CHAPTER 3

Italy in the European energy transition: the role of hydrogen

Introduction

The development of a European (green) hydrogen economy within a long-term energy transition path involves an essential role for those Member States that combine two main elements: the industrial readiness to develop clean energy technologies and a large potential for exploiting renewable energy sources, on the one hand, and the presence of hydrogen off-takers that can drive demand, on the other. However, the adoption of hydrogen is dependent on both the maturity of its production technologies and the cost-efficiency of its end-use applications. Therefore, only a simultaneous transition both in supply (through construction of new H_2 generation plants and infrastructures) and in consumption (through the substitution of transport means and/or industrial processes) can limit the «chicken-or-egg» problem that affects the H_2 value chain.

The path towards increased H_2 deployment has been made clearer by the EU Hydrogen Strategy, published in 2020. Its adoption has been followed by the rollout of national H_2 strategies in more than 19 EU Member States so far, including the major EU economies - Germany, France, Italy Spain and Poland. However, among these countries - which also represent the top energy-consuming and the largest GHG emitting EU Member States - Italy has been the last one to adopt a more comprehensive, long-term vision for the development of a hydrogen economy within its borders. Until late 2024, when the natural gas and hydrogen sector had already started forming private initiatives to give

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shape to the future H2 economy, Italy's "Hydrogen Strategy Preliminary Guidelines" were the only official policy document specifically addressed to the development of a national H_2 value chain. Later in 2021 Italy's hydrogen policy was almost entirely based on the different H_2 targets and investments included in its National Recovery and Resilience Plan (NRRP), whose implementation continues to this day.

Analysing the Italian case can prove to be interesting because, while it remained without a defined H_2 strategy during the decisive years of the energy crisis in which the EU decided to dramatically reduce its energy dependence on its historically largest gas supplier (Russia), the interest in developing hydrogen steadily increased in recent years, leading to improved investments in R&D for H_2 deployment and to participation in several international projects, including Important Projects of Common European Interest (IPCEI) and Mission Innovation (IEA, 2023a). At the same time, Italian decision-makers, especially after the start of Russia's war against Ukraine, have been increasingly advocating for Italy's potential role as an «energy bridge» between Europe and North Africa, focusing on natural gas imports in the short term and on clean hydrogen in the longer term, whereby the molecule can be produced from renewables at lower costs and imported into Europe, by taking advantage of Italy's geographic location and extensive gas network and interconnections.

Italy's relevance for the development of a hydrogen economy is given also by its territorial configuration. For instance, lower costs of electricity production through solar PV in the southern part of the country can raise the attractiveness of creating H_2 production hubs in southern Europe (together with Spain and Greece), which would then determine a different structure of the future hydrogen network. This would involve the creation of pipeline routes to import renewable hydrogen that cannot be produced domestically and achieve the EU's targets.

Given the recently approved EU Delegated Regulations on the criteria defining hydrogen as renewable (RFNBO) or low-carbon, and the adoption of the Hydrogen and Decarbonised Gas Package, it is essential for a country like Italy to develop its gas and power systems by considering the need for new cross-sector infrastructures. To this end, cooperation between the national gas and electricity transmission system operators (TSOs) must be enhanced, also because - especially after 2030, the development of new and repurposed hydrogen pipelines will unlock new possibilities for locating electrolysers, i.e. outside the areas where H_2 is consumed, thus reducing the need to reinforce the electricity grid in those areas where electrons will be used to both meet the conventional demand and feed the electrolysers. The potential cost savings resulting from the reduced need for further reinforcements of the electricity system will be compensated by increased investments in the hydrogen transport network.

Another critical part of the hydrogen infrastructure consists of H_2 storages (mainly salt caverns), which must be considered when deciding where to locate electrolysers. These can indeed adapt their electricity consumption for producing hydrogen based on their proximity to an H_2 storage site, resulting in a truly flexible use of the electricity system. In the presence of large storage capacities, the production of renewable hydrogen can be concentrated during the periods when the electricity system presents renewable production margins, avoiding the simultaneous operation of electrolysers and thermal power plants. The flexible operation of electrolysers has several advantages for system stability and the cost-effective integration of wind and solar generation, leading to low curtailment rates of renewables and a lower requirement for firm capacity[1] (Neumann et al. 2023).

Given the above-mentioned aspects, this chapter is divided into two sections. Drawing from the discussion on the EU's hydrogen production and import targets, the first section analyses the European hydrogen supply corridors, based on the figures produced by the European Hydrogen Backbone Initiative (EHBI) and the national targets set by the countries that have already released a national hydrogen strategy or that have been planning to do it. This will allow a comparison between a private sector initiative (the EHBI) and an institutional perspective. Given Italy's status as a potential import corridor that only recently started developing a long-term hydrogen roadmap, the second section will evaluate Italy's domestic policy initiatives towards H_2 development, thus preparing the ground for an in-depth discussion on hydrogen use in the hard-to-abate sectors in the final chapter of this thesis.

3.1 The European Hydrogen Supply Corridors

Higher costs, limited space for installing renewable power plants and the slow pace of new hydrogen capacity projects in Europe contribute to making H_2 imports (also in form of its chemical derivatives) more attractive. The establishment of several hydrogen import routes into the EU is necessary to achieve the H_2 supply targets set by REPowerEU (10 Mt of green H_2 production and 10 Mt imported). The key question is related to where such imports should come from and what the potential export or transit countries are doing to expand their hydrogen production capacities. Three main hydrogen import routes have been identified in REPowerEU, which states that the European Commission «could facilitate coordinated EU action in cooperation with industry to develop by 2030 three major hydrogen import corridors to North Africa, to the North Sea area and as soon as conditions allow to Ukraine» (European Commission 2022).

Therefore, based on several analyses of supply and demand potentials, as well as the TSOs' technical assessments of the ability to repurpose their natural gas pipelines and build new hydrogen pipelines, the European Hydrogen Backbone Initiative (EHBI) identified up to six supply corridors (North Sea, Baltic, Southeast and East, Southwest, North Africa-Italy). Those import routes were also integrated in a document of the European Clean Hydrogen Alliance (ECHA) in 2023, with the aim to accelerate their establishment. Nonetheless, it is important

[1] Firm capacity can be understood as a guarantee of a level of supplied power, which a supplier has committed to always make available during the period of commitment.

to define and justify the spatial dimension in which EU H_2 imports will occur, as several countries across the globe have pledged to start exporting hydrogen from their shores either via ship or via pipeline[2].

As was seen in the first chapter, while transporting ammonia appears much cheaper than pure hydrogen transport, for distances below 2000 km transporting hydrogen gas by pipeline is likely to be the cheapest delivery option, and above 1500 km ammonia (NH_3) or liquid organic hydrogen carriers (LOHC) delivered via ship become cost-effective[3]. Therefore, the identification of the EU's H_2 supply corridors has also been determined by the distance of supplier countries from the EU Member States, as well as by the already existing infrastructural links between potential hydrogen suppliers and EU importers. Depending on the carrier and the transport distance, costs can shift the competitiveness in favour of domestic production, which however in the case of the EU will not be enough to achieve the hydrogen targets for 2030 and beyond. Figure 18 shows the estimated significant differences in hydrogen import costs between geographical supply regions and between transport means and forms of hydrogen (liquid, compressed, or chemical carriers). Northwest Europe (Germany in particular) is considered as an example of a potential demand centre.

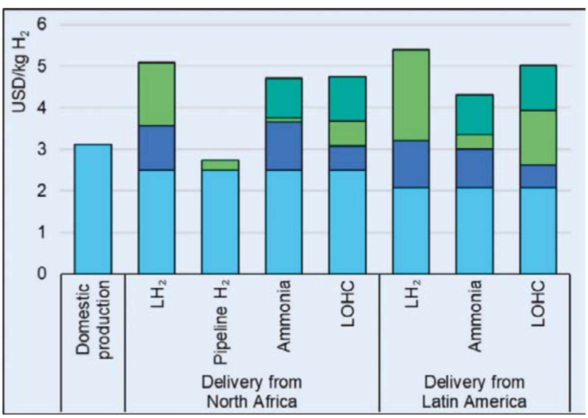

Figure 18 – Supply costs of hydrogen and ammonia in North-west Europe compared to imports ($\$/kg_{H2}$). Source: IEA (2023b). Notes: each colour represents the cost of one stage of H2 delivery: light blue = production, dark blue = conversion, light green = transport, dark green = re-conversion (e.g. ammonia cracking).

2 Potential hydrogen-exporting countries based on announcements made so far include Chile, Brazil, Canada, the US, Egypt, Saudi Arabia, the UAE, Namibia, Oman, Australia, and regions such as MENA and Latin America (IEA 2023b).

3 Around 10% of global ammonia demand was met through international trade (import-export) in 2021, and for methanol the trade share was 20%. However, existing trade is linked to use in the chemical industry, and international trade in ammonia and methanol for fuel purposes has only been tested in some first pilot projects (IEA, 2023b).

As shown in the figure, export from North African countries appears as the cheapest option among those present, mainly because hydrogen delivery via pipeline does not involve conversion and re-conversion costs. Although hydrogen levelised production costs (LCOH) in Latin America are cheaper than European domestic production, the transport costs (only possible via ship in form of ammonia or other chemical carriers) do not make Latin America optimal for supplying the EU countries with clean hydrogen. According to the International Energy Agency's «Global Hydrogen Review 2023», transporting compressed hydrogen via pipeline can indeed be the most competitive option in terms of cost, adding only about 0.4-0.5 $\$/kg_{H2}$ for a 3000 km distance, and potentially lowering this transport cost further if repurposed pipelines will become available[4].

However, there are several obstacles that must be addressed before new hydrogen trade routes can be opened. One important issue concerns the lack of a common internationally agreed methodology to determine the emission intensity of hydrogen (while it exists for EU domestic production), potentially leading to a fragmented market. Guaranteeing compliance of imported hydrogen with the EU's certification standards is necessary to develop import-export value chains. For this reason, strategic dialogue and partnerships are needed between the EU and exporters to create a framework for future H_2 trade (Directorate-General for Energy 2022)[5].

It is also important to define the most useful tools to ensure investment certainty in hydrogen trade. Bilateral trade agreements, often between companies, but in some cases involving government institutions, currently account for the majority of announced import-export projects (IEA 2023b). These provide clear pricing mechanisms that encourage investments in capital-intensive hydrogen projects. Auctions are another instrument for awarding trade contracts, by creating a bidding competition and helping move the demand- and supply-side price levels closer (IEA 2023b). The result of those not yet defined issues can be seen in the discrepancy between the EU policy targets for hydrogen import, and the announced hydrogen export projects to Europe. While the former set a 10 million tonnes of (clean) H_2 import target by 2030, the latter amount to around 5 Mt of hydrogen (IEA 2023b). This numbers are also due to the difficulty of exporters to identify potential hydrogen off-takers for their projects.

An analysis of the EHBI, conducted at the onset of Russia's war against Ukraine in 2022, has also shown that potential clean H_2 imports into Europe

[4] It should be considered that currently, the repurposing of existing methane pipelines faces potential availability constraints due to long-term natural gas commitments and capacity contracts which have been signed for the years to come. This signals that some pipelines might be unavailable for eventual repurposing to hydrogen transport, depending on the demand quantities after 2030. But as natural gas demand decreases in line with decarbonisation efforts, import capacities are likely to free up for hydrogen transport (Directorate-General for Energy 2022).

[5] On 5th December 2023, during the 28th Conference of the Parties to the U.N. Framework Convention on Climate Change, 39 countries (including Germany, Italy, the US, India and Brazil) endorsed the COP28 «Declaration of Intent on the Mutual Recognition of Certification Schemes for Renewable and Low-Carbon Hydrogen and Hydrogen Derivatives», thus signalling an increased but still slow pace in the international clean hydrogen trade.

could amount to around 5.4 million tonnes, while the study identified 12 Mt of domestic hydrogen supply potential by 2030 (European Hydrogen Backbone 2022). Such an amount of H_2 supply and import will be driven mainly by the German economy, which - according to its updated national H_2 strategy - expects demand of around 3 Mt (95-130 TWh) of H_2 across all sectors in 2030, including the need to decarbonise its current fossil-based unabated H_2 demand of 55 TWh (European Clean Hydrogen Alliance 2023). Having the largest gas storage capacity in the EU and the fourth in the world (after the USA, Russia and Ukraine), Germany can also gradually repurpose its gas storage sites to provide much-needed hydrogen storage capacity (including new salt caverns that are available adjacent to existing storage sites). The development of the German domestic hydrogen market has therefore significant effects on the overall realisation and speed of the EU hydrogen supply corridors (European Clean Hydrogen Alliance 2023). That is also why Germany has been included in each of the corridors identified in the EHBI study in 2022, and the German gas transmission operator Open Grid Europe (OGE) is involved in the establishment of all six corridors[6]. Those supply routes consider the same H_2 demand for Germany, and then add the projected demand of the countries concerned in each region.

3.1.1 North Sea Corridor

The potentially interconnected hydrogen supply corridor (Figure 19) in the North Sea area involves nine (both EU and non-EU) countries: Belgium, the Netherlands, Denmark, Germany, the UK, France, Luxembourg, Norway, and Ireland. By developing mainly offshore wind, large-scale integrated hydrogen projects and ramping up ship imports of H_2 derivatives (ammonia, methanol and LOHC), the corridor could help meet the demand of the energy-intensive industrial clusters in and around Rotterdam, Zeebrugge, Antwerp, Wilhelmshaven, le Havre, and the Ruhr area, to name a few.

Nonetheless, in the near term the corridor offers access to abundant low-cost blue hydrogen supply, thanks to the combination of existing natural gas reserves in the North Sea and the higher number of existing and planned CCS facilities compared to other parts of the continent (IOGP 2023). According to North Sea Energy (2022), green hydrogen production will steadily grow and be at par with blue H_2 by 2040, mainly thanks to wind energy produced offshore[7]. Indeed, the

[6] On 15th November 2023, the German government unveiled the details of the country's future hydrogen pipeline network, which is set to span 9,700 km by 2032, requiring a total investment of around €20 billion (which will be covered by private funding), and comprising 60% of existing natural gas pipelines. Construction of the hydrogen network is expected to commence next year, and the German government will provide financial support in the first 20 years to ensure commercially viable tariffs and promote the growth of a hydrogen economy, given the initially limited number of users of the network (HydroNews 2023).

[7] On 24th April 2023, the nine countries involved in shaping the North Sea hydrogen supply corridor signed the «Ostend Declaration» aiming to jointly build at least 120 GW of offshore wind energy capacity by 2030 and at least 300 GW by 2050 in the North Sea (Taylor 2023).

United Kingdom in its national H_2 strategy has foreseen to develop large-scale blue hydrogen projects to kick-start the H_2 economy from the mid-2020s, whereas renewable electrolysis will be developed through small-scale projects (HM Government 2021). While the exact hydrogen production mix by 2030 will be influenced by a range of factors such as the CO_2 and electricity prices, the UK's targets are expected to generate up to 42 TWh of «low-carbon hydrogen» by 2030 (HM Government 2021). Blue hydrogen supply will play an important role also for Norway, which since the start of Russia's war against Ukraine has become the EU's largest single natural gas supplier. The Norwegian Government's hydrogen strategy (published in 2020) explicitly promotes the production of methane-based hydrogen coupled with CCS, claiming that Norwegian authorities will work to ensure that natural gas reforming combined with CCS can compete on equal terms with hydrogen from water electrolysis in the European energy market (Norwegian Ministry of Petroleum and Energy 2020). Given the EU's current policy framework, it is essential to better coordinate the EU's import targets with the exporters' intentions regarding the nature of hydrogen. In its updated National Hydrogen Strategy, Germany claims to support «a limited amount of low-carbon blue hydrogen» (Bundesministerium für Wirtschaft und Klimaschutz 2023), thereby adopting a more flexible stance compared to its previous intention to invest only in green H_2.

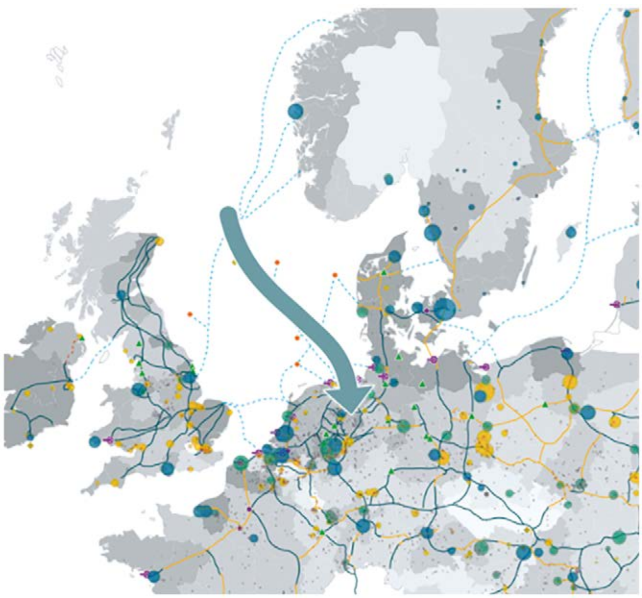

Figure 19 – The North Sea H_2 Supply Corridor. Source: European Hydrogen Backbone (2022).

Due to an already highly integrated offshore and onshore gas infrastructure and the national hydrogen backbones in the Netherlands, Belgium and Germany currently under construction, this North Sea import corridor is arguably the most advanced in terms of development stages. Up to 2030, industrial clusters in the UK and north-western Europe will drive hydrogen demand, whose estimates (including H_2 supply) are reported in Table 19. The transport and power sectors will contribute to increasing H_2 demand from 2040 onwards. On the other side, the corridor enables access to a hydrogen supply potential of around 250 TWh by 2030, increasing to roughly 850 TWh by 2040, with a significant increase of green H_2, which will represent around 70% of all hydrogen supply by 2040. The remaining supply will be made of blue (20%) and grid-based hydrogen (10%)[8]. As can be seen in the table, these last two hydrogen categories will increase less than the green supply between 2030 and 2040.

Table 19 – Demand and Supply of H_2 in the North Sea Corridor [TWh/year]. Source: own elaboration based on European Hydrogen Backbone (2022).

	2030	2040
Total demand[9]	~260	~900
Total supply (green H_2)	106	181
Total supply (blue H_2)	69	568
Total supply (grid-based H_2)	74	103

The demand centres in the North Sea area will be able to access hydrogen, whose production costs will progressively decrease. These will range between 1.6 and 3.5 €/kg_{H2} by 2030, and they will further diminish to around 1.5-2.6 €/kg_{H2} by 2040, due to increased supply options and decreased technology costs (European Hydrogen Backbone 2022). If we compare the costs of hydrogen supply with those of methane (CH_4), reported in Table 20, we can clearly note that hydrogen will more likely start replacing methane in the hard-to-abate industrial sectors from 2040 onwards, since its costs per MWh will still largely exceed those of natural gas by 2030[10].

With regard to the North Sea, central Europe and Germany in particular, a recent study from Aurora Energy Research (Tracey 2023) has shown that renewable hydrogen imports could compete with EU production by 2030, as the levelised cost of hydrogen in Germany will range between 3.9 and 5 €/kg_{H2} in 2030 compared to 3.1 €/kg_{H2} in Australia and Chile, 3.2 €/kg_{H2} in Morocco

[8] Grid-based hydrogen is produced from water electrolysis with a grid-connected electrolyser, which therefore does not guarantee the renewable nature of that hydrogen.

[9] The demand for 2030 is mostly concentrated in Germany (90-100 TWh per year), the Netherlands (46), Denmark (27), the UK (27) and Belgium (25 TWh). By 2040, the UK and the Netherlands increase their demand above 100 TWh.

[10] In order to compare methane with hydrogen, the costs of hydrogen have been converted from «per kg» to «per MWh»: 1 €/kg = 30 €/MWh (knowing that 1 kg of hydrogen has an energy value of about 33 kWh).

and 3.6 €/kg_{H2} in the UAE. Despite additional transport and conversion costs, Aurora claims that imports remain competitive, and that pipelines would provide the cheapest transport option for renewable hydrogen imports to Germany (Tracey 2023). According to the study, imports from Morocco via pipeline would cost 3.72 €/kg_{H2} in 2030, but currently the EU is not on track to have an operational hydrogen pipeline network that could deliver supplies from Morocco to Germany by 2030. Action to accelerate pipeline development could reduce import costs by at least 20% compared to transporting renewable hydrogen by ship (Tracey 2023).

Table 20 – Cost-competitiveness of hydrogen with natural gas in the North Sea Corridor [€/MWh]. Source: own elaboration based on European Hydrogen Backbone (2022).

	2030	2040
Hydrogen[11]	48-105	45-78
Methane	59-73	62-69

3.1.2 Nordic and Baltic Corridor

The development of offshore wind power supply is one of the main drivers also for the corridor (Figure 20) that can bring H_2 towards industrial clusters in the Baltic region, in Poland and eastern Germany. It is estimated that the Baltic Sea area holds a potential of 93 GW of offshore wind energy (Jordaens 2023). This corridor involves nine countries, which are all part of the EU: Finland, Sweden, Denmark, Estonia, Latvia, Lithuania, Poland, Czechia and Germany. One of the earliest, greenfield hydrogen infrastructure projects in Europe is indeed located in the Bothnian Bay (between Finland and Sweden) and has been identified as the «Nordic Hydrogen Route». Finland already has an onshore wind capacity of 5.7 GW, but the 42 MW «Tahkoluoto wind farm» in the Gulf of Bothnia is the only operational offshore wind farm it has so far (Jordaens 2023). The first sections of the Nordic Hydrogen Route project are expected to be operational by 2030, while the on- and off-shore wind capacity could reach 28 GW by 2030 and 48 GW by 2040, thus exceeding the growth of the regional electricity demand[12]. The Nordic Hydrogen Route investment is estimated at €3.5 billion, offering a hydrogen transportation cost (which adds to the production cost) of 0.1-0.2 €/kg_{H2} (European Hydrogen Backbone 2022). In early 2024, the «Nordic-Baltic Hydrogen Corridor» pipeline project, first presented

[11] The cost range for hydrogen includes green (wind and solar PV), blue and grid-based hydrogen. The lowest cost both for 2030 and 2040 is represented by the production cost of Norway's blue hydrogen, and the upper limit is given by Germany's grid-based and green H_2.

[12] Retrieved from the website of the «Nordic Hydrogen Route»: https://nordichydrogenroute.com/project/

in 2022, took a decisive step forward, as the concerned TSOs signed the contract assigning the specialised company AFRY Management Consulting Oy to carry out the pre-feasibility study for this future Northern European H_2 corridor (Hydronews 2024).

Figure 20 – The Nordic and Baltic H_2 Supply Corridor. Source: European Hydrogen Backbone (2022).

The demand and supply potentials of this corridor are mostly driven by the steel sector in Germany and in the Nordic countries, together with H_2 adoption in some transport applications. In this case, after Germany, Sweden is the leading driver of H_2 demand by 2030 (50 TWh), followed by Denmark (27 TWh), Finland (25 TWh) and Poland (22 TWh). By 2040, the hydrogen demand of all these countries is expected to increase, doubling in the case of Finland and Sweden, and rising six-fold for Poland (European Hydrogen Backbone 2022). On the side of hydrogen supply, both Sweden and Finland will contribute to a larger extent to ramping up green H_2. As shown in Table 21, renewable (mostly wind-based) hydrogen will dominate H_2 supply, leaving a smaller fraction to grid-based H_2. No blue hydrogen is instead envisaged in this corridor, except for Poland, whose national H_2 strategy points to a role for «low-carbon» (and thus also blue) hydrogen in partially decarbonising the country's economy (Ministerstwo Klimatu i Środowiska 2021).

In the envisioned hydrogen corridor, the evolution of production costs points to a region that is actively pursuing cost-effective production methods, while expanding renewable capacity. The levelised costs of hydrogen range from 2.1

to 3.8 €/kg$_{H2}$ in 2030, and they are projected to decrease significantly reaching 1.5-2.7 €/kg$_{H2}$ in 2040 (European Hydrogen Backbone 2022). The cost comparison between hydrogen and methane confirms the pattern identified in the North Sea corridor. While methane has an economic advantage over hydrogen in 2030 (Table 22), the cost dynamics begin to shift by 2040, as the cost of H_2 drops and becomes more competitive, whereas methane shows a much narrower range, which incorporates CO_2 costs.

Table 21 – Demand and Supply of H_2 in the Nordic and Baltic Corridor [TWh/year]. Source: own elaboration based on European Hydrogen Backbone (2022).

	2030	2040
Total demand	~220	~725
Total supply (green H_2)	130	423
Total supply (blue H_2)	-	-
Total supply (grid-based H_2)	54	48

Table 22 – Cost-competitiveness of hydrogen with natural gas in the Nordic and Baltic Corridor [€/MWh]. Source: own elaboration based on European Hydrogen Backbone (2022).

	2030	2040
Hydrogen[13]	63-114	45-81
Methane	59-73	63-69

Finland and Estonia published their hydrogen roadmaps in 2023. While the latter is focused on the first H_2 deployment steps until 2030, Finland's strategy explicitly states that the Nordic country aims to become «the leading high-value hydrogen economy in Europe by 2035» (Hydrogen Cluster Finland 2023), both by developing domestic clean H_2 production and by increasing its export of hydrogen-related technologies and services. According to Finland's strategic document, the country could produce 12 to 98 TWh/y of hydrogen by 2035 and between 80 and 212 TWh/y by 2024 (Hydrogen Cluster Finland 2023). Sweden has been focusing its efforts on upscaling hydrogen in industry and heavy-duty vehicles, as well as by setting electrolyser capacity targets (European Hydrogen Backbone 2022). However, as of late 2023, Sweden's hydrogen strategy is still in the draft stage.

[13] The lowest cost of hydrogen for both 2030 and 2040 is represented by the production cost of Denmark offshore wind-based hydrogen, and the upper limit is given by Poland's grid-based and green H_2.

Given the high dependency that green hydrogen production in this corridor will have on the installation of new wind farms, it is important to mention the current crisis that is affecting the wind power industry, and especially offshore wind. The global supply chain disruption caused by the Covid-19 pandemic pushed up the costs also for wind energy technologies, but while most companies could offset the cost increases by raising prices, several wind developers have been locked in contracts to sell power at rates set years ago (Paulsson et al. 2023). Therefore, the owners cannot adjust the price of the power they will sell when the projects come into operation. Companies have faced cost increases of 40% in the space of 12 to 18 months, according to the Swedish utility Vattenfall AB, and higher interest rates make it more expensive for wind developers to borrow from investors (Paulsson et al. 2023).

3.1.3 Eastern Corridor

The hydrogen supply route involving the EU's eastern Member States and neighbouring Ukraine features several short- and long-term uncertainties. For the purposes of this thesis, it is essential to highlight the potential contribution of Ukraine to the EU's hydrogen targets, while considering the existing bottlenecks and obstacles resulting from the ongoing war with Russia. Besides the current difficulties in kick-starting the development of hydrogen supply chains within its borders, Ukraine's situation has sparked concerns regarding the speed of its economic recovery and the operational state of its natural gas infrastructure. Ukraine would boast ideal conditions for the development of large-scale, renewable hydrogen production, thanks to its high renewable energy capacity potential, estimated at around 500-800 GW, with an H_2 supply potential of approximately 1000-1500 TWh (European Clean Hydrogen Alliance 2023). However, some of the best (sunnier and windier) locations for renewables are in the south and east of the country, where much of the Russian invasion has concentrated. Ukraine's well-established ammonia and steel production industries would be suitable candidates to consume (offtake) the green hydrogen produced, to create a first national hydrogen market. Additionally, the country features a substantial number of large-scale underground gas storage facilities, that could be retrofitted for storing H_2 (European Clean Hydrogen Alliance 2023)[14].

Notwithstanding the status quo, and given the existing large gas pipeline connections between Ukraine and the EU countries, different initiatives have taken shape with the goal to prepare the ground for clean hydrogen imports from Ukraine. The «Central European Hydrogen Corridor» is an initiative launched in 2021 by four gas infrastructure companies of the four countries involved in creating the corridor (Figure 21): OGE (Germany), NET4GAS (Czech Republic), Eustream (Slovakia), and Gas TSO of Ukraine (Ukraine) (CEHC 2023). This initiative ex-

[14] Moreover, at the end of 2021, Ukraine's national oil and gas company Naftogaz joined the European Clean Hydrogen Alliance, with the ambition to become a national leader in hydrogen production for export to EU countries.

plores the feasibility of creating a hydrogen «highway» through Central Europe, mainly relying on repurposed natural gas pipelines, combined with targeted investments in new H_2 lines and compressor stations. The project is currently in the pre-feasibility study, while the first results indicate that it is technically feasible to transport up to 52 TWh (or 1.5 Mt) of hydrogen per year by 2030. Total investment for the 1225-km hydrogen corridor, from the Ukraine/Slovakia border to large hydrogen demand centres in southern Germany, is estimated in €1-1.5 billion (CEHC 2023), which is relatively low. This is mainly because of the repurposing of already existing transport infrastructures. On the other hand, the investment costs of the Ukrainian part of the corridor will depend on the exact location of the hydrogen production sites in the country. Finally, the total expected levelised cost of hydrogen transmission (which adds to the production cost) is estimated to be in the range of 0.1-0.15 €/kg_{H2} per 1000 km, which is in the lower range of the cost estimated by the EHBI (0.11-0.21 €/kg_{H2})[15].

Figure 21 – The Central European Hydrogen Corridor. Source: https://www.cehc.eu/cehc-project/.

Before its invasion of Ukraine, Russia had also drafted a plan to ramp up low-carbon hydrogen exports to Europe (up to 2 Mt by 2035) to meet the demand from its former gas customers' growing commitments to decarbonisation (Martin 2023). But while there are currently no potential European buyers of Russian hydrogen (mainly due to the ongoing war and the effects of Western's sanctions), there are also no known incentives for Russian industries to switch from fossil-based hydrogen and fossil fuels to low-carbon hydrogen in the near term.

3.1.4 South-eastern Corridor

Another attractive route along which hydrogen can be produced and cost-effectively transported stretches over south-eastern Europe, involving Greece,

[15] Retrieved from: https://www.cehc.eu/cehc-project/

Bulgaria, Romania, Hungary, Slovenia, Croatia, Slovakia, Czechia, Austria as well as Germany. The opportunities offered by this corridor (Figure 22) are mainly due to the abundant renewable potential and the vast land availability coupled with high-capacity factors for solar PV and onshore wind especially in Romania, Ukraine and Bulgaria (European Hydrogen Backbone 2022).

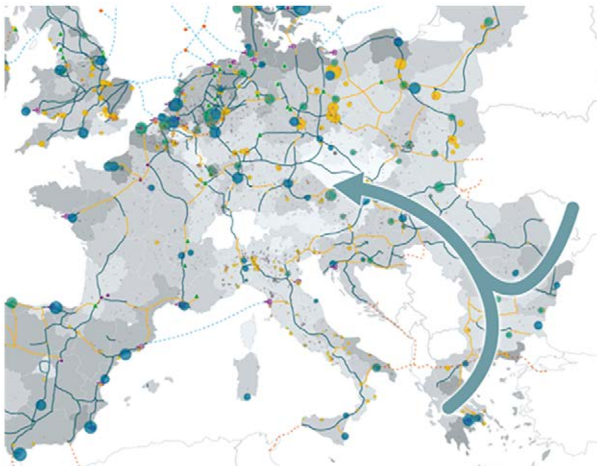

Figure 22 – The South-eastern H_2 Supply Corridor. Source: European Hydrogen Backbone (2022).

Table 23 reports the total hydrogen demand and supply potentials along the south-eastern corridor, where the major driver of H_2 adoption is the industrial sector, that uses hydrogen mainly as a feedstock. Besides Germany, the countries driving the demand in this area up to 2030 are Romania (14 TWh) and Austria, while they (together with Greece, Slovakia and Hungary) will increase their H_2 consumption more significantly by 2040, when e-fuels will be playing a greater role (European Hydrogen Backbone 2022). The corridor enables access to a hydrogen supply potential of around 50 TWh by 2030, of which 65% is made of grid-based hydrogen, increasing to roughly 350 TWh by 2040, with an 85% share of green hydrogen and a 15% grid-based H_2.

Table 23 – Demand and Supply of H_2 in the South-eastern Corridor [TWh/year]. Source: own elaboration based on European Hydrogen Backbone (2022).

	2030	2040
Total demand	~165	~660
Total supply (green H_2)	14	292
Total supply (blue H_2)	-	-
Total supply (grid-based H_2)	38	54

Compared to the other corridors analysed so far, the south-eastern supply route presents a much wider gap between demand and supply potentials, as demand is almost twice as the hydrogen supply in 2040. Such a scenario can be also due to the fact that some countries along this corridor have not yet adopted their hydrogen strategy and have not identified specific demand centres, that could help direct investments and provide for the creation of regional hydrogen markets. Austria, which adopted its H_2 strategy in 2022, emphasises the role of «climate-neutral hydrogen», thus including also blue H_2, as a necessary means to decarbonise up to 80% of its current industrial hydrogen use by 2030 (Bundesministerium, Klimaschutz, Umwelt, Energie, Mobilität, Innovation un Technologie 2022). Hungary, which adopted a strategy for H_2 in 2021, also highlights the need to develop blue hydrogen in the near term (up to 2030) for cost-efficiency reasons and, only after, start developing what the strategy calls «carbon-free hydrogen», produced via electrolysis. In particular, the strategic document sets a target of 20 000 tonnes per year of low-carbon H_2 and 16 000 tonnes of green H_2 by 2030, together with 240 MW of electrolyser capacity (Innovációs és Technológiai Minisztérium 2021). Slovakia also adopted its national H_2 strategy in 2021, planning to consume - mainly in industry, transportation and, only later, energy sectors - around 0.2 Mt/year of hydrogen domestically by 2030, while reaching around 0.4-0.6 Mt by 2050, 90% of which will be covered by low-carbon sources (Sinay 2021). The document further argues that the main goal will be to cover as much of the hydrogen needs as possible from domestic sources only, but in the long-term, it will be necessary to cover some of the consumption by import from abroad.

This is also why the role of (current or potential) transit countries such as Greece and Bulgaria proves important to enable hydrogen imports along this corridor from outside the EU. These two countries have indeed expressed their interest to enhance cooperation on hydrogen production and infrastructure planning. Greece's national natural gas system operator (DESFA) and Bulgaria's Bulgartransgaz signed a letter of intent for cooperation in the field of hydrogen, while the Bulgarian company is developing a project for retrofitting the national gas transmission system for transporting H_2[16].

In the south-eastern corridor, the ranges of the levelised cost of hydrogen generation are slightly above those examined in the previous corridors. By 2030, the south-eastern supply route features costs from 2.5 to 4.5 €/kg_{H2}, while these production costs decrease to 1.7-3.1 €/kg_{H2} as supply options increase, technology costs decrease and imports from Ukraine (ideally) scale up (European Hydrogen Backbone 2022). When comparing hydrogen and methane supply costs in this area, the data reported in Table 24 indicate a competitive edge for CH_4 around 2030, even when CO_2 costs are included. By 2040, however, the cost range for hydrogen decreases significantly, while methane costs remain rela-

[16] Retrieved from: https://www.desfa.gr/en/press-center/press-releases/desfa-and-bulgartransgaz-will-cooperate-in-the-field-of-hydrogen

tively high, thus suggesting that hydrogen will likely become more competitive as economies of scale are realised and investments in new natural gas supplies start decreasing.

Table 24 – Cost-competitiveness of hydrogen with natural gas in the South-eastern Corridor [€/MWh]. Source: own elaboration based on European Hydrogen Backbone (2022).

	2030	2040
Hydrogen[17]	75-135	51-93
Methane	59-73	62-69

3.1.5 South-western Corridor

The south-western hydrogen supply route can become a fundamental building block for hydrogen supply to north-western Europe. This corridor (Figure 23) includes Portugal, Spain, France, Belgium, Luxembourg and it terminates in Germany. While potentially exploiting green hydrogen production in the Iberian Peninsula in the short term, such corridor could also benefit from the existing interconnection between Spain and Morocco, thus providing access to hydrogen imports from the Maghreb country in the longer term[18].

Despite hosting around one third of the EU's LNG regasification capacity which can be repurposed for receiving hydrogen and a wide renewable potential that can be used to generate green H_2, the Iberian Peninsula currently suffers from a lack of energy interconnections with the rest of Europe, thus making the establishment of a south-western H_2 corridor more challenging. While being defined as an «energy island», Spain has been insisting on the need to urgently increase gas and electricity interconnections across the Pyrenees, but France steadily opposed such calls for several years and has only recently changed its position (Escribano 2022)[19]. Spain had claimed that France's continued opposition was due to its intention to safeguard its nuclear energy sector (which generates around three quarters of the nation's electricity) from the competitive influence of Spain and Portugal's ample renewable resources. Paris has further argued that technical difficulties for its predominantly nuclear-based grid could emerge if more Iberian renewable energy streams across France's borders are allowed.

17 The lowest cost of hydrogen for 2030 is represented by grid-based H_2 in Austria, and the lowest cost for 2040 is given by the import cost from Ukraine, while the upper limit is represented by Romania's wind-based green H_2.

18 Spain has two gas pipeline connections with Algeria: the first (Medgaz) is operating at full capacity; and the second (Maghreb Europe) transits through Morocco, but it was discontinued by Algeria in October 2021.

19 Resistance from Spain's northern neighbour has kept Spain far below the EU target for electricity interconnection, which is under 5%, compared with the targets of 10% for 2020 and 15% for 2030 (Escribano 2022).

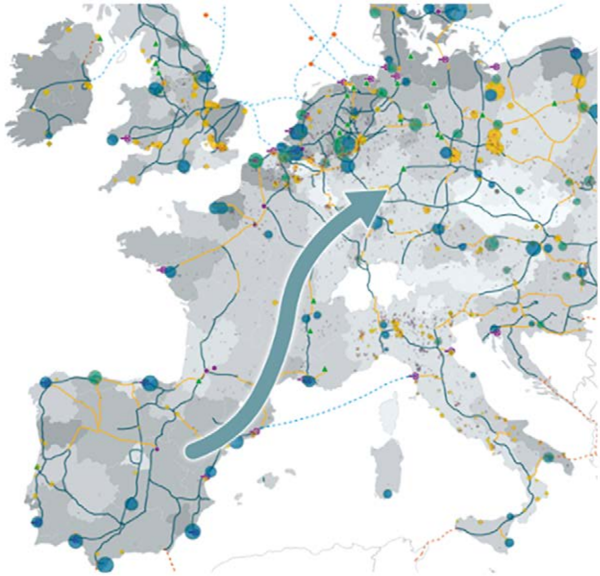

Figure 23 – The South-western H_2 Supply Corridor. Source: European Hydrogen Backbone (2022).

None of the interconnection summits held by successive French presidents with Spain led to tangible results, but now the newly re-launched «H2-Med» project could signal an improved effort towards the creation of a dedicated supply route. «H2-Med» indeed represents the third version of a suggested pipeline linkage between eastern Spain and France, which had been initially conceptualised as the «Midi-Catalonia» project, but this was put on hold and rejuvenated in 2021 as a hydrogen-ready natural gas interconnection linking Barcelona and Marseille (known as the «Bar-Mar»). However, the fact that this pipeline would have not been operational until 2030, led Spain to dump the project in favour of directly transporting hydrogen through the «H2-Med» subsea pipeline, thus also benefitting from facilitated EU financing (Onyango 2022). The planned interconnection has been included in the list of the «Projects of Common Interest» (PCI)[20] at the EU level, which was published by the European Commission (2023a) on 28th November 2023. One month earlier, Open Grid Europe (OGE), one of Germany's major gas grid operators which is also involved

[20] As was mentioned in the second chapter, PCI are energy infrastructure projects that link the energy systems of the different EU countries and can therefore benefit from accelerated permitting procedures and funding. The selection of those projects is made by the European Commission through a list that has been published every 2 years since 2013, and it gives preference to projects in corridors identified in the TEN-E Regulation.

in the development of the other corridors, had officially joined the «H2-Med» pipeline project (Kyllmann 2023).[21]

On the southern side of Spain, one long-term opportunity for this corridor would be the potential repurposing of the Maghreb-Europe pipeline, to enable low-cost hydrogen supply from Morocco in particular. The African country has been implementing its national hydrogen strategy (adopted in 2021), which is divided into three main phases. Up to 2030, Morocco plans to upscale the hydrogen market by producing green ammonia for domestic industrial use, and by exporting hydrogen products. Up to 2040, green hydrogen projects will become economically viable thanks to the decline in the cost of the technology and the export of e-fuels will increase, while by 2050 hydrogen use will expand beyond industry and heavy transport (Ministère de l'Énergie des Mines et de l'Environnement 2021). Nonetheless, the first step for fulfilling ambitious plans to export green hydrogen is to install more renewable energy capacity in Morocco, where, according to Franza (2021), political support is strong. The country set the target to reach 52% RES capacity in the power sector by 2030 and has had a good track record in RES deployment (Franza 2021).

The gap between potential hydrogen demand and supply in the south-western corridor is relatively narrow, even though significant. According to the EHBI projections, which are reported in Table 25, total H_2 demand is set to increase more than three-fold between 2030 and 2040, mainly due to the wider adoption of e-fuel solutions and the balancing role of hydrogen in an increasingly renewable-based power sector. Green (renewable) hydrogen will likely constitute around 85% of total H_2 supply by 2040, up from roughly 65% in 2030. On the other hand, by analysing the national H_2 strategy already adopted by the countries along this route, it can be argued that blue hydrogen will hardly play a considerable role. Both Spain and France do not mention this type of H_2 in their roadmaps for 2030 and 2050. The French strategy instead mentions the role of renewable H_2 and «decarbonised hydrogen», produced via electrolysis (Gouvernement 2020), which clearly points to nuclear-based electricity, since neither the production nor the use of such hydrogen emits CO_2. Moreover, given the already low CO_2-intensity of France's electricity grid, this country could even be able to meet the criteria outlined by the EU Delegated Acts to recognise grid-based hydrogen as renewable H_2 in the not-too-distant future.

The French and Spanish H_2 strategies emphasise the need to first and foremost decarbonise the current hydrogen use in industry, and then develop clean H_2 solutions also in transport. A significant difference between the various strategic documents is that Spain only mentions renewable hydrogen (Ministerio para la Transición Ecológica y el Reto Demográfico 2020), which signals the willingness to strongly enhance the renewable installed capacity in the country. It is important to point out that no H_2 imports are reported for Morocco up to

[21] Open Grid Europe signed a memorandum of understanding with the existing consortium partners Enagás (Spain), REN (Portugal), GRTgaz and Teréga (both from France).

2030, as hydrogen flow through the existing interconnection with that country would likely not be possible until after 2030, but both the Moroccan H_2 strategy and the EHBI projections show that Morocco could be able to export around 10 TWh after 2030 and 46 TWh per year from 2040 (Ministère de l'Énergie des Mines et de l'Environnement 2021).

Table 25 – Demand and Supply of H_2 in the South-western Corridor [TWh/year]. Source: own elaboration based on European Hydrogen Backbone (2022).

	2030	2040
Total demand[22]	~200	~720
Total supply (green H_2)	107	488
Total supply (blue H_2)	23	28
Total supply (grid-based H_2)	34	53

The levelised cost of hydrogen production in the south-western corridor appears much more competitive than the south-eastern supply route, and substantially in line with the Nordic-Baltic and North Sea corridors. By 2030, the south-west corridor provides access to hydrogen costs ranging from 2 to 3.8 €/kg_{H2}, decreasing to 1.4-2.7 €/kg_{H2} by 2040, especially thanks to imports from Morocco and the wider deployment of solar PV in Spain and Portugal (European Hydrogen Backbone 2022). When comparing methane and hydrogen costs, (Table 26), hydrogen becomes materially more competitive with fossil CH_4 only from 2040 onwards.

Table 26 – Cost-competitiveness of hydrogen with natural gas in the South-western Corridor [€/MWh]. Source: own elaboration based on European Hydrogen Backbone (2022).

	2030	2040
Hydrogen	60-114	42-66
Methane	59-73	62-69

3.1.6 North Africa-Italy Corridor

As the other two major hydrogen corridors identified in REPowerEU, the North Africa-Italy supply route could prove to be critical for low-cost hydrogen supply to industrial clusters in Europe. Such long-term perspective entails a pivotal role for the Italian energy (mainly gas) transmission infrastructure, whose

[22] The demand for 2030 is mostly concentrated in Spain (46 TWh/y), France (33), Belgium (25), and - as already mentioned several times - Germany (90). All these countries' H_2 demand will triple by 2040.

abundance, coupled with Italy's geo-economic position, could significantly enhance the country's role in the international H_2 value chains. Figure 24 shows the corridor - primarily involving Italy, Austria, Slovakia, Czechia, and Germany - which currently includes two major infrastructural projects aimed at creating an H_2 backbone. This will consist mainly of repurposed pipelines, which could potentially allow to reduce upfront investment costs.

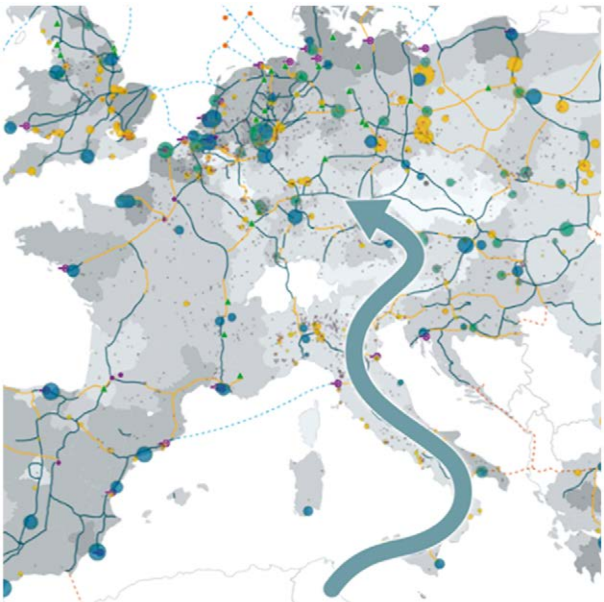

Figure 24 – The North Africa-Italy H_2 Supply Corridor. Source: European Hydrogen Backbone (2022).

It is however crucial to identify the specific North-African countries that could potentially supply the corridor with clean hydrogen. According to the European Hydrogen Backbone (2022), potential producer countries, which are also directly connected via a single pipeline to Italy (Sicily), are Tunisia and Algeria, but other suppliers can be included as well, Egypt being one of them[23]. Although direct pipelines links between this country and EU countries do not exist now, Egypt's potential role in contributing to the EU's 20 Mt of green H_2 target by 2030 could be enhanced. At COP27 in November 2022, the European Commission signed a Memorandum of Understanding (containing non-binding measures) with the Egyptian Ministry for Petroleum, Electricity and Renewable Energy, aimed at establishing a strategic partnership on renewable hydro-

[23] Italy is connected to North Africa both via the «Enrico Mattei-Transmed» pipeline (Algeria-Tunisia-Sicily) and also via the «Greenstream» pipeline (Libya-Sicily).

gen and providing funds for Egypt's domestic transition away from fossil fuels (European Commission 2022b)[24]. However, this country needs to cope with recurrent sovereign debt issues, high inflation rates and severe environmental degradation, which also include water scarcity, potentially affecting green hydrogen production, as well as the need for a more robust domestic regulatory framework (Dargin 2023).

A similar scenario also characterises Tunisia, the North African country geographically closest to Italy. As was seen in the south-western H_2 supply corridor with Morocco, Tunisia is also poor in indigenous fossil fuel resources, and it is dependent on foreign energy exports. Therefore, this country could benefit from the development of a renewable hydrogen export infrastructure. As Morocco for Spain, so is Tunisia a transit country for Algerian natural gas to Italy, thus already providing for a first constraint, as Tunisian operators would need to coordinate with Algeria to make use of existing pipelines to transport hydrogen. In addition, despite having a regulatory framework governing renewable energy that could be adapted to the green hydrogen sector (Bouafif 2023), Tunisia currently does not have a defined roadmap to produce and export clean H_2. A November 2023 World Bank report confirms that Tunisia's H_2 strategy has yet to be adopted, but it claims that this country could supply, through Italy, markets in Germany and Austria with a strong green hydrogen demand (World Bank Group 2023). The report further argues that several studies see the export market for green H_2 in Tunisia expanding rapidly after an initial market catalyst through the local market in replacement for grey hydrogen, mostly used in the fertiliser sector (World Bank Group 2023). If we look back at the time when most national H_2 strategies started to be adopted following the publication of the EU Hydrogen Strategy (2020), Tunisia was listed in the same category as Morocco in terms of attractiveness as a future hydrogen supplier, with lower potential volumes but comparable costs of delivery Franza (2021).

We can measure such attractiveness by looking at the investment conditions and the hydrogen production costs in those specific countries. If we consider the first criterion, we can see that Tunisia, Egypt and Morocco perform much better than the other countries in the Middle East and North Africa (MENA) region, according to the World Bank's Regulatory Indicators for Sustainable Energy (RISE). Those can be used to understand whether a country presents good or bad investment conditions in the categories of energy access, energy efficiency and renewable energy, thus allowing to calculate the potential capital costs for major infrastructural projects (Braun et al. 2023)[25]. Countries with good in-

[24] The European Commission has contributed with around €35 million to Egypt's Energy Wealth Initiative, and the European Bank for Reconstruction and Development (EBRD) has been lending Egypt $80 million for its nascent green hydrogen industry (Dargin 2023).

[25] According to Braun *et al.* (2023), low-carbon energy (planned and committed) investments in the MENA region are dominated by solar PV (50%), followed by clean hydrogen (21%), nuclear (14%) and wind (10%).

vestment conditions will have lower capital costs[26]. The other useful indicator for determining the countries with the highest H_2 supply and export potential in the region is the hydrogen production cost. Figure 25 clearly shows that H_2 costs for 2030 (in green) and mean production costs for 2050 (in red) are lower for Morocco, Tunisia and Egypt. Using the conversion formula mentioned above (1 €/kg_{H2} = 30 €/MWh), we can compare the costs in the figure with those estimated by the European Hydrogen Backbone Initiative. Table 27 reports the cost ranges for hydrogen supply for the MENA region as a whole, in order to have a realistic estimate. It is important to consider that the cost range of the EHBI also includes H_2 production in the other countries of the North Africa-Italy import corridor, thus contributing to lowering the overall cost. While in 2030 natural gas will still be much more affordable than hydrogen, in 2040 it has a cost range of 62-69 €/MWh along this corridor, against a range of 42-84 for hydrogen (European Hydrogen Backbone 2022). This can have wider impacts on the adoption of H_2 in hard-to-abate sectors.

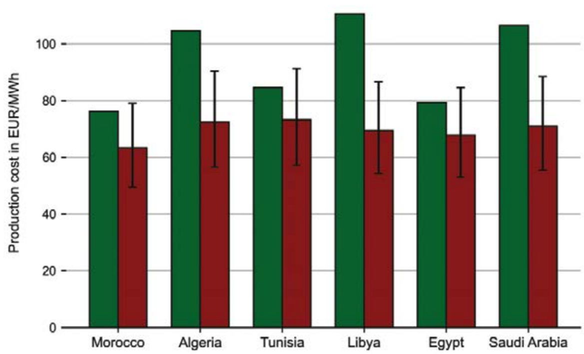

Figure 25 – Hydrogen production costs for 2030 and mean production costs for 2050 in the MENA region [€/MWh]. Source: Braun et al. (2023).

According to the EHBI, the German and Italian industrial sectors will drive H_2 demand, which is projected to increase fourfold between 2030 and 2040 in this corridor and will consist mostly of green hydrogen, as reported in Table 28 (European Hydrogen Backbone 2022)[27]. It is interesting to note that the 70 TWh of green H_2 in the EHBI projection for 2030 are entirely supplied by North African imports (mainly from Tunisia and Algeria via pipeline). However, given

[26] The cost of capital for an investment can be expressed as the weighted average cost of capital (WACC), which includes all the sources of capital (debt and equity) that a company pays to finance its assets.

[27] Italy's hydrogen demand is projected to increase from 23 TWh/year in 2030 to 89 TWh in 2040 and more than 187 by 2050 (European Hydrogen Backbone 2022). For the current demand scenario, see the next section.

the untapped potential and the slow pace of H_2 development in North African countries, such a scenario will be hardly feasible.

Table 27 – Comparison of hydrogen production costs in the MENA region. Source: own elaboration based on European Hydrogen Backbone (2022) and Braun et al. (2023).

	2030	2040	2050
European Hydrogen Backbone (2022)	2.1-3.8	1.4-2-8	-
Braun et al. (2023)	2.5-3.7	-	2.1-2.4

Table 28 – Demand and Supply of H_2 in the North Africa-Italy Corridor [TWh/year]. Source: own elaboration based on European Hydrogen Backbone (2022).

	2030	2040
Total demand	~140	~550
Total supply (green H_2)	70	303
Total supply (blue H_2)	-	-
Total supply (grid-based H_2)	26	37

At the same time, several European TSOs involved in the corridor are planning to invest in building a hydrogen transport network and facilitate market ramp-up. So far, two significant infrastructural projects have been developed to enable H_2 imports through the North Africa-Italy corridor, both via Austria and also Switzerland. The «SoutH2 Corridor» and the «SunsHyne Corridor» involve several TSOs, and both projects foresee a total hydrogen pipeline length of 3000-3400 km, largely consisting of repurposed lines. Table 29 summarises the main elements of the two projects, which aim to connect each country's H_2 pipeline systems operated by the national TSOs into one large supply route. Some national governments of the countries concerned have already endorsed the projects, in particular those of Austria, Germany and Italy, whose Energy Ministries, on 9th April 2023, signed a joint letter of support for a «Southern Hydrogen Corridor», thus supporting the projects in obtaining the status of Projects of Common Interest (Gas Connect Austria 2023). Like the previously mentioned «H2-Med» pipeline, all the projects that constitute the southern hydrogen corridor have obtained the PCI status[28].

Notwithstanding the ongoing planning and development process of the H_2 infrastructure along this corridor, many challenges are likely to remain unmet in the near term. The limited renewable energy infrastructure and the low re-

[28] Out of the 166 selected PCI, over half (85) are electricity, offshore and smart grid projects, and for the first time 65 hydrogen and electrolyser projects are included, together with 14 CO_2 network projects that will help create a market for carbon capture and storage.

newable penetration in the energy systems of the North African countries is an obstacle to the production of clean hydrogen. Although countries like Tunisia and Algeria have been taking part in some renewable and hydrogen development projects and they are already interconnected to Italy, the flow of hydrogen towards Europe largely depends on the repurposing of pipelines connecting Algeria and Tunisia and on their respective financing. Moreover, the North African region is currently affected by severe political instability. Algeria, which is one of the main natural gas suppliers for Italy, has been experiencing a protracted domestic tension between the political-military complex and societal pressures for reform, as well as the willingness of the country's leaders to weaponise energy in inter-state controversies (Giuli 2022), as happened with neighbouring Morocco.

Table 29 – The «SoutH$_2$ Corridor» and the «SunsHyne Corridor» projects. Source: own elaboration based on the projects' official websites: https://www.south2corridor.net, https://www.sunshynecorridor.eu.

	SoutH2 Corridor	SunsHyne Corridor
Project partners	**SNAM** (Italy), **TAG** (Austria), **GCA** (Austria), **Bayernets** (Germany)	**SNAM** (Italy), **TAG** (Austria), Eustream (Slovakia), **NET4GAS** (Czechia), **OGE** (Germany)
Planned national infrastructures	· **Italy**: Italian H2 Backbone (SNAM) · **Austria**: H2 Readiness of the TAG Pipeline System (TAG), H2 Backbone WAG + Penta-West (GCA) · **Germany**: HyPipe Bavaria – The Hydrogen Hub (Bayernets)	· **Italy**: Italian H2 Backbone (SNAM) · **Austria**: H2 Readiness of the TAG Pipeline System (TAG) · **Slovakia**: H2 repurposing project (Eustream) · **Czechia**: H2 repurposing project (Czechia) · **Germany**: H2ercules (OGE)
Length [km]	· **Italy**: 2300 · **Austria**: 380 · **Germany**: 300	· **Italy**: 2300 · **Austria**: 380 · **Slovakia**: no data available · **Czechia**: ~400 · **Germany**: 1500 (whole H2ercules project)
Estimated import capacity [TWh/y]	· **Italy**: 165 (62 export) · **Austria**: 61 (TAG) + 54 (GCA) · **Germany**: 52 (From Austria)	· **Italy**: 165 · **Austria**: 61 · **Slovakia**: no data available · **Czechia**: 52 · **Germany**: 52

3.2 The development of a hydrogen economy in Italy

An analysis of Italy's potentially strategic role in connecting hydrogen supply in North Africa to the demand centres in Europe cannot however disregard the Italian domestic policy efforts to give shape to a low-carbon and clean hydrogen value chain. Such initiatives include the Italian integrated National Energy and Climate Plan (NECP), whose development is mandated by EU Regulation

2018/1999 on Governance of the Energy Union, to detail national objectives for each of the five dimensions of the Energy Union[29]. While the European Commission closely monitors and regularly reports on the progress made in these plans, the current ones (submitted by 31 December 2019) cover the period 2021 to 2030, but Member States were due to submit their draft updated NECPs, in line with article 14 of Regulation 2018/1999, by 30th June 2023[30]. Therefore, by looking at Italy's 2019 and 2023 versions of the NECP, it can be possible to determine the importance accorded to hydrogen development in the Italian plan. Following the adoption of the NECP's first version in 2019, the Italian Ministry of Economic Development (MISE) published a document containing «Preliminary Guidelines for a National Hydrogen Strategy», with the aim of setting electrolyser and renewable hydrogen targets which however have not so far been clearly linked to a specific demand.

In 2022 hydrogen (mainly fossil-based grey H_2) consumption in Italy was approximately 0,6 Mt/year (European Hydrogen Observatory 2023), which roughly correspond to 19 TWh, equal to slightly more than 1% of overall national energy consumption (1300 TWh in 2022)[31]. It is important to assess whether the electrolyser (GW) and hydrogen (Mt) targets set by the H_2 Strategy Preliminary Guidelines can both decarbonise the current unabated hydrogen consumption and increase the hydrogen contribution to the national energy mix from 1% to 2% by 2030. The interest in accelerated (clean) hydrogen development is also emphasised in the National Recovery and Resilience Plan (NRRP), approved in 2021 and where around €3.7 billion in funds are allocated to measures explicitly dedicated to hydrogen-related projects. The financing of the NRRP (through the Recovery and Resilience Facility) is based on the performance of the single country in attaining specific «milestones» (qualitative indicators) and «targets» (quantitative indicators), which have been included in the plan and are subject to regular assessments by the European Commission every 2 months[32]. Hydrogen funding in this instrument is assigned mainly through grants, managed either by the national Ministry of Environment and Energy Security (MASE) or by

[29] The five dimensions are: 1) security, solidarity, and trust; 2) a fully integrated internal energy market; 3) energy efficiency; 4) climate action and decarbonisation; 5) research, innovation, and competitiveness. Retrieved from: https://energy.ec.europa.eu/topics/energy-strategy/energy-union_en.

[30] Art. 14 states that «by 30 June 2023, and subsequently by 1 January 2033 and every 10 years thereafter, each Member State shall submit to the Commission a draft update of the latest notified integrated national energy and climate plan or shall provide the Commission with reasons justifying why the plan does not require updating».

[31] As shown in the previous chapter, if we consider that 1 million tonnes of hydrogen have an energy value of around 33 TWh, then it is correct to consider the above-mentioned numbers.

[32] To benefit from support under the Recovery and Resilience Facility, EU governments have submitted national recovery and resilience plans, outlining the reforms and investments they will implement by end-2026, with clear milestones and targets. The plans had to allocate at least 37% of their budget to green measures and 20% to digital measures.

local (regional) authorities. Against this background, the final adoption of the updated NECP and the adoption of a dedicated National Hydrogen Strategy, both completed at the end of 2024, represent the two most recent and significant steps undertaken by the Italian government in defining its medium- and long-term objectives for hydrogen development.

3.2.1 Hydrogen in the 2019 National Energy and Climate Plan[33]

The Italian NECP sets national targets for 2030 concerning energy efficiency, renewable sources, and reduction of CO_2 emissions, as well as goals related to energy security, interconnections, the single energy market, competitiveness, and sustainable mobility. However, the first version of the NECP does not include a specific chapter or section dedicated to hydrogen development and integration into the Italian energy system. Instead, the 2019 NECP only mentions hydrogen when outlining the 2030 scenarios in the transport sector, as well as potential energy storage options, but without setting overall targets. According to the plan, a contribution of around 1% of the renewable transport target was expected for hydrogen (Ministero dello Sviluppo Economico 2019). This would involve direct use in hydrogen-powered cars, buses, heavy transport, and trains (especially on some non-electrified routes), and also potential applications in maritime transport or through integration into the methane network for transportation purposes[34]. The plan then claims that, in the context of hydrogen development in the mobility sector, integrated solutions for multi-fuel distribution through fuel cells could play a significant role, as the Renewable Energy Directive II (adopted in 2018 and then revised under Fit-for-55) set a specific target for hydrogen in the transport sector of 14% by 2030. It was indeed the RED II that provided the definition of renewable fuels of non-biological origin (RFNBOs), whose deployment, as was seen in Chapter 2, was foreseen only in the transport sector. The scope of RFNBOs has been extended to industry and heating with the new RED III adopted in October 2023, and it is thus not covered by the 2019 Italian NECP.

The 2019 plan only makes a general mention to the need to attract private investments for developing the clean hydrogen value chain in Italy and stresses the importance of developing storage and power-to-gas facilities, particularly aimed at storing excess production from non-programmable renewables «through safe and reliable storage of hydrogen in liquid and gaseous energy carriers» (Ministero dello Sviluppo Economico 2019). This could indeed address the so-called «electricity overgeneration», a phenomenon that can derive from two situations. Overgeneration from congestion occurs when there is a high renewable energy

[33] Italy's NECP is officially known as «Piano Nazionale Integrato per l'Energia e il Clima (PNIEC)».

[34] The plan continued stating that, within that 1% for renewable transport, a differentiated usage approach could include 0.8% H_2 injection into the network in a mixture with natural gas and/or H_2 conversion into methane, and 0.2% for direct use in cars, buses, and trains.

generation, but the transport capacity of the electrical grid is insufficient, and thus the demand-supply balance (which needs to be maintained in every moment) prevents the full exploitation of renewable electricity. Overgeneration from lack of demand, instead, can occur when, even with sufficient transport capacity, the intensity of production from non-programmable renewables cannot be entirely absorbed by the system, due to a lack of demand.

It is important to recall that renewable energy sources and green hydrogen are mutually dependent. While the production of energy from renewable sources enables the production of green hydrogen, H_2 enables the levelling out of peaks in energy production from renewables through H_2 storage. Although Italy's 2019 NECP outlines the growth trajectories of renewable energy sources up to 2030, it does not identify a specific portion of the RES generation that could be entirely dedicated to producing green H_2. Regardless of the possibility of importing hydrogen and/or renewable electricity produced in North Africa, questions remain about the gap between the renewable electricity produced and not consumed, and the potential foreseeable demand for hydrogen in 2030, which could be met using that renewable electricity. This aspect has been only partially clarified by the 2023 version of the NECP, which outlines more precise H_2 targets and raises the RES installed capacity trajectory (see section 3.2.4.).

3.2.2 The Italian Hydrogen Strategy: Preliminary Guidelines

The ambition outlined in Italy's Preliminary Guidelines to the National Hydrogen Strategy lies in doubling hydrogen's contribution to the national final energy demand, and increase the electrolyser installed capacity. H_2 penetration in the Italian energy mix should increase to 2% from the current 1%, while electrolysis would see 5 GW of new capacity by 2030 (Ministero dello Sviluppo Economico 2020). The guidelines further state that around €10 billion in investments would be needed for achieving such targets, but it does not identify the amount of resources that should be earmarked for renewables, which would provide the electricity to feed the electrolysers. Within those €10 billion, the guidelines claim that around €5-7 billion would be destined to H_2 production, and around €3 billion to distribution and consumption infrastructures (such as hydrogen refuelling stations, H_2 trucks etc.), but without mentioning potential necessary investments in the construction of new hydrogen pipelines or in the repurposing of existing gas lines to transfer the molecule.

Three main hydrogen use categories can be identified by analysing the strategy's preliminary guidelines. While in the long-term up to 2050, hydrogen is expected to be largely used in the hard-to-abate sectors involving energy intensive production processes (Ministero dello Sviluppo Economico 2020), H_2 will need to become more competitive up to 2030 in order to enable the development of a national hydrogen ecosystem. As we explained in Chapter 1, in the steel industry, for instance, green hydrogen represents the only emission-free alternative for the direct reduction of iron (DRI), which currently uses natural gas as the preferred feedstock. The second use-case for this molecule is envisaged in the transport sector, especially in heavy-duty vehicles such as long-haul trucks and in railways (Ministero dello Sviluppo Economico 2020)[35]. More than for other applications, consumer (users') choices in this sector are driven both by the total cost of ownership (TCO) and by other parameters such as the refuelling time and the range (km) of the vehicle. The TCO for fuel cell trucks will hardly become competitive in the near future. According to the Government's guidelines, instead, fuel cell-powered trains could become cost-competitive with diesel-fuelled ones in the next decade (Ministero dello Sviluppo Economico, 2020)[36]. The third way in which hydrogen can be employed, as mentioned in the preliminary guidelines, is in a blend with natural gas in the national gas transport network. The ministerial document mentions blending for both «low-carbon» and green H_2. While no specific target for either of the two types is envisaged, the guidelines state that overgeneration from renewables can be leveraged to produce green H_2 «for blending at lower cost» (Ministero dello Sviluppo Economico 2020).

In Chapter 2 we mentioned the issue of hydrogen blending in the gas grid, since there is currently no common framework but there are only national rules in each EU country that regulate blending at different percentages, thus hampering cross-border hydrogen flows. Furthermore, blending should be given a precise scope, but Italy's preliminary guidelines to the H_2 strategy claim that «blending low-carbon hydrogen into the network can be an effective method to contribute to decarbonisation goals» (Ministero dello Sviluppo Economico 2020), without linking it to potential national demand clusters. Although some recent studies conducted on the Italian gas distribution network show that hydrogen blending can help decarbonise the energy sector by supporting the penetration of renewables (Guzzo et al. 2022), the design of a clear strategy moving towards a growing percentage of hydrogen injection into the gas network is essential. Moreover, since power-to-hydrogen plants will be needed to blend green hydrogen into the Italian gas network, the planning of new P2H facilities cannot be realised without taking into consideration the current location of renewable power plants as well as the setting up of new ones (Pellegrini et al. 2020).

As shown by another study (Kanellopoulos et al. 2022), Italy currently presents a discrepancy between the potential technical capacity for hydrogen blending and the electrolyser (P2H) target set by the preliminary guidelines, and also included in Italy's National Recovery and Resilience Plan (see section 3.2.3). The study has indeed calculated that a 5% of hydrogen blending in the European gas network would need around 18 GW of electrolyser capacity, while around 40-70 GW would be needed to reach a 20% blending level. Italy, which

[35] According to the Preliminary Guidelines, the long-haul truck segment is among the sectors with a significant responsibility for emissions, accounting for 5-10% of all transportation emissions. A penetration of at least 2% of long-haul fuel cell trucks can be anticipated by 2030, within a total national fleet of approximately 200,000 vehicles (Ministero dello Sviluppo Economico 2020).

[36] Currently, about one third of the railways in Italy are dedicated to diesel trains.

has a 5 GW electrolyser target by 2030, would need around 14 GW to be able to inject a 20% hydrogen blend into the gas grid (Kanellopoulos et al. 2022). This means that the electrolyser capacity should be further boosted, if Italy plans to increase its H_2 blending targets.

Regarding where best to locate H_2 production, the preliminary guidelines point out that both decentralised and centralised hydrogen production could have different benefits. The major advantage of fully on-site production is the absence of transport for both hydrogen and electricity; however, producing enough hydrogen through on-site renewables may not be technically possible due to space constraints, requiring on-site balancing of supply and demand (Ministero dello Sviluppo Economico 2020). On the other hand, centralised production could allow economies of scale on electrolysers and benefit from higher load factors of renewables located in sunny or windy areas such as southern Italy. This option would however imply the accurate planning of a hydrogen (or hydrogen-ready) transmission infrastructure and/or new investments in the reinforcement of power lines.

3.2.3 Hydrogen in the National Recovery and Resilience Plan

Around €23.7 billion have been allocated to the second «Component» of Mission 2 (Green revolution and ecological transition) of the Italian National Recovery and Resilience Plan (NRRP), including around €3.6 billion for investments in H_2 technology (Presidenza del Consiglio dei Ministri 2021). Component 2, labelled «Renewable energy, hydrogen, grid and sustainable mobility», foresees reforms and investments aimed at enhancing renewables penetration via decentralised and utility-scale solutions, and strengthening the grid to accommodate and synchronise the new renewable sources and decarbonise end uses. Table 30 outlines the different investments and reforms related to the development of a hydrogen value chain and their current status, together with the funding that has been issued for those measures and the target that must be met by end-2026, as mandated by the Recovery and Resilience Facility Regulation.

By examining the measures and the relevant amount of funding provided, a focus on medium-to-large scale investments in the industrial sector can be observed. €500 million (Investment 3.1) are allocated for the production of hydrogen in disused industrial areas, which are known as «Hydrogen Valleys». Those are regional integrated hydrogen ecosystems, which can be distinguished into three archetypes: 1) local, small-scale and mobility-focused (green) hydrogen production projects serving mobility applications, usually involving dozens of local stakeholders and being led by public-private partnerships or regional public authorities; 2) locally integrated, medium-scale producers and consumers of hydrogen with a focus on industrial feedstock and 3) large-scale hydrogen production and international export focus (Weichenhain et al. 2022). Hard-to-abate sectors (such as steel, glass, ceramics, paper etc.) constitute the primary destination for boosting hydrogen use and decarbonise production, according to investment 3.2 (€2 billion) of the Italian plan.

Table 30 – Investments and Reforms in the Italian NRRP related to hydrogen technology. Source: own elaboration based on Ministero dell'Ambiente e della Sicurezza Energetica (2023a) and Ministero delle Infrastrutture e dei Trasporti (2023). Notes: letter M refers to the Mission, letter C refers to the Component, letter I to the Investment and letter R to the Reform included in the Plan.

Measure	**Status**[37]	Total funding [€]	Target by 2026
M2, C2, I3.1: **Hydrogen production in disused industrial areas**	The Government adopted two Decrees in late 2022 for the allocation of resources and the definition of tenders for the Regions. All Regions have published the public notices and are finalising the **adoption of Decrees to allocate the grants**.	€500 million	· Completion of **at least 10 hydrogen production projects** with an average capacity of at least 1-5 MW each
M2, C2, I3.2: **Hydrogen use in hard-to-abate sectors**	After the adoption of a Decree in late 2022, the Government has started the **selection procedure for hydrogen projects** in mid-2023.	€2 billion	· **Decarbonisation of at least one industrial facility** in a hard-to-abate sector
M2, C2, I3.3: **Testing hydrogen for road transport**	In mid-2023 the Ministry of Transports and Infrastructures published the final **public notice to allocate the funds**	€230 million	· Construction of **40 hydrogen refuelling stations**
M2, C2, I3.4: **Testing hydrogen for rail transport**	An **Executive Decree adopted in March 2023** allocated the financial resources to the applicant Regions	€300 million	· Construction of **at least 10 renewable hydrogen refuelling facilities** on at least 6 railway lines
M2, C2, I3.5: **Hydrogen R&D**	**R&D contracts** have been awarded between mid-2022 and 2023	€160 million	· **At least 4 R&D projects** completed
M2, C2, I5.2: **Hydrogen (electrolysers)**	**IPCEI agreements** between the Italian Government and relevant industries have enabled the subsidised production of electrolysers	€450 million	· Commissioning of **one industrial facility for the production of electrolysers** with a 1GW capacity per year

[37] at the time of editing (January 2026).

Measure	**Status**[37]	Total funding [€]	Target by 2026
M2, C2, R3.1: **Administrative simplification and reduction of regulatory barriers to hydrogen deployment**	Several Decrees adopted to introduce **simplifications for the manufacturing of electrolysers** and **guarantees of origin** for renewable hydrogen		
M2, C2, R3.2: **Measures to promote the competitiveness of hydrogen**	**Tax incentives** entered into force with Law 2022/79 and Ministerial Decree 2022/347		

It is nonetheless important to point out that since mid-2023 the NRRP has been partially revised, because of the adoption of the REPowerEU Plan at the EU level, which provides additional funding for energy transition measures, but requires Member States to update their national recovery plans to integrate those funds. The revised Italian NRRP, which was approved by the European Commission in November 2023, will allocate an additional €2.76 billion from REPowerEU, through ETS revenues[38]. However, due to the de-financing and reshaping of some chapters of the NRRP, around €1 billion (out of the initial €2 billion) have been eliminated from the funds allocated to hydrogen use in hard-to-abate sectors (Dipartimento per le Politiche Europee 2023). Instead, Hydrogen Valley projects have received further support (around €90 million) from their initial €500 million. Such investments can serve the purpose of enabling the creation of local hydrogen markets thus fostering the development of a H_2 value chain. It can be further argued that one of the core aims of creating H_2 Valleys is to focus the production and consumption of green hydrogen on strategic areas already connected to the electricity grid, especially where the renewable potential is higher[39]. Indeed, southern Italy is the area that hosts most H_2 Valley projects, with 26 of the 54 projects covering 50% of the total available funds, while, in the North, 18 projects will come to life (covering 36% of the budget) and in the Centre 7 (18% of the total funds) (Energia&Mercato 2023).

Another major target to be accomplished by 2026 is the construction of an industrial plant to produce 1 GW-capacity electrolysers, known as «Gigafactory». This project was declared eligible by the European Commission to receive funding under the IPCEI *Hy2Tech* project, which we mentioned in Chapter 2 as one of the major State aid instruments to foster the growth of

[38] The funds allocated by the revised NRRP increase from the initial €191.5 to €194.4 billion, mainly due to €2.7 billion from ETS quotas and €146 millions in GDP adjustments. The total reprogramming carried out amounts to €21.4 billion, of which €2.8 billion in additional resources (Il Sole 24Ore 2023).

[39] The claim that the RES electricity potential is higher in southern Italy will be demonstrated and discussed in Chapter 4 of this thesis.

hydrogen supply chains. The Gigafactory project includes six major Italian companies (Ansaldo, Fincantieri, Iveco Italia, Alstom Ferroviaria, Enel and De Nora in partnership with SNAM) and two research organisations (ENEA and Fondazione Bruno Kessler) (Hydronews 2023a). From a total of around €1 billion destined to Italy for this first IPCEI on hydrogen, the electrolyser «Gigafactory» project will receive around €63 million in public funding[40]. Such initiative can be seen as complementary to the second project aimed at producing GW-scale electrolysers, namely the new Gigafactory that Ansaldo Green Tech - a subsidiary of Ansaldo Energia - will build in Genoa. This plant, expected to reach a 600 MW/year capacity by 2026, will focus on the most innovative electrolysis technologies, i.e. SOEC (Solid Oxide Electrolysis Cells) and AEM (Anion Exchange Membrane) and will not produce alkaline or PEM electrolysers (Hydronews 2023c)[41].

3.2.4 Hydrogen in the new National Energy and Climate Plan

The 2024 National Energy and Climate Plan (NECP) is currently the most updated version of the renewable and low-carbon energy targets set by the Italian Government to contribute to the EU's climate goals. The Ministry of Environment and Energy Security formally submitted to the European Commission the proposal to update the NECP on 30th June 2023 and the plan was finally adopted in the second half of 2024. Unlike the previous one, the updated NECP includes a chapter dedicated to the deployment of renewable hydrogen in the transport and industry sectors by 2030, thus already signalling an increased interest in developing this molecule. This can be mainly explained by the fact that the new Renewable Energy Directive (RED III) sets mandatory overall targets for the uptake of renewable hydrogen in transport, industry and heating in the form of RFNBO by 2030, as discussed in Chapter 2. Together with such type of renewable H_2, the Italian plan includes an unquantified contribution of renewable biomass-based hydrogen to the national targets up to 2030[42]. However such form of H_2 is not included in the definition of renewable hydrogen provided by the RED II Delegated Acts, which have been designed to provide regulatory clarity for hydrogen generation and deployment. A brief mention in the NECP is made for blue hydrogen as well, but without setting specific

[40] The first phase of the work involves the demolition of the old facility on an area of 25,000 m^2. The new centre is estimated to have a production capacity of 2 GW (Hydrogen-News 2023).

[41] At the end of November 2023, the Italian Ministry of Environment and Energy Security launched a €100 million incentive, in form of non-repayable grants financed through the NRRP (under investment 5.2), to support the development of the components of the renewable hydrogen value chain, thus including those for manufacturing electrolysers. Around 40% of the resources are allocated to the southern Regions and to the islands (Invitalia 2023).

[42] As was seen in Chapter 1, this type of hydrogen is produced from the gasification of biomass in the form of crop residues, forest residues and solid waste.

targets[43]. Therefore, uncertainty remains about the exact amount of blue and biomass-based H_2 that should be deployed to achieve the NECP's targets. The second type, in particular, has a renewable nature but cannot count in reaching the RED III targets. The Italian NECP clearly states that «this type of fuel will play an increasing role in achieving decarbonisation, but the extent of its contribution is difficult to quantify at present» (Ministero dell'Ambiente e della Sicurezza Energetica 2023b).

In December 2023 the European Commission released its opinion on the draft updated NECP, recommending Italy to include more detailed and quantified policies in a way that enables a timely and cost-effective achievement of its national contribution to the EU's binding renewable energy target of at least 42.5% in 2030, as well as to describe in particular how it plans to further facilitate permitting with faster and simpler procedures, and how the design of the obligation on fuel suppliers in the transport sector will be covered and include measures for promoting hydrogen in industry and prepare the EU for renewable hydrogen trade (European Commission 2023b).

Therefore, we should look at the real contribution of sector-specific targets for renewable hydrogen set by the new version of the NECP to assess their real weight in the current and estimated final energy consumption by 2030. Table 31 outlines the new NECP targets for renewable hydrogen demand by 2030, together with the total final energy demand of all sectors by 2030 - which we have converted into TWh for comparability reasons. Projections of hydrogen use in industry indicate that about 0.115 Mt (3.8 TWh) of renewable H_2, both bio and non-bio (RFNBO), will be needed to reach the industry target in 2030. For transport, a total consumption of about 0.136 Mt (4.5 TWh) of renewable H_2 is estimated. No targets have been set for the residential, tertiary and agricultural sectors, as the NECP stresses the importance to foster hydrogen use in the hard-to-abate industrial and transport sectors, while considering H_2 blending into the gas grid (Ministero dell'Ambiente e della Sicurezza Energetica 2023b), which is in line with the H_2 Strategy Preliminary Guidelines (see section 3.2.2). Overall, the targets for renewable hydrogen by 2030 would lead to a consumption of about 0.25 Mt/year (8.2 TWh), 80% of which is estimated to be produced domestically, and the remainder will be imported according to the NECP[44].

[43] The final version of the Italian NECP of 2024 states that blue hydrogen production, which is complementary to renewable hydrogen and features lower production costs compared to it, could facilitate a faster decarbonisation of industrial sectors, particularly those that currently rely on grey hydrogen (Ministero dell'Ambiente e della Sicurezza Energetica 2024a).

[44] The final version of the NECP of 2024 includes roughly the same quantities of H2 for the same sectors (industry and transport). The latest version of the NECP also states that the largest contribution to the growth of renewable energy will come from the electricity sector itself: generation from renewable energy sources is expected to reach around 237 TWh by 2030, including approximately 10 TWh allocated to the production of green hydrogen (Ministero dell'Ambiente e della Sicurezza Energetica 2024a).

Table 31 – Estimated renewable hydrogen consumption targets over final energy demand by sector by 2030. Source: own elaboration based on Ministero dell'Ambiente e della Sicurezza Energetica (2023b, 2024a).

Sector	H_2 amount [Mt]	H_2 energy value [TWh]	Final energy demand [TWh]
Industry	0.115	3.8	282
Transport	0.136	4.5	379
Residential	-	-	308
Tertiary	-	-	168
Agriculture	-	-	29
Total	0.251	8.2	~1160

Nevertheless, a question remains on the actual contribution of renewable hydrogen to the final energy demand by 2030. As can be seen from the table, final energy consumption across all sectors is projected to be around 1160 TWh in 2030, which is slightly less than the current 1300 TWh (Ministero dell'Ambiente e della Sicurezza Energetica 2023c). With such data in mind, we can calculate the approximate share of H_2 in the final energy demand, which according to the H_2 Strategy Preliminary Guidelines and the new NECP could rise to 2% from the current 1%. If we consider the (mostly unabated) H_2 demand of around 19 TWh in 2022, we can see that it is equal to roughly 1.4% of the 2022 final energy demand (1300 TWh). But then if we take only the projected renewable hydrogen demand (8 TWh) and compare it to the final energy demand across all sectors in 2030 (1160 TWh), renewable H_2 contribution is barely 0.7%. In order to reach the 2% of H_2 in final energy demand as mandated by the NECP and the preliminary guidelines, we have considered the current unabated grey hydrogen demand (19 TWh) and added the projected renewable H_2 demand, thus obtaining around 27 TWh of hydrogen, which correspond to around 2.3% of the final energy demand across all sectors in 2030. These estimates on hydrogen contribution to the Italian energy mix are summarised in Table 32.

Table 32 – Hydrogen contribution to the final energy demand in 2022 and 2030 [%]. Source: own elaboration. Notes: P.G. stands for Preliminary Guidelines.

Hydrogen targets	% of final energy demand in 2022	% of final energy demand in 2030
NECP and H_2 Strategy P.G.	1%	2%
Actual projection Renewable H_2	~0%	0.7%
Actual projection All types of H_2	1.4%	2.3%

3.2.5 "Strategia Nazionale Idrogeno": The Italian Hydrogen Strategy[45]

In November 2024, the Italian Ministry of Environment and Energy Security (Ministero dell'Ambiente e della Sicurezza Energetica 2024b) presented the Italian National Hydrogen Strategy ("the Strategy"), outlining a more comprehensive policy framework for the deployment of renewable and low-carbon hydrogen over the short (today-2030), medium (2030-2040) and long (2040-2050) term. While positioning H_2 as a key pillar of Italy's decarbonisation pathway, the Strategy is fully aligned with the objectives of Italy's 2024 NECP and the EU target of climate neutrality by mid-century. It therefore does not introduce brand new hydrogen targets at national level for 2030, but it goes beyond the NECP's time horizon, and it identifies the potential H_2 demand and supply by 2050. By adopting a scenario-based approach on three levels ("base", "intermediate", "high-diffusion"), the Strategy acknowledges that the future role of hydrogen will depend on multiple cross-cutting factors, including technological maturity, market development and system integration.

As reported in Table 33, the Strategy estimates a potential national hydrogen demand between 2 and 4.16 Mt H_2 by 2050 across the three scenarios (Ministero dell'Ambiente e della Sicurezza Energetica 2024b)[46]. While the document discusses the potential costs of different hydrogen production methods (electrolysis, SMR, pyrolisis etc.), we cannot find any direct quantitative target for renewable (green) hydrogen compared to what is outlined in the 2024 NECP. The Strategy mentions instead electrolyser capacity targets (from 3 GW by 2030 to 15-30 GW by 2050), which can be considered only a proxy measure of the potential renewable H_2 production.

Table 33 – Total Hydrogen Demand in Italy by 2050 (Three Scenarios). Source: own elaboration based on Ministero dell'Ambiente e della Sicurezza Energetica (2024b).

Scenario	Total Hydrogen Demand [Mt H_2]	Total Energy Demand [TWh]
Base	~2.23	~74.3
Intermediate	~3.17	~105,7
High diffusion	~4.16	~138.7

Decarbonisation is envisaged as the result of a portfolio of solutions, combining increased renewable electricity generation (of which up to 90 GW of new

[45] The final document on the Italian hydrogen strategy was published after the conclusion and the defence of this thesis. For this reason, the updated data and information that are present in this publication were added afterwards.

[46] The Strategy reports all the values in million tons of oil equivalent (Mtoe). For the sake of consistency with the rest of this publication, all the values in Mtoe have been converted to million tons (Mt) of H_2 and in TWh, based on the lower heating value (LHV) of hydrogen, assumed at approximately 120 MJ/kg, and on the equivalence 1 Mtoe = 41.868 PJ.

renewable capacity to feed the above-mentioned electrolyser capacity), carbon capture and storage (CCS), biofuels, biomethane and hydrogen, with the possible contribution of next-generation nuclear power. Within this mix, H_2 is primarily targeted at the transport (2.34 Mt out of the 4.16 Mt of the high diffusion scenario) and hard-to-abate sectors (1.29 Mt). H_2 in the civil sector has instead almost no penetration (Ministero dell'Ambiente e della Sicurezza Energetica 2024b). Although the share of hydrogen projected to be used in the transport sector is almost double of that foreseen for the industrial HTA sector, we can argue that H_2 will not be used directly to fuel transport means like airplanes or ships but it will be rather used to produce the synthetic fuels that will be actually employed in those applications (see also Section 1.3.2.).

Beyond climate objectives, the Strategy emphasises broader policy goals, including energy security, the development of a competitive national hydrogen value chain, and the ambition for Italy to act as a Mediterranean energy hub, supported by international cooperation and dedicated infrastructure. In this context, the Strategy identifies projects like the Southern Hydrogen Corridor as strategic enablers for positioning Italy as a key entry point for hydrogen imports into the European market. The document indeed projects that around 70% of the total H_2 supply by 2050 will be produced domestically, and it points to a significant share in imports, at around 30% (Ministero dell'Ambiente e della Sicurezza Energetica 2024b).

Conclusions

The analysis carried out in this chapter has evaluated the plans to create several import routes for clean hydrogen into the EU from a cost-effectiveness and geoeconomic points of view, emphasising the need to accurately combine the construction of new H_2 transport infrastructures with potential demand clusters in Europe. At a domestic level, new areas where to locate renewable power plants must be identified considering the construction of new electrolysers directly connected to a renewable facility or the need to strengthen the electricity grid to bring green electrons to the P2H plants. However, the production of hydrogen from grid-based electrolysis can eventually limit the supply of green H_2, because in the 90% of EU countries the national electricity grid is not decarbonised enough to be considered renewable according to the EU's rules (see Chapter 4). In the above discussion we have also mentioned the need to simplify and shorten planning and permitting procedures for the full value chain of renewable and hydrogen projects, which is critical for the establishment of all corridors.

At the external level, several obstacles must be addressed before new hydrogen trade routes can be opened. One important issue concerns the lack of a common internationally agreed methodology to determine the emission intensity of hydrogen (while it exists for EU domestic production), potentially leading to a fragmented market. Guaranteeing compliance of imported hydrogen with the EU's certification standards is necessary to develop import-export value chains.

For this reason, strategic dialogue and partnerships are needed between the EU and exporting countries.

A country that could facilitate such partnerships especially with potential green hydrogen suppliers on the southern shores of the Mediterranean is Italy. The overview of the infrastructural projects related to the H_2 corridors highlights the pivotal role played by Italy's transmission infrastructure. The Italian hydrogen «backbone» promoted by SNAM is not only the longest of those in the North Africa-EU corridor, but it could also enable the EU to access the cheapest alternative among all other import options to achieve the H_2 targets and meet growing industrial (mainly German) H_2 demand. For this reason, SNAM's technical document on the «Italian H2 Backbone» will be analysed in Chapter 4, along with the discussion of the current status and planning of the Italian gas and electricity transmission systems.

Nonetheless, the analysis of Italy's policy initiatives towards clean H_2 development has highlighted that initial efforts should be on decarbonising the current unabated fossil-based hydrogen consumption, by setting more ambitious targets. Italy must compete with its international peers, aiming to assume an enabling role in the entire European strategy, but playing this role means defining a long-term and ambitious vision, and leading to useful actions to create a competitive advantage for national industrial supply chains. Although the Italian National Hydrogen Strategy argues that renewable H_2 should have priority over other types of hydrogen[47], it does not define binding quantitative targets for renewable H_2 production. Instead, it adopts a scenario-based approach, providing indicative ranges for hydrogen demand, electrolyser capacity and domestic production, while referring to renewable and low-carbon hydrogen jointly. More specific quantitative references to green hydrogen emerge indirectly through the NECP, notably via electricity generation targets allocated to electrolysis, rather than through explicit hydrogen output targets.

[47] Italy's national strategy prioritizes the development of hydrogen produced from renewable sources as a key pillar of the energy transition, while not excluding other production pathways. In particular, it acknowledges the potential role of blue hydrogen - especially in connection with advances in carbon capture and storage (CCS) - as well as hydrogen generated from nuclear energy, consistent with ongoing sustainable nuclear programs (Ministero dell'Ambiente e della Sicurezza Energetica 2024b).