CENTRE INTERNATIONAL DE FORMATION EUROPEENNE
INSTITUT EUROPEEN · EUROPEAN INSTITUTE

SCHOOL OF GOVERNMENT

Green hydrogen: A major player for road transport decarbonisation? The case of Italy

BY
Laura Angelini

A thesis submitted for the Joint Master degree in

EU Trade & Climate Diplomacy (EUDIPLO)

Academic year
2021 – 2022

June 2022

Supervisor: Giacomo Luchetta
Reviewer: Gaby Umbach

PLAGIARISM STATEMENT

I certify that this thesis is my own work, based on my personal study and/or research and that I have acknowledged all material and sources used in its preparation. I further certify that I have not copied or used any ideas or formulations from any book, article or thesis, in printed or electronic form, without specifically mentioning their origin, and that the complete citations are indicated in quotation marks.

I also certify that this assignment/report has not previously been submitted for assessment in any other unit, except where specific permission has been granted from all unit coordinators involved, and that I have not copied in part or whole or otherwise plagiarized the work of other students and/or persons.

In accordance with the law, failure to comply with these regulations makes me liable to prosecution by the disciplinary commission and the courts of the French Republic for university plagiarism.

Abstract

In recent years, hydrogen has risen up the international and European climate and energy agenda and it is increasingly being considered as the ‘missing link’ of clean energy transition and ‘second leg of electrification’. The European Union published its Hydrogen Strategy in July 2020, and a growing number of Member States have been working on national hydrogen strategies since then. As a versatile energy carrier, hydrogen can contribute to the decarbonisation of hard-to-abate sectors, including long-haul and heavy-duty road transport. Greenhouse gas emissions from transport increased steadily over the last decade and they account for a quarter of total greenhouse gas emissions in the EU – revealing an urgent need to shift to zero-emission mobility to achieve EU’s decarbonisation targets. This thesis investigates to what extent existing strategies at European and national level are adequate to support large-scale deployment of green hydrogen for road transport decarbonisation. Italy has been chosen as case-study. Accordingly, a critical analysis of European and Italian climate, energy and mobility strategies entailing a hydrogen dimension is carried out with the aim to assess their consistency with the overarching European Green Deal and to what extent they are expected to mainstream green hydrogen use in road transport. Key findings suggest an unprecedented business and political momentum for hydrogen. Though, hydrogen still needs to overcome significant barriers, mainly related to production costs, storage and infrastructure development, before it can become a game-changer in the road transport segment.

Table of contents

List of acronyms *5*

List of figures *6*

Introduction **7**

Research question and methodology 10

Chapter 1 – HYDROGEN: A TECHNICAL FRAMEWORK **13**

1.1. Hydrogen supply chain 13

1.1.1. Production 13

1.1.2. Transportation 15

1.1.3. Storage 16

1.2. The role of hydrogen in the energy transition. Hydrogen applications 17

Chapter 2 – DECARBONISING THE TRANSPORT SECTOR IN EUROPE: A FOCUS ON ROAD TRANSPORT **24**

2.1. Transport sector in the EU: State of the art 24

2.2. FCEV for road transport decarbonisation: opportunities and challenges 25

Chapter 3 – THE EUROPEAN POLICY FRAMEWORK **30**

3.1. Enhanced climate ambitions: The European Green Deal and the European Climate Law 30

3.2. A EU strategy for energy system integration 32

3.3. A hydrogen strategy for a climate-neutral Europe 34

3.4. The REPowerEU Plan 39

3.5. The Smart and Sustainable Mobility Strategy 43

3.6. Fit for 55 Package 44

3.6.1. Revision of the Alternative Fuels Infrastructure Directive (AFID) 45

3.6.2. Amendment of the Regulation setting CO2 emission performance standards for new passenger cars and for new light commercial vehicles 47

3.6.3. Amendment of the Renewable Energy Directive (RED II) 48

3.6.4. Revision of the EU Emission Trading System (EU ETS) 49

Chapter 4 – THE ITALIAN POLICY FRAMEWORK **51**

4.1. Transport sector in Italy: State of the art 51

4.2. The Italian National Energy and Climate Plan 52

4.3. Preliminary Guidelines on the National Hydrogen Strategy 54

4.4. The National Recovery and Resilience Plan 55
4.4.1. Hydrogen-related projects under the NRRP 59
4.5. Hydrogen Valleys in Italy 60
4.5.1. The Hydrogen Valley South-Tyrol 60
4.5.2. The Life3H Project: Three Hydrogen Valleys in Central Italy 61
4.6. Final remarks 61

Conclusion 65

Limitation and future research 66

References 67

Bibliography 67
Official Documents 78

List of acronyms

BEV	Battery Electric Vehicle
CCS	Carbon Capture and Storage
CNG	Compressed Natural Gas
EC	European Commission
EEA	European Environment Agency
EEB	European Environmental Bureau
EGD	European Green Deal
EP	European Parliament
ETS	Emission Trading System
EU	European Union
EV	Electric Vehicles
FCEV	Fuel Cell Electric Vehicles
FCH JU	Fuel Cells and Hydrogen Joint Undertaking
GHG	Greenhouse Gas
HDV	Heavy-duty Vehicle
ICE	Internal Combustion Engine
IEA	International Energy Agency
NDC	Nationally Determined Contribution
NECP	National Energy and Climate Plan
NPF	National Policy Framework
IRENA	International Renewable Energy Agency
LOHC	Liquid Organic Hydrogen Carrier
LNG	Liquefied Natural Gas
MFF	Multiannual Financial Framework
MS	(EU) Member State

NECP	National Energy and Climate Plan
NGEU	NextGenerationEU
NRRP	National Recovery and Resilience Plan
NGO	Non-Governmental Organisation
RES	Renewable Energy Source
RRF	Recovery and Resilience Facility
SMR	Steam Methane Reforming
TEN-T	Trans-European Transport Network
ZLEV	Zero- and Low-Emission Vehicle

List of figures

Figure 1: Clean hydrogen projects and investments, 2021

Figure 2: Selected shades of hydrogen

Figure 3: Potential applications of clean hydrogen

Figure 4: The Italian NRRP – Breakdown by Missions and Components, in billion €

Word count

18,741 words [Cover page, plagiarism statement, list of acronyms, list of figures, table of contents, abstract, references and footnotes are excluded].

Introduction

Paris, December 2015: 195 countries signed a legally binding agreement, committing to keep global warming "to well below 2°C above pre-industrial levels" and preferably to 1.5°C through nationally determined contributions (NDCs) – an ambitious target requiring major economies to decarbonise their energy systems (Hydrogen Council, 2017). Since then, transition from fossil fuels to cleaner energy sources has risen up the global sustainability agenda, but the scale of the challenge remains huge. Clean energy transition requires massive installation and integration of renewable energy in existing grids, as well as large-scale decarbonisation of end-use sectors (Hydrogen Council, 2017).

Against this backdrop, green hydrogen (i.e., generated using renewable electricity) is increasingly being considered as the "missing link" of the clean energy transition and "second leg of electrification", and it is gaining unprecedent business and political momentum (IRENA, 2022a; Capurso *et al.,* 2022; Noussan *et al.,* 2020; Alverà, 2020; Van de Graaf *et al.,* 2020). Dedicated hydrogen strategies – addressing the different steps of the value chain – are being developed by major economies, including Japan, South Korea, Australia, Canada, France, Germany, and the EU as a whole (IRENA, 2022a; Noussan *et al.,* 2020; Van de Graaf *et al.,* 2020). At the 2021 United Nations Climate Change Conference (COP26) in Glasgow, 35 countries and the EU committed to work together to speed-up green hydrogen deployment and ensure that "affordable renewable and low-carbon hydrogen is globally available by 2030" (UNFCCC, 2021).

The appeal of hydrogen stands in its versatility and multiple potential end-use applications. It can be generated either from renewable electricity or carbon-abated fossils fuels. It can be stored and transported in liquid or gaseous form and produces zero emissions at the point of use – while life-cycle emissions depend on the production pathway (Hydrogen Council, 2017). Hydrogen is already used as a feedstock in certain industrial application. Although global hydrogen demand for industry has increased more than threefold globally over the past decades[1], it is mostly supplied by fossil fuels, being the cheapest production pathway. Hence, abating costs for green hydrogen

[1] From less than 20 Mt in 1975 to more than 70 Mt in 2018 (IEA, 2019).

production is one of the challenges ahead for hydrogen to contribute to clean energy transition. Used as a feedstock, it has the potential to decarbonise existing industrial uses (Noussan *et al.,* 2020; IEA, 2019). As an energy carrier, it can power fuel-cell electric vehicles (FCEVs) or be the base for synthetic fuels, thus contributing to decarbonise transport. Acting as buffer and energy storage medium, it balances electricity grids, providing a solution to cope with the low flexibility of an energy system based on electricity from renewable energy sources (RES).

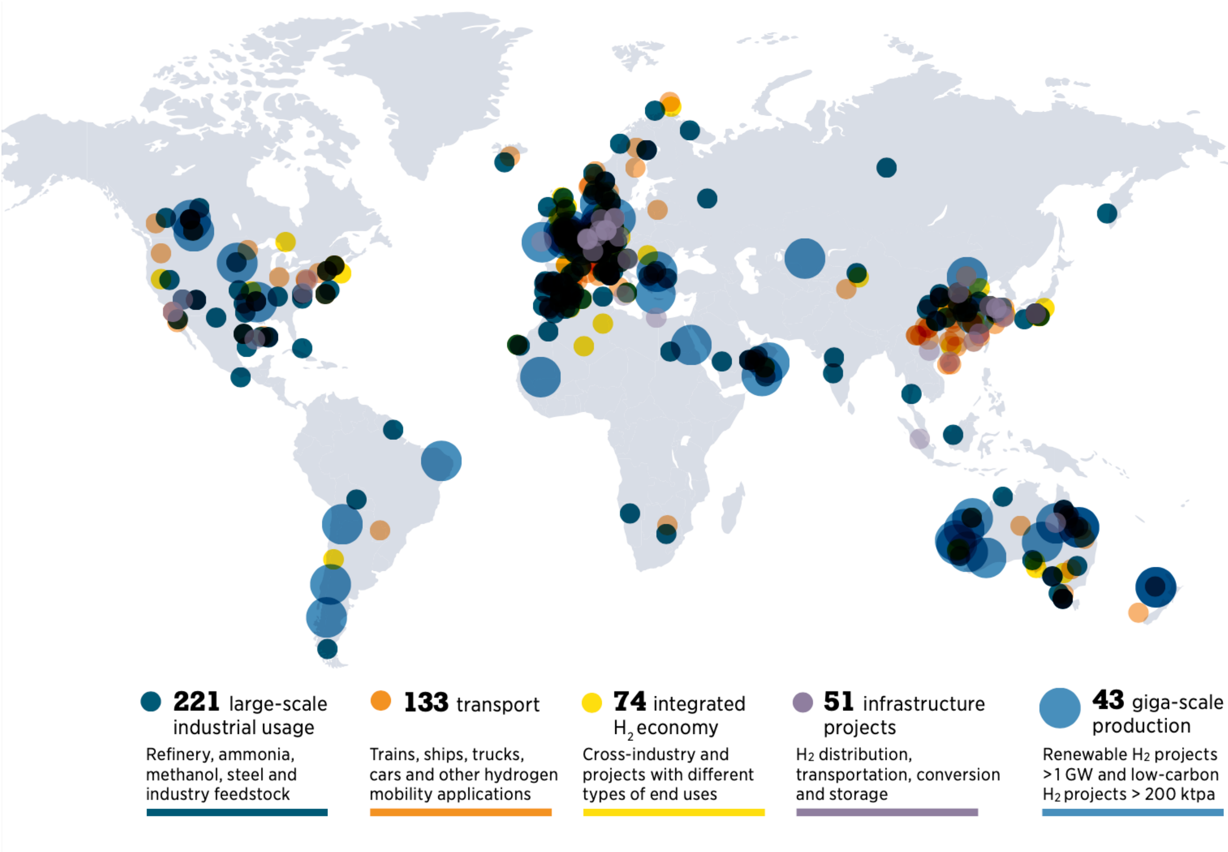
However, interest in hydrogen as a potential low-carbon energy carrier is not brand new and there have been at least other three waves of enthusiasm (Noussan *et al.,* 2020; Alverà, 2020; Van de Graaf *et al.,* 2020; IEA, 2019). The first time was during the oil crisis in the 1970s, when the world started to look for alternatives to oil – due to incumbent fear for oil shortages and rising prices as well as pressing environmental problems such as local pollution and acid rains. Projection indicated that hydrogen generated from coal or nuclear electricity could provide energy, particularly for transport (IEA, 2019). Hence, research programmes started but they did not lead to significant outcomes, as new oil was discovered, prices decreased and nuclear power was not socially accepted. Then, interest in hydrogen resumed in the 1990s and during the global financial crisis in late 2000s, due to new oil peak scenarios. However, similarly to the 1970s, decreasing oil prices, along with high prices for renewables, limited the diffusion of hydrogen technologies. These last waves of interest, however, coincided also with a period of growing awareness and concerns about climate change – which were leading to first global climate actions and commitments[2].

Today, a new wave of interest is growing around hydrogen – but political and economic scenarios are different. Firstly, climate change and energy transition are now at the top of global political agenda and are widely recognised as pressing issues to be addressed. After recording a GHG emission peak in 2018, the UN called on all signatory parties of the

[2] The United Nation Framework Convention on Climate Change (UNFCCC) was signed by 154 countries in 1992 and has as "ultimate objective" the stabilisation of "greenhouse gas concentration in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system" (Article 2). The Kyoto Protocol, signed in 1997 and in force from 2005 to 2020, was the first legally binding international agreement concerning GHG emissions. It set binding obligations for developed countries to reduce their GHG by an average of 5% below 1990 levels between 2008-2012, and for all signatory parties to cut their GHG emissions by at least 18% below 1990 levels between 2013-2020.

Paris Agreement to strengthen their NDCs threefold to meet the “well below 2°C” target and more than fivefold for the 1.5°C target (UNEP, 2019). Hence, renewables, energy efficiency and end-use sectors decarbonisation were identified as key factors to succeed. Green hydrogen came at the forefront as promising solution to decarbonise those sectors where limited solutions exist, including long-haul transport and heavy industry. As of 2021, around 500 large-scale hydrogen projects had been announced worldwide (IRENA, 2022a, p.43).

Figure 1: Clean hydrogen projects and investments, 2021. Source: IRENA, 2022a, p.43



Secondly, the price of renewable power generation is plummeting. Between 2010-2020, the cost of electricity from solar photovoltaics fell by 85%, from onshore wind by 56% and offshore wind by 48% (IRENA, 2021a). Over the same period, 644 GW renewable power generation capacity was added worldwide (IRENA, 2021a). Hence, green hydrogen production is becoming more cost-competitive, and the increasing share of variable renewables create demand for grid flexibility and storage capacity, whereby hydrogen can contribute to deliver (IRENA, 2022a).

Thirdly, hydrogen entails a geopolitical and geostrategic dimension. As potential internationally tradeable commodity and building block of a nascent economy, it could reshape trade patterns and energy dependencies between countries and allow some regions to emerge as front-runners and leading markets in hydrogen technologies (Van de Graaf *et al.* 2020; IRENA, 2022a). Alongside the potential contribution to decarbonisation, this latter aspect appears relevant for the EU, which is surging ahead with around half of the world's announced hydrogen projects, as shown in Figure 1 (IRENA, 2022a). Furthermore, the ongoing Russian-Ukrainian conflict and subsequent EU's commitment to reduce fossil fuels imports from Russia might further accelerate the deployment of hydrogen technologies with the aim of contributing to EU's energy security and independence[3].

Research question and methodology

Against this backdrop, green hydrogen has been considered a relevant topic to discuss, as it is expected to be one of the main pillars of the European political, climate and energy agenda in the upcoming years. Green hydrogen transition is opening up a set of broader questions on geopolitical implications, technical and regulatory barriers to a full-scale hydrogen economy, cost-competitiveness, short- and long-term application in end-use sectors and effective contribution to their decarbonisation.

As regards end-use sectors, transportation is the major source of pollution in the EU, accounting for 25.8% of total GHG emissions (EC, 2021a, p.127). Need for zero-emission mobility is evident, yet it poses major challenges, as electrification is not technically or economically feasible for some segments, including aviation, maritime and long-haul road transport, whereas green hydrogen has been identified as a possible solution. Considering that road transport accounts for more than 70% of EU's GHG emissions from transport (EC, 2021a, p.125), it has a key role to play in the path towards zero-emission mobility. Hence, this thesis seeks to investigate to what extent existing strategies are

[3] This latter aspect concerning the EU plan to exit its fossil fuel dependence from Russia and the role envisaged for hydrogen will be discussed more in details in section 3.4. However, the geopolitical implications of the emerging hydrogen economy, e.g., potential new dependencies between states if the path of large-scale imports is chosen, a possible intensification of technological and geo-economic rivalry between countries, the fear of "green colonialism" (Van de Graaf *et al.*, 2020; Scita *et al.,* 2020) would deserve a separate discussion, which is not covered by this thesis.

adequate to support the development of green-hydrogen mobility – the scope has been narrowed down to application in road transport. Accordingly, the following research question will guide the discussion: "*Are existing EU and national strategies adequate to enable large scale deployment of green hydrogen to decarbonise road transport?"*. To answer this question, a qualitative approach will be adopted and a case study will be presented – namely, the Italian policy framework on hydrogen. More specifically, the thesis offers an in-depth analysis of those European and Italian climate, energy and mobility strategies which entail a hydrogen dimension. The analysis of strategies includes two parts: a descriptive one, which elaborates on objectives, key elements and targets; and a critical one which assesses the consistency of the strategies at stake with the overarching European Green Deal, their feasibility, their strengths, weaknesses and limitations and to what extent they are expected to mainstream green hydrogen use in road transport. Descriptive parts are based on an analysis of the official text of strategies (or legislative acts/proposals, whenever mentioned), as published by EU institutions or Italian government ministries. Critical parts build on, compare and discuss contributions[4] from research bodies, think tanks, and stakeholders (industry, environmental NGOs and civil society). Alongside strategies, the European framework also includes a set of legislative proposals, whose analysis has been deemed relevant to this thesis. Also in this case, the analysis revolves around a descriptive and a critical part. The descriptive part includes also an overview of the on-going legislative procedure, i.e., which stage has been reached in the European Parliament (EP) and in the Council of the EU[5], and compare specific parts of the text proposed by the European Commission (EC) with Council's or EP's amendments, if available.

In details, the thesis is structured as follows. Chapter 1 provides an overview of key aspects of the hydrogen supply chain, including technologies for production, storage and transport, as well as potential applications in end-use sectors. Chapter 2 presents key data on transport's environmental impact in the EU, providing evidence on the need for a

[4] Including reports, studies, articles, policy briefs and position papers.

[5] Information provided is up-to-date at the time of writing. However, it should be noted that the legislative procedure is at early stages for most of the proposals, meaning that the EP or the Council have not adopted their negotiating position yet and, in any case, interinstitutional negotiations on final texts have not started yet. Relevant EP Plenary discussions (and votes) and Council meetings are scheduled for weeks and months ahead (see section 3.6 for details).

transition toward zero-emission mobility. Then, it explores potential advantages and disadvantages of FCEVs and discusses some existing barriers to their large-scale market uptake and commercialisation. Chapter 3 analyses the existing European policy framework for hydrogen, following the methodology explained above. Finally, building on the European framework, and following the same methodology, chapter 4 presents relevant Italian policies entailing hydrogen and its application in road transport, as well as selected projects for hydrogen mobility. Emerging strengths and limitations in the Italian framework will be then discussed and related to the overarching European framework. A final chapter wraps-up key findings and lists research limitations.

Chapter 1 – HYDROGEN: A TECHNICAL FRAMEWORK

1.1. Hydrogen supply chain

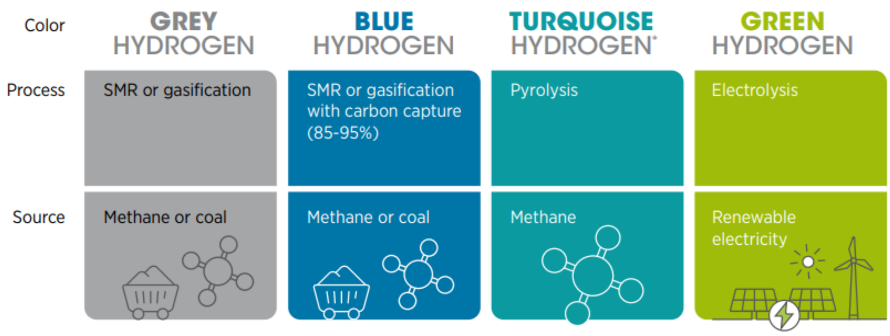
This section presents the main aspects of the hydrogen supply chain – including production, storage, transport, distribution and final uses – discussing the current situation and underlying the role of hydrogen – particularly green hydrogen – in the clean energy transition.

1.1.1. Production

Hydrogen is the third most abundant chemical substance on Earth's surface, after oxygen and silicon. Despite its abundance, it is rarely available in its pure form and exists mainly in combination with other elements, e.g., water molecules and fossils fuels. Consequently, it shall be derived from its compounds through chemical conversion processes and, similarly to electricity, it cannot be considered as an energy source – like oil, coal or other combustibles – but as an energy carrier to be produced from other sources (Noussan *et al.*, 2020). This implies that the hydrogen carbon-footprint depends on its production pathway.

A variety of processes and energy sources can be used to isolate hydrogen from other compounds and a colour code nomenclature (Figure 2) is commonly used to refer to different hydrogen production methods. Each colour defines the technology and energy source used, which determines the carbon footprint of the production pathway. Specifically, "grey hydrogen" is GHG emissions-intensive, "blue hydrogen" and "turquoise hydrogen" are lower GHG emissions-intensive, whereas "green hydrogen" is considered GHG emissions-free.

Figure 2: Selected shades of hydrogen. Source: IRENA, 2020, p.8



To date, up to 96% of hydrogen produced worldwide is “grey”, i.e., generated from fossil fuels via steam methane reforming (SMR) of natural gas or coal gasification. Large scale production of grey hydrogen via SMR is a mature technology, it is widely used in chemical and refining industries, and accounts for three quarter of global hydrogen production to date. Both SMR and coal gasification generates hydrogen and significant amounts of CO2 as by-products. The CO2 generated is directly emitted in the atmosphere, thus making such hydrogen technologies unsuitable for a route toward net-zero emissions (Howarth and Jacobson, 2021).

The SMR technology is also used for “blue hydrogen” production, which is referred to as low-carbon hydrogen, though. Indeed, CO2 produced as by-product is not directly released into the atmosphere, but trapped and stored underground via carbon capture and storage (CCS) technologies. Although having the potential to reduce – not eliminate – CO2 emissions, blue hydrogen shall be considered exclusively as a short-term transition to facilitate the uptake of green hydrogen and the growth of a green hydrogen economy in the early stages of energy transition (IRENA, 2020, p.9). Indeed, considering that three quarter of hydrogen is generated from natural gas and that some energy-intensive industrial processes, e.g., steel making, require a continuous flow of hydrogen, retrofitting CO2 with CCS would allow to continue producing hydrogen with lower emissions to meet continuous flow requirement, while green hydrogen production ramps-up. However, uncertainties related to the use of exhaustible resources and relevant price fluctuations, concerns about energy security, the long-impact of CO2 storage on environment and climate, as well as about the release of fugitive methane[6] make blue hydrogen unfitted to the goal of net-zero in the long run (Howarth and Jacobson, 2021; IRENA, 2020, p.9).

Another form of hydrogen is “turquoise hydrogen” which is generated from a thermal process, known as methane pyrolysis, whereby methane is split into hydrogen and solid carbon. Unlike SMR, carbon is in solid form. As this can be stored more easily than gaseous CO2, there is no need of using CCS. Although the process of pyrolysis might be zero-carbon – if reactors used to split methane are powered by renewable energy –

[6] Howarth and Jacobson (2021) argue that CO2 equivalent emissions for blue hydrogen are only 9%-12% less than those for grey hydrogen. Furthermore, fugitive methane emissions for blue hydrogen are higher than those for grey hydrogen due to an increased use of natural gas to power the carbon capture.

turquoise hydrogen is usually not completely climate-neutral when the entire production process is considered, as the extraction of raw materials, i.e., natural gas, produces emissions (IRENA, 2020, p.9).

"Green hydrogen" is produced from water by renewables-powered electrolysis and is the type of hydrogen which would help most achieve decarbonisation and climate targets. During the electrolysis process, which takes places within a unit called electrolyser, renewable electricity is used to split water into its constituent elements, i.e., hydrogen and oxygen. As neither the process itself nor its outputs generate CO2 as by-product, green hydrogen is recognised as climate-neutral and regarded as an essential element for the decarbonisation of the energy system that is required to meet climate targets in line with Paris commitments (IRENA, 2022b, p.13). However, water electrolysis accounts for less than 1% of global hydrogen production (IRENA, 2021b, p.82), and IRENA (2022a, p.31) has recently identified a set of barriers preventing development and deployment of green hydrogen at scale. These includes, i.a. (i) cost competitiveness of green hydrogen vis-à-vis fossil-based hydrogen, (ii) policy and regulatory uncertainties; (iii) lack of harmonised standards and certification schemes to track the production and consumption of any shade of hydrogen and clean hydrogen's contribution to emission reduction targets; (iv) deployment of enabling infrastructures for hydrogen transport and distribution in end-use sectors. However, research and innovation, carbon pricing policies, plummeting cost of renewables and rising cost of carbon are set to make green hydrogen cost-competitive with grey hydrogen and infrastructure roll-out is expected to speed-up.

1.1.2. Transportation

Hydrogen transportation is a key enabling factor to promote hydrogen economy and a fundamental elements of the hydrogen supply chain and its sustainability – both in environmental and economic terms (Capurso *et al.,* 2022; Abdin *et al.*, 2020; Noussan *et al.*, 2020). Indeed, based on distances and volumes, hydrogen can be transported from production facilities to retailers via various means and in various forms. This might require significant energy consumption, either to compress or liquefy it or to convert it into other chemicals that are easier to handle, such as ammonia or other liquid organic hydrogen carriers (LOHC) (Noussan *et al.*, 2020).

Pipelines are the cheapest option to transport hydrogen over medium distances, either in gaseous form or converted into ammonia. Gaseous hydrogen can be either transported and distributed through dedicated pipelines or injected in the exiting natural gas grids, with mixtures ranging from 5% to 10% in volume of hydrogen (Capurso *et al.,* 2022; Alverà, 2020). Although the latter solution, commonly referred to as blending, is still in the early stages of its development, it is being proposed in different European countries, e.g., Italy, France and Germany, and would allow to exploit existing infrastructure to start deploying green hydrogen and decreasing carbon intensity of natural gas (Noussan *et al.*, 2020). However, although repurposing existing natural gas grids could considerably reduce upfront capital costs for the installation of new dedicated pipelines and lead to significant economic benefits, it should be remarked that technical issues may arise, such as the need to adapt pipeline materials to cope with hydrogen embrittlement and higher corrosion of hydrogen compared to natural gas (Noussan *et al.*, 2020).

While pipelines are the most cost-effective option for hydrogen transportation over medium distances, other solutions appear more suitable for long-distance transportation. Indeed, hydrogen is increasingly regarded as an energy carrier to be traded globally, meaning that it would be produced in favourable regions, e.g., with abundance of low-cost renewable sources, and then shipped to countries with high demand and lower possibilities for on-site production. Since hydrogen cannot be transported in ships in its gaseous form, other solutions are under evaluation, including liquid hydrogen, ammonia or LOHC (Noussan *et al.*, 2020). In addition to long-distance transportation, hydrogen also needs to be supplied to final users. In this case, transport of gaseous hydrogen via pipeline, or liquid or compressed hydrogen via trucks would be the preferred options.

1.1.3. Storage

Alongside transportation, also storage, including both small-medium and large storage, is a key aspect of the hydrogen supply chain and needs to be addressed properly to minimise safety risks, energy consumption and losses (Noussan *et al.*, 2020). Depending on its physical form (liquid/gaseous), and the duration of storage, different technologies and solutions can be deemed as more appropriate. Indeed, a major distinction arises between the small-medium storage of hydrogen, which is needed to operate its supply chain, and the large seasonal storage to cope with output variability of RES power plants over the year. While large storage occurs in underground salt caverns, aquifers, or depleted oil and gas reservoirs, hydrogen required to operationalise its supply chain is stored at terminals such as ports and hydrogen refuelling stations (HRS) or also on the different vehicles used along the pathway, including ships and trucks (Noussan *et al.*, 2020).

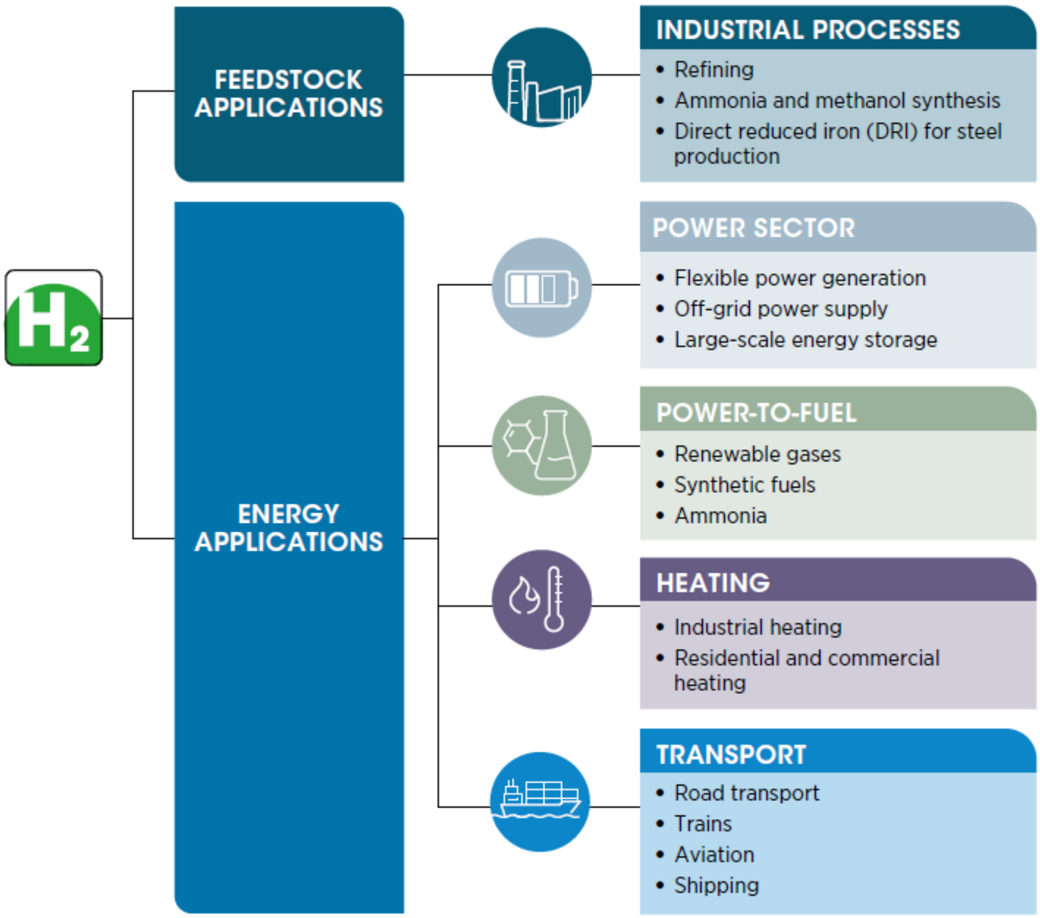
As regards physical form, vessels of different materials (e.g., steel, glass fibre, polymers) are generally used to store hydrogen at high pressure in its gaseous form. Conversely, storage of liquid hydrogen is generally limited to those cases in which hydrogen is already available in in its liquid form. Indeed, ad-hoc liquefaction is a highly energy-intensive process. Furthermore, liquid hydrogen storage is usually affected by boil-offs of 0.2%–0.3% per day. The subsequent evaporation of hydrogen leads to a pressure increase in the tank, and needs to be expelled for safety reasons– thus causing also losses. (Noussan *et al.*, 2020).

1.2. The role of hydrogen in the energy transition. Hydrogen applications

As of today, roughly two third of global hydrogen production serves industrial applications. More specifically, oil refining and ammonia production are the prime purposes, accounting for 33% and 27% of total hydrogen use, respectively (IEA, 2019; Hydrogen Council and McKinsey & Company; 2021)[7]. However, most of hydrogen used in those processes is produced via SMR and this makes the transition from fossil-fuels challenging. If the costs of production and utilisation develop favourably compared to other options, green hydrogen holds the long-term potential to decarbonise those industrial processes in which (grey) hydrogen is already used and also go beyond industrial applications, thus supporting the transition to a cleaner energy system and bringing potential benefits to both the energy system and end-use applications. Indeed, as shown in Figure 3, not only would green hydrogen facilitate the decarbonisation of the so called hard-to-abate sectors, i.e., those sectors where direct renewable electrification is hindered by technological, logistical and economic challenges, including heavy-duty and maritime transport, aviation, heating and power sector, but would also serve as a seasonal storage medium and increase the resilience and efficiency of the energy system.

[7] Methanol production (11%) and steel production (3%) follow. Source: IRENA, 2019, p.89

Figure 3: Potential applications of green hydrogen. Source: IRENA, 2022a, p.29



Feedstock applications

As already mentioned, grey hydrogen is already used extensively as a feedstock in several industrial segments, including refining of petrochemicals, ammonia and methanol production. Currently, over 90% of hydrogen produced in Europe is used as a feedstock in those industrial processes, which account for about the 41% of total EU's industrial emissions (Capurso *et al*., 2022). As hydrogen demand for feedstocks is projected to increase between 1% and 3% on an annual basis (FCH JU, 2019, p.40), replacing existing fossil fuel-based hydrogen feedstocks with green hydrogen would contribute significantly to the decarbonisation of industry. Besides current uses of feedstock, green hydrogen can contribute to decarbonise also other high-carbon and high-energy intensive industrial processes which currently rely on more carbon-intensive inputs. Among these, there is steel-making where green hydrogen could replace coal or natural gas as process agent (FCH JU, 2019, p.40; Capurso *et al*., 2022).

Energy applications

- Power sector

Replacing fossil fuels requires substantial increase in renewable power generation and massive electrification of end-use sectors. Supply and demand of power from RES are volatile and this poses a major challenge to the stability of the energy system. On the supply side, RES power, such as solar and wind power, is subject to significant seasonal variations. At the same time, hourly, daily, weekly, monthly, and seasonal variations have significant impacts also on the demand side, especially in the building sector. Such demand-supply mismatch needs to be balanced through mechanisms which stabilise the grid, by absorbing excessive power generation (e.g., in summer) and providing power in periods of high energy demand and low renewable production capacity (e.g., in winter). Multiple balancing options already exists, but efficiency should also be taken into account when choosing a solution. For instance, turning off wind generators during times of oversupply would solve the mismatch problem, but would turn out to be highly inefficient in terms of investment use. Conversely, turning on additional generators during times of undersupply would not be consistent with overall decarbonisation targets. In this regard, hydrogen use can improve efficiency and flexibility of the energy system, as well as its reliability, by acting as energy storage medium and carrier and by enabling sector coupling. Sector coupling allows to connect power generation with other demand sectors, such as transportation or building. This implies that power does not need to be generated neither at the location, nor at the time when it is required, as it can be transported from production to consumption sites via energy carriers, such as hydrogen (Van Nuffel, 2018; Erbach, 2019). In addition to sector coupling, balancing the grid requires storage and discharge of power. Batteries proved efficient to store energy for short-period of times. However, due to their low energy density, they are ill-suited and expensive to store large amounts of energy over long periods of time. Conversely, due to its physical characteristics, hydrogen can be stored for long period of time at competitive costs, compared to conventional large-scale energy storage means. Hydrogen can act also as energy carrier: particularly when using RES, power is not necessarily generated close to demand sites. Therefore, electricity can be converted into hydrogen and transported to demand sites via different means and in various forms, as briefly discussed in section 1.3.

- Heating

With particular reference to residential and commercial heating, green hydrogen can contribute to energy transition through direct use for heat production. Either by being injected into existing natural gas grids or distributed via new built dedicated infrastructure, it has the potential to accelerate building decarbonisation. Similarly to power sector, other options exist but buildings should satisfy certain upfront requirements. For instance, introducing energy efficiency measures, such as improved insulation, building automation or switching heat systems to heat pumps would reduce energy use in new buildings but would also turn out to be costly or unfeasible for old ones, due to technical impediments. Full direct heating electrification would also be challenging, as this would create a substantial mismatch in power demand and supply e.g., due to seasonal differences, and would require energy providers to build power generation assets to cover demand peaks. Considering that in the EU natural gas is the main fuel for heating buildings – used by 42% of all households (an estimated 90 million households) (FCH JU, 2019, p.33) – decarbonising natural gas grids through green hydrogen would prove a cost-effective solution. As briefly discussed in section 1.2, gas grids can be decarbonised either by blending hydrogen with natural gas up to a certain threshold, or by upgrading the gas network to use pure hydrogen. Putting aside technical issues that need to be addressed when repurposing existing natural gas grids (e.g., hydrogen embrittlement, hydrogen higher corrosion levels and subsequent need to adapt pipeline materials), hydrogen blending would offer key advantages for decarbonising building heating compared to other solutions mentioned above. Firstly, this would be compatible with existing building stocks, meaning that households do not need to upgrade their appliances. Secondly, decarbonisation strategies would be managed centrally by energy utilities, ensuring a speedy and more uniform transition (FCH JU, 2019, p.35).

Besides feedstock applications, green hydrogen can contribute to industry decarbonisation also by replacing fossil fuels in energy-intensive and high-temperature industrial processes, such as aluminium, cement, iron and steel production. In the EU, six energy-intensive industries, i.e., aluminium, cement, chemicals, refining, iron and steel, pulp and paper, consume 60% of final energy, and 40% of total energy demand from these sectors comes from high-grade heat (FCH JU, 2019, p.37). Different options to decarbonise industrial heating exist and they include fuel substitution, carbon capture, circularity and energy efficiency measures. Among fuel substitution options, electrification would be the most cost-efficient solution to decarbonise low- and medium-grade heat segments like pulp and paper. Besides complementing electricity also in low- and medium grade heat systems, hydrogen would be the most cost-efficient options for high-grade heat industrial segments like cement, aluminium and steel making, and particularly in those processes where it already serves as a feedstock or results as a by-product. Since each industrial sector requires specific heat temperatures and pressure ranges, decarbonisation technologies and benefits deriving from hydrogen use vis-à-vis other technologies should be assessed individually. However, on a general note, electric heaters, boilers and furnace become less efficient when temperature increases and their use would require major adaptation of production processes. Conversely, hydrogen would be able to generate high temperatures using process set-ups similar to the ones already in place – thus, hydrogen use would not require major shifts in production processes (FCH JU, 2019, p.37).

- Transport

Green hydrogen can contribute to transport decarbonisation either through direct use in FCEVs to store and convert energy, or as a synthetic fuel for shipping and aviation. Decarbonisation of transport revolves around two key technological challenges: (i) storing large amounts of energy at low weight and in a restricted space within a vehicle; (ii) creating an enabling network of recharging and refuelling infrastructures to distribute energy from RES power plants to vehicles (FCH JU, 2019, p.25).

As regards road transport, it is worth mentioning that hydrogen has higher energy density than batteries. This implies that it allows the storage of larger amounts of energy and FCEVs can drive longer ranges compared to battery electric vehicles (BEVs). For long-distance heavy-duty vehicles (HDVs), the low energy density of batteries is a significant disadvantage: a hydrogen-powered FCEV would weigh similarly to a conventional internal combustion engine (ICE) vehicle, while a battery for a 40-ton truck would add approximately three tons of payload to the vehicle, already accounting for the advantage of the electric motors compared to the combustion engines (FCH JU, 2019, p.27)[8]. In terms of recharging and refuelling infrastructures, existing power grids can serve small fleets of electric vehicles; massive transport decarbonisation would require either significant upgrades to existing grids and additional peak generation capacity to cope with demand peaks or different mechanisms to distribute energy. Instead, HRS have a built-in energy storage mechanism, which enable them to store hydrogen or receive it from pipelines or trucks (see sections 1.1.2 and 1.1.3), stabilising the energy grid. As regards rail transport, 56% of railway lines in the EU are electrified (EC, 2021a, p.80), although considerable differences among MS exist, e.g., Belgium ranks first (86.4%) and Ireland last (5.6%). While direct electrification can be competitive for new tracks, fuel cells may offer some advantages for the decarbonisation of existing railway lines. Indeed, adjusting tunnels and bridges on train routes to accommodate catenary for electricity would require massive investment and pose technical challenges (FCH JU, 2019, p.30).

Alongside conversion into energy in a fuel cell, hydrogen can also be converted into synthetic fuel, by adding CO2 from the atmosphere or resulting from other processes as by-product (FCH JU, 2019, p.31). While not contributing to reduce CO2 emissions, these fuels can reduce CO2 output significantly. Chemical properties of synthetic fuels are similar to those of existing fuels, therefore current infrastructures and some engines may be directly used. One remaining challenge would be linked to synthetic fuels' lower conversion efficiency. This means that their production would require higher amounts of hydrogen for the same amount of final energy.

To wrap, cutting GHG emissions is not enough to succeed in the path towards clean energy transition. A successful transformation should also boost industry competitiveness, reduce resource dependency, cut energy costs and improve citizens' lives, e.g., by improving air quality. Reaching this objective requires systemic changes in the entire value chain, from energy generation to consumption. Green hydrogen has the potential to enable such changes: as flexible storage medium and energy carrier, it allows to cope with demand-supply seasonal variability, to stabilise grids and enable sector coupling through cost-efficient mechanisms to store, transport and distribute energy. In end-use segments, hydrogen technologies provide an alternative path to other low-carbon

[8] Advantages and disadvantages of FCEVs vis-à-vis BEVs will be further discussed in Chapter 2.

solutions, e.g., electrification, whereas their application is not technically or commercially feasible. Lastly, at least in early stages, existing assets and infrastructures, e.g., natural gas networks, industrial heaters and boilers, can be used to start ramping up green hydrogen.

Chapter 2 – DECARBONISING THE TRANSPORT SECTOR IN EUROPE: A FOCUS ON ROAD TRANSPORT

As outlines in Chapter 1, green hydrogen can become an essential energy carrier for transport decarbonisation, and therefore a driver of sustainable mobility. Whether by powering FCEVs such as cars, trucks, and trains or as a feedstock for synthetic fuels for ships and aircrafts, hydrogen can complement ongoing efforts to electrify road and rail transportation and provide a scalable option to decarbonise shipping and aviation. In line with the objective of this dissertation, this section narrows down the scope to road transport. This chapters firstly describes the environmental impact of transport in the EU in terms of GHG emissions. Then, it elaborates on advantages and disadvantages of FCEVs for the decarbonisation of road transport, comparing them with BEVs and ICE vehicles. Lastly, it briefly discusses existing barriers to large-scale market uptake and commercialisation of FCEVs.

2.1. Transport sector in the EU: State of the art

Transportation and transport-related industries play a significant role in the European economy and are essential enabler of growth and prosperity. They contribute to around 5% of EU GDP and employ directly more than 10 million Europeans (EC, 2021a, p.19). At the same time, this does not come without costs: indeed, transport is the major source of pollution in the EU, responsible for a third of total energy use and accounting for 25.8% of EU's total GHG emissions[9] (EC, 2021a, p.127)[10].

Road transport is the biggest emissions-emitter in the EU: related GHG emissions have increased by over a quarter compared to 1990 levels[11] (EC, 2021a, p.138) and it is the most polluting mode of transportation to date, amounting to more than 70% of EU's total GHG emissions from transport (EC, 2021a, p.135). The largest percentage of road transport emissions is caused by cars (60.6%), followed by HDVs and buses (27.1%) (EC, 2021a, p.139)[12].

[9] Data mentioned in this section refers to 2019 (EC, 2021a)

[10] Excluding international maritime (international traffic departing from the EU), including international aviation.

[11] From 620.1 million tonnes in 1990 to 792.8 million tonnes in 2019.

[12] Light-duty trucks and motorcycles account for 11% and 1.3% of EU's total GHG road transport emissions (EC, 2021a, p.139).

GHG emissions from the EU's transport sector increased steadily between 2013 and 2019– a trend that diverges significantly from those in other sectors over the same period. Only between 2018 and 2019, they increased by 0.8% (EEA, 2021). Although preliminary estimates for 2020 indicate a drop by 12.7% in transport emissions, mainly due to decreased transport activities during the Covid-19 pandemic, national projection compiled by the EEA indicate that MS expect "a significant rebound in transport emissions after 2020" (EEA, 2021). If additional measures are not implemented, 2030 transport emissions will be around 10% above 1990 levels. (EEA, 2021). Conversely, with the implementation of planned additional measures which promote low-carbon fuels, EVs, and a modal shift to public transport, 2030 emissions would be 6% below 1990 levels (EEA, 2021).

As highlighted in the European Green Deal (EGD) Communication[13], in order to contribute to the overall climate neutrality objective by 2050, emissions from transportation need to be reduced by 90% by 2050. Consequently, due to its considerable share in total emissions from transport, road transport has a key role to play to ensure a clear pathway towards zero-emission mobility. While representing the most emitting transport mode, it also holds the largest untapped potential for further decarbonisation, as the majority of existing and planned measures in Member States focus on road transport, and this segment can be decarbonised faster compared to others, such as aviation or maritime (FSR, n.d.). To reduce these emissions, a mix of technology and policy options would be needed (EASAC, 2019, p.14). One promising approach is the transition from vehicles with ICEs to EVs, accompanied by low-carbon electricity generation. Technologies for zero-emission vehicles are already available on the market or are under development, however their demand and uptake shall be supported by suitable policies, regulatory measures and financial incentives.

2.2. FCEV for road transport decarbonisation: opportunities and challenges

Due to pressing environmental concerns arising from GHG emissions from road transport, major effort is put on the use of alternative automotive powertrains, as well as

[13] COM (2019) 640 final

low-carbon fuels. In this regard, interest in electric vehicles (EVs) has increased significantly over the last decade (Ajanovic *et al*., 2019; De Blasio, 2021; Ajanovic *et al*., 2021). Furthermore, access restrictions for ICE vehicles implemented in some Member States, as well as announced plans to end sales or registration of new ICE vehicles in the upcoming decade also contributed to make EV more attractive (Ajanovic *et al*., 2019). Various types of EVs are available on the market and they present different advantages and disadvantages compared to ICE vehicles, different levels of electrification and consequently different potentials for GHG emission reduction. Zero-emission vehicles, i.e., BEVs and FCEVs are of special interest for reduction of GHG emissions from road transport (Ajanovic *et al.,* 2019; Ajanovic *et al*., 2021). Indeed, these categories of EV generates zero-emissions at the point of use and can contribute significantly to road transport GHG emissions reduction if electricity and hydrogen used to power them are generated from RES (Ajanovic *et al*., 2021; Miotti *et al*., 2017). Particularly as regards FCEVs, Miotti *et al.* (2017) showed that FCEVs can decrease life-cycle GHG emissions by 50% compared to gasoline, while Liu *et al*. (2020) demonstrated that even when FCEVs are fuelled by hydrogen produced via SMR, i.e., grey hydrogen, GHG emissions can still be 15%-45% lower compared to conventional ICE vehicles.

In terms of market progression and technological advancements, BEVs have become the leading green mobility solution in recent years for the decarbonisation of passenger car and light-duty segments. Globally, the EV stock reached 10 million units in 2020, marking a 43% increase compared to 2019, and reaching 1% of total stock (IEA, 2021a). In 2020, BEVs accounted for two-thirds of new electric car registrations worldwide (IEA, 2021a). In the EU, there were more than 2 million electrically chargeable cars (0.87 % of the total car fleet) at the end of 2020, out of which 1.13 million were BEVs (Soone, 2021). Although BEVs sales are on the rise, and their demand increased by 56.7% in Q3 2021 compared to Q3 2020 (ACEA, 2021a), there are still some unresolved issues, also related to battery performance and environmental sustainability, which make BEVs unsuitable for heavy-duty transport and also limit their market penetration in the light-duty segment. These include (i) short driving range, (ii) long charging time, (iii) limited recharging infrastructure; (iv) sustainability of battery production and recycling. In the case of BEVs, battery capacity is the major challenge (Ajanovic *et al*., 2019; Ajanovic *et al.,* 2021). Such obstacles demonstrate the need for additional technologies – and consequently policies and strategies – to be on track with EU emissions reduction targets. To this end, hydrogen-powered FCEVs could be a promising solution, complementing BEVs in the decarbonisation of road transport, particularly long-distance HDVs.

Like all EVs, FCEV is powered by electricity. However, conversely to other EVs, FCEVs produce electricity by using a fuel cell powered by hydrogen, rather than electricity from a battery. They present advantages over BEVs in terms of refuelling times and driving ranges. Driving ranges tend to be similar to those of conventional ICE vehicles, i.e., 400-600 km, up to 800 km, compared to 300 km for BEVs. Increasing driving range of BEVs would require an increase in battery capacity, which would lead to increasing weight of vehicles (De Blasio, 2021; Ajanovic *et al.*, 2021; Hydrogen Council, 2017; Ogden, 2018). Secondly, FCEVs refuel quickly (3 to 5 minutes), resembling refuelling times of conventional ICE vehicles. In contrast, recharging a BEV can take between 20 minutes to 12 hours, depending on the battery size, charger capacity, and depth of charge (De Blasio, 2021; Ajanovic *et al.*, 2021; Hydrogen Council, 2017). Thirdly, hydrogen can be blended in and distributed via existing natural gas pipelines (see section 1.1.2). This method could supplement to the lack of dedicated infrastructures for hydrogen transport and distribution – at last in early stages (De Blasio, 2021; Hydrogen Council, 2017). Lastly, in terms of environmental impact, both FCEVs and BEVs are emissions-free at the point of use. However, fuel cells are less energy intense to produce than batteries (FCH JU, 2019, p.28).

However, although FCEVs' market has developed in recent years, their penetration appears still limited compared to other EVs and ICEs vehicles, and a number of significant issues hindering their large-scale deployment needs to be addressed. As of June 2021, there were 40 000 FCEVs registered worldwide, and this marked an annual average increase by 70% from 2017 to 2020 (IEA, 2021). Nevertheless, they accounted for a very small share of global stock of total vehicles (<0.01%) and of electric vehicles (0.3%). The situation in the EU mirrors this global trend: although the market for hydrogen-powered FCEVs has grown significantly in recent years, there were roughly 1,800 FCEVs by the end of 2020 (Soone, 2021).

Various studies discuss potential existing barriers to broader use and faster market penetration of FCEVs (EC, 2018a; EASAC, 2019; Confindustria, 2020; H2ME, 2021;

European Clean Hydrogen Alliance, 2021; De Blasio, 2021; Ajanovic *et al*., 2021; Mims, 2022) and major challenges identified can be divided into two macro-categories, i.e., (i) economics and (ii) infrastructure.

FCEVs are still expensive compared to both conventional ICE cars and other cleaner alternatives, such as BEVs. Although production costs have been falling in recent years, green hydrogen is not competitive yet. Hence, the total cost of ownership of a FCEV is still high. Some studies show that it is becoming competitive exclusively for specific fleets, such as taxis in polluted urban centres and urban delivery vehicles (H2ME, 2021, p.20; EASAC, 2019, p.25). Although some car manufacturers have already started to move from prototypes to products, achieving mass commercialisation would require a price reduction through economies of scale. In turn, economy of scale should be supported by an increase in demand (H2ME, 2021, p.20). With the exception of costs, FCEVs are comparable to conventional ICE vehicles in terms of driving range and refuelling time. In addition, they are quiet and have zero-emissions at the point of use, and as demonstrated by Liu *et al*. (2020) even if they are powered by grey hydrogen, their GHG emissions would be still lower than emissions from ICE vehicles.

Another key barrier for the large-scale adoption of FCEVs is the insufficient deployment of an infrastructure network to transport hydrogen over long distances, and of dedicated HRS. HRS are key enabler of hydrogen-based mobility, since they act as hubs for hydrogen distribution (Genovese *et al.*, 2022). As of 2020, there were more than 540 HRS worldwide, with Japan ranking first (135 HRS), followed by the EU (125 HRS), China (86 HRS), the US (65 HRS) and Korea (49 HRS). Of the 125 HRS in the EU at the end of 2020, the vast majority were in Germany (84) and France (19) (Soone, 2021; IEA, 2021b). Besides harmonised technical requirements to ensure HRS interoperability, an enabling infrastructure network should offer wider HRS coverage, i.e., enough HRS to enable both short-and long-distance journeys, and capacity to meet hydrogen demand as soon as FCEV fleet expands (Ogden, 2018; H2ME, 2021; Genovese *et al.,* 2022). The FCEV fleet in the EU is still limited, and as a result early HRS have low utilisation rates which limits revenue for investors and hamper further investment (H2ME, 2021). Indeed, the deployment of a wider infrastructure network would be commercially justified by larger demand for FCEVs. In turn, availability of infrastructure is regarded as a critical point to help boost demand for FCEVs.

Hydrogen applications are at the end of the supply chain (downstream). This implies that progress in downstream areas is also dependent on progress in upstream areas, e.g., abatement of production costs and regulatory barriers for production, storage and transport, availability of infrastructure. In order to speed-up green-hydrogen mobility, both stakeholders and academia (Genovese *et al.*, 2022; De Blasio, 2021; Ajanovic *et al.*, 2021; European Clean Hydrogen Alliance, 2021; FCH JU, 2019) agree upon the need of an enabling policy and regulatory framework to boost demand, supply and infrastructure development, in order to address bottlenecks in the entire hydrogen value chain and overcome the ‘chicken-and-egg problem’ posed by the interlinkage between FCEVs demand and deployment of refuelling infrastructures. This means that a strong policy framework for zero-emission mobility with corresponding funding and guarantee mechanisms to unlock investment in HRS should be accompanied by measures to address remaining barriers in upstream areas. A credible and feasible roadmap should provide industry with clear signals to scale-up FCEVs production and invest in product development, thus leading to cost reduction and greater consumer choice (De Blasio, 2021; European Clean Hydrogen Alliance, 2021).

Chapter 3 – THE EUROPEAN POLICY FRAMEWORK

Launched in 2019, the European Green Deal (EDG) shapes the EU's energy and climate policy framework for the next decades. Labelled as the EU's "new growth strategy", it enhances EU climate ambition and GHG emission reduction targets, aiming at making the EU the first climate-neutral continent by 2050, while boosting industry's competitiveness, protecting EU sovereignty in key economic sectors and ensuring a fair and just transition. Green hydrogen is recognised as a key enabler of a clean and circular economy and it is recurrently mentioned as part of the solutions to support the decarbonisation of hard-to abate sectors or as a milestone of a more integrated energy system. This chapter provides an overview of recent EU strategies to mainstream green hydrogen use in the European economy – and particularly in road transport sector. The discussion will revolve around key aspects of the presented strategies, their contribution to large scale deployment of hydrogen applications and their contribution to the overarching EGD objectives.

3.1. Enhanced climate ambitions: The European Green Deal and the European Climate Law

In line with international legally-binding commitments under the 2015 Paris Agreement to limit global warming "to well below 2°C above pre-industrial levels" and preferably to 1.5°C, the EC adopted the "Clean Planet for all" Communication[14] in November 2018. Under this Communication, the EC presented a strategic a long-term vision to achieve net-zero GHG emissions by 2050 through a socially-fair and cost-efficient transition, and framed the long-term contribution of EU climate and energy policy to Paris Agreement objectives. Already in this Communication, green hydrogen is regarded as indispensable to climate neutrality and features in all eight net-zero emissions scenarios for 2050 presented in the in-depth analysis accompanying the Communication (EC, 2018b; van Renssen, 2020).

Building on this vision, the EC presented the European Green Deal (EGD) Communication in 2019, with the aim of transforming the EU into a "modern, resource-efficient and competitive economy where there are no net emissions of greenhouse gases

---

[14] COM (2018) 773 final

in 2050 and where economic growth is decoupled from resource use"[15]. Under the EGD, the EC aims at making the EU a climate-neutral continent by 2050 and proposes a more ambitious GHG emission reduction target for 2030, i.e., -55% (up from -40%) compared to 1990 levels. In line with updated climate ambitions, it announces a broad revision of existing climate- and energy-related instruments, new proposals paving the way for the decarbonisation of EU economic sectors, as well as new funding and financial mechanisms to ensure a just transition while continuing boosting EU competitiveness and protecting EU sovereignty in key industrial sectors. In spite of its non-binding nature, the EGD sets a roadmap to reduce GHG emissions and transform EU industry for a climate-neutral economy by 2050. The objective of achieving climate neutrality marks a paradigm shift compared to previous climate ambitions, as it requires all sectors to consider technological changes to gradually reduce their carbon footprint.

Within this framework, the role of green hydrogen has been recognised as crucial to underpin the decarbonisation of EU industrial and economic sectors as well as the evolving energy system. To this end, under the EGD, the EC launched two interlinked initiatives – the Energy System Integration Strategy[16] and the EU Hydrogen Strategy[17]. Both are discussed more in details in sections 3.2 and 3.3.

The first envisages the need to move towards a more flexible energy system, with more integrated end-use energy sectors. Within this framework, it outlines a plan for a coordinated planning and operation of the whole energy system, specifying the role of low-carbon fuels, including hydrogen, which play a key role in this Strategy. Building on that, the EU Hydrogen explores the potential of green hydrogen to help decarbonise the EU economy cost-effectively and sets a roadmap to boost demand for green hydrogen, support its production, as well as the market uptake of hydrogen technologies.

Furthermore, the EGD highlights the urgent need to shift to zero-emission mobility and demonstrates that emissions from transport need to be reduced by 90% by 2050 in order to contribute to the overall climate neutrality objective. However, if the legislation remains unchanged, they are projected to be only 25% lower by 2050, compared to 1990

---

[15] COM (2019) 640 final
[16] COM (2020) 299 final
[17] COM (2020) 301 final

levels (EC, 2020a, p.9) – a significant emissions reduction gap that needs to be closed to deliver on increased GHG emission reduction targets. To this end, the EGD unveils i.a. the adoption of a dedicated strategy for sustainable and smart mobility to set the path towards zero-emission mobility. Moreover, it explicitly mentions the critical role of sustainable alternative transport fuels (including hydrogen) to enable zero-emission mobility and the subsequent need to ramp-up their production and deployment, asserting that 13 million zero- and low-emission vehicles (ZLEVs) are expected on European roads by 2025 and 1 million public recharging and refuelling infrastructure would be therefore needed. Consequently, the EC considers the revisions of several legislative acts impacting road transport, including the Alternative Fuels Infrastructure Directive (AFID), the Regulation setting CO2 emission performance standards for new cars and vans and the Renewable Energy Directive (RED II). Besides boosting the production and uptake of sustainable alternative fuels (including hydrogen), as well as expand the infrastructure network to support the transition, such proposals are also meant to accelerate the deployment and market penetration of ZLEVs, such as FCEVs.

EGD targets for carbon neutrality are enshrined into law by the European Climate Law[18], which establishes a legally binding framework to implement the vision of the EGD. It was adopted in July 2021 and sets a binding target of net zero GHG emissions by 2050, as well as a binding intermediate target of reducing net domestic GHG emissions by at least 55% by 2030, compared to 1990 levels. To operationalise the European Climate Law, the EC adopted the Fit for 55 Package[19] thereafter. It embodies a plan to deliver on the updated 2030 target and consists of a set of interlinked-legislative proposals to align existing EU legislation with the enhanced climate ambitions. Some of the legal texts under revisions cover road transport and might offer opportunities to mainstream hydrogen applications.

3.2. A EU strategy for energy system integration

Published on 8th July 2020, the EU Strategy for energy system integration[20] is among the milestones of the EGD and aims at accelerating the transition towards a more integrated

[18] Regulation (EU) 2021/1119
[19] COM (2021) 550 final
[20] COM (2020) 299 final

energy system to support both EU climate neutrality and energy security ambitions. It builds on three pillars, namely (i) circularity and energy efficiency; (ii) electrification of end-use sectors, and (iii) complementary use of renewable and low-carbon fuels. An immediate switch to an all-electric energy system might not be neither economically nor technically feasible for hard-to-abate sectors and would require massive investment in infrastructure to cope with the low flexibility of an energy system based exclusively on electricity from RES (FSR, 2020). Hence, the transition to a zero-carbon economy does not require only a cut in GHG emissions but also an integrated energy system, which relies on flexible energy carriers to complement electricity, as well as on sectoral integration (sector coupling). To this end, this Strategy revolves around six pillars for actions, which notably include speeding-up "the electrification of energy demand, building on a largely renewables-based power system" and promoting "renewable and low-carbon fuels, including hydrogen, for hard-to-decarbonise sectors". Thus, the Strategy underlines the "nodal role" of hydrogen, which is regarded as an integral part of an integrated energy system, thanks to its capacity to link the components of the energy system, by serving as energy storage medium and balance the grid, (see section 1.1.3). Moreover, a specific section is dedicated to hydrogen and its potential to decarbonise hard-to-abate sectors, either as a feedstock or as a fuel. The Strategy recognises the need of setting up a harmonised terminology as well as a European certification "based notably on full life cycle greenhouse gas emission savings and sustainability criteria" to track hydrogen carbon footprint in the entire value chain and guarantee transparency.

All in all, the Strategy sets forth a holistic approach to clean energy transition, underlying that sector integration is not a target itself but a complementary instrument to more direct decarbonising ways and brings together multiple dimensions. Specifically, on the demand side, it proposes more efficiency and demand flexibility, promoting electrification, while leaving room for other sustainable alternatives, such as green hydrogen, when deemed more technically feasible or cost-effective; on the supply side, it supports an efficient use of resources, while demanding harmonised standards to define green products. In a holistic logic, the Strategy also emphasise the role of infrastructure planning as enabler of integration, research and innovation, digitalisation and tax harmonisation.

3.3. A hydrogen strategy for a climate-neutral Europe

Alongside the Energy System Integration Strategy, the EC published the EU Hydrogen Strategy[21] on the same day – a landmark document driving the EU hydrogen agenda and setting forth a vision for the creation of a European hydrogen ecosystem. The Strategy considers hydrogen as "essential to support the EU's commitment to reach carbon neutrality by 2050" and it also places it as "a key priority to achieve the European Green Deal and Europe's clean energy transition", envisaging a share of up to between 10% and 23% of the 2050 EU final energy mix (JRC, 2019). Taking stock of the current status quo, i.e., hydrogen accounts for less than 2% of the EU energy mix with challenges related to cost-competitiveness, production pathways, infrastructures and perceived safety, the Strategy explores (i) how hydrogen production can be decarbonised; (ii) how green hydrogen can replace fossil fuels in end-use sectors, contributing to decarbonise the European economy cost-effectively, in line with the overarching EGD objectives. It also touches upon the need of a clear pipeline of viable investment projects, as well as of government support schemes to incentivise necessary private investments. Furthermore, while prioritising green hydrogen in the long-run, the Strategy also acknowledges the role of "other forms of low-carbon hydrogen" in "the short and medium term" to rapidly reduce GHG emissions from existing hydrogen production and underpin the transition itself– although no clear deadline for the phase-out of low-carbon hydrogen is indicated. Concretely, the roadmap presented takes a three-step phased approach to scale-up green hydrogen production, transport and end-use applications:

- The first phase, running from 2020 to 2024, foresees the installation of "at least 6 GW of renewable hydrogen electrolysers in the EU and the production of up to 1 million tonnes of renewable hydrogen". The focus is on decarbonising existing hydrogen application, e.g., in the chemical sector. In this first stage, consumption is expected to be mostly on-site. Consequently, the deployment of an EU-wide infrastructure network for transporting hydrogen is not foreseen, although blending options in natural gas grids could be considered for distribution at later stage.

[21] COM (2020) 301 final

- The second phase, running from 2025 to 2030, foresees the installation of "at least 40 GW of renewable hydrogen electrolysers by 2030 and the production of up to 10 million tonnes of renewable hydrogen in the EU". Although green hydrogen production "is expected to become cost-competitive with other forms of hydrogen production" if dedicated strategies are developed, low-carbon hydrogen production is expected to continue also in this phase. Furthermore, green hydrogen is expected to decarbonise steelmaking, trucks, rail and maritime as well as balance the energy grid, serving as buffer and seasonal storage medium. This phase will set forth the development of hydrogen valleys, i.e., regional hydrogen clusters where hydrogen applications in end-use sectors and energy grid are integrated, and it also envisage the design of a pan-European infrastructure backbone, including a network of HRS, to prepare for the next phase.

- In the third phase, running from 2030 and beyond, renewable hydrogen technologies are expected to reach a certain level of maturity to be deployed at large scale and used in all sectors where it is technically feasible and more competitive compared to other green alternatives.

To promote a timely rollout, the Strategy foresees also a set of funding instruments, including the Strategic Investment Facility under InvestEU, the ETS Innovation Fund, and the Recovery and Resilience Facility under the Next Generation EU. The European Clean Hydrogen Alliance, announced as part of the New Industrial Strategy for Europe[22] and launched in the context of the EU Hydrogen Strategy, brings together industry, public authorities and civil society, with the aim of developing a "concrete pipeline of projects" as well as an investment agenda to facilitate the implementation of the EU Hydrogen Strategy vision across the entire value chain and taking into consideration all actors involved.

On transport, the Strategy recognises hydrogen as an enabler of zero-emission mobility and considers transport, particularly long-haul, as a major potential end-use sector for hydrogen integration. In early stages, hydrogen can be used for commercial fleets, e.g., taxis and local city buses, or in specific parts of the rail network, where electrification is

[22] COM (2020) 102 final

not an option. Given the relative low demand, local electrolysers would be able to supply HRS – although some technical adjustments will be needed to make them suitable for both light- and heavy-duty vehicles. At later stage, hydrogen technologies will be used to power HDVs, trains and ships. The Strategy itself recognised the need of dedicated measures and policies addressing the use of hydrogen in the transport segment, and specifies that they will be detailed in the upcoming Sustainable and Smart Mobility Strategy.

Despite the scale of ambition, the adoption of the Strategy triggered mixed reactions. Among the main debated issues, there are the lack of a clear carbon-content threshold for low-carbon hydrogen, as well as further investments into low-carbon hydrogen at least until 2030 – and consequently the extended use of fossil fuels. Although the EC specifies that this would be a short-medium term solution to facilitate the transition, environmental NGOs did acknowledge the potential of green hydrogen to decarbonise energy-intensive industries, as well as some transport segments, such as aviation, shipping and long-distance road travel, but they warned about the risk of carbon lock-in, deriving from a postponed phase-out of fossils fuels, and the underlying risk to undermine both green hydrogen potential and 2050 climate-neutrality ambition (EEB, 2021a; WWF, 2020; Friends of the Earth and Food&Water Action Europe, 2020). They argue that the EU's Hydrogen Strategy, as it is today, would slow down the pace of decarbonisation, locking EU economy in a fossil-fuel-based logic and investing huge amounts of private and public funds for repurposing existing gas infrastructures – thus continuing to benefit the gas industry and delaying the market uptake and competitiveness of green hydrogen (EEB, 2021a). Furthermore, while investing in CCS and pyrolysis, i.e., blue and turquoise hydrogen, would mitigate GHG emissions from hydrogen production, it would also deepen EU's dependence on fossil fuels and unsustainable resource exploitation. To this end, the EEB[23] points out to the evident gas industry influence in the roadmap outlined in the Hydrogen Strategy – particularly as regards hydrogen production and transport infrastructure deployment. In its position paper (EEB, 2021a), it refers to a June 2020

[23] The European Environmental Bureau (EEB) is a network of environmental citizens' organisations in Europe, currently consisting of 180 member organisations in 38 countries and representing some 30 million individual members and supporters. Source: EEB (n.d), 'About EEB' [online]. Available at: https://eeb.org/homepage/about/ [Lastly accessed 28th May 2022]

letter to the EC President Von der Leyen from a number of organisation, mainly operating in energy-production or energy-intensive industries, which emphasises the importance of technological neutrality and the role of low-carbon hydrogen for a smooth transition, thus supporting a Strategy that would include "all clean hydrogen production pathways" to "drive a cost-efficient and cost-effective decarbonisation" (Letter to president VDL, 2020). Furthermore, right after the publication of the Strategy, with the long-term goal of supporting the hydrogen economy, 11 gas infrastructure companies across 9 Member States announced plans to create 6,800 kilometres of hydrogen dedicated infrastructure, out of which 75% would be repurposed natural gas pipelines, while 25% new built sections (Wang *et al.*, 2020, p.8). EEB believes that the path to clean energy transition should prioritise new business models, which boost energy efficiency and circularity and promote a rethinking of production and consumption patterns – before investing in new technologies that may hamper overarching climate ambitions, in the end. However, while the need of a clear carbon-threshold for low-carbon hydrogen, and more broadly a harmonised certification scheme for green hydrogen to guarantee transparency and origin of imported hydrogen is recognised by the industry (Hydrogen Europe, n.d.) and the EC themselves (for instance, this is mention in the Energy System Integration Strategy), a more flexible approach in early stages would respect the principle of technology neutrality (McWilliams and Zachmann, 2021), help industry adapt accordingly and foster cooperation between forward-looking companies on projects that unleash hydrogen's potential across Europe and benefit the clean energy transition in the end (Faber, 2022). Moreover, although gas infrastructure network might clearly benefit from natural gas network repurposing, it is worth consider that the natural gas grid is already a significant existing asset, capable of holding large volume of energy (McWilliams and Zachmann, 2021). Provided that certain technical standards are satisfied[24], retrofitting existing assets is faster and more cost-efficient than building new dedicated grids. This would accelerate initial deployment of low carbon hydrogen and start reducing, albeit not eliminate carbon emissions from energy-intensive sectors (McWilliams and Zachmann, 2021; Stagnaro, 2021) – a step forward, considering that more than 90% of currently used hydrogen

[24] Under the "Hydrogen and decarbonised gas market package", published in December 2021, the "Proposal for a Regulation on the internal markets for renewable and natural gases and for hydrogen (recast)" (COM/2021/804 final) proposed harmonised rules on gas quality, allowing the blending of hydrogen up to 5% (Article 20).

derives from SMR, i.e., grey hydrogen, and GHG emissions from low-carbon hydrogen are lower than those from grey hydrogen (Liu *et al.,* 2020). While electrolyser manufacturing capacity is expected to scale-up, green hydrogen production costs to sink and demand to rise, short-term use of low-carbon development would ease the pathway towards net-zero (Stagnaro, 2021; IEA, 2021c).

However, in light of the on-going Russian-Ukrainian conflict, uncertainty of gas supply and rising prices, as well as EU commitment to diversify gas supply chains and phase-out coal and natural gas import from Russia – which accounted for 45 % of EU gas imports, 27% of oil imports and 46% of coal imports in 2021 (EC, 2022a)– the overall scenario might evolve quickly, limiting the role of gas as transitional fuel and boosting the uptake of more sustainable alternatives. The EC's plan for energy independence from Russia, the REPowerEU plan, foresees a massive scaling-up and speeding-up of renewable energy rollout in power generation, industry, building and transport. Besides reducing fossil fuel dependency from Russia, the plan is expected to accelerate the EU's clean energy transition and green hydrogen is given a central role. Indeed, the "Hydrogen Accelerator" – which will be discussed in the next section – is expected to scale-up green hydrogen production and import, as well as the development of infrastructure for hydrogen transport and distribution, in order to underpin both energy transition and security.

All in all, the EU Hydrogen Strategy is a significant milestone in the EU decarbonisation path. It provides an indication on the role of hydrogen towards the achievement of overarching EGD objectives, as enshrined in the European Climate Law, and on the urgency of actions from both public and private stakeholders to support projects for green hydrogen deployment at scale. It does acknowledge the potential of low-carbon hydrogen in early stages of the transition, as well as the need of further dedicated strategies detailing the role of hydrogen in the decarbonisation of each economic sector. Investments to support the uptake of low-carbon hydrogen, as well as the lack of clear harmonised definition of carbon-content threshold for low-carbon hydrogen have been criticised by certain stakeholders and considered as obstacles to the achievement of climate-neutrality objectives to the benefit of industry. However, clean energy transition is a big challenge which encompasses a plethora of EU policies – energy and climate policy, industrial policy, social policy, quest for strategic autonomy, to name a few – and consequently involves a wide range of stakeholders with diverse and sometimes competing short- and long-term interests. Adopting a forward-looking approach and balancing those interests, both in the short- and long-term, trying to take as much as stakeholders on board is key to succeed.

3.4. The REPowerEU Plan

Adopted on 18th May 2022, the REPowerEU plan[25] details measures to exit EU fossil fuel dependence from Russia by 2027 (EC, 2022b, p.2), while strengthening energy security in the EU and respecting the decarbonisation path. The urgency of the matter was prompted not only by political and geopolitical reasons but also by significant pressure from the civil society, urging the EU to stop contributing to finance the war through its imports of fossil fuels (EC, 2022c). Indeed, as mentioned in section 3.3, Russia accounted for approximately 45% of EU's gas imports, 27% of its oil imports and 46% of its coal imports in 2021. Concretely, the EU plans to shift away from fossil fuel imports from Russia by promoting energy efficiency and savings; diversifying gas supply chains, e.g., via higher LNG imports non-Russian supplier; and accelerating the clean-energy transition. To deliver on REPowerEU objectives, the EC estimates additional investment of €210 billion between now and 2027 – on the top of those necessary to achieve the Fit for 55 objectives. This would reduce fossil fuel imports by €100 billion per year in the end (EC, 2022b, p.15). Out of these €210 billion, €10 billion goes to investment for gas infrastructures, as the diversification of supply chains would require a sufficient level of infrastructure, including LNG terminals, pipelines and reverse flow capacities (EC, 2022b, p.17). While the focus on energy efficiency and gas supply chain diversification are measures to be taken in the short-term, ramping-up renewables to accelerate renewable energy use in industry, building, transport and power generation are mid- and long-term measures. To this end, the Plan proposes to increase the 2030 targets for renewable energy in the overall energy mix from 40% to 45%[26]. It also frames green

[25] COM (2022) 230 final
[26] The current target is 32%. The proposal for the Revision of the Renewable Energy Directive, presented as part of the Fit for 55 Package in July 2021, proposes to raise 2030 target from 32% to at least 40% (see section 3.6.3)

hydrogen as a key driver to achieve the set objectives and includes a dedicated "Hydrogen Accelerator", whereby the EC:

- Sets an overall target of 20 million tonnes of green hydrogen production by 2030 (10 million tonnes to be produced domestically and 10 million tonnes to be imported)–a considerable increase compared to the 2020 Hydrogen Strategy. The EC also plans a joint procurement mechanism for hydrogen imports.

- Targets 75% green hydrogen share in industry (up from 50%, as proposed in the Fit for 55 package) and 5% share in transport fuel (up from 2.6% as proposed in the Fit for 55 package) by 2030

- Targets to double the number of hydrogen valleys

- Announces the publication for feedback of two proposals for Delegated Acts, namely on criteria to define products falling into renewable hydrogen (i.e., green), and a scheme to calculate the life-cycle emissions of renewable hydrogen

- Commits to report on green use in hard-to-abate industry segments and transport from 2025, in coordination with MS

Some criticisms have been moved to the EC plan, particularly towards an alleged paradox: while recognising a promising agenda for renewables and welcoming the revamped focus on energy efficiency, certain stakeholders claim that such ambitions are overshadowed by further investments in gas and gas infrastructure, warning about the risk of new path dependencies and of undermining climate neutrality objectives (EEB, 2022; ECCO, 2022; Global Witness, 2022). On the diversification of gas supply chains, the Italian think tank ECCO acknowledges that this is a necessary measure in the short-term to continue meeting energy demand, however, it counters the EC plan of building new gas infrastructures, rather than relying exclusively on the existing ones. In their view, further investments in gas infrastructure would slow down the projected decrease in gas demand. On the top of that, a study carried out by four European think-tanks (Ember, E3G, RAP and Bellona, 2022) concludes the EU could end imports of all Russian fossil gas by 2025, namely two years earlier than envisaged by the EC, without building new gas import infrastructure, but by accelerating the deployment of clean energy solutions (particularly a more ambitious outlook for solar power), promoting energy efficiency, fully implementing Fit for 55 package and removing existing barriers to domestic wind and solar growth. While the EC Plan does foresee investments for gas infrastructure to serve its scope – which, however, account for roughly 4% of additional investment, while the remaining share will support solar, wind and other low-carbon technologies (EC, 2022d) – these are not expected to undermine gas reduction targets. The scenarios presented in the EC study accompanying the REPowerEU Plan demonstrates that, compared to the Fit for 55 proposals, there is additional scope for decreasing natural gas consumption in all industrial sector by 2030. The study argues that implementing REPowerEU would lead industry to switch from natural gas to hydrogen and coal (and oil to a lesser extent). Natural gas consumption in industry is 35% lower in the REPowerEU scenario than in the Fit for 55 and major reductions are assumed in refineries (-6.2 bcm), chemicals (-6.6 bcm), and non-metallic minerals (-7.8 bcm) (EC, 2022b, p.19). These three sectors together would account for roughly 60% of industry's gas consumption in 2030. The study, however, also acknowledges that such reductions might be somewhat compensated by slight increases in oil and coal in the short-term. In the long-run, REPowerEU places greater emphasis on gas alternatives (bio-methane, green hydrogen) compared to Fit for 55. For instance, green hydrogen consumption is higher in all sectors, particularly in industrial heating (by a factor of 4.8), refineries (by a factor of 3.7), petrochemicals and transport (by a factor of 2.5 each) (EC, 2022b, p.21).

The Plan is framed as accelerator of EU's climate strategy and driver for strengthened energy security. As regards climate targets, the Plan could result in GHG emission cuts in line with the 55% reduction target by 2050 – and this is hinted at in the document itself, which states that "[the plan] will have a positive impact on EU's emission reduction over the decade". The scale of ambition is certainly high – the EC itself is aware of some uncertainty and bottlenecks that may hinder the path towards accelerating roll-out of renewable and strengthening energy security, such as the dependence on critical raw materials or hindrances to kick-off green hydrogen production at scale[27]. Also IEA

[27] The study accompanying the REPowerEU plan states: "The REPowerEU measures combined with the Fit for 55 proposals rely heavily on a quick and ambitious deployment of fossil-free technologies. Various bottlenecks may put this deployment and the energy security objectives at risk, such as the dependence on

(2022), when provided the EU with recommendations to reduce reliance on Russian gas, acknowledged that any plan would present trade-offs in the short-term[28]. The short-time horizon to phase-out imports of fossil fuels from Russia raised the level of short-term challenges. Coping with a fast-changing reality while ensuring consistency with long-term objectives might require a certain degree of flexibility in the short-term, as well as adapting measures, plans, strategies and rethinking previous approaches – without necessarily undermining the long-term overarching targets. The success of REPowerEU, i.e., achievement of its ambition, depends on several factors, including the outcomes of EP and Council negotiations on the Fit for 55 legislative proposals (which needs to be delivered in its entirety to match REPowerEU ambitions), ability of industry to adapt e.g., scale-up electrolysers manufacturing to ramp-up green hydrogen production (Hydrogen Europe, 2022), evolving geopolitical situation and relevant economic and political implications, and not least responses and actions across EU MS, considering that many of the measures proposed would require national implementation or coordination between EU MS (Tagliapietra, 2022). Drawing conclusion is premature[29] and it certainly remains to be seen whether measures proposed under REPowerEU will provide both short-term remedy and long-term boost to decarbonisation and EU energy supply security and independence, in the end; however, what is evident is that REPowerEU attempts to reconfigure key energy pathways – consistently with the pillars of EU energy policy, i.e., (i) affordability and accessibility of supply, (ii) security of supply; (iii) sustainability, while maintaining consistency with workstream in other policy areas and without watering-down long-term climate target (Kneebone and Conti, 2022). Actually, ambitions were also raised, e.g., proposals to increase the final share of renewable in the 2030 energy mix, double solar photovoltaic capacity, double the deployment rate of heat pumps

rare earths, supply chain constraints, skilled labour shortages and financing. In particular, renewable hydrogen needs new production capacity and dedicated transport infrastructure; and may only start to contribute significantly after 2027." (EC, 2022b, p.11)

[28] "The 10-Point Plan is consistent with the EU's climate ambitions and the European Green Deal […]. We also consider possibilities for Europe to go even further and faster to limit near-term reliance on Russian gas, although these would mean a slower near-term pace of EU emissions reductions. […] The analysis highlights some trade-offs. Accelerating investment in clean and efficient technologies is at the heart of the solution, but even very rapid deployment will take time to make a major dent in demand for imported gas. […] Reducing reliance on Russian gas will not be simple, requiring a concerted and sustained policy effort across multiple sectors, alongside strong international dialogue on energy markets and security" (IEA, 2022).

[29] At the time of writing.

replacing gas boilers. This is particularly true for green hydrogen, which has been given prominence in the plan. As highlighted by Hydrogen Europe[30] (2022), the enhanced targets for green hydrogen production and use, as well as the two proposed Delegated Acts for defining common EU rules applicable to renewable hydrogen could support the hydrogen economy and reinforce the hydrogen regulatory framework.

3.5. The Smart and Sustainable Mobility Strategy

Reducing GHG emissions from transport has been part of several EU strategic documents, notably of the 2011 White Paper “Roadmap to a Single European Transport Area: Towards a competitive and resource efficient transport system”[31] which proposed a reduction of transport GHG emissions by 60% by 2050 compared to 1990 levels and by 20% compared to 2008 levels. The same ambition was reiterated in the 2016 Strategy for Low Emission Mobility[32], and increased by the EGD Communication in 2019, which calls for a 90% reduction by 2050 compared to 1990 levels.

The Smart and Sustainable Mobility Strategy[33], announced in the EGD and adopted in December 2020, provides a vision on how the European transport sector could contribute to decarbonisation targets and outlines a roadmap for the next decades, which revolves around ten flagship initiatives. Aiming at contributing to both pillars of the EU ‘twin transition’, i.e., green and digital, the Strategy adopts a holistic approach to transport, meaning that beyond outlining actions to reduce GHG emissions by e.g., reducing fossil-fuel use, it also investigates the role of digitalisation and automation for smart transport, smart cities, etc. This latter aspect, however, will not be discussed here. The Strategy sets targets for 2030, 2035 and 2050 and calls for a paradigm shift in transport, pledging to make all transport modes more sustainable and reduce fossil-fuel dependence by replacing existing vehicles with ZLEVs; shifting demand and promoting multimodal transport; providing financial incentives to drive the transition.

---

[30] Hydrogen Europe is the main European association representing European industries, national associations and research centres active in the hydrogen and fuel cell sector.
[31] COM (2011)144 final
[32] COM (2016) 0501 final
[33] COM (2020) 789 final

Limiting the scope to road transport, the EC expects at least 30 million zero-emissions car and 80,000 zero-emissions lorries on European roads by 2030, while nearly all cars, vans, buses and HDVs shall be zero-emissions by 2050. The EC recognises that a large-scale uptake of ZLEVs should be aligned with the deployment of an enabling infrastructure network of refuelling and recharging infrastructures provides indication on targets. Namely, on hydrogen, the Strategy expects 500 HRS by 2025 and 1,000 by 2030 (up from the current 125). To this end, it recalls the AFID revision under the Fit for 55 Package as an important step forward to set national binding targets for HRS.

Hydrogen is given prominence in the Strategy, as transport is one of the main potential end-use sectors. The EC estimates that renewable and low-carbon fuels would account for 10-11% of the fuel mix by 2030, and 94-98% by 2050. By 2050, electricity would account for 30-42% of energy use in the road transport sector, while hydrogen for 31-40%, and e-fuels for 10-17% (EC, 2020a, p.15).

As mentioned above, the Strategy takes a holistic approach to transport, detailing plans for all transport modes, as well as proposing actions for smart cities and urban mobility. Consequently, it triggered mixed reactions from a wide range of different and diverse stakeholders. Hydrogen Europe welcomed the enhanced ambition to boost hydrogen mobility and stressed that industry is up to the task, as they expect to deploy up to 10,000 hydrogen-powered trucks by 2025 and up to 100,000 by 2030 (Hydrogen Europe, 2020). On HRS, the need identified by the industry is larger, i.e., 1,500 HRSs by 2030. Overall, although they welcome the Strategy, they stress that a feasible and smooth transition toward zero-mobility requires to address all dimensions of the supply chain, i.e., boosting both supply and demand of FCEVs, supporting the creation of an enabling hydrogen infrastructure network, as well as establishing financial mechanisms to produce vehicles and support their purchase as well.

3.6. Fit for 55 Package

As mentioned in section 3.1, the Fit for 55 Package consists of a set of interlinked legislative proposals concerning climate, energy, land use, transport and taxation policies to align EU law with new European Climate Law's target. The package includes 8 revisions of existing legislation and 5 new proposals[34]. This section discusses the proposals which are more likely to mainstream green hydrogen use in road transport, and provides an overview of the EC's proposed amendments – with a focus on those concerning hydrogen – as well as some indications on the stage reached in the legislative procedure.

3.6.1. Revision of the Alternative Fuels Infrastructure Directive (AFID)

Adopted in 2014, this Directive[35] established a framework for coordinating the deployment of alternative fuels across the EU and spurring further investments. AFID required MS to develop national policy frameworks (NPFs) to ensure the installation of a sufficient number of refuelling and recharging points for alternative fuels vehicles and vessels, namely electric recharging points, CNG and LNG refuelling points. On HRS, the Directive left up to MS the decision to include them in their NPFs. As of 2017, 14 MS had included HRS in their plans (EC, 2017, p.7).

Within the Fit for 55 Package, the EC proposes to turn this Directive into a Regulation, arguing that this change of instrument would ensure a "swift and coherent implementation" of minimum requirements and hence faster creation of a strong alternative fuel infrastructure network across the EU. Secondly, the proposed regulation sets binding national targets for alternative fuel infrastructure deployment. On hydrogen, it mandates the installation of "a sufficient number" of HRS "with a maximum 150 km distance in-between them along the TEN-T" core for gaseous hydrogen, while liquid hydrogen shall be made available "with a maximum distance of 450 km in-between them"

---

[34] New proposals include: (1) Carbon Border Adjustment Mechanism (CBAM); (2) ReFuelEU Aviation; (3) FuelEU Maritime; (4) Social Climate Fund; (5) EU forest strategy. Updates to existing legislation concerns: (1) Revision of the EU emission trading scheme (EU ETS); (2) Amendment to the renewable energy directive (RED); (3) Amendment to the energy efficiency directive (EED); (4) Revision of the effort sharing regulation (ESR); (5) Revision of the alternative fuels infrastructure directive (AFID); (6) Revision of the regulation on land use, land-use change, and forest (LULUCF); (7) Amendment of the regulation setting CO2 emissions standards for cars and vans; (8) Revision of the energy taxation directive (ETD). Source: EC (2021) 'European Green Deal: Commission proposes transformation of EU economy and society to meet climate ambitions' [online], 14 July 2021. Available at: https://ec.europa.eu/commission/presscorner/detail/en/IP_21_3541 [Lastly accessed: 2nd June 2022]

[35] Directive 2014/94/EU

by 31 December 2030 (Article 6). By this date, MS shall also ensure the deployment of at least one HRS in each "urban node".

In the EP, this file has been referred to the Transport and Tourism Committee (TRAN), which adopted its draft report in February 2022 (OEIL, 2022a). On hydrogen, the draft report raises ambition and tightens EC's proposed provisions by indicating that there should be more HRS along the TEN-T, namely one every 100 km for gaseous hydrogen and one every 400 km for liquid hydrogen and that they should be available earlier, namely by 2027 (Article 6)[36]. The EP shall vote the Committee's draft report, hence adopt its position in September 2022 (OEIL, 2022a). Negotiations with the Council on the final text are expected thereafter. The Council has already adopted its negotiating position (Council of the EU, 2022) – which seems to be closer to the EC's proposal than to the TRAN draft report. On hydrogen, the Council backs the EC's proposal to place HRS along the TEN-T core network and urban nodes by 2030, and slightly lower ambitions for the distance, by proposing "a maximum distance of 200 km in-between them along the TEN-T core network" (Article 6)[37].

Although welcoming the introduction of mandatory targets for MS and the change of the legislative instrument, both ACEA[38] and Hydrogen Europe raised concerns about the lack of ambition in the proposal, arguing that this could undermine the path towards zero-emission mobility. Due to the interlinkage between availability of infrastructures, demand for alternative-fuelled vehicles and transport emission reduction targets, all proposals aiming to zero-emission mobility should be equally ambitious and need to progress consistently together (ACEA, 2021b; Hydrogen Europe, 2021a). On HRS, their position

[36] European Parliament – Committee on Transport and Tourism, Draft Report on the proposal for a regulation of the European Parliament and of the Council Deployment of alternative fuels infrastructure, and repealing Directive 2014/94/EU of the European Parliament and of the Council. 2021/0223(COD), 14 February 2022. Available at: https://www.europarl.europa.eu/doceo/document/TRAN-PR-719568_EN.html.

[37] Council of the European Union – General Secretariat of the Council, General Approach on the Proposal for a Regulation of the European Parliament and of the Council on the deployment of alternative fuels infrastructure, and repealing Directive 2014/94/EU of the European Parliament and of the Council, 9585/22. 3 June 2022. Available at: https://data.consilium.europa.eu/doc/document/ST-9585-2022-INIT/en/pdf

[38] ACEA (Association des Constructeurs Européens d'Automobiles) is the European Automobile Manufacturers' Association, representing the 16 major Europe-based car, van, truck and bus makers, namely: BMW Group, DAF Trucks, Daimler Truck, Ferrari, Ford of Europe, Honda Motor Europe, Hyundai Motor Europe, Iveco Group, Jaguar Land Rover, Mercedes-Benz, Renault Group, Stellantis, Toyota Motor Europe, Volkswagen Group, Volvo Cars, and Volvo Group.

is aligned with the TRAN Committee's draft report (one HRS every 100 km on the TEN-N core by 2027) and Hydrogen Europe stresses that depending on the final content of the Regulation, the creation of a HRS network can be significantly speed-up, leading to an increased uptake of FCEVs.

3.6.2. Amendment of the Regulation setting CO2 emission performance standards for new passenger cars and for new light commercial vehicles

Regulation (EU) 2019/631 sets average CO2 emission reduction targets for EU new cars and vans. Specifically, the reduction targets are set as follows: -15% in 2025 for both cars and vans compared to 2021 levels; -37.5% for cars and -31 % for vans in 2030 compared to 2021 levels. The Regulation also establishes an incentive mechanism to speed-up the uptake of ZLEV, i.e., manufacturers meeting certain benchmarks for the sales of ZLEVs are allowed to apply less strict CO2 targets.

The EC proposal for amendment leaves 2025 targets unchanged and strengthens CO2 emissions targets for 2030, namely: -55% for cars and -50% for vans compared to 2021 levels. The EC also proposes to delete the incentive mechanism for ZLEV sales from 2030 as well as a -100% reduction target by 2035, meaning that all new vehicles would be zero-emission from 2035 onwards. The EP has adopted its position on this file – backing EC's proposal to reach zero-emission road mobility by 2035 and strengthen 2030 emission reduction targets (EP, 2022a). The Council is now expected to adopt its position and then start negotiations with the EP on the final text.

Since the Regulation incentives manufactures to integrate a rising share of ZLEV in their fleets, FCEVs are set to benefit from it. However, Hydrogen Europe (2021b) recommends to "soften the trajectory" for vans as they present specific characteristics requiring much time to be adapted, as well as to ensure an adequate network of HRS via the AFID Revision. The same stance is seconded by ACEA (2021c).

3.6.3. Amendment of the Renewable Energy Directive (RED II)

Under RED II[39], the EU as a whole shall ensure 32% of energy from RES in its gross final energy consumption by 2030 (Article 1). The proposed amendment strengthens this provision, by raising the share to at least 40% by 2030. To this end, the EC also proposes to tighten sectoral targets, particularly in those sectors where progress has been slow, i.e., industry, buildings and transport. As regards transport, RED II already requires MS to impose fuel suppliers to ensure that minimum 14% of the energy supplied for road and rail transport comes from RES. The proposed amendments include: (i) a target for reducing GHG intensity of transport fuels by 13% by 2030; (ii) a sub-target of 2.2% for advanced biofuels; (iii) a sub-target of 2.6% of renewable fuels from non-biological origin (RFNBO), which includes hydrogen (although not specifically mentioned in the proposed amended text) (Article 25).

As regards the legislative process, the file has been referred to the Committee on Industry, Research and Energy (ITRE) in the EP. The rapporteur's draft report was adopted in February 2022; the final adoption by the Committee is expected in July 2022, while the Plenary vote – and thus the adoption of EP's negotiating position with the Council – is planned in September 2022 (OEIL, 2022b). While seconding the proposed increase to 40% for renewable energy share by 2030, the draft report raises ambitions for renewable fuels. Specifically, it proposes to: (i) increase the target for GHG emission reduction from transport fuels to 20% with the aim of incentivising the use of advanced biofuels and RFNBO; (ii) increase the target for advanced biofuels to 5% in 2030; (iii) increase the target for RFNBO to at least 2,6 % in 2028 and 5 % in 2030. Furthermore, the draft report also modifies the wording of Article 25 RED II, by specifically mentioning low-carbon hydrogen among RFNBO[40].

[39] Directive (EU) 2018/2001

[40] European Parliament – Committee on Industry, Research and Energy, Draft Report on the proposal for a directive of the European Parliament and of the Council amending Directive (EU) 2018/2001 of the European Parliament and of the Council, Regulation (EU) 2018/1999 of the European Parliament and of the Council and Directive 98/70/EC of the European Parliament and of the Council as regards the promotion of energy from renewable sources, and repealing Council Directive (EU) 2015/652. 2021/0218(COD), 14 February 2022. Available at: https://www.europarl.europa.eu/doceo/document/ITRE-PR-719550_EN.html.

This EC proposal received mixed reactions from stakeholders. Overall, environmental NGOs criticise the lack of ambition of the proposed RED II amendment. Greenpeace (2021) argues that the 40% target for renewable energy is not sufficient neither to meet EU nor global decarbonisation targets; EEB (2021b), seconded by the WWF (2021) calls on the EC to raise ambitions and set a 50% target for renewable energy. Industry is more supportive, in general – particularly renewable producers (Wilson, 2021). In particular, Hydrogen Europe supports the introduction of the target for RFNBO in transport (Chatzimarkakis, 2021).

3.6.4. Revision of the EU Emission Trading System (EU ETS)

The EU ETS is a market-based mechanism based on a "cap-and-trade" principle for cutting GHG emissions cost-effectively (EC, 2021d). Sectors covered by the current Regulation include: (i) power and heat generation; (ii) energy-intensive industries, e.g., oil refining, steel-making, iron and aluminium; (iii) aviation within Europe. The cap, i.e., the upper limit for GHG emissions from ETS-covered sectors, decreases every year, hence providing an incentive to reduce emissions. In line with previous EU's GHG emission reduction target (-40% by 2030 compared to 2005 levels), the Regulation sets a 2030 reduction target for ETS-covered sectors of 43% compared to 2005 levels.

The EC proposed revision aims to reduce the ETS-covered GHG emissions by 61% by 2030 compared to 2005 levels, by *i.a.* (i) tightening the annual cap reduction; (ii) extending the scope of ETS to maritime transport; (iii) building a separate ETS for road transport and buildings; (iv) increasing funds for the Innovation and Modernisation Fund – a EU programme for demonstration of innovative low-carbon technologies, partially funded by revenues generated by the ETS. The file has been referred to the ENVI Committee in the EP, whose draft report was rejected in the Plenary and now needs to be reworked in the Committee (EP, 2022b). Neither the Council and nor the EP have adopted their negotiation position yet and there is no clear timeline for interinstitutional negotiations to start.

The scope of the ETS covers energy-intensive sectors where green hydrogen can act as a feedstock. The EC proposals for an increased GHG emission reduction target and more funds for the Innovation Fund, are likely to incentivise the roll-out of clean hydrogen technologies in those sectors. Finally, the deployment of hydrogen in the transport sector is also expected to benefit from the proposal to establish a separate ETS for road transport and building (Hydrogen Europe, 2021c), as this is expected to incentivise the transition to cleaner road transport (and heating) fuels by putting a price on fuels' carbon emissions at the level of suppliers (EC, 2021d).

Chapter 4 – THE ITALIAN POLICY FRAMEWORK

This chapter firstly describes the environmental impact of transport in Italy in terms of GHG emissions. Then, it explores national policies and strategies supporting hydrogen economy – discussing how they resonate the overarching European agenda and hydrogen ambitions, and how they are expected to mainstream green hydrogen application in transport, particularly road transport segment. An overview of selected green-hydrogen mobility projects and a wrap-up discussion will follow.

4.1. Transport sector in Italy: State of the art

As of 2019, the Italian transport sector accounted for 25,2% of total GHG emission and for 30.7% of total CO2 emissions[41]. In line with the EU trend (see section 2.1), road transport is the biggest emissions-emitter: related GHG emissions amounts to 92.6% of Italy's domestic GHG emissions from transport. While overall GHG emissions decreased by 19% between 1990 and 2019, road transport emissions increased by 3.2% over the same period (Mims, 2022, p.6).

In order to contribute to EU's 2030 and 2050 climate targets, as well as to Italy's emission reduction targets, which will be discussed in the next sections, transport has a key role to play. The last Mims[42] report on transport decarbonisation demonstrates that, beyond promoting a shift towards alternative fuels, a number of structural issues shall be addressed to succeed in transport decarbonisation: for instance, Italy is the EU MS with the highest number of cars per inhabitant (second only to Luxembourg); there are large gaps among regions as regard the availability and efficiency of local public transport and infrastructures; and there is an excessive prevalence of road transport over other less polluting means (Mims, 2022, p.9). Indeed, as of 2019, the total stock of Italian vehicle fleet amounted to 52.7 million vehicles, including 39.8 million cars, 7.2 million motorcycles, 3.7 vans, 700,000 heavy-trucks and 100,000 buses. The large majority were ICE vehicles (99%) (Mims, 2022, p.15). The report also highlights that electrification should be preferred, whenever technically feasible – for cars and light duty vehicles, it seems the most suitable option both in terms energy efficiency and emission reduction.

[41] Excluding international shipping and aviation (Mims, 2022, p.6)
[42] Mims is the Italian Minister for infrastructure and sustainable mobility (Ministero delle infrastrutture e della mobilità sostenibili).

Indeed, it has been estimated that with the current energy mix, replacing ICE cars and light duty vehicles with BEVs would result in a 50% reduction over the entire lifecycle. This percentage would rise, if electricity from RES rose (Mims, 2022, p.11). Estimate indicates that fuel-cell electric cars could amount to 27,000 units by 2025 (0.1% of total fleet), to 290,000 by 2030 (0.7 % of total fleet), and to 8,5 million by 2050 (20% of total fleet) (H2IT, 2019, p.66). For buses and heavy trucks, hydrogen may represent a viable alternative in nascent Italian hydrogen valleys – at least in early stages (Mims, 2022, p.31; H2IT, 2019, p.11). Indeed, projections for future market share are more ambitious compared to those for fuel-cell electric cars: hydrogen-powered buses are expected to reach 1,100 units by 2025 (up from 10 in 2019; 1.1% of total fleet), 3,700 units by 2030 (3.8% of total fleet) and 23,000 units by 2050 (25% of total fleet) (H2IT, 2019, p.67). For heavy truck, projections indicate a share of 29% of total fleet by 2030 (49,000 units) (H2IT, 2019, p.70). Although some pilot projects (particularly for buses) are already ongoing, massive R&D investments and an enabling HRS infrastructure network are needed to meet projected increases in FCEV fleet (H2IT, 2019, p.13). 197 HRS – satisfying technical requirements for cars, buses and HDVs – would be needed by 2025. A study of European House Ambrosetti for SNAM[43] (2020, pp.141-145) estimates that hydrogen (blue or green) would amount to 23% of the Italian total energy demand by 2050, leading to a 28% GHG emission reduction compared to 2018 levels. Transport would account for 39% of the overall hydrogen demand.

4.2. The Italian National Energy and Climate Plan[44]

National Energy and Climate Plans (NECPs) are 10-years plans adopted by EU MS for the period 2021-2030 under the Regulation (EU) 2018/1999 on the Governance of the Energy Union and Climate Action. The Italian NECP addresses all five dimensions of the Energy Union, i.e., decarbonisation, energy efficiency, energy security, internal energy markets and research, innovation and competitiveness.

[43] SNAM is an Italian leading infrastructure operator in natural gas transport and storage.
[44] Piano Nazionale Integrato per l’Energia e il Clima (PNIEC)

It was officially released in December 2019 and among the targets for 2030 it includes a 30% share of renewable energy in the 2030 national gross final energy mix[45]. The different sectors are expected to contribute as follows: 55% renewables share in electricity; 33.9% in heating and cooling sector; 22% in transport. As acknowledged by the EC itself in its assessment of the Italian NCEP, the share of renewables in the transport sector is "particularly ambitious and well above the EU target of 14%" (EC, 2020b, p.5) set by RED II. RED II sets an overall target of 32% for energy from RES in the EU's final gross consumption by 2030. Subsequently, as per the Directive, each MS is required to impose fuel and electricity suppliers to supply a minimum of 14% of the energy consumed in road and rail transport by 2030 as renewable energy. In this framework, the Italian Plan recognises the role of hydrogen, especially green hydrogen, as carrier for transport applications (particularly rail and HDVs) suggesting that it will provide 1% of RES for transport. Within this amount, 80% per cent would be injected in the existing gas grid, while 20% would be used in pure form for bus and trains. Although the Plan foresees scope for hydrogen also for other applications, e.g., long-term storage of renewable electricity and refining industry, and promotes relevant R&D activities, the only specific target concerns transport.

The Plan also propose to accelerate the deployment of alternative fuel vehicles, by providing that, when replacing their fleets of cars, buses and public utility vehicles, public administration (including Regions, local bodies and providers of public utilities) must ensure that 30% by 2022, at least 50% by 2025 and 85% by 2030 of new vehicles purchased are electric, hybrid with off-vehicle charging, powered by methane and hydrogen or electricity and methane in the case of buses[46]. Furthermore, the Plan also specifies that EU financial instruments, e.g., Innovation Fund, Connecting Europe Facility, InvestEU, shall complement national and regional instruments for the development and demonstration of clean technologies and IPCEIs (Important Project of Common European Interest) are seen as enabler for R&D projects in hydrogen supply chain.

[45] PNIEC (2019, p.11) Available at: https://www.mise.gov.it/images/stories/documenti/PNIEC_finale_17012020.pdf

[46] Ibid., p.145

The NECP was framed in line with previous EU climate targets. In light of the enhanced climate ambitions and the legislative proposals of the Fit for 55, the Italian NECP shall be updated accordingly. Considering the new EU targets for hydrogen, as well as the emphasis put on hydrogen in the PNRR, it is likely that ambitions with respect to hydrogen will be revised upwards in the NECP (Giuli, 2022, p.27).

4.3. Preliminary Guidelines on the National Hydrogen Strategy

Following the adoption of the EU Hydrogen Strategy in July 2020, as well as the publication of national hydrogen strategies by other EU MS, e.g., Germany, France and the Netherlands, the Italian Minister for Economic Development published the Preliminary Guidelines on the National Hydrogen Strategy[47] in November 2020 and launched a public consultation until December 2020. The document outlines a scenario for hydrogen demand, production and application by 2030 and 2050, seeking to identify sectors in which green hydrogen could become competitive in the short-, medium- and long-term.

Based on this document, hydrogen is expected to cover 2% of the final energy demand by 2030 and up to 20% by 2050 from the current 1% (MISE, 2020, pp.5-9). In terms of end-use application, the Guidelines set both short- and long-term targets. The main objective for 2030 is making green hydrogen production cost-competitive, developing hydrogen valleys and using low-carbon hydrogen in selected mobility segments such as long-distance HDVs and rail, and as feedstock in some industrial processes such as oil refining. Also some demonstration projects in local public transport are foreseen. By 2050, hydrogen technologies are expected to reach a certain level of maturity and their application is foreseen in hard-to-abate sectors, such as aviation and maritime. The document also opens to the possibility of blending hydrogen in existing natural gas grids, in order to start boosting demand and creating an internal market for hydrogen.

The projected 2030 hydrogen demand would be partly supplied by 5 GW electrolyser capacity to be installed over the same period (MISE, 2020, p.20) and partly by importing

[47] MISE (2020), Strategia Nazionale Idrogeno - Linee Guida Preliminari. Available at: https://www.mise.gov.it/images/stories/documenti/Strategia_Nazionale_Idrogeno_Linee_guida_preliminari_nov20.pdf.

low-carbon hydrogen. In terms of investment, the Guidelines foresees €10 billion investments between 2020 and 2030, specifically: €5-7 billion for hydrogen production; €2-3 billion for transport and distribution infrastructures; € 1 billion for R&D activities. Up to 50% of such investments would come from both national instruments and European instruments, such as the NGEU (Next Generation EU) and the Innovation Fund. In economic terms, these investments are expected to generate €27 billion additional GDP, and to contribute to the creation of approximately 200,000 temporary jobs in the short-term and 10,000 permanent jobs in the medium-term. In terms of environmental benefits, 2% of hydrogen share in final energy demand would reduce emissions by approximately 8 megatonne of CO2, contributing to 4% of NCEP's objectives (MISE, 2020, p.13).

Although the document sketches the potential role of hydrogen in different end-use sectors, sectoral objectives are only foreseen for long-distance HDVs. They account for 5-10% of total emissions from transport. However, considering that car manufactures are required to reduce average CO2 emission from new HDVs by 15% by 2025 and by 30% by 2030[48], they are investing in alternative-fuelled vehicles. Hence, hydrogen-powered HDVs are projected to account for 2% of total fleet by 2030 (roughly 200,000 units) and up to 80% (MISE, 2020, pp.5-6). The 2030 share might reach 5-7%, depending on the outcomes of the Fit for 55 legislative proposals, the establishment of an enabling regulatory framework and financial mechanisms, and the development of a strong infrastructure backbone. The Guidelines recommend the installations of HRS in strategic areas for long-distance trucks, as well as further investments in R&D to improve technologies across the entire hydrogen value chain.

4.4. The National Recovery and Resilience Plan

In 2020, the EU provided an unprecedented stimulus package worth € 2.018 trillion[49] to address the immediate economic and social consequences of the Covid-19 crisis, as well as to boost a green and digital recovery in line with EU's long-term objectives. The package consists of €1.211 trillion from the 2021-2027 MFF and € 806.9 billion from

[48] Regulation (EU) 2019/1242 sets EU-wide CO2 emission standards for HDVs for 2025 and 2030. In its 2022 work programme, the EC announced a revision of this Regulation by the fourth quarter of 2022 (COM/2021/645)
[49] € 1.8 trillion in 2018 prices.

NextGenerationEU (NGEU), a dedicated temporary instrument to power the recovery (EC, 2021b, p.6)[50].

The Recovery and Resilience Facility (RRF) is the main pillar of NGEU. It is worth €723.8 billion to be distributed to MS in grants (€ 338 billion) and loans (€ 385.8 billion) between mid-2021 and 2026 and to be repaid by 2058. In order to receive those funds, MS shall submit their national recovery and resilience plans (NRRPs) to the EC for approval. The RRF revolves around seven flagship areas (EC, 2021b, p.8), namely:

- *Power up* to accelerate the roll-out of clean technologies and use of renewables
- *Renovate* to improve energy efficiency of public and private buildings
- *Recharge and Refuel* to accelerate the deployment of recharging and refuelling stations to promote smart and sustainable mobility
- *Connect* for a faster roll-out of broadband services across the EU, including 5G
- *Modernise* to digitalise public administration and services
- *Scale-up* to increase European industrial data cloud capacities
- *Reskill and upskill* to adapt education systems in order to support digital skills and educational and vocational training

Under the RRF, Italy will receive € 68.9 billion in grants and €122.6 billion in loans (current prices), totalling € 191.5 billion (EC, 2021c). The Italian NRRP was submitted to the EC for assessment on 30 April 2021. After positive assessment by the EC on 22 June 2021 and its approval by the Ecofin Council on 13 July 2021, Italy and the EC signed a financing agreement for grants and a loan agreement and the EC disbursed the pre-financing of €24.9 billion on 13 August 2021. Payments under the RRF are performance-based. Hence, upon achievement of 2021 objectives, Italy submitted to the EC a payment request for the disbursement of €21 billion on 30 December 2021. After EC's positive preliminary assessment and Ecofin Council's approval, Italy received the €21 billion-worth first instalment on 13 April 2022 (Camera dei Deputati, 2022; EC, n.d.-a).

The Italian NRRP plan revolves around six "Missions" and includes 16 components (Figure 4) to be implemented through a mix of investments and reforms. Those related to

[50] MFF is worth € 1.074 trillion in 2018 price, while NGEU € 750 billion in 2018 prices.

green hydrogen are included in Mission 2 (M2) "green revolution and ecological transition" under component C2 "renewable energy, hydrogen, grid and sustainable mobility". Overall budget for Mission 2 amounts to €59.46 billion (31.05% of the total value of the NRRP) and component C2 is worth almost its half (€ 23.78 billion).

Figure 4: The Italian NRRP – Breakdown by Missions and Components, in billion €.
(Source: EC, 2021e, p.32)

Mission	Component	Costs (EUR million)
Mission 1 (digitalisation, innovation, competitiveness, culture and tourism)	M1C1. Digitalisation, innovation and security in the PA	9 722
	M1C2. Digitalisation, innovation and competitiveness in the production system	23 895
	M1C3. Tourism and culture 4.0	6 675
Mission 2 (green revolution and ecological transition)	M2C1. Circular economy and sustainable agriculture	5 265
	M2C2. Renewable energy, hydrogen, grid and sustainable mobility	23 778
	M2C3. Energy efficiency and renovation of buildings	15 362
	M2C4. Protection of land and water resources	15 054
Mission 3 (infrastructures for sustainable mobility	M3C1. Investments in the rail network	24 767
	M3C2. Intermodality and integrated logistics	630
Mission 4 (education and research)	M4C1. Strengthening the provision of education services:from crèches to universities	19 436
	M4C2. From research to business	11 440
Mission 5 (inclusion and cohesion)	M5C1. Employment policies	6 660
	M5C2. Social infrastructure, households, the community and the third sector	11 216
	M5C3. Special interventions for territorial cohesion	1 975
Mission 6 (health)	M6C1. Local networks, facilities and telemedicine for local health care	7 000
	M6C2. Innovation, research and digitalisation of the national health service	8 626
	Total	**191 499**

Under Mission M2C2, the Plan allocates €3.19 billion to green hydrogen production, distribution and final uses, namely:

- €500 million for green hydrogen production (Investment 3.1). This investment aims at creating from 5 to 10 hydrogen valleys in disused industrial areas already connected to the electricity grid. This means that such areas will be reconverted to test green hydrogen production and local distribution via trucks or existing natural gas networks. For each area a production capacity of 1-5 MW is expected to be developed. Furthermore, investment 5.2[51] allocates additional €450 million for the production of electrolysers, with the aim of reaching approximately 1 GW of electrolysis capacity by 2026 and 5GW by 2030, in line with the objectives of the EU Hydrogen Strategy, and the RFF flagship "Power Up", which supports the instalment of 500 GW renewable power generation (EU-wide) by 2030 (40% to be installed by 2025).

- €2 billion for the use of green hydrogen as a feedstock in hard-to-abate sectors (Investment 3.2), namely chemical, oil refining, steel-making, glass and paper sectors.

- €230 million for demonstration projects in road transport (Investment 3.3), aiming at reaching the 5-7% share of hydrogen-powered truck by 2030, as foreseen in the Preliminary Guidelines on the National Hydrogen Strategy. In line with the RFF flagship "Recharge and Refuel" which aims at building 500 HRS along the TEN-T core by 2025 (and 1,000 HRS by 2030), the Italian NRRP foresees the installation of 40 HRS for trucks in strategic areas for long-distance travels by June 2026.

- €300 million for demonstration projects in rails (Investment 3.4) to introduce hydrogen-powered trains into the national rail network and replace diesel trains where electrification is not economically feasible (currently about 40% of the national network). Accordingly, 9 HRS for trains will be installed, serving 6 railway lines.

[51] Investment 5.2 is under M2C2 as well; however, it belongs to another set of investments, i.e., to "develop an international, industrial and R&D leadership in key sectors for the green transition" (translated from Italian). Source: Italia Domani (n.d.)

- €160 million for R&D activities to improve technologies across the entire value chain (Investment 3.5)

Investments will be backed up by a set of reforms to streamline bureaucracy, reduce regulatory barriers to hydrogen deployment and boost hydrogen competitiveness. These include *i.a.* simplification of administrative procedures for building small-scale green hydrogen production plants; technical standards for green hydrogen production, transportation, storage and use; system of guarantees of origin for green hydrogen; harmonised measures for the installations of HRS along motorways, in ports and logistic warehouses; tax incentives to support green hydrogen production.

4.4.1. Hydrogen-related projects under the NRRP

The Italian Minister of Ecological Transition, in charge of implementing the green dimension of the NRRP, has published a call for expressions of interest and two bidding notices for hydrogen-related projects to be financed with NGEU funds.

In line with the investment to kick-off green hydrogen production provided for under M2C2, the call for expressions of interest, launched in December 2021, is directed to Regions and aims at identifying and funding projects to convert disused industrial areas into sites for green hydrogen production and distribution. Eligible projects for funding shall be completed by the end of 2025[52].

The two bidding notices aim at allocating a total of €50 million for hydrogen R&D projects, as provided for under the M2C2. The first bid (€20 million)[53] targets research bodies and universities, while the second (€ 30 million) targets private companies (with the possibility of including research bodies in the agreement)[54]. Both notices specify that projects eligible for funding shall concern R&D activities on (i) green hydrogen production; (ii) innovative technologies for green hydrogen storage, transport and

[52] G.U. n. 21 of 27 January 2022, Serie Generale, p. 69. Available at: https://www.gazzettaufficiale.it/eli/gu/2022/01/27/21/sg/pdf.

[53] MITE, Avviso Pubblico, 23 March 2022 n.0000004. Available at: https://www.mite.gov.it/sites/default/files/archivio/bandi/avviso_R_S_H2_tipo_a_23_03_2022.pdf

[54] MITE, Avviso Pubblico, 23 March 2022 n.0000005. Available at: https://www.mite.gov.it/sites/default/files/archivio/bandi/avviso_R_S_H2_tipo_b_23_03_2022.pdf.

conversion in e-fuels; (iii) development of fuel cells for both stationery and mobility applications. Furthermore, they shall last at least 12 months and shall be completed by end of 2025.

4.5. Hydrogen Valleys in Italy

4.5.1. The Hydrogen Valley South-Tyrol

The Hydrogen Valley South-Tyrol is one of the 40 flagship projects selected by the EC Mission Innovation, as a successful project for the promotion of hydrogen as sustainable link between energy and mobility (FuelCellsWorks, 2022). The project, running from 2014 to 2035, aims at decarbonising mobility and covers the entire hydrogen value chain. It is leaded by the Institute for Innovative Technologies (IIT) in Bolzano in cooperation with the Brenner motorway, and sponsored by the Autonomous Region of Bolzano (FCH JU, n.d.). In 2014, the first Italian centre for green hydrogen production, storage and distribution was opened in Bolzano. It was financed by the European Regional Development Fund (ERDF), and as of today it is regarded as one of the most innovative European hydrogen centres, with a production, storage and distribution capacity able to supply up to 700 buses per day or up to 700 hydrogen-powered cars (Autostrada del Brennero, n.d.). Contextually to its opening, South Tyrol participated in two EU-funded pilot projects, i.e., HyFIVE (Hydrogen For Innovative Vehicles) and CHIC (Clean Hydrogen in European Cities). Under HyFive, the IIT was able to manage a fleet of 10 FCEVs available to both private and corporate customers for long term rental. Data shows that more than 860,000 kilometres were driven (H2IT, 2019, p.47); whereas CHIC supported the deployment of 5 buses for public transports, operating 6 days per week, 12 hours per day. Data collected for the CHIC project shows that pilot hydrogen-powered buses drove around 630,000 kilometres between 2014 and 2016, saving some 270,000 litres of diesel (H2 South Tyrol, n.d.-a). The HRS in Bolzano supplied more than 10,5000 refuelling as of 2019 (H2IT, 2019, p.47).

Building on the success of CHIC, a new fleet of 12 hydrogen buses was purchased as part of the JIVE (Joint Initiative for Hydrogen Vehicles across Europe) project, funded by the FCH JU. This fleet features among the largest in the EU (Provincia di Bolzano, 2021). The Province of Bolzano co-financed the purchase, continuing to invest in hydrogen mobility. Moreover, it also decided to co-finance, as part of the MEHRLIN (Models for Economic Hydrogen Refuelling Infrastructure) project, the installation of another HRS, directly at the depot of hydrogen buses in the city (H2 South Tyrol, n.d.-b; Provincia di Bolzano, 2021).

4.5.2. The Life3H Project: Three Hydrogen Valleys in Central Italy

The one in South Tyrol was the first hydrogen valley in Italy. However, due to rising interest around hydrogen over last years, other demonstration projects are on-going.

Life3H is a demonstration project running from September 2021 to September 2025, co-founded by the EU programme LIFE 2020 and coordinated by Regione Abruzzo, in partnership with public bodies, research institutions, industrial partners and consultancies (Regione Abruzzo, 2022). The project aims at setting up three Hydrogen Valley in three different regional contexts, namely: seaport (Port of Civitavecchia, Lazio), urban (historical city of Terni, Umbria) and mountain/park areas (Altopiano delle Rocche, Abruzzo) – thus paving the way for a trans-regional hydrogen valley. Concretely, the project supports the deployment of 6 hydrogen buses (2 per each site) fuelled with surplus hydrogen coming from local industries – in a circular economy approach – and 3 HRS. The buses in Civitavecchia will serve a transport line dedicated to cruise passengers within the areas of the Port of Civitavecchia, while the ones in Terni and Altopiano delle Rocche will drive in urban areas, and main urban and touristic routes, respectively (Life3H, n.d.). SNAM has already been commissioned the building of two of the three HRS. Beyond supporting the deployment and gradual uptake of zero-emission vehicles, the project also aims at raising citizens' awareness and policy commitment towards hydrogen-based mobility, and promotes the implementation of integrated local regulatory approaches, e.g., inclusion of hydrogen in regional transport and energy plans to bolster the deployment of HRS (Life3H, n.d).

4.6. Final remarks

Based on a Confindustria's assessment (2020), Italy has the potential to become a prominent European hydrogen hub and driver of hydrogen economy – if it builds on some features characterising its economy and if enabling policy and regulatory frameworks are established. Firstly, Italy can count on a strategic position in the Mediterranean See and on an extensive natural gas network, which might be repurposed for hydrogen transport and distribution – at least in early stages. If properly integrated, both elements would configure Italy as a central hydrogen distribution and storage hub (Confindustria, 2020, p.19), able not only to serve internal demand but also to distribute hydrogen to other European clusters. Secondly, a country expertise in core and ancillary hydrogen technologies is a significant factor for its prominence in the hydrogen economy. Although fuel cell production is not particularly well established in Italy – amounting to € 1billion in 2018 compared to € 21.8 billion in Germany (European House Ambrosetti, 2020, p.180) – Italy is the second EU manufacturer of electrolysis' core technologies, accounting for 25.2% of total EU production in 2018 (European House Ambrosetti, 2020, p.180).

In line with the overarching European energy and climate agenda, which has been giving an increasingly prominent role to hydrogen in recent years, and following other EU MS, Italy has also started to include hydrogen in its national energy and climate policies in recent years, and published preliminary guidelines on an upcoming national hydrogen strategy, which seem to have been integrated in the NRRP.

Green hydrogen use in transport sector is addressed either in the preliminary guidelines and in the NRRP, although to different extent compared to upstream areas or other end-use application, e.g., industrial process where (grey) hydrogen is already used as a feedstock. On road transport, targets and projection for market uptake of FCEVs, particularly HDVs, are mentioned in both documents; however, projects are limited to some road transport segments (e.g., buses) and to the demonstration stage, suggesting that this is not a key priority in the short-term – presumably also due to the fact that other clean alternative, such as BEVs, are already mature and cost-competitive, at least for the car segment.

The lower scale of ambition for green hydrogen use in road transport is evident also from the scale of the investments: More than the half of funds allocated to green hydrogen under the NRRP goes to the decarbonisation of existing hydrogen industrial uses (€2 billion out of €3.19 billion), followed by green hydrogen production and subsequent creation of hydrogen valleys (€500 million), demonstration projects in rails (€300 million) and lastly demonstration projects in road transport (€230 million). Also R&D activities – and related bidding notices recently published by the Italian Minister of Ecological Transition – are expected to focus mainly on scaling-up of green hydrogen production in order to abate cost, and deploying innovative technologies for hydrogen storage and transportation. Although there are examples of successful private-public projects in road transport, they are limited to some regional areas and it remains to be seen whether there will be a follow-up at national level. Lastly, it is worth pointing out that the preliminary guidelines foresee scope for blue hydrogen in a transitional phase (although not produced domestically, but imported), whereas investments of the NRRP are devoted exclusively to green hydrogen.

The Italian approach seems to be consistent with certain recommendations from both industry and academia concerning priorities for the development of a hydrogen economy. As previously discussed in section 2.2, hydrogen applications are at the end of the supply chain. Taking stock from that, and considering that hydrogen economy is still in its infancy and is not fully regulated, it becomes clear that progress in downstream areas can be achieved if bottlenecks and barriers in upstream areas are fixed, e.g., abatement of production costs, regulatory barriers for production, availability of infrastructure. Hence, the subsequent priority of governments to focus first and foremost on upstream areas and then on end-use applications. Furthermore, the Italian pathway seems to go in the direction set by the overarching EU Hydrogen Strategy, which aims at scaling-up green hydrogen production and decarbonising existing hydrogen application, first. Then, once technologies reach a certain level of maturity and green-hydrogen become cost-competitive, its application will be mainstreamed across end-use sectors, including transport.

Finally, the Italian policy (and regulatory) framework cannot be considered in isolation, disregarding developments at European level. Centrepieces of the European energy and climate legislation are under revision to be adapted to the enhanced climate ambitions. The Fit for 55 Package includes a number of legislative proposals affecting the hydrogen dimension in road transport to different extents. The legislative procedure is in early stages for most of the proposals – and the outcomes of interinstitutional negotiations, i.e., the content of final texts adopted, and their implementation at MS level (when required) are likely to affect future direction and developments.

Conclusion

This thesis had the objective to investigate to what extent existing EU and national strategies are adequate to support large-scale development of green-hydrogen solutions in road transport. The analysis of the European and Italian policy frameworks illustrates that hydrogen is gaining interest for its versatility and multiple application in end-use sectors, thus for its potential contribution to decarbonisation objectives. Considering that hydrogen economy is still in its infancy, a sound policy (and regulatory) framework is needed – and some progress has been made in recent years. The EU published its ad-hoc hydrogen strategy in 2020, providing a vision on the role of hydrogen towards the achievement of EGD objectives and setting short-, mid- and long-term targets. Since then, a rising number of MS announced their national hydrogen strategies or included hydrogen targets in their NRRPs. Some of the legislative proposals within the Fit for 55 Package concerns different stages of the hydrogen value chain and are likely to impact green hydrogen mainstreaming in end-use sectors, including road transport.

Italy has not adopted a national hydrogen strategy yet. Nevertheless, preliminary guidelines have been issued and the NRRP allocates a dedicated budget for green hydrogen production, distribution and final uses (particularly in industry) as well as for demonstration projects in rail and road transport. However, the scale of investments for those latter projects in downstream areas is considerably lower compared to investments foreseen in upstream areas, e.g., production and distribution – and the same applies at EU level.

Thanks to short refuelling times, lower added weight for stored energy, and zero emissions at the point of use, FCEVs would be a promising solution for the decarbonisation of specific road transport segments, e.g., long-haul and heavy-duty. Existing pilot private-public projects in road transport, as well as roadmaps which include hydrogen as a part of a systemic transformation do represent a step forward towards its integration in the path towards zero-emission mobility and are encouraging indicators of political and business commitment. However, large-scale deployment of hydrogen technologies in downstream areas is largely dependent on progress achieved in upstream areas, where barriers and bottlenecks still need to be addressed, e.g., abatement of production costs, regulatory barriers for production and storage, infrastructure development and availability. Before green hydrogen can be mainstreamed and become a game-changer in road transport, those upstream barriers need to be overcome. This is the priority and main focus of existing European and Italian strategies which, consequently, do not seem to be adequate to enable large-scale deployment of green hydrogen in road transport.

Limitation and future research

Although it was possible to provide a clear answer to the overarching research question, findings need to be interpreted in light of some limitations. As already pointed out in the discussion, the hydrogen economy is still in its infancy and has not been fully regulated yet. This research focused on strategies which set a vision and (non-binding) targets for green hydrogen deployment across the entire value chain – although to different extents and different timeframes. However, considering that legislative proposals touching upon the hydrogen dimension in transport are currently under negotiation at EU level, this research could be repeated at a later stage – with the aim of understanding whether strategies' commitments translated into law and to what extent barriers and bottlenecks identified have been solved.

References

Bibliography

ACEA (2021a) 'Fuel types of new cars: battery electric 9.8%, hybrid 20.7% and petrol 39.5% market share in Q3 2021' [online]. ACEA. Available at: https://www.acea.auto/fuel-pc/fuel-types-of-new-cars-battery-electric-9-8-hybrid-20-7-and-petrol-39-5-market-share-in-q3-2021/. [Lastly accessed: 23rd May 2022]

ACEA (2021b) 'Position paper on the Proposal for the Alternative Fuels Infrastructure Regulation (AFIR)', November 2021. Available at: https://www.acea.auto/publication/position-paper-proposal-alternative-fuels-infrastructure-regulation-afir/.

ACEA (2021c) 'Position paper on the Proposal for the revision of the CO2 targets for cars and vans', November 2021. Available at: https://www.acea.auto/publication/position-paper-proposal-for-the-revision-of-the-co2-targets-for-cars-and-vans/.

Abdin, Z., Zafaranloo, A., Rafieed, A., Mérida, W., Lipiński, W., Khalilpouraef, K.R. (2020) 'Hydrogen as an energy vector', *Renewable and Sustainable Energy Review,* 120. doi: https://doi.org/10.1016/j.rser.2019.109620.

Ajanovic, A., Haas, R. (2019), 'Economic and Environmental Prospects for Battery Electric- and Fuel Cell Vehicles: A Review'. Available at: https://doi.org/10.1002/fuce.201800171.

Ajanovic, A. and Haas, R. (2021) 'Prospects and impediments for hydrogen and fuel cell vehicles in the transport sector', *International Journal of Hydrogen Energy,* 46(16), pp. 10049–10058. doi: https://doi.org/10.1016/j.ijhydene.2020.03.122.

Alverà, M. (2020) Rivoluzione idrogeno. La piccola molecola che può salvare il mondo. Milano: Mondadori Electa.

Autostrada del Brennero (n.d) 'Idrogeno' [online]. Available at: https://www.autobrennero.it/it/sostenibilita/idrogeno. [Lastly accessed: 04th June 2022]

Camera dei Deputati (2022), 'Il Piano Nazionale di Ripresa e Resilienza (PNRR)', 13 April 2022 [online]. Available at: https://temi.camera.it/leg18/temi/piano-nazionale-di-ripresa-e-resilienza.htm. [Lastly accessed: 11th June 2022]

Capurso, T., Stefanizzia, M., Torresia, M., Camporeale, S.M,. (2022) 'Perspective of the role of hydrogen in the 21st century energy transition', Energy Conversion and Management, 251. doi: https://doi.org/10.1016/j.enconman.2021.114898.

Chatzimarkakis, J. (2021) 'Fit for 55: looking for a hero net zero' EURACTIV, 19 July 2021. Available at: https://www.euractiv.com/section/energy-environment/opinion/fit-for-55-looking-for-a-hero-net-zero/. [Lastly accessed: 03rd June 2022]

Confindustria (2020) 'Piano d'azione per l'idrogeno'. Available at: https://www.confindustria.it/home/policy/position-paper?filter_start_date=2020-09-01&filter_end_date=2020-10-31&dti=01/09/2020&dtf=31/10/2020&filter_category [Lastly accessed: 31st May 2022]

Council of the EU, (2022) 'Fit for 55 package: Council adopts its position on three texts relating to the transport sector' [online], 2 June 2022, Council of the European Union. Available at: https://www.consilium.europa.eu/en/press/press-releases/2022/06/02/fit-for-55-package-council-adopts-its-position-on-three-texts-relating-to-the-transport-sector/. [Lastly accessed: 10th May 2022]

De Blasio, N. (2021) 'The role of clean hydrogen for a sustainable mobility', Harvard University Belfer Center. Available at: https://www.belfercenter.org/publication/role-clean-hydrogen-sustainable-mobility.

EASAC – European Academies Science Advisory Committee (2019) *Decarbonisation of Transport: options and challenges*. Halle (Saale): German National Academy of Sciences. Available at: https://easac.eu/publications/details/decarbonisation-of-transport-options-and-challenges/.

EC – European Commission (n.d.-a) 'Recovery and Resilience Scoreboard. Country overview: Italy' [online]. Available at: https://ec.europa.eu/economy_finance/recovery-and-resilience-scoreboard/country_overview.html?country=Italy. [Lastly accessed: 1st June 2022]

EC – European Commission (2017), Commission Staff Working Document: Detailed Assessment of the National Policy Frameworks accompanying the EC Communication 'Towards the broadest use of alternative fuels Infrastructure under an Action Plan on Alternative Fuels Article 10(6) of Directive 2014/94/EU'. SWD (2017) 0365 final, 8 November 2017. Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52017SC0365.

EC – European Commission, Directorate-General for Research and Innovation (2018a) *Final report of the of the high-level panel of the of the European Decarbonisation Pathways Initiative*. Luxemburg: Publication Office of the European Union. doi: https://data.europa.eu/doi/10.2777/636.

EC – European Commission (2018b) 'In-Depth Analysis in Support of the Communication COM (2018) 773: A Clean Planet for All. A European long-term strategic vision for a prosperous, modern, competitive and climate neutral economy'. Available at https://knowledge4policy.ec.europa.eu/publication/depth-analysis-support-com2018-773-clean-planet-all-european-strategic-long-term-vision_en.

EC – European Commission (2020a), Commission Staff Working Document accompanying the document 'Sustainable and Smart Mobility Strategy – putting European transport on track for the future'. SWD/2020/331 final, 9 December 2021. Available at: https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX%3A52020SC0331.

EC – European Commission (2020b), Commission Staff Working Document 'Assessment of the final national energy and climate plan of Italy'. SWD (2020) 911 final, 14 October 2020. Available at: https://ec.europa.eu/energy/sites/ener/files/documents/staff_working_document_assessment_necp_italy.pdf.

EC – European Commission, Directorate-General for Mobility and Transport (2021a) *EU transport in figures: statistical pocketbook 2021*. Luxemburg: Publication Office of the European Union. doi: https://data.europa.eu/doi/10.2832/27610.

EC – European Commission, Directorate-General for Budget (2021b) *The EU's 2021-2027 long-term budget and NextGenerationEU: facts and figures*. doi: https://data.europa.eu/doi/10.2761/808559.

EC – European Commission (2021c) 'NextGenerationEU: European Commission endorses Italy's €191.5 billion recovery and resilience plan', 22 June 2021 [online]. Available at: https://ec.europa.eu/commission/presscorner/detail/en/ip_21_3126. [Lastly accessed: 1st June 2022]

EC – European Commission (2021d) 'Questions and Answers - Emissions Trading – Putting a Price on carbon, 14 July 2021 [online]. Available at: https://ec.europa.eu/commission/presscorner/detail/en/qanda_21_3542. [Lastly accessed: 3rd June 2022]

EC – European Commission (2021e) 'Commission Staff Working Document 'Analysis of the recovery and resilience plan of Italy' accompanying the Proposal for a Council Implementing Decision on the approval of the assessment of the recovery and resilience plan for Italy'. SWD (2021) 165 final, 22 June 2021. Available at: https://eur-lex.europa.eu/legal-content/IT/TXT/?uri=CELEX:52021SC0165.

EC – European Commission (2022a), 'In focus: Reducing the EU's dependence on imported fossil fuels' [online], European Commission, 20 April 2022. Available at: https://ec.europa.eu/info/news/focus-reducing-eus-dependence-imported-fossil-fuels-2022-apr-20_en [Lastly Accessed: 30 May 2022]

EC – European Commission (2022b) Commission Staff Working Document accompanying the document 'REPoweEU Plan'. SWD (2022) 230 final, 18 May 2022. Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=SWD%3A2022%3A230%3AFIN.

EC – European Commission (2022c) 'Eurobarometer: Europeans approve EU's response to the war in Ukraine' [online], European Commission, 5 May 2022. Available at: (https://ec.europa.eu/commission/presscorner/detail/en/ip_22_2784. [Lastly accessed: 30 May 2022]

EC – European Commission (2022d) 'Factsheet on Financing REPowerEU' [online], European Commission, 18 May 2022. Available at: https://ec.europa.eu/commission/presscorner/detail/en/FS_22_3135 [Lastly accessed: 30 May 2022]

ECCO (2022) 'Abbandono gas russo: Bruxelles accelera su efficienza energetica e rinnovabili. e l'Italia?' [online] 18 May 2022. Available at: https://eccoclimate.org/wp-content/uploads/2022/05/Comunicato-Stampa_REPowerEU.pdf. [Lastly accessed: 30 May 2022]

EEA - European Environment Agency, (2021) 'Greenhouse gas emissions from transport in Europe' [online]. European Environment Agency. Available at: https://www.eea.europa.eu/ims/greenhouse-gas-emissions-from-transport#:~:text=It%20is%20anticipated%20that%20transport,their%201990%20level%20in%202029 [Lastly accessed: 17th May 2022]

EEB – European Environmental Bureau (2021a) *Hydrogen: The reality behind the hype [Position Paper],* European Environmental Bureau, Brussels. Available at: https://eeb.org/library/hydrogen-eeb-position-paper/.

EEB – European Environmental Bureau (2021b) 'EU's 'Fit for 55' is unfit and unfair' [online], 14 July 2021. Available at: https://eeb.org/eus-fit-for-55-is-unfit-and-unfair-ngos-say/. [Lastly accessed: 3rd June 2022]

EEB – European Environmental Bureau (2022) 'REPowerEU paves the way for renewables but also undermines environmental legislation' [online] European Environmental Bureau, 18 May 2022. Available at: https://eeb.org/repowereu-paves-the-way-for-renewables-but-also-undermines-environmental-legislation/. [Lastly accessed: 30 May 2022]

Ember, E3G, RAP and Bellona (2022) ‘EU can stop Russian gas imports by 2025’. Available at: https://bellona.org/news/climate-change/2022-03-eu-can-stop-russian-gas-imports-by-2025)

EP – European Parliament (2022a) ‘Fit for 55: MEPs back objective of zero emissions for cars and vans in 2035’[online], 8 June 2022, European Parliament. Available at: https://www.europarl.europa.eu/news/en/press-room/20220603IPR32129/fit-for-55-meps-back-objective-of-zero-emissions-for-cars-and-vans-in-2035. [Lastly accessed: 10th May 2022]

EP – European Parliament (2022b) ‘Fit for 55: Environment Committee to work on way forward on carbon-pricing laws’[online], 8 June 2022, European Parliament. Available at: https://www.europarl.europa.eu/news/en/press-room/20220603IPR32130/fit-for-55-environment-committee-to-work-on-way-forward-on-carbon-pricing-laws. [Lastly accessed: 10th May 2022]

European Clean Hydrogen Alliance (2021) *Reports of the Alliance Roundtables on barriers and mitigation measures.* Available at: https://ec.europa.eu/growth/system/files/2021-11/ECH2A%20RTs%20reports%20on%20barriers%20and%20mitigation%20measures_FINAL.pdf [Lastly accessed: 23rd May 2022]

European House Ambrosetti (2020) *H2 Italy: Una filiera nazionale dell'idrogeno per la crescita e la decarbonizzazione dell'Italia* [online]. Available at: www.snam.it/export/sites/snam-rp/repository/file/Media/news_eventi/2020/H2_Italy_2020_ITA.pdf.

Erbach, G. (2019) *Energy storage and sector coupling Towards an integrated, decarbonised energy system*, European Parliamentary Research Service. Available at: https://www.europarl.europa.eu/thinktank/en/document/EPRS_BRI(2019)637962.

Erbach, G. (2021) *EU hydrogen policy: Hydrogen as an energy carrier for a climate-neutral economy,* European Parliamentary Research Service. Available at: https://www.europarl.europa.eu/thinktank/en/document/EPRS_BRI(2021)689332.

Faber, V. (2022) ‘Why Europe’s hydrogen ambitions need a flexible policy approach’, EURACTIV, 12 April 2022. Available at: https://www.euractiv.com/section/energy-environment/opinion/why-europes-hydrogen-ambitions-need-a-flexible-policy-approach/. [Lastly accessed: 29th May 2022]

FCH JU – Fuel Cells and Hydrogen Joint Undertaking (n.d.) ‘Hydrogen Valley South Tyrol’ [online]. Available at: https://www.h2v.eu/hydrogen-valleys/hydrogen-valley-south-tyrol. [Lastly accessed: 04th June 2022]

FCH JU – Fuel Cells and Hydrogen Joint Undertaking (2019) *Hydrogen roadmap Europe: a sustainable path for the European energy transition.* Luxemburg: Publication Office of the European Union. Available at: https://www.fch.europa.eu/news/hydrogen-roadmap-europe-sustainable-pathway-european-energy-transition.

FCHO – Fuel Cells and Hydrogen Joint Undertaking Observatory (n.d.) *EU Policies – Hydrogen end use. Transport. Road Transport.* Available at: https://www.fchobservatory.eu/observatory/policy-and-rcs/eu-policies?term_node_tid_depth=156 [Lastly accessed: 31 May 2022]

Friends of the Earth and Food&Water action Europe (2020) On *The Inside: How the gas lobby infiltrates EU decision making on energy. An obscure body representing the gas industry.* Available at: https://friendsoftheearth.eu/publication/how-gas-lobby-infiltrates-eu/. [Lastly accessed 28th May 2022]

FSR – Florence School of Regulation (n.d.) 'Road transport' [online]. Available at: https://fsr.eui.eu/transport/road/ [Lastly accessed: 28th May 2022]

FSR – Florence School of Regulation (2020) 'Sector Coupling and Energy System Integration' [online], 22 December 2020. Available at: https://fsr.eui.eu/sector-coupling-and-energy-system-integration/ [Lastly accessed: 28th May 2022]

FuelCellsWork (2022) 'South Tyrol: "Hydrogen Valley South Tyrol" selected as a lighthouse project' [online], 5 May 2020. Available at: https://fuelcellsworks.com/news/south-tyrol-hydrogen-valley-south-tyrol-selected-as-a-lighthouse-project/. [Lastly accessed: 04th June 2022]

Gabbatiss, J. (2022) 'In-depth Q&A: How the EU plans to end its reliance on Russian fossil fuels' [online], Carbon Brief, 20 May 2022. Available at: https://www.carbonbrief.org/in-depth-qa-how-the-eu-plans-to-end-its-reliance-on-russian-fossil-fuels/. [Lastly accessed: 30 May 2022]

Genovese, M., Cigolotti, V., Jannelli, E., Fragiacomo, P. (2022) 'Comparative study of Global, European and Italian Standards on Hydrogen Refueling Stations', *E3S Web Conference, EFC21 - European Fuel Cells and Hydrogen Piero Lunghi Conference*, Volume 334. doi: https://doi.org/10.1051/e3sconf/202233409003.

Giuli, M. (2022) *Italy in the international hydrogen economy*, Istituto Affari Internazionali, Roma. Available at: https://www.iai.it/en/pubblicazioni/italy-international-hydrogen-economy. [Lastly accessed: 8th June 2022]

Global Witness (2022), 'REPowerEU plans will pour billions into gas for decades to come, costing consumers and the climate' [online], Global Witness, 18 May 2022. Available at: https://www.globalwitness.org/en/press-releases/repowereu-plans-will-pour-billions-gas-decades-come-costing-consumers-and-climate/ [Lastly accessed: 30th May 2022]

Greenpeace (2021) 'EU Commission 'Fit for 55' package unfit to contain climate crisis' [online] Greenpeace, 14 July 2021. Available at: https://www.greenpeace.org/eu-unit/issues/climate-energy/45795/eu-commission-fit-for-55-package-unfit-to-contain-climate-crisis/. [Lastly accessed: 3rd June 2022]

H2 South Tyrol (n.d.-a) 'CHIC' [online]. Available at: https://www.h2-suedtirol.com/en/chic. [Lastly accessed: 04th June 2022]

H2 South Tyrol (n.d.-b) 'MEHRLIN' [online]. Available at: https://www.h2-suedtirol.com/en/mehrlin. [Lastly accessed: 04th June 2022]

Hydrogen Council (2017) *How hydrogen empowers the energy transition*. Available at: https://hydrogencouncil.com/en/study-how-hydrogen-empowers/.

Hydrogen Council, McKinsey & Company (2021*) Hydrogen Insights: A perspective on hydrogen investment, market development and cost competitiveness*. Available at: https://hydrogencouncil.com/en/hydrogen-insights-2021/.

Hydrogen Europe (n.d), 'Policy priorities', Hydrogen Europe. Available at: https://hydrogeneurope.eu/policy-priorities/ [Lastly accessed: 30th May 2022]

Hydrogen Europe (2020) 'Hydrogen Europe position paper on the Sustainable and Smart Mobility Strategy' [Position Paper], May 2020. Available at: https://hydrogeneurope.eu/position-papers/.

Hydrogen Europe (2021a) 'Alternative fuels infrastructure as the key to unlock the potential of hydrogen-fuelled mobility' [Position Paper], November 2021. Available at : https://hydrogeneurope.eu/position-papers/.

Hydrogen Europe (2021b) 'CO2 emissions standards for cars and vans: a powerful instrument for new clean vehicle fleets' [Position Paper], November 2021. Available at : https://hydrogeneurope.eu/position-papers/.

Hydrogen Europe (2021c) 'Reforming carbon markets to enable a liquid, sustainable and affordable hydrogen markets' [Position Paper], November 2021. Available at : https://hydrogeneurope.eu/position-papers/.

Hydrogen Europe (2022) ‘Delivering REPowerEU through a strong European hydrogen industry’ [Position Paper], May 2022. Available at: https://hydrogeneurope.eu/position-papers/.

H2IT – Associazione Italiana Idrogeno e Celle a Combustibile (2019), *Piano Nazionale di sviluppo – Mobilità idrogeno Italia*. Associazione Italiana Idrogeno e Celle a Combustibile. Available at: https://www.h2it.it/h2it-pubblica-il-piano-nazionale-di-sviluppo-mobilita-idrogeno-italia/.

H2ME – *Hydrogen Mobility Europe (2021), Emerging Conclusions 2021 – H2ME Phase 1*. Available at: https://h2me.eu/publications/emerging-conclusions-2021-h2me-phase-1/. [Lastly accessed: 23rd May 2022]

Howarth, R.W. and Jacobson, M.Z. (2021) ‘How green is blue hydrogen?’, *Energy Science & Engineering*, 9(10), pp. 1676–1687. doi: https://doi.org/10.1002/ese3.956.

IEA (2019) *The future of hydrogen*, International Energy Agency, Paris. Available at: https://www.iea.org/reports/the-future-of-hydrogen.

IEA (2021a) *Global EV Outlook 2021: Accelerating ambitions despite the pandemic*, International Energy Agency, Paris. Available at: https://www.iea.org/reports/global-ev-outlook-2021.

IEA (2021b), *Hydrogen,* International Energy Agency, Paris. Available at: https://www.iea.org/reports/hydrogen.

IEA (2021c), *Net Zero by 2050*, International Energy Agency, Paris. Available at: https://www.iea.org/reports/net-zero-by-2050.

IEA (2022), *A 10-Point Plan to Reduce the European Union’s Reliance on Russian Natural Gas, International Energy Agency*, Paris. Available at: https://www.iea.org/reports/a-10-point-plan-to-reduce-the-european-unions-reliance-on-russian-natural-gas.

IRENA (2020) *Green Hydrogen: A guide to policy making,* International Renewable Energy Agency, Abu Dhabi. Available at: https://irena.org/publications/2020/Nov/Green-hydrogen.

IRENA (2021a) *Renewable Power Generation Costs in 2020*, International Renewable Energy Agency, Abu Dhabi. Available at: https://www.irena.org/publications/2021/Jun/Renewable-Power-Costs-in-2020.

IRENA (2021b) *World energy transitions outlook: 1.5°C pathway,* International Renewable Energy Agency, Abu Dhabi. Available at: https://irena.org/publications/2021/Jun/World-Energy-Transitions-Outlook.

IRENA (2022a) *Geopolitics of the Energy Transformation: The Hydrogen Factor*, International Renewable Energy Agency, Abu Dhabi. Available at: https://www.irena.org/publications/2022/Jan/Geopolitics-of-the-Energy-Transformation-Hydrogen.

IRENA (2022b) *Global hydrogen trade to meet the 1.5°C climate goal: Part III – Green hydrogen cost and potential*, International Renewable Energy Agency, Abu Dhabi. Available at: https://www.irena.org/publications/2022/May/Global-hydrogen-trade-Cost.

Italia Domani – Piano Nazionale di Ripresa e resilienza, (n.d) 'Hydrogen' [online], Italia Domani. Available at: https://italiadomani.gov.it/en/Interventi/investimenti/idrogeno.html. [Lastly accessed: 9th June 2022]

JRC – Joint Research Centre (2019) 'Hydrogen use in EU decarbonisation scenarios'. Available at: https://joint-research-centre.ec.europa.eu/jrc-news/hydrogen-use-eu-decarbonisation-scenarios-2019-04-17_sl [Lastly accessed: 24th May 2022]

Kneebone, J. and Conti, I. (2022) 'A first look at the REPowerEU: The European Commission's plan for energy independence from Russia' [online], Florence School of Regulation, 19 May 2022. Available at: https://fsr.eui.eu/first-look-at-repowereu-eu-commission-plan-for-energy-independence-from-russia/. [Lastly accessed: 31st May 2022]

Lambert, M. (2020) 'EU Hydrogen Strategy – A case for urgent action towards implementation', The Oxford Institute for Energy Studies. Available at: https://www.oxfordenergy.org/publications/eu-hydrogen-strategy-a-case-for-urgent-action-towards-implementation/.

Letter to European Commission President Von der Leyen (2020), *Wide industry coalition call for a Hydrogen Strategy inclusive of all clean hydrogen pathways* (24 June 2020). Available at: https://iogpeurope.org/resource/wide-industry-coalition-call-for-a-hydrogen-strategy-inclusive-of-all-clean-hydrogen-pathways/. [Lastly accessed: 28th May 2022]

Life3H (n.d) 'Making Hydrogen Valley a Reality'. Available at: https://www.life3h.eu/. [Lastly accessed: 04th June 2022]

Liu, X., Reddi K., Elgowainy A., Lohse-Busch H., Wang M., Rustagi N. (2020) 'Comparison of well-to-wheels energy use and emissions of a hydrogen fuel cell electric vehicle relative to a conventional gasoline-powered internal combustion engine vehicle', *International Journal of Hydrogen Energy*, 45(1), pp. 972–983. doi: https://doi.org/10.1016/j.ijhydene.2019.10.192.

McWilliams, B. and G. Zachmann (2021) 'Navigating through hydrogen', Policy Contribution 08/2021, Bruegel. Available at: www.bruegel.org/wp-content/uploads/2021/03/PC-08-2021_.pdf. [Lastly accessed: 30th may 2022]

Miotti, M., Hofer, J. and Bauer, C. (2017) 'Integrated environmental and economic assessment of current and future fuel cell vehicles.', *The International Journal of Life Cycle Assessment*, 22, pp. 94–110. doi: https://doi.org/10.1007/s11367-015-0986-4.

Mims – Ministero delle infrastrutture e della mobilità sostenibili (2022) *Decarbonizzare i trasporti: Evidenze scientifiche e proposte di policy.* Mims, April 2022. Available at: https://www.mit.gov.it/comunicazione/news/rapporto-stemi-presentato-ministro-giovannini-decarbonizzazione-trasporti.

MISE – Ministero dello Sviluppo Economico (2020), *Strategia Nazionale Idrogeno - Linee Guida Preliminari,* November 2020. Available at: https://www.mise.gov.it/images/stories/documenti/Strategia_Nazionale_Idrogeno_Linee_guida_preliminari_nov20.pdf.

Noussan, M., Raimondi, P.P., Scita, R., Hafner, M. (2020) 'The Role of Green and Blue Hydrogen in the Energy Transition—A Technological and Geopolitical Perspective', *Sustainability 2021*, 13(1), 298. doi: https://doi.org/10.3390/su13010298.

OEIL – Observatoire Législatif Institutionnel Législatif (2022a) 'Deployment of alternative fuels infrastructure - 2021/0223(COD)' [online]. Available at: https://oeil.secure.europarl.europa.eu/oeil/popups/ficheprocedure.do?reference=2021/0223(COD)&l=en. [Lastly accessed: 9th June 2022]

OEIL – Observatoire Législatif Institutionnel Législatif (2022b) 'Renewable Energy Directive - 2021/0218(COD)' [online]. Available at: https://oeil.secure.europarl.europa.eu/oeil/popups/ficheprocedure.do?reference=2021/0218(COD)&l=en. [Lastly accessed: 9th June 2022]

Ogden, J.M. (2018) 'Prospects for Hydrogen in the Future Energy System', Institute of Transportation Studies – University of California, Davis. Available at : https://escholarship.org/content/qt52s28641/qt52s28641_noS(plash_dfcf3398196d9cc9eab57e4d6aa83fdc.pdf?t=pvz5it.

Provincia di Bolzano (2021) 'Mobilità sostenibile: dodici nuovi bus a idrogeno, tre per Bolzano' [online], 13 May 2021. Available at: https://news.provincia.bz.it/it/news-archive/655761. [Lastly accessed: 04th June 2022]

Regione Abruzzo (2022) 'LIFE3H (Hydrogen demonstration in city, port and mountain area to develop integrated hydrogen valleys)', 15 February 2022. Available at: https://www.regione.abruzzo.it/content/life3h-hydrogen-demonstration-city-port-and-mountain-area-develop-integrated-hydrogen-0. [Lastly accessed: 04th June 2022]

Scita, R., Raimondi, P.P., & Noussan, M. (2020) 'Geopolitical implications of the future hydrogen economy'. In M. Hafner (Ed.), *Green Hydrogen: the Holy Grail of Decarbonisation? An Analysis of the Technical and Geopolitical Implications of the Future Hydrogen Economy* (pp. 16–28). Fondazione Eni Enrico Mattei (FEEM). doi: http://www.jstor.org/stable/resrep26335.6.

Soone, J. (2021) *Alternative fuel vehicle infrastructure and fleets: State of play*, European Parliamentary Research Service. Available at: https://www.europarl.europa.eu/thinktank/en/document/EPRS_BRI(2021)698794.

Stagnaro, C. (2021), 'Case study Italy: Optimising emissions cuts means we'll need "grey" and "blue" Hydrogen too' [online], Energy Post. Available at: https://energypost.eu/case-study-italy-optimising-emissions-cuts-means-well-need-grey-and-blue-hydrogen-too/. [Lastly accessed 28th May 2022]

Transport & Environment (2020) *How European transport can contribute to an EU -55% emissions target in 2030, Transport and Environment*, Brussels. Available at : https://www.transportenvironment.org/wp-content/uploads/2021/07/2020_02_TE_EGD_vision_How_EU_transport_can_contribute_minus_55.pdf.

UNEP (2019), *Emissions Gap Report 2019,* United Nations Environment Programme, Nairobi. Available at: https://www.unep.org/resources/emissions-gap-report-2019.

UNFCCC (2021), 'COP26 world leaders summit- statement on the breakthrough agenda' [online], *UN Climate Change Conference UK 2021*, United Nations Framework Convention on Climate Change, 2 November 2021. Available at: https://ukcop26.org/cop26-world-leaders-summit-statement-on-the-breakthrough-agenda/. [Lastly accessed: 06th June 2]

Van Nuffel, L. (2018) *Sector coupling: how can it be enhanced in the EU to foster grid stability and decarbonise?,* Policy Department for Economic, Scientific and Quality of Life Policies Directorate-General for Internal Policies – Study for the ITRE Committee. Available at: https://www.europarl.europa.eu/RegData/etudes/STUD/2018/626091/IPOL_STU(2018)626091_EN.pdf.

Van de Graaf, T., Overland, I., Scholten, D., Westphal, K. (2020) 'The new oil? The geopolitics and international governance of hydrogen', *Energy Research & Social Science*, 70, 101667.doi: https://doi.org/10.1016/j.erss.2020.101667.

van Renssen, S. (2020) 'The hydrogen solution?', *Nature Climate Change*, 10, pp. 799–801. doi: https://doi.org/10.1038/s41558-020-0891-0.

Wang, A., van der Leun, K., Peters, D., Busema, M. (2020) 'European Hydrogen Backbone: How a dedicated hydrogen infrastructure can be created'. Available at: https://gasforclimate2050.eu/sdm_downloads/european-hydrogen-backbone/

Widuto, A. (2022) *Preparing for 'RepowerEU': Action for more secure, more affordable and cleaner energy,* European Parliamentary Research Service. Available at: https://www.europarl.europa.eu/thinktank/en/document/EPRS_ATA(2022)729421.

Wilson, A.B (2021), *Revision of the Renewable Energy Directive: Fit for 55 package*, European Parliamentary Research Service. Available at: https://www.europarl.europa.eu/thinktank/en/document/EPRS_BRI(2021)698781.

WWF – World Wide Fund for Nature (2020) 'EU Hydrogen Strategy Opens Arms to Fossil Fuels' [online], World Wide Fund for Nature, 21 July 2020. Available at: https://wwf.panda.org/discover/knowledge_hub/where_we_work/black_sea_basin/danube_carpathian/?364637/EU-Hydrogen-Strategy [Lastly accessed 28th May 2022].

WWF (2021) 'Half-baked EU climate proposals missing key ingredients' [online], World Wide Fund for Nature, 14 July 2021. Available at: https://www.wwf.eu/wwf_news/media_centre/?uNewsID=4039866. [Lastly accessed: 03rd June 2022]

Official Documents

Legislative acts – European Union

Directive 2014/94/EU of the European Parliament and of the Council of 22 October 2014 on the deployment of alternative fuels infrastructure (2014) Official Journal L 307/1, 1-20.

Directive (EU) 2018/2001 of the European Parliament and of the Council of 11 December 2018 on the promotion of the use of energy from renewable sources (2018) Official Journal L 328/82, 82-209.

Regulation (EU) 2018/1999 of the European Parliament and of the Council of 11 December 2018 on the Governance of the Energy Union and Climate Action, amending Regulations (EC) No 663/2009 and (EC) No 715/2009 of the European Parliament and of the Council, Directives 94/22/EC, 98/70/EC, 2009/31/EC, 2009/73/EC, 2010/31/EU, 2012/27/EU and 2013/30/EU of the European Parliament and of the Council, Council Directives 2009/119/EC and (EU) 2015/652 and repealing Regulation (EU) No 525/2013 of the European Parliament and of the Council. Official Journal L328, 1-77.

Regulation (EU) 2019/631 of the European Parliament and of the Council of 17 April 2019 setting CO2 emission performance standards for new passenger cars and for new light commercial vehicles, and repealing Regulations (EC) No 443/2009 and (EU) No 510/201. Official Journal L 111/13, 13-53.

Regulation (EU) 2021/1119 of the European Parliament and of the Council of 30 June 2021 establishing the framework for achieving climate neutrality and amending Regulations (EC) No 401/2009 and (EU) 2018/1999 ('European Climate Law'). Official Journal L 243, 1-17.

Non-legislative acts – European Union

Council of the European Union – General Secretariat of the Council, General Approach on the Proposal for a Regulation of the European Parliament and of the Council on the deployment of alternative fuels infrastructure, and repealing Directive 2014/94/EU of the European Parliament and of the Council, 9585/22. 3 June 2022. Available at: https://data.consilium.europa.eu/doc/document/ST-9585-2022-INIT/en/pdf.

EC – European Commission (2011), "White Paper: Roadmap to a Single European Transport Area – Towards a competitive and resource efficient transport system". COM (2011)144 final, 28 March 2011.

EC – European Commission (2016), Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions, "A European Strategy for Low-Emission Mobility" COM/2016/0501 final, 20 July 2016

EC – European Commission (2018), Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee, the Committee of the Regions and the European Investment Bank, "A Clean Planet for all: A European strategic long-term vision for a prosperous, modern, competitive and climate neutral economy." COM/2018/773 final, 28 November 2018.

EC – European Commission, (2019), Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the regions, “The European Green Deal”. COM(2019)640 final, 12 December 2019.

EC – European Commission, (2019), Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the regions, “A New Industrial Strategy for Europe”. COM/2020/102 final, 10 March 2020.

EC – European Commission (2020), Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions, “A hydrogen strategy for a climate-neutral Europe.” COM/2020/301 final, 8 July 2020.

EC – European Commission (2020), Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions, “Powering a climate-neutral economy: An EU Strategy for Energy System Integration.” COM/2020/299 final, 8 July 2020.

EC – European Commission (2020), Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions, “Sustainable and Smart Mobility Strategy – putting European transport on track for the future.” COM/2020/789 final, 9 December 2020.

EC – European Commission (2021), Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions, “Fit for 55: delivering the EU's 2030 Climate Target on the way to climate neutrality”. COM (2021) 550 final, 14 July 2021.

EC – European Commission (2021), Proposal for a Directive of the European Parliament and of the Council amending Directive 2003/87/EC establishing a system for greenhouse gas emission allowance trading within the Union, Decision (EU) 2015/1814 concerning the establishment and operation of a market stability reserve for the Union greenhouse gas emission trading scheme and Regulation (EU) 2015/757. COM/2021/551 final, 14 July 2021.

EC – European Commission (2021), Proposal for a Regulation of the European Parliament and of the Council amending Regulation (EU) 2019/631 as regards strengthening the CO2 emission performance standards for new passenger cars and new light commercial vehicles in line with the Union’s increased climate ambition. COM/2021/556 final, 14 July 2021.

EC – European Commission (2021), Proposal for a Directive of the European Parliament and of the Council on amending Directive (EU) 2018/2001 of the European Parliament and of the Council, Regulation (EU) 2018/1999 of the European Parliament and of the Council and Directive 98/70/EC of the European Parliament and of the Council as regards the promotion of energy from renewable sources, and repealing Council Directive (EU) 2015/652. COM (2021) 557 final, 14 July 2021.

EC – European Commission (2021), Proposal for a Regulation of the European Parliament and of the Council on the deployment of alternative fuels infrastructure, and repealing Directive 2014/94/EU of the European Parliament and of the Council. COM/2021/559 final, 14 July 2021.

EC – European Commission (2021), Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions 'Commission work programme 2022: Making Europe stronger together'. COM/2021/645 final, 19 October 2021.

EC – European Commission (2022), Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions, "REPower EU Plan". COM/2022/230 final, 18 May 2022.

EP – European Parliament – Committee on Transport and Tourism, Draft Report on the proposal for a regulation of the European Parliament and of the Council Deployment of alternative fuels infrastructure, and repealing Directive 2014/94/EU of the European Parliament and of the Council. 2021/0223(COD), 14 February 2022. Available at: https://www.europarl.europa.eu/doceo/document/TRAN-PR-719568_EN.html

EP – European Parliament – Committee on Industry, Research and Energy, Draft Report on the proposal for a directive of the European Parliament and of the Council amending Directive (EU) 2018/2001 of the European Parliament and of the Council, Regulation (EU) 2018/1999 of the European Parliament and of the Council and Directive 98/70/EC of the European Parliament and of the Council as regards the promotion of energy from renewable sources, and repealing Council Directive (EU) 2015/652. 2021/0218(COD), 14 February 2022. Available at: https://www.europarl.europa.eu/doceo/document/ITRE-PR-719550_EN.html.

Italy

Ministero dello Sviluppo Economico, Ministero dell'Ambiente e della Tutela del Territorio e del Mare, Ministero delle Infrastrutture e dei Trasporti (2019), Piano Nazionale Integrato per l'Energia e il Clima. Available at: https://www.mise.gov.it/images/stories/documenti/PNIEC_finale_17012020.pdf.

Ministero dello Sviluppo Economico (2020), Strategia Nazionale Idrogeno - Linee Guida Preliminari. Available at: https://www.mise.gov.it/images/stories/documenti/Strategia_Nazionale_Idrogeno_Linee_guida_preliminari_nov20.pdf.

Piano Nazionale di Ripresa e Resilienza – PNRR (2021). Available at: https://www.camera.it/temiap/2021/06/25/OCD177-4986.pdf.

Ministero della Transizione Ecologica, Avviso Pubblico del 15 Dicembre 2021, Registro Ufficiale U.0027509. Available at: https://www.mite.gov.it/sites/default/files/archivio/bandi/AECE/2021_12_15_Avviso_pubblico_PNRR_M2C2_Investimento_3.1.pdf. Published in the Official Journal G.U n. 21 of 27 January 2022, Serie Generale, p. 69.

Ministero della Transizione Ecologica, Avviso Pubblico del 23 Marzo 2022 n.0000004. Available at: https://www.mite.gov.it/sites/default/files/archivio/bandi/avviso_R_S_H2_tipo_a_23_03_2022.pdf

Ministero della Transizione Ecologica, Avviso Pubblico del 23 Marzo 2022 n.0000005. Available at: https://www.mite.gov.it/sites/default/files/archivio/bandi/avviso_R_S_H2_tipo_b_23_03_2022.pdf.