CHAPTER 4

The Italian hard-to-abate sectors: a case study on potential hydrogen use

Introduction

Due to the net-zero and low-carbon objectives enshrined in the policy frameworks which we analysed both for Italy and the EU, governments and industries have been examining the potential solutions to decarbonise those parts of the economy which are labelled hard to abate (HTA). Despite being poorly defined, this concept can be used to include sectors such as steel, iron, non-metallic minerals (glass, ceramics, cement), paper, chemicals and refinery, as well as some transport applications such as maritime shipping and aviation. Heavy industry contributes to over 17% of global CO_2 emissions, including an 8% from cement production and 7% from iron and steel, which account for more than twice as much CO_2 as shipping (3%) and aviation (2.5%) (Oxford Institute for Energy Studies 2023). In the EU, heavy industry sectors account for roughly 21% of total emissions (European Environment Agency 2023), while Italian HTA industries represent 16% of total CO_2 emissions in the country (ISPRA 2022)[1]. The value added of Italy's HTA sectors is around €94 billion, representing about 7% of Italy's gross added value, while these sectors' employees are 1.25 million, or 5% of total employment (The European House - Ambrosetti 2023).

1 Total emissions are roughly 418 Mt of CO_2 equivalent, while those of HTA sectors amount to 64 Mt/CO_2eq (ISPRA 2022).

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The feature that all these sectors have in common is the technical inability to partly or completely electrify their energy inputs, thereby requiring other solutions to reduce their emission intensity. Indeed, electricity is expected to contribute mainly to decarbonisation in the light industries, while for HTA sectors, hydrogen will play a more important role, reaching around 31% of total energy consumption compared to an electricity demand of 25% by 2050 (Eurelectric 2023). The significance of hydrogen for decarbonising hard-to-abate sectors has been also stressed in the recently adopted Hydrogen and Decarbonised Gas Markets Package at the EU level (see Chapter 2). The rules set the playing field for investments into hydrogen, prioritising HTA industries like steel and chemicals (Kurmayer 2023). By considering the average estimated hydrogen demand by sector in the EU from 2022 to 2050 (Figure 26), it becomes clear that industry - and in particular HTA sectors - will drive H_2 demand in the medium-to-long term. According to the European Hydrogen Observatory (2023), the refining sector currently stands out as the primary driver of conventional hydrogen consumption in most countries accounting for 57% of the total demand, while Germany, Italy and Spain had the largest consumption, contributing to 10.7%, 6.1% and 5.9% of the total demand, respectively. In many countries such as Italy, Greece, Finland, Slovakia, Portugal, Croatia, Denmark and Ireland, the refining industry accounts for most of the domestic conventional hydrogen consumption (>80%)[2]. Following is the ammonia industry with 24% of total H_2 demand, and another 12% is consumed for methanol production and other uses in the chemical industry (European Hydrogen Observatory 2023).

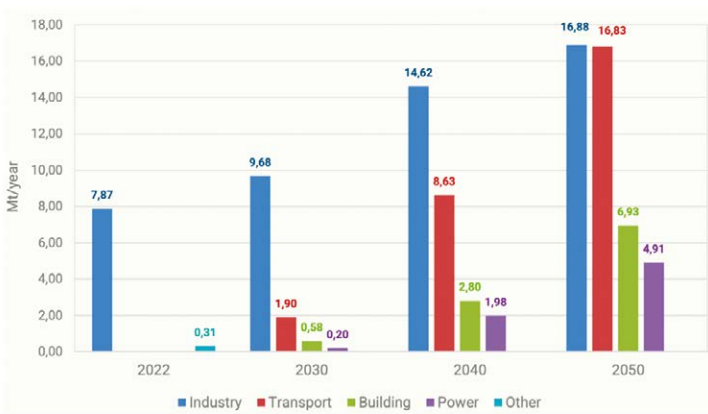

Figure 26 – Average projected hydrogen demand by sector in the EU [Mt/year]. Source: European Hydrogen Observatory (2023).

[2] In refineries, hydrogen plays a pivotal role in hydrotreating and hydrocracking operations. Hydrotreatment constitutes a vital component of diesel refining, encompassing various processes such as hydrogenation, hydrodesulfurization, hydrodenitrification, and hydrodemetallization (European Hydrogen Observatory 2023).

While progressively adopting non-polluting hydrogen in their production processes, HTA sectors will need to accelerate the reduction of their CO_2 emissions in the next decade. The entry into the new phase of the EU Emission Trading System will involve an increase in the price of carbon allowances, since it will be coupled with a progressive reduction of available permits until 2030 and with the elimination of allowances allocated free of charge to HTA sectors. For this reason, carbon capture and storage (CCS) technologies can be further developed, to penetrate energy-intensive industries and contribute to the separation of CO_2 emissions from industrial processes (Oxford Institute for Energy Studies 2023).

If we consider the current scenario in Europe and in Italy, in particular, CCS can complement hydrogen in enabling decarbonisation. In Chapter 1 we argued that (clean) hydrogen will compete with bioenergy and fossil fuels with CCS in decarbonising HTA sectors. Such competition can however be replaced by the progressive integration of grey H_2 production coupled with CCS, especially because - as we have seen in Chapter 3 - many EU countries will not be able to replace their unabated H_2 consumption with renewable hydrogen in the near term. If we consider just the steel sector, for instance, nearly half of Europe's current wind and solar output would have to be dedicated to the region's steel plants (Oxford Institute for Energy Studies 2023). As we outlined in the examination of the EU hydrogen supply corridors, CCS facilities in Europe are mostly located around the North Sea (IOGP 2023). However, a new project specifically involves the establishment of a CCS hub in the offshore depleted gas fields off the coast of Ravenna, in the Italian part of the Adriatic Sea. After having created a Joint Venture, the Italian energy company Eni and the Italian gas TSO Snam have been implementing the project, whose initial phase started in 2024, with the perspective to capture CO_2 from multiple industrial sources in the Po Valley.

As far as technologies for producing renewable hydrogen are concerned, Italy is potentially well positioned in the European manufacturing ecosystem. The country has had a 25% share of the total EU production value in technologies potentially related to green hydrogen production, second only to Germany (29%) (The European House - Ambrosetti 2020). Core technologies include electrolysers, blue hydrogen production technologies and plants, and fuel cells. In the cluster of ancillary technologies are included thermal (burners, exchangers), mechanical (pipes, valves, filters), electrical (inverters, photovoltaic panels, electric motors), control and plants for using hydrogen as feedstock. Notwithstanding such a solid H_2 technology manufacturing base, Italy has been lagging behind its major European partners in the development of new hydrogen projects. By looking at the International Energy Agency's hydrogen projects database, we can indeed see that Italy is home to only around 40 projects (most of which are in the concept or feasibility study phase), while France, Germany and Spain are hosting 121, 198 and 142 hydrogen projects respectively (IEA 2023).

As we saw in Chapters 2 and 3, besides the single technologies enabling H_2 production and a favourable regulatory framework, the development of regional and national hydrogen markets requires the presence of an integrated infrastructure, capable of moving ever-increasing amounts of low-carbon and renewable hydrogen, and of transporting clean energy to where it is consumed or transformed into H_2. This is why the first section of this chapter examines the status and planning of Italy's gas and electricity networks from a broader perspective, in view of cross-vector and hydrogen integration needs. The second section will analyse the dynamics around the transition from natural gas and grey hydrogen to blue and green H_2 in hard-to-abate sectors, while the last section will provide an overview of a case study on the adoption of clean hydrogen in the production process of ceramics, one of Italy's most important and innovative energy-intensive sectors, as Italy is the seventh largest ceramics manufacturer in the world and more than four fifths of the sector's revenue is given by exports (Confindustria Ceramica 2023).

4.1 Fine-tuning the electricity and gas networks for hydrogen integration

The process for developing Italy's energy scenarios is characterised by cooperation between the two main national transmission system operators: Terna (for electricity) and Snam (for gas). As we stated in the previous chapters, close collaboration between the electricity and gas sectors is key to enable sector coupling and energy system integration, thus eventually carving out a role for hydrogen. If we consider the planning of gas and electricity networks in Italy until 2030, the only document that is drawn up jointly (every two years) by the gas and electricity TSOs is the so-called «Scenarios Description Document» (*Documento di Descrizione degli Scenari* - DDS), which is a preliminary evaluation of the gas and electricity grid development plans, that are prepared separately by Terna and Snam. Because the DDS is a comprehensive document representing a declination at the national level of the European ENTSO-G and ENTSO-E scenarios, it is important to consider it when analysing potential hydrogen integration in the policy scenario towards 2030 and 2040, in continuity with what we outlined in chapters 2 and 3 regarding hydrogen infrastructural needs, both for production and for import.

Just as the target set by Italy's 2023 National Energy and Climate Plan (NECP), so too has Terna (2022) foreseen a share of 65% of renewables in total electricity consumption by 2030, thus increasing the potential contribution of green hydrogen to the total H_2 that will be produced in Italy. The country's renewable installed capacity starts however from a relatively narrow level, totalling around 63 GW at the end of 2022 (Terna 2023), compared to the 2024 NECP target of 131 GW by 2030, meaning that new RES capacity would need to be installed at a rate of more than 9 GW per year to achieve such objective. Both the 2022 level and the 2030 target include hydropower in the calculation of total RES capacity, but the NECP does not provide for an increase in hydro until 2030, which remains stable at around 19 GW[3]. This means that solar and

[3] These numbers are in line both with the 2022 and with the latest 2024 Scenarios Description Document of Snam and Terna. The 2030 policy (NECP) scenario envisages that around 110

wind power will need to make the largest contribution to achieving the 2030 RES goals. In 2022 there has been a significant acceleration of new RES installed capacity, with more than 3 GW of new renewable plants available compared to the previous year, in which only around 1.3 GW were installed (Terna 2023). Such increase was mainly due to the ramp-up of PV capacity, which at the end of 2022 totalled 25 GW, while wind power plants were at 11.8 GW, all on-shore (IRENA 2023). Table 34 compares the data for 2022 with the targets of the old (2019) and the new (2024) NECP, thus providing a clearer picture of the evolution of the electricity system.

Table 34 – Electricity consumption and RES targets in Italy by 2030. Source: own elaboration based on Ministero dell'Ambiente e della Sicurezza Energetica (2023a; 2023b; 2024) and Ministero dello Sviluppo Economico (2019).

Year	Situation in 2022	2030 (2024 NECP)	2030 (2019 NECP)
Electricity consumption [TWh]	316	350	339.5
RES installed capacity (total) [GW]	63	131.3	95.2
Solar PV [GW]	25	79.9	52
Wind [GW]	11.8	28 of which offshore: 2.1	19.3 of which offshore: 0.9

Notwithstanding its ambitious RES targets, the new NECP also claims that natural gas will continue to play a major role for the Italian energy system in the near future. The diversification of supply channels combined with the new demand for transit of gas through Italy to supply adjacent European markets determine new needs for the development and maintenance of the gas transport infrastructure system in full efficiency (Ministero dell'Ambiente e della Sicurezza Energetica 2023b). Moreover, on a national level, the projected increase in RES capacity will need to be followed by an adequate amount of back-up capacity, which will be provided by new thermal power plants, since natural gas will remain more competitive than hydrogen at least until after 2030, as demonstrated when we compared methane and hydrogen prices in 2030 and 2040 (see Chapter 3).

Such scenario has two main implications for the gas sector. On the one hand, an extended use of natural gas will require continued maintenance and

GW of new installed solar and wind capacity will be required, corresponding to an increase of around +65 GW compared to the 42 GW installed in 2023 (+49 GW of solar and +16 GW of wind) (Terna 2024). If we take the new 110 GW and add the already existing hydropower capacity, we achieve around 130 GW, which corresponds to the 2030 objective foreseen by the Italian National Energy and Climate Plan (see below).

investment in transmission infrastructure. On the other hand, however, with the projected increases in electrification and use of hydrogen and the corresponding decreases in natural gas demand in the long term, it can be expected that grid expansion investments will become less relevant when compared to replacement investments by natural gas TSOs (Grote et al. 2022). This development can facilitate the creation of a new hydrogen transport network, which can largely rely on the repurposing of existing natural gas pipelines, thus being quicker and cheaper than the construction of new H_2 infrastructure and allowing to avoid pipelines' decommissioning costs. This is also why more than 70% of the southern (North Africa-Italy) hydrogen supply corridor is expected to be constituted by repurposed pipelines.

When focusing on hydrogen use, both the NECP and the National Recovery and Resilience Plan (NRRP) foresee a primary role for HTA sectors, whose current main feedstock and fuel is natural gas. Indeed, around 17% of the natural gas consumed in Italy in 2022 was used in industry (Ministero dell'Ambiente e della Sicurezza Energetica 2023a). If we look at the Scenario Description Document (Terna 2022), while natural gas will continue to play a predominant role, its use in HTA sectors will decrease to around 9.9 bcm (100 TWh) by 2030, and hydrogen consumption will increase to around 2.2 bcm (23 TWh), as was estimated in Chapter 3 by the European Hydrogen Backbone Initiative. Such amount of H_2 will continue to be used mostly in refining and chemical sectors, but it will start to expand also to other HTA sectors. Table 35 summarises the above data and compares the current natural gas and hydrogen uses with the future scenarios.

Table 35 – Natural gas and hydrogen consumption scenarios in Italy by 2030 and 2040 [TWh]. Source: own elaboration based on Ministero dell'Ambiente e della Sicurezza Energetica (2023a) and Terna (2022).

Year	Situation in 2022	2030 (DDS)	2040 (DDS)
Natural gas consumption	674 (69 bcm)	566 (58 bcm)	375 (35 bcm)
Industrial natural gas consumption	117 (12 bcm)	100 (9.9 bcm)	58 (~6 bcm)
Industrial HTA hydrogen consumption	~16	23	21-40

These estimations on H_2 consumption in the industrial hard-to-abate sectors up to 2040 (21-40 TWh) can be considered in line with the value indicated by the new Italian hydrogen strategy, which is equal to 43 TWh (1.29 Mt of H_2) by 2050. Table 36 outlines the potential (not only green) hydrogen demand in the HTA sectors in the high diffusion scenario by 2050, as foreseen in the Strategy.

Table 36 – Hydrogen Demand in Hard-to-Abate Sectors (2050, High Diffusion Scenario). Source: own elaboration based on Ministero dell'Ambiente e della Sicurezza Energetica (2024b).

Sector	Hydrogen Demand [Mt H_2]	Hydrogen Demand [TWh]
Hard-to-abate industry (total)	~1.29	~43
Chemicals (feedstock)	~0.41	~13.7
Steel	~0.39	~13
Glass	~0.17	~5.7
Refineries (feedstock)	~0.12	~4
Ceramics	~0.1	~3.3
Cement	~0.07	~2.3
Foundries	~0.03	~1

4.1.1 Gas network development

The Italian gas TSO Snam adopted a medium-term plan covering the years 2022-2031 which envisages investments both in the development and maintenance of pipelines and storage facilities and in the realisation of the «Italian Hydrogen Backbone» to support the creation of a national H_2 market and to export the additional volumes available from domestic production and import. Within such plan, according to which there could be over €20 billion of investment opportunities in 2022-2031, in late January 2024 Snam released the «2023-2027 Strategic plan», that provides for €11.5 billion in total investments of which €10.3 billion are directly related to infrastructure development (Snam 2024). €7.4 billion are earmarked for the gas transport component, that includes the construction of the «Adriatic pipeline» to increase the south-north gas and, in the future, hydrogen transport capacity; €1.4 billion will be used for expanding and upgrading storage sites; €1.5 billion dedicated to the purchasing and installation of two LNG regasification plants[4] and the related infrastructure. However, by considering the whole 2022-2031 plan, we can see that maintenance interventions (around 30) far outnumber the construction of new pipelines (6), thus confirming that grid expansion investments are likely to become less relevant compared to replacement investments by gas TSOs.

It is important to emphasise that investments for the development and modernisation of Snam's transportation and storage infrastructure are being made with a view to H_2 asset readiness, while Snam is carrying out H_2 certification activities on the existing network and checks on storage, compressor stations and the metering system. To this effect, the Italian H_2 backbone (Figure 27) has been developed with a view to reusing the pipelines of the methane transporta-

[4] These consist of two floating storage and regasification units (FSRUs).

tion network «as far as possible through repurposing activities» (Snam 2023), which firstly involve verifying the suitability of existing pipelines to carry H_2. The pipelines' adaptation process needs to consider that the existing natural gas consumption will gradually diminish but it will still be present for several years, and therefore the transport of methane must be ensured. This is why Snam is also conducting transport and demand coverage checks on the downstream transport network, to ensure that natural gas transport continues to be reliable and secure, taking into account the expected medium-to-long term demand (Snam 2023). According to Snam's strategic planning document, initial assessments on the repurposing activities suggest that the capacities of the resulting natural gas network will in any case be sufficient to meet the system's demand for natural gas.

Figure 27 – The planned Italian Hydrogen Backbone. Source: Snam (2023).

The Italian Hydrogen Backbone project, with a total CAPEX of about €3.2 billion (Snam 2023)[5], is currently in its pre-feasibility stage, and it envisages the preparation of the H_2 network to cover the needs of the hydrogen market until 2040, developing sufficient import capacity from Africa to guarantee coverage of the expected demand. The project is also set up to allow export to and import from Austria and Switzerland, ensuring flexibility and security of supply to the Italian and European hydrogen transport system as soon as these interconnections are developed.

[5] In Snam's new 2023-2027 Strategic Plan, €100 million are scheduled to be invested in the hydrogen business, of which 20 million in the engineering phase of the SoutH2 Corridor (Snam 2024).

The future domestic hydrogen network will mainly consist of grid sections converted for H_2 transport, with small exceptions. We can see that in northern Italy the H_2 backbone essentially splits into two sections, each of which will serve an interconnection with Austria and Switzerland respectively. In addition to the main backbone, six branches have been defined that will constitute the first connection between the hydrogen backbone and the main consumption and/or production centres. In particular, the areas planned to be reached are those where a significant switch from the consumption of natural gas or other fossil fuels to hydrogen is envisaged, namely the hard-to-abate sectors (in particular petrochemicals and steelworks) (Snam 2023).

It is interesting to notice that Snam's gas grid development plan includes a section dedicated to the Poseidon pipeline (Figure 28), which is the final stretch of a Greece-Italy interconnection system that would connect the Italian grid to the gas volumes available in the Eastern Mediterranean (the Levantine Basin), thanks to the «EastMed» pipeline project[6] and to the gas volumes available at the Turkish/Greek border through an overland extension in Greece. With a total length of around 2000 km, the project (expected to become operational in 2026) would serve Europe's gas supply diversification strategy in the short term, while in the longer term it could also be used as a hydrogen supply route (Snam 2023). However, despite having been kept in the list of Projects of Common Interest (PCI) published in November 2023 by the European Commission, the EastMed-Poseidon pipeline project, has been subject to both economic and geopolitical difficulties. On the one hand, the commercial viability of a new natural gas pipeline to Europe has been questioned due to the Green Deal objectives for the next decades which would see a lower demand for natural gas. On the other hand, Turkey, whose territory is bypassed by the current project, has raised doubts about the pipeline's feasibility.

Figure 28 – The EastMed-Poseidon pipeline complex. Source: Agenzia Nova (2022).

[6] The EastMed project is being carried out by IGI Poseidon, a joint-venture of EDISON S.p.A. (Italy) and DEPA International Projects SA (Greece).

4.1.2 Electricity network development

The evolution of the electricity transport network is increasingly dependent on the shift of power installed capacity from demand centres, thus being critical for deciding where to establish renewable hydrogen production plants. In order to achieve the Fit-for-55, REPowerEU and national RES targets, Italy's electricity TSO Terna has been investing around €11 billion in new gird development interventions, under the umbrella of the so-called «Hypergrid» project (Terna 2023)[7]. The latter will exploit high-voltage direct current (HVDC) transmission technologies which will imply a massive modernisation of existing power lines on the country's east and west ridges, including the southern regions and islands, accompanied by new submarine connections. According to Terna's 2023 grid development plan, «Hypergrid» will increase the performance of power lines, minimising their environmental impact and transferring more and more power generated by renewables in southern Italy to the load areas in the north, where the bulk of demand is concentrated. The «Hypergrid» project consists of five main cable backbones (Terna 2023): «HVDC Montalto di Castro-Milan» (to transfer electrons from central to northern Italy), «Central link» (to move electricity from central Italy to the main consumption areas in Tuscany), «Sardinian backbone» (to enable better RES integration on the island, including electricity produced by future off-shore power plants), «Ionian-Tyrrhenian backbone» (to transport renewable energy produced in Sicily and other southern areas towards northern Italy), «Adriatic backbone» (connecting Apulia with Emilia-Romagna and allowing to reduce grid congestion in areas with high renewable generation like Apulia).

The planned and ongoing interventions on the electricity network also arise from an increasing number of requests for connection to the national transmission grid from new renewable power plants. At the end of 2022, Terna had received approximately 311 GW of active requests for connection to the national transmission grid (high and extra-high voltage) for RES electricity, of which 302 GW for photovoltaic and wind power plants (on-shore and off-shore) (Terna 2023). Although the forwarding of the connection request does not guarantee the actual construction of the plant[8], such numbers signal a clear tendency towards exploiting Italy's renewable potential. Around 80% of connection requests are indeed located in southern Italy and on the islands (Figure 29), which are characterised by greater windiness and irradiation (Terna 2023).

[7] Terna (2023) estimates that the total costs of investments in RES, storage and grid infrastructures necessary to reach the 2030 targets are in the range of €150-180 billion.

[8] Following the user's request for connection, the preliminary phase begins in which Terna draws up the connection estimate containing the General Minimum Technical Solution (*Soluzione Tecnica Minima Generale*), expressing the time and cost of the planned grid interventions necessary for connection. If the request is accepted, there are two more steps, concerning authorisation procedures and the signing of a connection contract. Only then can the construction phase begin (Terna 2023a).

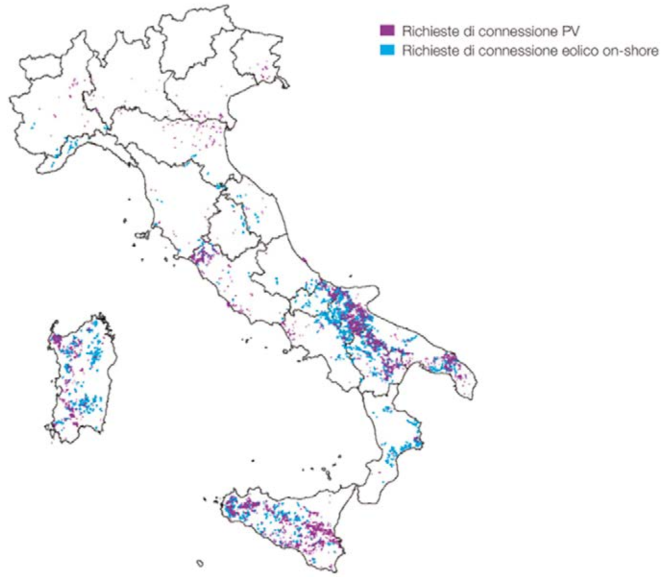

Figure 29 – Localisation of connection requests for photovoltaic and wind power plants in Italy. Source: Terna (2023).

With a view to a coordinated planning of the various resources to 2030, the high increase in RES and thus in intermittent electricity generation implies an increase in periods of overgeneration and, consequently, curtailment of renewable electricity. Here is where hydrogen comes into play, as electrolysers represent an opportunity to exploit system overgeneration to produce and store green H_2, and use it in turn in other sectors. Given that, according to Terna and Snam's DDS (Terna 2022), around 3.5 out of 5 GW of the planned electrolysis capacity will be installed in southern (including islands) and central Italy, the potential matching of overgeneration from renewables in the South with hydrogen production could give a decisive breakthrough to the creation of a national hydrogen market. However, the «additionality» rule imposed by the RFNBO Delegated Acts (DA) at the EU level means that electrolyser operation should coincide with hours when the RES production can neither be utilised nor exported. In its energy scenarios, Terna expects a renewable hydrogen production from electrolysis in Italy of around 10 TWh and 20 TWh for 2030 and 2040 respectively (Terna, 2024). Such numbers, especially the projection for 2030, are close to the amount of renewable H_2 consumption that we estimated in Chapter 3 when we considered the 2023 version of NECP, which expects around 9 TWh of green hydrogen to be used at a national level in 2030.

Further elements suggest the potential creation of renewable hydrogen production hubs in southern Italy in particular. Snam's ten-year plan 2022-2031 includes the construction of electrolysers in Apulia and Sicily collecting (renewable) electricity otherwise subject to curtailment (due to overgeneration) and transforming it into an energy vector that can be transported and stored (Snam 2023). A first phase of the project will involve the installation of a 90 MW electrolyser by 2026 near the pipeline dedicated to natural gas import from Azerbaijan (the Trans Adriatic Pipeline) so that the hydrogen produced can be blended into the natural gas network up to a maximum percentage of 2% (Snam 2023). The second phase of the initiative will instead facilitate the recovery of the increasing volumes of overgeneration envisaged by the above-mentioned scenarios, and it will require the installation of a further 800 MW of electrolyser capacity near the most congested grid nodes. According to Snam (2023) the electrolyser's commissioning date is scheduled for 2031 following the development of the Italian hydrogen backbone, so that the H_2 produced can then be injected into a dedicated grid and destined for hard-to-abate consumer sectors first.

It is important to emphasise that green hydrogen production will mostly be based on off-grid renewable electricity at least in the short term, as grid electricity feeding electrolysers would not be decarbonised enough to allow for the resulting hydrogen to be considered renewable under the EU rules. If we consider the carbon intensity (measured in gCO_2eq/MJ) of the electricity system in the different EU Member States (Figure 30), we can see that Italy is currently far from the carbon intensity targets for the power grid set at the EU level by the RFNBO DA. The first DA, in particular, outlines the main alternative options under which it can be demonstrated that grid electricity used in the electrolyser is renewable: either in a bidding zone with 90%+ renewables in the electricity mix, or in a «low-carbon» bidding zone with a carbon intensity lower than 18 gCO_2eq/MJ, or any other grid solution where however the additionality, spatial and temporal correlation criteria must be met.

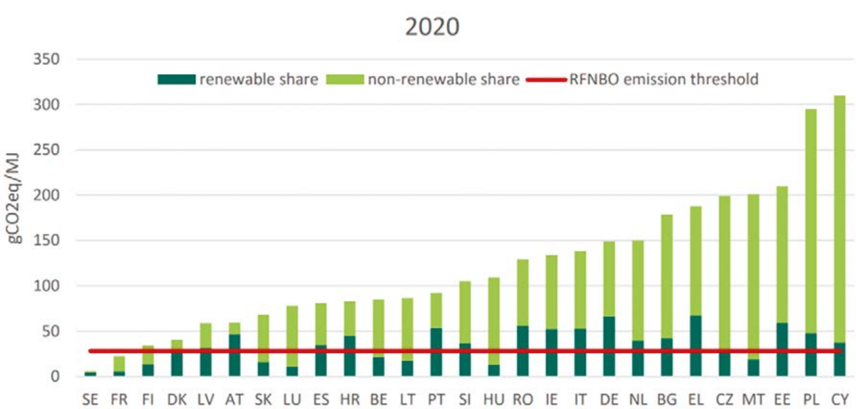

Figure 30 – hydrogen GHG emission intensity and renewable energy share from grid electricity in 2020 [gCO_2eq/MJ]. Source: Hydrogen Europe (2023).

Although the emission intensity of Italy's electricity grid is likely to remain above the RFNBO threshold also by 2030 (Hydrogen Europe 2023), this situation could change if we consider the regional development of renewable energy installed capacity. Given that Italy's electricity market is split into different bidding zones[9] - contrary to most EU countries whose entire national territory corresponds to one large bidding zone - the requirements for producing renewable hydrogen could materialise in the bidding zones (mainly in the South of the country) where large new renewable power plants will be built. This means that in those southern bidding zones - especially «Sud», «Calabria», «Sicilia» and «Sardegna» - we could see over 90% of the electricity mix covered by renewables, and prior to this, such bidding zones could become «low-carbon», thus needing to meet the spatial and temporal correlation criteria. This means that the electrolysers should be in the same bidding zones as the renewable power plants, thereby creating the need for hydrogen transport towards the North.

4.2 Demand and supply dynamics in Italy's hard to abate sectors

4.2.1 From grey hydrogen to green H_2

Hydrogen used in hard-to-abate (HTA) sectors is currently almost entirely represented by grey H_2, produced mainly through the steam-methane reformation (SMR) process (using natural gas), that results in high levels of CO_2 emissions into the atmosphere. Enabling the penetration of renewable hydrogen in HTA sectors is thus extremely important to achieve the decarbonisation targets and meet the specific objectives for RFNBOs enshrined in the Renewable Energy Directive. As we saw in Chapter 2 regarding industry, the RED III sets both minimum thresholds for green hydrogen usage by 2030 (42% of all H_2 used in industry must be renewable) and upper limits for fossil-based unabated hydrogen (up to 23% of all H_2 used in industry can be produced using fossil fuels). The bulk of the grey hydrogen used in HTA industries is directly produced by the same companies that use it for their production process, as a feedstock (e.g. in the chemical sector) or as a fuel for industrial heat (e.g. in the paper, steel or ceramics sectors). Such configuration is known as "captive production", taking place within the limits of the industrial plant's H_2 generation capacity. To have a specific order of magnitude, Table 37 reports the amounts of unabated hydrogen produced and used in the main energy-intensive industries in Italy.

Refineries are by far the largest hydrogen consumer, and they also use the SMR process for producing most of their H_2. According to Confindustria (2024), between 40 and 50% of that hydrogen is produced through SMR in plants lo-

[9] Italy's electricity market bidding zones as revised in 2021 are: Nord, Centro-Nord, Centro-Sud, Sud, Calabria, Sicilia, Sardegna (Terna 2022). The difference in the number of market zones compared to other EU countries stems from the geographical conformation of the Italian peninsula, which results in almost all interconnections with foreign countries on the northern border and the need to optimise energy flows with the islands.

cated within refineries, while between 30 and 35% comes from the catalytic reforming of gasoline, and the remainder is purchased from specialised operators, who produce hydrogen by SMR and transport it to the refinery. In the chemical sector, around two thirds of the hydrogen used is produced through SMR and it is destined to produce ammonia and derivatives (Confindustria 2024).

Table 37 – Grey hydrogen used in the hard to abate sectors [Mt/year]. Source: own elaboration based on Confindustria (2024).

Sector	Refining	Chemicals	Total
Total H_2 produced and used	0.361	0.153	0.514
Of which produced using SMR	0.240	0.108	0.348

If we compare the numbers of the above-mentioned sectors with the targets for renewable hydrogen included in the Italian NECP, discussed in Chapter 3, we can clearly conclude that those targets are not ambitious enough to achieve the 42% renewable hydrogen (RFNBO) target in industry by 2030 foreseen by the RED III. Indeed, Italy's NECP provides for 0,115 Mt of renewable H_2 to be used in industry (see section 3.2.4.), which however correspond to just around 22.4% of the total amount used in refining and chemicals today (0.514 Mt). A 42% renewable hydrogen target would instead require an almost double quantity (0.215 Mt) compared to what is currently indicated in the NECP for industry (0.115 Mt).

As we saw in Chapter 1, however, today's green hydrogen production cost is still not competitive with grey H_2 generation methods. Therefore, besides setting more ambitious quantitative targets, the levelized cost of hydrogen (LCOH), i.e. the price at which the hydrogen produced would have to be sold to offset the total production costs over the lifetime of the project, should be supported through incentive mechanisms. The structure and the amount of support should be determined taking into account two factors in particular: the electricity costs faced by national producers and the equivalent hours of operation of electrolysers, which are conditioned by the type of renewable electricity sources that can be used (e.g. Italy cannot currently count on the high load factors that are accessible to northern European countries that have a high generation from offshore wind) (Confindustria 2024). It could be thus interesting to assess whether such gap in the quantity of decarbonised hydrogen could be compensated, at least in the medium term, by blue hydrogen.

4.2.2 The blue hydrogen factor

The transition from production modes with a high environmental impact to sustainable ones in the hard-to-abate industrial sectors could see blue hydrogen as a bridging opportunity in the short to medium term. Nevertheless, investment in research and development is needed to build industrial-scale plants that will demonstrate its viability for widespread applications, as the production of blue hydrogen requires efficient carbon capture and storage (CCS) to drastically reduce emissions from the steam methane reforming process. CO_2 can be captured through three main types of processes: post-combustion, pre-combustion or combustion in oxygen. All methodologies have either an intermediate or high technology readiness level, and the average demonstrated carbon capture efficiency of the capture methodologies is about 90% (The European House - Ambrosetti 2022).

As we saw in Chapter 1, blue hydrogen can serve as a complementary technology to green hydrogen for various reasons. First, blue H_2 can facilitate the uptake of hydrogen in marginal demand sectors thus lowering the overall cost of hydrogen in the longer term and putting significant pressure on the CO_2 price, as demand for CO_2 would increase when a market is created. Second, using blue hydrogen to meet the short-to-medium term H_2 demand significantly reduces the necessary investments into renewable power generation capacity, leading to savings in the energy system (Durakovic et al. 2023). Third, low-carbon hydrogen can be exploited especially in areas not particularly favourable to the development of renewable sources - both because of geographic characteristics, as well as for scarce land availability (The European House - Ambrosetti 2023).

The new CCS project off the coast of Ravenna in the Adriatic Sea could become a potential enabler of blue hydrogen supply to the HTA sectors soon. This new CCS facility can prove critical to the decarbonisation of the unabated hydrogen that is currently used in energy-intensive industries in northern Italy that use it either as a feedstock (chemicals, refineries) or as a fuel for combustion. By removing the CO_2 produced when grey hydrogen is generated, H2 could thus become «low-carbon». The project, implemented jointly by the Italian TSO Snam and by Eni and officially named «Callisto» (CArbon LIquefaction transportation and STOrage) is one of the few CCS projects in southern Europe compared to the North Sea area (IOGP 2023), and it will be one of the largest CO_2 storage sites in the world and the largest in the Mediterranean[10]. The project envisages an initial phase, which started in 2024, aimed at capturing 25,000 tonnes of CO_2 from Eni's natural gas processing plant in Casalborsetti (Eni 2023). Once captured, the CO_2 will be piped to the «Porto Corsini Mare Ovest» platform and injected into the depleted gas field of the same name in the Ravenna offshore area. In the second phase, from 2026, 4 million tonnes of CO_2 are expected to be stored to contribute to the decarbonisation of the hard-to-abate industries in the Ravenna area and Northern Italy (Eni 2023). From 2030 onwards, the large capacity of the reservoirs would make it possible to increase the project's capacity to 16 or more million tonnes per year, depending on market demand.

While at the infrastructural level projects are being developed, we should assess the actual possibility to introduce low-carbon hydrogen in the H_2 mix in accordance with EU and therefore national legislation. The European Commis-

[10] Callisto was selected by the European Commission to be part of the new list of Projects of Common Interest (PCI), released in late 2023.

sion's Delegated Act on low-carbon hydrogen (see Chapter 2) defines the concept of low-carbon hydrogen and sets out the methodology for calculating the required 70% greenhouse gas emission savings compared to unabated fossil fuels, in line with the methodology established in the RFNBO Delegated Act of 2023. The 70% threshold applies to blue hydrogen produced from natural gas using CCS technology, low-carbon electrolytic hydrogen produced by electrolysis using electricity from the grid, and hydrogen produced from methane pyrolysis (European Parliament 2025). The delegated act aims to standardise the calculation of emissions savings by accounting for the full life-cycle emissions from producing low-carbon fuels, including indirect emissions, as well as upstream methane emissions and actual carbon capture rates (European Parliament 2025). Nonetheless, there exists a loophole in the Renewable Energy Directive III that allows to reduce the share of RFNBO (green hydrogen) foreseen by the industry-specific target, thus potentially enabling Member States to increase the share of other types of hydrogen in their total H_2 amount. Whereas the green H_2 target for the industry sector is set at 42%, Article 22b of the RED III states that «A Member State may reduce the contribution of renewable fuels of non-biological origin [...] by 20% in 2030», meaning that green hydrogen can be 22% instead of 42% in industry. Such possibility would perfectly fit the NECP's projections, that foresee a 22% share of green hydrogen in industry by 2030 (see previous section). This scenario can however be employed only under two conditions: first, the country has to be on track to meet its national contribution to the EU's overall target of 42.5% renewables in final energy consumption by 2030; second, the share of hydrogen made using fossil fuels has to be 23% or below in 2030 (Official Journal of the European Union 2023). Italy is not close to either objective, as its renewable share in final energy consumption was just around 19% in 2022 (Ministero dell'Ambiente e della Sicurezza Energetica 2023a) and it has currently no nuclear plants that can power electrolysers to produce hydrogen, which would not be renewable but neither would it be fossil. Despite being largely decarbonised thanks to CCS, blue hydrogen instead remains a fossil-based H_2 type, thus not being able to fulfil the requirements of the more flexible scenario foreseen by the RED III.

4.3 Decarbonising the ceramics industry using hydrogen

A recent study by Confindustria (2024) explores the feasibility of hydrogen use in different hard-to-abate and energy-intensive sectors of the Italian industrial landscape. One of the sectors analysed is the ceramics industry, which comprises six product sectors: ceramic tiles, bricks, sanitary ware, tableware, refractory materials, and technical ceramics. In Italy, these sectors consist of 260 companies and 300 plants, with an overall turnover of €7.5 billion, and count 27000 direct employees (Confindustria 2024). Ceramic manufacturers use natural gas as a fuel for creating heat (usually above 1000°C) needed in the production process. The most significant sub-sectors in terms of natural gas consumption and CO_2 emissions are the ceramic tile industry (85% gas, 15% electricity) and the brick industry (90% gas, 10% electricity) (Confindustria 2024), both sectors being subject to the CO_2 market regulated by the EU Emission Trading System.

Natural gas is used in different volumes along the production process, which for tiles involves five main steps. After the grinding of the raw material, the spray-drying[11] involves the first use of natural gas (5% of the overall volume used in the process). The third step consists of drying the resulting material, which consumes around 10% of the total natural gas required in tile production. After that and only for tiles, there is an additional step for decoration, which is followed (for all types of ceramics) by firing in an industrial oven, where the bulk of the natural gas is used (60%)[12]. Tile production also makes extensive use of high-efficiency cogeneration[13], i.e. the combined generation of heat and electricity, fuelled by natural gas (25% of the total amount used in the production process), whose heat is used for spray-drying.

Considering that the use of hydrogen involves a higher flame temperature and an increase in the amount of generated steam (Confindustria 2024), issues with the quality of the final product could emerge. This aspect, however, still requires further investigation with process modelling and experimental tests, including on the quality and conformity of the final product itself. Precisely for this reason, in an initial phase, blending (i.e. mixing) hydrogen with natural gas up to 20% by volume is preferable (Confindustria 2024), instead of just abruptly shifting from one fuel to the other. It is however likely that H_2 utilisation will be limited, at least initially, to the firing stage. The compatibility of hydrogen use with the drying and spray-drying steps must indeed be further investigated, since - for the same heat output - the combustion of H_2 generates greater volumes of water (Confindustria 2024).

According to the Confindustria study, there are three different scenarios for hydrogen use in the ceramics industry, based on the blending percentage. If we consider that the average annual natural gas consumption of one ceramics plant is around 11 million cubic metres (or around 0.118 TWh), we can estimate the hydrogen and electrolyser capacity required to supply the plant with green hydrogen. The first two scenarios consider a H_2 blending of 20% and 50% respectively. The third scenario instead assumes twice as much hydrogen as the second, meaning that the ceramics company either wants to decarbonise two firing lines both using a 50% blending, or it wants to decarbonise 100%, the latter option requiring an appropriate repurposing of the plant, provided the available technology allows it. As to the hydrogen demand and the corresponding electrolyser capacity needs, Confindustria's estimates are reported in Table 38.

11 Spray-drying is a method of forming a dry powder from a liquid or slurry by rapidly drying with a hot gas.

12 The furnace is of a roller type and involves the contact of the flame with the tiles.

13 «High-efficiency cogeneration» means cogeneration production resulting in primary energy savings of at least 10% compared to the generation of electricity and heat separately using the same type and quantity of fuel (DGEG 2021).

Table 38 – Three scenarios for green hydrogen use in the ceramics production process. Source: own elaboration based on Confindustria (2024).

	Hydrogen blending [%]	Hydrogen demand [t/y]	Electrolyser capacity [MW]
Scenario 1	20	200	2
Scenario 2	50	500	5
Scenario 3	100 (50+50)	1000	10

Given the different scale of the hydrogen production plants, economies of scale cannot be exploited in all three cases. The study selects proton exchange membrane (PEM) electrolyser for producing hydrogen from renewable energy sources, as this technology allows for a reduction in land occupation and better responds to intermittent loads typical of renewable profiles. However, as we saw in the Chapter 1, PEM electrolysers entail higher investment costs (CAPEX) and operational costs (OPEX) per unit of hydrogen produced, thus being less competitive for H_2 generation compared to their alkaline (ALK) counterparts.

Electrolyser costs are only one of the factors that determine the cost of hydrogen production (LCOH), the other major component being the cost of renewable electricity used during electrolysis. The cost of renewable power, in turn, largely depends on how and where the electricity is generated. As we saw when we analysed the RFNBO Delegated Acts, two options for producing renewable hydrogen are possible: with an off-grid renewable plant directly connected to the electrolyser, or with a grid-connected electrolyser using a Power Purchase Agreement (PPA) and meeting the additionality, spatial and temporal correlation criteria to demonstrate that the electricity is renewable. Moreover, since the ceramics plant needs a constant supply of fuel during the production process, hydrogen storage is necessary to compensate the intermittency of renewable plants.

The main advantage of having a dedicated renewable power plant at the ceramics site is the savings on the energy component of the grid charges (Confindustria 2024), provided, however, that the cost of electricity (LCOE) is not higher than the energy market price. The study simulates the installation of solar PV panels (located either on the roof of the ceramics facility or on adjacent plots of land, if present) to power the electrolysis. However, having one single renewable (intermittent) power plant can be a problem in terms of load factor, i.e. the ratio between the average electricity generation and the maximum (peak) generation over a specific period. A high load factor indicates that the load (the electrolyser) uses electricity more efficiently, because the peaks (the denominator) are lower. But Confindustria (2024) estimates that with only one solar plant, the load factor is between 25 and 39%, meaning that the electrolyser would be largely under-utilised if compared to a potential load factor of 63%, corresponding to 5500 hours per year.

Therefore, it is important to guarantee a renewable electricity supply for a greater number of hours. Such condition can be achieved only if either more renewable power capacity is installed at the ceramics site, or if the electrolyser is connected to the electricity grid (using a PPA). In most cases, and also due to the strong impact of the CAPEX for installing new renewable power plants, the grid option is preferable. As we saw in section 4.1.2., most renewable energy generation potential is in southern Italy, but most ceramic manufacturing plants are located in the North of the country (mainly in the «Sassuolo» ceramics district). This example, like with other hard-to-abate industries, further shows that the installation of electrolysers in areas with greater renewable potential (in the South) could create a significant demand for centralised hydrogen production and the subsequent development of a transport network towards end-use sites.

4.3.1 The case of Iris Ceramica Group

A case in point is provided by Iris Ceramica Group, one of Italy's top-three ceramics manufacturers with an annual revenue of over €500 million. This company, whose main production facilities are distributed between the Provinces of Modena and Reggio Emilia[14], has become the first ceramics manufacturer in the world to develop hydrogen-based ceramic production. Iris Ceramica Group signed two different agreements in 2021 and in 2023 with the Italian gas TSO Snam and with Edison Next[15], respectively, in order to implement the use of green hydrogen - initially in a blend with natural gas - in the firing stage of the ceramics production process.

In September 2021, Snam and Iris signed a memorandum of understanding aimed at developing a project for producing ceramics surfaces using a blend of green hydrogen and natural gas. The H_2 is produced from solar energy, via a dedicated 2.5 MW photovoltaic plant, installed on the rooftop of one of Iris Ceramica's factories located in Castellarano, in the Province of Reggio Emilia (Snam 2021). The PV plant is coupled with an electrolyser and a storage system for on-site H_2 generation, while the company's long-term aim is to switch to a fully decarbonised production.

For this very reason, in July 2023, Iris Ceramica Group signed an agreement with Edison Next to develop what has been named the «H2 Factory™», a new project always located in the Castellarano production facility, that will develop green hydrogen generated thanks to a custom-made system installed on site (Edison Next 2023). The partnership between Iris Ceramica Group and Edison Next has marked the beginning of the second phase of the project that was launched through the 2021 agreement with Snam. The first step towards decarbonisation, which saw Iris Ceramica Group engaged over the last two years in the feasibility study and construction of the H2 Factory™ site, suitable for hosting the green hydrogen production plant, has been successfully completed (Edison Next 2023).

[14] Retrieved from Iris Ceramica Group official website.

[15] Edison Next belongs to the Edison group and it has been created in 2022 to assist businesses and territories in the energy transition and decarbonisation processes.

In order to enable the hydrogen blend, and even more for a 100% hydrogen system, several arrangements are required. Technical modifications do not only concern the plant engineering, such as the furnace engineered to be fuelled with a blend of hydrogen and natural gas, but involve also strategic site works, including the construction of rainwater collection tanks, the installation of the PV panel system on the roof of the ceramics facility, and ad hoc hydrogen production and storage areas. Iris Ceramica Group has set up the entire infrastructure for the distribution of hydrogen within the plant.

Edison Next will provide an electrolyser with a capacity of 1 MW, fuelled by renewable energy, as part of a €50 million investment by Iris Ceramica Group (Edison Next 2023). The renewable hydrogen production plant (splitting water into H_2 and oxygen) will use rainwater from the collection tanks, thus also promoting virtuous water management, and it will take the electricity from a new PV plant of around 1.2 MW in addition to the existing plant of 2.5 MW mentioned above. Hydrogen will be used in particular to fuel the furnace, which will be mixed with natural gas up to a percentage of about 50%, while a furnace that will run on 100% hydrogen is being studied (Edison Next 2023). The expected production of about 132 tonnes of green hydrogen per year will replace about 500,000 cubic metres of natural gas per year, starting from 2025 (Edison Next 2023).

Conclusions

By carrying out the above analysis with regard to the hard-to-abate sectors, we can conclude that hydrogen does not represent the development of a single technology, but it entails the development of a portion of the entire future energy system, which must combine industrial development, investments in manufacturing, and the parallel construction of a market framework able to ground such investments. Hydrogen requires a national plan consisting of progressive steps starting from the current situation. This mandates the adoption of a technologically neutral approach, based on the understanding that multiple sources can contribute to decarbonisation.

At the infrastructural level, while new investments are being implemented to repurpose the natural gas transmission network to carry hydrogen, with a focus on the transport from South to North, identifying the areas where electrolysers (producing green hydrogen) can have the highest possible load factor proves critical. This, in turn, means that the installation of renewable power plants must be accelerated, but to realise Italy's potential in terms of RES electricity, where possible, not only solar technology should be considered, but also wind or other types of renewables.

For the creation of an effective hydrogen supply chain and market, Italy should favour a commercial scale-up of electrolysers, also with centralised production solutions (in southern Italy) and the transport of high volumes of renewable hydrogen (to the north of Italy), to allow for cost reduction and economies of scale. An incentive mechanism that is not only limited to partial financing of the projects' CAPEX but which is also extended to OPEX can prove useful to make renewable hydrogen competitive with fuels currently used in hard-to-abate sectors, also in light of the temporal and geographic constraints foreseen by the EU rules on RFNBOs.

Given that hard-to-abate industries use hydrogen both as a fuel (ceramics) and as feedstock (e.g. chemicals) and that our analysis showed the gap that exists between the EU targets for sectoral green H_2 use and Italian policy targets, it could be interesting to explore the gradual replacement of the current grey hydrogen with blue H_2 in the short term. This scenario could potentially materialise also thanks to the CCS projects under development and thanks to those that will emerge in the years to come.

To kick-start the decarbonisation process in those sectors and industries that can afford - both in financial and spatial terms - to install renewable power plants inside their production areas, it can be appealing to implement initial projects aimed at introducing green hydrogen produced on-site in a blend with natural gas. While progressively increasing the H_2 contribution, technology and innovation will have to move accordingly to satisfy the needs of the industry for new components (such as ceramics furnaces) of a decarbonised production process.