.2.2 Industry Sector

Another important area of use is the industrial sector. Hydrogen can be used as a fuel to provide high-temperature heating for industrial processes, representing a form of indirect electrification when the hydrogen is produced using renewable electricity. It can also function as a feedstock in chemical production processes, such as the manufacture of ammonia, methanol, and other chemical products.

Furthermore, hydrogen is already widely used in sectors such as oil refining and fertilizer production, where it plays a key role in chemical conversion processes [24].

2.2.3 Energy Sector

Hydrogen can also support the power sector. It can be used for energy storage and electricity generation. In this context, hydrogen allows surplus renewable electricity to be converted into a storable energy carrier, which can later be reconverted into electricity when needed. This function can contribute to balancing electricity systems with a high share of variable renewable energy [25]. It should, however, be noted that all energy conversions have energy losses and by converting electricity to hydrogen and further into a synthetic hydrocarbon that is easy to store (e.g. methanol or methane), less than 20% of the initial electricity remains when the synthetic fuel is converted back to electricity again [26].

2.2.4 Heat and Power

Hydrogen can further be used in combined heat and power (CHP) systems and for domestic heating, where it can provide both heat and electricity for buildings [25]. In CHP systems, hydrogen is typically converted into electricity through fuel cells or gas turbines, while the waste heat generated in the process is recovered and utilized for heating purposes [27].

However, the overall efficiency of hydrogen for heating applications is generally lower than direct electrification options, such as heat pumps, due to the multiple conversion steps required in hydrogen production and utilization [27]. As a result, hydrogen-based heating is often considered more suitable for applications where alternative low-carbon solutions are limited.

2.2.5 Mixing into Natural Gas Grid

Another potential application of hydrogen is the partial integration into existing natural gas infrastructure. This approach involves injecting limited proportions of hydrogen into natural gas grids, typically at low volumetric shares, while natural gas remains the primary energy carrier, utilizing existing pipelines and end-use technologies. This approach offers a way to reduce the carbon intensity of gas systems without major infrastructure changes. In addition to direct hydrogen blending, hydrogen can also be converted into synthetic methane through methanation processes. Synthetic methane is chemically compatible with conventional natural gas systems and can be distributed and used in the same way as natural gas [28, 29].

2.3 Infrastructure

Currently, most hydrogen is produced and consumed locally. However, as hydrogen production expands and supply chains develop, efficient storage and transportation solutions become increasingly important [30].

2.3.1 Storage

There is a variety of hydrogen storage technologies. Common storage options include compressed hydrogen gas, liquid hydrogen, and chemical carriers such as ammonia [30, 31].

One of the most widely used storage methods is where compressed hydrogen gas (CGH_2) is stored in pressurized containers. Typically, hydrogen is stored at pressures in either 350 or 700 bar tanks. Compressing hydrogen allows a larger amount of gas to be stored in a smaller volume, making it a practical solution for many applications. The most common approach is to store compressed hydrogen in steel cylinders at pressures up to 700 bar. However, alternative storage technologies are emerging, including lightweight carbon-fiber-reinforced composite tanks [23, 32].

Another approach is underground hydrogen storage, which can be used for large-scale energy storage. Hydrogen can be stored in geological formations such as salt caverns, depleted gas fields, and aquifers, allowing for the storage of very large volumes of energy. However, a key challenge is that suitable geological formations may not be located in close proximity to industrial sites. In such cases, additional infrastructure is required to transport hydrogen to and from the storage location, leading to increased costs and system complexity [30].

Hydrogen can also be stored as liquid hydrogen (LH_2). To liquefy hydrogen, it must be cooled to cryogenic temperatures, typically below -253 °C. The liquid hydrogen is then stored in insulated cryogenic tanks, often designed as double-walled vessels with vacuum insulation to minimize heat transfer and reduce boil-off losses. These tanks are typically made from materials such as stainless steel or aluminum alloys. After storage and transport, liquid hydrogen is vaporized back into gaseous hydrogen at high pressure for final use. Liquid hydrogen storage allows for a higher energy density compared to compressed gas, but requires energy-intensive cooling processes and careful thermal management [30, 31].

In addition to physical storage methods, hydrogen can also be stored and transported using chemical carriers. One important example is ammonia. Ammonia offers a relatively high volumetric energy density, while also functioning as a carbon-free chemical energy carrier [30, 31]. Other potential hydrogen carriers could be methanol and methane, which can also be used to store hydrogen in chemical form.

2.3.2 Transportation

Due to the complex physicochemical properties of hydrogen, its handling requires careful management during both storage and transportation. Transportation conditions are often less stable than stationary storage, which makes safety considerations particularly important when moving hydrogen between locations [33].

One common method of transporting hydrogen is via trucks or tankers, especially when hydrogen is used as a fuel for vehicles. In these cases, hydrogen is transported in pressurized gas cylinders or tube trailers from production sites to distribution points such as refueling stations [33, 34].

Hydrogen can also be transported through pipelines in a manner similar to natural gas. Compared with road transport, pipelines are generally considered a more cost-efficient solution for transporting large quantities of hydrogen over longer distances [33, 31].

2.4 Technological Diffusion

Understanding how technologies diffuse over time can help estimate their maturity level and potential future development.Technological diffusion is often described using an S-shaped curve, where the adoption of a new technology follows a characteristic temporal pattern. In the early stages, diffusion tends to be slow, followed by a period of accelerating growth, and eventually a slowdown as the technology approaches market saturation. This pattern reflects the broader dynamics of technological change, where new technologies gradually replace or compete with existing technologies within a market [35].

The S-curve is commonly divided into three main phases, see Figure 2.1. The first stage is the formative phase, which is characterized by experimentation, pilot projects, and the involvement of innovators and early adopters. During this phase, markets are typically uncertain and technologies are still under development [36]. Emerging technologies are often developed within protected niche environments where experimentation and learning can take place before large-scale diffusion occurs [37].

The second stage is the growth phase, during which the technology begins to scale rapidly. In this phase, increased deployment often leads to cost reductions, technological improvements, and expanding markets. Finally, in the maturity phase, the technology becomes widely established and growth slows as the market approaches saturation. Technological development continues in this stage, but improvements are typically incremental rather than transformative [35].

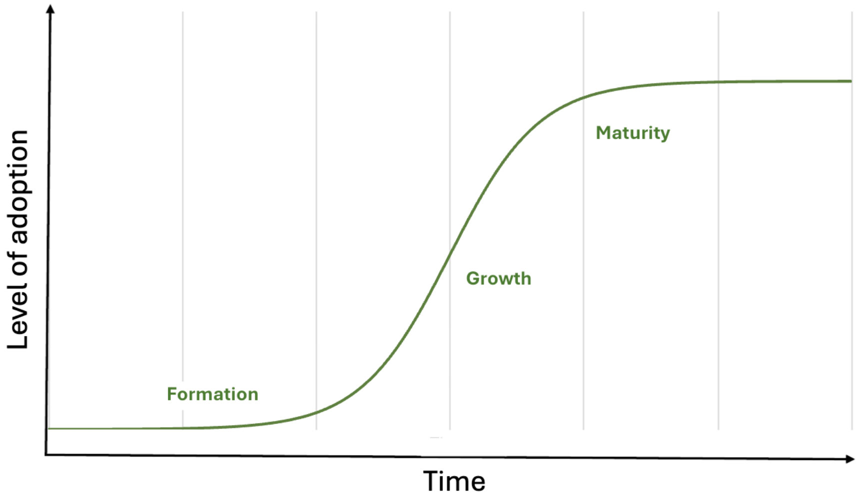


Figure 2.1: S-curve: The typical shape of technical diffusion

Studies of technology diffusion show that growth trajectories for clean technologies often accelerate faster than anticipated, creating advantages for early movers that invest in innovation and scaling [38].

The position of green hydrogen on the S-curve varies across sectors. Current hydrogen initiatives indicate that adoption remains in a formative, pre-commercial phase across all sectors. The aviation sector is still at the earliest stage of technological and market development, while sectors such as agriculture and steel have progressed further through pilot and demonstration projects, indicating a higher level of technological readiness. However, deployment in these sectors remains limited in scale and has not yet transitioned to widespread commercial adoption [38]. Targeted policy interventions are likely to play a decisive role in accelerating diffusion across sectors with slower initial uptake [38].

2.4.1 Technological Competition and Path Dependency

Technological change in energy systems rarely occurs in isolation. Instead, new technologies typically emerge in environments where multiple technological options compete to provide similar services. The substitution of one technology by another can therefore be understood as part of a broader process of technological competition [35].

The speed of technological diffusion also depends on the scale and complexity of the technology involved. Large-scale technological systems, such as energy infrastructures or transport networks, typically diffuse much more slowly. These systems involve extensive physical infrastructure, large investments, and complex institutional arrangements. For example, the diffusion of canal networks in the United States took approximately 31 years to increase from 10% to 90% adoption. Similarly, transitions involving large energy systems—such as the decarbonization of energy infrastructures—are often characterized by long time frames due to their scale, complexity and interdependencies [35].

Technical diffusion depends on the knowledge base surrounding the innovation, such as organizational and institutional forms (including markets), norms and attitudes, this sets the rate at which they become incorporated into a socioeconomic setting [35].

Positive feedback mechanisms and increasing returns can lead to situations where technologies become “locked in”, even if they are not necessarily the most efficient alternatives. This phenomenon is commonly referred to as path dependency, where early advantages or historical investments reinforce the continued use of a particular technology over time [37].

In the context of the energy transition, green hydrogen competes with several alternative technologies and energy carriers. These include direct electrification, bioenergy, fossil fuels and other hydrogen production pathways such as grey, blue or pink hydrogen.

2.4.2 Technological Learning and Cost Reduction

Technological diffusion is often accompanied by processes of technological learning that lead to declining costs over time. As production and deployment increase, firms gain experience in manufacturing, installation and operation, which can lead to improved efficiency and lower production costs [35].

Empirical studies suggest that technological cost reductions may occur in different phases. An early phase of rapid cost reduction is often associated with research, development and technical demonstrations during the innovation stage. This may be followed by slower cost reductions during the commercialization and diffusion phase as technologies scale up and mature [35].

In the case of hydrogen, current costs vary significantly depending on the production pathway, energy input, and regional conditions.

In addition to production costs, system-level factors play a critical role in determining the cost of hydrogen. The utilization rate of production, transport and storage infrastructure has been identified as a key cost driver, as low utilization increases the cost per unit of hydrogen by spreading fixed investments over smaller volumes [39]. This is particularly relevant in early-stage markets, where demand is still limited and infrastructure is not yet fully developed.

These characteristics illustrate that hydrogen is currently in a relatively early phase of technological and market development, where costs remain high but are expected to decrease over time as deployment increases, technologies mature, and system utilization improves.

2.4.3 Policy Directionality

The development and diffusion of new technologies are not driven solely by technical performance or market dynamics. Instead, technological pathways are shaped by the strategic choices and coordinated actions of policymakers, firms, and other actors within the broader innovation system. This phenomenon is commonly described as the directionality of technological change [40].

Within this perspective, policy plays a central role in guiding emerging technologies such as green hydrogen toward societal objectives. By designing targeted support instruments, such as public procurement schemes, investment subsidies, or dedicated funding programs, policymakers can reduce uncertainty, mitigate early cost disadvantages, and signal long-term commitment to the technology. Such interventions help create the conditions under which early adopters are willing to invest despite high initial costs, thereby accelerating the market along the S-curve [38].

2.5 The Swedish Electricity System

The development of green hydrogen production is closely linked to the characteristics of the electricity system, in which electrolysis takes place. Sweden has a favorable context for green hydrogen production. The energy mix in Sweden has a large share of fossil-free electricity, mostly from hydro power, nuclear power, wind power and bio power, while solar power constitutes a small but growing part of the market. Less than 2% comes from fossil fuels and residues from steel industry [41].

The Swedish electricity market is divided into four bidding zones from north to south. Electricity prices are determined separately in each zone based on market conditions, reflecting regional differences in electricity supply, demand, and transmission capacity within the grid [41].

Electricity prices are primarily determined by the balance between supply and demand and by the available transmission capacity between regions. The Swedish electricity market follows a marginal pricing principle, meaning that the price at a given time is set by the cost of the last unit of electricity required to meet demand. On the supply side, both the volume of electricity generation and the type of energy sources used influence market outcomes [41].

External factors may also affect electricity prices. These include geopolitical circumstances, political decisions, and regulations at the European Union level, as well as cross-border electricity trade through imports and exports [42].

These structural characteristics are particularly relevant for hydrogen production through electrolysis, which is electricity-intensive. At the same time, electrolysis offers a degree of operational flexibility, allowing hydrogen production to be adjusted in response to electricity market conditions. In periods of high electricity generation, such as during strong wind conditions, electricity supply may exceed demand, leading to very low or even negative prices. In such situations, hydrogen production can act as flexible energy storage, utilizing excess electricity that would otherwise have limited economic value or require producers to curtail generation or face costs for feeding electricity into the grid.

Large-scale hydrogen production will increase electricity demand and thereby place additional pressure on the electricity grid. However, if strategically deployed, it may also contribute to improved system balance by absorbing surplus generation. The expansion of the Swedish electricity system will therefore play a central role in determining where and when green hydrogen production may emerge.

3

Methods

This project is based on three main parts: a literature search, interviews, and an analysis phase. Although these components are presented in the order in which they are generally carried out, they overlap and are partly conducted in parallel throughout the research process. The study begins with a literature review to build a basic understanding of key concepts relevant to the research topic. The focus of the methodology, however, is data collection, mapping, and analysis through further literature studies and interviews. A more detailed description of each method is provided in the following sections.

3.1 Literature Review

In the initial phase of the thesis, a literature review is conducted to gain a knowledge base of the relevant topics. The findings are presented in the theoretical framework, providing the reader with essential background information and context. The literature review supports and complements the interviews throughout the project. More specifically, the review serves as a foundation for the development of the interview guide, for quantitative data collection and helps to identify factors that drive or hinder hydrogen production.

Unlike a fully systematic review, this study intentionally adopts a semi-structured, integrated and iterative approach [43]. The review evolves throughout the research process, allowing flexibility in order to capture the most relevant and timely sources. The semi-structured approach combines traditional literature searches with complementary sources. This includes grey literature (material produced outside academic publication channels), expert recommendations and industry data, to ensure that both academic and real-world perspectives are considered.

This approach is particularly suited to this specific research context, as the study is interdisciplinary and the field is rapidly evolving and highly driven by market and real-world developments [43]. Many important insights, such as project updates, technical reports, and other industry data, are not yet published in academic journals. Including these sources ensures that the review captures the most current state of the field, bridging the gap between theory and practice.

To capture the most recent developments, grey literature is therefore deliberately included, such as project reports, industry publications, policy briefs, and other non-academic sources. In addition, expert and industry recommendations are used to identify additional relevant literature through snowballing, helping to uncover sources that may not appear in conventional databases. This combination of approaches allows the review to remain both comprehensive and up-to-date.

3.1.1 Literature Search Strategy

The literature search begins with a broad exploration of the research topic in order to identify relevant publications and gain an overall familiarity with the field. This initial exploration help map central themes and concepts related to hydrogen production, applications, and market development. The primary database used for the initial academic literature search was Google Scholar. To ensure transparency and reproducibility, a set of structured search strings are applied, including: (Green OR Renewable*) AND Hydrogen* AND (production* OR process*), (Green OR Renewable) AND Hydrogen* AND (application* OR product* OR end-use* OR usage* OR utilization*), Hydrogen AND Sweden AND (product* OR usage* OR utilization* OR end-use* OR application*), Electrolysis AND (cell OR electrolyzer technology), and Scenario AND Analysis*. These searches are iteratively refined as the study progresses.

Expert consultation is used to complement formal database searches, where supervisors and field specialists provide recommendations for relevant literature, enabling a snowballing approach. Based on these findings, key terms and search words are identified and used to refine and deepen searches [44]. As the research progresses, insights from the interviews are also used to generate additional keywords and guide further literature searches. This iterative approach ensures that the literature review remains relevant and closely aligned with both the theoretical development and the empirical findings of the study.

For grey literature, a more flexible search approach is adopted without strict search strings. Instead, combinations of Swedish and English keywords are used, such as “vätgas” + “Sverige”, “vätgasprojekt Sverige”, "eFuels Sverige" and “vätgas” combined with specific stakeholders or company names. This iterative and adaptive search strategy ensure that the literature review remained relevant and closely aligned with both the theoretical development and the empirical findings of the study.

3.2 Stakeholder Identification

Identifying relevant stakeholders is a crucial step of the study to ensure validity and completeness of the analysis. The study aims to find stakeholders who both influence and are influenced by the green hydrogen market, including present and prospective actors.

Identification is done through literature searches and are complemented by expert consultation. Supervisors and field specialists involved in the project provided recommendations for relevant actors, using existing networks and enabling a snowballing strategy. The snowballing approach is also adapted during the interview process, meaning that the interviewed stakeholders are asked to suggest additional relevant actors, which allows the stakeholder network to expand. This approach enables the collection of diverse insights and supports the development of a rigorous system mapping.

Additionally, relations between producer and current as well as future consumers will be identified to the biggest extent. Finding these interconnections helps capture the structure of the hydrogen system and minimizes the risk of overlooking influential actors that could significantly affect green hydrogen production and market development.

3.3 Interviews

The goal with the interviews is to collect data that can be used to quantify hydrogen production, as well as to gather information that maps the current position of the identified stakeholders.

Furthermore, the interviews aim to identify key factors that drive or hinder the production of green hydrogen. These findings will then be used as the foundation for the scenario analysis.

3.3.1 Planning and Preparing Interviews

The planning and preparation of the interviews are based on the development of an interview guide constructed from the literature review. This interview guide serves as a foundational tool for the interviews and ensures that relevant topics identified in previous research are addressed. The interview guide is not fixed; instead, it evolves over time as interviews are conducted and new topics and perspectives are introduced by the interview participants. Preliminary research on the stakeholder interviewees' roles and contexts are conducted ahead of the interviews to support well-informed discussions and improve the analytical value of the interviews.

3.3.2 Conducting Interviews

The interviews are primarily conducted using a semi-structured format. An interview guide is used as a baseline to ensure a degree of consistency across interviews, while still allowing conversations to evolve and diverge into related topics as they naturally arose. This approach enable the collection of comparable data while maintaining flexibility to explore emerging themes in greater depth.

However, due to practical constraints such as the limited time frame of the thesis and the availability of interviewees, the format vary across cases. Some interviews are conducted in a more informal and unstructured manner, often in shorter sessions where the focus is placed on mapping the current status of ongoing projects and an overview of market dynamics rather than following the full interview guide. In addition, a number of responses are collected via email when interviewees do not have the opportunity to participate in a scheduled meeting. This variation in data collection methods allow for broader coverage of relevant actors while accommodating time constraints, though it also results in differences in depth and level of detail across the collected data.

3.3.3 Documentation and Summarizing

There is no assigned note taker during the interviews to promote and ensure active dialog and open discussions. Instead, the interviews are recorded, with the help of AI dictation tools, provided that informed consent is given. The dictations are then rewritten into a clean copy afterwards, which is then used as a base for the analysis. After publication of the thesis, the recordings are deleted.

3.4 Data Processing

The data processing aims to transform qualitative and quantitative inputs into a consistent format that enables comparison across projects and supports the subsequent scenario analysis.

3.4.1 Insight Summarization

Insights from the literature and interviews are compiled into structured tables covering the identified hydrogen projects within the scope of the study. For each project, key characteristics such as location, production capacity, targeted sector, and project status are documented.

In addition, insights from the interviews are synthesized to identify key drivers, barriers, and critical factors influencing the development of the hydrogen market. These insights are organized using a thematic approach, allowing recurring patterns and perspectives across stakeholders to be captured and integrated into the analysis.

3.4.2 Anonymization of Stakeholders

The stakeholders who contributed to the study through interviews are anonymized to ensure full confidentiality for all participants. The stakeholder groups represent different roles across the hydrogen value chain and related support functions. By presenting the interviewees in anonymized form, the analysis can draw on their insights without disclosing sensitive organizational or personal information.

Stakeholders categorized as *Only mapping* are not interviewed but contributed information relevant to the project mapping. All interviewed participants are presented in anonymized form in Table 4.5, together with an assigned participant number and the market role represented by their organization.

The stakeholder roles are categorized based on the primary function of the represented organization in the hydrogen system. The categorization reflects the current and anticipated role of the actors in the hydrogen system up until 2030. In Table 3.1 the abbreviations and chosen categories are presented.

Table 3.1: Abbreviations and Categories

Abbreviation	**Stakeholder category**
P	Production actors
D	Distribution actors
I	Industrial actors
M	Mobility actors
RES	Research actors
GOV	Government actors
ORG	Trade organization actors
Only mapping	Actors contributing solely to project mapping

3.5 Scenario Analysis

The study applies a combined qualitative and quantitative scenario analysis to examine possible future developments of hydrogen production. By integrating these approaches, the analysis captures both the underlying mechanisms shaping the system and the range of potential outcomes. The qualitative component provides an understanding of the structural and contextual conditions influencing project realization, while the quantitative component enables the exploration of how these conditions translate into different future trajectories.

In addition to a baseline scenario reflecting current conditions, two alternative scenarios are developed to capture possible developments in the external environment. These scenarios reflect variations in key contextual conditions, such as policy support, market development, and energy system constraints. Changes in these conditions lead to adjusted project probabilities, which in turn result in different projected outcomes. In this way, the scenario analysis enables a structured comparison of how different future contexts may influence hydrogen production.

These scenarios are based on three different shared socioeconomic pathways (SSPs) *(SSP1 - Sustainability, SSP2 - Middle of the Road and SSP3- Regional Rivalry)*, which are narratives that outline plausible trajectories of demographic, economic, technological, and institutional change, and are designed to capture how different societal conditions influence sustainable development challenges [45].

3.5.1 SSP2 - Middle of the Road

The first scenario represents a business as usual trajectory, aligned with the SSP2 "Middle of the Road" storyline. In this world, current trends continue without major disruptions or breakthroughs. Social, economic, and technological developments follow historical patterns, and no dramatic policy shifts occur. Existing structures dominate, and progress is incremental rather than transformative [46].

This creates a stable environment in which hydrogen deployment grows, yet not fast enough to fundamentally transform the energy system in the near term. The scenario does not introduce strong accelerators or strong barriers; instead, it reinforces the structural conditions already present in the Swedish energy and industrial landscape.

In short, SSP2 reinforces the existing hierarchy of project readiness: mature projects remain likely, early projects remain uncertain, and structural constraints persist. Projects with strong fundamentals—advanced status, secured funding, favorable location, and established sectoral demand score well. Projects that rely on future policy shifts, rapid grid expansion, or breakthrough cost reductions do not receive scenario-driven uplift.

3.5.2 SSP1 - Sustainability

SSP1 describes a world where countries, companies, and individuals actively work together to achieve long-term sustainability goals. It is a stable, cooperative, and predictable future, shaped by high trust between actors and strong alignment across political, industrial, and societal priorities. The global system is characterized by coordination rather than fragmentation, and by long-term planning rather than short-term crisis management [45].

Technological development in sustainable energy accelerates quickly, supported by ambitious climate targets and clear, long-term policy frameworks. Investments in renewable energy, grid expansion, and enabling infrastructure are prioritized, and regulatory environments are harmonized across the EU and internationally. Financing risks are low, as both public and private capital flow toward green technologies.

In this world, climate and sustainability are overarching goals. Policy, industry, and the energy system move in the same direction, reinforcing each other rather than working at cross-purposes. The result is a future where the broader system actively supports the realization of hydrogen projects: permitting is faster, funding is more accessible, electricity systems expand in line with demand, and cross-sector coordination reduces uncertainty.

SSP1 is therefore a scenario in which the world helps projects succeed. Structural barriers are systematically addressed, long-term strategies guide investment, and hydrogen development benefits from a policy environment designed to accelerate the transition rather than just accommodating it.

3.5.3 SSP3 - Regional Rivalry

This scenario represents a future characterized by unfavorable conditions for the development of green hydrogen production. The global context is marked by increasing regional rivalry, a strong focus on national self-sufficiency, and limited international cooperation. Climate and sustainability concerns are not prioritized on the political agenda, and governance is largely reactive rather than guided by long-term strategic planning. Economic growth is weak, resulting in limited access to capital for large-scale investments, while technological development progresses slowly [45]. This delays cost reductions for key technologies such as electrolyzers, keeping them relatively expensive. Reduced trade and international collaboration further constrain access to technology, expertise, and critical resources. In addition, the energy system evolves in a more nationally oriented direction, with lower levels of integration between countries and regions. Taken together, these conditions create a context in which the development of hydrogen projects is significantly constrained, affecting investment, technological progress, and market formation.

3.5.4 Factor Analysis

The scenario analysis is designed to evaluate future production outcomes based on identified hydrogen projects. Drawing on the literature and conducted interviews, a set of key factors influencing project realization is established. Each project is assessed against these factors, assigned points (1-10), which are then weighted according to their relative importance. Based on this assessment, each project is assigned a probability of realization. These probabilities form the basis for the quantitative analysis, including timeline visualizations and Monte Carlo simulations.

Based on interviews and literature, a set of assessment factors is identified and used to evaluate each project. These factors are assessed through a structured scoring approach, where each project is assigned a relative score (1-10) depending on how well it fulfills certain criteria. The scoring reflects the degree to which a factor supports or hinders project realization, rather than representing exact quantitative measures.

The factors are further weighted to reflect their relative importance for project realization. For example, in some scenarios, greater weight is assigned to factors considered strong predictors of whether a project will be realized, such as overall project maturity and decision status, while other factors, such as geographical or sectoral conditions, are given moderate influence. In cases where information is limited or uncertain, a neutral assessment, relative to the grading scale, is applied.

To support interpretation, the resulting probabilities are translated into a qualitative classification using a traffic-light system, as seen in Figure 3.1. Projects are categorized into high, medium, or low likelihood of realization, providing an overview of the distribution of project feasibility across scenarios. This classification serves as a bridge between the qualitative assessment and the quantitative modeling.

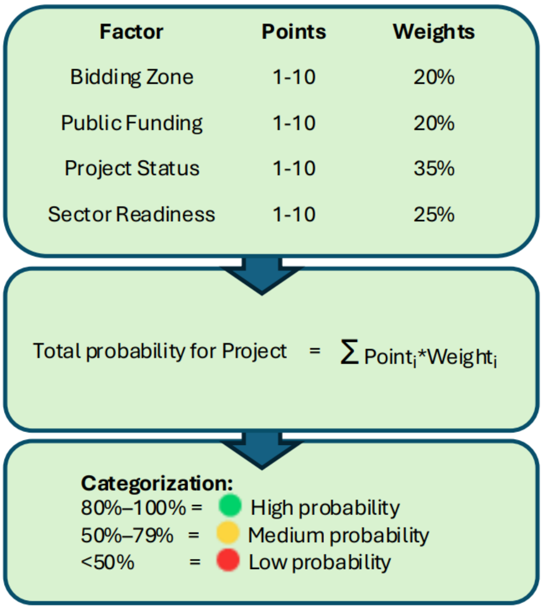


Figure 3.1: Visualization of the factor analysis method to sort hydrogen projects in different probability categories

For the SSP1 and SSP3 scenario, the factors are reevaluated from the Business as Usual trajectory (SSP2) factors. This is done by evaluating which factors are most affected by the SSP scenario, both through adjusting the points, as well as the weights for each scenario.

3.5.5 Timeline

To visualize how hydrogen production may develop over time, a timeline analysis is conducted. In this step, projects are plotted based on their expected start year and probability classification, allowing for a temporal representation of potential production capacity. The timeline illustrates how different categories of projects contribute to total capacity over time and highlights the role of uncertainty by distinguishing between projects with varying likelihoods of realization. This provides insight into both the pace and structure of the potential market development. When the reported start of production (SOP) dates span two different years, the later year is selected. Projects lacking an SOP date are placed after 2030 in the timeline.

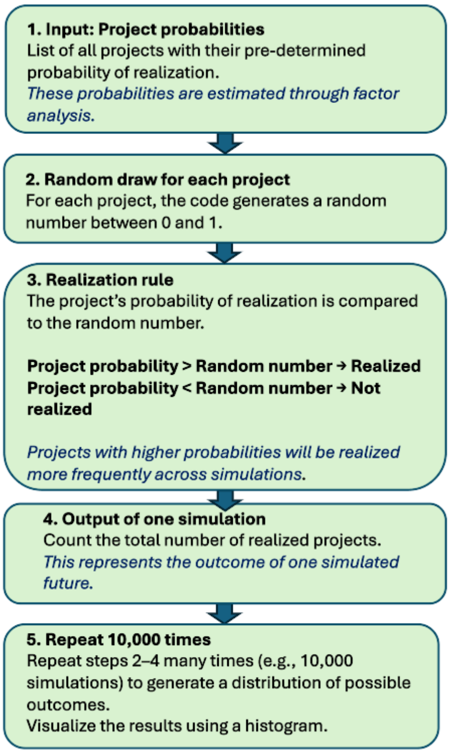
3.5.6 Monte Carlo Simulations

A Monte Carlo simulation is used to quantify the uncertainty associated with project realization. While each project is assigned a probability of realization, this does not imply that projects are automatically realized even under favorable scenario conditions. Real-world project development is subject to stochastic influences, unforeseen factors, that are not fully captured by scenario assumptions alone. The simulation addresses this by generating a large number of possible future scenarios through repeated random sampling based on these probabilities, thereby introducing a stochastic “realization layer” that reflects real-world uncertainty beyond deterministic scenario inputs. Monte Carlo simulation introduces a realistic uncertainty dimension, where projects are more likely, but never guaranteed, to be realized, even under favorable scenario conditions.

In this study, each project is represented as a Bernoulli variable, meaning that it can either be realized or not. For each simulation, a random draw is performed for every project, where the outcome is determined by comparing a randomly generated number with the project's assigned probability (See figure 3.2). Projects with higher probabilities are therefore more likely to be realized across simulations, while those with lower probabilities are realized less frequently. This reflects a fair and consistent treatment of the assigned probabilities over many iterations.

Each simulation produces a possible realization outcome across all projects, from which metrics, such as the number of realized projects can be calculated. By repeating this process a large number of times, a statistical distribution of possible outcomes is obtained. This distribution captures the variability and uncertainty inherent in the system and is summarized using mean value, as well as visualized through histograms.

The Monte Carlo approach thus complements the deterministic elements of the scenario analysis by providing a probabilistic perspective. Rather than describing a single expected outcome, it allows for the exploration of a range of possible futures and highlights the degree of uncertainty associated with hydrogen market development.



1. Input: Project probabilities
List of all projects with their pre-determined probability of realization.
These probabilities are estimated through factor analysis.

2. Random draw for each project
For each project, the code generates a random number between 0 and 1.

3. Realization rule
The project's probability of realization is compared to the random number.

Project probability > Random number → Realized
Project probability < Random number → Not realized

Projects with higher probabilities will be realized more frequently across simulations.

4. Output of one simulation
Count the total number of realized projects.
This represents the outcome of one simulated future.

5. Repeat 10,000 times
Repeat steps 2–4 many times (e.g., 10,000 simulations) to generate a distribution of possible outcomes.
Visualize the results using a histogram.

Figure 3.2: Visualization of Monte Carlo method

3.6 Ethical Aspects

This section presents the ethical considerations guiding the study, including source evaluation, stakeholder privacy and data protection, and the interpretation of results.

3.6.1 Critical Assessment of Sources

Critical thinking is essential in the literature review process. Given the high degree of uncertainty regarding future developments of the hydrogen industry, it is particularly important to select sources with high credibility, such as peer reviewed academic literature, reports from established institutions, governmental publications and industry organizations. This approach reduces the risk of misinformation and strengthens the reliability of the analysis [44].

3.6.2 Stakeholder Privacy and Data Protection (GDPR)

Ethical considerations related to stakeholder privacy, company confidentiality, and data protection have been carefully addressed throughout the study. During the interview process, particular attention was given to handling potentially sensitive information, and informed consent was obtained from all participants prior to including any direct quotations in the thesis. In accordance with the General Data Protection Regulation (GDPR) [47], stakeholders are referred to by their role in the hydrogen market rather than by personal name, ensuring anonymity. To further ensure transparency and accuracy, the final thesis was shared with participating stakeholders, allowing them to review the cited material and identify any information considered sensitive or unsuitable for public disclosure; such information has subsequently been excluded or presented in an anonymized form.

3.6.3 Accuracy and Interpretation of Results

The accuracy and interpretation of results are considered throughout the research process. Interview-based data are subjective and reflect the experience and perspectives of the selected stakeholders. In the context of this thesis, this subjectivity is a strength, as industry actors provide valuable knowledge that is essential for understanding and anticipating developments in the hydrogen market. However, it is acknowledged that these insights represent informed expectations rather than objective and definitive predictions.

4

Results

This chapter presents the results in three parts. First, the mapping of green hydrogen projects identified within the scope of the study, followed by key insights derived from interviews with relevant actors associated with these projects or the hydrogen market in general.

4.1 Mapping of Green Hydrogen Projects

The projects identified within the scope of this study are visually presented in the map (Figure 4.1). Project colors indicate different categories based on the role of hydrogen in the business model, these include pure production (Blue), integrated production-consumption systems (Pink), consumption (Orange) and projects linked to distribution (Green). In total, 26 production projects, 17 integrated production and consumption projects, 2 consumption projects, and 23 distribution projects were identified. Electricity bidding zones are also visualized in the map, illustrating the bidding zone in which each project is located. More information about each project on the map can be found in Tables 4.1 - 4.4. The numbers found to the far left in these tables correspond to the numbers on the map.

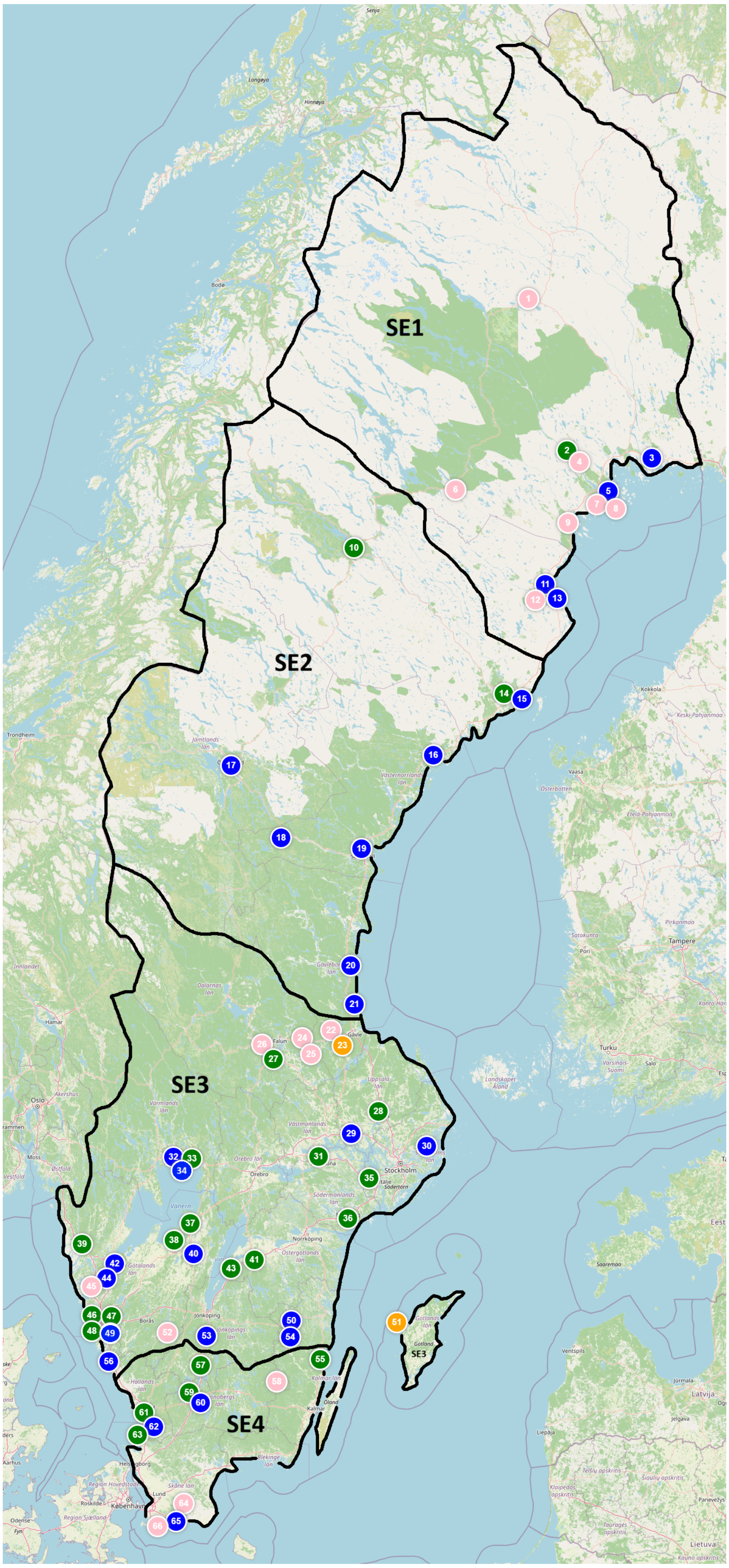
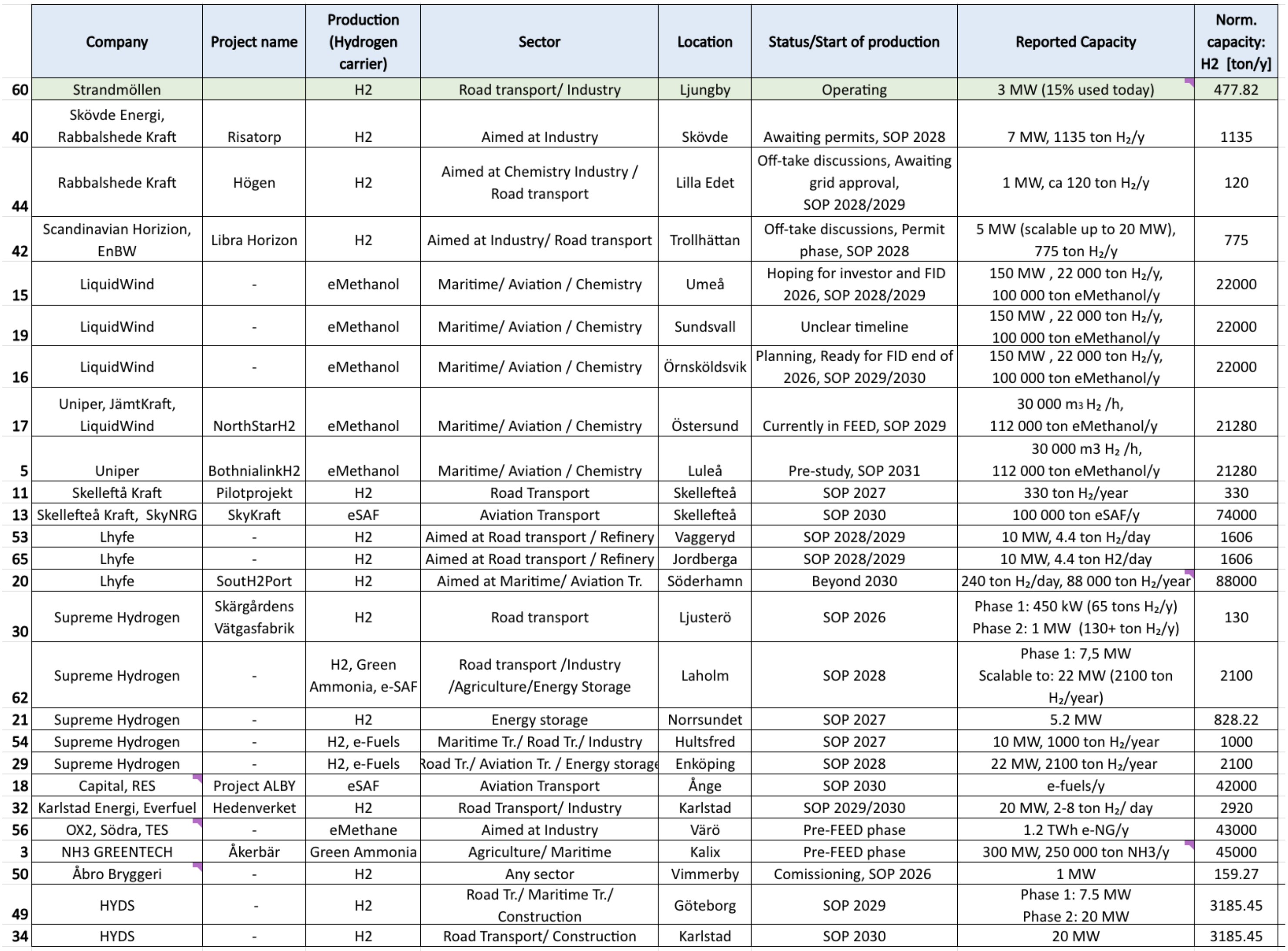


Figure 4.1: Map of Swedish green hydrogen projects in different electricity bidding areas.

Table 4.1: Producers of Green Hydrogen



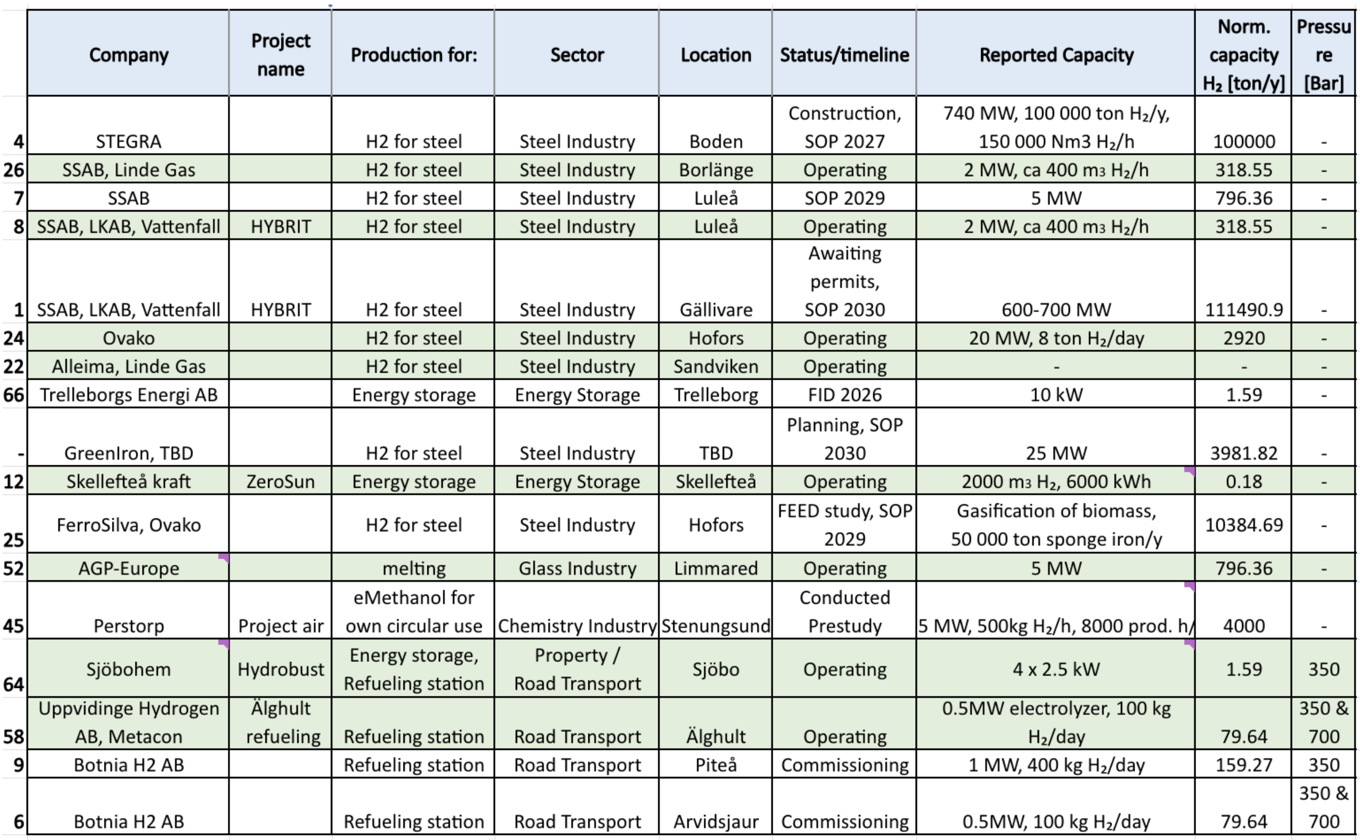
	Company	Project name	Production (Hydrogen carrier)	Sector	Location	Status/Start of production	Reported Capacity	Norm. capacity: H2 [ton/y]
60	Strandmöllen		H2	Road transport/ Industry	Ljungby	Operating	3 MW (15% used today)	477.82
40	Skövde Energi, Rabbalshede Kraft	Risatorp	H2	Aimed at Industry	Skövde	Awaiting permits, SOP 2028	7 MW, 1135 ton H_2/y	1135
44	Rabbalshede Kraft	Högen	H2	Aimed at Chemistry Industry / Road transport	Lilla Edet	Off-take discussions, Awaiting grid approval, SOP 2028/2029	1 MW, ca 120 ton H_2/y	120
42	Scandinavian Horizion, EnBW	Libra Horizon	H2	Aimed at Industry/ Road transport	Trollhättan	Off-take discussions, Permit phase, SOP 2028	5 MW (scalable up to 20 MW), 775 ton H_2/y	775
15	LiquidWind	-	eMethanol	Maritime/ Aviation / Chemistry	Umeå	Hoping for investor and FID 2026, SOP 2028/2029	150 MW , 22 000 ton H_2/y, 100 000 ton eMethanol/y	22000
19	LiquidWind	-	eMethanol	Maritime/ Aviation / Chemistry	Sundsvall	Unclear timeline	150 MW , 22 000 ton H_2/y, 100 000 ton eMethanol/y	22000
16	LiquidWind	-	eMethanol	Maritime/ Aviation / Chemistry	Örnsköldsvik	Planning, Ready for FID end of 2026, SOP 2029/2030	150 MW , 22 000 ton H_2/y, 100 000 ton eMethanol/y	22000
17	Uniper, JämtKraft, LiquidWind	NorthStarH2	eMethanol	Maritime/ Aviation / Chemistry	Östersund	Currently in FEED, SOP 2029	30 000 m_3 H_2 /h, 112 000 ton eMethanol/y	21280
5	Uniper	BothnialinkH2	eMethanol	Maritime/ Aviation / Chemistry	Luleå	Pre-study, SOP 2031	30 000 m3 H_2 /h, 112 000 ton eMethanol/y	21280
11	Skelleftå Kraft	Pilotprojekt	H2	Road Transport	Skellefteå	SOP 2027	330 ton H_2/year	330
13	Skellefteå Kraft, SkyNRG	SkyKraft	eSAF	Aviation Transport	Skellefteå	SOP 2030	100 000 ton eSAF/y	74000
53	Lhyfe	-	H2	Aimed at Road transport / Refinery	Vaggeryd	SOP 2028/2029	10 MW, 4.4 ton H_2/day	1606
65	Lhyfe	-	H2	Aimed at Road transport / Refinery	Jordberga	SOP 2028/2029	10 MW, 4.4 ton H2/day	1606
20	Lhyfe	SoutH2Port	H2	Aimed at Maritime/ Aviation Tr.	Söderhamn	Beyond 2030	240 ton H_2/day, 88 000 ton H_2/year	88000
30	Supreme Hydrogen	Skärgårdens Vätgasfabrik	H2	Road transport	Ljusterö	SOP 2026	Phase 1: 450 kW (65 tons H_2/y) Phase 2: 1 MW (130+ ton H_2/y)	130
62	Supreme Hydrogen	-	H2, Green Ammonia, e-SAF	Road transport /Industry /Agriculture/Energy Storage	Laholm	SOP 2028	Phase 1: 7,5 MW Scalable to: 22 MW (2100 ton H_2/year)	2100
21	Supreme Hydrogen	-	H2	Energy storage	Norrsundet	SOP 2027	5.2 MW	828.22
54	Supreme Hydrogen	-	H2, e-Fuels	Maritime Tr./ Road Tr./ Industry	Hultsfred	SOP 2027	10 MW, 1000 ton H_2/year	1000
29	Supreme Hydrogen	-	H2, e-Fuels	Road Tr./ Aviation Tr. / Energy storage	Enköping	SOP 2028	22 MW, 2100 ton H_2/year	2100
18	Capital, RES	Project ALBY	eSAF	Aviation Transport	Ånge	SOP 2030	e-fuels/y	42000
32	Karlstad Energi, Everfuel	Hedenverket	H2	Road Transport/ Industry	Karlstad	SOP 2029/2030	20 MW, 2-8 ton H_2/ day	2920
56	OX2, Södra, TES	-	eMethane	Aimed at Industry	Värö	Pre-FEED phase	1.2 TWh e-NG/y	43000
3	NH3 GREENTECH	Åkerbär	Green Ammonia	Agriculture/ Maritime	Kalix	Pre-FEED phase	300 MW, 250 000 ton NH3/y	45000
50	Åbro Bryggeri	-	H2	Any sector	Vimmerby	Comissioning, SOP 2026	1 MW	159.27
49	HYDS	-	H2	Road Tr./ Maritime Tr./ Construction	Göteborg	SOP 2029	Phase 1: 7.5 MW Phase 2: 20 MW	3185.45
34	HYDS	-	H2	Road Transport/ Construction	Karlstad	SOP 2030	20 MW	3185.45

References (in order of appearance): [48], [49], [50], [51], [52], [53]

Box 4.1: Clarifications and Disclaimers regarding Tables 4.1 - 4.4

- All green rows marks projects that are currently operating.
- The symbol ” – ” indicates that no information regarding the respective subject was either confirmed or denied.
- The values presented in column *Normalized Capacity* is based on assumptions explained in Appendix C, while the values in column *Reported Capacity* is given through interviews or through publicly available web sources.
- In cases where reported capacities correspond to different development phases, the maximum reported capacity is used for normalization.
- Unless otherwise stated, all information without a reference originates from interviews conducted within the scope of this study.
- In the tables, cells marked with a purple corner indicate that sources have been used. The corresponding references are presented below each table.

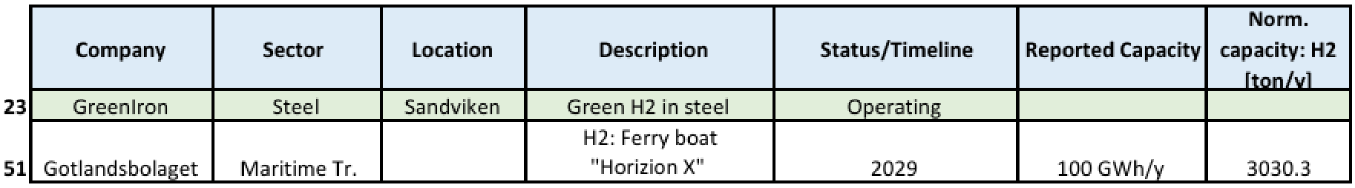
Table 4.2: Producers and Consumers of Green Hydrogen



	Company	Project name	Production for:	Sector	Location	Status/timeline	Reported Capacity	Norm. capacity H_2 [ton/y]	Pressure [Bar]
4	STEGRA		H2 for steel	Steel Industry	Boden	Construction, SOP 2027	740 MW, 100 000 ton H_2/y, 150 000 Nm3 H_2/h	100000	-
26	SSAB, Linde Gas		H2 for steel	Steel Industry	Borlänge	Operating	2 MW, ca 400 m$_3$ H_2/h	318.55	-
7	SSAB		H2 for steel	Steel Industry	Luleå	SOP 2029	5 MW	796.36	-
8	SSAB, LKAB, Vattenfall	HYBRIT	H2 for steel	Steel Industry	Luleå	Operating	2 MW, ca 400 m$_3$ H_2/h	318.55	-
1	SSAB, LKAB, Vattenfall	HYBRIT	H2 for steel	Steel Industry	Gällivare	Awaiting permits, SOP 2030	600-700 MW	111490.9	-
24	Ovako		H2 for steel	Steel Industry	Hofors	Operating	20 MW, 8 ton H_2/day	2920	-
22	Alleima, Linde Gas		H2 for steel	Steel Industry	Sandviken	Operating	-	-	-
66	Trelleborgs Energi AB		Energy storage	Energy Storage	Trelleborg	FID 2026	10 kW	1.59	-
-	GreenIron, TBD		H2 for steel	Steel Industry	TBD	Planning, SOP 2030	25 MW	3981.82	-
12	Skellefteå kraft	ZeroSun	Energy storage	Energy Storage	Skellefteå	Operating	2000 m$_3$ H_2, 6000 kWh	0.18	-
25	FerroSilva, Ovako		H2 for steel	Steel Industry	Hofors	FEED study, SOP 2029	Gasification of biomass, 50 000 ton sponge iron/y	10384.69	-
52	AGP-Europe		melting	Glass Industry	Limmared	Operating	5 MW	796.36	-
45	Perstorp	Project air	eMethanol for own circular use	Chemistry Industry	Stenungsund	Conducted Prestudy	5 MW, 500kg H_2/h, 8000 prod. h/	4000	-
64	Sjöbohem	Hydrobust	Energy storage, Refueling station	Property / Road Transport	Sjöbo	Operating	4 x 2.5 kW	1.59	350
58	Uppvidinge Hydrogen AB, Metacon	Älghult refueling	Refueling station	Road Transport	Älghult	Operating	0.5MW electrolyzer, 100 kg H_2/day	79.64	350 & 700
9	Botnia H2 AB		Refueling station	Road Transport	Piteå	Commissioning	1 MW, 400 kg H_2/day	159.27	350
6	Botnia H2 AB		Refueling station	Road Transport	Arvidsjaur	Commissioning	0.5MW, 100 kg H_2/day	79.64	350 & 700

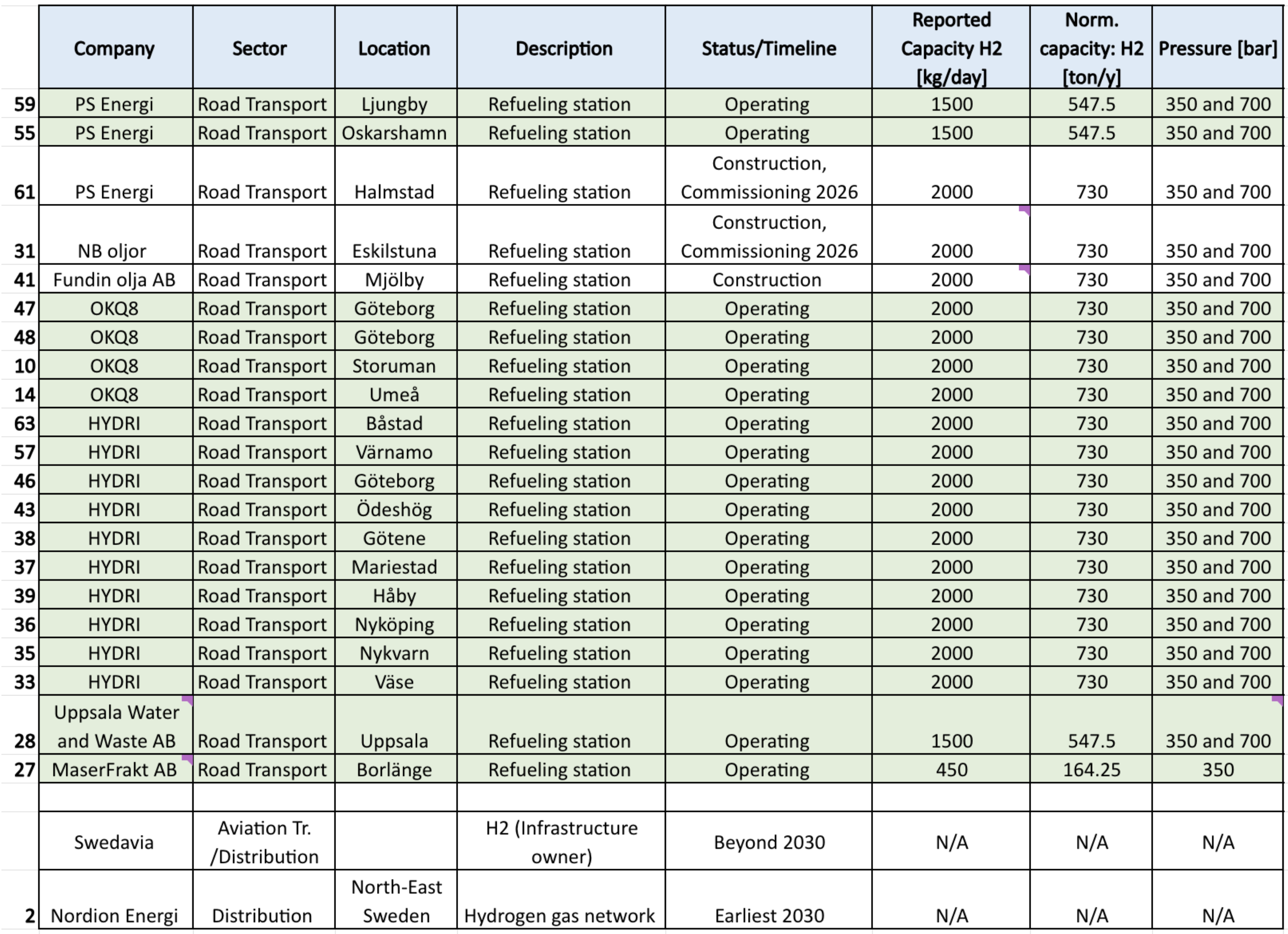
References (in order of appearance): [54], [55], [56], [57], [58]

Table 4.3: Consumers of Green Hydrogen



	Company	Sector	Location	Description	Status/Timeline	Reported Capacity	Norm. capacity: H2 [ton/y]
23	GreenIron	Steel	Sandviken	Green H2 in steel	Operating		
51	Gotlandsbolaget	Maritime Tr.		H2: Ferry boat "Horizion X"	2029	100 GWh/y	3030.3

Table 4.4: Distribution of Green Hydrogen



	Company	Sector	Location	Description	Status/Timeline	Reported Capacity H2 [kg/day]	Norm. capacity: H2 [ton/y]	Pressure [bar]
59	PS Energi	Road Transport	Ljungby	Refueling station	Operating	1500	547.5	350 and 700
55	PS Energi	Road Transport	Oskarshamn	Refueling station	Operating	1500	547.5	350 and 700
61	PS Energi	Road Transport	Halmstad	Refueling station	Construction, Commissioning 2026	2000	730	350 and 700
31	NB oljor	Road Transport	Eskilstuna	Refueling station	Construction, Commissioning 2026	2000	730	350 and 700
41	Fundin olja AB	Road Transport	Mjölby	Refueling station	Construction	2000	730	350 and 700
47	OKQ8	Road Transport	Göteborg	Refueling station	Operating	2000	730	350 and 700
48	OKQ8	Road Transport	Göteborg	Refueling station	Operating	2000	730	350 and 700
10	OKQ8	Road Transport	Storuman	Refueling station	Operating	2000	730	350 and 700
14	OKQ8	Road Transport	Umeå	Refueling station	Operating	2000	730	350 and 700
63	HYDRI	Road Transport	Båstad	Refueling station	Operating	2000	730	350 and 700
57	HYDRI	Road Transport	Värnamo	Refueling station	Operating	2000	730	350 and 700
46	HYDRI	Road Transport	Göteborg	Refueling station	Operating	2000	730	350 and 700
43	HYDRI	Road Transport	Ödeshög	Refueling station	Operating	2000	730	350 and 700
38	HYDRI	Road Transport	Götene	Refueling station	Operating	2000	730	350 and 700
37	HYDRI	Road Transport	Mariestad	Refueling station	Operating	2000	730	350 and 700
39	HYDRI	Road Transport	Håby	Refueling station	Operating	2000	730	350 and 700
36	HYDRI	Road Transport	Nyköping	Refueling station	Operating	2000	730	350 and 700
35	HYDRI	Road Transport	Nykvarn	Refueling station	Operating	2000	730	350 and 700
33	HYDRI	Road Transport	Väse	Refueling station	Operating	2000	730	350 and 700
28	Uppsala Water and Waste AB	Road Transport	Uppsala	Refueling station	Operating	1500	547.5	350 and 700
27	MaserFrakt AB	Road Transport	Borlänge	Refueling station	Operating	450	164.25	350
	Swedavia	Aviation Tr. /Distribution		H2 (Infrastructure owner)	Beyond 2030	N/A	N/A	N/A
2	Nordion Energi	Distribution	North-East Sweden	Hydrogen gas network	Earliest 2030	N/A	N/A	N/A

References (in order of appearance): [59], [60]

Table 4.5: Interviewee Organizations' System Function and Abbreviations

Abbreviation	Market role
P1	H_2 Producer
P2	H_2 Producer
P3	H_2 Producer
P4	H_2 Producer
P5	H_2 Producer
P6	H_2 Producer
P7	Project Developers of e-Fuel Production
P8	H_2 Production Actor
P9	H_2 Production Actor
P10	H_2 Producing Actor
D1	Gasgrid Company
D2	Refueling Station
D3	Refueling Station
D4	Refueling Station
I1	H_2 Producing Steel Company
I2	H_2 Producing Steel Company
I3	H_2 Producing Steel Company
I4	H_2 Producing Steel Company
I5	Steel Company
I6	Refinery Company
I7	Refinery Company
I8	Chemistry Company
I9	Chemistry Company
I10	Fertilizer Company
M1	Passenger Shipping Company
M2	Truck Producing Company
M3	Airport Company
RES1	Research Actor
RES2	Research Actor
RES3	Research Institute
GOV1	Public Funding Actor
GOV2	Public Funding Actor
ORG1	Industry Organization
ORG2	Industry Organization
Only mapping	H_2 Producer
Only mapping	H_2 Producer
Only mapping	Ammonia Production
Only mapping	Refueling Station Developers/e-Fuel Production

4.2 Interviews and Literature Insights

In total, 34 were conducted, complemented by 3 additional *Only mapping* stakeholder interactions (shown in Table 4.5). This section presents the results derived from the conducted interviews, structured thematically to reflect the key dimensions relevant to the study. The interview material has been analyzed using a thematic analysis approach, through which recurring patterns and central topics were identified. This approach enables the identification of common viewpoints, challenges, and opportunities as perceived by the interviewed actors. For each theme, individual responses have been synthesized and grouped to capture overarching trends rather than isolated statements.

The themes identified as most relevant to the study are: *Geopolitics and global situation*, *Political governance and policy instruments*, *Economy and investments*, *Market and consumer relations*, *Electricity and infrastructure*, *Technical maturity*, and *Competences and standardizations.*

4.2.1 Geopolitics and Global Situation

The interviews show clearly that politics and the global situation play a critical role in the development of the hydrogen market. All actors emphasise that geopolitics shape the market conditions and are vital to the deployment of hydrogen, both as a driving force and as a barrier, through their impact on energy prices, the investment climate, and political priorities. It is also pointed out (P9) that less mature markets risk being more severely affected by instability and uncertainty.

The drivers behind the transition are no longer solely climate-related but increasingly concern resilience and energy security (I1, RES3, P9). Hydrogen is described as a key component in Sweden and Europe becoming more independent, offering value beyond climate mitigation. This includes resilience thinking and enhanced energy security, benefits closely connected to the risks associated with import dependence (M2, RES3, P5, P6, P9, I1, I10, GOV1, P10, D1).

Several actors highlight the importance of demonstrating leadership in the climate transition (D3, D2, I3, I5, M1, M2, M3). The ambition to contribute to a more robust and flexible energy system is also emphasized (P10). Developments in China are pushing the pace for hydrogen development globally, and the EU aims to avoid falling behind (RES3, P3). Competition is another central aspect, with companies underscoring the importance of not lagging behind global competitors (M2).

4.2.1.1 Global Economic Conditions

Economic conditions have a significant impact on hydrogen market development. Previous drivers, such as low electricity prices, favorable financing conditions, and strong momentum for hydrogen development, diminished over time (P4, I1). At the same time, geopolitical tensions and conflicts have contributed to rising electricity prices (P4, I7), further complicating investment conditions for hydrogen-related projects. In parallel, developments in the international context have driven up oil prices, which has increased interest in alternative fuels (M2). Diesel prices are also expected to rise, driven both by the effects of ongoing conflicts and by stricter regulatory requirements (D2). Together, these developments point to a complex price environment, in which rising costs both encourage a shift toward alternative fuels and place increasing pressure on investment conditions.

In addition, macroeconomic downturns form a clear barrier to development. Under recessionary conditions, companies tend to prioritize core business activities, while climate-related investments are postponed or deprioritized (I3, RES2, RES3). These economic pressures affect the entire value chain, and constraints on the climate transition are further reinforced by weakening demand for green and low-carbon products (I3, I9, M3).

The combined effects of the COVID-19 pandemic and ongoing conflicts have led to delays in multiple projects. These disruptions have occurred through disturbed supply chains and delayed wind power expansion, particularly along the east coast, which has affected related hydrogen developments (M2).

4.2.2 Political Governance and Policy Instruments

Policy instruments are underscored as essential for enabling development. Recommendations include designing smart policy tools that link requirements to tangible measurable outcomes (ORG2), as well as emphasizing the need for political involvement to initiate market development (P3). At the same time, a lack of market competence and political decision-making is identified as a cause of delays (ORG2).

4.2.2.1 Strategy and Direction

The transition away from fossil fuels represents a substantial systemic change, as existing regulations, institutions, and market structures have largely been shaped around fossil energy (ORG1). This structural lock-in creates significant challenges for the development of alternative energy systems such as hydrogen.

A barrier identified is that current policy frameworks are primarily oriented toward electrification and battery solutions (D2), with hydrogen often treated as a subcategory of electrification rather than as a distinct system solution in its own right (ORG2). In addition, there is a lack of regulatory drivers and an overarching hydrogen policy framework (P1, GOV1), including the absence of a coherent national hydrogen strategy (P1, P3, D2, RES2, I5). Such challenges are compounded by insufficient national coordination, and it is argued that energy policy should be approached from a broader socio-economic perspective, given that energy affects all sectors of society (P3).

Uncertainty surrounding political governance and long-term regulatory frameworks creates additional challenges (RES2, P9). Actors point to the absence of a stable, long-term, and economically viable political strategy, which undermines investment confidence (P3, P9, P10, I7, RES3, GOV2, ORG2). This uncertainty is reinforced by a shifting political narrative around the climate transition (P4, I1, RES2), making it difficult for companies to assess long-term conditions.

A recurring finding is that actors call for clearer political targets and the explicit inclusion of hydrogen in national strategies (P10, D2, P1, P4, P8, GOV2, I5, ORG1, ORG2). Market development and demand are described as being largely policy-driven, underscoring the central role of political direction. Several respondents stress that regulatory requirements and clear national guidelines are needed to create momentum for hydrogen development. Without binding requirements, many industries remain in a wait-and-see position, as the current policy framework, such as the EU ETS (European Union Emissions Trading System), is perceived as insufficient for a transition, partly because environmental costs are not fully internalized (P1, P3, P4, P9, P10, I5, I6, GOV1, GOV2, RES2).

At the European level, the EU's increasing focus on energy self-sufficiency and reduced dependence on fossil fuels is viewed as a positive trend that should be further strengthened (P9). Meeting the goals of the Paris Agreement will require, among other measures, a large-scale transition of existing fossil-based hydrogen production (P9). In this context, it is stressed that Sweden needs a stable, clear, and cross-party energy policy to enable long-term investment in new energy production. Without such stability, the risk of losing industrial investments due to uncertainty and rising energy prices is significant (I5).

4.2.2.2 Regulatory Frameworks and Policy Requirements

Future regulatory frameworks and expected requirements emerge as one of the most critical factors influencing investments in hydrogen (I3, P9, RES3). Several actors stress that, as long as hydrogen and e-fuels remain significantly more expensive than fossil alternatives, market uptake depends on targeted incentives and regulatory intervention. This includes both policies that actively steer markets toward sustainable solutions and regulations that phase out fossil alternatives, ensuring that societal climate ambitions are reflected in policy frameworks (P7, I3, ORG2). See Box 4.2 for an overview of key instruments mentioned by the actors.

A recurring policy insight is that demand must be actively created through regulation and mandatory requirements in order to trigger large-scale green investments. Without such demand-side drivers, producers are unlikely to commit capital. At the same time, actors warn that delayed policy action risks creating supply shortages once requirements are eventually introduced (RES3). Consequently, multiple stakeholders emphasize the need for policies that steer markets toward sustainable solutions, increase the relative cost of fossil alternatives, and mandate the gradual phase-out of fossil fuels (P4, P7, RES3, I9, ORG2, P5, P3, M3, D1).

Several actors argue that stronger forms of regulatory pressure, rather than voluntary incentives, are needed to accelerate transition, alongside green quotas and robust incentive structures (I3, I9). At the EU level, RED III (Renewable Energy

Directive III) introduces binding targets, including a requirement that 42% of hydrogen used in industry be renewable (RFNBO) by 2030 [61]. Several actors stress that achieving these targets will require a combination of incentives and regulatory pressure, commonly described as a balance between "carrots and sticks" (P1). Stable political frameworks, reliable support schemes, and effective enforcement of EU regulations are considered essential to enable industry investment and ensure that regulatory objectives translate into real market outcomes (P9, P8). EU regulations must not only be introduced, but also consistently enforced (P8).

Clear and long-term policy instruments, such as binding quotas, for example for RFNBOs in aviation, alongside the EU ETS, are therefore regarded as decisive for market development (I6). However, actors highlight substantial variation in how regulatory frameworks affect different sectors. EU regulations are expected to drive the strongest momentum in the transport and refining sectors (P1), while the chemical industry remains largely dependent on the EU ETS as its primary and, in some cases, sole regulatory driver (RES1). In the near term, several regulatory developments are anticipated, including restrictions on diesel sales and a gradual contraction of the fossil fuel market (D2, P1), as well as broader climate transition requirements affecting multiple sectors (D3, M1, M3, P8).

Industry Sector

Despite regulatory developments, significant market barriers remain. The chemical industry is currently described as facing a crisis, with crackers in Europe shutting down, as regulatory pressure and global competition undermine competitiveness, causing production to shift to lower-cost countries (I8) [62]. Furthermore, CBAM (Carbon Border Adjustment Mechanism) does not currently cover all product categories, for example it does not apply to plastics, which weakens incentives for transitioning parts of the chemical sector (I8).

Several actors also highlight that markets for green chemicals currently lack sufficient willingness to pay, with companies awaiting EU quotas or higher fossil costs before investments become economically viable (I9, I8). Similarly, lower-than-expected EU ETS prices have weakened the financial incentives for emission reductions (I3). At the same time, increasing emission requirements throughout the value chain are placing pressure on the food and agricultural sector (I10). For ammonia in particular, the EU ETS, CBAM, and overarching EU climate targets are described as central determinants of future market conditions (I10).

Transport Sector

In the maritime sector, EU regulations on emissions and mandatory blending of e-fuels are identified as important drivers (P7, M1, GOV2), although expectations regarding IMO regulations (International Maritime Organization Net-Zero framework), initially seen as a key strategic trigger, have been postponed (P7). Despite this, the maritime sector continues to act as a significant driver for hydrogen and e-fuel development (P5, P8).

Additional sector-specific drivers include the Alternative Fuels Infrastructure Regulation (AFIR), which supports the roll-out of hydrogen refueling infrastructure (GOV2). In aviation, transition efforts are described as almost entirely regulation-driven, notably through initiatives such as ReFuelEU Aviation (M3), although uncertainty remains regarding whether hydrogen can be fully accounted for within these frameworks (M3). Depending on whether it can be included, this may constitute a driver for hydrogen investments.

Within transport infrastructure, the Sustainable Transport Investment Plan STIP is highlighted as a strategic EU initiative aimed at accelerating deployment of renewable and low-carbon fuels for aviation and maritime transport (ORG1) [63]. The plan is considered to imply temporary losses for investors, effectively functioning as an indirect subsidy to support the long-term transition (ORG1).

Box 4.2: Key policy instruments mentioned in this chapter

- **EU ETS:** A cap-and-trade system where companies must acquire emission allowances for their CO_2 emissions [64].
- **CBAM:** An EU mechanism that applies a carbon price on certain imported goods to prevent carbon leakage and ensure fair competition with EU producers [65].
- **RED III:** An EU directive that sets binding targets for renewable energy, including requirements for renewable fuels and hydrogen use in industry and transport, as well as targets for RFNBOs by 2030 [61].
- **AFIR:** An EU regulation establishing binding targets for alternative fuel infrastructure, including hydrogen refueling stations deployed at regular intervals (with a maximum distance of 200 km between stations) along the Trans-European Transport Network [66].
- **ReFuelEU Aviation:** An EU regulation requiring the uptake of sustainable aviation fuels (SAF) as a key measure to reduce emissions from the aviation sector [67].
- **IMO Net-Zero Framework:** A global framework for the maritime sector, aimed at achieving net-zero GHG emissions from international shipping by around 2050, through emission limits and market-based measures [68].
- **STIP:** An EU roadmap aimed at mobilizing investments in renewable and low-carbon transport solutions, supporting the deployment of infrastructure and production of renewable fuels in aviation and maritime sectors [63].

4.2.2.3 Public Support

Public support is widely highlighted as a critical enabler for the development of a hydrogen economy. In both Sweden and the EU, investment support needs to remain in place over the long term, signaling a clear governmental direction and a willingness to share risks with private actors (GOV2). This is particularly important given that green hydrogen is still far from being competitive with fossil-based hydrogen, which creates a strong rationale for continued financial support through mechanisms such as Klimatklivet (GOV2).

Despite the recognized importance of public support, several challenges remain. There are relatively few calls for public funding (D2), and existing schemes are highly competitive, limiting the number of supported projects (GOV1). In addition, Swedish investment support is considered relatively small compared to that of many other countries (I10). It is also argued that the current way of distributing smaller amounts of funding across many projects is inefficient, and that a greater impact could be achieved by concentrating resources on fewer, larger, and more established actors (D2).

Access to financing has become more difficult compared to the period around 2021-2022, partly due to reduced market interest around hydrogen (RES2). Financial institutions today are perceived as acting with a short-term perspective (P5), and capital provision remains a major bottleneck due to low investor knowledge of hydrogen and a general reluctance among companies to invest in alternative technologies, reflecting a lack of private risk capital and risk appetite (P5). Public support therefore play a key role in reducing the financial burden on project developers and is considered essential for ensuring that EU targets are met (GOV2, P9). Investment support can also lower capital costs by reducing the required loan amounts and by involving the state as a co-financier (GOV2).

At present, virtually all hydrogen projects require some form of support to reach a final investment decision (FID), as green hydrogen remains too expensive due to high capital expenditures (P3, P5, P9). At the same time, uncertainty surrounding public support mechanisms is delaying FIDs (P9). There is a broader need to better coordinate support instruments and policy efforts in order to achieve greater overall efficiency in project outcomes (ORG2). More broadly, investment support and risk-sharing mechanisms are viewed as decisive factors for enabling project development. Stakeholders emphasize the need for future support mechanisms that further reduce investment risks (P2, P1, I8). It is also emphasized that sharing risks early in the development and establishing shared value chains is of importance (I8, P1, P10, I4).

Stable support schemes covering both capital expenditure (CAPEX) and operational expenditure (OPEX) are also considered necessary (P9, I5, I7). In certain cases, operational support may be necessary, for example for hydrogen refueling stations before sufficient market demand has developed and sufficient vehicle demand materializes (ORG2, GOV1, D4, D3, P10). In addition to investment support, there is a growing call for production support (ORG1, I5, ORG2, P5). Additional support needs are also identified for infrastructure related to hydrogen logistics and local production (P10).

Furthermore, there is an emphasis on shifting parts of the support further down the value chain to stimulate demand. So far, support schemes have largely focused on investments, but incentives targeting end-users could help drive demand for hydrogen solutions (D3). This includes support mechanisms that make the business case viable for more expensive fuels (M1), as well as broader political instruments and market incentives aimed at stimulating demand (GOV1). Support on the user side is particularly important to enable consumers to make sustainable choices by creating clear incentives to opt for green alternatives (P4). To reach reasonable price levels for green hydrogen, support for hydrogen usage is necessary (RES1, D3, GOV1).

4.2.2.4 Administrative and Permitting Processes

Administrative and permitting processes are identified as an additional challenge for hydrogen project development, as they can affect actors across the entire value chain. In particular, permitting procedures are often described as lengthy and variable, contributing to project delays. From this perspective, administrative processes related to permits and support schemes are seen as an additional layer of complexity that can slow down implementation across projects and organizations (D2, P4, P2, I2, I9, P9, P10, D1).

The perception of permitting processes and interactions with authorities also plays an important role in whether they are viewed as a structural barrier or as a normal part of project development (P3). In many cases, the application processes for support schemes such as Klimatklivet (Sweden) and EU funding mechanisms are considered administratively heavy and complex (P2, I5, P5, M2, P10). In addition, application processes are sometimes described as fragmented, with short and irregular application windows, making it difficult to align suitable projects with available funding calls (I7). Stakeholders also emphasize that permitting processes are particularly challenging in new and emerging contexts, where established routines and standardized procedures are lacking (P4). However, experience appears to reduce this burden, as first-time permitting processes are described as difficult, while subsequent processes become more manageable as actors gain experience (P7, I3).

Specific experiences further illustrate these challenges. For example, funding schemes such as Klimatklivet have in some cases been strictly tied to specific site locations, meaning that projects could not be relocated even when physical constraints were identified, and applications to adjust locations were rejected (D4).

Against this background, there is a clear call for more predictable and transparent permitting frameworks (P2, P4, P9), as well as faster and more harmonized permitting processes across jurisdictions and authorities (P10).

4.2.3 Economy and Investments

Green hydrogen is currently more expensive than fossil-based alternatives, which constitutes a major economic barrier to large-scale deployment (P8, I2, I3, P3, P4, I8, I7, I6, D1, ORG1). Hydrogen projects are associated with very high investment costs, particularly in the early development phase and before production volumes increase (P10, I3, P5). This significantly affects project viability and increases financial risk.

Several hydrogen projects have experienced delays due to financial constraints. In many cases, projects proved significantly more expensive than initially anticipated, with limited possibilities to absorb or manage the cost overruns (RES2, ORG1, I7, GOV1). A lack of financing and uncertainty regarding future funding have also been identified as key barriers to project development (I5, I4, P9).

To make projects economically feasible and enable the delivery of more competitively priced hydrogen, financial support schemes are widely regarded as necessary (P3, I6, ORG1, RES3, M2). Several actors highlight a continued dependence on public support mechanisms in the current market landscape (P9).

The high initial price of green hydrogen is partly explained by characteristics of a young market: A limited customer base and uncertainty regarding the ability to sell the full production volume (P2, P3). In addition, hydrogen production projects are generally still in early development stages, which temporarily affects cash flow and investment attractiveness (P9).

Additionally, a lack of anticipated rise in carbon prices related to the EU ETS has also negatively impacted the business case for green hydrogen in the short term (I6, I3, ORG1).

Several additional factors further contribute to high costs. Hydrogen storage is expensive and associated with significant technical complexity (P9). Rising inflation and higher interest rates have increased both capital expenditures and operational costs, particularly for raw materials and system components (P9). The high price of key technologies, especially electrolyzers, remains a dominant cost driver (P2, P4, P3, RES2, I3, RES3, I7, GOV1), alongside generally high component costs (M2).

Electrolyzers represent a central but costly technology in green hydrogen production. Contrary to earlier expectations of declining prices, electrolyzer costs have instead increased in recent years (P4, I3, RES3, RES2). Nevertheless, cost reductions in electrolyzer technology are considered a decisive factor for the long-term development of the hydrogen market (I7).

As a result, hydrogen investments are currently characterized by long payback periods, which has discouraged market entry for many actors. Several stakeholders note that stronger demand for green products would significantly improve investment conditions (I3).

At the same time, continued technological development is expected to reduce costs over time. First-of-a-kind projects are typically expensive, but as operating experience is gained, costs are expected to decrease (RES3). Such cost reductions would also lower barriers for subsequent customers and project developers (P9). Furthermore, if additional hydrogen production facilities are established in Sweden and across Europe, electrolyzer costs could decline through economies of scale and increased manufacturing capacity (GOV2).

4.2.4 Market, Demand and Consumer Relations

A broad societal transition is considered necessary, but stakeholders emphasize that transforming the energy market takes time (P3, P5, P9). Views on the current rate of development of the hydrogen market differ. The actors agree that the market is in an early phase, and while some actors envision a clear growth trajectory, others point to recent stagnation in development. According to P9, the market is expected to evolve from pilot projects to large-scale, system-critical production facilities, driven by political support and the EU's ambitions related to climate targets and energy self-sufficiency. In contrast, several actors note that although market sentiment was strongly positive a few years ago, momentum has since slowed (P6, P4). It is worth noting that this does not necessarily mean that the actors mean that the development stopped.

Despite this uncertainty, several drivers for market development are identified. There are multiple potential customer sectors that could create demand for hydrogen (P2), and collaboration between actors on technology development and standards, particularly related to refueling infrastructure, is seen as an important enabler (D2). At the same time, there appears to be an emerging market for products with a lower climate footprint, indicating demand for greener alternatives (I10).

However, stakeholders stress that certain conditions must be met for a functioning hydrogen market to develop. Fossil-based alternatives need to be phased out, as green hydrogen cannot compete if options such as diesel remain cheap (P4). Several actors argue that there is no market space for green hydrogen if it remains a costly option, as current price levels of green hydrogen limit its competitiveness (P3, M2). Several actors report difficulties in finding end customers who are prepared to pay a premium for fossil-free hydrogen or hydrogen-based products (I3, RES3, M3). At the same time, it is noted that green hydrogen does not necessarily need to become significantly cheaper; if diesel prices return to the higher level prior to tax reductions, it could be sufficient to improve the market position for hydrogen (P3).

Securing off-take agreements and committed end customers is repeatedly highlighted as a decisive factor for project realization, as these agreements reduce risk and enable investment decisions (P4, P7, P1). Furthermore, actors emphasize that once a market is established, companies will have stronger incentives to actively reduce costs and optimize production (RES3).

Several reasons for project delays are also identified. In some cases, expectations regarding the speed of market and project development are considered unrealistic given the scale and complexity of hydrogen investments (ORG2). Other delays have been caused by external factors, such as end customers going bankrupt (P5). In addition, multiple projects encounter significant challenges when transitioning from the planning phase to implementation, highlighting execution-related risks in the current market environment (GOV1).

4.2.4.1 Demand Formation and Market Synchronization

From a market perspective, the scarcity of green hydrogen has both positive and negative implications. On the one hand, limited availability can incentivize producers to invest and position themselves early in the market (P5). At the same time, the hydrogen market is widely described as young and immature, which increases risk and requires actors to be willing to invest under uncertain conditions (All actors). At this early stage of industry development, there is significant uncertainty regarding both market development and future demand (P10, P9, I5, D2). This uncertainty makes it difficult for individual actors to justify investments on their own.

Several stakeholders emphasize that the investment burden becomes particularly heavy when market actors do not develop in symbiosis across the value chain (D2, P3, GOV2). Infrastructure and production assets are costly to maintain even when utilization is low or nonexistent, which further strains project economics in the absence of solid demand (D2, D4). These challenges are especially pronounced for start-ups, which face substantial difficulties in establishing entirely new value chains while simultaneously driving industrial transition (I5).

Despite these barriers, producers actively develop hydrogen solutions both for sectors where demand already exists and for areas where they anticipate significant future demand growth (P10). The transport sector is an example of this, as both transport buyers and logistics operators express a willingness to transition, driven by a clear need for zero-emission mobility solutions (P3, P10).

The market is often described as being locked in a classic "Catch-22" situation, where producers and consumers wait for each other to take the leap (D2, P4, P1, GOV2). While both sides are generally willing to transition to hydrogen-based solutions, investment decisions are postponed due to uncertainty about the actions of others (P4, P1, GOV2, D2).

This dilemma is particularly evident in the transport sector, where a clear Catch-22 exists between freight operators and vehicle manufacturers on the one hand, and refueling companies on the other. Freight operators and vehicle producers are hesitant to scale up hydrogen vehicle deployments due to the lack of a sufficiently dense refueling infrastructure to ensure operational viability. Importantly, interviewees note that even if the Swedish hydrogen refueling network were to meet the minimum requirements set out in the AFIR directive, this would not necessarily be sufficient to trigger large-scale investment in hydrogen vehicles. At the same time, actors developing hydrogen refueling infrastructure remain reluctant to expand the network beyond minimum levels without a critical mass of hydrogen vehicles on the road, as increased capacity would otherwise risk being underutilized (D2, D3, D4).

A similar dynamic can also be observed between market actors and policymakers. Limited or inconsistent policy enforcement reduces the perceived need for consumers, especially in hard-to-abate sectors, to transition, resulting in weak demand signals (RES3). This, in turn, discourages producers from investing in supply. When the policies are finally realized, the lack of transition can be justified by pointing to insufficient supply from producers, reinforcing the perception of a stalled transition. This “chicken race” reinforces market inertia, as neither supply nor demand materializes at scale (RES3). To break out of these lock-in effects and overcome the prevailing Catch-22 situations, stakeholders highlight the need for clear political direction and targeted economic support to stimulate coordinated action across the entire value chain (P4).

4.2.4.2 Coordination and Institutional Alignment

Several actors emphasize that national-level coordination is necessary to initiate and scale the hydrogen market and ultimately reduce fossil dependency (RES3, P9). Collaboration and coordination across the value chain are considered particularly important, as hydrogen development involves multiple interconnected actors spanning production, infrastructure, and end use (M2, D1, P2).

At the same time, there is also a need for coordination between regulatory frameworks and permitting authorities to ease the development. Improved alignment and coordination between authorities are considered necessary to simplify development processes and reduce administrative complexity (P10).

Local political initiatives are highlighted as important drivers that can accelerate the development, especially the development of local hydrogen ecosystems within municipalities, promoting coordination, holistic planning, and alignment between stakeholders (P6).

Early involvement of authorities and key stakeholders is repeatedly identified as critical to project success (P10). Early engagement enables smoother permitting processes and allows risks to be addressed proactively. In addition, several actors stress that standardized technical solutions can reduce both costs and risks, while clear dimensioning of projects based on actual demand is essential for maintaining economic viability (P10).

Examples from industrial clusters illustrate the benefits of coordinated action. In Stenungsund, for instance, collaboration within the chemical cluster has facilitated the expansion of electricity capacity, demonstrating how joint efforts can enable infrastructure development (I8). At the same time, authorities are described as being in a learning phase with respect to hydrogen-related processes. While this learning curve is acknowledged, closer coordination among authorities and with other actors such as emergency services is seen as desirable to ensure safety and efficiency (P4).

4.2.4.3 Consumer Commitment and Off-take Dynamics

To address the prevailing “Catch-22” situation in market development, companies may use non-binding instruments such as Letters of Intent to signal future demand or supply commitments (GOV2). However, producers highlight that it is challenging to maintain meaningful dialogue with off-takers when they cannot guarantee a specific SOP or delivery timeline (P4, P1).

Producers therefore face significant challenges in securing binding long-term contracts, which are widely regarded as necessary for financing and scaling up hydrogen projects (P7, P8). Matching demand volumes presents another key difficulty. Many current hydrogen projects operate at pilot or intermediate scale, while potential customers, particularly in sectors such as the chemical industry, often require large and continuous hydrogen volumes. This mismatch makes alignment challenging in early project phases (P4, P8). Investment contracts are consequently seen as essential for producers to commit capital and move beyond pilot stages (P7).

In the absence of firm off-take agreements, determining the most suitable design for hydrogen production becomes difficult. Decisions about production location, whether it should be closer to the electricity generation or to end users become difficult. While proximity to electricity generation can reduce power-related costs, locating production closer to consumers minimizes hydrogen transport requirements, creating trade-offs that are hard to resolve without confirmed demand (P4).

A fundamental market mismatch is frequently highlighted. End customers tend to prefer short-term contracts for more flexibility, when producers require long-term agreements, often up to ten years, to reduce risk and secure financing (P8, ORG1, D2, P7, D3). The divergence in preferences creates a barrier to market formation. Publicly owned actors, however, are perceived as more willing to enter into longer-term contracts due to more predictable and secure market conditions, which can reduce overall investment risk (M1).

Several potential solutions are proposed. Compromises on contract length between producers and end users, especially within the transport sector, are seen as necessary to enable progress (P8). In addition, actors call for market mechanisms that can act as a “shock absorber” between investors seeking long-term price and volume certainty and customers preferring short-term commitments, thereby reducing overall risk exposure (P7, P1, P8). Broad coordination across the market is repeatedly emphasized, with stakeholders noting that synchronized development is essential to prevent individual actors from carrying disproportionate risk (D1, P1, P8, I8, I5, ORG2).

Financial support mechanisms are also viewed as a way to reduce producer risk and potentially increase their willingness to accept shorter contracts (P8). Concepts such as contracts for difference are discussed as possible tools to guarantee a certain price level and contract duration for investors. Some actors suggest that additional mechanisms, such as auctions or other price-stabilizing instruments, may be required (P7, P8, ORG1, ORG2). Risk-sharing arrangements in the early development phase are considered particularly important (P10, I8, D1).

At the EU level, the European Commission has introduced the H_2 Mechanism platform, which enables producers to register hydrogen and raw material volumes and allows potential buyers to view available supply. This initiative is seen as a step toward improved market transparency and coordination (P3).

4.2.5 Electricity and Infrastructure

The development of a hydrogen market requires extensive expansion of both hydrogen and electricity infrastructure (P10, P9, I8, I5, GOV1, ORG2). Investments in grid connections, transmission capacity, and storage infrastructure are therefore considered essential enablers for large-scale hydrogen deployment (P9, P10, GOV1, I8, D1).

4.2.5.1 Electricity

Hydrogen is widely viewed as a valuable way to utilize surplus electricity from renewable energy sources, creating additional system value and flexibility (P4, P3, P5). Together with eMethanol, hydrogen is also highlighted as an important energy carrier within energy trading and system balancing contexts (P8). Across the majority of the interviewed actors, electricity capacity, electricity generation, and electricity prices are identified as key factors influencing hydrogen development.

Compared to the rest of Europe, Sweden has relatively low electricity prices, which is considered a potential competitive advantage for hydrogen production, provided that sufficient grid capacity and supporting infrastructure can be secured (I10). Within Sweden, electricity prices vary significantly between electricity price areas. Hydrogen production is considered particularly advantageous in SE1 and SE2, where prices are generally lowest (P8, ORG2). Conversely, high electricity prices, especially in SE3 and SE4, are viewed as a barrier to hydrogen investments, making it costly to establish electrolysis capacity in these regions (I3).

For hydrogen market development to take shape, access to fossil-free electricity at reasonable and stable prices is repeatedly emphasized as a prerequisite (P9, I10, I8, GOV2, I3, I9). Several actors stress that stable and affordable access to fossil-free electricity is one of the most decisive factors for scaling hydrogen production (P9, I3, I8, I7, I6, GOV2, I10). At the same time, a paradox is noted: electricity prices are perceived as too high to enable competitive hydrogen production, yet too low to sufficiently incentivize investments in additional electricity generation capacity (RES3).

The energy system is shaped by both electricity capacity (power) and energy volumes (kWh), and stakeholders stress that both dimensions must be addressed in parallel, as neglecting either would constrain hydrogen development (P3). Challenges related to accessing fossil-free electricity at the right price and in the right location are therefore frequently highlighted (P9, I10, I8, GOV2, I3, I9).

Grid capacity is widely identified as a major bottleneck for hydrogen development. In several parts of Sweden, limited or lacking transmission infrastructure restricts where and at what scale hydrogen facilities can be established (P8, I2, P10, P9, I8, I9, RES2, M1). Many actors report insufficient electricity capacity and difficulties in obtaining grid connections, particularly for large industrial projects (RES1, I2, I6, RES2, RES3, ORG2, M3, P8).

Dialogue with grid operators regarding available capacity is often described as challenging, with limited transparency during application and permitting processes (P3, P10, P9). Improved coordination and collaboration with energy suppliers and grid operators are therefore seen as important enablers for securing electricity capacity and grid connections (P5, D1). Lengthy grid connection processes are frequently cited as a major source of project delays, and faster procedures related to grid investigations and connections are considered important to facilitate industrial establishments and hydrogen refueling infrastructure (RES2, ORG1, I5, P9, P10, D1). It is also noted that hydrogen refueling stations have relatively modest power demands, typically around 400 kW, comparable to a single fast charger for passenger vehicles (D2, D4).

Looking ahead, several actors warn that current and planned electricity production may be insufficient to support future hydrogen demand, highlighting the need for continued expansion of fossil-free electricity generation (RES2, RES3, P9, P10, I10, I8, GOV2). While forecasts indicate increasing electricity production, this expansion is perceived as slower than required (P8). Finally, digital tools such as digital twins are highlighted as promising instruments to support system optimization and improve the efficiency and cost-effectiveness of hydrogen production (GOV1).

4.2.5.2 Infrastructure

Hydrogen infrastructure in Sweden is currently limited, which constitutes a significant barrier to market development (RES1, ORG1, I7, I5, GOV1, P8). The absence of gas infrastructure is described as both a driver and a constraint for the hydrogen market. The lack of fossil gas pipelines in eastern and northern Sweden, limits the ability to rely on fossil-based gas and thereby incentivizes investments in green hydrogen (I2). On the other hand, the absence of gas infrastructure severely limits access to customers and makes production highly location-dependent, forcing producers to increasingly co-locate hydrogen production facilities close to end users (P8, I2, I7, GOV1).

To bypass this co-location constraint, hydrogen transmission infrastructure is critical. By enabling the transport of hydrogen between regions, such infrastructure would allow production and consumption to be decoupled, facilitating larger-scale production, improving system efficiency, and connecting supply with demand more effectively (P5, P9, I7, D1).

Moreover, hydrogen is difficult and costly to transport, particularly over long distances, which further limits flexibility in infrastructure planning and reinforces the need for localized production (I2, P4, I3, M3). Therefore, targeted support for hydrogen logistics infrastructure is considered necessary to enable early market development (P10).

In addition, Sweden has limited options for large-scale hydrogen storage. The absence of salt caverns, combined with the lack of economic viability for cryogenic storage and storage in bedrock, poses a structural challenge for long-term and large-scale storage solutions (GOV1, P5).

4.2.6 Technical Maturity

Technical maturity is identified by the actors as a decisive factor for the development of a hydrogen economy, particularly as hydrogen is seen as a compliance pathway for meeting future emission reduction requirements (M2). This is especially relevant given the scale of transition required across both transport and industrial sectors (P9, P10, M2, P8), where hydrogen is positioned as an important enabler alongside other solutions.

Overall, hydrogen technologies are increasingly regarded as sufficiently mature to be brought to market, and technical readiness is therefore described as a driver for deployment (P1, P3). At the same time, interviewees highlight that high technology costs and persistent early-stage operational challenges remain significant obstacles (I8, D3, RES2, I3, D4, GOV1). In particular, challenges related to scaling are identified as overarching barriers to widespread implementation.

A recurring theme is that hydrogen is not viewed as a standalone solution, but rather as one component within a broader portfolio of decarbonization technologies. Several actors note that direct electrification and battery-based solutions are insufficient in certain applications due to limitations related to material availability, ethical considerations, and technical feasibility (D2, P3, P7, I3, P5, M2). It is therefore emphasized that not all sectors can be directly electrified, and that these sectors will require alternative renewable fuels such as hydrogen, e-methanol, or biogas, with fossil-free production being the primary goal (P7). In this context, hydrogen is highlighted as particularly important for heavy transport (where electrification has grid and battery limitations), maritime and aviation (which require high-energy-density solutions, making e-fuels especially relevant (RES3)) and heavy industry (P6, P3, I7).

4.2.6.1 Technical System Integration

Certain industrial sectors are described as being structurally dependent on hydrogen or hydrogen-derived fuels. In existing industrial processes, hydrogen is sometimes produced as a by-product but also serves as a central input that is deeply integrated into fossil-based production systems (I6, I8). Several actors stress that hydrogen is embedded throughout the entire production process, meaning that changes cannot be made incrementally without affecting the system as a whole. Instead, transitioning away from fossil hydrogen often requires a comprehensive redesign of entire facilities, making system integration complex and capital-intensive (I8). In the cracker process, it is possible to use renewable feedstocks such as bio-based inputs to a limited extent without major retrofitting. However, actors note that there is currently no customer willing to pay the resulting cost premium, which constrains implementation (I8). Instead, CCS is brought up as a more feasible solution, which is possible to integrate with current systems, as a possible way to fulfill emission requirements.

In this context, one actor distinguishes between different strategic objectives. Actors primarily aiming to reduce their carbon footprint may prioritize solutions such as CCS, whereas actors pursuing true sustainable, fossil-free production are more likely to rely on green hydrogen produced through electrolysis (I10).

Methanol is described as a mature and well-understood molecule, and e-methanol is highlighted as a relatively accessible entry point into renewable fuels due to established handling procedures, existing transport infrastructure, and compatibility with current engines, with no or minor modifications (P7). However, the production of e-methanol requires secure access to biogenic CO_2, creating an additional system dependency (P7, P8).

4.2.6.2 Technical Pathways

For companies that already use hydrogen in their industrial processes, primarily fossil-based hydrogen, additional challenges arise. Industries aiming to reduce their emissions report that feasibility studies indicate that replacing grey hydrogen with green hydrogen produced through electrolysis is not economically viable under current conditions (I6, I8). Instead, they are exploring alternative decarbonization pathways, such as increasing the share of renewable feedstock or implementing carbon capture utilization and storage. These pathways appear to involve lower investment costs (I6, I10) and can more easily be integrated into existing processes, making them a more immediate and accessible option compared to integrating hydrogen across the entire production system (I8).

The goal of reducing emissions is also reflected in the choice of decarbonization strategy. One interviewee highlights that actors primarily aiming to comply with policy requirements are more likely to opt for lower-cost solutions such as CCS, whereas those pursuing true climate mitigation tend to favor electrolyzers and green hydrogen instead (I10).

With regard to green hydrogen production pathways, two main perspectives emerge among the interviewed actors, reflecting differing views on the most suitable technological route. On the one hand, electrolysis is described as the dominant and, in many cases, most realistic pathway for new hydrogen production in Sweden. Several actors highlight that the market currently appears more ready for electrolysis, and that any new production facilities are expected to be based on fossil-free pathways rather than fossil alternatives (P9, I10). From this perspective, electrolysis is considered the most viable option, particularly given concerns that biomass resources may not be available in sufficient volumes to support large-scale hydrogen production (I10).

On the other hand, some actors emphasize the limitations and risks associated with an exclusive focus on electrolysis. These include unresolved challenges related to technological maturity, high electricity demand, and cost, as well as the risk of technological lock-in (I4). From this viewpoint, biomass-based hydrogen production through gasification is presented as a promising complementary pathway (I4). This pathway is highlighted for its potential advantages in terms of cost and energy efficiency, particularly through the utilization of residual biomass (GROT), which is described as a substantial untapped energy resource. Furthermore, it is characterized as potentially carbon-negative, less electricity-intensive than electrolysis, and capable of contributing additional value by integrating carbon into downstream industrial processes (I4). The Nordic region is also considered particularly well-suited for such pathways due to favorable access to biomass resources, energy availability, and industrial competence (I4).

Taken together, these perspectives illustrate a tension between a dominant pathway centered on electrolysis and a more diversified approach that incorporates alternative technologies. While electrolysis is widely regarded as the most immediately deployable option, actors caution that neglecting complementary pathways may limit long-term system efficiency.

4.2.6.3 Technical Difficulties

Several technical challenges related to hydrogen infrastructure and deployment are covered in the interviews. For hydrogen refueling stations operating at 700 bar, cooling requirements are described as particularly complex (D2, D4). During refueling, hydrogen heats up as it flows, requiring rapid cooling, often to temperatures around -40°C, to avoid damage to vehicle tanks. This places high demands on both hardware and control systems, as cooling systems must be able to activate instantly without operating continuously due to high electricity consumption and associated costs (D2). Testing and optimization of such equipment is further complicated by the limited number of current vehicles, which restricts opportunities for operational learning (D4).

Beyond infrastructure, actors also point to significant technical challenges in scaling up electrolyzers (I3, RES3, P4). Large-scale deployment has not previously been achieved, and several respondents emphasize the importance of collaboration to overcome these challenges (RES3, P4). Supplier-side constraints are also reported, with increased demand driven by support schemes and investment programs leading to longer delivery times for key technologies (D3, D2, P5, P10).

Finally, several actors stress the need for more reliable and cost-effective electrolysis technologies (I10). The establishment of production facilities on a large scale is considered essential for driving down electrolyzer costs over time (GOV2). In parallel, there is also a call for further research and development in hydrogen storage technologies to reduce storage costs and improve overall system efficiency (P9).

4.2.7 Competences and Standardizations

Sufficient competences and standardization is important for the development of a hydrogen economy, largely due to the inherent complexity of hydrogen systems and value chains. The hydrogen system is described by the interviewees as large and highly complex, involving interconnected value chains and a high technical level that requires detailed understanding in order to grasp the system as a whole. This includes knowledge across customers, technology, permitting, contracts, energy production, transport, policy coordination, business models, and industrial symbiosis concepts (P3, P9, ORG2, RES3). It is emphasized that a strong system-level competence in hydrogen is needed to support development (ORG2, RES3, M1), and that significant information and expertise are required simply to initiate projects. A key lesson is therefore that all processes tend to take more time than anticipated.

A broader challenge is the limited level of hydrogen-related competence and experience in Sweden (P2, I2, D3, P1, P5). This includes both technical and practical experience in integrating hydrogen systems. In this context, one actor highlights that there are advantages to making projects as standardized and similar as possible, as this can facilitate learning curves, improve coordination, and enhance efficiency in operations and maintenance. It is also noted that standardization can help align project scale with available grid capacity and infrastructure constraints (P8).

Beyond technical competence, societal understanding and perception also play an important role. From a regulatory and institutional perspective, there is a strong need for coordinated frameworks governing hydrogen handling, particularly regarding safety measures and operational standards (P5). Concerns about safety among the general public are highlighted as a relevant factor (D3, M1), and the way hydrogen is discussed in media narratives can significantly influence acceptance and development trajectories (M2, I2). Understanding of safety requirements related to gas handling is also very important (I2). Safety is emphasized as a particularly important dimension given that hydrogen remains a relatively young industry, which is highly sensitive to societal trust and discourse. Negative media attention, for example in the event of accidents, is seen as having the potential to significantly impact the sector (I2).

The interviewees call for coordination of national competence, regulations, guidelines, and standards across the system (P3, P2, ORG2, P5, P10, D4). At the same time, progress is being made through collaborative efforts, for example in the development of standardized procedures for hydrogen permitting processes in cooperation with Energigas and the Swedish civil defense and resilience agency, as well as the development of standardized guidelines for hydrogen refueling station design (P3).

4.3 Scenario Analysis Outcomes

In this chapter, the analysis focuses only on projects that aim to produce hydrogen. Identified projects that exclusively focus on consumption or transmission are excluded, as demand volumes and off-take structures remain too uncertain at this stage to be meaningfully quantified. In total, **47 production projects** are assessed.

The future conditions explored in this chapter are structured around three SSP narratives. These narratives define the broader global context in which hydrogen development takes place, shaping the policy environment, technological progress, economic conditions, and the overall pace at which projects can move toward realization.

Based on the interview responses, the following four factors were selected as quantifiable decisive factors for realization: **Project status, Electricity bidding zone, Securement of public funding and Sector readiness.**

4.3.1 Factor Analysis

Each project is evaluated across the four key factors to assess the probability of project realization.

4.3.1.1 Scenario Case 1: SSP2 - Middle of the Road

This scenario represents a continuation of current trends, where no major structural shifts occur. The following section outlines how key factors influence project realization under these conditions.

Status: Status is, in this case, the strongest predictor of realization. With no major policy push or rapid technological leap, projects that are already mature continue to dominate the probability distribution. Early-stage projects struggle to gain momentum, not because of new obstacles, but because the system does not change fast enough to reduce their risks.

Public funding: Public funding is important for hydrogen projects, although they can come in late in the project development. Therefore this gets a lower weight amongst the factors. Public funding remains selective and constrained. SSP2 does not introduce new large-scale hydrogen support schemes, nor does it remove existing ones. Instead, funding availability mirrors today's landscape: competitive, targeted, and often insufficient for large CAPEX-heavy projects.

Bidding zones: Electricity price differences and grid constraints are influencial factors connected to bidding zones. SSP2 assumes slow grid expansion and persistent bottlenecks, meaning that bidding zones continue to shape project competitiveness in much the same way as today.

Based on electricity prices and available net transmission capacity, SE1 and SE2 are considered equally favorable bidding zones, followed by SE3 and then SE4. Large-scale projects are assigned a lower score for this factor than small-scale projects, reflecting the greater difficulty of accessing large volumes of net capacity. Projects that rely on alternative production pathways than electrolysis, or that have dedicated on-site electricity generation, are assumed to be independent of bidding zone constraints and therefore receive full scores in this category.

Sector: Sectoral readiness and policy direction continue to matter. In SSP2, industrial hydrogen use is assumed to grow gradually, driven by EU-level commitments and existing decarbonization plans. Other sectors: transport, maritime, aviation expand more slowly due to cost barriers and limited policy pressure.

Weight distribution:
Bidding zone: 20%
Status: 35%
Public funding: 20%
Sector: 25%

4.3.1.2 Scenario Case 2: SSP1 - Sustainability Future

This scenario reflects a highly supportive policy and market environment, where strong climate ambition and coordinated action accelerate the development of the hydrogen sector. The following are the production outcomes given SSP 1 conditions.

Bidding Zone: In SSP1, differences between bidding zones lose much of their significance. Rapid expansion of renewable generation, accelerated grid investments, and politically driven efforts to remove bottlenecks reduce regional price disparities. As a result, electricity becomes more accessible and predictable across the country. This creates a strongly positive effect on project probability.

Status: Project status also benefits from the SSP1 environment. Faster permitting processes, greater availability of capital, and strong market demand shorten development timelines and reduce uncertainty.

Public funding: Public funding becomes highly favorable. Ambitious climate goals, long-term policy stability, and EU-wide harmonization lead to generous and predictable support schemes. Both CAPEX and OPEX instruments are strengthened, and financing risks decrease substantially. This factor therefore contributes to a very strong positive adjustment, reflecting that SSP1 is a world where public institutions actively enable hydrogen investments.

Sector: Sector readiness improves significantly. Climate policy is prioritized, and industry is steered decisively toward hydrogen adoption. Hard-to-abate sectors receive strong regulatory and financial support, and cross-sector coordination accelerates the shift away from fossil fuels. This creates a very strong positive effect on project probability.

Based on these assumptions, all factors were deemed to experience a positive effect under the SSP1 scenario. Each factor was therefore adjusted upward on the scoring scale, with the magnitude of the increase depending on how strongly the factor is expected to benefit from the improved system conditions. Electricity bidding zones, public funding, and sector readiness receive the largest positive adjustments, while project status is also positively affected, although to a lesser extent. The relative weighting of the factors remains unchanged, as the scenario influences all factors without altering their underlying importance.

Overall, these adjustments resulted in a total increase of +23% for each project probability compared to SSP2.

Taken together, these conditions create a world with minimal structural barriers, where the broader system actively helps projects move forward. Because the scenario improves the environment for all projects rather than changing the relative importance of individual factors, the factor weights remain unchanged.

Weight distribution:
Bidding zone: 20%
Status: 35%
Public funding: 20%
Sector: 25%

4.3.1.3 Scenario Case 3: SSP3 - Regional Rivalry Future

In this section presents the outcomes given a scenario which represents a fragmented and constrained development pathway, where economic and geopolitical challenges limit the expansion of hydrogen projects.

Bidding zones: Slow grid expansion combined with increasing market fragmentation makes bidding zones highly binding constraints. Political decision-making becomes more locally focused and less coordinated at the European level, reinforcing regional price differences and transmission bottlenecks. Hydrogen production in southern Sweden (SE3 and SE4) is particularly negatively affected due to structural grid constraints and higher electricity prices. Project location is therefore makes a big difference in project realization and this factor is weighted of high importance.

Public funding: Overall budget constraints significantly limit the scope of public support, which is assumed to be largely restricted to mandatory or security-critical investments. Funding for climate innovation is largely withdrawn, while reduced EU coordination results in fewer European support mechanisms. Projects linked to energy security and resilience, such as hydrogen storage or emergency production capacity, remain more likely to receive public funding. Given the anticipated scarcity of future funding availability, having already secured financial support becomes a key determinant toward project realization, and this factor is therefore assigned high importance.

Status: Project development timelines lengthen as capital scarcity constrains investment capacity. Limited access to financing, combined with higher capital costs, slows down the maturation of new projects. In parallel, the import of critical technologies and equipment becomes more expensive and logistically challenging, further increasing project risk. Permitting and approval processes are increasingly politicized, creating regulatory uncertainty and prolonging decision-making. Under these conditions, only projects that demonstrate a clear and direct societal benefit, most notably contributions to security of supply or strategic autonomy, are prioritized by policymakers and authorities.

Sector: Reduced harmonization at the EU level leads to weaker regulatory pressure from European institutions. This results in a more fragmented policy landscape, with greater reliance on national frameworks and fewer common standards guiding sector development.

Based on the SSP3 assumptions, factor values were adjusted relative to SSP2 to reflect a less favorable system environment. Electricity bidding zone conditions and sector readiness display strongly negative shifts, while project status remains broadly unchanged, though constrained by the SSP3 context. With respect to public funding, reduced funding availability is assumed to affect project scale and scope more than the probability of project realization within the funding factor itself.

Overall, these adjustments result in a uniform decrease of -24% in project probabilities compared to SSP2.

Weight distribution:
Bidding zone: 25%
Status: 25%
Public funding: 30%
Sector: 20%

4.3.2 Timeline

Figure 4.2 illustrates the projected development of hydrogen production capacity over time under the SSP2 (Business as Usual), SSP1 (Sustainability), and SSP3 (Regional Rivalry) scenarios. The projects are categorized according to their probability of realization (low, medium, high), based on the factors evaluated in the factor analysis (see Chapter 4.3.1).

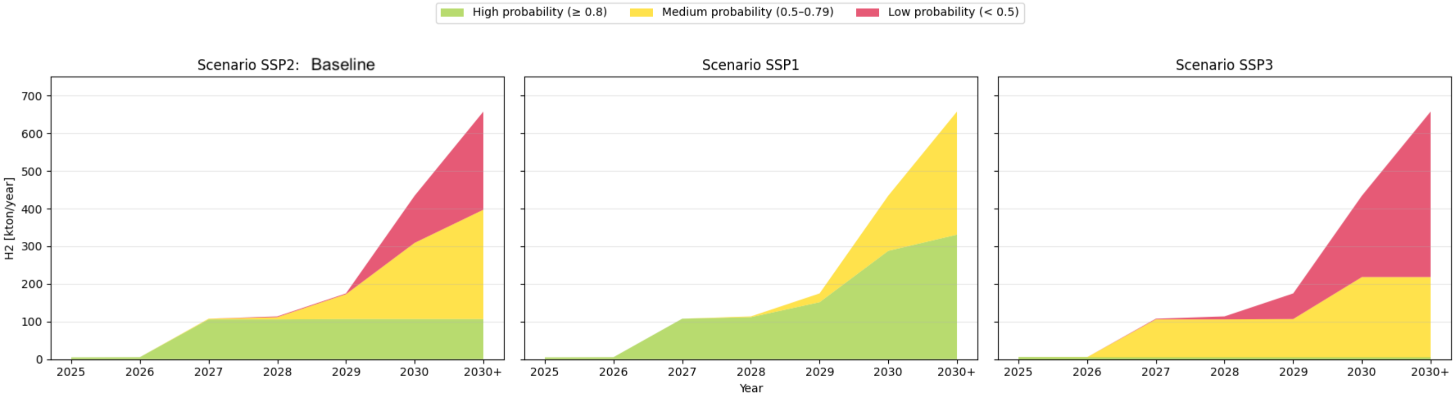


Figure 4.2: Hydrogen production capacity over time, sorted by probability, across different surrounding environments. From left to right, the panels show SSP2, SSP1, and SSP3.

The total estimated hydrogen production capacity reaches approximately approximately 660,000 tonnes of H_2 per year, assuming that all probability categories are included and that all projects planned for 2030 and beyond are realized. However, this figure should be interpreted as an upper-bound estimate rather than a guaranteed outcome, as it includes projects with varying likelihoods of realization. Notably, the total remains the same across all scenarios when considering all probability categories.

Focusing only on the most probable ("green") projects under each set of surrounding conditions, SSP2 is estimated to reach approximately 100,000 tonnes of H_2 per year by 2030. Under SSP1, where structural barriers are reduced and a broader set of projects can progress, the distribution reflects a significantly more favorable system environment, resulting in an estimated capacity of around 320,000 tonnes of H_2 per year by 2030.

In contrast, SSP3 the total projected capacity is substantially lower, and the growth trajectory remains relatively flat, indicating delayed or canceled project development. This reflects the persistence of structural barriers such as constrained public funding, weak policy support, and limited electricity infrastructure capacity. As a result, only projects that are already operational are expected to remain in operation by 2030. The estimated hydrogen production from the most probable projects in 2030 is approximately 5,000 tonnes of H_2 per year, indicating a highly constrained development pathway.

4.3.3 Monte Carlo Simulation

To account for uncertainty in project realization, a Monte Carlo simulation was conducted based on the assigned probabilities for each project. The results are presented in Figure 4.3 as a probability distribution of the total number of projects realized. The distribution follows an approximately normal shape, indicating that most outcomes cluster around a central value, with fewer extreme scenarios.

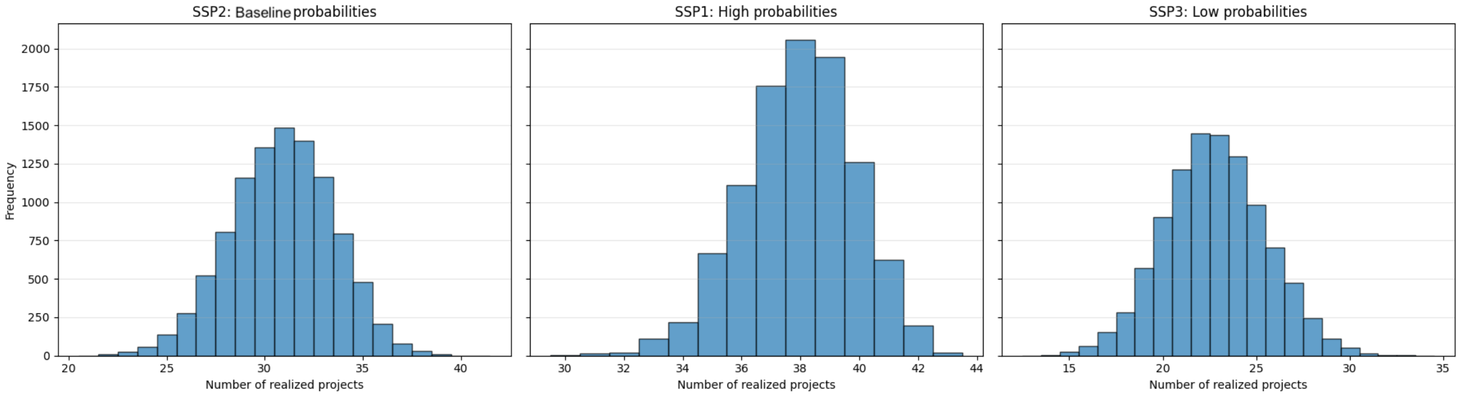


Figure 4.3: Normal distribution curve of number of projects realized. From left to right, the panels show SSP2, SSP1, and SSP3.

For SSP 2, the mean number of realized projects is approximately 31, which can be interpreted as the most likely outcome under SSP2 conditions. Under SSP1, the increased project probabilities raise the expected realization rate, resulting in a most likely outcome of about 38 projects. When incorporating the reduced probabilities that reflects the constrained system environment SSP3, the mean number of realized projects decreases to approximately 23.

5

Methodology Consideration

This chapter reflects on the methodological choices made in the study and discusses how these may have influenced the results. Particular attention is given to potential sources of uncertainty and bias, as well as to explaining why the findings appear as they do in relation to the current state of the hydrogen market.

5.1 Choice of Stakeholder Interactions

One important limitation of the stakeholder mapping is the under-representation of end users or pure consumers of hydrogen. This can largely be explained by the current stage of market development. The hydrogen market, particularly in the Swedish context, is still emerging and has not yet reached a level of maturity where demand is clearly defined across sectors. As a result, many potential future consumers may not yet identify themselves as hydrogen users, or may not have evaluated hydrogen as a viable alternative. Consequently, such actors are difficult to identify and include in the mapping process, which may lead to an incomplete representation of future demand. This reflects a broader structural characteristic of early-stage markets, where supply-side actors are more visible and established than demand-side actors.

5.2 Data Collection

The interpretation of the interview results should also be considered in light of inherent uncertainties in qualitative data collection. During interviews, participants may not explicitly address all relevant drivers, barriers, or perspectives, either because certain aspects are perceived as self-evident or because the conversation naturally shifts focus toward specific topics. In some cases, interviewees may also not reflect on particular issues in the moment, even though they might have agreed with them if they had been explicitly raised. As a result, the findings reflect the themes that emerged within the context of each interview rather than a complete representation of each actor's perspective.

Furthermore, the interviews were not conducted in a fully standardized way. Due to practical constraints, it was not always possible to arrange the same type of interaction with all stakeholders. As a result, the format, duration, and focus of the interviews varied. In some cases, time limitations meant that not all questions were covered, while in others the discussion focused more narrowly on specific aspects of the actor's role. Consequently, not all stakeholders were asked identical questions and were not given the opportunity to comment on all topics.

It is important to note that the data collection was conducted during the early stages of the project, specifically between February and April 2026. The hydrogen sector is currently undergoing rapid development, and significant changes may occur within short timeframes. Consequently, the findings presented in this study reflect the state of the market during this specific period. Developments occurring after the data collection phase, such as changes in policy, market conditions, or the financial status of key actors, including recent bankruptcy filings, may not be fully captured in the analysis. This should be considered when interpreting the relevance and timeliness of the results.

5.3 Interview Responses

Interpretation of the interview responses was also influenced by analytical choices made during synthesis of the findings. In particular, emphasis was placed on drivers and barriers that were raised by multiple interviewees and that could be considered relevant across several actors in the hydrogen market. This approach was adopted to identify patterns and systemic challenges rather than company-specific circumstances. Therefore, barriers or perspectives that appeared to be unique to a single actor or organization may be underrepresented in the results. While this enhances the generalization of the findings, it may also introduce a bias toward more frequently mentioned themes, which should be taken into account when interpreting the results.

Taken together, these factors imply that certain statements presented in the results may be supported by more stakeholders than explicitly indicated. Some perspectives may not have been captured simply because they were not discussed during the interview process, rather than because stakeholders disagreed with them. This should be considered when interpreting the breadth and representativeness of the findings.

5.4 Scenario Analysis

The scenario analysis conducted in this study should be understood primarily as an exploratory tool rather than a predictive model. The scenarios are not intended to forecast the future development of the hydrogen market, but rather to provide an approximate indication of how market conditions may evolve under different high-level assumptions. By structuring uncertainty into distinct scenarios, the analysis aims to support comparison between alternative development paths.

A key source of uncertainty in the scenario analysis lies in the translation of qualitative insights into quantitative inputs. The probability scores and weighting of factors are inherently subjective and were constructed based on interview insights and synthesis of stakeholder perspectives. While these estimates are grounded in empirical input, they remain informed judgments rather than empirically measurable quantities. This reflects a broader methodological challenge in scenario analysis, where qualitative narratives must often be operationalized into simplified numerical representations. The chosen scale and weighting system were specifically designed for this study and should therefore be interpreted as approximate and indicative rather than precise.

Furthermore, the relative differences between the scenarios, particularly between SSP1 and SSP3 compared to the baseline SSP2, are difficult to estimate with a high degree of confidence. While it is possible to identify which factors are likely to be more positively or negatively affected under different socio-economic pathways, assessing the magnitude of these differences is more challenging. For example, improved policy support or technological learning in one scenario may clearly influence hydrogen market development, but determining whether this effect is marginally or significantly stronger than in another scenario is subject to considerable uncertainty. As a result, the scenario outcomes should be interpreted in terms of relative direction and sensitivity rather than exact quantitative deviation.

Another limitation is that the scenarios necessarily simplify complex, interdependent dynamics within the hydrogen market. Interactions between policy, infrastructure development, technological maturity, and demand evolution are treated as separable factors, even though in practice they influence each other in non-linear ways. This simplification is common in scenario-based methodologies but may lead to an underrepresentation of feedback effects and tipping points that could accelerate or delay market realization.

6

Analysis

This chapter synthesizes the key findings of the study through a combination of quantitative insights derived from the scenario analysis and qualitative interpretations based on interview findings and project mapping.

6.1 Hydrogen Production Towards 2030

The current development of green hydrogen production in Sweden can be characterized as expanding but structurally heterogeneous, reflecting an early-stage market with a wide range of actors and project types. Importantly, the project mapping evolved over the course of the study, as projects were both added and withdrawn, illustrating the fluid nature of investment decisions in this emerging market. This highlights the dynamic and uncertain nature of the hydrogen market, where stakeholder positions and project feasibility can change rapidly.

The mapped hydrogen production landscape in Sweden towards 2030 reveals a system characterized by both diversity and fragmentation. This diversity indicates a system in an early formative phase, where multiple technological pathways and business models are being explored in parallel.

A key observation is the significant variation in project size. While a few large-scale industrial projects dominate in terms of potential output, a substantial share of projects remain small to medium in size. This heterogeneity makes direct comparison between projects challenging, as they differ in maturity, scale, and purpose. Smaller projects are generally easier to realize due to lower capital requirements and fewer infrastructure dependencies, whereas large-scale projects represent transformative system investments associated with considerably higher risk.

From a system perspective, this project mix creates both resilience and uncertainty. Diversification across project types and scales enhances robustness in early market development, but the absence of standardization and large-scale deployment limits system-wide efficiency.

Importantly, large industrial projects function as system anchors: if realized, they enable stepwise increases in production capacity; if delayed or canceled, they significantly reduce the expected total output. As a result, market development is not incremental, but characterized by non-linear dynamics tied to individual investment decisions. The successful realization of such large-scale projects would demonstrate the feasibility of green hydrogen production and use at industrial scale, providing a strong signal for further market expansion.

The geographical distribution of projects further reflects underlying system conditions. Smaller projects, particularly within transport and mobility applications, are often located close to major road corridors, particularly in the south of Sweden. In contrast, larger production projects tend to cluster within established industrial regions, notably along the coast of northern Sweden. These locations benefit from proximity to industrial demand, access to electricity, and, in some cases, existing infrastructure and logistical advantages.

This spatial pattern suggests that hydrogen production does not emerge independently, but is embedded within existing energy and industrial systems. While such clustering may support efficient early deployment, it also implies potential regional imbalances if grid capacity and supporting infrastructure do not expand in parallel. Regions facing higher electricity prices or limited grid access risk falling behind, reinforcing unequal market development.

6.1.1 Hydrogen Production Levels

Based on the projects identified within the scope of this study, the total potential hydrogen production capacity in Sweden is approximately 660,000 tonnes of H_2 per year. Importantly, this production level should not be interpreted as a guaranteed outcome, but rather as a conditional upper-bound dependent on project realization. The scope of this study extends to “2030 and beyond”, meaning that several of the mapped projects are unlikely to be fully realized before 2030. Many early-stage projects have long development timelines, and their expected start of production may likely occur after 2030. Consequently, the comparison implicitly assumes full project realization within the given time frame, an optimistic and unlikely assumption.

This estimated production level assumes ideal conditions. In practice, delays, cancellations, and extended timelines are likely to reduce the actual production capacity achieved by 2030. Also, achieving this theoretical level of production is highly dependent on the realization of a limited number of large-scale projects, indicating a strong concentration risk in the projected output.

This sensitivity becomes particularly evident when considering only projects classified as most probable (Green), the resulting production capacity then decreases significantly to 107,000 tonnes of H_2 per year.

These findings indicate that Swedish hydrogen actors are making measurable progress. However, when comparing the aggregated production capacity identified in this study with the targets and strategies observed in other Nordic countries, a clear gap becomes evident. Under current conditions, the Swedish project pipeline appears insufficient to reach similar levels by 2030. Consequently, Sweden is at risk of falling behind in the Nordic context.

6.2 Demand and Sectoral Development

Hydrogen demand in Sweden is currently heterogeneous across sectors and relatively immature. As a result, demand is often uncertain, fragmented, and not yet formalized through binding off-take agreements. Many investments are therefore based on expectations of future market development rather than established demand. At the same time, it is reasonable to assume that demand will increase in parallel with expanding hydrogen production.

The industrial sector, for example steel and fertilizer production, represents the most structured and high-volume demand potential. These sectors are relatively more mature due to existing hydrogen use and clear decarbonization pathways, but demand remains highly dependent on economic conditions and policy incentives. Their demand is often linked to large-scale projects, reinforcing the importance of integrated production-consumption systems where supply and demand are co-developed.

Similarly, the refinery and chemical industries also already rely on hydrogen as an input, but switching to green hydrogen is not economically viable today. In particular, existing carbon pricing mechanisms, such as the EU ETS, do not yet provide sufficient incentives to justify the higher cost of green hydrogen. For the chemical sector, additional challenges arise from policy gaps such as the limited scope of the CBAM, which does not fully cover products like plastics. As a result, there is limited economic incentive for emission reductions in these segments. This highlights the importance of well-designed policy frameworks that both strengthen incentives and prevent carbon leakage in international markets.

The aviation and maritime sectors are also identified as important long-term demand drivers, although their development is strongly policy-dependent. Demand in these sectors depends heavily on regulatory instruments such as fuel mandates and sustainability requirements. Without clear and stringent policy enforcement, demand risks remaining limited despite technological potential.

The road transport sector emerges as one of the most frequently discussed sectors. Even in projects where it is not considered the primary off-take sector, it is often described as a “fallback” option due to the market’s flexible demand. Several hydrogen producers highlight that, in the absence of secured off-take agreements, hydrogen can be redirected to the transport sector as an alternative outlet. This suggests that demand in this segment is not always project-defining, but can function as a residual or balancing market if primary demand does not materialize.

Smaller-scale applications, such as local energy systems, represent a different type of demand. These applications are typically easier to implement but have a more limited impact on overall market volumes. At the municipal level, hydrogen is increasingly considered as part of integrated energy systems, where it can serve multiple functions, including energy storage, backup power, and sector coupling between electricity, heating, and transport. For municipalities pursuing hydrogen solutions, system integration and coordination across applications are critical to achieving efficiency gains and enhancing energy system resilience.

The emission reduction potential associated with hydrogen use also varies significantly between sectors. Industrial applications, particularly within steel, chemical, and fertilizer production, represent the largest potential for absolute emission reductions due to their high fossil fuel consumption and large hydrogen volumes. As a result, these sectors are likely to have the greatest systemic impact if green hydrogen is successfully implemented at scale. In contrast, road transport applications generally involve smaller hydrogen volumes and therefore lower total emission reduction potential, but they offer greater modularity and flexibility, enabling faster implementation and earlier market development. Aviation and maritime transport also present considerable long-term decarbonization potential, particularly in segments where direct electrification is difficult, although realizing this potential will require substantial technological development, infrastructure expansion, and supportive regulatory frameworks.

Overall, hydrogen demand is closely linked to policy frameworks, sector-specific conditions, and the ability to coordinate actors across the value chain. Demand is not absent, but rather fragmented, uncertain, and highly dependent on effective coordination mechanisms and policy support.

6.3 Key Factors for Market Development: Drivers and Barriers

The results from the 34 interviews and the reviewed literature show that the development of a Swedish hydrogen market is influenced by a combination of strongly interrelated structural conditions related to governance, infrastructure, cost structures, and demand formation. Market development is therefore not limited by a lack of ambition or technological feasibility, but by difficulties in coordinating parallel progress across the system.

External conditions play a decisive role in shaping market dynamics. Geopolitical uncertainty and adverse macroeconomic conditions increase investment risk and weaken firms' willingness to commit capital to long-term, capital-intensive hydrogen projects. During economic downturns, hydrogen investments are often deprioritized in favor of lower-risk alternatives, reinforcing delays in market formation.

Hydrogen market development is strongly dependent on clear, stable, and coordinated political direction. Stakeholders emphasize that long-term policy frameworks, binding regulatory requirements, and well-designed support mechanisms are essential to create investment security and stimulate demand. EU-level regulation currently plays a central role by shaping incentives and reducing uncertainty, as the market is not yet self-propelling.

At the national level, the absence of a coherent hydrogen strategy in Sweden is identified as a key barrier, particularly in relation to infrastructure planning and long-term investment conditions. In this context, policy consistency and credible long-term commitments are critical for building investment confidence. Binding instruments such as quotas, mandates, and guaranteed demand mechanisms are seen as decisive, as they create stable demand signals and enable coordinated investments across the value chain.

Economic conditions constitute another major constraint. High production costs, expensive electrolyzer technologies, long payback periods, and uncertain future demand limit the financial viability of projects. Stakeholders highlight that green hydrogen is still not competitive with fossil-based alternatives or other decarbonization pathways. Therefore, demand-side incentives and OPEX support are critical in early market phases, as capital subsidies alone are insufficient.

These economic challenges form part of a broader system-level dynamic. High costs suppress demand, resulting in low utilization rates of infrastructure and production assets, which in turn further increases unit costs. This dynamic suggests that the economic barrier is not static, but self-reinforcing, creating a lock-in where both producers and consumers hesitate to commit.

Infrastructure emerges as a central bottleneck, as constraints related to electricity availability, especially grid capacity and connection timelines, limit the feasibility of hydrogen production. Moreover, transport, storage, and refueling infrastructure play a key role in enabling system expansion and demand growth, particularly in road transport, where actors view current refueling requirements as insufficiently dense.

At the core of these issues lies a persistent coordination problem between supply and demand. Producers are reluctant to invest without secure off-take agreements, while potential consumers hesitate due to uncertain supply and pricing. This interdependence is reinforced by mismatches in contract preferences, where producers favor long-term agreements and consumers prefer shorter commitments. The result is a “Catch-22” situation across the value chain, where producers, infrastructure providers, and end users wait for each other before acting.

This lack of synchronized development increases investment risk and slows market formation. Off-take agreements, risk-sharing mechanisms, and stronger policy-driven demand are therefore identified as critical tools for overcoming these barriers and enabling market maturation. At present, the market remains immature, characterized by uncertainty regarding future demand, volumes, and timing.

6.3.1 Political Governance and Policy instruments

Political governance plays a central role in shaping the hydrogen market. Many stakeholders identify fossil-based alternatives as one of the main barriers to hydrogen deployment, primarily due to their cost competitiveness and established infrastructure. However, this perspective must be nuanced. There is a broad political consensus, both nationally and internationally, to phase out fossil fuels, as reflected in agreements such as the Paris Agreement. This suggests that fossil competition is not a static barrier but a transitional one. Over time, policy instruments such as carbon pricing, regulatory mandates, and subsidies are expected to shift the competitive balance. The key challenge is therefore not the existence of fossil alternatives, but the speed and consistency of policy implementation. Uncertainty regarding future regulation creates hesitation among investors and slows down decision-making processes.

Still, the challenge of getting sufficient policy regulations in place for deployment of green hydrogen is identified as a key decisive factor, indicating that there is a notable gap between EU-level ambitions and national-level implementation. While the European Union has established ambitious targets and regulatory frameworks to accelerate hydrogen deployment, their translation into concrete national measures remains uneven. This creates friction in market development, as actors must navigate differing timelines, support schemes, and regulatory clarity across governance levels. In the Swedish context, this gap is further reinforced by the absence of a fully coherent and comprehensive national hydrogen strategy. Such a strategy would be essential not only for aligning national actions with EU ambitions, but also for ensuring that policy measures effectively stimulate demand and enable coordinated infrastructure and market development.

6.3.2 Public Support

The hydrogen market remains in a formative phase, which means that its development is highly sensitive to external conditions and continued policy support. In this context, public support plays a systemic role by reducing risk and enabling coordination in a market that is not yet commercially self-sustaining. Long-term support frameworks at both the EU and national levels therefore function not only as financial instruments, but as signals of political commitment and risk-sharing.

A key analytical insight is that support mechanisms focusing solely on investments are insufficient. Hydrogen projects are characterized by high capital expenditure and long payback periods, with investment risk concentrated at early project stages. While CAPEX support can lower entry barriers, it does not address the operational risks that come with underutilization. Actors therefore emphasize the importance of OPEX support before sufficient demand materialize, which can help bridge the gap between production and consumption and reduce the risk of underutilized infrastructure and assets.

From a system perspective, shifting parts of public support further down the value chain is critical for market formation. Incentives targeting end users and hydrogen consumption can stimulate demand and improve project success, complementing production-side support.

At the same time, several actors point to limitations in existing support schemes, which are often described as rigid and narrowly designed. For example, funding programs have in some cases been tied to specific locations, reducing flexibility and preventing project adaptation when physical or system constraints emerge. This highlights the need not only for continued support, but for support mechanisms that are sufficiently adaptive to evolving system conditions.

6.3.3 Market Formation

To accelerate the development of the hydrogen market, certain key projects play a particularly important role. Large-scale initiatives such as Stegra and HYBRIT represent a substantial share of the planned hydrogen production capacity. As such, their successful implementation would demonstrate the feasibility of large-scale electrolyzer deployment. This could serve as a proof of concept and reduce perceived risks for subsequent projects.

If these projects are successfully realized and operate as intended, they may contribute to technological learning and cost reductions over time. As first-of-a-kind installations, they are associated with high initial costs; however, accumulated experience and increased deployment are expected to improve efficiency and reduce costs. This learning process could incentivize further investments in hydrogen production, potentially generating a positive feedback loop. In such a development, the market may transition into a new phase of the S-curve, not by supply expansion, but by technological maturity and increased confidence among market actors.

Notably, these industrial large-scale projects often have integrated systems, meaning that hydrogen production is directly linked to internal consumption. While this reduces project risk and facilitates investment decisions, it limits the amount of hydrogen exposed to an open market. As a result, the broader development of a supply market may remain constrained, despite increasing production capacity.

To address this limitation, an alternative model could be considered. Integrated producers could allocate a share of their production capacity to external sales, thereby contributing to the emergence of a functioning supply market. Since these actors already have established production systems and internal demand, the additional risk of producing surplus hydrogen is lower compared to standalone production projects. Excess production capacity could be utilized flexibly, either through long-term contracts or on-demand supply, depending on market conditions.

Such an approach may improve the overall market dynamic by gradually introducing larger volumes of hydrogen supply into circulation. Selling even a relatively small share of output could have a meaningful impact if originating from large industrial facilities. These actors, with large production volumes, may also contribute to reducing unit costs through economies of scale affecting OPEX. Lower hydrogen prices would improve the business case for downstream applications and stimulate demand, further reinforcing market development.

This surplus of hydrogen could be supplied to the open market at competitive prices, while simultaneously providing an additional revenue stream for producers. It may also support further decarbonization within these industries, particularly in their transport and logistics operations. Given the scale of industrial transport activities, such hydrogen volumes could contribute to emission reductions, especially within the heavy transport sector.

However, the realization of this pathway is highly dependent on the successful implementation of the initial large-scale projects. If such projects are delayed or fail to materialize, there is a significant risk that the overall development of the hydrogen market will be slowed. In such a scenario, fewer investments may be undertaken, limiting both technological progress and market expansion.

It should also be noted that expectations of declining costs over time are not unproblematic. Limited cost reductions in electrolyzers challenge the assumption of a straightforward learning curve. This suggests that external factors such as supply chain constraints, material availability, and broader macroeconomic conditions may, at least temporarily, outweigh the effects of technological learning. Consequently, cost development must also be viewed in relation to evolving market conditions.

6.3.4 Technical Maturity

While hydrogen technologies are generally mature at the component level, their integration into industrial processes remains a key challenge. Large-scale deployment therefore requires coordination across production, storage, transport, and end-use applications.

Issues related to competences and standardization were not identified as critical barriers in the current stage of market development. However, this may be partly explained by the limited extent of large-scale deployment to date. As the hydrogen market expands, the need for new competences, particularly related to system integration, scaling of production, and cross-sector collaboration, is expected to increase. In this context, standardization can play a key role by reducing costs, mitigating risks, and simplifying permitting processes, thereby facilitating more rapid deployment.

Furthermore, the results indicate a degree of tension regarding technological pathways. While electrolysis emerges as the dominant and most widely supported hydrogen production method, particularly due to its compatibility with renewable electricity and alignment with EU policy frameworks, some stakeholders highlight alternative technologies such as biomass gasification as potentially more optimal under certain conditions. This raises important questions for market development. A diversified technology portfolio could provide a more balanced and resilient pathway.

At the same time, the use of biomass for hydrogen production introduces its own challenges. The availability of sustainable biomass resources is limited, and there is competition with other sectors where biomass may create higher value or be more difficult to substitute. Ensuring that biomass used for hydrogen production originates from genuine residues and is managed in a sustainable manner is therefore critical. Without such safeguards, large-scale reliance on biomass could lead to unintended environmental or economic trade-offs.

In addition, the sustainability of biomass-based hydrogen remains contested, its climate impact depends on assumptions related to lifecycle emissions, carbon accounting, and time horizons. Claims of carbon neutrality or even negative emissions are therefore dependent on methodological assumptions and time horizons, making biomass a more complex and debated resource compared to wind- or solar-based electricity.

As a result, biomass is often treated as a separate category within renewable energy policy frameworks - separate from RFNBO, which affects how it is incentivized and integrated into hydrogen strategies. This creates differences in how technologies are supported, potentially influencing investment decisions alongside technical and economic considerations.

Similarly, an overly narrow focus on electrolysis may be problematic. Expectations that future hydrogen production will be based predominantly on electrolysis assume sufficient expansion of renewable electricity generation and grid infrastructure, which remains uncertain. A combination of technological pathways could therefore help mitigate risks associated with resource constraints and infrastructure limitations, while also avoiding technological lock-in. Such an approach may support a more flexible and adaptive market development.

6.3.5 Electricity Bidding Zones

Electricity prices represent a critical factor influencing the development of hydrogen production, particularly for electrolysis-based pathways. However, both the current structure of electricity price areas and the uncertainty surrounding future developments introduce significant complexity for investment decisions. While current price patterns provide a strong incentive to locate production in low-cost regions, these patterns are not static and may change as grid infrastructure expands and market conditions evolve. As a result, electricity bidding zones function as an important but uncertain planning signal, creating locational risk for long-term investments. Consequently, investors must not only consider current price differences but also form expectations about future market conditions, which introduces an additional layer of risk.

Current location patterns may reinforce a geographically concentrated system. As projects cluster in regions with favorable electricity conditions, spatial path dependencies emerge, potentially leading to lock-in effects that shape future infrastructure needs and industrial development. While such clustering may be economically rational for individual actors, it does not necessarily align with system-wide efficiency, particularly if transmission capacity and regional electricity balances evolve over time.

Taken together, regional electricity price differences and the uncertainty surrounding their future development are likely to play a decisive role in shaping both the spatial distribution of new hydrogen projects and the operational strategies of existing ones. Electricity prices and their volatility influence the utilization rates of electrolyzers, affecting both profitability and overall system efficiency.

6.4 Realization Outcomes Across Scenarios

The scenario analysis demonstrates that hydrogen project realization is highly sensitive to external conditions. Small changes in the broader socio-economic and political context lead to significant shifts in project probabilities, highlighting the non-linear nature of market development.

This highlights the non-linear nature of market development, where improvements in framework conditions can unlock realization of a wide range of projects, while deteriorating conditions can significantly constrain market growth. In this context, policy coherence affecting sector demand, a favorable electricity system, project status, and institutional support emerge as critical determinants of realization.

When considering only projects categorized as most probable (green), the resulting production capacity in the SSP1 scenario is approximately 331,000 tonnes of H_2 per year. In contrast, the SSP3 scenario results in a substantially lower production capacity of 5,000 tonnes of H_2 per year.
In the SSP2 scenario, which represents a continuation of current trends, structural barriers, such as grid constraints, investment risks, and immature demand, limit the probability of full project execution. This reinforces the conclusion that the hydrogen market is not constrained by a lack of planned supply, but by the ability to realize projects in practice. The SSP2 scenario represents a middle-ground outcome, where development occurs gradually through incremental additions rather than rapid scaling. The distribution of projects across probability categories is relatively balanced, with a mix of green, yellow, and red projects. Notably, projects with longer timelines tend to exhibit higher uncertainty and are more frequently categorized as less probable, reflecting the risks associated with early-stage project development.

Under the SSP1 scenario, characterized by strong policy support, improved financing conditions, and accelerated technological diffusion, realization rates increase substantially. Projects previously categorized as uncertain (yellow) are shifted toward higher likelihoods, and no projects remain in the lowest probability category. The timeline shows a more rapid and pronounced increase in production capacity compared to SSP2, reflecting a system where institutional support, infrastructure development, and market formation actively facilitate project realization. Some projects remain uncertain, indicating that even in an optimal environment, full realization is not guaranteed. This highlights the inherent complexity and risk associated with large-scale industrial transformation.

Beyond 2030, if early projects are successfully implemented, they may generate positive feedback effects by demonstrating feasibility, reducing perceived risks, and enabling technological learning. Such developments could attract further investments and participation, resulting in increased production capacity.

In contrast, under unfavorable conditions represented by SSP3, realization rates decline sharply. Limited access to capital, weak policy support, and slower technological progress create a constrained environment in which only a small number of robust and strategically prioritized projects are realized. The analysis indicates that no new projects beyond those already in operation are likely to be commissioned under such conditions. As a result, market development remains limited, and the hydrogen sector does not achieve significant scale.

Beyond 2030 in the SSP3 scenario, the lack of successful project realization may lead to a loss of momentum in the hydrogen market. Reduced investor confidence and unfavorable external conditions could result in a slowdown in new project initiation, potentially delaying market development until a future phase of renewed interest or improved conditions emerges.

Overall, a key insight from the scenario analysis is that project realization is not only determined by project-specific characteristics, but is fundamentally system-dependent. Even well-developed projects with strong underlying fundamentals may fail to materialize in unfavorable conditions, while less mature projects may succeed in a supportive environment.

7

Concluding Remarks

7.1 Answers to Research Questions

Where and in what quantities is green hydrogen estimated to be produced in Sweden 2030 and beyond?

Green hydrogen production in Sweden is expected to be geographically concentrated in regions with strong industrial clusters and access to low-cost electricity, see project mapping in Chapter 4.1. The project pipeline indicates a production capacity of 660,000 tonnes of H_2 per year by 2030+, although actual volumes remain uncertain and rely on project realization (See Chapter 6.1).

Which sectors are expected to generate demand?

Demand is primarily expected to originate from hard-to-abate sectors. Several sectors emerged as potential target areas for green hydrogen use. These include industrial applications, such as steel production, fertilizer manufacturing, and other process industries, where hydrogen can replace fossil-based inputs or gases. The chemical and refining industries were also frequently highlighted. The transport sector is also expected to play an important role, including road transport, maritime applications, and aviation. Finally, hydrogen is seen as a potential solution for energy storage within the broader energy system.

These sectors differ in terms of readiness and required support. Some are closer to large-scale implementation, while others depend more heavily on the development of infrastructure, financial incentives, and regulatory frameworks. These aspects are discussed further in Chapters 4.2 and 6.2.

What drivers and barriers can be identified for the green hydrogen market?

Key drivers include the growing need for decarbonization and reduced fossil fuel dependency, supported by policy frameworks that incentivize green energy. At the same time, increasing concerns related to energy resilience and security, together with global technological competition, further reinforce the momentum for hydrogen development.

However, this development is constrained by several interrelated barriers. High production costs, limited infrastructure, and regulatory uncertainty continue to pose significant challenges. Persistent coordination problems between supply and demand slow market formation. The absence of a coherent national hydrogen strategy in Sweden further amplifies these issues by weakening long-term investment signals to market actors. Read more about drivers and barriers in Chapters 4.2 and 6.3.

Which factors most significantly influence the development of this market?
The development of the hydrogen market is highly dependent on policy support, regulatory frameworks, electricity supply, and coordination mechanisms such as risk-sharing arrangements and off-take agreements. In particular, market evolution relies on clear, stable, and coordinated political directions. EU regulation plays a key role in shaping incentives and reducing uncertainty and the establishment of a coherent national hydrogen strategy is crucial for enabling effective policy mechanisms and coordination across the value chain. Given that the market is not yet self-sustaining, continued and expanded support is widely regarded as essential. This includes facilitating early-stage investments as well as stimulating demand further downstream through targeted support. For a more in-depth discussion, see Chapters 4.2 and 6.3.

What realization outcomes can be expected for planned green hydrogen projects in Sweden, according to scenario-based modeling?
Scenario-based modeling shows that realized production capacity is not determined solely by project-specific characteristics, but varies significantly depending on surrounding conditions. In the SSP2 scenario, production from the most probable projects reaches approximately 107,000 tonnes of H_2 per year. Under the more favorable SSP1 scenario, this increases significantly to around 331,000 tonnes of H_2 per year, while the SSP3 scenario yields a substantially lower production capacity of only about 5,000 tonnes of H_2 per year. Further details can be found in Chapters 4.3 and 6.4.

7.2 General Insights

The Swedish hydrogen market is characterized by high ambition, with numerous planned projects, particularly at pilot and smaller scales. At the same time, a limited number of large-scale industrial projects account for a substantial share of the total projected production capacity, functioning as system anchors, whose realization determine future trajectory of the market. At present, market development is constrained by a persistent coordination problem, where producers face high risks without secured off-take agreements, while consumers hesitate to commit in the absence of reliable supply. Overcoming this “Catch-22” requires coordinated business models, risk-sharing arrangements, and contract structures.

In this early market phase, active governance and intentional orchestration are essential. Uncertainty regarding future demand highlights the need for stronger demand-side drivers. Green hydrogen remains uncompetitive under current conditions, with limited willingness to pay, implying continued and expanded support is necessary. While policy has primarily focused on CAPEX support, there is a growing need for OPEX and production support, as well as mechanisms targeting end-users to stimulate demand and provide clear investment signals.

These findings underscore the importance of a coherent and long-term policy framework, including a national hydrogen strategy, binding regulatory requirements, and well-designed policy instruments that link targets to measurable outcomes. Support mechanisms must be adapted to different market phases to enable cost reductions and scale-up.

Ultimately, hydrogen development in Sweden toward 2030 and beyond is not constrained by a lack of projects, but by realization conditions. Policy coherence, electricity system conditions, project maturity, and institutional support emerge as critical determinants. Enabling coordinated development across the value chain will be essential for translating ambition into realized production capacity. These conditions are embedded within a broader global system, where external dynamics continuously shape the possibilities for national market development.

7.3 Recommendations for Future Research

Given the complexity and early-stage nature of the hydrogen market, future research should further develop scenario analysis methodologies to better capture system dynamics. Expanding the range of included variables could improve the depth and robustness of scenario outcomes, and allow for a more comprehensive representation of system-level interactions.

A central area for further investigation concerns the development of hydrogen demand. In particular, future research should examine formation of binding off-take agreements, how risks are allocated between actors, and demand across different sectors. Better understanding of sector-specific demand volumes would provide a stronger foundation for assessing market growth and investment needs.

Building on this, future studies could quantify the potential emission reduction impacts of hydrogen deployment across different sectors. By linking estimated demand volumes to decarbonization pathways, it would be possible to assess the contribution of hydrogen to climate targets and to compare its effectiveness relative to alternative technologies.

Finally, given the strong policy dependence of hydrogen market development, future research should analyze the effectiveness of different policy instruments in stimulating both supply and demand.

Bibliography

[1] United Nations. (2022). Causes and Effects of Climate Change. United Nations. `https://www.un.org/en/climatechange/science/causes-effects-climate-change`

[2] Bataille, C., Åhman, M., Neuhoff, K., Nilsson, L. J., Fischedick, M., Lechtenböhmer, S., Solano-Rodriquez, B., Denis-Ryan, A., Stiebert, S., Waisman, H., Sartor, O., & Rahbar, S. (2018). A review of technology and policy deep decarbonization pathway options for making energy-intensive industry production consistent with the Paris Agreement. Journal of Cleaner Production, 187, 960–973. `https://doi.org/10.1016/j.jclepro.2018.03.107`

[3] Khaleel, M., Yusupov, Z., & Rekik, S. (2025). Advancing hydrogen as a key driver for decarbonized power systems. Unconventional Resources, 9(100278). `https://doi.org/10.1016/j.uncres.2025.100278`

[4] European Commission. (2023). Hydrogen. EU: Energy, Climate Change, Environment. `https://energy.ec.europa.eu/topics/eus-energy-system/hydrogen_en`

[5] Vätgasens utveckling nationellt och internationellt. (2024). Energimyndigheten. `https://www.energimyndigheten.se/4ad744/globalassets/klimat--miljo/elektrifiering/vatgas/underlagsrapport-vatgasens-utveckling-nationellt-och-internationellt-pdf.pdf`

[6] Vätgas Sverige. (2025, December 8). Vätgas Sverige förtydligar målbilden för föreningens verksamhet - Vätgas Sverige. Vätgas Sverige. `https://vatgas.se/2025/12/08/vatgas-sverige-fortydligar-malbilden-for-foreningens-verksamhet/`

[7] Incer-Valverde, J., Korayem, A., Tsatsaronis, G., & Morosuk, T. (2023). "Colors" of hydrogen: Definitions and carbon intensity. Energy Conversion and Management, 291(117294). `https://doi.org/10.1016/j.enconman.2023.117294`

[8] Uniper Terminates 200 MW Hydrogen Project in Sweden - Fuelcellsworks. (2024, October 10). Fuelcellsworks.com; Fuel Cells Works. `https://fuelcellsworks.com/2024/10/10/energy-policy/uniper-terminates-200-mw-hydrogen-project-in-sweden-due-to-market-and-regulatory-challenges`

[9] Burges, James. Orsted Scraps Swedish FlagshipONE Emethanol Project under Development." S&P Global, 15 Aug. 2024, `www.spglobal.com/energy/en/news-research/latest-news/energy-transition/081524-orsted-scraps-swedish-flagshipone-e-methanol-project-under-development.`

[10] Vattenfall continues review of HySkies project scope. (2024). Vattenfall. `https://group.vattenfall.com/press-and-media/newsroom/2024/vattenfall-continues-review-of-hyskies-project-scope`

[11] Blomberg, C. (2024, December 23). Map of Swedish hydrogen projects - Vätgas Sverige. Vätgas Sverige. `https://vatgas.se/en/2024/12/23/map-of-swedish-hydrogen-projects/`

[12] Paltsev, S. (2016). Energy scenarios: the value and limits of scenario analysis. Wiley Interdisciplinary Reviews, 6(4). `https://doi.org/10.1002/wene.242`

[13] Incer-Valverde, J., Korayem, A., Tsatsaronis, G., & Morosuk, T. (2023). “Colors” of hydrogen: Definitions and carbon intensity. Energy Conversion and Management, 291. `https://doi.org/10.1016/j.enconman.2023.117294`

[14] Gencer, E. (2021, June 23). Hydrogen. MIT Climate Portal. `https://climate.mit.edu/explainers/hydrogen`

[15] Yu, M., Wang, K., & Vredenburg, H. (2021). Insights into low-carbon hydrogen production methods: Green, blue and aqua hydrogen. International Journal of Hydrogen Energy, 46(41). `https://doi.org/10.1016/j.ijhydene.2021.04.016`

[16] Green Hydrogen - an overview | ScienceDirect Topics. (n.d.). Sciencedirect. `https://www.sciencedirect.com/topics/engineering/green-hydrogen`

[17] European Commission. (2022, November 15). Renewable fuels of non-biological origin in the European Union. Europa.eu. `https://setis.ec.europa.eu/renewable-fuels-non-biological-origin-european-union_en`

[18] Algburi, S., Munther, H., Al-Dulaimi, O., Fakhruldeen, H. F., Sapaev, I. B., Seedi, K. F. K. A., Khalaf, D. H., Jabbar, F. I., Hassan, Q., Khudhair, A., & Nakimera, G. (2025). Green Hydrogen Role in Sustainable Energy Transformations: A Review. Results in Engineering, 26. `https://doi.org/10.1016/j.rineng.2025.105109`

[19] EMBER. (2025, April 14). Sweden | Ember. Ember. `https://ember-energy.org/countries-and-regions/sweden/`

[20] Water Electrolysis - an Overview | ScienceDirect Topics. (n.d.). Sciencedirect. `https://www.sciencedirect.com/topics/engineering/water-electrolysis`

[21] Greitzer, Maria. Iridium and Platinum Availability for Electrolyser Production up to 2030. Green Energy and Technology, 2024, pp. 257–279, `https://doi.org/10.1007/978-3-031-62411-7_10.`

[22] Gao, Y., Wang, M., Raheem, A., Wang, F., Wei, J., Xu, D., Song, X., Bao, W., Huang, A., Zhang, S., & Zhang, H. (2023). Syngas Production from Biomass Gasification: Influences of Feedstock Properties, Reactor Type, and Reaction Parameters. ACS Omega. `https://doi.org/10.1021/acsomega.3c03050`

[23] Yue, M., Lambert, H., Pahon, E., Roche, R., Jemei, S., & Hissel, D. (2021). Hydrogen energy systems: A critical review of technologies, applications, trends and challenges. Renewable and Sustainable Energy Reviews, 146. `https://doi.org/10.1016/j.rser.2021.111180`

[24] Hassan, Q., Algburi, S., Sameen, A., Salman, H. & Al-Jiboory, A. (2024). A review of green hydrogen production by renewable resources. Energy Harvesting and Systems, 11(1), 20220127. `https://doi.org/10.1515/ehs-2022-0127`

[25] RISE. (n.d.). Hydrogen can carry renewable energy. RISE. `https://www.ri.se/en/story/hydrogen-can-carry-renewable-energy`

[26] DiChristopher, T. (2021). Hydrogen technology faces efficiency disadvantage in power storage race. S&P Global Market Intelligence. `https://www.spglobal.com/market-intelligence/en/news-insights/articles/2021/6/hydrogen-technology-faces-efficiency-disadvantage-in-power-storage-race-65162028`

[27] Loncar, M. (2025, January 6). Hydrogen Heating System for Buildings. H2Heat Project. `https://h2-heat.eu/blog/hydrogen-heating/`

[28] Pleshivtseva, Y., Derevyanov, M., Pimenov, A., & Rapoport, A. (2023). Comprehensive review of low carbon hydrogen projects towards the decarbonization pathway. International Journal of Hydrogen Energy, 48(10). `https://doi.org/10.1016/j.ijhydene.2022.10.209`

[29] Naturgas. (2026, January 30). Energimyndigheten. `https://www.energimyndigheten.se/energiberedskap/om-el-fjarrvarme-och-naturgas/naturgas/`

[30] Ma, N., Zhao, W., Wang, W., Li, X., & Zhou, H. (2024). Large scale of green hydrogen storage: Opportunities and challenges. International Journal of Hydrogen Energy, 50. `https://doi.org/10.1016/j.ijhydene.2023.09.021`

[31] IRENA (2022). Global hydrogen trade to meet the 1.5°C climate goal: Part II – Technology review of hydrogen carriers. International Renewable Energy Agency. `https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2022/Apr/IRENA_Global_Trade_Hydrogen_2022.pdf`

[32] U.S. Department of Energy. (2022). 2022 grid energy storage technology cost and performance assessment. U.S. Department of Energy, Office of Electricity. `https://www.energy.gov/sites/default/files/2022-09/2022%20Grid%20Energy%20Storage%20Technology%20Cost%20and%20Performance%20Assessment.pdf`

[33] Xie, Z., Jin, Q., Su, G., & Lu, W. (2024). A Review of Hydrogen Storage and Transportation: Progresses and Challenges. Energies, 17(16). `https://doi.org/10.3390/en17164070`

[34] Vätgas Sverige. (n.d.). Distribution. Vätgas Sverige. `https://vatgas.se/fakta/distribution/`

[35] Grubler, Arnulf. (1997). "Time for a Change: On the Patterns of Diffusion of Innovation". IEEE Engineering Management Review. vol. 25. `https://www.researchgate.net/publication/239928230_Time_for_a_Change_On_the_Patterns_of_Diffusion_of_Innovation`

[36] Bergek, A., Jacobsson, S., & Sandén, B. A. (2008). 'Legitimation' and 'development of positive externalities': two key processes in the formation phase of technological innovation systems. Technology Analysis & Strategic Management, 20(5), 575–592. `https://doi.org/10.1080/09537320802292768`

[37] Geels, F. W. (2005). Processes and patterns in transitions and system innovations: Refining the co-evolutionary multi-level perspective. Technological Forecasting and Social Change, 72(6), 681–696. `https://doi.org/10.1016/j.techfore.2004.08.014`

[38] Mills, R., Numata, Y., Speelman, L., Pesta, N., Tatarenko, O., & Janzow, N. (2022, October 12). Green hydrogen on an S-curve: Fast, beneficial, and inevitable. Rocky Mountain Institute. `https://rmi.org/green-hydrogen-fast-beneficial-and-inevitable/`

[39] Ny studie visar: Utnyttjandegrad nyckeln till kostnadseffektiv vätgaslogistik - Maserfrakt. (2026). Maserfrakt. `https://www.maserfrakt.se/ny-studie-visar-utnyttjandegrad-nyckeln-till-kostnadseffektiv-vatgaslogistik/`

[40] Andersson, J., Hellsmark, H., Sandén, B. (2021). The outcomes of directionality: Towards a morphology of sociotechnical systems. Environmental Innovation and Societal Transitions, 40, 108–131.`https://doi.org/10.1016/j.eist.2021.06.008`

[41] Om det svenska elsystemet. (2025, December 9). Energimyndigheten.se. `https://www.energimyndigheten.se/energisystem-och-analys/nulaget-i-energisystemet/om-det-svenska-elsystemet/`

[42] Elpris. (2021, December 8). Energimarknadsinspektionen.se. `https://ei.se/konsument/el/elmarknaden/elpris`

[43] Snyder, Hannah. “Literature Review as a Research Methodology: An Overview and Guidelines.” Journal of Business Research, vol. 104, no. 1, Nov. 2019, pp. 333–339. ScienceDirect. `www.sciencedirect.com/science/article/pii/S0148296319304564,https://doi.org/10.1016/j.jbusres.2019.07.039`

[44] Onwuegbuzie, Anthony J, and Rebecca Frels. Seven Steps to a Comprehensive Literature Review. SAGE , 4 Feb. 2016, pp. 48–64.

[45] O’Neill, B. C., Kriegler, E., Ebi, K. L., Kemp-Benedict, E., Riahi, K., Rothman, D. S., van Ruijven, B. J., van Vuuren, D. P., Birkmann, J., Kok, K., Levy, M., & Solecki, W. (2017). The roads ahead: Narratives for shared socioeconomic pathways describing world futures in the 21st century. Global Environmental Change, 42(42), 169–180. `https://doi.org/10.1016/j.gloenvcha.2015.01.004`

[46] SMHI. (n.d.). SSP-scenarier. SMHI. `https://www.smhi.se/kunskapsbanken/klimat/klimatmodeller-och-scenarier/ssp-scenarier`

[47] GDPR. General Data Protection Regulation (GDPR). 23 May 2018, `gdpr-info.eu/`

[48] von Schultz, C. (2026). Elektrolysören levererar – men marknaden hänger inte med. Ny Teknik. `https://www.nyteknik.se/energi/elektrolysoeren-levererar-men-marknaden-haenger-inte-med/4447840`

[49] SoutH2Port Sweden Vätgas. (2025). Skyborn Renewables. `https://www.skybornrenewables.com/markets/sweden/local/south2port_vaetgas`

[50] Fueling the future: Norsk e-Fuel partners with Prime Capital and RES to produce Sustainable Aviation Fuel in Sweden. (2025). Norsk E-Fuel. `https://www.norsk-e-fuel.com/articles/project-alby`

[51] OX2, Södra och TES går vidare med projekt för elektrisk naturgas i Värö, Sverige - OX2. (2026). OX2. `https://www.ox2.com/sv/sverige/media/nyheter/2026/ox2-sodra-och-tes-gar-vidare-med-projekt-for-elektrisk-naturgas-i-varo-sverige/`

[52] Industriklivet. (2025). NH3 GREENTECH. `https://www.nh3greentech.se/industriklivet`

[53] Kristensson, J. (2026). Bryggeriets vätgasanläggning är på plats – men bränslecellsfordon får vänta. Ny Teknik. `https://www.nyteknik.se/energi/bryggeriets-vaetgasanlaeggning-aer-pa-plats-men-braenslecellsfordon-far-vaenta/4459304`

[54] Skellefteå Kraft. (2014). Zero Sun. `https://www.skekraft.se/wp-content/uploads/2018/05/SKEL14_A4_ENG-small.pdf`

[55] Ardagh pioneers onsite hydrogen energy. (2024). Ardagh Group. `https://www.ardaghgroup.com/press-releases/detail/13159/Ardagh+pioneers+onsite+hydrogen+energy`

[56] Vätgas i industrin – kemiindustrin. (2023). Vätgas Sverige. `https://vatgas.se/vatgas-i-kemiindustrin/`

[57] Sjöbohem - Hydrobust. Hydrobust - modern energihållning. (n.d.). `https://hydrobust.se/`

[58] Krook, J. (2026). Sjöbohem går mot strömmen: Vätgassatsning blev lönsam – ”Får kalkylen att gå ihop”. Ny Teknik. `https://www.nyteknik.se/energi/de-gar-mot-stroemmen-vaetgassatsning-blev-loensam-far-kalkylen-att-ga-ihop/4446032`

[59] Luleå tekniska universitet. (2025). Hydrogen map: Sweden and Finland. `https://ltu.instante.se/V%C3%A4tgas/Hydrogen_map_English_112024.html`

[60] Energimyndigheten. (2025). Underlag till handlingsprogram enligt artikel 14 i AFIR. `https://www.energimyndigheten.se/4aa351/globalassets/klimat/transporter/underlag-till-handlingsprogram-enligt-artikel-14-i-afir.pdf`

[61] European Commission. (2023). Renewable energy directive. `Energy.ec.europa.eu.https://energy.ec.europa.eu/topics/renewable-energy/renewable-energy-directive-targets-and-rules/renewable-energy-directive_en`

[62] Cefic. (2026, January 28). European Chemical Closures & Investments Radar 2022-2025 . `Cefic.https://cefic.org/resources/european-chemical-closures-investments-radar-2022-2025/`

[63] European Commission. (n.d.). Sustainable transport investment plan. Mobility and Transport. `https://transport.ec.europa.eu/transport-themes/clean-transport/sustainable-transport-investment-plan_en`

[64] European Comission. (2024). About the EU ETS. Climate Action. `https://climate.ec.europa.eu/eu-action/carbon-markets/about-eu-ets_en`

[65] European Commission. (2025). Carbon Border Adjustment Mechanism. European Commission. `https://taxation-customs.ec.europa.eu/carbon-border-adjustment-mechanism_en`

[66] European Commission. (2024). Alternative Fuels Infrastructure. `Transport.ec.europa.eu.https://transport.ec.europa.eu/transport-themes/clean-transport/alternative-fuels-sustainable-mobility-europe/alternative-fuels-infrastructure_en`

[67] European Commission. (2023). ReFuelEU Aviation - European Commission. `Transport.ec.europa.eu.https://transport.ec.europa.eu/transport-modes/air/environment/refueleu-aviation_en`

[68] International Maritime Organization. (2025). IMO approves net-zero regulations for global shipping. `https://www.imo.org/en/MediaCentre/PressBriefings/pages/IMO-approves-netzero-regulations.aspx`

[69] European Commission, Joint Research Centre. (2023). Energy efficiency of water electrolysers for hydrogen production. Publications Office of the European Union. `https://publications.jrc.ec.europa.eu/repository/bitstream/JRC140567/JRC140567_01.pdf`

[70] Singh, H., Li, C., Cheng, P., Wang, X., Liu, Q. (2022). A critical review of technologies, costs, and projects for production of carbon-neutral liquid e-fuels from hydrogen and captured CO2. Energy Advances, 1(9), 580–605. `https://doi.org/10.1039/d2ya00173j`

[71] Neuling, U., Berks, L., Schwab, T., Barbosa, R., Kast, U., Michel, C. (2024). Defossilising aviation with e-SAF An introduction to technologies, policies, and markets for sustainable aviation fuels ANALYSIS. Agora Verkehrswende and PtX Hub. `https://www.agora-verkehrswende.de/fileadmin/Projekte/2024/E-Fuels-im-Luftverkehr_EN/111_Defossilising_Aviation_with_e-SAF.pdf`

[72] Wai, S., Ota, Y., Sugiyama, M., & Nishioka, K. (2020). Evaluation of a Sabatier Reaction Utilizing Hydrogen Produced by Concentrator Photovoltaic Modules under Outdoor Conditions. Applied Sciences, 10(9). `https://doi.org/10.3390/app10093144`

[73] In a Nutshell. (2022). NH3 GREENTECH. `https://www.nh3greentech.se/in-a-nutshell`

[74] Trinca, A., Patrizi, D., Verdone, N., Bassano, C., & Vilardi, G. (2023). Toward green steel: Modeling and environmental economic analysis of iron direct reduction with different reducing gases. Journal of Cleaner Production, 427. `https://doi.org/10.1016/j.jclepro.2023.139081`

Appendix A

Interview Guide - Original

Introduktion

- Berätta lite kort om dig själv. Din roll, vad du gör på företaget.
- Var i utvecklingsfasen befinner sig ert projekt?

Tematiskt

- Vilket är det mest realistiska scenariot för er verksamhet år 2030?
- Hur stor kapacitet planerar ni att ha? Hur stor elektrolysör vs. hur mycket vätgas motsvarar det hos er?
- Lärdomar: Vilka är de viktigaste lärdomarna ni har dragit från processen att utveckla vätgasprojekt hittills?
- Vad drev er till att satsa på vätgas?
- Vad har ni upplevt som de största hindren?
- Vilka faktorer är mest avgörande för att den generella vätgasmarknaden växer till 2030?

Förseningar och grön vätgas

- Förseningar: Relativt ofta blir vätgasprojekt fördröjda. Beror det främst på personalfrågor, utmaningar med tillståndsprocesser eller andra faktorer? Följer ni er tidsplan?
- Grön vätgas: Hur central är grön vätgas för era projekt, och hur verifierar ni dess gröna ursprung?

Teknik

- Elektrolysör: Vilken typ av elektrolysör har ni valt – alkalisk eller PEM – och varför valde ni just den tekniken?
- Lagring: Vilken strategi har ni för lagring av vätgas på produktion/stationsområdet, och hur stor är er totala lagringskapacitet?
- Koldioxiduppskattning: Vilka fossila bränslen eller processer ersätter er vätgas? Har ni räknat på hur mycket CO_2 ni kan undvika genom att byta till vätgas?
- Är det något steg i produktionen som ni ser som en risk / flaskhals / tekniskt utmanande?

- Standardisering: Ser ni ett behov av tydligare eller nya standarder inom vätgaskedjan, till exempel för tryck eller säkerhetsprotokoll?

Infrastruktur

- Pipeline: Har ni några planer på att ansluta stationen till en framtida vätgaspipeline? Vilka tidsperspektiv och eventuella kostnadsberäkningar ser ni för det?
- Elnätet: Har ni stött på utmaningar med elnätskapaciteten för er verksamhet? Hur har samarbetet med det lokala nätbolaget fungerat?

Affärsmodeller

- Producerar ni er produkt för att ni ser en efterfrågan bland era nuvarande konsumenter eller för att skapa efterfrågan (och ligga i framkant)?
- Nätverk & kunder: Hur arbetar ni för att bygga upp ett lokalt och regionalt nätverk av kunder (särskilt när det gäller kopplingen till åkerier?)
- Kundunderlag: Har ni redan nu regelbundna kunder som tankar hos er? Vilken typ av fordon handlar det i så fall om?
- Har ni en bild av vilka som kommer bli era framtida kunder?
- Kontrakt: Strävar ni efter att teckna långsiktiga leveranskontrakt med era kunder, och hur ser i så fall ett sådant upplägg ut?

Policy och regelverk

- Offentligt stöd: Vilka former av offentligt stöd har ni tagit del av, till exempel från Klimatklivet eller regionala elektrifieringspiloter?
- Stödprocessen: Vilka är era erfarenheter av själva ansökningsprocessen och administrationen kring dessa stöd?
- Myndighetskontakt: Hur omfattande har er kontakt med olika myndigheter (t.ex. kommun, länsstyrelse) varit under projektets gång, och vilka är era främsta erfarenheter från det?
- Framtida stödbehov: Vilken typ av politiskt stöd eller vilka regeländringar ser ni som mest angelägna på både kort och lång sikt för att underlätta er och branschens expansion?
- Räddningstjänst: Hur har samarbetet med den lokala räddningstjänsten fungerat, särskilt gällande tillstånd, riskbedömning och säkerhetsaspekter?
- Myndighetsstöd: Finns det något specifikt som myndigheter eller andra offentliga aktörer skulle kunna göra annorlunda för att underlätta för liknande vätgasprojekt i framtiden?

Allmän acceptans

- Allmänheten: Hur har allmänheten/grannar/närliggande företag reagerat på vätgasprojektet? Är de informerade – saknas kunskap – har ni behövt arbeta med frågorna, till exempel kopplat till bygglov?

Information och kompetens

- Kompetens: Vilka kompetens- och utbildningsbehov ser ni generellt i branschen? Om en aktör som [H2Ignite] skulle anordna en utbildning, vad vore viktigast att fokusera på?

Appendix B

Interview Guide - Translated

Introduction

- *Could you briefly introduce yourself? Your role and what you do at the company.*
- *At what stage of development is your project currently?*

Thematic

- *What is the most realistic scenario for your operations in 2030?*
- *What capacity are you planning to have? How large is your electrolyzer capacity, and how much hydrogen does that correspond to?*
- *What are the most important lessons you have learned from the process of developing hydrogen projects so far?*
- *What motivated the investment in hydrogen?*
- *What have you experienced as the main barriers?*
- *Which factors are most critical for the overall hydrogen market to grow by 2030?*

Delays and Green Hydrogen

- *Hydrogen projects are often delayed. Is this mainly due to staffing issues, permitting challenges, or other factors? Are you following your planned timeline?*
- *How central is green hydrogen to your projects, and how do you verify its green origin?*

Technology

- *Which type of electrolyzer have you chosen – alkaline or PEM – and why did you choose that technology?*
- *What is your strategy for hydrogen storage at the production/site level, and what is your total storage capacity?*
- *Which fossil fuels or processes does your hydrogen replace? Have you estimated how much* CO_2 *emissions you can avoid by switching to hydrogen?*
- *Are there any steps in the production process that you see as a risk, bottleneck, or technically challenging?*
- *Do you see a need for clearer or new standards within the hydrogen value chain, for example regarding pressure levels or safety protocols?*

Infrastructure

- *Do you have plans to connect your facility to a future hydrogen pipeline? What timelines and potential cost estimates do you foresee?*
- *Have you encountered challenges related to the electricity grid capacity for your operations? How has the collaboration with the local grid operator worked?*

Business Models

- *Are you producing based on existing demand from your customers, or are you aiming to create demand and be a first mover?*
- *How are you working to build a local and regional customer network, particularly in relation to transport and logistics companies?*
- *Do you already have regular customers refueling at your station? If so, what type of vehicles are they?*
- *Do you have a view on who your future customers will be?*
- *Do you aim to establish long-term supply contracts with your customers, and what would such arrangements look like?*

Policy and Regulation

- *What forms of public funding or support have you received, for example from programs such as Klimatklivet or regional electrification initiatives?*
- *What are your experiences with the application process and administration related to these support schemes?*
- *How extensive has your interaction with authorities (e.g. municipalities, county administrative boards) been during the project, and what are your main takeaways?*
- *What types of policy support or regulatory changes do you see as most important in the short and long term to enable your and the industry's expansion?*
- *How has the collaboration with local emergency services worked, particularly regarding permits, risk assessments, and safety aspects?*
- *Is there anything that authorities or public actors could do differently to facilitate similar hydrogen projects in the future?*

Public Acceptance

- *How have the public, neighbors, or nearby businesses responded to the hydrogen project? Are they well-informed, is there a lack of knowledge, and have you needed to actively address these issues?*

Information and Competence

- *What competence and training needs do you see in the industry in general? If an actor such as [H2Ignite] were to organize a training program, what should be the main focus?*

Appendix C

Energy Conversion Calculations

To enable a consistent comparison of expected hydrogen production across different data sources, several methodological assumptions and conversion steps are required. All production values are normalized to the common unit *ton H_2 per year*, which serves as the reference metric throughout the analysis.

C.1 Assumptions for hydrogen output per installed MW of electrolyzer capacity

The conversion from installed electrolyser capacity (MW) to annual hydrogen production (ton H_2/year) is based on the following assumptions:

- **Full load operation:** The electrolyser is assumed to operate continuously throughout the year (load factor = 1), enabling a direct conversion from daily to annual hydrogen output.
- **Electrolyser efficiency:** The conversion from electrical power input (MW) to hydrogen mass output requires an assumed efficiency. This is expressed as the ratio between the specific energy content of hydrogen and the electrical energy required for its production. The specific energy content of hydrogen is assumed to be 33.3 kWh/kg H_2 [69], and the typical electricity demand for electrolysis is assumed to be 55 kWh/kg H_2 [69].

  These values provide the basis for estimating the hydrogen yield per unit of installed electrical capacity.

C.2 Conversion Factors for e-Fuels and Derived Products

In cases where collected data were reported in terms of end product rather than hydrogen mass, additional conversion factors were applied to determine the corresponding hydrogen demand:

Conversion Factors for e-Fuels and Hydrogen Derivatives

- **H_2 to eMethanol:** Producing 1 kg of eMethanol requires approximately 0.189–0.20 kg H_2 [70].

- **H_2 to eSAF:** The production of e-kerosene requires 1 kg H_2 per 0.74 kg e-kerosene [71].
- **H_2 to eMethane:** Based on the stoichiometry of the Sabatier reaction, 4 moles of hydrogen (H_2) are required for the formation of 1 mole of methane (CH_4) [72]. Using molar masses, this corresponds to a theoretical conversion factor of approximately 2 kg CH_4/kg H_2.
- **H_2 to Ammonia:** The production of 1 kg NH_3 requires approximately 0.18 kg H_2, based on the hydrogen content of ammonia and the stoichiometry of the Haber–Bosch process [73].

Gasification of biomass for DRI reduction

- In cases where hydrogen or syngas is produced via biomass gasification, and hydrogen is subsequently used as the reducing agent in iron ore reduction, the equivalent conversion factor between produced syngas and DRI amounts to 493 kg syngas/ton DRI [74].
- The hydrogen content of the syngas amounts to 42%. [74].

These conversion factors ensure that all reported production volumes, can be translated into a consistent hydrogen-equivalent metric.

Appendix D

Code for Monte Carlo Simulation

```python

import numpy as np
import pandas as pd
import matplotlib.pyplot as plt

# ----------------------------
# Data
# ----------------------------
projects = pd.DataFrame({
   "project_name": ["P1", "P2", "P3", "P4", "P5", "P6", "P7",
       "P8", "P9", "P10", "P11", "P12", "P13", "P14", "P15",
      "P16","P17", "P18", "P19", "P20", "P21", "P22", "P23",
      "P24", "C1", "C2", "C3", "C4", "C5", "C6", "C7", "C8",
      "C9", "C10", "C11", "C12", "C13", "C14", "C15", "C16",
      "C17", "C18", "C19"],

    "start_year": [2025, 2028, 2029, 2028, 2029, 2031, 2030,
       2029, 2031, 2027, 2030, 2029, 2029, 2031, 2026, 2028,
       2027, 2027, 2028, 2030, 2030, 2031, 2031, 2026, 2027,
       2025, 2029, 2025, 2030, 2025, 2025, 2031, 2030, 2025,
       2029, 2025, 2031, 2025,2025, 2026, 2026, 2029, 2030],

    "norm_production": [477.82, 1135, 120, 775, 22000, 22000,
        22000, 21280, 21280, 330,74000, 1606, 1606, 88000,
       130, 2100, 828.22, 1000, 2100, 42000, 2920, 43000,
       45000, 159.27, 100000, 318.55, 796.36, 318.55,
       111490.9, 2920, 0, 3.98, 3981.82, 0.18, 10384.69,
       796.36, 4000, 1.59, 79.64, 159.27, 79.64, 3185.45,
       3185.45],

    "probability": [1, 0.725, 0.815, 0.69, 0.57, 0.395,
       0.615, 0.535, 0.43, 0.815, 0.495, 0.645, 0.605, 0.36,
       0.85, 0.45, 0.695, 0.69, 0.705, 0.345,0.715, 0.62,
       0.515, 0.975, 0.82, 1, 0.845, 1, 0.75, 1, 1, 0.785,
       0.475, 1, 0.68, 1, 0.375, 1, 1, 0.865, 0.865, 0.645,
       0.495],

    "spp1_probablities": [1, 0.955, 1.045, 0.92, 0.8, 0.625,
       0.845, 0.765, 0.66, 1.045, 0.725, 0.875, 0.835, 0.59,
```

```
       1.08, 0.68, 0.925, 0.92, 0.935, 0.575, 0.945, 0.85,
       0.745, 1.205, 1.05, 1.23, 1.075, 1.23, 0.98, 1.23, 1,
       1.015, 0.705, 1.23, 0.91, 1.23, 0.605, 1.23, 1.23,
       1.095, 1.095, 0.875, 0.725],

    "spp3_probablities": [1, 0.44, 0.595, 0.415, 0.31, 0.185,
        0.405, 0.285, 0.21, 0.595, 0.295, 0.42, 0.37, 0.16,
       0.62, 0.175, 0.44, 0.415, 0.415, 0.145, 0.485, 0.46,
       0.29, 0.745, 0.56, 1, 0.61, 1, 0.51, 1, 1, 0.515,
       0.24, 1, 0.44, 1, 0.16, 1, 1, 0.62, 0.62, 0.42, 0.25]

})

# ----------------------------
# Settings
# ----------------------------
n_simulations = 10000
n_projects = len(projects)

# ----------------------------
# Functions
# ----------------------------
def run_monte_carlo(probabilities, n_simulations=1000):
    probabilities = np.clip(np.array(probabilities), 0, 1)
    n_projects = len(probabilities)

    random_draws = np.random.rand(n_simulations, n_projects)
    realized = random_draws < probabilities
    realized_counts = realized.sum(axis=1)

    return realized_counts


def print_summary(name, realized_counts):
    histogram = pd.Series(realized_counts).value_counts().
       sort_index()

    print(f"\n{name}")
    print("Histogram:␣antal␣realiserade␣projekt")
    print(histogram)
    print(f"Medelv rde:␣{realized_counts.mean():.1f}")
    print(f"P10:␣{np.percentile(realized_counts,␣10):.1f}")
    print(f"P50␣(median):␣{np.percentile(realized_counts,␣50)
       :.1f}")
    print(f"P90:␣{np.percentile(realized_counts,␣90):.1f}")


def plot_histogram(realized_counts, title):
```

```
    bins = np.arange(realized_counts.min() - 0.5, realized_counts.max() + 1.5, 1)

    plt.figure(figsize=(10, 6))
    plt.hist(realized_counts, bins=bins, edgecolor="black", alpha=0.7)
    plt.xlabel("Number␣of␣realized␣projects")
    plt.ylabel("Frequency")
    plt.title(title)
    plt.grid(axis="y", alpha=0.3)
    plt.show()


# ----------------------------
# Scenario 1: original probabilities
# ----------------------------
scenario_1_counts = run_monte_carlo(projects["probability"], n_simulations)
print_summary("Scenario␣SSP2:␣Original␣probabilities", scenario_1_counts)
plot_histogram(scenario_1_counts, "Monte␣Carlo␣histogram␣-␣Scenario␣SPP2:␣Original␣probabilities")


# ----------------------------
# Scenario 2: new_probabilities1
# ----------------------------
scenario_2_counts = run_monte_carlo(projects["spp3_probablities"], n_simulations)
print_summary("Scenario␣SPP3:␣Alternative␣probabilities", scenario_2_counts)
plot_histogram(scenario_2_counts, "Monte␣Carlo␣histogram␣-␣Scenario␣SPP3:␣Low␣probabilities")


# ----------------------------
# Scenario 3: new_probabilities_plus_015
# ----------------------------
scenario_3_counts = run_monte_carlo(projects["spp1_probablities"], n_simulations)
print_summary("Scenario␣SPP1:␣Alternative␣probabilities␣+0.15", scenario_3_counts)
plot_histogram(scenario_3_counts, "Monte␣Carlo␣histogram␣-␣Scenario␣SPP1:␣High␣probabilities")
```

DEPARTMENT OF MECHANICS AND MARITIME SCIENCES
CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden
www.chalmers.se

CHALMERS
UNIVERSITY OF TECHNOLOGY