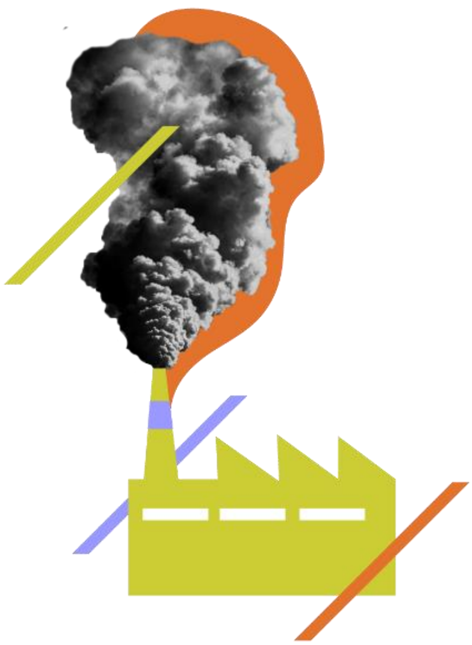
THE ITALIAN CLIMATE CHANGE THINK TANK

A GREEN STEEL STRATEGY
OPTIONS AND CHALLENGES OF DECARBONISATION

TECHNICAL REPORT
SEMPTEMBER 2022



SUMMARY

1 EXECUTIVE SUMMARY

Italy is the second steel producer in Europe and the eleventh in the world: in 2021 in our country almost 25 million tons (Mt) of steel were produced. Of these, 84% is recycled steel, i.e. produced by the remelting of ferrous scrap in Electric Arc Furnaces (EAF). The remaining 16% is primary steel, produced with the BF - BOF (Blast Furnace - Basic Oxygen Furnace) full cycle at the *Acciaierie d'Italia* plant in Taranto, the only full cycle with production of steel from ore in Italy.

Steel is used in several sectors in the Italian production context and the main consumers are the construction, mechanical and metal products sectors. For our country, it is necessary to maintain a presence in primary steel both because now it is the only material that can be used in certain applications (such as car bodies and food cans) and to guarantee the availability of scrap to the many companies that produce recycled steel in Italy. The complete transition to electric furnace production using scrap appears difficult to achieve because the annual demand for steel is growing faster than the scrap available and the quality of the latter is a significant constraint. **This leads to consider primary steel production a necessary process. In fact, depending on scrap imports exposes the entire national steel sector and many fundamental sectors of our country's economy to high risks and uncertainties.**

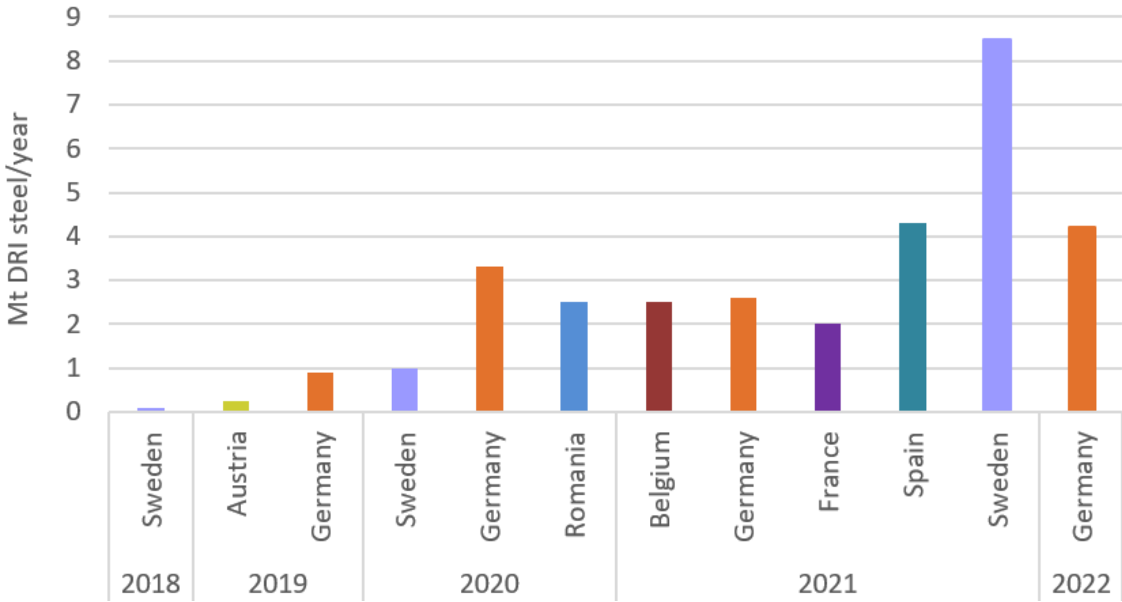
The aim of this paper is to provide an overview of the technologies available for the decarbonisation of the steel sector in Italy and to identify a decarbonisation path in response, on one hand, to the risks of de-industrialisation and, on the other hand, to the risks of lock-in of investments in supply chains that are not compatible with the net zero emissions perspective.

To reduce greenhouse gas emissions from the production of primary steel, ECCO's proposal is to switch to DRI (Direct Reduced Iron) technology, initially fueled by natural gas and then gradually switching to green hydrogen. In addition to progressively reducing CO_2 emissions, DRI technology provides an immediate benefit in environmental terms, guaranteeing a high-quality end product. There are therefore no valid reasons for postponing this investment. On the contrary, the continuation of blast furnace production is in complete contradiction with climate neutrality objectives and risks setting Italy back on the path to decarbonising steel, making it lose competitiveness in future low carbon product markets.

DRI technology has already reached full technological maturity and is already being used in some countries, such as India (28 Mt/year of DRI capacity) and Iran (26 Mt/year of DRI capacity)[1]. Several European countries have announced their intention to invest in this technology in recent years, including Germany, Sweden and Spain (Figure 1).

[1] Swalec, Caitlin; "Pedal to the Metal," *Global Energy Monitor*, June 2022.

Figure 1 - European countries that have announced investments in DRI technology[2].



Many companies in the downstream sectors have also already indicated that they will use green steel in the manufacture of their products. These include *Volvo,* which has signed an agreement with *SSAB* to design, manufacture and bring to market the first cars made with green steel. *Mercedes is* also on the same trajectory, having already announced that from 2025 for the manufacture of some of its models it will use green steel , supplied by the Swedish start-up *H2 Green Steel*. The partnership with *HSGS* is another step towards the climate neutrality that *Mercedes* is pursuing as part of *Ambition 2039*, its goal of achieving a fleet of carbon-neutral vehicles by 2039.

In its strategic programme, *Kia* plans to reduce carbon emissions in every operational aspect (supply, logistics, production, use and disposal of vehicles) by 97% by 2045, compared to 2019. To achieve this goal, the Korean automaker outlines to use green steel extensively. Other companies that have made similar announcements are *Schaeffler* (manufacturer of bearings for various industries), *Scania* (Swedish manufacturer of industrial vehicles and 46% owner of *Volkswagen*), *BMW, Orsted* (Danish multinational electricity producer that will use green steel in its wind farms). The market is clearly expanding and these years are decisive for the position that Italy can have: taking the right direction now means gaining and maintaining a competitive advantage for the Italian industrial chain.

About secondary steel, the options for decarbonisation identified are of two levels:

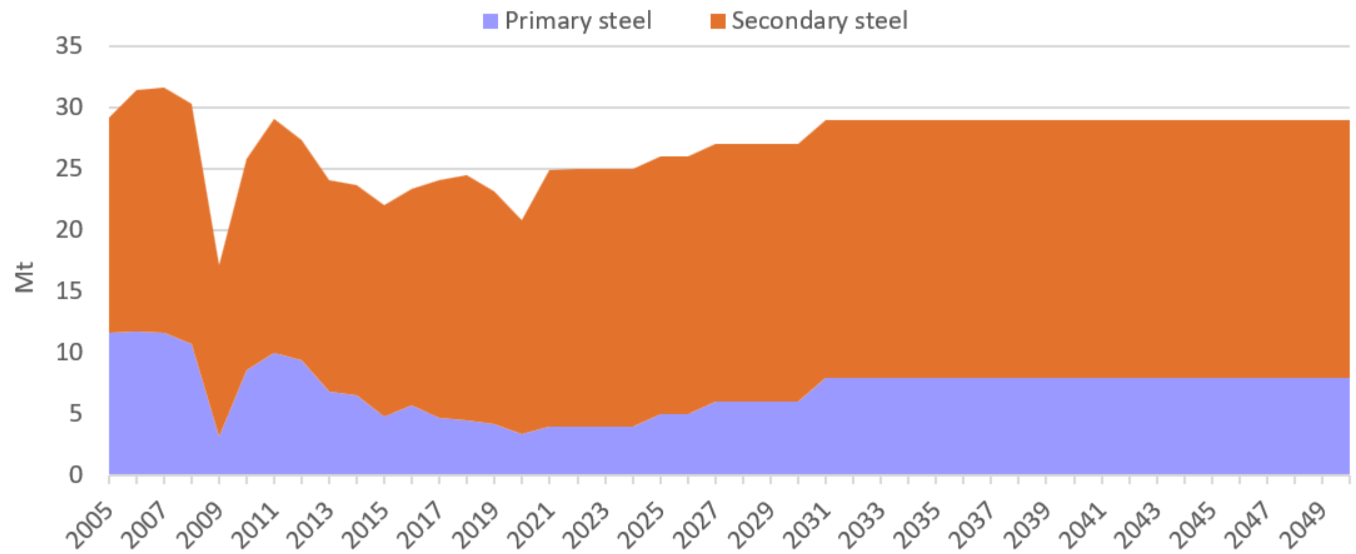
1. **Reducing direct emissions from electric arc furnaces** by fueling the burners with green hydrogen and using biocarbon as an additive;
2. **The improvement of scrap collection and sorting processes to improve the quality of the secondary steel produced.** A modern line should be divided into a stage dedicated to scrap thinning, magnetic selection, optical selection, followed by a final stage of manual sorting.

For the decarbonisation of the primary steelmaking process, the 2050 scenario envisages the transition from full cycle steelmaking based on blast furnace and oxygen reducer (BF - BOF) to

[2] "Global Steel Transformation Tracker," *Agora Energiewende*.

plants based on direct gas reduction and electric arc furnaces (DRI - EAF). The end point of the complete reconversion envisages the use of green hydrogen, both as a fuel and as a reducing agent. Based on these considerations, in the scenario developed it is assumed that coal-fired blast furnaces are kept in operation until 2028. A 1 Mt/year natural gas-fired DRI plant is also assumed to come on line in 2025, growing to 2 Mt from 2027 and 6 Mt from 2029. From 2031 onwards it is assumed that the production level will grow to 8 Mt/year and that all primary steel will be produced using DRI technology only, initially with natural gas and green hydrogen, and then switching to production based solely on the use of green hydrogen. As regards secondary steel, a constant production level of 21 Mt of steel per year is assumed, corresponding to the Italian secondary steel production recorded in 2021[3]. Figure 1 reports primary and secondary steel production in Italy in the proposed scenario.

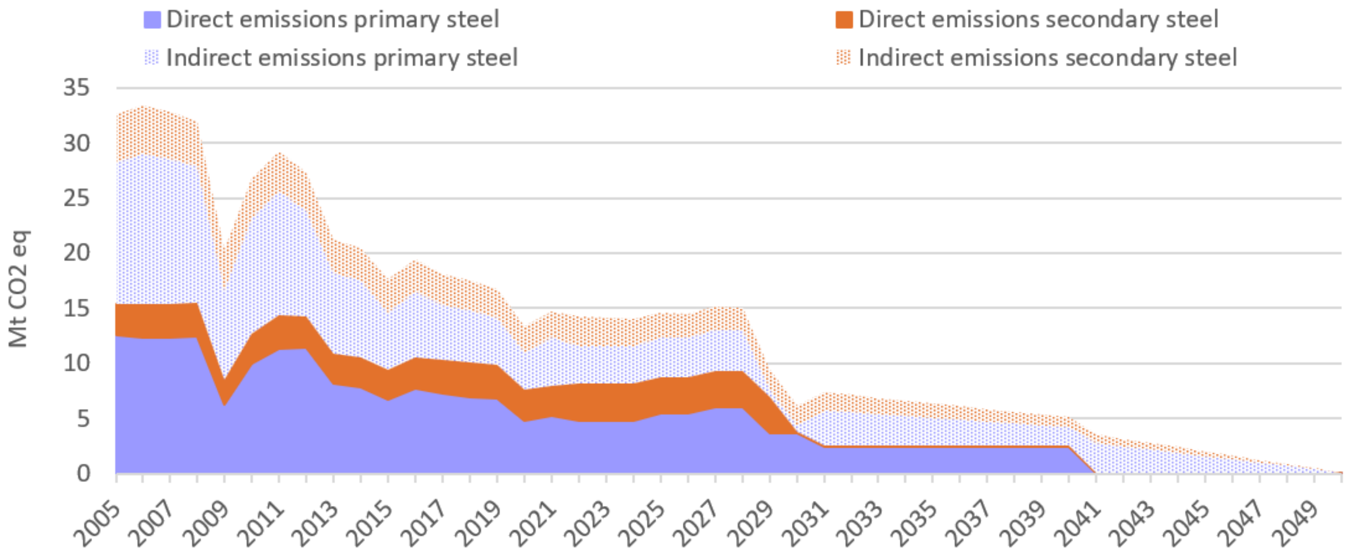
Figure 1 - Trend in primary and secondary steel production in Italy in the scenario developed.



Looking at the greenhouse gas emission trends in the graph below (Figure 2), it can be seen that up to 2028, i.e. during the operating period of the blast furnaces, emissions will remain high. From 2028 onwards the switch to DRI technology provides an immediate climate and environmental benefit. Finally, with full green hydrogen supply, emissions from primary steel production can be reduced. Direct emissions from secondary steel are reduced from 2030, when the EAF burners are assumed to be fueled with green hydrogen and biocarbon is used as an additive.

Figure 2 - Trend of direct and indirect emissions from primary and secondary steel production in Italy in the developed scenario.

[3] "The Italian steel industry in figures", *Federacciai*.



The analysis presented aims at laying the foundations for the construction of an Italian industrial and climate policy to support a sustainable conversion of the steel sector, aimed at maintaining industrial production and the related supply chain, with a view to decarbonisation and in consideration of international market dynamics. **An effective industrial policy should set concrete objectives in the short, medium and long term and develop a set of policies to promote and accelerate technological innovation and, at the same time, support businesses, for example through the creation of a market for low-carbon products.**

Accelerating the development of low-emission production processes requires the construction of pilot plants. **Direct public funding for such plants can allow companies to invest in technologies characterized by high CAPEX and reduce the risk associated with the adoption of innovative solutions.** The publication of the new Taranto industrial plan may represent a unique opportunity to program interventions and reconversion solutions that can combine the economic and social sustainability of investments with the environmental and climate sustainability of the project.

In this regard, the ongoing revision of the EU ETS Directive may also represent an opportunity to support investments in low-carbon technologies. Currently, the steel sector receives a free amount of ETS emission permits that allows it to cover almost all its CO_2 emissions. This amount is expected to be reduced over the coming years, in conjunction with the implementation of the Carbon Border Adjustment Mechanism (CBAM). If the CBAM is adopted, by 2030 a steel producer will only receive 50% of the allowances needed to cover the emissions of a blast furnace for free. The remaining 50% of allowances will have to be purchased on the ETS market, where the average price of CO_2 is currently around €81/t[4] . As a result, **the costs of carbon-intensive processes are set to increase, making investments in the sector that do not include GHG emission reductions less profitable.**

Even if today the production of the so-called 'green steel' is still at an early stage at international level, the particular historical circumstances offer an opportunity for Italy to become a leader in the production of green steel in Europe and in the world, leading the change and bringing to the market a product whose demand can only grow in the future. In this regard, **policies are needed to stimulate demand and foster a thriving market for low carbon products, leveraging first on**

[4] "Spot Market," *eex.*

public procurement. The same behavior should also be encouraged in the private sector, with industrial partnerships between steel producers and consumers. Such partnerships could be guaranteed by the state with instruments such as contracts for difference, so that the buyer can buy green steel at a price that is competitive with that of steel from coal-fired blast furnaces. The excess cost would be paid to the producer by the state.

2 THE ITALIAN STEEL INDUSTRY

Italy is the second largest steel producer in Europe and the eleventh in the world: 24.9 Mt of steel was produced in our country in 2021. Italian steel production is mainly concentrated in the North (Figure 4) and is characterized by the EAF (Electric Arc Furnace) cycle. **84% of the steel produced in Italy is recycled steel**, i.e. produced from the remelting of ferrous scrap (as well as the addition of pig iron and sponge iron) in electric arc furnaces. In Italy there are 32 plants of this type, with an average production capacity of 0.7 Mt of steel per year.

The remaining 16% is primary steel, produced with the BF - BOF (*Blast Furnace - Basic Oxygen Furnace*) integral coal cycle starting from iron ore at the *Acciaierie d'Italia* plant in Taranto, the only plant with production of steel from ore in Italy. In fact, the hot areas of the Piombino and Trieste plants were closed in 2014 and 2020 respectively.

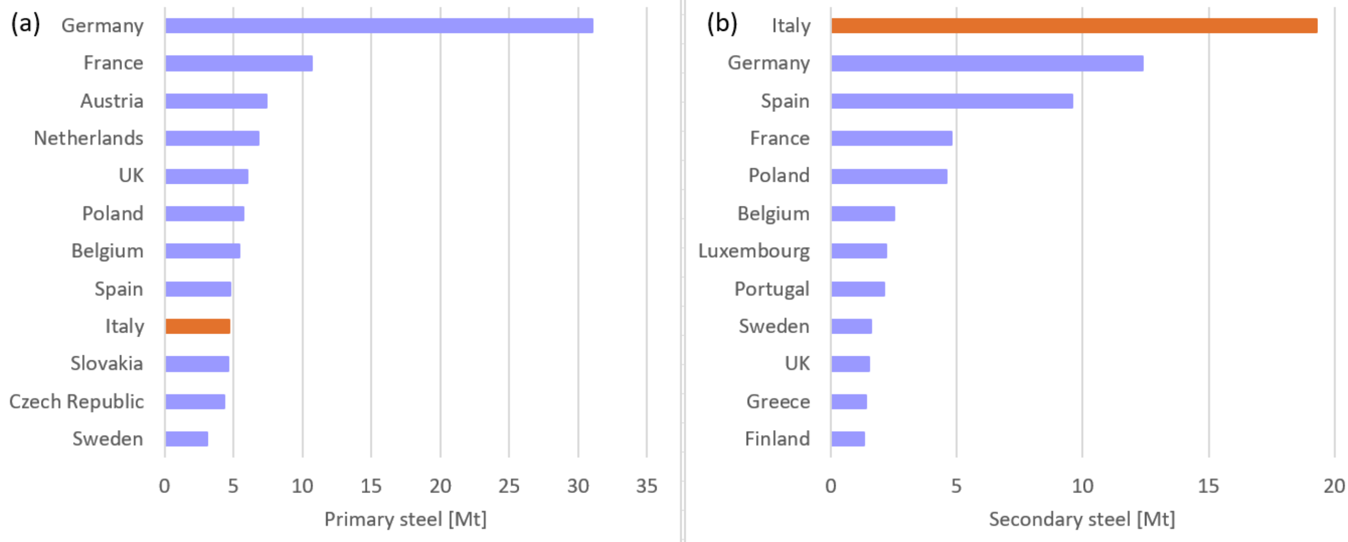
Figure 3 - Geographical distribution of Italian steelmaking sites.

Since the 1990s, the Italian steel industry has been the second largest market in Europe in terms of both production and employment and is the leading European market in terms of volume of recycled steel[5] , as shown in Figure 4[6].

[5] "It's time to act - The Italian steel industry 2019", *Federacciai.*

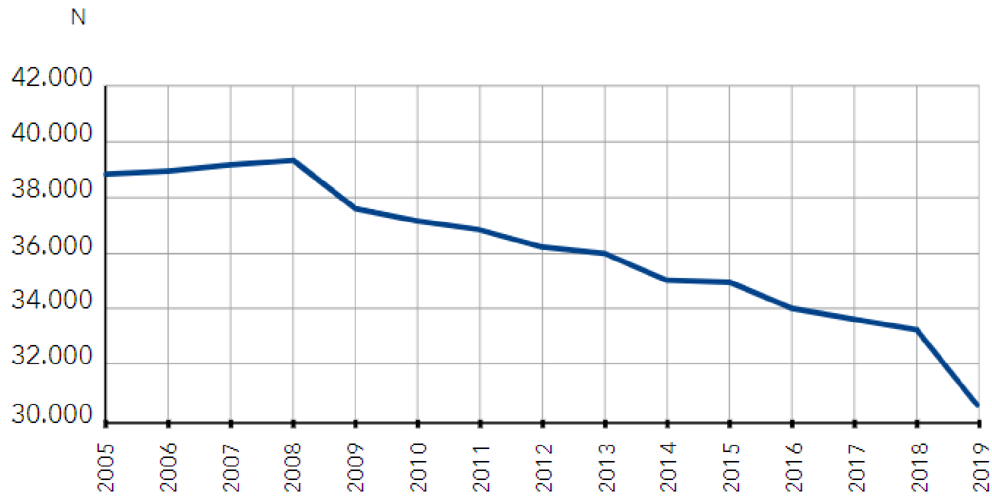
[6] "Breakthrough Strategies for Climate-Neutral Industry in Europe," *Agora Energiewende,* April 2021.

Figure 4 - Major European producers of primary steel (a) and secondary steel (b) in 2017[7].



In Italy, the primary steel industry employs almost 31 thousand people, considering both the production of semi-finished products (billets, slabs, blooms and ingots) and rolling and forging operations[8]. The Italian steel sector has suffered heavily from the effects of the economic crisis of 2008, so much so that from 2008 to 2019 it has lost about 9 thousand employees and production has dropped by 24%[9] (Figure 5). Overall, the steel sector, from the production of raw steel to its transformation into final products, employs 70 thousand workers, with an employment impact estimated at three times higher if we also consider the allied industries[10]. The reconversion towards decarbonisation can and must be an opportunity to relaunch the sector and create new jobs.

Figure 5 - Employment trends in primary steelmaking from 2005 to 2019[11].

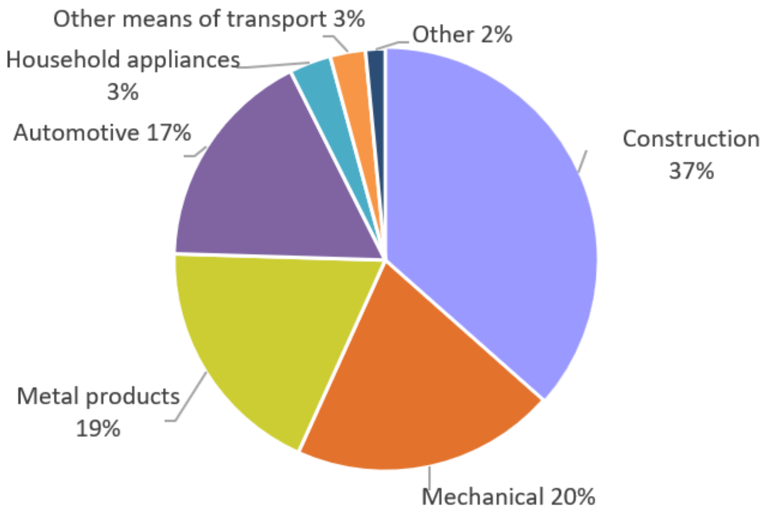


[7] "World steel in figures 2009", *World Steel Association*.
[8] "The Italian steel industry in figures," Production Italy, *Federacciai,* April 15, 2021.
[9] "World steel in figures 2009", *World Steel Association*.
[10] "The Italian steel industry in figures," Production Italy, *Federacciai,* April 15, 2021.
[11] "It's time to act - The Italian steel industry 2019", *Federacciai.*

In 2021, the turnover of the primary steel industry was 37 billion euros, with an important share deriving from activities in foreign markets, testifying that the Italian steel industry is an international excellence.

Steel is used in several sectors in the Italian manufacturing context, with the main consumers being the construction, mechanical and metal products sectors (Figure 6). Under 'Other' of Figure 6 the use of steel for the production of food tinplate plays an important role.

Figure 6 - Distribution of consumption among the main steel-using sectors in Italy[12].



2.1 THE IMPORTANCE OF MAINTAINING DOMESTIC PRIMARY STEEL PRODUCTION

For our country it is necessary to maintain a presence in primary steel both because, now, it is the only material that can be used for certain applications and to guarantee the availability of scrap to the many companies that produce recycled steel in Italy.

There are some sectors in which the use of primary steel, i.e. steel produced from iron ore, is essential. In these sectors it is necessary for steel to have excellent surface characteristics (both for aesthetic reasons and to better resist certain failure phenomena such as corrosion) and excellent ability to deform without fracturing (high ductility). These applications concern car bodies, food cans, rails, complex profiles for furniture and parts of mechanical systems that need deep deformation. These sectors cover about 30% of the applications of primary steel [13].

Every year in Italy about 17 million tons of ferrous scrap are recycled, 73% of which comes from the domestic market (Figure 7). Secondary steel producers therefore depend heavily on the availability of scrap on the domestic market and maintaining primary steel production in Italy is also necessary to ensure stability and security of supply for companies. It should also be remembered that during use and disposal, steel tends to be contaminated by undesirable elements, such as tin and copper. A refill of primary steel is therefore necessary to produce good quality recycled steel.

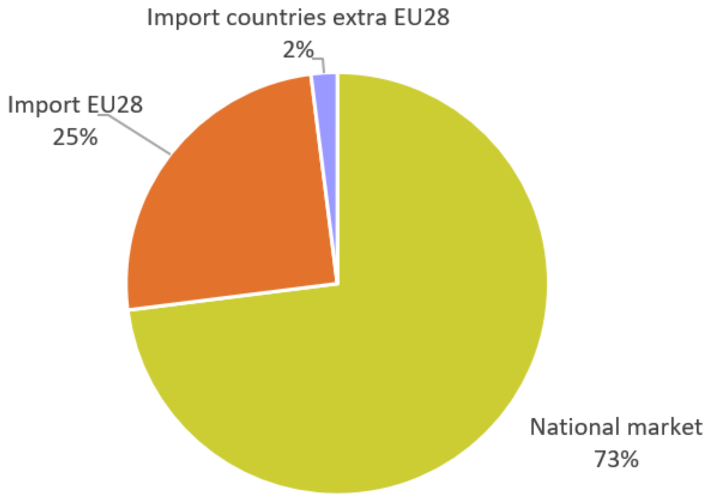
---

[12] "The user sectors," *Siderweb,* 2020.

[13] "Steel Statistical Yearbook 2020 concise version", *World Steel Association*.

[8] "Climate: Xi promises China zero emissions by 2060," *Ansa*, November 17, 2020.

Figure 7 - Distribution of scrap origin in 2019 in Italy[14] .



The availability of scrap is therefore a key variable, both at the Italian level and at international scale. Looking at China as an example, in 2019 996 Mt of steel were produced in this country, 89% of it with integral cycle[15] . This share is so high also because China is a fast-growing economy, which has seen a significant increase in production in recent years. Therefore, China has not yet accumulated a large amount of ferrous scrap and currently has limited availability. However, as products and infrastructure reach end-of-life in the coming years, the increasing availability of ferrous scrap and China's climate neutrality targets to 2060 will support a gradual shift from primary steel production to electric arc furnace technology[16] . This shift assumption will have a significant impact on scrap demand both in China and globally. Assuming that China converts even 15% of its installed full-cycle capacity to electric arc furnaces, China alone would have a scrap demand of about 220 million tons per year. The availability of scrap, especially of good quality, is therefore a potentially critical variable.

In the light of this, and of the fact that the complete transition to electric furnace production with scrap exploitation appears difficult to achieve, it is clear that primary steel production is necessary for Italy. Being **dependent on scrap imports exposes the entire Italian steel industry and several other sectors of the Italian economy to high risks and uncertainties.**

2.2 THE POST COVID RECOVERY AND THE EFFECT ON STEEL DEMAND

Between January and November 2021, the output of Italian steel mills rose by 22% compared to the corresponding period of 2020, touching 23 million tons. Despite this, last year the trade balance of the Italian steel industry showed a deficit of 1.1 million tons, compared to 354 thousand tons in the corresponding period of 2020. The deficit import-export, therefore, increased by more than 730 thousand tons, due to the strong demand for steel by the Italian industry. In particular, it is trade with non-EU countries, as per tradition, that shows the greatest imbalance, with imports exceeding exports by over 900 thousand tons, while for trade with EU countries there was an import deficit of

[14] "It's time to act - The Italian steel industry 2019", *Federacciai*.

[15] "Steel Statistical Yearbook 2020 concise version", *World Steel Association*.

187 thousand tons. Figure 10 shows the trend of the import - export balance of steel products in Italy from 2005 to 2020. As can be seen from the figure, our country was a net exporter from 2011 to 2014; in these years the domestic market had undergone a strong downsizing, a factor that led to an increase in exports. Since 2015 there has been a recovery in domestic consumption and a drop in production, which again made our country a net importer. In 2019, imports fell slightly following the introduction of the European Union's Safeguard Measures, measures consisting of a combination of quotas and tariffs to ensure traditional levels of steel trade are maintained in the EU market. Imports then contracted sharply in 2020 due to the Covid-19 pandemic.

Figure 8 - Steel import trends in Italy from 2005 to 2020[17] .

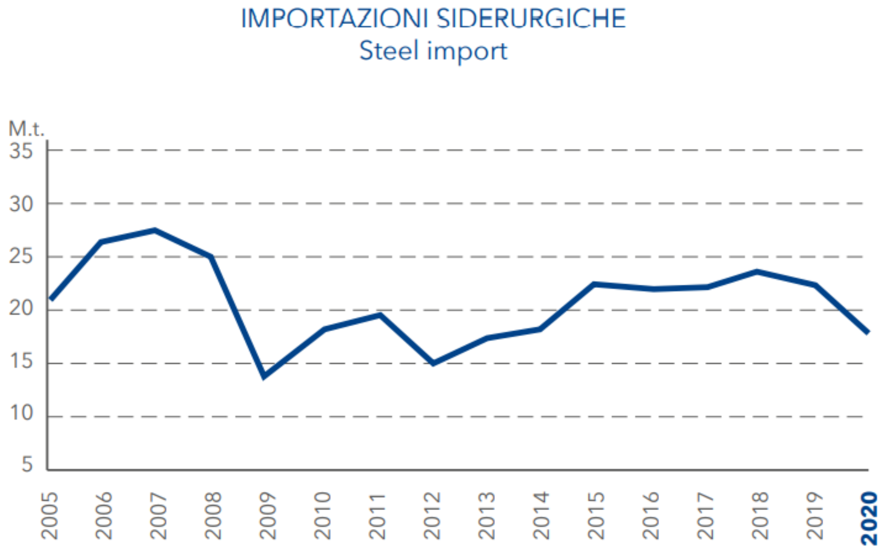
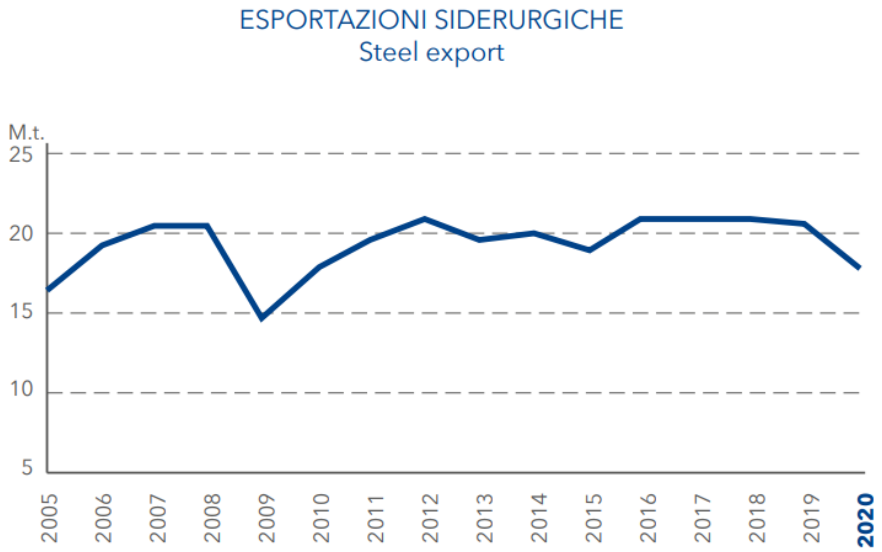
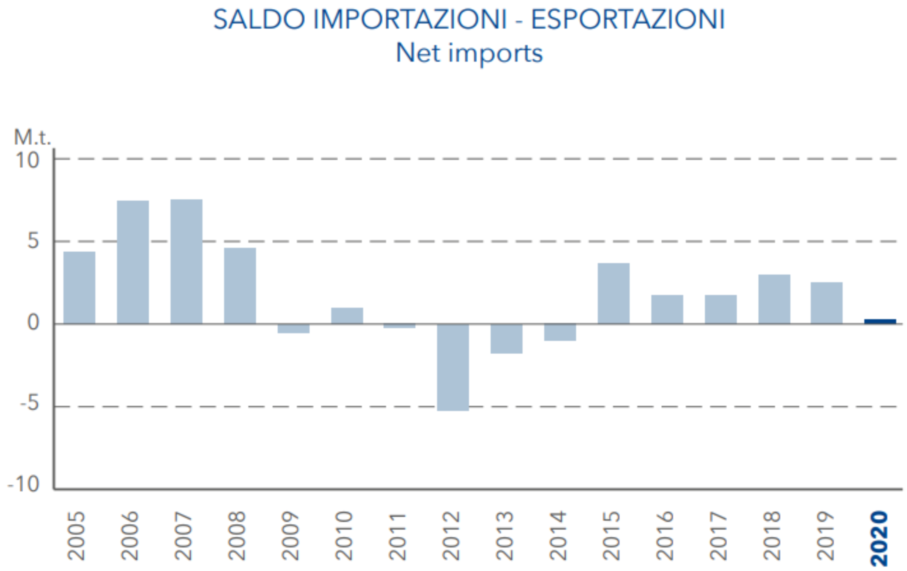


Figure 9 - Steel export trends in Italy from 2005 to 2020.



[17] "The Italian steel industry in figures," Production Italy, *Federacciai,* April 15, 2021.

Figure 10 - Trend of the import-export balance in Italy from 2005 to 2020.



Italy imports steel mainly from Ukraine, Germany and France (Table 1). In 2020, imports from China and Russia almost halved, as an effect of the Safeguard Measures.

Table 1 - Main countries of origin of imports

Country	Import 2019 [Mt]	Import 2020 [Mt]	Change % 2020-2019
Ukraine	2,4	2,1	-13,6%
Germany	1,9	1,8	-5,6%
France	1,9	1,3	-34,7%
Turkey	1,6	1,2	-26,8%
Russia	1,7	1	-41,8%
India	1,2	1	-23,6%
Austria	0,8	0,9	+11,5%
South Korea	0,8	0,9	+7,3%
Spain	0,8	0,6	-24,8%
China	1	0,5	-48,3%

Italy exports steel products mainly to the European market and, in particular, to Germany, France and Austria (Table 2).

Table 2 - Main countries of origin of exports.

Country	Export 2019 [Mt]	Export 2020 [Mt]	Change % 2020-2019
Germany	2,5	2	-20,2%
France	1	0,8	-21,7%
Austria	0,8	0,7	-8,7%
Poland	0,6	0,6	-3,7%
Spain	0,8	0,5	-32,1%
Romania	0,5	0,4	-3,9%
Czech Republic	0,4	0,4	-7,6%
Turkey	0,4	0,4	-4,5%
Slovenia	0,4	0,4	-1%
Switzerland	0,5	0,4	-17,6%

One of the peculiar aspects of 2021 was certainly also the scarcity of supply compared to demand. This imbalance, which began to be felt during the latter part of 2021 and which affected first and foremost the carbon steel tops segment (and then expanded to the other segments of the market as well), led to a search for volumes by steel users and, consequently, also by traders. **At many points in 2021 the main variable for the steel market was not price, but material availability: good performance in many sectors and availability of credit led to a substantial increase in demand.** This conducted to a sharp drop in supply chain inventories, which returned closer to standard values only in the latter part of the year. This frantic search for steel, which also added to the scarce availability of materials from third countries (due to the good self-consumption of those countries and to customs obstacles) and to the high cost of energy, could not but have a logical repercussion on market prices, which were under pressure until late summer, reaching new historical records in many cases. Prices deflated slightly in the final part of the year, remaining however, at values clearly higher than the historical average (Figure 11). The war between Ukraine and Russia, respectively the first and fifth country from which Italy import steel, created further tensions on the steel trade, aggravated by the rationing of natural gas from Moscow and by the price trend of all energy commodities. Due to the combination of several critical factors, it is difficult to make a forecast on steel prices in the coming months. It is reasonable to assume that if the war continues and fossil fuel supplies are uncertain, steel prices will remain high.

Figure 11 - Trend of the Dow-Jones Commodity Index, a synthetic parameter of the price trend of a series of basic materials quoted on the main world markets. The graph combines the dynamics of two subsets of the general index (in black, on the right-hand side): energy commodities (in orange) and metals (in green), both on the left-hand side[18] .

[18] "2021 outcomes and 2022 outlook in steel price performance," *Siderweb*, December 29, 2021.

BOX 1

THE ITALIAN STEEL INDUSTRY - HISTORICAL NOTES

To better understand and frame the sector and its potential evolution, it is useful to recall the history of the national iron and steel industry. In Italy the birth of this sector dates to the first half of the 19th century, but the first important phase of technological development began in 1870, with the diffusion of the modern Martin-Siemens furnaces. In a decade the national steel production went from a little more than 4 thousand tons (average of the years 1881-1885) to almost 158 thousand tons in 1889[19] .

In the first half of the 20th century, the supply of steel products was characterised by strong cyclical swings, particularly during the two world wars. In 1950, at the height of post-war reconstruction, there were 210 steel companies in Italy. Large and medium-sized companies accounted for 90% of steel production and 87% of rolled products.

In the period 1953 - 1974 there was a strong increase in demand for steel products, to the benefit of the Italian steel industry and industry in general. At the beginning of this period Italy was the fifth largest steel producer in Europe, while in 1975 it was in second place, behind Germany and ahead of Belgium, Great Britain and France, countries with a long steelmaking tradition. Among the factors contributing to the expansion of supply, of great importance was the growing weight of public shareholding companies; these companies specialized in flat products, for which large plants were necessary. The development policies of southern Italy placed great trust in the iron and steel industry, which was thought to contribute to the development of the southern regions. It was with this in mind that in the sixties it was decided to build the integral cycle plant in Taranto.

From the 1950s to the 1970s the private steel industry also experienced a dynamic development in complementary processing and secondary steel production. The private steel industry was characterised by small and medium-sized enterprises, high operational and managerial flexibility and dynamic research. These "mini-steel mills" were mostly located in Northern Italy, an area that could guarantee the necessary electricity and scrap supplies. Northern Italy was also close to the major European markets. It was therefore between the 1950s and the 1970s that the Italian steel industry took on the characteristics that still distinguish it today.

The years of peak supply coincided with a period of falling demand for steel products, causing problems of overcapacity. This depression, particularly relevant in the years between 1975 and 1977, affected all the European producers. In Italy, however, it was aggravated by the lack of flexibility on the part of the large public undertakings, which in the years of falling demand were unable to adapt their employment levels, consequently losing market share. On the other hand, medium-small enterprises had a different evolution: their expansion continued during the seventies.

[19] Goglio, Alessandro; Rosa, Giuseppe; "Siderurgica, industria", *Treccani,* 1994.

The eighties began with a new drop in demand, which lasted for three years, during which more than 50 thousand jobs were lost, equal to 50% of the total in 1980. Production was therefore optimised to favor activities with a higher added value. Private companies also participated in this program and accepted the cuts in exchange for aid. These allowed the private steel industry to face the new wave of crisis and to strengthen its competitiveness, innovating production processes (with the spread of oxyfuel burners and scrap pre-heating) and diversifying production. This reorganisation further marked the characteristics that still today distinguish the Italian steel industry from the rest of Europe. The main European producers, in fact, are more specialised in the processing of flat products with integral cycle plants, while our country has increasingly distinguished itself in long products using electric arc furnaces.

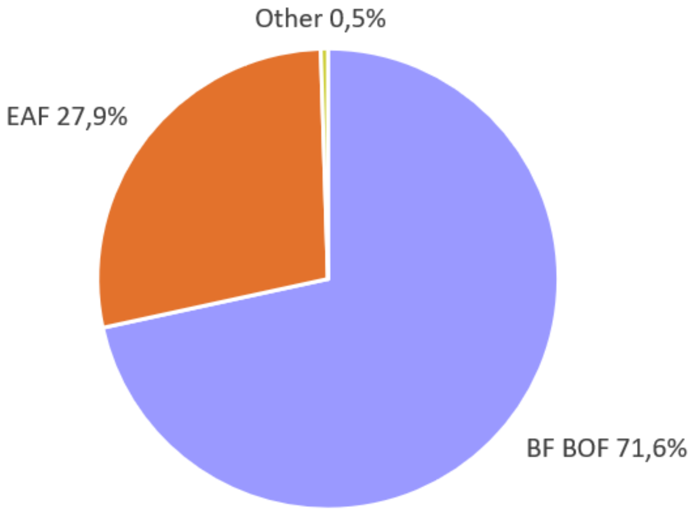
From the 1990s onwards, the sector has undergone profound changes, with the gradual further dismantling of large public production centers and the privatisation of existing ones. The progressive dismantling of primary steel production is still in progress: the last closure dates back only to 2020, with the shutdown of the hot area of the *Arvedi* plant in Trieste and its industrial reconversion program. Secondary production, in parallel, continues on its path of specialisation towards special steels and high-quality products, with expanding market segments.

3 STEEL AND CLIMATE RISK EXPOSURE

There are different steelmaking techniques and multiple types of steels. The main ways of production are:

- From ore through an integral BF - BOF cycle. This is the most widespread system in the world and covers 65% of global steel production ;
- From ore by Direct Reduced Iron (DRI) process and Electric Arc Furnace (EAF). This system has already reached commercial maturity, although it is not very widespread;
- From scrap (secondary steel) in electric arc furnaces (EAF) (Figure 12).

Figure 12 - Processes used for steel production worldwide. Total: 1˙874 Mt produced in 2019[20] .



3.1 THE INTEGRAL CYCLE BF - BOF

The integral cycle with blast furnace (BF) and oxygen converter (Basic Oxygen Furnace - BOF) consists of the following stages:

1. Preparation of raw materials (iron ore and coal). The ferrous ores are sent to the sintering and pelletizing plants, to obtain agglomerates of adequate size. In coking furnaces, coke is produced from coal, which acts both as a reducing agent and as a structural stabilizer of the charged materials;
2. Production of pig iron. Iron ore, coke and limestone are loaded into the blast furnace and hot air is blown in from below. The air reacts with the coke, forming carbon monoxide (CO):
$$C + O_2 \rightarrow CO_2$$
$$CO_2 + C \rightarrow 2CO$$

   Carbon monoxide is the reducing agent that allows the separation of the iron present in the ores, according to the following overall chemical reaction:
$$Fe_2O_3 + 3CO \rightarrow 2Fe + 3CO_2$$
   Liquid cast iron is thus obtained, i.e. an alloy characterised by a carbon concentration of about 4.3%. The cast iron is collected in the crucible and delivered to the steelworks;
3. Steel production. To make steel, which has a carbon content of between 0.005% and 2.11%, the pig iron is fed into the basic oxygen converter together with a certain amount of scrap

[20] "Steel Statistical Yearbook 2020 concise version", *World Steel Association*.

(which acts as a coolant) and is converted to steel by a jet of oxygen. The oxygen reacts with the carbon in the pig iron to form carbon dioxide, reducing the carbon content and producing steel. The steel is then sent to secondary metallurgy treatments and continuous casting machines for solidification. The entire BF - BOF process is schematized in Figure 14.

Figure 13 - BF-BOF integral cycle configuration.

In the integral cycle process, coal has multiple functions:

- is one of the 'ingredients' in the production of steel;
- is the source of the reducing chemical species for the production of cast iron;
- is used as an energy source for heat generation;
- performs a structural function to support the material loaded into the blast furnace.

As a result of this intensive use of coal, the integral cycle process is characterised by high CO_2 emissions, equal to 2 t_{CO2} /t_{steel}. The production of steel by integral cycle is also particularly emissive in terms of gaseous and dust pollutants. The integral cycle generates emissions of carcinogenic and genotoxic pollutants, such as dioxins and benzo(a)pyrene.

Full cycle plants are net exporters of energy through the export of coke oven gas (COG), blast furnace gas and converter gas which, when converted to electricity, can fully meet the needs of the steelmaking cycle and also sell electricity to external customers. This represents a significant advantage for steel producers.

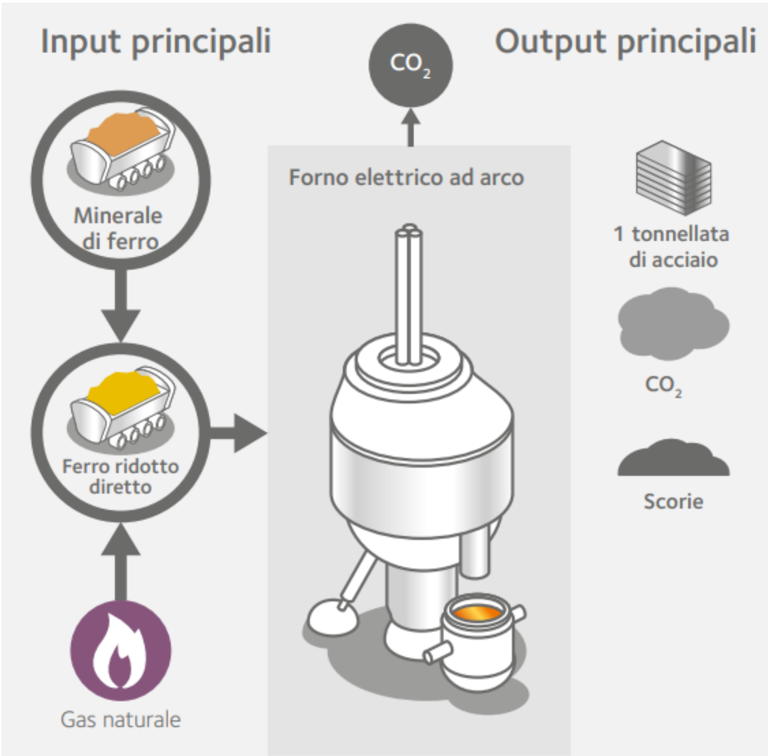
3.2 DIRECT REDUCED IRON (DRI) TECHNOLOGY

With the process of direct reduction of ore, it is possible to produce steel without the use of carbon coke and without the transition of the metal to a liquid state. The process begins with the reforming of natural gas and the consequent formation of carbon monoxide (CO) and hydrogen (H_2), which in turn react with the iron ore and transform it into iron sponge (DRI). In detail, the overall reaction governing this process:

$$\frac{4}{3}Fe_2O_3 + CH_4 \rightarrow \frac{8}{3}Fe + CO_2 + 2H_2O$$

The resulting product is then supplied as a raw material to electric arc furnaces, where the pre-burnt product, potentially together with a fraction of scrap, is melted by electricity and natural gas (or, in the future, hydrogen) burners and primary steel is produced (Figure 14). From a technical point of view, therefore, DRI makes it possible to produce steel of a quality fully comparable to that of the product of full-cycle mills, since the steel comes directly from the reduction of the ore and its quality does not depend on the scrap sorting processes.

Figure 14 - Steel production using DRI technology and electric arc furnace[21] .



An overall analysis of this cycle must also consider the environmental impact of the pelletizing plant (PP), which supplies the iron ore pellets necessary for the pre-reduction furnace. The consumption

---

[21] "Climate Action," *ArcelorMittal,* May 2019.

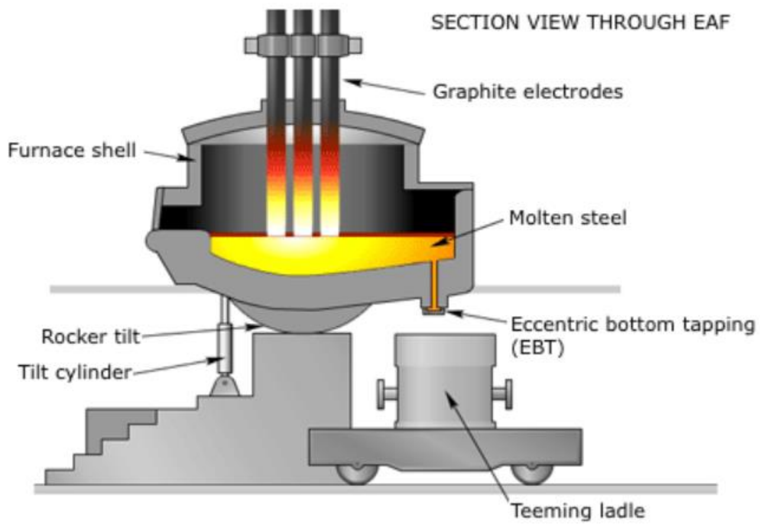
of natural gas to feed the entire production process, considering therefore pelletizers, DRI units, electric arc furnace and post-heating furnace, is equal to 381 Nm^3 /t_{steel}, of which 81% is used to feed the direct reducer. The electricity consumption of the process is 634 kWh/ t_{steel}, 80% of which is used to power the electric arc furnace.

Direct emissions from the natural gas DRI process are 816 kg_{CO2} /t_{steel}. 35% of these (282 kg_{CO2} /t_{steel}) is pure CO_2 selectively separated without the need for additional processes. This share of CO_2 can be avoided by replacing natural gas with green hydrogen as a reducing agent in the DRI system (see DECARBONISATION OF PRIMARY STEEL). Alternatively, for the abatement of emissions, it is possible to opt for solutions based on the capture of CO_2; in this case, an evaluation of the potential for storage or use of the sequestered carbon dioxide is necessary (BOX 2 *CARBON CAPTURE USE OR STORAGE* (CCUS)).

3.3 ELECTRIC ARC FURNACES

Secondary steel production is based on the melting of scrap, pig iron and sponge iron (the 'pre-batch') in electric arc furnaces. It is, therefore, the so-called 'secondary processing' of steel, since it starts from scrap material mixed with pig iron and/or reduction steel and other additives to produce new steel. The electric arc strikes between three electrodes and the metal charge and temperatures can reach up to 2000°C. After melting, the cast steel is transferred to secondary metallurgy and continuous casting or ingot pit for solidification of semi-finished products (i.e. billets, blooms, slabs). The entire process is depicted in Figure 15.

Figure 15 - Configuration of an electric arc furnace.



To power the electric arc furnaces, an electricity input of 510 kWh/t_{steel} is required. To optimize the melting process of scrap, the electric arc furnaces are equipped with natural gas burners; 24 Nm^3 of natural gas is required to produce one ton of secondary steel.

4 OPTIONS FOR THE DECARBONISATION OF THE STEEL PRODUCTION PROCESS

In the following paragraphs, solutions for the decarbonisation of the production process of both primary and secondary steel are analyzed.

4.1 DECARBONISATION OF PRIMARY STEEL

Already with the dismantling of coal-fired blast furnaces and the switch to natural gas DRI technology, CO_2 emissions can be reduced by about 70%, with significant benefits also in terms of environmental pollution. To achieve long-term climate neutrality objectives, natural gas can be gradually replaced with green hydrogen, without the need for major plant modifications. During the natural gas DRI process, in fact, the hydrogen contained in the reducing gas contributes to the reduction of 66% of iron ore, while the remaining 34% is reduced by carbon monoxide, which then gives rise to CO_2. Only hydrogen can be used to reduce iron ore, and by using 'green' hydrogen (i.e. produced using electrolysis and renewable electricity), CO_2 emissions from primary steel production can be substantially reduced, as well as all emissions associated with the use and transport of natural gas. The system also avoids the need to capture CO_2 through CCS plants.

Steel production by green hydrogen DRI implies an electricity requirement of 4˙576 kWh/t_{steel}[22], with the assumption of a specific electrolyzer consumption of 4.25 kWh/Nm^3 of hydrogen (APPENDIX 1 - HYPOTHESIS). The electricity is mainly used to power the electrolyzers to produce green hydrogen (Table 3). The technology is also established for use with hydrogen only and has a TRL[23] equal to 9.

Table 3 - Comparison of energy consumption and CO_2 emissions of steelmaking technologies.

Production process	**Coal consumption [kg/t_{steel}]**	**Consumption of natural gas [Nm^3 /t_{steel}]**	**Electricity consumption [kWh/t_{steel}]**	**Direct CO_2 emissions [kg_{CO2} /t_{steel}]**	**Indirect and fugitive emissions of CO_2 [kg_{CO2eq} /t_{steel}]**
BF BOF	365,2	30,5	166	1˙912 - 2˙035	54
Natural gas DRI[24]	0	381	634	816	243
Green hydrogen DRI	0	0	4˙576	3,7	
Change % green hydrogen DRI		-100%	+622%	-99,5%	

[22] Expected average value for the low-temperature electrolysis technologies (alkaline and PEM) available today. The technological evolution in progress could allow a reduction of the electricity demand, also in relation to the availability of high temperature electrolysis systems. In agreement with the values reported in the literature, it is also assumed that 60 kg of hydrogen are required to produce one tonne of steel.
[23] The acronym TRL - Technology Readiness Level - indicates a methodology for the evaluation of the maturity level of a technology. For further information please refer to APPENDIX 2 - TECHNOLOGY READINESS LEVEL.
[24] The values shown in the table for DRI technologies refer to the entire production process and therefore include consumption and emissions of pelletizing plants, direct reducers, electric arc furnaces and post-heating furnaces.

Production process	Coal consumption [kg/t_{steel}]	Consumption of natural gas [Nm^3 /t_{steel}]	Electricity consumption [kWh/t_{steel}]	Direct CO_2 emissions [kg_{CO2} /t_{steel}]	Indirect and fugitive emissions of CO_2 [kg_{CO2eq} /t_{steel}]
- natural gas DRI					
EAF	0	24	510	157	160

Indirect emissions associated with green hydrogen DRI depend on the average emission factor of the national electricity production. With an emission factor of 300 g_{CO2} /kWh, this results in 1˙373 kg_{CO2}/t_{steel} of indirect emissions. However, with the progressive decarbonisation of the electricity sector, indirect emissions are set to decrease. In fact, the Proposal for the Ecological Transition Plan (PITE)[25] published by the Ministry of Ecological Transition in July 2021, envisages that by 2030 the contribution of renewables to meeting gross final consumption will be 70% in the electricity sector. This value represents the electricity sector's contribution to the new greenhouse gas emission reduction target contained in the European *Fit for 55* package[26] (-55% to 2030 compared to 1990 levels).

If the target of 70% renewables for the electricity sector is reached by 2030, it is estimated that the emission factor of national electricity production would be 161 g_{CO2} /kWh. In this scenario, indirect emissions related to green hydrogen DRI technology would be 737 kg_{CO2} /kWh, about half of those with the current emission factor.

If the targets in the PITE Proposal are not met, the indirect emissions associated with green hydrogen DRI process would be higher. If by 2030 the contribution of renewables will be 55% in the electricity sector, in line with the provisions of the National Integrated Energy and Climate Plan (PNIEC)[27] , this would result in an emission factor of 205 g_{CO2} /kWh. In this scenario, indirect emissions would be 938 kg_{CO2}/kWh. It is **clear that the penetration of renewables in the electricity system is a necessary condition for the reduction of indirect emissions associated with steel production. For this reason, it is essential to maintain high levels of new renewable installations, in order to reach, and if possible exceed, the targets set by PITE.**

BOX 2

CARBON CAPTURE USE OR STORAGE (CCUS)

CCUS (*Carbon Capture Use or Storage*) technologies allow carbon dioxide to be sequestered and stored in permanent reservoirs or used in certain production processes. It could be convenient to capture CO_2 emissions generated by the natural gas DRI process since 35% of direct emissions (equal to 282 kg_{CO2} /t_{steel}) are obtained in the form of pure CO_2 selectively separated, without the need for additional processes. These concentrated emissions can be

[25] "Proposal for the Ecological Transition Plan," July 28, 2021.
[26] "2030 Climate and Energy Framework", *European Commission.*
[27] "Integrated National Energy and Climate Plan," December 2019.

abated with CCS technologies with a power consumption about 10% higher than the natural gas DRI process without capture systems (Table 4).

In the case more stringent emission abatement is desired, it is possible to apply CO_2 capture to all emission points, i.e. the pelletizer stack, the DRI kiln, the concentrated emissions of the DRI process, the fumes of the electric arc furnace, the fumes of the lime plant and the fumes exiting from the post-heating kiln. In this way it is possible to obtain a direct emission abatement of 97% with respect to the natural gas DRI process, with residual emissions equal to 27 kg_{CO2}/t_{steel}, attributable to the incomplete capture of CO_2 from the emission points. This results in an increase in electricity consumption of 66% (Table 4).

Table 4 - Comparison of energy consumption and CO_2 emissions of natural gas DRI, green hydrogen DRI, natural gas DRI and CO_2 capture pure and natural gas DRI and CO_2 capture technologies across all emission sources.

Production process	**Consumption of natural gas [Nm^3/t_{steel}]**	**Electricity consumption [kWh/t_{steel}]**	**Direct CO_2 emissions [kg_{CO2}/t_{steel}]**	**Indirect and fugitive emissions of CO_2 [kg_{CO2eq}/t_{steel}]**
Natural gas DRI[28]	381	634	816	243
Green hydrogen DRI		4˙576[29]	3,7	
Natural gas DRI + pure CO_2 capture[30]	381	695	535	53
Natural gas DRI + CO_2 capture on all emission sources	381	1˙054	27	53

For the storage of CO_2, large-scale geological storage is required. Geological storage sites need to be characterized by a number of parameters, such as:

1. Presence of porous and permeable rocks (called reservoir rocks);
2. Presence of overlying impermeable rocks (called cap rocks), which act as a cap for the CO_2 preventing it from leaving the site;
3. Absence of potable water (a resource too valuable to be used in confinement processes);

[28] The values shown in the table refer to the entire production process and therefore include consumption and emissions of pelletizing plants, direct reducer, electric arc furnaces and post-heating furnaces.
[29] Expected average value for the low-temperature electrolysis technologies (alkaline and PEM) available today. The technological evolution in progress could allow a reduction of the electricity demand, also in relation to the availability of high temperature electrolysis systems. In agreement with the values reported in the literature, a requirement of 60 kg of hydrogen is assumed to produce one ton of steel and a specific consumption of the electrolyser of 4.25 kWh/Nm^3 of hydrogen.
[30] The following assumptions are made for CO_2 capture and storage processes:

- Consumption for compression and transport of 220 kWh/t_{CO2}, to be applied to all CO_2 sources for CCS;
- For CO_2 sources to which a post-combustion capture process is applied (i.e. from low pressure gas diluted in N_2), a CO_2 capture efficiency of 95% and an electricity consumption of 486 kWh/t_{CO2} are assumed, corresponding to the consumption of a heat pump with COP of 2 providing 3.5 MJ/kg_{CO2} of heat for the regeneration of the solvent used for capture;
- Use of only renewable electricity.

4. At least 800 m depth to get the right conditions of pressure and temperature[31] .

Potential geological storage sites are depleted hydrocarbon extraction wells or saline aquifers. In Italy a possible storage site is in the Adriatic Sea, with a capacity of 500 Mt of CO_2[32] . Assuming that CO_2 is applied to all emission sources, that 8 million tons of steel are produced per year at the ILVA Taranto plant and that the storage capacity of the Adriatic Sea is used only for emissions from the Taranto steel mill, it would be possible to store CO_2 in the Adriatic Sea for 79 years. In order to take advantage of capture technologies for a longer period of time, the CO_2 could be brought abroad to areas where the largest storage reservoirs are located, such as Russia, the United States and Canada. However, this would make Italy dependent on other countries for the geological containment of CO_2. It should also be borne in mind that exporting CO_2 for storage has a cost, which would inevitably be reflected in the price of the final products.

For all these reasons it is considered that CCS is not a competitive and meaningful option in the decarbonisation strategy also because, after receiving considerable public subsidies, to date the projects implemented have not yielded any relevant result. After decades of development, CO_2 capture has reached a capacity of about 40 Mt CO_2 /year[33], corresponding to 0.1% of all CO_2 emitted globally in 2019[34]. The only examples of relatively mature applications are related to the oil industry, but going against decarbonisation targets.

4.2 DECARBONISATION OF SECONDARY STEEL

Moving on to secondary steel, the options for decarbonisation identified are two:

1. **The reduction of direct emissions from electric arc furnaces;**
2. **The improvement of scrap collection and sorting processes to improve the quality of the secondary steel produced.**

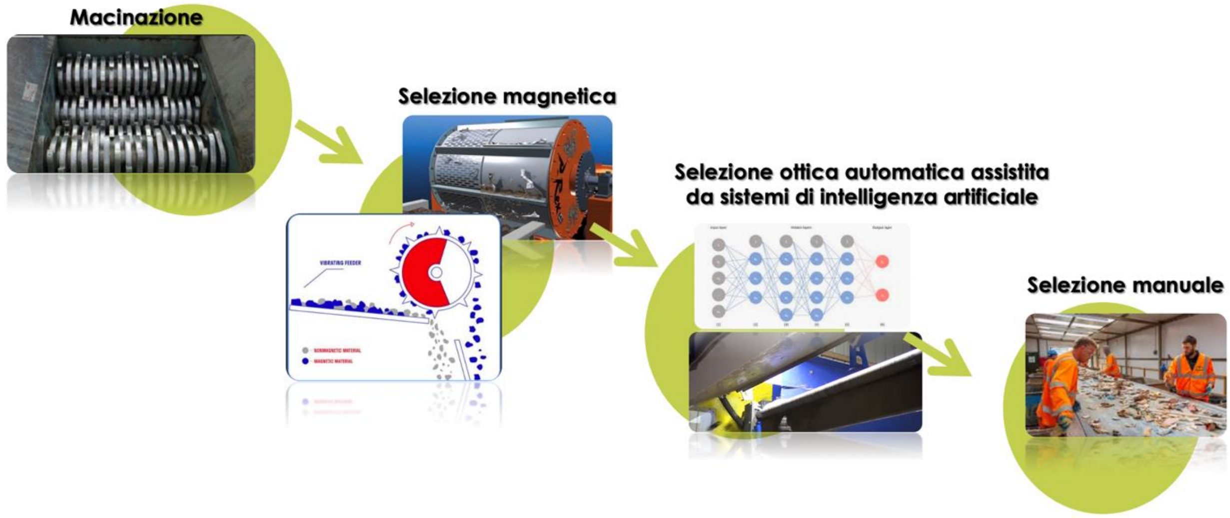
To reduce direct emissions from electric arc furnaces, it is possible to feed the burners with green hydrogen and use biocarbon as an additive, to be loaded into the furnace together with the scrap. In this way it is possible to reduce the direct emissions of EAF by 98%, from 157 kg_{CO2}/t_{steel} to 3.7 kg_{CO2}/t_{steel}. The residual emissions are due to the consumption of the graphite electrodes.

To produce good quality secondary steel, ferrous scrap must not be contaminated with undesirable elements such as copper and tin. For example, a copper content of 0.15% or less makes the steel unusable for the manufacture of many products. Currently, the average copper content in scrap from OECD countries is about 0.2% to 0.25%[35]. The improvement of the quality of steel obtained from recycled scrap must therefore be based on the modernisation of the scrap sorting chain, to avoid progressive metallurgical pollution due to the increased presence of copper and tin. A

[31] "The sites for geological storage", *ENEA*.
[32] "Local Sustainability Report," *ENI*, 2020.
[33] "Special Report on Carbon Capture Utilisation and Storage in clean energy transitions", *IEA*, 2020 .
[34] Data compiled from "Tons of Co2 emitted into the atmosphere", *The World Counts*.
35 "The Circular Economy - A Powerful Force for Climate Mitigation," *Material Economics*, 2018.

modern line should consist of a stage for thinning the scrap, magnetic sorting and optical sorting, followed by a final stage of manual sorting (Figure 16).

Figure 16 - Diagram of a modern scrap sorting line.



5 SCENARIOS FOR THE DECARBONISATION OF THE ITALIAN STEEL INDUSTRY

One of the objectives of this paper is to provide an overview of the decarbonisation options available for steel production. A decarbonisation scenario of both primary and secondary steel production process in Italy has been elaborated and then compared and integrated with the decarbonisation of the energy and industrial system. The social implications of the reconversion, in particular in terms of employment, and the necessary support mechanisms and public interventions are also considered in this study.

The only active primary steel production plant in Italy is the full-cycle *Acciaierie d'Italia* plant in Taranto. In 2021, the *ILVA* produced 4 million tons of steel, emitting 9.7 Mt of CO_2[36] into the atmosphere. Given the high emission intensity of this production process, maintaining the coal-fired blast furnaces is not a viable option in the medium - long term. The emission profile of blast furnaces is in no way compatible either with the environmental context of Taranto or with climate protection objectives.

The transition from full-cycle steelworks based on blast furnace and oxygen reducer (BF - BOF) to plants based on direct reduction with natural gas and electric arc furnaces (DRI - EAF) is recognized as the first step to reduce emissions of CO_2 and pollutants with local effects, such as particulate matter, NO_X, SO_X , etc., from the primary steelmaking process. The end point of the complete conversion involves the use of green hydrogen, both as a fuel and as a reducing agent, and the subsequent abandonment of gas. However, two issues stand out at present:

1. The share of installed renewables is not yet sufficient to cover the high electricity demand needed to power the electrolysers;
2. The investments required to store a quantity of hydrogen sufficient to ensure the continuity of operation of a steel plant of this size are high (€8.2 - 8.9 billion). However, by 2030 it is expected to decrease significantly to €5.5 - 6.2 billion (for more details see THE COSTS OF DRI TECHNOLOGY IN THE MEDIUM TERM). It is therefore more convenient to postpone the necessary investments for the transition from natural gas to green hydrogen to the coming years.

Based on these considerations, the scenario developed assumes that the coal-fired blast furnaces will be kept in operation until 2028, with a production level of 4 million tons of steel per year, approximately equal to the output achieved in 2021. The studies carried out show that the existing blast furnaces in Taranto can continue to operate until 2028 with only routine maintenance, without the need for major restoration work.

It is assumed that the environmental protection measures will be completed by 2023, in accordance with *Acciaierie d'Italia*'s statement. These interventions concern the completion of the roofing of the ore, fossil and agglomerate park, the wind barriers and the treatment plants for meteoritic water and

---

[36] "Exercise Report 2020 Annex-1.2 Materials Produced in Plant," *Ministry of Ecological Transition*. "European Union Transaction Log, *European Commission*.
It should be noted that this value also includes emissions from the ex-ILVA cogeneration plant in Taranto, operated by *ArcelorMittal Italy Energy Srl*. In the EUTL register, the *Main Activity Type of* the power plant is classified as *Combustion of fuels*. However, the plant burns off-gases from the steel plant, to which it transfers electricity and heat. Therefore, in this analysis the emissions from the power plant are grouped together with those from the steel plant.

water from the park. It is assumed that a 1 Mt/year natural gas DRI plant will be commissioned in 2025; the production level of this plant increases to 2 Mt from 2027. From 2029, it is assumed that the coal-fired blast furnaces will be shut down and steel will be produced solely by natural gas DRI (6 Mt per year). From 2031 it is assumed a production of 4 Mt/year with natural gas and 4 Mt/year with green hydrogen, and then, from 2041, a production based only on the use of green hydrogen. Table 5 summarizes the production levels and technologies assumed in the scenario developed.

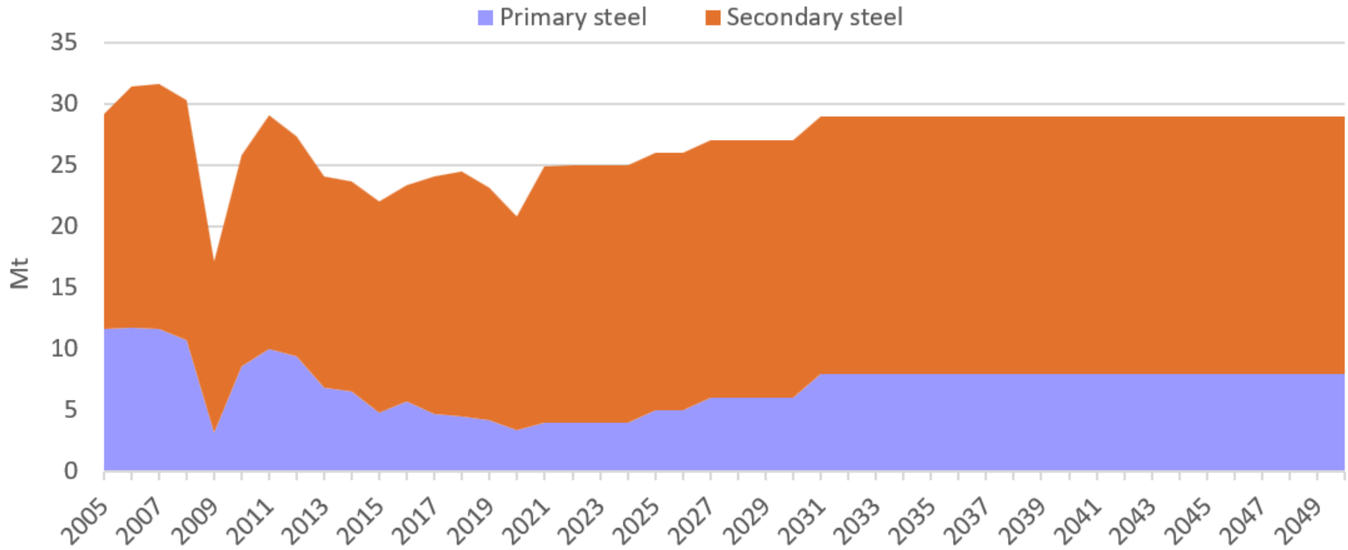
Table 5 - Assumptions of the primary steel production level underlying the scenario presented.

Years	Production BF -BOF	DRI GN production	Production DRI H_2
2021 - 2024	4 Mt/year		
2025 - 2026	4 Mt/year	1 Mt/year	
2027 - 2028	4 Mt/year	2 Mt/year	
2029 - 2030		6 Mt/year	
2031 - 2040		4 Mt/year	4 Mt/year
2041 - 2050			8 Mt/year

As regards secondary steel, a constant production level of 21 Mt of steel per year is assumed, corresponding to the Italian secondary steel production recorded in 2021.

Figure 17 reports primary and secondary steel production in Italy in the proposed scenario.

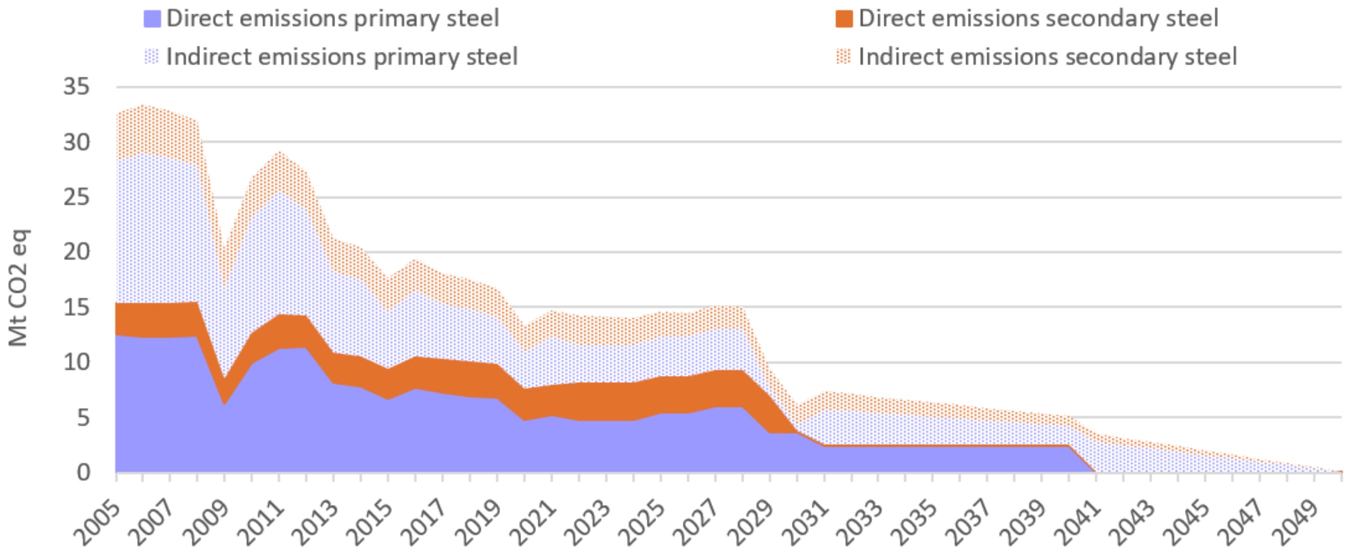
Figure 17 - Trend in primary and secondary steel production in Italy in the scenario developed.



Analyzing the trend of GHG emissions, direct emissions from primary steel production are increasing until 2028, when they reach 6.1 Mt CO_{2eq} (Figure 18). This is due to the progressive increase in the production level (up to 6 Mt of steel per year) and the operation of coal-fired blast furnaces. With the closure of the blast furnaces and the use of DRI technology fueled partly by natural gas and partly by green hydrogen, emissions are reduced to 2.5 Mt CO_{2eq} by 2031. Finally, with the complete fueling with green hydrogen, emissions from primary steel production can be reduced to zero from 2041.

Direct secondary steel emissions are reduced from 2030, when it is assumed that EAF burners will be fueled by green hydrogen and biocarbon will be used as an additive.

Figure 18 - Trend of direct and indirect emissions from primary and secondary steel production in Italy in the developed scenario.



The use of green hydrogen and electric furnaces for steel production causes a shift from direct energy consumption of primary fuels (coal and natural gas) to electricity consumption. Although, therefore, direct CO_2 emissions are cancelled out, it is also important to monitor indirect emissions (scope 2), i.e. those deriving from the production of electricity used in steelmaking processes. For the estimation of indirect emissions, it is assumed that the target of 70% of renewables for the electricity sector will be reached by 2030, with an emission factor of national electricity production equal to 161 g_{CO2} /kWh. The share of renewables in the electricity system increases in the following years, reaching 100% in 2050.

5.1.1 CURRENT COSTS OF DRI TECHNOLOGY

Natural gas DRI technology is a tried and tested solution that is already being used by some steel mills, especially in the Middle East, where companies have access to low-cost natural gas. With a view to decarbonising primary steel production, natural gas is a transitional fuel, as it still involves the emission of greenhouse gases both directly and along the extraction, transport and distribution chain. The use of gas is motivated by the timing of the reconversion, which involves the closure of coal-fired blast furnaces and the need to wait for a greater penetration of renewables in the national electricity system. It is also necessary to develop appropriate technologies to produce the necessary quantities of green hydrogen; the maximum size of electrolysers today is a few MW, while it is estimated that for the complete reconversion of the Taranto steelworks an electrolysis capacity of 2.1 - 2.7 GW is required.

DRI technology is of strategic interest in the decarbonisation process, since it makes it possible to switch from natural gas to hydrogen with modest interventions on the plants, since optimization is mainly related to operational and product quality aspects, rather than to basic plant engineering.

Based on the considerations set out in the previous paragraphs, it is assumed that, when fully operational, the Taranto plant can reach a production of 8 Mt of steel per year. Hydrogen should be produced on site, given the complexity and safety issues related to its transport. It is not necessary that all electricity is produced on site with a dedicated renewable plant, but it is assumed to be supplied from the grid. However, it may be energetically and economically convenient to exploit the large sealed and roofing areas already present in the steel plant for the possible installation of photovoltaic systems. It will also be possible to exploit the overproduction of renewables present locally with storage systems. Investments in renewables are not, therefore, directly related to the Taranto steel mill, but must be integrated into the broader context of the decarbonisation of the national electricity system.

The investments necessary for the conversion of the Taranto plant from coal-fired blast furnaces to natural gas-fired DRIs are estimated considering those relating to the construction of direct reduction units, electric arc furnaces and pelletizers for processing iron ore.

The investment costs of a DRI plant are €185/$t_{DRI\_}$ y (t_{DRI} _y is per ton of iron sponge produced per year); this gives an investment of €1,7 billion for the production of 8 million tons of steel per year. For the electric arc furnaces, an investment of €0.5 billion is estimated, assuming the re-use of some of the highly efficient auxiliary installations already present in the plant. To produce steel from DRI, the pelletizer is also to be built, at a cost of €0,3 to 0,4 billion. In total, the changeover of the plant to natural gas results in an investment of €2,5 billion, to which must be added the costs relating to the decommissioning of the existing blast furnaces and those relating to the plant adaptation resulting from the change in layout.

For the subsequent switch from natural gas to green hydrogen, electrolysers and hydrogen storage systems are required to ensure continuous operation of the plant. Considering that 60 kg of hydrogen are required to produce one ton of steel, when fully operational, 0,5 Mt of hydrogen per year must be produced, resulting in a requirement of 56,4 tons of hydrogen per hour, assuming continuous operation of the electrolysers. Considering a specific electricity consumption of the electrolysers of 48 MWh_e/t_{H2}, the nominal capacity required is 2,7 GW_e. At a current electrolysis technology cost of 1 million euros per MW_e , this results in an investment of 2,7 billion euros.

Even with a continuous operation of the electrolysers, a steel plant requires the accumulation of a certain quantity of hydrogen, to ensure safety and continuity of operation. For a large steel plant, it is reasonable to accumulate a quantity of hydrogen corresponding to five working days, which for Taranto is equivalent to 6,8 kt of hydrogen once the production target of 8 Mt of steel per year is reached[37]. Considering that compressed hydrogen tanks cost between 500 and 600 €/kg_{H2} and that compressors can be estimated to cost 1˙500 €/kW_e[38] , an investment of 5,3 – 5,9 billion € is needed for hydrogen storage systems. This means that an additional investment of 8 to 8,6 billion € is needed to switch from natural gas to green hydrogen. Table 6 summarizes the investment needed to convert the Taranto plant from coal-fired blast furnaces to green hydrogen DRI technology.

Table 6 - Investments necessary for the reconversion of Taranto steel from coal-fired blast furnaces to green hydrogen DRI technology (current costs).

	Investment [billion €]
DRI Units	1,7
EAF Units	0,5
Pelletizers	0,3 - 0,4

[37] Bhaskar, Abhinav; Assadi, Mohsen; Somehsaraei, Nikpey, Homam; "Decarbonization of the Iron and Steel Industry with Direct Reduced of Iron Ore with Green Hydrogen", *energies,* February 9, 2020.
[38] Although this value has little impact on the final result, we signal that the figure is highly uncertain.

	Investment [billion €]
Subtotal switch from coal to NG	**2,5**
Electrolyzers	2,7
Storage H_2	5,3 - 5,9
Subtotal changeover from NG to H_2	**8 - 8,6**
Total	**10,4 - 11,1**

5.1.2 THE COSTS OF DRI TECHNOLOGY IN THE MEDIUM TERM

As highlighted above, currently the switch to steel production via green hydrogen DRI is costly in terms of the investment capital required, mainly due to the high prices of hydrogen production and storage systems. However, it is realistic to assume that the costs for green steel production will decrease in the coming years, mainly due to the expected decrease in electrolyser prices, improved efficiency of these technologies and economies of scale. Assuming that 37 kWh of electricity will be required to produce one kilogram of green hydrogen in 2030 and that the cost of electrolysers will fall to €0,5 million per MW, this results in an investment of €1 billion for electrolysers[39] .

From the literature[40] it emerges that also the prices of the hydrogen storage tanks will decrease, to 375 - 490 € per kg of hydrogen, resulting in an investment of 2,5 – 3,3 billion euros. This means that the extra investment needed to switch from natural gas to green hydrogen will be between €5,5 and €6,2 billion, about 30% less than at current prices. Table 7 summarizes the investment needed to convert the Taranto plant from coal-fired blast furnaces to green hydrogen DRI technology with prices to 2030.

Table 7 - Investment needed to convert Taranto steel from coal-fired blast furnaces to green hydrogen DRI technology (costs in 2030).

	Investment [billion €]
DRI Units	1,7
EAF Units	0,5
Pelletizers	0,3 - 0,4
Subtotal switch from coal to NG	**2,5**
Electrolyzers	1
Storage H_2	4,4 - 5,2
Subtotal switching from NG to H_2	**5,5 - 6,2**
Total	**7,9 - 8,7**

5.1.3 IMPACTS ON EMPLOYMENT

Over the last few years, the Italian steel industry has been affected by the closure of many plants and by a strong employment downsizing, so much so that from 2008 to 2019 it has lost about 9 thousand employees[41] . This drop in employment also affects primary steel production and is still ongoing, especially following the closure of the hot areas of Piombino and Trieste and the drop in production levels in Taranto. If we do not invest in innovation and do not reposition ourselves in the market of

[39] *Hydrogen Europe* hypothesis.
[40] Gorre, Jachin; Ruoss, Fabian; Hannu Karjunen; Schaffert, Johannes; Tynjälä, Tero; "Cost benefits of optimizing hydrogen storage and methanation capacities for Power-to-Gas plants In dynamic operation", *Applied Energy*, 2020.
[41] "World steel in figures 2009", *World Steel Association*.

low carbon products, where today we can be pioneers, we run the risk of increasingly competing with other economies on the lowest selling price (on which we are disadvantaged) and of being excluded from the new green markets.

The Taranto plant currently employs 8˙200 people, 5˙000 of whom work in the hot area[42] . An average of 300 people is employed in a recycled steel plant for every million tons of steel produced annually[43] . If the electric furnace were combined with plants for pre-reduction of iron sponge from ore, an additional 100 people would have to be employed for every ton of iron sponge produced annually. If 8 million tons of primary steel are produced at the ex-ILVA site using green hydrogen DRI technology, this would result in a workforce for the operation of the hot area of 3˙200 people, with 1˙800 redundancies compared to current employment levels. There will therefore be fewer direct jobs, but it is a way to prevent a crisis that is already underway.

While some of these redundancies can be absorbed through active labor and social policies, such as early retirement, the reduced employment needs of DRI technology can also be compensated by developing alternative employment opportunities, such as those in the green hydrogen and renewables sectors. Converting the production process to green hydrogen would in fact create the economies of scale needed to create a local green hydrogen supply chain, which would obviate the complexities and safety problems associated with hydrogen transport.

The Preliminary Guidelines of the National Hydrogen Strategy[1] foresee the creation of more than 200 thousand temporary jobs and up to 10 thousand permanent jobs associated with the installation of 5 GW of electrolysis capacity for green hydrogen production. With the production level assumed in Taranto, an electrolysis capacity of 2,1 – 2,9 GW is required. Based on the Preliminary Guidelines, it is therefore estimated that in Taranto the positive impacts on employment, only related to green hydrogen production, could be 83 - 117 thousand temporary jobs during the construction phase and 4 - 6 thousand permanent jobs.

5.1.4 EXAMPLES OF BEST PRACTICES

In Europe, many large steelmakers are already investing in projects that aim to develop green hydrogen DRI technology on a large scale. In 2016 *SSAB, LKAB* and *Vattenfall* started the *HYBRIT* project (*HYdrogen BReakthrough Ironmaking Technology*[44]), a *joint venture* with the aim of developing coal replacement with green hydrogen in the steelmaking process. A year ago, the first tests for green steel production started at the Lulea steel mill in northern Sweden. The first batches of steel have been sent to the *Volvo* Group to design prototype vehicles made with this steel and the goal is to develop the DRI technology on an industrial scale by 2026. The *joint venture* also announced that a green hydrogen DRI plant will be built in Gaellivare, Sweden, with a production capacity of 1,3 Mt of steel per year, which will come on stream in 2026 and reach an output of 2,7 Mt/year in 2030[45] .

---

[42] "Proposed technical solution for the revitalization of the Taranto plant", *Federmanager,* May 2020.
Bentivogli, Marco; "Against the steel wafflers," *FIM-CISL*, November 27, 2019.
[43] Data from *Politecnico di Milano*.
[44] HYBRIT project.
[45] "HYBRIT: SSAB, LKAB and Vattenfall to begin Industrialization of future fossil-free steelmaking by establishing the world's first production plant for fossil-free sponge Iron In Gällivare", *SSAB,* 24 March 2021.

In 2019, *ArcelorMittal* launched a €65 million project to test steel production with green hydrogen in Hamburg, Germany[46] . DRI technology has been used at this plant since 1971, based on the use of natural gas. Now the goal is to produce 100 kt per year of steel using first grey hydrogen, i.e., made from gas, and then gradually switch to green hydrogen.

With the *H2FUTURE* project[47] , funded by the European Union in 2019, the production of green hydrogen on an industrial scale is being investigated for later use in the steel industry. To this end, what is currently the largest pilot plant to produce hydrogen for the steel industry has been built at the *Voaestalpine* plant in Linz, Austria, with an electrolysis capacity of 6 MW[48] . The total funding for the project is €18 million. Initial tests are proving successful.

5.2 INTEGRATION AND INTERACTION WITH THE ITALIAN ENERGY AND INDUSTRIAL SYSTEM

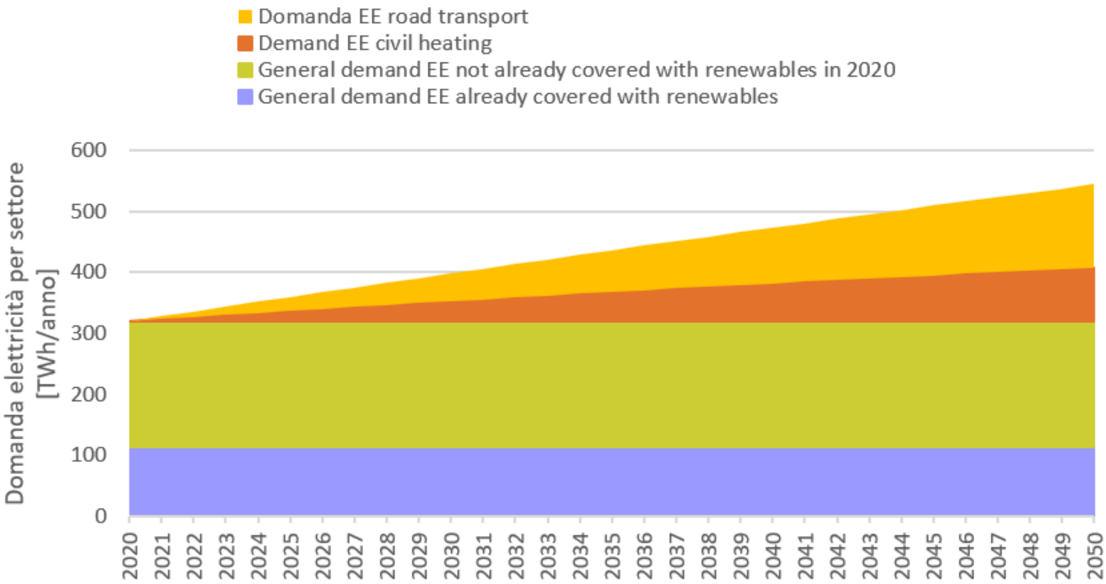
The decarbonisation option for steel goes through a transfer of consumption from the fossil sector (coal first and gas later) to the electricity sector, for the production of green hydrogen and to power electric arc furnaces. The renewable electricity for the steel production of 8 million tons of primary steel through green hydrogen DRI is 36,6 TWh/year, corresponding to 8% of the estimated electricity demand in 2040[49] .

The impacts of this transformation on the Italian electric power system and the implications for the decarbonisation of other sectors are discussed below. The electrification option for primary steel production has been contextualized in an overall decarbonisation scenario with the following assumptions:

- **At the end of the full transition, the electricity consumption of the road transport sector is assumed to be 138 TWh_e/year.** In 2018, the road transport sector consumed 31 Mtoe of oil products and 1 Mtoe of natural gas. The decarbonization of this sector assumes the complete electrification of demand by 2050 through the replacement of internal combustion engine vehicles with battery-powered electric cars;
- **For the civil heating sector, the electricity consumption at the end of the transition is assumed to be 88 TWh_e per year.** In 2018 in Italy the heat demand for civil heating amounted to 316 TWh_{th}. For the energy transition of this sector, it is assumed the complete electrification of demand by 2050 through the replacement of gas boilers with electric heat pumps, with an average COP of 3, and a simultaneous reduction of demand to 263 TWh_{th}/year thanks to the energy efficiency of buildings;
- **The electricity requirements of the other sectors are assumed to remain constant at 320 TWh_e,** as recorded in 2019, due to the combined effect of energy efficiency and electrification of final consumption.

[46] "Climate Action," *ArcelorMittal,* May 2019.
[47] H2FUTURE Project.
[48] "H2FUTURE", *Voestalpine.*
[49] Estimate by *Politecnico di Milano*. Demand from the road transport, civil heating and general consumption sectors is considered. General consumption means all the civil and industrial consumption already present today, to which is added the future demand for electricity for civil heating with heat pumps and that for transport. By 2040 this electricity demand is estimated to be 473,7 TWh.

Figure 19 - Electricity demand by sector.



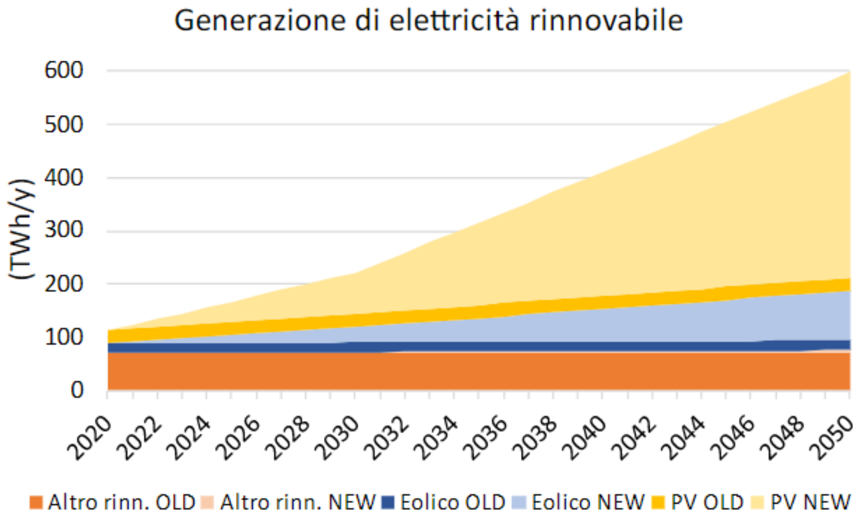
In Table 8 the annual average installation rates of intermittent renewables required to align their evolution with the PITE perspective, which envisages that the contribution of renewables to the satisfaction of gross final consumption is 70% in the electricity sector by 2030 (Figure 20).

Table 8 - Installation rates of intermittent renewables from 2020 to 2050.

		u.d.m.	Installed capacity in developed scenarios	Objectives of the national plans
Solar PV installation rate 2020-2030	5,5	GW/year	75.9 GW by 2030	64 GW (RSE "new PNIEC" proposal of 2021[50])
Solar PV installation rate 2030-2050	11	GW/year	295.9 GW by 2050	200-300 GW (LTS 2050)
Wind installation rate 2020-2030	1,3	GW/year	23.7 GW by 2030	23 GW (RSE "new PNIEC" proposal of 2021)
Wind installation rate 2030-2050	1,5	GW/year	53.7 GW by 2050	40-50 GW (LTS 2050)

[50] Geri, Alberto; Delfanti, Maurizio; Benini, Michele; "Informal hearings - Draft Legislative Decree implementing EU Directive 2018/2001 on the promotion of the use of energy from renewable sources (AG 292) - Draft Legislative Decree implementing EU Directive 2019/944 on common rules for the internal market in electricity (AG 294)", *RSE*, 16 September 2021.

Figure 20 - Hydro, bioenergy, geothermal, wind and solar PV installed capacity assumptions in Italy from 2020 to 2050.



A significant contribution from offshore wind has not been considered, as it is not currently included in the Italian strategies and in the NIPCE. However, the mix of sources represents only the construction of a hypothetical scenario to support the analysis of integration of steel transformation in the electricity system. A different distribution by production capacity of renewables does not change the results of the work.

For every million tons of steel produced in Italy would be necessary to invest at least 100 - 150 million in renewable[51] . A study by *Federacciai* showed that only half of the companies registered to the federation has 1˙200 hectares available to install photovoltaic panels, which could produce almost a gigawatt of electric power. In addition to these solutions, it is also possible to invest in PPAs (Power Purchase Agreements), i.e. long-term contracts that regulate the exchange of electricity between a producer and a buyer.

Replacing natural gas with green hydrogen for primary steel production, if not accompanied by sufficient penetration of renewables, risks taking away renewable energy shares from other sectors, which would slow down their decarbonisation process. To ensure that this does not happen, it is important to increase the rate of new renewable installations now, so that decarbonisation proceeds in every sector of the economy.

[51] Meneghello, Matteo; "Italy's steel industry exceeds European CO2 targets", *Il Sole 24 Ore*, 29 June 2022.

6 POLICY OPTIONS

To achieve the 2050 net zero emissions target for the steel sector, an effective set of policies is needed that on the one hand promote and accelerate technological innovation and on the other hand can support companies in making the necessary investments. Efforts are needed from all the main players in the steel value chain: steel producers, consumers and policymakers. If planned and implemented at the right time and in the right way, the sector's decarbonisation strategy can allow the Italian industry to remain competitive in the long term, gaining a leading position in some market segments and contributing to the preservation and creation of jobs.

6.1 INDUSTRIAL POLICY MEASURES DEDICATED TO THE STEEL SECTOR

Accelerating the development of low-emission production processes requires the construction of pilot and demonstration plants. For companies to be pushed in this direction, **direct public funding for demonstration plants is needed**, so that significant increases in CAPEX are limited and the business risk associated with adopting innovative technological solutions is reduced.

The forthcoming publication of the new Taranto industrial plan, linked to the changed company structure, represents a unique opportunity to plan interventions and reconversion solutions that can combine the economic and social sustainability of the investments with the environmental and climate sustainability of the project. It is necessary to avoid wasting economic resources in a double tranche of investment, first in the restructuring of the blast furnaces and coke ovens and then in their dismantling and the transition to DRI technology.

In this regard, the ongoing revision of the EU ETS Directive may also represent an opportunity to support investments in low-carbon technologies. Currently, the steel sector receives an number of free allocations that allows it to cover virtually all of its emissions within the ETS. The plan of the European Commission foresees to reduce annually by 10% the share of free emissions that are issued to those sectors that will be included in the Carbon Border Adjustment Measure (CBAM), a new regulation that will be introduced starting from 2026. By 2035 the implementation of the CBAM will be completed and the free allocation will be eliminated. Taking 2030 as a base year, a steel producer will only receive 50% of the allowances needed to cover the emissions of a blast furnace for free. The remaining 50% of allowances will have to be purchased on the ETS market, where the average price of CO_2 is currently around €84/t[52] . Consequently, the costs for carbon-intensive processes are bound to increase, with a high risk of stranded assets.

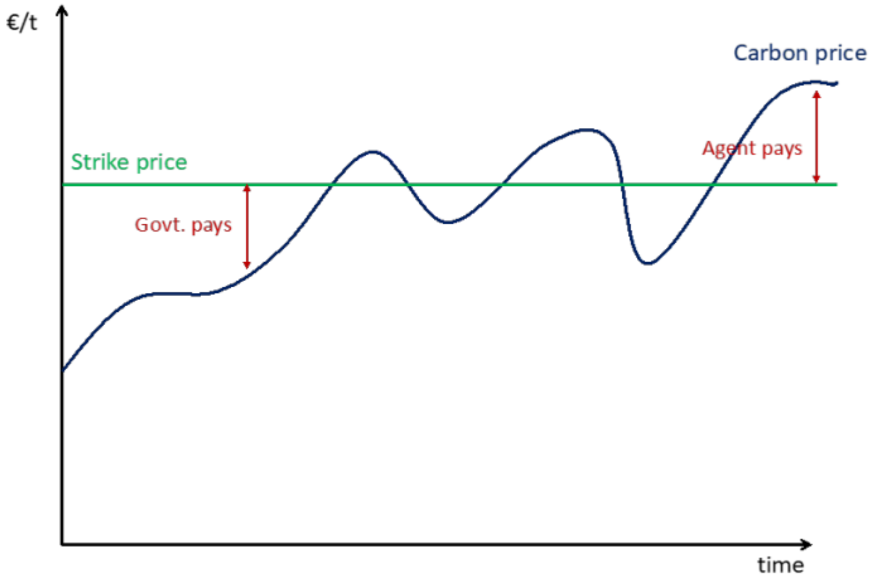
Based on the Commission's proposal, the free allowances that will no longer be allocated to the sectors included in the regulation for the Carbon Border Adjustment Measure (CBAM), will be channeled into the Innovation Fund, which is expected to be fed by the auctioning of allowances related to the CBAM sectors, including the steel production sector. The fund is one of the largest funding programs for the demonstration of innovative zero/low emission technologies and processes and also products that replace carbon-intensive ones. It could also be further strengthened to ensure

[52] "Spot Market," eex.

that allowances from CBAM sectors are prioritized to finance concrete decarbonisation projects in those sectors.

Another interesting element of the proposal under discussion is the possibility to use competitive tendering mechanisms, such as Carbon Contracts for Difference (CCfD), which would guarantee the investment and its return. A Carbon Contract is a contract through which a government or an institution agrees with a private producer a fixed carbon price ("strike price") for a given period. If the market price is lower than the agreed price, the producer receives the difference from the government; if, on the other hand, the market price is higher, then the private producer must return the surplus revenue to the government. Carbon Contracts are an instrument to counterbalance the volatility of the price of CO_2. They are a form of subsidy that reduces the risk associated with investments and allows for long-term financial planning.

Figure 21 - Principle of operation of Carbon Contracts for Differences[53].



6.2 A MARKET FOR GREEN STEEL

To enable companies to invest in low carbon technologies and circular economy solutions, it is also necessary to stimulate the creation of a robust demand for green products. Many manufacturers are already working to foster a market for climate-neutral products, but face several barriers such as, for example, the higher costs of these products, the lack of familiarity with the new materials by users, the lack of transparency and clear and easy-to-understand benchmarks for potential buyers to compare different low-carbon alternatives.

For all these reasons, policies are needed to stimulate demand and foster a thriving market for low-carbon products, first and foremost by leveraging public procurement, which can create an outlet for these products in the infrastructure and building sectors. The same behavior should also be encouraged in the private sector, with particular reference to the downstream sectors of primary steel production. There are industrial partnerships in the automotive sector, such as the one between

[53] "Carbon Contracts for Differences: their role in European industrial decarbonization", *Climate Friendly Materials Platform*, September 2020.

SSAB and *Volvo*, or the one *H2 Green Steel* is signing with *Mercedes* and *Schaeffler*, which could also be promoted in the electromechanical, naval, rail, construction and packaging sectors. Such partnerships could be guaranteed by the state with instruments such as contracts for difference, so that the buyer can purchase green steel at a price that is competitive with that of steel from coal-fired blast furnaces. The excess cost would be paid to the producer by the state.

Secondary steel also finds its way into the low carbon market. A high share of scrap-based production requires a very controlled collection and sorting chain, with well separated scrap flows to avoid contamination with undesirable elements. A constant availability of high-quality scrap can also allow Italy to remain a European leader in the production of recycled steel. Investments are therefore necessary for the technological innovation of scrap sorting plants.

The green steel market can also be promoted through the introduction of Product Carbon Requirements, i.e. specific requirements that, in the long term, require the use of low carbon steel for certain applications. For example, legislation has been proposed in France, Sweden and some Northern European countries to place a cap on CO_2 emissions associated with steel used in buildings.

Even if today at international level the production of the so-called 'green steel' is still in its infancy, the historical circumstances offer the possibility for the Taranto site to represent a 'beacon' project of green steel in Europe and in the world, anticipating and leading the change and bringing to the market a product whose demand can only grow in the future.

7 CONCLUSIONS

Italy is the second steel producer in Europe and the eleventh in the world. 84% of the steel produced in Italy is recycled steel, while the remaining 16% is primary steel produced at the *Acciaierie d'Italia* plant in Taranto. This study proposes some technological solutions for the decarbonisation of the Italian steel industry, both primary and secondary, and identifies policy mechanisms to accelerate the transition to climate neutrality and at the same time allow companies to remain competitive at the international level. Employment impacts are also considered and a cost estimate is provided for each solution identified.

For the decarbonisation of primary steel production, ECCO's proposal is to switch to DRI (Direct Reduced Iron) technology, initially fueled by natural gas, and then gradually switching to green hydrogen. This solution has already reached full technological maturity, as evidenced by the many European countries that have already announced significant investments in DRI plants. This technology allows to obtain benefits in environmental terms, but also to position Italy at the forefront of the emerging green steel market.

About secondary steel, the options for decarbonisation identified are of two levels:
1. Reducing direct emissions from EAFs by fueling the burners with green hydrogen and using biocarbon as an additive;
2. The improvement of scrap collection and sorting to refine the quality of the secondary steel produced.

To achieve these goals, policies are needed to promote and accelerate technological innovation, support businesses, implement pilot projects and create green demand. **As explained in the study, it is essential that the policy implements tools, such as direct public funding for demonstration plants, public procurement tied to green steel, partnerships in the private sector between steel producers and companies active in the downstream supply chain, employment policies aimed at relocating workers to related sectors, such as green hydrogen production.**

In the absence of an industrial policy that pushes the reconversion, there is the risk of seeing the collapse of a sector - that of steel - very important for the Italian economy. **Decarbonisation, on the other hand, offers a precious opportunity to plan the transformation of the production sector and give Italy a competitive advantage and a leading position in a market, that of green steel, which is destined to grow.**

APPENDIX 1 - HYPOTHESIS

The main assumptions underlying the analysis presented are reported:

- Natural gas is considered to be methane, with a CO_2 emission factor of 1,96 kg_{CO2}/Nm^3, to which fugitive emissions of 0,14 kg_{CO2}/Nm^3 should be added, corresponding to the supply chain emissions for gas from conventional fields;
- The electricity consumed is assumed to have an emission factor of 300 kg_{CO2}/MWh, corresponding to the average emission factor of electricity consumed in Italy in 2018[54];
- In the case of certified contributions of renewable electricity and their storage systems, an emission factor of 0 kg_{CO2}/MWh is assumed;
- In the case of replacement of natural gas by hydrogen in the iron ore reduction process, a hydrogen consumption of 632 Nm^3/t_{DRI} was assumed, in line with the data present in the literature. The specific consumption of the electrolyser was assumed to be 4,25 kWh/Nm^3, corresponding to an efficiency of 70%, in agreement with long-term projections for low-temperature electrolysers. The total energy consumption (hydrogen + heat) of the green hydrogen DRI system is assumed to be 8 GJ/t_{DRI}, compared to 10 GJ/t_{DRI} of the conventional gas DRI system;
- The consumption of DRI per unit of final steel produced was assumed to be 1,1 kg_{DRI}/kg_{steel}.

The analysis also includes economic considerations based on the following main assumptions:

- Natural gas cost of €7/GJ (2020 value);
- Investment cost of the electrolyser of 450 €/kW, corresponding to a long-term scenario;
- Long-term cost of renewable electricity including storage systems for intermittency management of 50 €/MWh. This is a questionable value, incorporating multiple assumptions, such as the costs of renewable electricity generation and electrical or hydrogen storage post 2030;
- 95% plant availability (i.e. operation for 8˙320 h_{eq}/year);
- Investment costs of thermal utility electrification neglected;
- Specific discounted cost for the CO_2 compression system of 5 €/t_{CO2} (not including electricity costs for compression);
- Specific discounted cost of capturing CO_2 post combustion equal to 50€/t_{CO2} (not including electricity costs for solvent regeneration, where it is assumed that solvent regeneration is performed by heat pump). The assumptions on CO_2 capture costs and electricity cost lead to a total cost of CO_2 captured of 90€/t_{CO2};
- Cost of transport and storage of CO_2 is €30/t_{CO2}. The transport and storage cost has a high variability and uncertainty, related to the transport distance, the geological nature of the storage site and the possibility of infrastructure sharing. The value assumed can be considered reasonable for transport over a distance of 700 km (corresponding to the

[54] "Indicators of efficiency and decarbonisation of the national energy system and the electricity sector", *ISPRA*, 2021.

distance between Taranto and Ravenna) via pipeline or ship (with costs between 15 and 20 €/t) and offshore storage (costs between 2 and 20 €/t)[55] .

Importantly, many of the assumptions in the economic analysis that have a significant impact on the results (e.g., cost of renewable electricity, cost of CCS, cost of natural gas) are subject to a high degree of uncertainty and variability.

[55] Smith, Erin; Morris, Jennifer; Kheshgi, Haroon; Teletzke, Gary; Herzog, Howard; Paltsev, Seregy; "The cost of CO_2 transport and storage in global integrated assessment modeling," *International Journal of Greenhouse Gas Control*, June 20, 2021.

APPENDIX 2 - TECHNOLOGY READINESS LEVEL

The acronym TRL - Technology Readiness Level - indicates a methodology for assessing the maturity level of a technology. The TRL was developed by NASA in 1974 and is now used by various research institutes and agencies around the world. This method can be applied to any technology to assess its degree of maturity on a scale of 1 to 9. The International Energy Agency (IEA) has extended the TRL scale by adding two more levels. TRL of 10 to indicate a technology that has already reached commercialization but requires further work to be integrated within the energy system and value chain. TRL of 11 for those solutions that have also been developed in this respect. In Table 9 the complete TRL scale is reported.

Table 9 - TRL Scale.

TRL	Description	
1	Basic research: review of fundamental principles	Basic research
2	Formulation of technologies: concepts and possible applications outlined	
3	Practical proof of concepts with first laboratory experiments performed	
4	Laboratory validated prototype	Applied research
5	Industrially validated prototype	
6	Technology proven in an industrial environment	Development
7	Prototype system demonstrated in real environment	
8	Complete system defined and qualified	
9	System tested in real environment	Implementation
10	Commercial and competitive solution, but requires further improvement efforts	
11	Solution that has reached full maturity	Full maturity

THE ITALIAN CLIMATE CHANGE THINK TANK

ECCO is the independent Italian climate *think tank*. The mission of ECCO's think tank is to work in the public interest to accelerate decarbonisation and build resilience in the face of the climate change challenge.
ECCO has a national, European and global reach.
ECCO works to develop and promote analyses, proposals and strategies for climate based on facts and science in constant dialogue with experts from the scientific community, policy makers, institutions, civil society, business, trade unions and philanthropy.
ECCO is a non-profit organization, unrelated to any private interest and funded exclusively through philanthropic and public resources.

This Report was edited by:
Giulia Novati, Industry Program Researcher, ECCO giulia.novati@eccoclimate.org

Managers and reviewers:
Matteo Leonardi, Co-Founder and Executive Director Home Affairs, ECCO
Luca Iacoboni, Country Programme Manager, ECCO

Carried out in collaboration with Professors Carlo Mapelli, Paolo Colbertaldo, Matteo Romano and Stefano Campanari of the Politecnico di Milano, who supported the quantitative analysis of the energy and carbon balance of the different plant solutions and scenarios.

For interviews or more information about the use and dissemination of the content in this briefing, please contact:

Andrea Ghianda, Head of Communication, ECCO

andrea.ghianda@eccoclimate.org

+39 3396466985

www.eccoclimate.org

Publication date:
September 2022