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# **Adopting Green Hydrogen by Finnish and Italian Companies: Drivers and Barriers**

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**ABSTRACT :**

In today's world, prioritising environmental sustainability is not a choice but a necessity, especially since the global energy sector plays a significant role in pollution. The urgency to take immediate action to reduce greenhouse gas emissions has never been clearer, and one effective approach among strategies is shifting toward energy sources like green hydrogen. This eco-friendly energy source, produced from renewable materials that emit no pollutants, serves as a key tool in supporting the development of sustainable industrial sectors and is also crucial for improving the quality of life. Beyond reducing energy consumption and pollution, the hydrogen economy boosts economic growth by creating new job opportunities and driving innovation.

Despite the recognised advantages of green hydrogen, there is still a notable lack of awareness about the factors influencing companies to adopt this technology within the EU market. To address this gap, this thesis aims to explore the main drivers and barriers to the adoption of green hydrogen among EU companies. Drawing on existing literature and incorporating institutional theory, a comprehensive framework of these drivers and barriers is developed to provide a deeper understanding of the dynamics at play.

The study uses qualitative data collected from four experts across the energy industry, two Finnish companies and one Italian company. The findings reveal several key insights. While falling renewable energy costs, technological advancements, and a supportive regulatory environment facilitate the adoption of green hydrogen, significant challenges remain. These include high initial investments, infrastructure complexities, and limited public awareness and acceptance of hydrogen technologies.

This research deepens our understanding of the factors impacting green hydrogen acceptance and offers practical recommendations for policymakers and industry leaders. For example, Sorgenia is cautious about committing to green hydrogen because of the high initial costs and the challenges of integrating it with the current energy infrastructure. In contrast, Vaisala Oyj in Finland recognises the obstacles to investing but strategically establishes its presence in the green hydrogen sector by leveraging its knowledge of measurement and monitoring technologies.

By evaluating the cost and environmental impact of hydrogen as a substitute for traditional energy sources, this report underscores the significant potential of hydrogen in achieving net-zero emissions in the future and effectively combating climate change. The transition to sustainable energy solutions highlights the critical role of green hydrogen in this transformative journey.

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**KEYWORDS:** green hydrogen, energy transition, climate change, hydrogen, electrolysis, hard-to-abate sectors.

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## SYMBOLS AND ABBREVIATIONS

### Symbols

CO <sub>2</sub>	Carbon Dioxide
H <sub>2</sub>	Hydrogen
H <sub>2</sub> O	Water
O <sub>2</sub>	Oxygen

**Abbreviations**

CCS	Carbon Capture and Storage
CEF	Connecting Europe Facility
CEO	Chief Executive officer
CSR	Corporate Social Responsibility
EIB	European Investment Bank
EU	European Union
EU ETS	European Union Emissions Trading System
FCVs	Fuel Cell Vehicles
ICCT	International Council on Clean Transportation
IEA	International Energy Agency
IPCEI	Important Projects of Common European Interest
IREA	International Renewable Energy Agency
PPAs	Power Purchase Agreements
UNEP	United Nations Environment Programme
UNFCC	United Nations Framework Convention on Climate Change

# 1 Introduction

The goal of this chapter is to present the thesis's background. It describes the research question, the objective, and the study's delimitations; defines the key terms used; describes relevant theories and previous studies in the same area; and explains the thesis structure.

## 1.1 Background of the study

The concept of “climate change” refers to temperature and weather changes over extended periods (United Nations, 2023). It has been an element throughout the history of our planet and is primarily influenced by human actions (United Nations, 2023). These changes occur faster than natural processes, as stated by the United Nations (2023). During the Industrial Revolution (XVIII-XIX century), humanity began exploiting fossil fuels, such as coal, oil and gas, for industrial and energy purposes (United Nations, 2023). This was the main cause of the massive release of harmful CO<sub>2</sub> into the atmosphere (United Nations, 2023).

Figure 1 displays the CO<sub>2</sub> emissions accumulated from 1750 to 2020 (Our World in Data, 2023). It shows the amount of CO<sub>2</sub> released by burning fossil fuels and industrial activities, excluding changes in land use (Our World in Data, 2023).

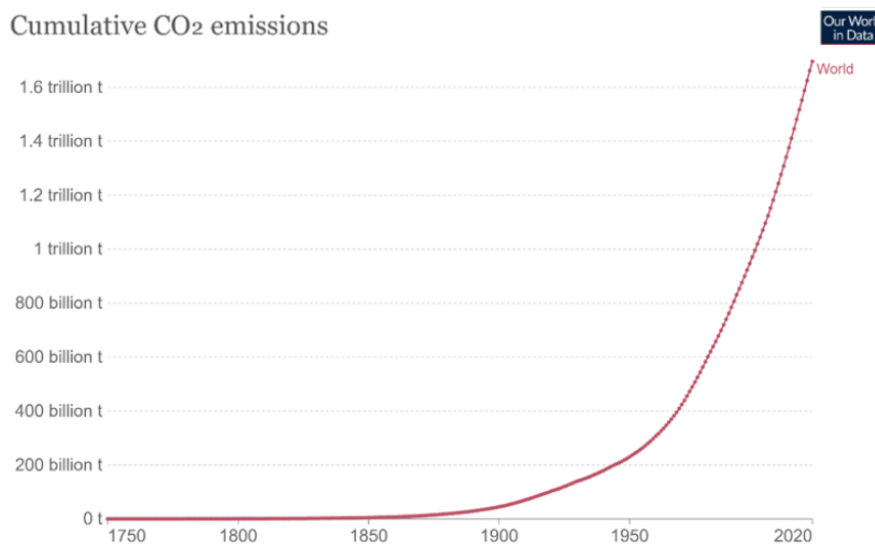


Figure 1. Cumulative CO<sub>2</sub> emissions. Source: Our World in Data, 2023.

The major consequence of this event is the 1.36°C increase in Earth's temperature in 2023 compared to the previous century (NASA, 2023). The rise in temperatures has led to challenges like droughts and wildfires, as well as the increase in sea levels and polar ice melt (NASA, 2023). According to UNEP (2022), people are working on approaches and technologies to combat this issue, which has affected our energy practices and sparked sustainable solutions. With a focus on reducing carbon emissions in mind, there has been an increasing emphasis on energy solutions in sectors that struggle to adopt eco-practices (Franco & Giovannini, 2023). This has caught the public's interest in industries, such as the hard-to-abate sectors (Franco & Giovannini 2023). Hydrogen can make a significant contribution to achieving these undeniable solutions; it has found a well-defined space in the chemical industry, oil refining, and the steel industry, where it serves as a reducing agent and uses its high calorific value to generate the necessary heat in production processes (Franco & Giovannini, 2023).

In today's energy industry, businesses are actively exploring energy sources with a growing interest in hydrogen, where green hydrogen is a promising option (Gulli et al., 2024). KPMG (2021a) reports that several investments by both national and European governments have motivated this increase in interest. There is intense competition and cooperation among businesses, notably European companies, as they invest heavily in identifying the most effective strategies for green hydrogen utilisation (KPMG, 2021a). However, according to the Finnish Ministry of Economic Affairs and Employment (2023) and Armaroli & Barbieri (2021), the integration of green hydrogen into markets such as Finland and Italy faces considerable obstacles. One such barrier is the high technological costs associated with its production (IEA, 2019). Green hydrogen production is currently more expensive than conventional fossil fuels, posing a substantial financial obstacle to its broader adoption (Kimberly, 2023). The lack of a global supply chain for green hydrogen represents another critical barrier (IEA, 2019). The absence of well-established infrastructure significantly obstructs the efficient production, distribution, and utilisation of green hydrogen worldwide (Kimberly, 2023). Public awareness and education are also lacking, limiting the broader understanding and acceptance of green hydrogen (Häußermann et al., 2023). Storage issues and the slow uptake of low-carbon and renewable

technologies further obstruct progress (Qiang et al., 2023). Moreover, despite growing interest and investment in this field, electrolyser capital costs, limited global production, and regulatory and political uncertainty add to the complexities of implementing green hydrogen as a sustainable energy source (IEA, 2023).

In recent years, society's consciousness of climate disasters has increased the popularity of green hydrogen, and it has been recognised as an essential part of the sustainable energy transition (Kane & Gil, 2022). First, one significant advantage of this transition is the international political commitment to cutting down carbon emissions (Kane & Gil, 2022). By participating in agreements such as the Paris Accord, countries pledge to decrease their greenhouse gas emissions and encourage the exploration of energy sources, like green hydrogen (European Commission, 2021). Second, technological progress in hydrogen production, particularly electrolysis, has helped green hydrogen become more accessible and cost-effective (Fernández-Arias et al., 2022). Furthermore, due to concerns about the environment and the prospect of long-term financial rewards, there has been an increase in investments in green energy infrastructure from both the public and private sectors (Blanc-Brude & Amenc, 2022). The increasing recognition, among society and consumers of the effects of climate change is also shaping how markets operate, pushing companies to adopt more sustainable practices and energy sources (Reichheld et al., 2023). Furthermore, the strategic geopolitical need to reduce dependency on fossil fuels and diversify energy sources for security and economic stability is guiding many countries toward green hydrogen (Sevencan, 2023). Also, hydrogen technology is becoming more and more useful in real life, from transportation to industrial processes (IEA, 2023). This is shown by the growing success and viability of pilot projects and research that boosts confidence and interest in this alternative energy source (IEA, 2023). Despite the popularity and benefits, there is a very limited understanding of the drivers and barriers to adopting green hydrogen by companies (Energy Policy, 2023).

## 1.2 Research question and objective of the study

The primary objective of this thesis is to empirically explore the drivers and barriers to adopting green hydrogen by EU companies, specifically Italian and Finnish. This comparative analysis between these two perspectives has not yet been conducted. Sector experts in the engineering and economic fields will be interviewed to examine the drivers and barriers to green hydrogen in the industry. Some of the companies where these experts work include Sorgenia (Green Tech Energy Italian Company), Danfoss (Global Engineered Solutions), and Vaisala Oyj (Power Industrial Solutions).

Accordingly, the main research question is:

**What are the drivers and barriers to adopting green hydrogen by EU companies?**

This study has the following sub-objectives:

- (1) To increase understanding of the global challenges, conceptualisation, and importance of adopting Green Hydrogen
- (2) To explore the drivers of adopting Green Hydrogen by companies.
- (3) To explore the barriers to adopting Green Hydrogen by companies.
- (4) To empirically explore the drivers and the barriers to adopting Green Hydrogen by Finnish and Italian companies.

## 1.3 Delimitations of the study

The study's clear objective is to investigate how businesses are employing green hydrogen, with a particular focus on Finland and Italy. This delimitation is essential because it helps the study explore in considerable detail the distinct political, economic, and environmental contexts of the two countries. The scope is further limited by its industry focus, which aims at sectors such as energy, chemicals, and industrial processing that are most relevant to green hydrogen. The study's theoretical frameworks, which may include environmental economics, policy analysis, or technological innovation, are fundamental because they influence the analytical framework used to evaluate the data. The study's

topic is also chosen to correspond with the rapid development of green hydrogen regulations and technology. The methodological approach is clarified by the types of data and sources employed, including expert interviews and policy analysis. Additionally, the study adopts a perspective that may include engineering, environmental, and economic aspects, directing the process of interpretation and conclusions. To temper expectations and clarify the study's emphasis, it is also important to describe what the research does not include, such as a specific analysis of experts from outside Finland and Italy. In conclusion, if legislative and regulatory contexts are indicated as drivers or barriers, they are explicitly acknowledged, highlighting the study's methodology in understanding the complexities of green hydrogen consumption. This delineation of scope ensures a focused and accurate investigation within the established limitations.

Furthermore, to ensure transparency and uphold ethical standards, it is crucial to disclose the use of artificial intelligence (AI) in the writing process. The thesis sections were reviewed with the aid of QuillBot's AI-powered Grammar Checker. The author independently composed the entire document, utilising QuillBot to enhance coherence and correct grammatical and formal inconsistencies. AI was employed exclusively for text verification, with no other intended uses.

#### **1.4 Definitions of key terms**

To ensure a clear and consistent understanding of the terminology used throughout this thesis, the following key terms are defined:

**Green hydrogen** = hydrogen produced by splitting water with renewable electricity with zero emissions (World Economic Forum, 2021).

**Energy transition** = a multi-dimensional, complex, non-linear, non-deterministic, and uncertain phenomenon, and, therefore, it is difficult to characterise. It requires a transformation of actors and their conduct, of markets, and a change in the existing regulations and policies (Blázquez et al., 2020).

**Climate change** = a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere, and that is in addition to natural climate variability observed over comparable periods (UNFCCC, 1992).

**Hydrogen** = a chemical element that is the lightest gas, has no colour, taste, or smell, and combines with oxygen to form water (Cambridge Dictionary, 2024).

**Electrolysis** = a chemical reaction that occurs when an electric current passes through a substance (Britannica, 2024).

**Hard-to-abate sectors** = the major industries that rely on fossil fuels, either for high-temperature energy or for chemical feedstocks (Harvard John A. Paulson School of Engineering and Applied Sciences, 2022).

**Institutional theory** = constellations of established practices guided by enduring, formalised, rational beliefs that transcend particular organisations and situations (Lammers & Garcia, 2017).

## 1.5 Previous studies

Table 1 presents the main studies used to analyse the topic of the thesis.

**Table 1.** Previous studies.

Title	Author(s) / Year	Methodology	Key Findings
Cost-competitive green hydrogen: how to lower the cost of electrolyzers?	Patagonia, A. & Poudineh, R. (2022).	Literature Review and Analysis.	The study highlights the potential for significant cost reductions and efficiency improvements in electrolyser technologies for green hydrogen production,

			emphasising the importance of economies of scale, technological advancements, and improved manufacturing processes.
Drivers and barriers for the large-scale adoption of hydrogen fuel cells by Nordic shipping companies	Latapi', M., Davi'osdottir, B., Johannsdottir, L. (2023).	Semi-structured interviews.	The study identifies and categorises the drivers and barriers to hydrogen fuel cell adoption in the shipping industry, offering a reference for policy and strategy development.
Green hydrogen production for oil refining – Finnish case.	Moradpoor, I., Syri, S., Santasalo-Aarnio, A. (2023).	A techno-economic analysis approach.	The study suggests that Power Purchase Agreements (PPAs) are becoming essential for green hydrogen production, with various scenarios impacting operation costs and break-even prices differently. It highlights the need for strategic choices in technology and energy sourcing for industrial companies.
Hydrogen from renewables: Is it always green? The Italian scenario	Liponi, A., Pasini, G., Baccioli, A., Ferrari, L. (2022).	Multiple case studies.	The study finds that increasing renewable energy capacity for electrolytic hydrogen production in Italy could either reduce energy consumption, raise hydrogen production costs, or worsen greenhouse

			gas emissions, depending on factors such as the renewable source mix and electrolyser utilisation.
Low-carbon hydrogen production in the EU: are 2030 targets achievable?	Boigontier T., Temmerman G., Girard R., Lamarque-Lacoste J., Motte Saint Pierre M., et al. (2023).	A techno-economic analysis approach.	The study illustrates that meeting the EU's ambitious 2030 targets for low-carbon hydrogen production necessitates a substantial increase in renewable energy sources and electrolyser capacity. It also highlights the necessity of integrating natural gas with carbon capture as an auxiliary method, amidst considerable challenges spanning technology, economics, and policy.
On the future relevance of green hydrogen in Europe	Ajanovic, A., Sayer, M., Haas, R. (2024).	Literature Review and Techno-economic analysis approach.	The document delineates how green hydrogen harbors promise for Europe's sustainable energy landscape, yet its broad implementation faces obstacles from economic, technological, and regulatory frameworks.
Towards effective monitoring of hydrogen economy development: A European perspective	Koneczna R., Cader J. (2024).	Literature Review and Analysis.	The study introduces a detailed framework of 124 indicators to effectively monitor and enhance the development of Europe's hydrogen

			economy, addressing a critical gap in evidence-based policy-making and strategic planning.
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## 1.6 Structure of the thesis

The objective of this study is to enhance the knowledge and understanding of green hydrogen by analysing its impact and development within two specific markets: Finland and Italy. This thesis comprises five chapters. The first chapter provides background information on the current situation and describes theories and studies relevant to the topic. Chapter two presents a comprehensive literature review, covering several interconnected topics within the broader subject of green hydrogen's role. This section analyses the challenges of green hydrogen as a sustainable energy source within the context of the global climate crisis, addressing global issues and their solutions by European nations. The third chapter explains the methodology employed in the study, detailing the framework and methods utilised to gather and analyse data concerning green hydrogen's economic and social impact in the Finnish and Italian contexts. It describes the companies selected for the qualitative analysis, the process of conducting interviews with sector experts, and the analytical techniques used to evaluate the findings. Chapter four presents the results of the study conducted in chapter three. The chapter examines and discusses key findings regarding the drivers and barriers to green hydrogen adoption by Finnish and Italian companies. It includes detailed insights gathered from interviews with industry experts and a thematic analysis of the data, aiming to provide a comprehensive understanding of the practical challenges and opportunities in the implementation of green hydrogen technologies. Finally, chapter five reflects on the research objectives and questions posed throughout the study. This chapter synthesises the empirical findings from both markets to identify common trends and distinctive elements. It offers a comparative perspective on the drivers and barriers to green hydrogen adoption, considering the economic, regulatory, technological, and market conditions unique to Finland and Italy. Additionally, the chapter discusses the implications of the findings for

companies, policymakers, and future research trends. The study concludes with recommendations aimed at supporting further development and adoption of green hydrogen as a sustainable energy solution in Finland and Italy.

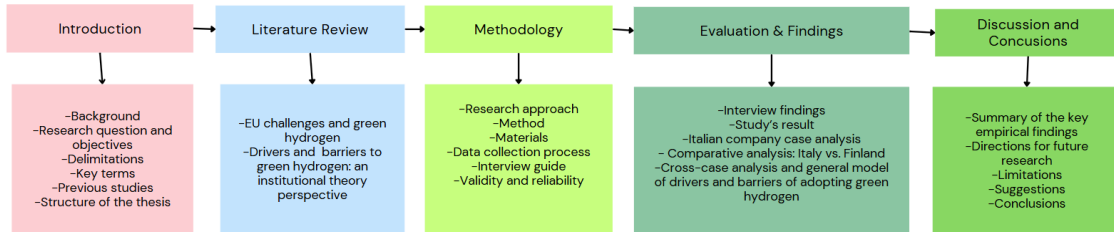


Figure 2. Structure of the thesis

## 2 Literature review

This chapter provides a detailed understanding of the topic and its integration into society. Exploring the trends and strategies related to the European challenges in adopting green hydrogen can give insight into the existing circumstances and suggested actions across different countries. This analysis aims to make the content accessible and comprehensible, especially for those new to the field, allowing them to understand the essential concepts and follow the arguments presented in this thesis comfortably.

### 2.1 Conceptualisation of green hydrogen

Hydrogen ( $H_2$ ) is the most abundant chemical element in the universe, forming about 75% of matter and stars, including the Sun (American Chemical Society, 2023). Despite being odourless, colourless, tasteless, and complex to extract, hydrogen is best identified as a carrier for energy transport and storage, not as a primary source (National Renewable Energy Laboratory, 2022). The focus on hydrogen as an energy carrier stems primarily from its unique characteristics: its lightweight nature, which makes it much easier and cheaper to store long-term than electricity, its reactivity, high energy content per unit mass, and its ease of production on an industrial scale (Kumar, 2015). Hydrogen is a low-polluting fuel with an impressive calorific value that makes it incredibly efficient (Kumar, 2015). It is considered to be the cleanest future energy source because its combustion product is water ( $H_2O$ ), presenting no substances that directly affect atmospheric pollution (Kumar, 2015). In contrast to other fuels that have a definite impact on our planet, hydrogen does not cause acid rain, deplete the ozone layer, or generate hazardous emissions (Kumar, 2015).

The production process categorises hydrogen into different 'colours', making it a key element in the transition to cleaner fuels (Newborough & Cooley, 2020). This colour coding is not based on the fact that hydrogen gas is colourless but rather on the environmental impact and production process (Newborough & Cooley, 2020). Hydrogen is

not found naturally; instead, it is derived from compounds such as H<sub>2</sub>O or fossil fuels (Giacomazzi et al., 2023).

This is why categorisation holds importance:

**Brown/black hydrogen:** Produced from coal through a polluting process called gasification, it is the most polluting type of hydrogen production and generates a significant amount of CO<sub>2</sub> (Enerdatix, 2021).

**Grey hydrogen:** This is the most common type of hydrogen, produced from natural gas without CO<sub>2</sub> capture in high volumes by steam methane reforming or autothermal reforming (Fikry & Esteves, 2023). The increase in carbon dioxide emissions due to these methods has been significant (Fikry & Esteves, 2023).

**Blue hydrogen:** Produced from natural gas, with CO<sub>2</sub> captured and either stored or utilised using CCS technologies, significantly reducing emissions (Fikry & Esteves, 2023). However, this process is energy-intensive and faces challenges with storage and potential leaks (Fikry & Esteves, 2023).

**Pink or purple hydrogen:** Produced using electricity from nuclear energy to electrolyse H<sub>2</sub>O (Newborough & Cooley, 2020). This method helps reduce CO<sub>2</sub> production but raises concerns about nuclear energy use (Newborough & Cooley, 2020).

**Turquoise hydrogen:** Acquired by splitting methane into hydrogen and solid carbon, this method offers a potentially cleaner alternative (Newborough & Cooley, 2020). However, there are challenges in energy use and process efficiency (Newborough & Cooley, 2020).

**Green hydrogen:** Produced using renewable energy sources such as wind, solar, or hydropower to electrolyse H<sub>2</sub>O, is the epitome of clean hydrogen (Fikry & Esteves, 2023). Lacking any greenhouse gas emissions, green hydrogen is a key pillar in achieving a clean energy transition (Marouani et al., 2023). However, addressing obstacles is necessary for its widespread adoption (Marouani et al., 2023). Production costs are high, and the elec-

trollysis technology is far too complex in its current form (Marouani et al., 2023). Nevertheless, developing these technologies and building the necessary renewable energy infrastructure can lower costs and create a brighter future for green hydrogen in a decarbonised world (Marouani et al., 2023).

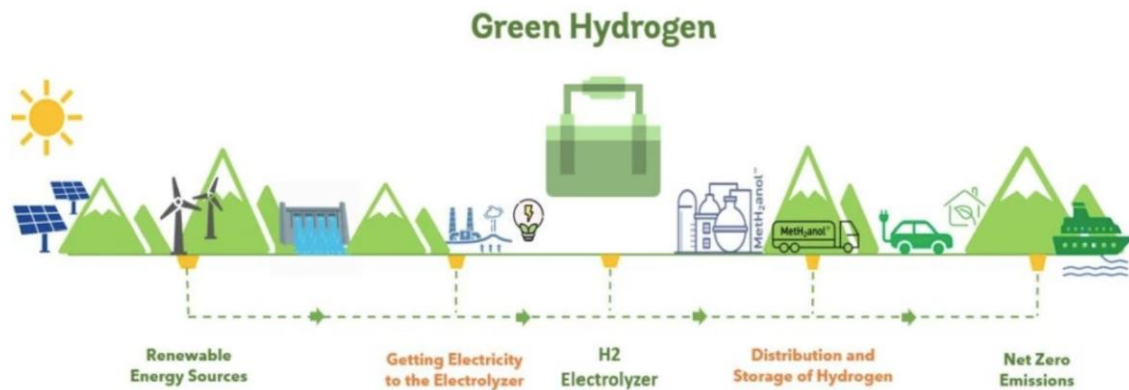


Figure 3. The Green Hydrogen lifecycle. Source: Kane & Gil, 2022.

Figure 3 outlines the journey of hydrogen, starting with harnessing energy sources like the sun, wind turbines, and solar panels to produce electricity (Kane & Gil 2022). The diagram then shows this electricity being used in an electrolyser to split water into hydrogen ( $H_2$ ) and oxygen ( $O_2$ ), leading to hydrogen production (Kane & Gil 2022). The next stage involves storing and transporting hydrogen using tanks and tanker trucks, indicating its versatility for applications (Kane & Gil 2022). Finally, the cycle concludes with the use of hydrogen in sectors such as transportation and industries to help achieve “Net Zero” emissions targets (Kane & Gil 2022). “Net Zero” proposes to balance greenhouse gas emissions with removal efforts (McKinsey & Company 2022b). Technological advancements and global partnerships are developing progress through hydrogen solutions (Muthukumar et al., 2023). Researchers are studying new and innovative methods such as power-to-gas technology and biomass conversion to enhance the efficiency and affordability of hydrogen production (Muthukumar et al., 2023). Advancements in hydrogen fuel cells also play a role in exploring approaches for enhancing scalability (Muthukumar et al., 2023). A concerted effort is required to improve electrolysis technology and expand energy generation, paving the way for hydrogen in the energy landscape

(Friedrich Ebert Stiftung, 2023). Establish supportive policy frameworks and raise awareness among the societies (Friedrich Ebert Stiftung, 2023). International collaboration is crucial for establishing standards, sharing ideas, and developing the global infrastructure required for the complete lifecycle of green hydrogen production (Friedrich Ebert Stiftung, 2023). The process entails the creation, storage, transportation, and utilisation of green hydrogen (Friedrich Ebert Stiftung, 2023).

### **2.1.1 Development and challenges of the green hydrogen market in the EU**

This section explores both the progress and the hurdles in the development of the EU green hydrogen market. The European Union's strategy on hydrogen (H<sub>2</sub>) involves targets for deploying electrolyzers by 2030 and creating a hydrogen market, as highlighted by Nuñez Jimenez and De Blasio (2022). However, the future beyond 2030 lacks strategies and raises questions about how the EU will meet its hydrogen needs (Nuñez-Jimenez & De Blasio, 2022). The success of this transition will rely on coordination among sectors, including government policies, technological advancements, financial support, and societal acceptance (Nuñez-Jimenez & De Blasio, 2022). The European Union needs to establish and implement a comprehensive plan to maintain its position as a leader in the hydrogen sector and meet its goals for climate and energy security (Nuñez-Jimenez & De Blasio, 2022). As the EU works together towards this goal, each member state will have roles depending on its resources and infrastructure (Nuñez-Jimenez & De Blasio, 2022). For instance, countries with energy reserves, such as Spain, could become suppliers of eco-friendly hydrogen within the regions (Ipieca, 2023). Meanwhile, some nations may need to depend heavily on imports to meet their demands (Ipieca, 2023). Concerning technology and market interest, the EU is looking to import renewable hydrogen from multiple partners to ensure a stable supply (Tatarenko et al., 2023). On the other hand, countries such as the United States and Australia are preparing to export hydrogen (Tatarenko et al., 2023).

The European Union is keen on establishing a hydrogen market, as outlined in the publication “A Hydrogen Strategy for a Climate-Neutral Europe” released by the European Commission on July 8, 2020. The primary aim of this report is to reduce greenhouse gas emissions by 50 to 55% by 2030, a target that might be challenging to achieve without the adoption of hydrogen technologies (European Commission, 2020a). The Commission suggests that cooperation within the EU and with non-EU partners, as well as the creation of a single market, are the right paths to provide tangible answers to the most urgent needs (European Commission, 2020a). This can be achieved with significant investments, a favourable regulatory framework, identifying lead markets for the technology, promoting research and innovation, and planning and developing a large-scale infrastructure network (European Commission, 2020a). The strategy also considers the role of carbon capture and storage technologies in enhancing sustainability (European Commission, 2020a). However, for strategic plans to materialise, both demand and supply in this new market must grow rapidly at the same level (European Commission, 2020a). To this end, targeted legislation and an incentive system are absolute priorities (European Commission, 2020a).

To stimulate demand in the end-use sectors, the European Commission identifies two initial lead markets: industrial applications (refineries, ammonia, and methanol production, metallurgy, and, later, the steel industry) and transportation (European Commission, 2020a). The factors identified as obstacles to the diffusion of technologies related to renewable and low-emission H<sub>2</sub> include the higher cost, largely due to additional investments for storage and refuelling, and low margins on final products (due to international competition), which amplify the potential impact related to risks and market uncertainty (European Commission, 2020a). For this reason, the European Commission stipulates the following demand-side incentives:

- a) Setting minimum hydrogen quotas.
- b) Setting a price on CO<sub>2</sub> emissions.

To reach the goals set by the strategy, technology needs to be supported until it can be cost-competitive (European Commission, 2020b). The industry and investors require

clarity on the technologies to develop for hydrogen production, as well as a clear taxonomy that clarifies the distinctions between renewable and low-emission hydrogen (European Commission, 2020b). Additionally, they must know the plan for European infrastructure as soon as possible so they can direct investments for electrolyzers to the best sites (European Commission, 2020b).

The European Commission has implemented several measures to support the hydrogen supply chain:

**-Incentive criteria based on calculating CO<sub>2</sub> emissions** throughout the lifecycle (European Commission, 2020b).

**-Carbon contracts for different systems**, where the public counterpart would pay the investor the difference between the exercise and CO<sub>2</sub> prices (European Commission, 2020b).

**-Direct market-based support through tendering systems**, focusing exclusively on renewable hydrogen and rewarding electrolyzers for the positive externalities they generate (European Commission, 2020b).

**-Guarantees of origin and sustainability certificates** can improve production cost-effectiveness and facilitate exchanges within the EU (European Commission, 2020b).

**-Evaluation of a carbon border adjustment mechanism** to combat the offshoring emissions by sectors exposed to this phenomenon (European Commission, 2020b).

**-Mixing hydrogen in the natural gas network** to enable decentralised production of renewable hydrogen during the transition phase and, combined with support procedures, generate revenues that would stimulate production (European Commission, 2020b).

These measures aim to develop a balanced and competitive hydrogen market in the EU while addressing the technological, infrastructural, and regulatory challenges (European Commission, 2020b). Here is an analysis of the European Union's support instruments for the hydrogen market:

**a) IPCEI (Important Projects of Common European Interest):** These projects aim to promote synergies across the EU competencies, knowledge, and resources to facilitate radical innovations (Sandberg, 2016). The IPCEI Communication addresses infrastructure and state support, concerning the European Commission's communication on the congruence of state aid for projects of European interest (Sandberg, 2016). This aims to establish a method, for handling state aid matters concerning infrastructure initiatives (Sandberg, 2016). The IPCEI Communication provides guidelines for dealing with state assistance in infrastructure that stand out (Sandberg, 2016). The two decisions made so far seem to differ from each other and the Commission's usual approach to infrastructure issues, as described by Sandberg (2016). Additionally, since the IPCEI Communication deals with state aid compatibility, it applies when infrastructure projects involve activities initially (Sandberg, 2016). This topic has sparked controversy, it has been at the centre of disputes and discussions in the Commission's recent Communication on Assistance (Sandberg, 2016). The issue is particularly crucial as President Juncker's European Fund for Strategic Investments dedicates a portion of the funding to infrastructure projects, which could face delays due, to state aid approval processes (Sandberg, 2016). These are European-funded (through national budgets) projects designed to address significant market failures and contribute to the Union's objectives (Sandberg, 2016). "Hy2Tech" was the first IPCEI dedicated to hydrogen, particularly in its first industrial application, with €5.4 billion allocated, of which over one billion was assigned to Italian companies (Helm, 2023). "Hy2Use" aims to reduce natural gas substitution with a €5.2 billion budget, focusing on hydrogen infrastructure and its integration into heavy industrial processes (Helm, 2023).

**b) InvestEU:** This fund is allocating €26.2 billion from 2021 to 2027 intending to promote investments (public and private) in a range of areas including research, innovation, digitalisation, sustainable infrastructure, SMEs, social investments, and skills (Demertzis et al., 2024). The goal is to attract more than €370 billion in total investments (Demertzis et al., 2024). It provides a budget guarantee to financial partners like the European Investment Bank (EIB), facilitating access to bank credit for riskier projects, especially those addressing market failures or critical investment shortages (Demertzis et al., 2024).

**c) Connecting Europe Facility (CEF):** This tool aims to accelerate investments in transport, energy, and digital infrastructure across the EU from 2021 to 2027 (Demertzis et al., 2024). The CEF for Energy (CEF-E) specifically supports the coordinated management and connection of energy infrastructure among Member States (Demertzis et al., 2024). With a budget of €5.84 billion, it focuses on demonstration projects, studies, and co-financing energy infrastructures to maximise value for Europe (Demertzis et al., 2024).

**d) Horizon Europe:** The European Union's Horizon Europe program emphasises research and innovation, with a budget of €95.5 billion allocated from 2021 to 2027 (Horizon Europe, 2024). Around 35% of this funding is dedicated to supporting the EU sustainability objectives (Horizon Europe, 2024). Additionally, funded research initiatives like the Hydra project, within Horizon Europe, are exploring the impacts of hydrogen usage (HYDRA Project Update 2024). Additionally, funded research initiatives like the Hydra project, within Horizon Europe, are investigating the impacts of hydrogen usage (HYDRA Project Update 2024). The Hydra project aims to comprehensively understand the socio-economic, environmental, and safety aspects associated with large-scale hydrogen deployment (HYDRA Project, 2024). A key aspect of this project is using an assessment model to explore situations and analyse how societal factors interact with economic and environmental considerations (HYDRA Project, 2024). Furthermore, it focuses on developing advanced sensors to detect and quantify hydrogen leaks, ensuring the safety of hydrogen technologies (HYDRA Project, 2024). The Hydra project is looking into how hydrogen could affect the atmosphere and climate to guide the development of sustainable hydrogen economy policies (HYDRA Project, 2024). Initiatives focusing on hydrogen can receive support through Horizon Europe to reduce carbon emissions in sectors, such as heavy industry and transportation (Horizon Europe, 2024).

**e) Innovation Fund:** This funding program supports the demonstration of innovative technologies for CO<sub>2</sub> emission reduction (Gao et al., 2024). Projects can span high-energy-intensity industries, renewable energies, energy storage, CCUS, and electrolyzers (Gao et al., 2024). The fund is particularly flexible, allowing hydrogen to be subsidised at all value chain levels, excluding pure research projects (Gao et al., 2024). The fund is

financed by the auctioning of 450 million EU ETS allowances and covers up to 60% of project costs, differentiating between large and small-scale projects (Gao et al., 2024). These instruments are designed to stimulate both demand and supply in the hydrogen sector, addressing technological, financial, and infrastructural challenges to facilitate the transition towards a green and sustainable economy (Gao et al., 2024).

### **2.1.2 Impact of the Russia-Ukraine war on European energy policies**

Since the conflict in Ukraine started in February 2022, Russia, which was one of the main providers of gas and oil to European nations, has caused significant changes in the global energy market and has contributed to a deepening crisis in the energy industry (IEA, 2024). As a solution to the problem, funding has been allocated for the development of sustainable alternatives, alongside European-level political commitments to help nations formulate strategies for energy independence from Russia (IEA, 2024).

One of Europe's main strategies is the REPowerEU plan, which aims to increase the contribution of renewable energy in final energy consumption to 45% by 2030 (IEA, 2022). In response to the crisis, experts predict that the EU's renewable electricity capacity will double between 2022 and 2027, with a significant increase in estimations following the start of the war (IEA, 2024). Moreover, Reuters reported that the war and subsequent Western sanctions against Russia have added new pressures on oil and gas supplies, leading to record-high natural gas prices and significant spikes in oil prices (Gaffen, 2022). This situation has pushed European nations and other global economies to accelerate the implementation of renewable energy sources, such as green hydrogen, and diversify energy supplies, with some countries even temporarily reverting to coal to meet immediate energy needs (Gaffen, 2022). The crisis has forced a reevaluation of energy relationships and encouraged significant investments in alternative energy sources to reduce dependence on Russian gas (Gaffen, 2022).

### 2.1.3 What are the green hydrogen sectors?

Until now, hydrogen has primarily been used in chemical processes such as oil refining and fertiliser production (IREA, 2024). However, its potential is expanding to substitute fossil fuels in buildings, electricity generation, industries, and transportation sectors (BloombergNEF, 2023). In a study by Suman and colleagues (2022), various industries are actively using green hydrogen technologies as part of their efforts to achieve zero emissions in key sectors. Table 2 below highlights industries actively involved in developing or utilising green hydrogen applications as part of a broader effort to achieve zero emissions across four primary sectors (Suman et al., 2022).

**Table 2.** A summary of the key sectors where green hydrogen can be utilised.

Sector	Applications of Green Hydrogen
<b>Buildings</b>	- Heating and cooling systems - Blending with or replacing natural gas
<b>Electricity</b>	- Energy storage - Electricity generation - Balancing renewable energy production
<b>Industry</b>	- High-temperature processes (e.g., steel, cement) - Chemical production (e.g., ammonia, methanol)
<b>Transport</b>	<b>Light Transport:</b> - Alternative fuel for cars and light-duty vehicles <b>Heavy Transport:</b> - Alternative fuel for buses, trucks, trains, ships, and aeroplanes

As shown in the Green Hydrogen Applications by sector, heavy transport is the most promising sector in which this new sustainable energy solution can truly make a difference (EAI, 2024). The considerable costs of new infrastructure must be taken into account, as well as the costs of new vehicles equipped with electric motors and fuel cells that produce electricity using hydrogen as a source (ICCT, 2019). However, the efficiency of these new vehicles would be much greater than that of today's combustion engine, which would offset the additional cost of the new equipment, easily amortised over the vehicle's lifespan (ICCT, 2019). Other important sectors of heavy transport include shipping and aircraft (Koehler Instrument Company, 2024). In the long run, there is no better

alternative than hydrogen for initiating the process of decarbonisation (Koehler Instrument Company, 2024). Specifically, the shipbuilding sector uses hydrogen as ammonia; the aviation sector uses hydrogen as synthetic paraffin kerosene for long-distance flights, and hydrogen in fuel cells could be ideal for short to medium-distance flights of 500–800 km (Koehler Instrument Company, 2024).

A big problem in these areas is that they are expensive to decarbonise because green hydrogen has to be made and then mixed with the other elements listed above (ammonia for example, carbon dioxide from burning biomethane or air capture for synthetic paraffin kerosene) (Koehler Instrument Company, 2024). In any case, Bloomberg NEF estimates indicate a very encouraging market outlook across various hydrogen sectors, with exponential growth in demand expected in the coming years.

Figure 4 below presents a graph of demand growth forecasts for hydrogen in various sectors by 2050.

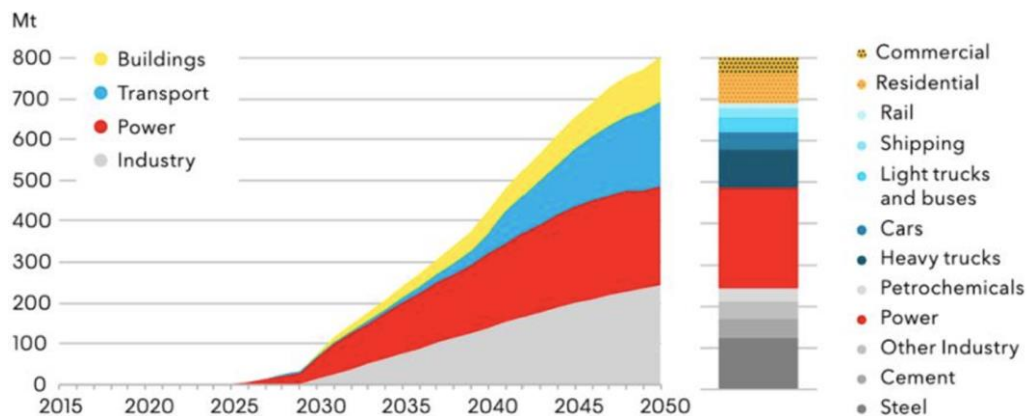


Figure 4. Hydrogen demand growth forecasts in various sectors by 2050 (BloombergNEF, 2023)

## 2.2 Drivers and barriers to green hydrogen: An institutional theory perspective

The extensive adoption of green hydrogen, supported by theories and recent technological progress, represents a significant step towards environmental sustainability and energy transition (Marouani et al., 2023). It is possible to draw upon the concepts of the adoption of green hydrogen, the drivers and barriers, with institutional theory and its

newer versions. Institutional theory focuses on the relationship between institutional context and organisation (Selznick, 1957). It observes that organisations adapt not only to the strivings of their internal groups but also to the values of external society (Selznick, 1957). The structure may be either formal (e.g., legislature, bureaucracy, political parties, mass media) or informal (e.g., a network of interacting organisations or a set of shared norms) (Selznick, 1957).

Institutional theorists suggest that institutions are relatively durable social structures that influence and limit the behaviour of actors operating within a specific social context, where actors can be individuals, groups, or organisations (IEEE, 2004). The stakeholder and legitimacy theories explain why managers of an organisation embrace a particular strategy, such as voluntary CSR disclosure, whereas institutional theory tends to take a broader macro view to explain why an organisation adopts a particular structure or reporting practice (IEEE, 2004). According to institutional theory, societal values and pressures from society, alongside industry trends, influence the adoption of hydrogen as an energy source (Hassan et al., 2024). Regulations and environmental policies set guidelines for the hydrogen market to promote the use of energy and reduce emissions (Hassan et al., 2024). Societal expectations for energy solutions also contribute to pushing industries towards adopting sustainable practices (Hassan et al., 2024). Additionally, industry leaders guide the use of hydrogen technologies by striving to meet or exceed evolving regulations and public expectations for energy solutions (Hassan et al., 2024).

A prime example showcasing this theory in action is the integration of hydrogen fuel cell vehicles (FCVs) within the sector as a response to increasing demands to cut down on carbon emissions worldwide (Hassan et al., 2023). In light of growing regulatory expectations, the automotive industry globally has delved into alternative energy solutions such as hydrogen fuel cells (Hassan et al., 2023). This change was chiefly driven by rules laid out by international and national regulations, such as the European Union's emission reduction targets, which created a push for car makers to embrace new energy technologies (Hassan et al., 2023). Pioneers in the industry, such as Toyota with their Mirai model and Hyundai with their Nexu, successfully introduced and promoted FCVs

(Fuel Cell Vehicles), setting a precedent for others (Hassan et al., 2023). Observing how these industry leaders smoothly integrated FCVs and received positive market responses, many competitors initiated hydrogen initiatives, demonstrating a notable trend of emulation within the sector (Hassan et al., 2023). This step was also motivated by the aim to meet evolving criteria and changing consumer demands, which increasingly favour vehicles providing environmental benefits without compromising performance (Hassan et al., 2023).

The growing public demand for eco-friendly energy solutions accelerated the transition of the industry, it is moving towards using hydrogen as a power source (Hassan et al., 2023). Consumers demonstrated a preference for vehicles that significantly reduced or eliminated emissions while maintaining high-performance standards and offering refuelling options (Hassan et al., 2023). This change in consumer preferences further solidified the sector's move towards hydrogen technologies, aligning with society's expectations for sustainable energy solutions (Hassan et al., 2023). As industry leaders implemented strategies to promote hydrogen fuel cell technology, other car manufacturers invested in research and development for hydrogen fuel cells, established partnerships to build hydrogen refuelling infrastructure, and advocated for policies supporting fuel cell vehicles (Hassan et al., 2023). This collective effort not only demonstrates the industry's dedication to meeting societal demands but also highlights the significant influence of pioneering companies in shaping trends related to the adoption of hydrogen technologies (Hassan et al., 2023). This real-world example of the automotive sector's embrace of hydrogen fuel cell vehicles effectively demonstrates how the integration of hydrogen technologies involves interconnected elements, as discussed by Hassan and colleagues (2023). It highlights the importance of understanding the relationship between institutional settings and organisational operations, as outlined by Bartolacci and colleagues (2022). Central to this understanding is the concept of "isomorphism," which explains why companies in similar contexts adopt strategies to bolster their credibility and align with their environmental context (Bartolacci et al., 2022). This concept sheds light on the adaptive strategies organisations employ to navigate their institutional landscapes,

furthering the adoption of green hydrogen as a cornerstone of sustainable energy solutions (Bartolacci et al., 2022).

Another version of institutional theory, called neo-institutionalism, explains better how practices and organisations become established over time (Lawrence & Suddaby, 2006). It examines “logics” and “institutional work” to analyse how practices like environmental reporting evolve under institutional pressures (Bartolacci et al., 2022; Lawrence & Suddaby, 2006). This perspective assists in examining how the combined institutional framework and organisational initiatives impact the uptake of hydrogen technology in practice (Helm, 2023). The significance of neo-institutionalism within the hydrogen sector is illustrated through energy companies taking part in hydrogen production as a result of a growing emphasis on ecological responsibility (Helm, 2023). These companies collaborate on initiatives such as partnering with governments to launch green hydrogen projects, supported by funding and regulatory assistance (Helm, 2023). Moreover, they support policies that promote the adoption of hydrogen technologies (Helm, 2023). For example, a group of energy companies collaborated with a government to establish a large-scale green hydrogen production facility (Helm, 2023). This demonstrates how they gain benefits from financial incentives and regulatory changes that support eco-friendly technologies (Helm, 2023). This alignment between norms favouring environmental sustainability and coordinated organisational actions demonstrates how societal expectations, regulations, and corporate strategies work together to advance the transition towards sustainable energy solutions in the sector (Helm, 2023). It shows how institutional influences play a role in driving the adoption of innovative technologies like green hydrogen (Helm, 2023).

In Europe, specifically in Italy and Finland, the change towards hydrogen is notably driven by institutional pressures related to technology, economics, environment, and society (Hassan et al., 2024). Addressing these challenges requires an approach that combines government backing, technological advancements, and collaborations across sectors to leverage the full range of benefits offered by green hydrogen (Hassan et al., 2024). This push is driving a transition towards sustainable energy sources (Hassan et

al., 2024). Furthermore, examining the potential of green hydrogen in various regions from an institutional theory perspective reveals different levels of market readiness and regulatory backing (Yap & McLellan, 2023). By evaluating how regulations, infrastructure readiness, and societal acceptance align, companies can strategically focus on markets that offer the most growth opportunities. It helps prioritise markets where the conditions are favourable for adopting green hydrogen technologies (Yap & McLellan, 2023). The theoretical foundations discussed in this study provide valuable insights into how companies develop their approaches to green hydrogen, taking into account structural and normative factors that impact their decision making strategies. The incorporation of hydrogen into the sustainable energy mix, influenced by institutional factors, calls for a strategic approach that goes beyond just technological advancements (Tiwary, 2023). It entails dealing with frameworks promoting sustainable practices and actively engaging in discussions about sustainable energy solutions (Tiwary, 2023). As specified at the beginning of the chapter, to define the size of the global green hydrogen market, it will be necessary to start with the general drivers and barriers analysed from the interviews.

### **2.2.1 Internal drivers**

Companies are increasingly adopting green hydrogen due to various internal drivers that extend beyond mere compliance or market trends, such as ethical behaviour, environmental commitment, visionary leadership, economic sensibility, and strategic resource utilisation (Kane & Gil, 2022). The decline in the price of renewable electricity, coupled with advancements in hydrogen production technologies, has rendered green hydrogen an economically viable and appealing choice for forward-thinking corporations (Kane & Gil, 2022). This shift towards green hydrogen not only boosts profitability and increases cost efficiencies, but it also aligns companies with the global movement towards cleaner energy sources, thereby amplifying their environmental credentials and stimulating demand for green hydrogen (Kane & Gil, 2022). In the following section, key internal drivers of adopting green hydrogen technology are discussed, including ethical considerations,

environmental awareness, visionary leadership, financial responsibility, and strategic resource planning.

**Ethical behaviour and environmental commitment:** Companies are showing their dedication to practices and environmental responsibility by incorporating hydrogen into their energy plans (Hydrogen Fuel News, 2023). This demonstrates an effort toward sustainability and addressing climate issues (Hydrogen Fuel News, 2023). For instance, a major global retailer has switched its fleet to hydrogen-powered trucks to align with its goal of achieving carbon neutrality (Hydrogen Fuel News, 2023). This decision is publicised in sustainability reports, enhancing the company's brand as an environmental leader (Hydrogen Fuel News, 2023).

**Visionary leadership and strategic resource utilisation:** Forward-thinking leaders are instrumental in integrating hydrogen into the principles of their organisation (Plug Power, 2024). They understand its significance in the growing green economy and maintaining a competitive advantage (Plug Power, 2024). An example is the case of an energy conglomerate CEO who steers the company toward hydrogen by investing significantly in research on advanced electrolysis technologies (Derkach et al., 2023). This approach not only positions the company as an industry innovator but also as a key influencer in shaping the future energy sector (Derkach et al., 2023).

**Economic viability due to declining renewable electricity prices:** The decreasing costs of energy sources have made green hydrogen more affordable, and this has led companies to consider adopting it for their eco-operations (Jovan & Dolanč, 2020). It not only reduces costs and improves profitability, but it also contributes positively to the environment (Jovan & Dolanč, 2020). An example scenario is where a company leverages the decreasing costs of energy to fuel its eco-hydrogen production process (Jovan & Dolanč, 2020). This results in savings on energy expenses and underscores the tangible financial benefits of adopting sustainable business practices (Jovan & Dolanč, 2020).

**Technological advancements in hydrogen production:** Recent progress in hydrogen production technology has simplified the integration of hydrogen solutions into industry

sectors, as noted by Halder and colleagues in 2024. For instance, a new tech startup has introduced a low-energy electrolyser, encouraged wider use of green hydrogen and forming partnerships with sectors like transportation and utilities (Halder et al., 2024).

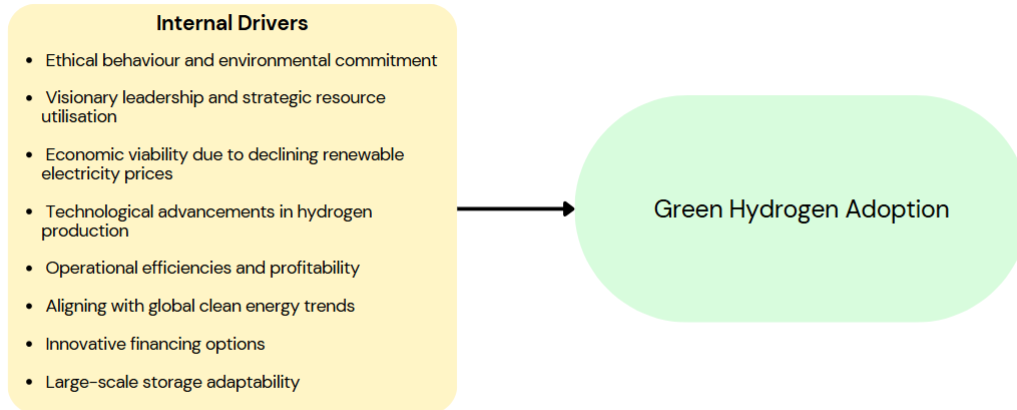
**Operational efficiencies and profitability:** The pursuit of efficiency and profitability motivates companies to embrace green hydrogen technologies, offering both environmental benefits and economic advantages (S&P Global Market Intelligence, 2021). For instance, a logistics firm switches its vehicle fleet to hydrogen fuel cells, resulting in reduced expenses and improved reliability, ultimately contributing to its financial performance (S&P Global Market Intelligence, 2021).

**Aligning with global clean energy trends:** Businesses around the world are embracing the shift by implementing energy projects to stay ahead of competitors in the market race (De-León Almaraz et al., 2024). They are adjusting to changing regulations and meeting the increasing demand for products among consumers (De-León Almaraz et al., 2024). For example, a company in the consumer goods industry uses hydrogen for its manufacturing processes, demonstrating its commitment to sustainability and appealing to environmentally conscious consumers (De-León Almaraz et al., 2024).

**Innovative financing options:** The rise of green bonds is providing the necessary funding for green hydrogen initiatives, mitigating financial risks, and attracting investment opportunities (Goyal, 2024). An energy company has chosen to issue bonds to fund a large-scale green hydrogen plant, which has attracted investors interested in backing clean energy initiatives and showcasing the company's commitment to sustainable energy finance (Goyal, 2024).

**Large-scale storage adaptability:** Hydrogen flexibility for storing energy on a scale helps overcome the intermittent challenges presented by renewable energy sources, making it an essential component of an energy system (Muthukumar et al., 2023). For instance, an electric utility has integrated hydrogen into its grid to store surplus renewable energy and release it during peak demand periods, highlighting how green hydrogen enhances grid stability and storage capabilities (Muthukumar et al., 2023).

The following visual representation in Figure 5 provides a concise summary, illustrating how these factors collectively influence corporate decisions to embrace green hydrogen.



**Figure 5.** The internal drivers of adopting green hydrogen

### 2.2.2 External drivers

Amid the emphasis on preserving the environment and embracing energy solutions, green hydrogen is emerging as a key player in this notable transition (Cheekatamarla, 2024). Stakeholders are increasingly acknowledging its role in reducing carbon emissions in various sectors such as industry and transportation, making it a central component in moving towards an eco-friendly future (Cheekatamarla, 2024). Not only are advancements within companies driving the growing support for hydrogen, but a combination of external factors also influence its adoption (Bolz et al., 2024). These external factors include regulatory requirements, technological innovations, government incentives, changing market needs, and unique geographical features that collectively pave the way for integrating green hydrogen into our energy systems (Bolz et al., 2024). This paper explores the interplay of these external influences through detailed analysis and practical examples that highlight how they are driving the global transition towards green hydrogen, a transition that promises to redefine our approach to sustainable energy practices.

**Environmental regulations and climate targets:** The implementation of environmental laws and global climate objectives compels countries and businesses to transition towards eco-friendly solutions (Keating, 2023). International agreements such as the Paris Agreement have set carbon reduction goals, prompting the exploration of sustainable energy options like green hydrogen (Keating, 2023). Following the EU's ambitious Green Deal, European energy companies are accelerating their hydrogen initiatives, aligning with the region's aim for carbon neutrality by 2050 (Mead, 2024). This involves investments in green hydrogen production facilities powered by offshore wind farms, demonstrating a direct response to regulatory demands (Mead, 2024).

**Technological progress:** Technological advancements in electrolysis and renewable energy contribute to the feasibility and cost-effectiveness of green hydrogen (Cheekatamarla, 2024). Enhancements in wind power efficiency and cost reduction directly contribute to the increased viability of green hydrogen production (Cheekatamarla, 2024). A great example is how technology companies and research institutions, working together, have created an electrolyser that can double the efficiency of converting water (H<sub>2</sub>O) into hydrogen using renewable energy sources (Cheekatamarla, 2024). This major advancement has notably reduced the cost of hydrogen production, making it an alternative and competitive option compared to fossil fuels (Cheekatamarla, 2024).

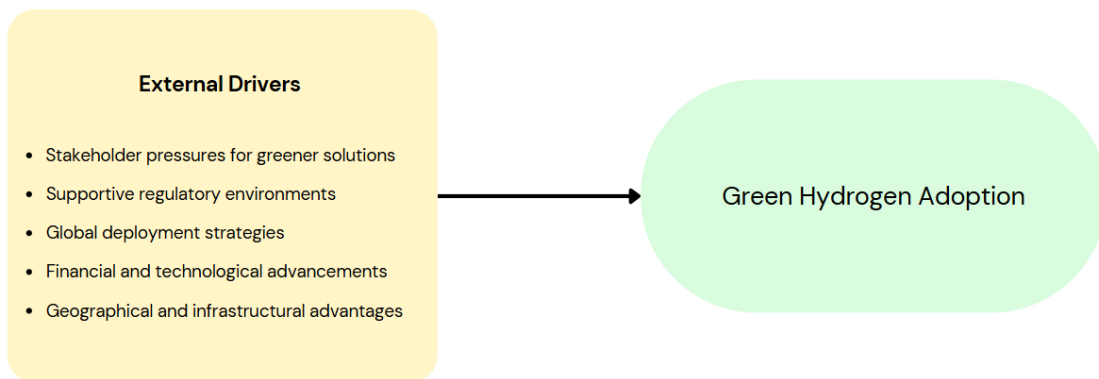
**Government incentives:** Governments worldwide are rolling out measures such as subsidies, tax benefits, and supportive policies to boost the green hydrogen sector (Saathoff, 2023). These initiatives aim to reduce market entry barriers for new projects and accelerate the adoption of hydrogen technologies (Saathoff, 2023). For instance, the Japanese government initiated a subsidy program for companies investing in hydrogen fuel cell technology, offering substantial incentives for setting up hydrogen refuelling stations (Dokso, 2023). A growth in the number of hydrogen-powered vehicles on Japanese roads was a direct consequence of enhanced infrastructure and greater accessibility for consumers (Dokso, 2023).

**Market demand and customer preferences:** Growing consumer awareness and demand for energy solutions are prompting businesses to invest in eco-friendly technologies,

with a notable emphasis on green hydrogen as a cleaner alternative (Saathoff, 2023). For instance, a leading automotive manufacturer introduces a range of hydrogen fuel cell vehicles in response to rising consumer interest in sustainable transportation options (Carpenter, 2024). This strategic move not only aligns with customer preferences but also establishes the company as an innovator in green technology (Carpenter, 2024).

**Geographical factors and infrastructure:** Certain areas have geographic and infrastructural benefits that support the creation, storage, and transportation of hydrogen, making it a strategic option for advancing a hydrogen-based economy (KPMG, 2021). For instance, the Netherlands utilises its network of natural gas pipelines by repurposing them for transporting hydrogen (KPMG, 2021). This strategic move, coupled with the country's strategic positioning and port capabilities, vaults it into a pivotal role within Europe's hydrogen economy, enabling efficient hydrogen import, export, and distribution (KPMG, 2021).

Figure 6 below provides a structured overview, outlining the main external factors that significantly influence the acceptance of green hydrogen.



**Figure 6.** The external drivers of adopting green hydrogen

### 2.2.3 Barriers to adopting green hydrogen by companies

As the world shifts towards sustainable energy solutions, green hydrogen is viewed as a promising option for reducing carbon emissions (Hassan et al., 2024). Despite its potential, there are challenges impeding the adoption of green hydrogen in various aspects, such as technology, infrastructure, society, and economy (Jayachandran et al., 2024).

**High technology costs:** One major challenge is the price tag associated with the technology needed for green hydrogen production (Jayachandran et al., 2024). Currently, producing hydrogen comes at a much higher cost than extracting traditional fossil fuels, posing a significant financial barrier to its extensive use (Jayachandran et al., 2024). For instance, the substantial upfront investment required for electrolysis equipment discourages a utility company from considering setting up a hydrogen production plant, making the project less competitive when compared to conventional energy sources (Scita et al., 2020).

**Lack of a global supply chain:** The absence of a global supply chain for green hydrogen components and fuel cells is affecting the production, distribution, and utilisation of green hydrogen on a global scale (Azadnia et al., 2023). For example, a company focusing on developing hydrogen fuel cell vehicles may face challenges if essential components are in supply (Azadnia et al., 2023). This can result in delays in launching products and impeding the growth of the market (Azadnia et al., 2023).

**Public awareness and acceptance:** The public's awareness and trust in green hydrogen technology are lacking, influencing its wider acceptance and adoption (Häußermann et al., 2023). For instance, when the government proposes implementing hydrogen-fuelled buses for transportation, the local community reacts with doubt and opposition (Häußermann et al., 2023). The community's hesitance is influenced by misunderstandings regarding the safety and eco-friendly advantages of hydrogen (Häußermann et al., 2023).

**Storage challenges:** Storing hydrogen efficiently presents challenges, particularly in the transportation and energy industries (William, 2022). For instance, an energy company's pilot project on hydrogen storage faces hurdles in achieving the required energy density

and stability (William, 2022). This complicates efforts to incorporate hydrogen into the energy grid (William, 2022).

**Slow uptake of low-carbon technologies:** The transition towards low-carbon and renewable technologies encounters obstacles due to existing infrastructure and investment inertia (Stent, 2021). This hinders the acceptance of green hydrogen. For example, a nation's established natural gas infrastructure discourages energy providers from investing in green hydrogen solutions because of lower initial costs (Stent, 2021).

**High electrolyser capital costs:** The substantial upfront costs linked with electrolysers present a challenge for investing in hydrogen production (Zun & McLellan, 2023). For example, a new energy tech startup faces difficulties in obtaining funding for projects because investors are concerned about the costs and uncertainties regarding profitability as mentioned by Zun & McLellan (2023).

**Limited production capacity:** The current production capacity for hydrogen falls short of meeting increasing demand, particularly from sectors seeking swift decarbonisation (Weeks, 2024). For example, industries eager for decarbonisation are facing challenges due to insufficient green hydrogen supply (Weeks, 2024). An international shipping company aiming to transition its vehicle fleet to hydrogen power is encountering difficulties due to insufficient local production of green hydrogen, which is hindering its ambitious conversion schedule (Weeks, 2024).

**Regulatory uncertainties:** The emerging green hydrogen market is facing regulatory and political uncertainties, making it complicated for investors and businesses (Stent, 2021). For instance, a global energy company aiming to build a green hydrogen pipeline is struggling with diverse regulatory requirements and approval processes across different regions, leading to delays and increased expenses (Stent, 2021).

The following figure 7 shows the classification of the main barriers to adoption.

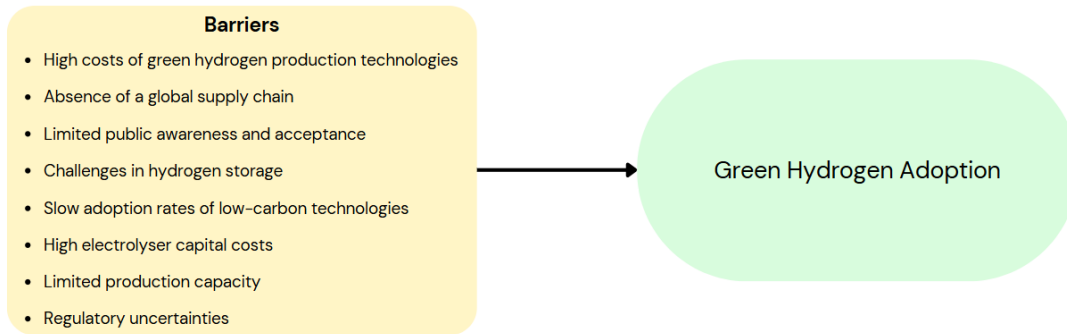


Figure 7. The barriers of adopting green hydrogen

#### 2.2.4 Model of the study

The main purpose of this thesis is to investigate the drivers and barriers that companies face when adopting green hydrogen. To achieve this research purpose, an extensive literature review was conducted, identifying several drivers and barriers to adopting green hydrogen.

Figure 8 below summarises these identified drivers and barriers.

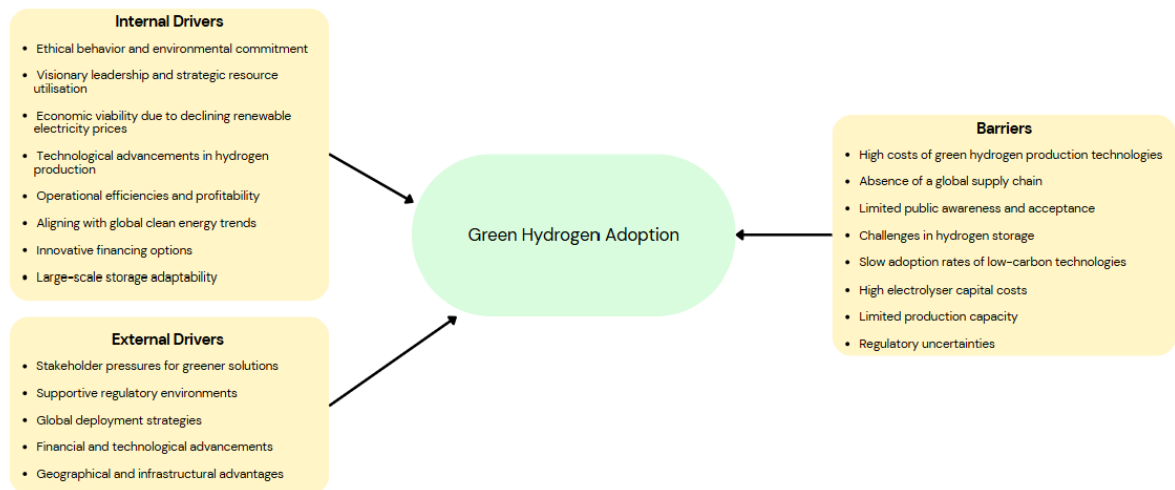


Figure 8. The framework of the study

The framework classifies drivers into internal and external categories. Internal drivers include ethical behaviour and environmental commitment, visionary leadership and

strategic resource utilisation, economic viability due to declining renewable electricity prices, technological advancements in hydrogen production, operational efficiencies and profitability, alignment with global clean energy trends, innovative financing options, and large-scale storage adaptability. External drivers include stakeholder pressures for greener solutions, supportive regulatory environments, global deployment strategies, financial and technological advancements, and geographical and infrastructural advantages. Further, barriers to adopting green hydrogen include the high costs of green hydrogen production technologies, the absence of a global supply chain, limited public awareness and acceptance, challenges in hydrogen storage, slow adoption rates of low-carbon technologies, high electrolyser capital costs, limited production capacity, and regulatory uncertainties.

### **3 Research methodology**

This chapter outlines the framework utilised in this thesis, focusing on the research approach, materials, methods, design strategy, and analysis techniques. It elaborates on the sampling approach, sample size, data collection process, and structured interviews conducted. Understanding this methodology is critical for comprehending the study's execution and validating the credibility of its conclusions about Finnish and Italian companies' adoption of green hydrogen. The primary aim of this research is to identify the drivers and barriers to the adoption of green hydrogen.

#### **3.1 Research approach and method**

This research study follows a “deductive” approach by using established theoretical frameworks to guide the investigation process. This method allows the development of hypotheses based on theories, which are subsequently tested against empirical data collected from case studies. The decision to adopt a deductive approach is motivated by the intention to apply established concepts to the specific context of green hydrogen adoption and create hypotheses that can be tested. Previous research, such as Patagonia & Poudineh (2022) and Boigontier et al. (2023), has shown that using deductive in similar situations can lead to new insights and proofs of theoretical claims. In the context of green hydrogen adoption, the deductive approach enables a systematic examination of how existing theories, such as institutional theory and the theory of planned behaviour, can explain the motivations and barriers faced by companies.

The chosen research method is qualitative, specifically a multiple-case study (Saunders, 2007). A qualitative approach is particularly valuable in this study, as the amount of existing research on green hydrogen adoption at organisational levels is still low, especially within the context of Finnish and Italian companies. Qualitative research can provide deeper insights into the phenomenon of the investigation, allowing for a more detailed understanding of the identified drivers and barriers (Saunders, 2007). Besides, this also helps in gaining appropriate insights into the factors of green hydrogen adoption in two

contextually different countries. The fact that both studies, Latapí et al. (2023) and Liponi et al. (2022), employed a qualitative approach to study the same subject matter supports this. The use of a multiple-case study design facilitates the comparison and contrast between a variety of companies and contexts (Saunders, 2007). Thus, it enhances the validity and generalisability of the findings, providing a broader understanding of the phenomenon (Saunders, 2007). Past studies that used qualitative case studies to research emerging technologies and energy transitions, such as the ones mentioned before, suggest that this is an appropriate methodology for the current study (Latapí et al., 2023; Liponi et al., 2022). This method enables the problem to be considered in real context and thus gives an insight into the complications and subtleties surrounding green hydrogen uptake. Cases of individual countries, including Finnish and Italian company examples, are looked at to be able to make an evaluation that validates and gives applicability to the results.

Additionally, the qualitative nature of this study allowed an exploration of different perspectives and experiences by professionals in the field, which was hence adequate for the capture of multifaceted aspects of factors influencing hydrogen adoption. The use of a multiple-case study method fits well with the analysis of this topic in very different contexts, as well as the revelation of trends and differences among the cases. The combination of the deductive approach and the qualitative multiple-case study method is going to build a robust framework for studying the motivations and obstacles faced by Finnish and Italian companies in adopting green hydrogen. This approach would enable the dissection of the intricate factors influencing the integration of green hydrogen in particular industries, thereby providing insights into the potential influence of operational practices, strategic decisions, and external factors on its adoption.

### **3.1.1 Materials**

Interviews with four experts from three companies—two from Danfoss, one from Sorgenia, and one from Vaisala Oyj—collected the primary data for this study. Although

convenient sampling might limit the generalisability of findings, it is often used in exploratory qualitative research, particularly with emerging fields like green hydrogen adoption, where participants are difficult to access (Etikan et al., 2016). The selected companies represented different sectors and geographical locations. Their contributions were rich in experiences and perceptions about heterogeneous drivers and barriers affecting green hydrogen adoption. Table 3 lists the companies chosen for the study and provides a brief description of each one.

**Table 3.** Companies represented by interviewed experts (Refinitiv, 2024).

COMPANY	Headquarters (HQ)	Revenue (2023)	Sector	Products
Danfoss	Nordborg, Denmark	\$10.7 billion	Industrial manufacturing sector	Hydraulic pumps and motors, AC drives, power semiconductor modules, heat recovery units, compressors.
Sorgenia	Milan, Italy	\$3.1 billion	Energy sector	Electricity generation (thermos-electric and renewable), natural gas distribution, and energy management solutions.
Vaisala Oyj	Vantaa, Finland	\$552 million	The environmental and industrial measurement sector	Weather and environmental instruments, industrial measurement solutions, road weather solutions, and life science measurement instruments.

### 3.2 Data collection process

The study utilised a purposive sampling method to select participants directly involved in implementing and managing green hydrogen operations within their companies, en-

asuring a diverse range of perspectives. This approach allowed for a deeper understanding of the similarities and differences in factors influencing green hydrogen adoption.

The interviewees included:

- **Helge Vandel Jensen**, Sales & Business Development Director at Danfoss, brings over 30 years of experience to the company, with the last three years dedicated to green hydrogen and Power2X.
- **Samuel Adams**, also from Danfoss, is actively involved in green hydrogen initiatives within the company.
- **Matteo Celani**, Energy Management Developer at Sorgenia, with six years of experience at the company.
- **Armando Uriel**, Sales Manager for EMEA Energy at Vaisala Oyj, is responsible for overseeing sustainability integration within the company.

Data were collected using structured interviews in the English language and audio recording. The interview questionnaire has been prepared with great care after reviewing prior literature that focused on the adoption of green hydrogen and insights from key studies pertaining to the topic, such as Patagonia & Poudineh (2022), and Latapí et al. (2023), and it was further refined through review by the thesis supervisor. These were designed to gather comprehensive information in relation to the drivers and barriers to green hydrogen adoption, focusing on both internal and external aspects that have an influence on the process. In this regard, the importance of the qualitative approach to the interviews is highlighted because it provides a unique window for participants to present their views and experiences. Views and experiences that otherwise quantitative surveys often fail to capture. According to Sandberg and Alvesson (2011), this offers a distinct opportunity for participants to convey perspectives and experiences that quantitative surveys often overlook.

### 3.3 Interview guide

To facilitate the interviews, a cover letter was sent to each participant, explaining the purpose of the study and ensuring the confidentiality of their responses. The letter outlined the significance of their cooperation and provided details about the interview process, including the duration and format. The interview guide was divided into several sections to systematically collect information from the participants.

#### 3.3.1 Interview sections

The interview guide was divided into four sections to systematically collect information from the participants. This structured approach ensures that each interview provides deep and actionable insights, contributing significantly to the empirical foundation of the study on green hydrogen initiatives. This meticulous design aids in capturing a holistic view of the current landscape and future potential of green hydrogen within the energy sector.

**Section A** contains personal and company information, including name, job title, role in green hydrogen initiatives, and duration of the current position. It also includes a thorough examination of company-related information, covering the company name, the extent of sustainability integration within core business strategies, pivotal challenges and drivers for adopting green hydrogen, technological advancements enhancing production, the impact of EU regulations and national policies, prospects in the EU market, advice for other entities, and personal insights garnered from managing green hydrogen projects.

**Section B** addresses company-specific questions, delving into the operational specifics and strategic approaches of individual companies. Danfoss focuses on the technological features of its electrolyser power supplies, market outreach, and innovation in electrolyser technology. Vaisala Oyj is examined for its response to market trends, technical features of its solutions, and competitive innovations. Sorgenia's partnership dynamics,

investment benefits, and strategic alignments are also explored to understand the different facets impacting the deployment of green hydrogen solutions.

**Section C** explores barriers and benefits, identifying both internal and external drivers influencing green hydrogen adoption, including environmental commitment, leadership prioritisation, cost factors of renewable energy, and technological advancements. The barriers section addresses challenges such as high setup costs, component availability, public perception, storage efficiency, infrastructure deficiencies, investor concerns, and regulatory heterogeneity.

**Section D** examines future trends and insights, assesses factors determining the success of green hydrogen as a sustainable energy solution, and gathers subjective evaluations on a scale of 1–5 to measure satisfaction with production and sales outcomes.

### **3.4 Validity and reliability in qualitative research**

Establishing validity and reliability in qualitative research is crucial for ensuring the integrity and trustworthiness of the findings (Lawrence, 2015). According to Lincoln and Guba (1985), trustworthiness includes credibility, authenticity, transferability, dependability, and confirmability. They emphasise the importance of extended engagement in the field, triangulation of data sources, and thick descriptions to achieve credibility and ensure the transferability of findings (Lincoln & Guba, 1985). This approach ensures that the results are well-grounded and accurately reflect the studied phenomena (Lincoln & Guba, 1985). Creswell and Poth (2013) further elaborate that validation in qualitative research involves assessing the “accuracy” of the results as perceived by the researcher, participants, and readers. This validation process is characterised by extensive fieldwork, detailed descriptions, and close researcher-participant relationships, which together improve the study's credibility and authenticity (Creswell & Poth, 2013).

According to Lawrence (2015), further details are offered on the notions of validity, reliability, and generalisability in qualitative research. The concept of validity pertains to the

appropriateness of the tools utilised and data gathered during the research endeavour (Lawrence, 2015). This includes aligning the research question with the desired outcomes, selecting appropriate methodologies, and ensuring that the design, sampling, and data analysis fit the context (Lawrence, 2015). The current study strengthened its validity by implementing several measures. The interview questions have been developed with utmost care in the sense of a thorough literature review of prior works related to green hydrogen adoption and by imbibing ideas from popular studies as well. The thesis supervisor reviewed and refined it to ensure its relevance to the objectives and ability to elicit valid responses from the interviewees. The choice of respondents also increased the validity of the study. The study purposefully selected experts who were directly involved in green hydrogen initiatives from their companies to ensure that the data collected would be practical and come from a well-informed expert.

Reliability, on the other hand, focuses on the consistency of the process and results (Lawrence, 2015). In qualitative research, exact applicability is less emphasised, and a certain margin of variability is accepted as long as the methodology consistently produces ontologically similar data, even if they differ in richness and nuance (Lawrence, 2015). To increase reliability, this thesis used several strategies. The inclusion of companies from both Finland and Italy allowed for comparison and contrast of the identified themes and patterns across different contexts, which assured the reliability of the findings. Moreover, respondents were assured that their responses would be held in confidence, an assurance that would also motivate them to freely give their candid views on the enablers and barriers they face when adopting green hydrogen. This is a way to minimise social desirability bias and enhance the trustworthiness of qualitative data (Lawrence, 2015). Techniques to enhance reliability include refutational analysis, constant data comparison, comprehensive data use, inclusion of deviant cases, and the use of tables for clarity (Lawrence, 2015).

## 4 Empirical findings

In this chapter, the material outlined in Chapter 3 will be analysed using the methods described therein. Key findings from the analysis will be outlined, followed by a detailed discussion, analysis, and summary of the results. The findings from this research aim to enhance the understanding of the drivers and barriers to green hydrogen adoption by Finnish and Italian companies. These insights are expected to be valuable for future research and policy development in this field.

### 4.1 Interview Findings

Section 4.1 examines the primary data obtained from the interviews with experts, covering insights from Danfoss, Sorgenia, and Vaisala Oyj. The findings from this thorough analysis will be presented in Section 4.2 as the study's results.

#### 4.1.1 Interview with Danfoss experts

The first interview was conducted with Helge Vandel Jensen (Interviewee 1, Danfoss), who has been with Danfoss for over 30 years, primarily in sales and business development, and Samuel Adams (Interviewee 2, Danfoss), who is also involved in green hydrogen initiatives at Danfoss. Jensen has focused on green hydrogen and Power2X for the past three years. The experts emphasised that sustainability has been integral to Danfoss's operations for many years, with a focus on energy efficiency and savings through products like motor drives, heat exchangers, and power converters.

Key points from the interview include:

- Danfoss's role in electrolysis is limited to manufacturing power supplies for electrolyzers.
- The most significant challenge is the higher cost of green hydrogen compared to fossil fuels.

- EU regulations and national policies are crucial to supporting green hydrogen projects.
- Danfoss aims to position itself as a supplier of key components, such as heat exchangers and power converters.
- The success of hydrogen in the future depends on cutting down expenses and improving the effectiveness of fossil fuels.

#### **4.1.2 Interview with Sorgenia expert**

Matteo Celani (Interviewee 3, Sorgenia) has been with Sorgenia for six years and currently serves as an energy management developer. In his role, Interviewee 3, Sorgenia provided valuable insights into Sorgenia's position and strategy regarding green hydrogen. Sorgenia is primarily an observer in the hydrogen market, carefully evaluating the economic returns of hydrogen initiatives. This approach allows the company to understand the potential benefits and challenges without making immediate, large-scale investments.

Key points from the interview include:

- The high production cost of green hydrogen is a significant challenge.
- Italy's fragmented renewable energy system presents unique obstacles that complicate the integration and scalability of green hydrogen projects.
- Biohydrogen could offer a more tangible solution for Sorgenia.
- To effectively support larger-scale green hydrogen projects, Italy's regulatory framework and national policies require substantial improvement.

### 4.1.3 Interview with Vaisala Oyj expert

At Vaisala Oyj, Armando Uriel (Interviewee 4, Vaisala) is the sales manager for EMEA Energy. In his position, he oversees the integration of sustainability within the company. Vaisala develops and produces technology for green hydrogen applications, focussing on measuring and monitoring green power processes.

Key points from the interview include:

- Significant challenges include investment, understanding, and access to technology.
- EU regulations and national policies play a crucial role in supporting the development of green hydrogen.
- Green hydrogen is essential for decarbonisation.
- The future success of green hydrogen initiatives depends on investment, support, and a favourable legal framework.

## 4.2 Study's result

The data collected from the interviews was reviewed using content analysis techniques (Mayring, 2000). This method allowed for the discovery of themes and trends surrounding the factors influencing the adoption of green hydrogen. The findings were grouped into themes that provide a thorough understanding of the obstacles and possibilities linked to implementing green hydrogen technology:

### Theme 1: **Economic obstacles to green hydrogen production**

The main focus of this theme is on the challenges involved in efficiently generating and using hydrogen. While creating hydrogen is costly compared to conventional grey hydrogen production, the significant barrier lies in the expenses associated with technological advancements, infrastructure establishment, and the absence of adequate financial incentives to counterbalance these costs.

**Supporting quotes:**

1. *"The current production costs of green hydrogen are a significant challenge. Green hydrogen production is more expensive compared to grey hydrogen, with costs ranging from 8 to 20 euros per kilo depending on various factors."* (Interviewee 3, Sorgenia)
2. *"It is still not competitive to fly on sustainable aviation fuel, but with various political initiatives, carbon taxes, etc. Then in the future, it will also be possible to fly on that, as an example."* (Interviewee 1, Danfoss)
3. *"Investment, understanding, and access to technology are significant challenges for adopting green hydrogen at EMEA."* (Interviewee 4, Vaisala)

**Theme 2: Regulatory and policy influence**

This topic delves into the effects of domestic rules and strategies, on the growth and planning of green hydrogen initiatives. Regulatory frameworks can either provide incentives or create barriers, significantly influencing market demand and project feasibility.

**Supporting quotes:**

1. *"Regulations and market demand have a significant impact. For operators like Sorgenia, demand is the key driver. Participating in auctions requires signed contracts with hydrogen consumers."* (Interviewee 3, Sorgenia)
2. *"If there were no funding, then many of these projects would not go ahead because it is still more expensive to make green hydrogen than it is to burn oil, coal and gas."* (Interviewee 1, Danfoss)
3. *"EU regulations and national policies play a crucial role in supporting the development of green hydrogen."* (Interviewee 4, Vaisala)

### Theme 3: **Technological and infrastructure barriers**

This topic brings attention to the obstacles related to incorporating hydrogen technology and infrastructure development. Issues such as the lack of efficient storage solutions, the need for technological advancements, and the infrastructural modifications required for large-scale hydrogen adoption are discussed.

#### **Supporting quotes:**

1. *"Transport and storage of hydrogen are also challenges, particularly in Italy due to the lack of salt caverns for storage."* (Interviewee 3, Sorgenia)
2. *"The beauty of hydrogen is that if we have a surplus of electricity, we can convert the electricity to hydrogen; we can even store it in underground cabins for days, weeks and months."* (Interviewee 1, Danfoss)
3. *"Our technology focuses on measuring and monitoring green power processes to support green hydrogen initiatives."* (Interviewee 4, Vaisala)

### Theme 4: **Market demand and strategic positioning**

This theme examines the current market demand for green hydrogen and how companies are strategically placing themselves in this growing market sector by discussing market preparedness and forming key partnerships that align with their company strategies.

#### **Supporting quotes:**

- *"Demand is the key driver. Participating in auctions requires signed contracts with hydrogen consumers."* (Interviewee 3, Sorgenia)
- *"We are trying to basically work with all the most important stakeholders to win the orders."* (Interviewee 1, Danfoss)

- *"Green hydrogen is essential for decarbonisation, and the future success of green hydrogen initiatives depends on investment, support, and a favourable legal framework."* (Interviewee 4, Vaisala)

#### Theme 5: **Global and regional comparisons**

This topic focuses on the differences in green hydrogen adoption and development across various regions, specifically comparing Northern Europe with Southern Europe and comparing Europe with other global regions. It examines how local policies, market conditions, and infrastructural capabilities impact green hydrogen projects.

#### **Supporting quotes:**

1. *"Northern countries have large consumption hubs and clear policies, while Italy has a fragmented system."* (Interviewee 3, Sorgenia)
2. *"A good example on the Atlantic side of Canada, they're planning to put up a lot of wind turbines... and their ports are relatively close to Europe, so they're actually planning on producing hydrogen, converting it to ammonia, which they can export to Germany."* (Interviewee 1, Danfoss)
3. *"Green policies have helped Green Hydrogen to develop in the EU."* (Interviewee 4, Vaisala)

### **4.3 Comparative analysis: Italy vs. Finland**

#### **Economic challenges**

In Italy, the high cost of green hydrogen production is a significant obstacle to sustainable development. As discussed by interviewee 3, Sorgenia emphasised that the expenses are approximately 8–20 euros per kilogram, a cost that makes it difficult for green hydrogen to compete with grey hydrogen in the market. This financial impediment is also

exacerbated by Italy's fragmented renewable energy system, which complicates integration and scale-up. These findings are consistent with prior research highlighting the economic challenges associated with green hydrogen production in Italy, particularly the high costs compared to fossil-fuel-based hydrogen (Liponi et al., 2022). The fragmented nature of the renewable energy system further adds to the complexity and cost of green hydrogen production in the country (Liponi et al., 2022). Meanwhile, Finland, with its coherent renewable energy policies, faces fewer economic barriers. However, Finnish companies still face high initial project costs, as well as the need for technological development to reduce production costs. This observation aligns with the broader European context, where the high initial investment required for green hydrogen projects remains a challenge even in countries with supportive policy environments (Boigontier et al., 2023).

### **Regulatory and policy influences**

*"The European Union also plays a vital role, but some aspects are better regulated at the national level."*(Interviewee 3, Sorgenia)

Interviewee 3, Sorgenia, criticised the lack of a consistent policy and regulatory process in Italy. He argued that entrepreneurs need incentives but, most importantly, a secure way to operate. These so-called Green Hydrogen Development Zones may be built without government help. Instead, they could be sustainable businesses supported by community power and EU funds. Moreover, Finland has a better regulatory environment, with clearer policies and better incentives for hydrogen-based technology. The statement released by the Greening of Road Transport (GORT) distinguishes the respective roles in the definition of Estonian road trafficking, claiming that road traffic, in which pollution is a parallel issue, is a major source. Finland is the largest producer of hydrogen, and the majority of Finnish cars use hydrogen-based technologies. The perceived lack of clear and consistent policies in Italy resonates with previous studies that have identified regulatory uncertainty as a barrier to green hydrogen adoption (Stent, 2021). In contrast, Finland's more favourable regulatory environment, with clearer policies and

incentives, relates to findings that emphasise the fact that supportive policy frameworks are important for green hydrogen development (IRENA, 2020).

### **Technological and infrastructure barriers**

Italy is still grappling with the main issue of power storage and the recognition that parties promoting green vehicles and hydrogen need to deploy the necessary infrastructure for the storage and supply of hydrogen. On the one hand, Italy has not yet been able to solve the problem as it does not have storage solutions or transportation of hydrogen. Interviewee 3, Sorgenia, mentioned the difficulties in transporting and storing hydrogen. Finland's problems primarily stem from technology, with scaling up production and improving storage solutions being the key challenges. Despite its associated difficulties, Latvia uses renewable energies and green hydrogen technologies, making the country a hub for this. The challenges related to hydrogen storage and infrastructure development in Italy are consistent with broader concerns about the lack of a well-established global supply chain for green hydrogen (IEA, 2019). Finland's focus on technological advancements to improve production and storage aligns with the global trend of overcoming technical barriers to make green hydrogen more accessible and cost-effective.

### **Market demand and strategic positioning**

The evolving market demand for green hydrogen is still only at the initial stage in Italy and Finland. In Italy, the market is characterised by disjointed policies and economic hurdles that have been a barrier to mass acceptance. Interviewee 3, Sorgenia, described market demand as the driving force behind green hydrogen projects. Finland's market is more cohesive, with clear policy support and a green signal from the government. Finnish companies such as Vaisala Oyj are strategically positioning themselves in the technology sector by supporting green hydrogen projects with their measuring and monitoring systems installed in the green power process. The level of market demand in both Italy and Finland for green hydrogen is on the same path as at a global level: it is in an early stage of formation, and serious problems with mass acceptance exist (Ajanovic et al., 2024). The current focus on strategic positioning on the side of Finnish

firms, in particular the technology-orientated firms, emphasises that there will be a need to find some kind of niche area along with the exploitation of technological competence in order to be ahead of the competition in this embryonic, green hydrogen market.

### Global and regional comparisons

The worldwide and local trends of green hydrogen acceptance reflect the impact of both Italy and Finland. Green hydrogen development in Northern European countries, such as Germany and the Netherlands, is not only a promising potential but also a reality due to their large consumption centres and transparent guidelines. Italy does not display unified practices in this respect, resulting in weaker integration and scalability compared to other countries. Finland, while having a strong relationship with its Northern European counterparts, still faces challenges in scaling up production and improving technology. Danfoss conducted research that highlighted the critical role of regional cooperation and green hydrogen support project initiatives. The observation that Northern European countries are leading in green hydrogen adoption due to favourable policies and infrastructure aligns with existing literature (Koneczna & Cader, 2024). Italy's challenges of scaling up are also found in fragmented policy approaches across different sectors and the presence of economic barriers. The cooperation between regions and strong initiatives to support suggest that collaborative inputs are needed as a driving force toward the transition of green hydrogen.

**Table 4.** Factors (drivers/barriers) explaining the adoption of green hydrogen.

		Finland		Italy
<b>Drivers / barriers</b>	<b>Sub-dimensions</b>	<b>Danfoss-Case A</b>	<b>Vaisala-Case B</b>	<b>Sorgenia-Case C</b>
Economic challenges	Cost	Low to medium	Low to medium	High
	Financing	Low to medium	Low to medium	High

Regulatory and policy influences	Regulatory Framework	Critical, depending on national regulations and EU incentives	Critical, depending on national regulations and EU incentives	Critical, depending on national regulations and EU incentives
Technological and infrastructure barriers	Technological Complexity	Present, but not detailed	Present, but not detailed	Significant issues with storage and transportation
	Infrastructure Development	In progress, generally adequate	In progress, generally adequate	Lagging, major barriers exist
Market demand and strategic positioning	Market Maturity	Emerging	Emerging	Fragmented policies, significant economic hurdles
	Strategic Alignment	Aligned with EU trends	Aligned with EU trends	Struggles with integration and scalability
Global and regional comparisons	Integration in Global Market	Supported by transparent policies and adequate infrastructure	Supported by transparent policies and adequate infrastructure	Weak integration and scalability compared to other European countries

## 5 Conclusions

The objective of this study was to answer the main research question: **What are the drivers and barriers to adopting Green Hydrogen by EU companies?**

Furthermore, the purpose was to concentrate on the subsequent sub-objectives:

- 1) **To increase understanding of the global challenges, conceptualisation, and importance of adopting Green Hydrogen**
- 2) **To explore the drivers of adopting Green Hydrogen by companies.**
- 3) **To explore the barriers to adopting Green Hydrogen by companies.**
- 4) **To empirically explore the drivers and the barriers to adopting Green Hydrogen by Finnish and Italian companies.**

The analysis led to the conclusion that the use of hydrogen, especially in its “green” form, could represent a revolution despite the high costs, particularly in hard-to-abate sectors, which are difficult to decarbonise and significantly contribute to global greenhouse gas emissions. A tangible example of this approach is the construction of Sweden's first green steel plant in Europe, located 900 km north of Stockholm, which will exclusively use green hydrogen. Generating and storing green hydrogen means conserving renewable electricity, which today has the major flaw of not being storable. This is a huge problem afflicting our society, and its resolution could, in turn, increase the production and use of renewable energy, contributing exponentially to the reduction of CO<sub>2</sub> emissions in the air. Outside of hard-to-abate sectors, without a clear roadmap at the project and legislative levels, the use of hydrogen is difficult to justify economically and environmentally. In the context of road transport, the use of hydrogen presents itself as an unfeasible option compared to the alternatives already available on the market. Electric car batteries utilise the existing energy supply infrastructure, which facilitates their distribution through the grid and distributors. On the other hand, hydrogen requires a long and very energy-intensive production and distribution chain to reach the refuelling pump. In conclusion, considering the entire process, a hydrogen car consumes three times the renewable energy compared to a battery vehicle, also resulting in higher costs. The same goes for hydrogen-powered buses. Numerous projects are underway, but not all have been successful. In recent years, the city of Montpellier, France, has cancelled the order of 51

hydrogen buses announced in 2019. Additionally, a year ago, the German town of Wiesbaden announced that it would stop using fuel-cell buses after just one year of activity due to inefficiencies. The phenomenon of “greenwashing” seems to affect the sector, as hydrogen, at least for now, does not significantly reduce emissions or costs for consumers.

One of the frequent questions I posed to interviewees was related to the issue of the feasibility of scaling up the green hydrogen economy without falling into speculative bubbles by investors and greenwashing by companies. The response was similar from all experts: the growth of this market is inevitable due to the significant increase in social interest. Even though it will take years, if not decades, before we can speak of a truly sustainable solution that works in the market, we need to wait, and we need to consider geopolitical aspects too, as green hydrogen production requires the use of renewable energy sources, often concentrated in countries with abundant resources, such as solar energy in Africa. Using African water reserves in hydrogen production through electrolysis for the West is not ethically sustainable, much like all those projects started in developing countries that do not consider engaging with local communities during the definition phase. In conclusion, although hydrogen could represent a solution to address greenhouse gas emission challenges in the future, considerable economic and ethical commitment from all stakeholders, from companies to policymakers, is necessary. In this research study exploring the usage of hydrogen technology, adoption trends are influenced by the decreasing costs of energy sources and advancements in hydrogen production techniques, alongside regulatory environments that drive its growth momentum forward. However, some obstacles remain in its path, including the high upfront investment required challenges related to infrastructure development and the necessity for greater public awareness and acceptance. The interaction between these driving forces and obstacles will determine how green hydrogen adoption unfolds over the years. However, hydrogen does not appear to be the current substance.

## **5.1 Summary of the key empirical findings**

This section summarises the key empirical findings derived from the analysis of the data collected throughout the study. The main findings from experts' interviews and literature analysis focus on the features of successful and unsuccessful green hydrogen applications in Finland and Italy, respectively. The key messages obtained from expert interviews and the qualitative content analysis are clustered under specified topics, each focusing on different aspects of the drivers and barriers to green hydrogen.

### **5.1.1 Economic barriers and challenges**

One of the most significant findings is the major economic barriers that arise from the production of green hydrogen. A huge challenge is the expensive production costs, especially compared to the low cost of traditional grey hydrogen. These costs result from the obligatory constant learning of new technologies, restructuring of old infrastructure, and the current situation where there are not enough financial incentives. The experts emphasised that the encouragement of green hydrogen can be contingent on economic expansion.

### **5.1.2 Technological advancements**

The study revealed that technologies are becoming increasingly developed, making green hydrogen more competitive. The article claims that new technologies in electrolysis, power conversion, and storage were outlined as key to saving money and being more efficient. Those interviewed pointed out that continuous research and development are essential to drive these technological advancements.

### **5.1.3 Regulatory and policy support**

Green hydrogen projects require regulatory frameworks and policies, which were found to be central to the success of such projects. Differentiating the regulatory environment between Italy and Finland was the basis of the research, and this aspect was regarded as playing a determinant role in green hydrogen's pace and success in these countries. Experts agreed that one of the key strategies for green hydrogen growth is the implementation of efficient regulations at both the European Union and member state levels. At the EU level, it is suggested that the policies should not be fragmented, and at the national level, policies should be harmonised with those of the European Union.

### **5.1.4 Market conditions and infrastructure**

Market conditions and the existing infrastructure were also reported as highly significant. The study demonstrates that geographical areas with sufficient infrastructure for renewable energy sources are more likely to adopt advanced technologies such as green hydrogen. Additionally, local market characteristics, such as the demand for pollution-free energy sources and the availability of investment, were also important in the outcomes of individual projects.

### **5.1.5 Environmental and sustainability considerations**

When it comes to renewable energy, people usually take for granted the current debate on environmental and economic issues. The present investigation also brought to the forefront the environmental benefits of green hydrogen. The decrease in carbon emissions and the potential for achieving sustainability were the primary factors that motivated companies to adopt green hydrogen. It was noted that the commitment to sustainability was a major motivation for companies when they involved green hydrogen in their operations.

## 5.2 Limitations

As mentioned in Section 1.3 of the study, it is important to acknowledge limitations. The study primarily concentrated on businesses headquartered in Finland and Italy, which may restrict the applicability of the results because of variations in regulations and market environments. The study primarily relied on information obtained from interviews with industry experts. While this method provided insights, it also introduced some subjectivity and potential biases. The perspectives shared by the interviewees might not fully capture the industry's viewpoints and encompass all factors influencing the adoption of hydrogen. Additionally, the study's scope is restricted by the number of experts interviewed from three companies, which could result in missing out on a diverse range of industry perspectives. The study mainly concentrated on the impacts of embracing hydrogen without examining the lasting effects, like advancements in technology and changes in regulations and market trends. It is recommended that upcoming research delve into these extended factors to gain insight into the advantages linked to integrating hydrogen technologies. Though recognising the importance of frameworks and strategies in promoting the adoption of hydrogen technology, the study failed to analyse these frameworks across different regions, which could provide insights into their effectiveness and best practices for global implementation. The research primarily concentrated on Finland and Italy; hence, its conclusions may not readily apply to nations with differing market conditions. Given the evolving nature of technology and market dynamics in the hydrogen industry, it is essential to observe and evaluate them. The study's conclusions could become outdated as new technologies emerge and market conditions shift. Ongoing research is necessary to ensure that insights remain relevant and accurate in this changing field. While this study provides insights into companies' adoption of hydrogen, it is important to acknowledge these limitations. Addressing these gaps through further research can enhance the reliability and relevance of the findings. The study's scope and available resources justify these limitations, highlighting the need for continued exploration in this domain.

### 5.3 Directions for future research

Looking ahead, research on the adoption of green hydrogen by companies, mainly in Finland and Italy, could benefit from a larger-scale study that uses similar methods to this one. Broadening the study would provide more general data and avoid the limitations noted in Section 5.1 of this study. Moreover, research showing the long-term effects of green hydrogen adoption by companies could provide insights into the environmental benefits and economic advantages over a period extending far beyond the short-term results reflected in this study. This research also highlighted the role of regulatory and policy frameworks in the implementation of green hydrogen. Future research should include a comparative study of these frameworks across regions. This approach would reveal the viability of various regulatory tactics and help identify the best global practices. Furthermore, given the systematic nature of the contributions from both external and internal factors, future studies could include detailed case studies of organisations that have successfully integrated green hydrogen into their operations. These real-life examples offer insights and a deeper comprehension of the obstacles and opportunities involved in transitioning to green hydrogen technology. The importance of considering the evolving technology landscape and prevailing market circumstances cannot be overstated.

Therefore, repeated observation and analysis of the green hydrogen sector are recommended. This continued research would not only show the alterations and consequences of new technologies, thus providing insights into current market trends and changes in the policy arena, but it would also guarantee the continuity of the search for authentic and up-to-date results.

## 5.4 Final considerations

The discussion delved into the possibilities of using hydrogen as a sustainable energy option for the future. Initially, it focused on understanding the context of hydrogen technology and examining its advantages and disadvantages. Based on the findings of the research project, it appears that transitioning to renewable energy alternatives like hydrogen could bring about significant changes in the energy field and other sectors facing challenges in reducing carbon emissions. Nevertheless, experts highlighted that widespread acceptance would need time, for ramping up production before actual integration takes place. There are still some obstacles to be overcome to sustain an active and profitable hydrogen economy: it is vital to create sites capable of supporting large-scale productivity and to make the distribution network fit; the economic and legislative support of the political opinion is essential to push the various energy markets to focus on this technology; to develop new constructive methods and create models with innovative designs and specifications; in addition to reducing purchase costs, it is crucial to increase consumer sensitivity and confidence. All these complications can be easily overcome if society stops being comfortable in the illusion that today's economy does not involve countless risks and costs, which, in the long run, will undoubtedly be greater than those that implementing a hydrogen economy would require.

Supporting research is necessary for technological development to lower costs, boost efficiency, and improve reliability. The future is not certain. We can make predictions, but we cannot have absolute certainty. We must remember, as history has taught us, that if a solution is not suitable for the present, it does not necessarily mean that it is not a valid idea for the future. We cannot expect that things will change if we keep repeating the same actions. Choosing and taking different paths from our usual ones is fundamentally important. A utopian hydrogen-based economy could only become a reality when political and environmental decisions actually support research and development. Hydrogen is not expected to replace electricity as the driving force in the fuel

market. However, it may serve as a supporting player in the realm of green energy, aiding us in lowering CO<sub>2</sub> emissions and shifting towards a more socially and environmentally sustainable economic model.

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## Appendices

### Appendix 1. Interview Structure

#### Section A: Personal and Company Information

##### Personal Information

- Name
- Job title
- Role in Green Hydrogen initiatives
- Number of years in current job

##### Company Information

- Company name
- Integration of sustainability into core business strategies related to Green Hydrogen
- Significant challenges and drivers for adopting Green Hydrogen
- Technological innovations enhancing Green Hydrogen production
- Influence of EU regulations and national policies
- Future prospects of Green Hydrogen in the EU market
- Advice for other companies on Green Hydrogen operations
- Personal lessons learned from managing Green Hydrogen projects

#### Section B: Company-Specific Questions

##### 1. Danfoss

- Technological features of Danfoss's electrolyser power supplies
- Industries and companies seeking Danfoss's electrolyser solutions
- International supply of electrolyser power supplies
- Innovations in electrolyser technology
- Key regulatory and economic factors influencing development and sales
- Challenges in the electrolyser market

##### 2. Vaisala Oyj

- Market trends influencing Green Hydrogen demand
- Technical features of power solutions for Green Hydrogen production

- Industries seeking Green Hydrogen solutions
- International market focus
- Innovations to maintain a competitive edge
- Key regulatory and economic factors
- Challenges in the Green Hydrogen market

### **3. Sorgenia**

- Challenges in partnership with Enel Green Power
- Integration of renewable energy sources
- Benefits from investment in Green Hydrogen infrastructure
- Management of technological and operational risks
- Strategies for enhancing scalability and efficiency
- Alignment of Green Hydrogen focus with broader business objectives
- Role of innovation
- Ensuring economic viability and sustainability
- Successful collaborations and partnerships

## **Section C: Barriers and Benefits**

### **• Internal Drivers**

- Commitment to environmental sustainability
- Leadership prioritising Green Hydrogen
- Declining renewable energy costs
- Technological improvements
- Industry demand for sustainable products
- Financing availability
- Increasing storage capacity

### **• External Drivers**

- Compliance with EU regulations
- Government incentives
- Customer demand for cleaner energy
- Infrastructure availability
- Suitable partners for Green Hydrogen production

- **Barriers**
  - Higher setup costs
  - Limited component availability
  - Public awareness and trust issues
  - Storage efficiency challenges
  - Infrastructure gaps
  - Investor concerns
  - Diverse regulatory requirements

#### **Section D: Future Trends and Insights**

- Factors determining the success of Green Hydrogen as a sustainable energy solution
- Satisfaction with production/sales of Green Hydrogen on a scale of 1-5