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Production costs from iron and steel industry in the EU and third countries

Medarac, H.

Moya, J.A.

Somers, J.

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Joint Research Centre

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Contact information
Name: Jose A. Moya
Address: European Commission, Joint Research Centre, Westerduinweg 3, 1755 LE, Netherlands
Email: Jose.MOYA@ec.europa.eu
Tel.: +31 224 56 5244

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Authors

Hrvoje Medarac, JRC
Jose A. Moya, JRC
Julian Somers, JRC

Abstract

This report provides an overview of the production costs in the iron and steel industry in the EU and third countries. The cost breakdowns are provided for two typical products of the integrated and recycling routes (hot rolled coil as a proxy of flat products and wire rod as a proxy of long products).

The analysis includes detailed information from 153 production facilities in the EU27 and 10 other countries (Russia, Turkey, United States, United Kingdom, Ukraine, China, India, Japan, South Korea and Brazil). The information is based on data from October 2019. This is the last available data before the COVID-19 pandemic affected the iron and steel industry.

The results show that the EU27 has the third highest production costs for hot rolled coil via the integrated route (458 EUR/t). The main contributors to these costs are the raw material costs 65%, the 'other costs' 27% and energy costs 17%. The CO_2 cost is included in 'other costs' and for the EU27 represents 2% of the total production costs. It is worth noting that the EU27 is among the world leaders in creating credits from recycling materials and energy. This shows a high optimisation of the integrated route processes in the European steel industry, as a result from cumulated investments in innovations over the years.

The results also show that the EU27 has the second highest production costs for hot rolled coil via the recycling route, which is however only 6% higher than the lowest production cost of all the countries in the analysis.

Finally, for the production of wire rod, the EU27 production costs are either the highest (when produced via the integrated route) or second highest (when produced via the recycling route). The materials cost in the EU27 are 68% and 58% of the production costs, for each of the two respective production routes. These shares for the material cost are similar in the rest of countries. The share of the energy costs in the EU in wire rod production in integrated route is 11%. This is close to the minimum observed share. In the recycling route the 20% is the highest share observed in any of the countries considered.

1 Introduction

The EU iron and steel industry employs around 330 000 employees in around 500 production sites in 22 EU member states, with a total annual turnover of around 170 billion EUR (EUROFER, 2020). The European Union is the second largest steel producer in the world (159 million tonnes in 2019), accounting for 8.5% of global steel output. EU production in 2019 was noticeably lower than in previous years, as it hovered around 170 million tonnes per year between 2010 and 2018. 139 million tonnes of the European steel production (88%) is traded; 111 million tonnes within the EU and 28 million tonnes outside of the EU (Worldsteel, 2020).

The iron and steel industry, together with other energy-intensive industries, is the focus of long-term strategic objectives of the European Union within the context of the *European Green Deal* (European Commission, 2019) and the aim for Europe to become the first climate-neutral continent by 2050. As a major contributor to EU greenhouse gas emissions, 4% of all EU emissions in 2017 and 23% of emissions of the manufacturing industry (Somers, 2020), the European steel industry is a key sector in the scope of the *New Industrial Strategy for Europe* (European Commission, 2020) published in March 2020.

The new industrial strategy leans on *The Masterplan for a Competitive Transformation of EU Energy-intensive Industries Enabling a Climate-neutral, Circular Economy by 2050* (High-Level Group on Energy-intensive Industries, 2019), an outcome of work of the High-Level Group on energy-intensive industries, composed of Member States, industry and civil society, published in November 2019.

This report analyses the production costs of the European iron and steel industry and its main competitors, providing an overview of the competitiveness of the European steel Industry. This includes a reflection of the effect of energy prices on the total costs and its effect on competitiveness.

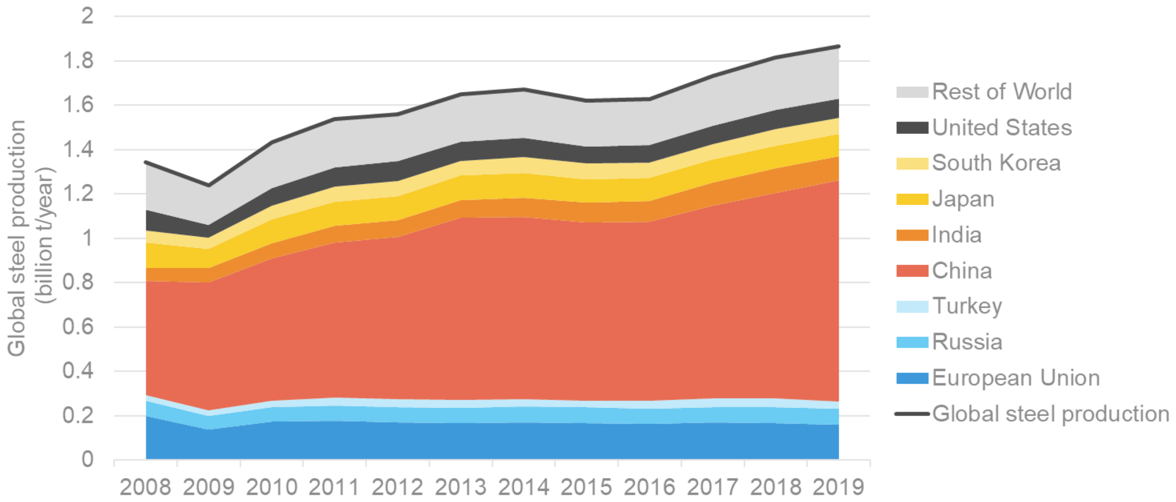
The methodology for calculating the costs in this report follows the approach of a previous JRC report, *Production costs from energy-intensive industries in the EU and third countries* (Moya and Boulamanti, 2016), and combines public and commercial data. It is worth mentioning that this study has the impact of the legislation incorporated in each component of the costs, and by itself, the cumulative regulatory cost for the European steel industry in 2013 represents approximately 3% of the total cost of production of the wire rods in the recycling route, and less than 2% of the total cost of producing hot rolled coil in the integrated route (CEPS, 2013).

The following third countries are included in the research: Russia, Turkey, United Kingdom, United States, Ukraine, China, India, Japan, South Korea and Brazil. For each of the countries the analysis was performed based on a representative sample of facilities provided by the data provider, CRU. The analysis was performed using the CRU Steel Cost Model 2019 and Macro 2019 Q3.

2 Global Iron and Steel Industry

Steel is a globally traded commodity and is produced worldwide. Figure 1 shows that in 2019, the global production of steel was 1.9 billion tonnes, and has been following an increasing trend since 2009, mainly on the back of increased Chinese production (and consumption). (Worldsteel, 2020; World Steel Association, 2019; Worldsteel, 2018). Despise this global trend, the EU's production is still below the 2008 pre-crisis levels.

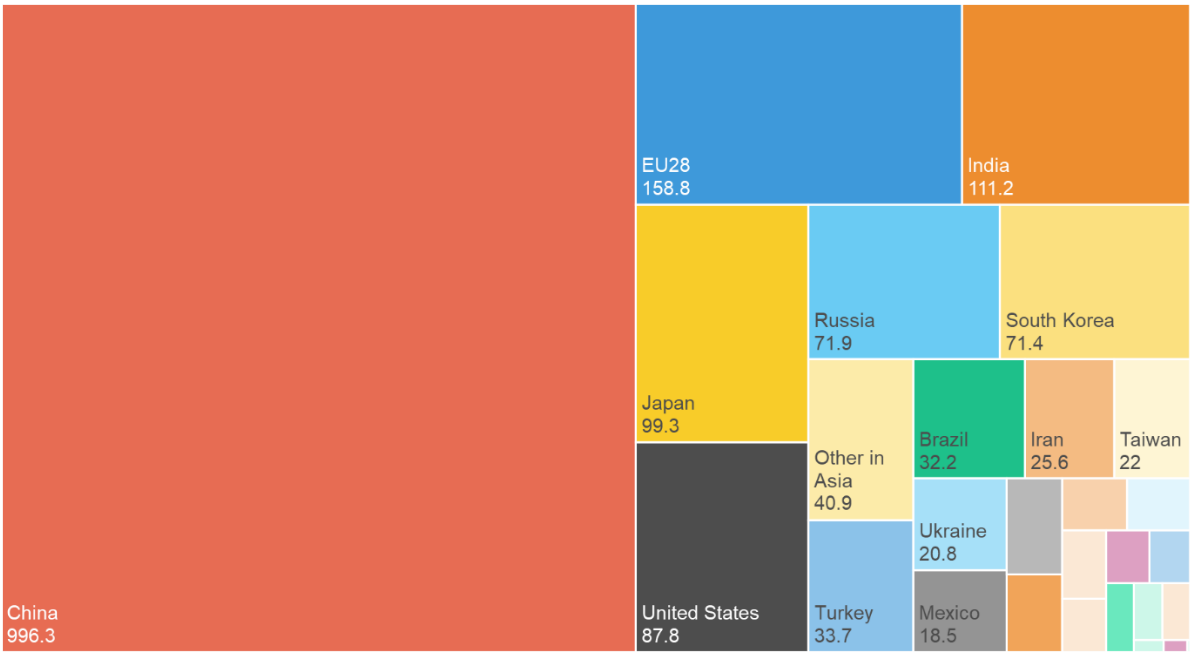
Figure 1. Global steel production



Source: JRC,. (Worldsteel, 2020; World Steel Association, 2019; Worldsteel, 2018)

Global steel production in 2019 (Figure 2) was dominated by China, which produced more than half of the world's steel (996 million tonnes or 53%). Almost three quarters of global steel was produced in Asian countries. With 8.5% (159 million tonnes) of global steel production, the EU28[1] was the second largest steel producer in the world, followed by India, Japan, the United States, Russia and South Korea (Worldsteel, 2020).

Figure 2. Steel production in EU28 and third countries in 2019 (in million t)



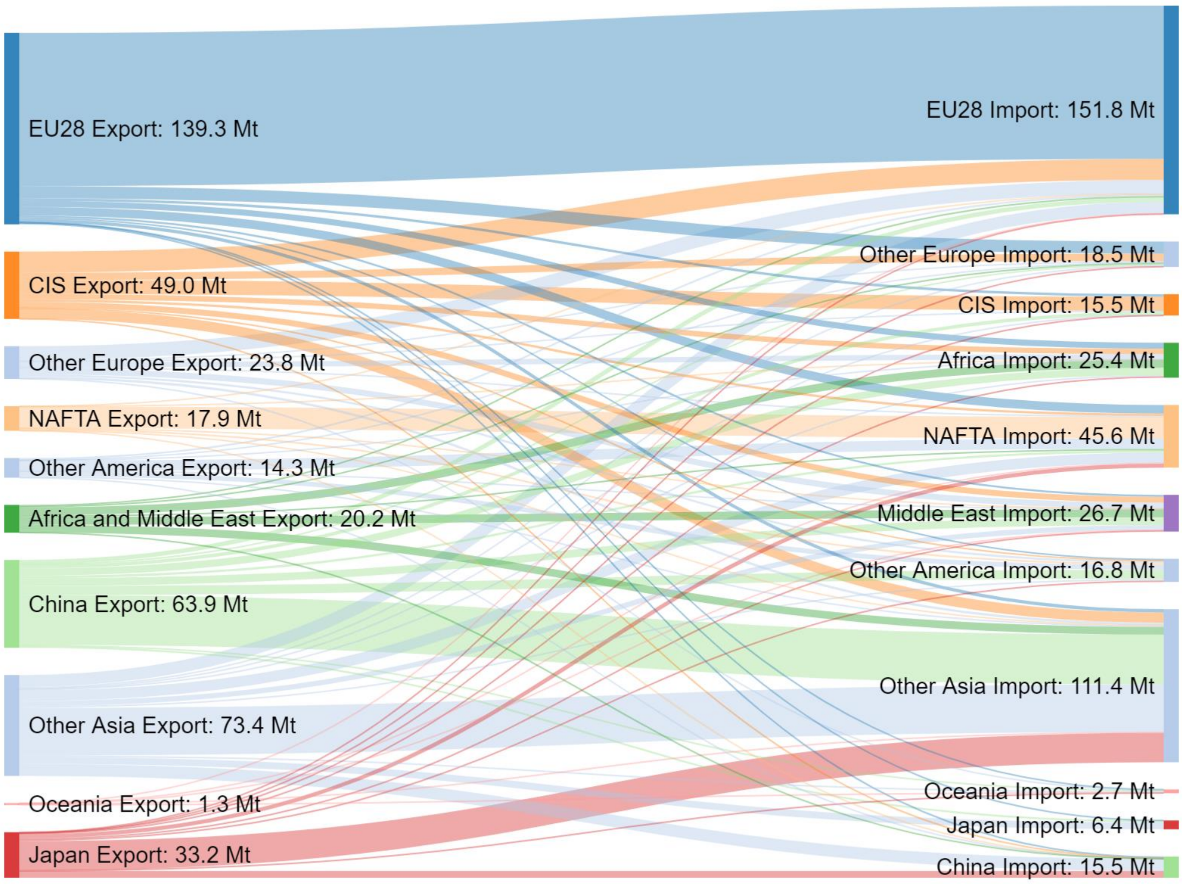
Source: JRC, (Worldsteel, 2020).

[1] Since in 2019 EU had 28 countries, historical data observed in chapter 2 refer to EU28. When analysing the costs in chapter 3, UK is observed as one of EU27 competitors.

This study includes the same countries as a previous JRC study on industry production costs, (Moya and Boulamanti, 2016), which covered Brazil, China, India, Japan, Russia, South Korea, Turkey, Ukraine, United States and EU.. The United Kingdom will also be included in this study as an important future trading partner with the EU after Brexit.

Figure 3 shows the global trade in steel 2019 (Worldsteel, 2020). It is worth noting that 88% of the steel produced in the EU in 2019 (139 million tonnes) was traded outside the country of origin, of which 111 million tonnes (70% of production) were traded on the EU internal market, while 28 million tonnes of steel (18% from production) were exported outside of the EU, mainly to other European countries (9 million tonnes) and North America (6 million tonnes). Although China produces half of all steel worldwide (996 million tonnes), it only exports 6% of its production (64 million tonnes), mainly to other Asian countries[2].

Figure 3. Global steel trade in 2019



Source: JRC, (Worldsteel, 2020).

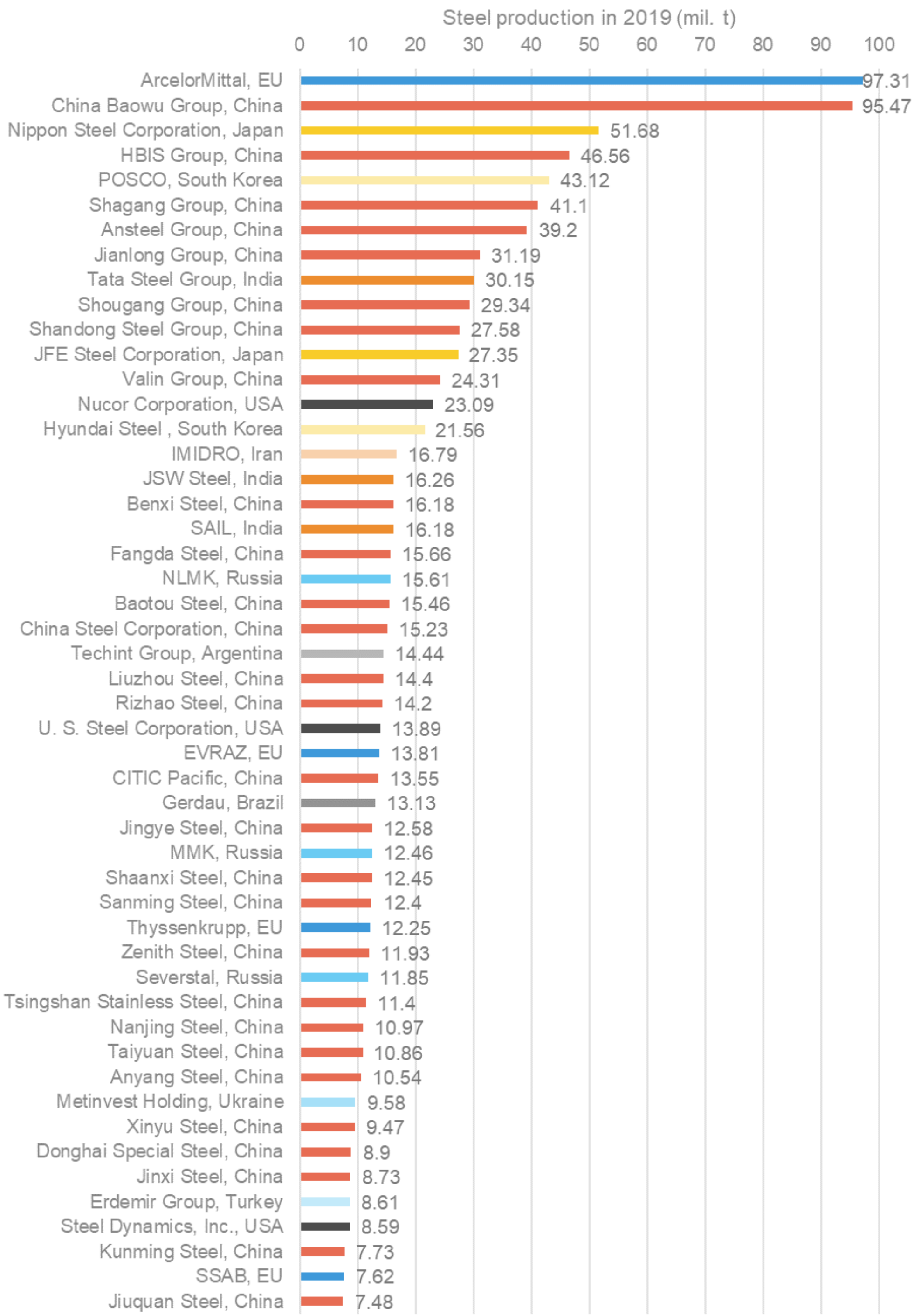
In 2019 the EU imported steel mainly from Commonwealth of Independent States (15 million tonnes), other European countries (10 million tonnes) and other Asian countries (9 million tonnes).

[2] Regions in Figure 3, defined in line with World Steel Association, had the following major steel producers in 2018:

- CIS (Commonwealth of Independent States)- 71% of production in Russia and 21% in Ukraine;
- Other Europe (non-EU and non-CIS European countries)- 88% of production in Turkey;
- NAFTA (North American Free Trade Agreement)- 72% of production in The United States, 17% in Mexico and 11% in Canada in 2018;
- Other America (non-NAFTA American countries)- 79% of production in Brazil and 11% in Argentina and
- Other Asia (Asian countries except China, Japan, CIS and Middle East)- 45% of production in India, 30% in South Korea and 9% in Taiwan.

Although the biggest global steel producer in 2019, ArcelorMittal (97 million tonnes) is headquartered in the EU, there are only four EU headquartered companies within the world's top 50, jointly producing 131 million tonnes. In comparison, 28 of the top 50 companies are Chinese, accounting for 575 million tonnes of steel. After the acquisition of Maanshan Steel, the biggest Chinese steel producer, China Baowu Group, has now reached a similar size to ArcelorMittal with 95 million tonnes of produced steel. India, United States and Russia had three producers each in the top 50, producing a total of 63, 46 and 40 million tonnes of steel respectively. (Figure 4).

Figure 4. Top 50 steel producers in 2019



Source: JRC, (Worldsteel, 2020).

3 Costs analysis

In line with the previous JRC analysis, the countries in scope of this analysis are: **EU27, Russia, Turkey, United States, United Kingdom, Ukraine, China, India, Japan, South Korea and Brazil.** The United Kingdom was added as it will be an important trade partner of the European Union after Brexit. These countries covered 90% of steel production worldwide in 2019 (Worldsteel, 2020).

The Annex provides a description of the main iron and steel manufacturing processes. This analysis includes the integrated route (Blast Furnace and Basic Oxygen Furnace: BF-BOF) and the recycling route (Electric Arc Furnace: EAF). Hot rolled coil (HRC) and wire rod (WR) are considered as proxy products for flat and long products respectively.

The detailed production costs data used in this analysis comes from the sample of steel plants provided by CRU. The costs correspond to the Steel Cost Model from October 2019[3]. (CRU, 2020). This is the latest updated information for 2019 without the influence of the COVID-19 pandemic, which was first reported in Wuhan, China in December 2019 (WHO, 2020). Table 1 shows the number of plants included in the CRU model in the above selected countries, per production route and final product.

Table 1. Number of plants from CRU model per technology and final product in the countries under study.

<table>
<tr><td colspan="2" rowspan="2">153 plants observed in 11 countries</td><td colspan="3">Production Routes:
Integrated Route (BF-BOF) and Recycling Route (EAF)</td></tr>
<tr><td>BF-BOF</td><td>BF-BOF and EAF</td><td>EAF</td></tr>
<tr><td rowspan="3">Production of Flat Products (Hot Rolled Coil) and Long Products (Wire Rod)</td><td>Hot Rolled Coil</td><td>56
EU27 15
Russia 1
Turkey 1
UK 1
US 9
Ukraine 1
China 15
India 3
Japan 7
South Korea 1
Brazil 2</td><td>7
China 1
India 4
South Korea 1
Brazil 1</td><td>15
EU27 2
Turkey 1
US 10
Japan 2</td></tr>
<tr><td>Hot Rolled Coil and Wire Rod</td><td>26
EU27 2
Turkey 1
China 16
India 1
Japan 4
South Korea 1
Brazil 1</td><td>7
Russia 3
China 3
India 1</td><td>0</td></tr>
<tr><td>Wire Rod</td><td>22
EU27 3
Turkey 1
UK 1
Ukraine 1
China 13
India 2
Brazil 1</td><td>2
China 2</td><td>18
EU27 9
Turkey 2
US 5
Brazil 2</td></tr>
</table>

Source: (CRU, 2020).

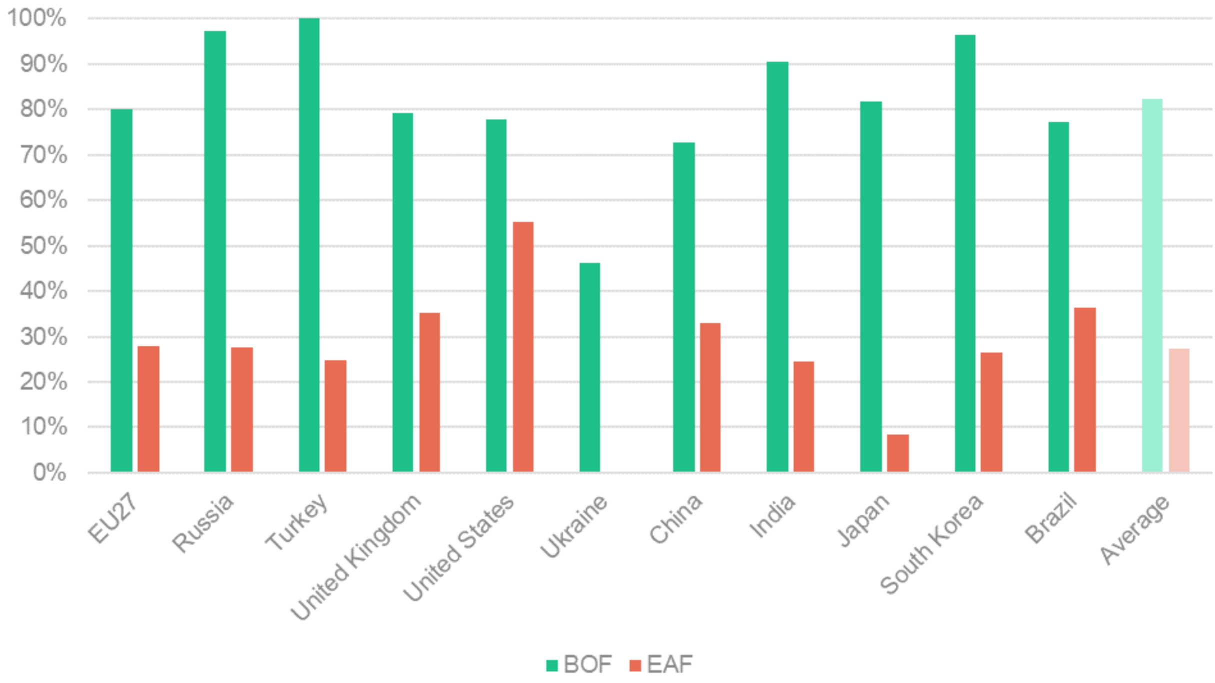
[3] CRU Steel Cost Model 2019 with Macro 2019 Q3

In total, 153 out of CRU´s 318 plants are located in the selected countries and have a production of hot rolled coil or wire rod in the BF-BOF or EAF production routes.

Some plants from Table 1 have both the integrated and recycling routes. For these plants, the CRU model did not provide information on which product is produced via which route. In these particular cases, this analysis assumes that hot rolled coil is produced through the integrated route and wire rod through the recycling route.

In order to assess the representativeness of the CRU database, Figure 5 compares the steel production of the plants from the CRU model, by country and production route, with the total installed steel production capacity, obtained from the Plantfacts database (WSD Plantfacts, 2019). In 2018, BF-BOF plants in the CRU database produced on average 82% of the total installed steel capacity in these countries, as reported by Plantfacts while plants with EAF facilities produced on average 27% of the total install steel capacity.

Figure 5. Share of CRU 2018 production in total country nominal capacity by Plantfacts



Source: JRC, (CRU, 2020; WSD Plantfacts, 2019).

3.1 Components of the costs

The breakdown of costs is based on the cost components from the analysis performed by Moya and Boulamanti and the costs breakdown from CRU, as shown in Table 2:

Table 2. Components of the cost

Cost breakdown	Cost components by Moya and Boulamanti	Elements of Stacked Cost Curve in CRU Steel Cost Model 2019
Energy	Energy (Electricity and Natural gas)	Energy (Coke oven gas, Blast furnace gas, Basic oxygen furnace gas, Corex as, Custom iron gas, Custom steel gas, Heavy fuel oil, Natural gas, Thermal coal, Other fuel and Steam)
		Purchased electricity
Labour	Labour	Labour
Raw Material	Raw Material (Iron ore, Scrap, Limestone, Oxygen, Ferrosilicon and Reductants)	Iron ore (Lump ore, Sinter fines, Pellet feed, 3rd party pellet and 3rd party sinter)
		Reductants (Coking coal, Injection coal, Anthracite, 3rd party coke, Injection natural gas, Injection heavy fuel oil and Injection other fuels)
		Metallics and ferroalloys (3rd party scrap, 3rd party direct reduced iron, 3rd party pig iron, Ferroalloys, Aluminium, Zinc and Tin)
		Purchased semis (Purchased slab, purchased hot rolled coil, purchased cold rolled coil and Purchased billet)
Credit[4]	Credit (savings from recycled scrap and self-power generation)	Credits (Blast furnace gas credit, Basic oxygen furnace gas credit, Corex gas credit, Custom iron gas credit, Custom steel gas credit, Steam credit, Scrap reverts, Fe reverts, Tar, Benzole and Slag)
Other	Other (fluxes and other consumables)	Other consumables (Fluxes, Electrodes, Refractories, Oxygen, Inert gases, Industrial water, Bentonite, Cold rolling oil, Pickling acid and Paint)
		Other costs (Overheads, Sustaining capital, Interest on working capital, Rolls and roll shop, Parts and spares and other costs)
		CO_2 costs

Source: (Moya and Boulamanti, 2016; CRU, 2020).

In order the results to remain comparable with the ones from the previous study by Moya and Boulamanti, the components of the costs from the right hand column of Table 2 (Costs of the CRU Steel Cost Model) are combined into the broader categories of the previous study. It is important to note that the ´other costs´ category includes also the CO_2 costs that exist only in the EU, the United Kingdom and South Korea.

CRU costs data is expressed in USD/t. In order to recalculate this data to EUR/t, an average exchange rate for 2019 was taken: 1 EUR = 1.1195 USD (ECB, 2020).

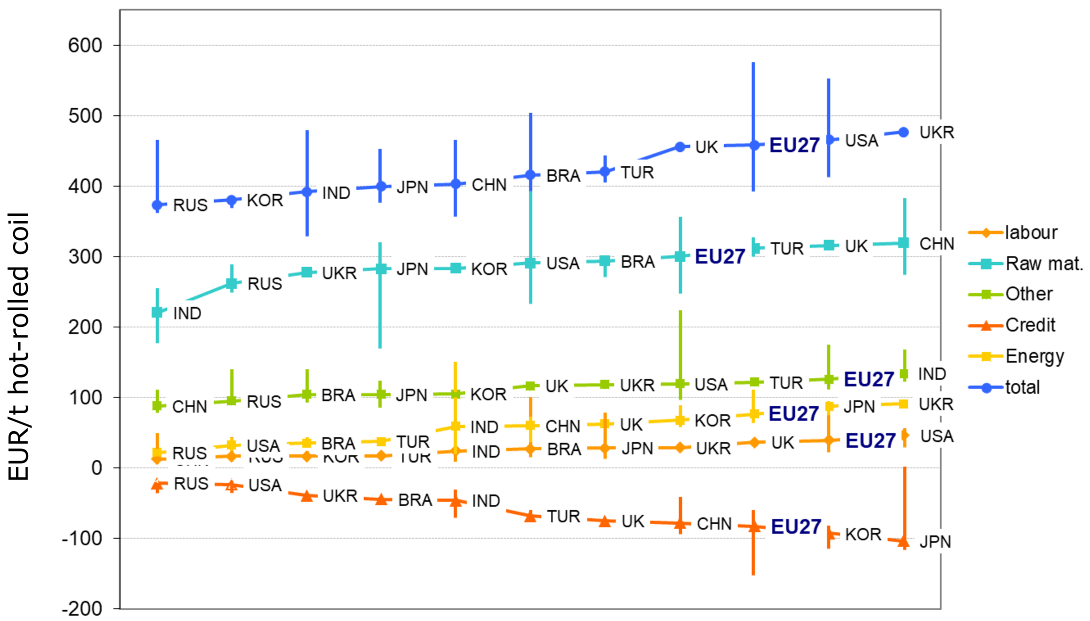
The costs are presented in diagrams where the weighted average costs are sorted from minimum to maximum, with a vertical line representing the range of costs in each country.

[4] Credits are generated from savings when raw materials are recycled inside the facility instead of purchased from external sources, or when energy is self-generated. By definition they decrease total costs, but in some cases, for instance when the recycled material can be sold to others, they may also increase total costs.

3.2 Hot rolled coil production costs in the integrated route

The breakdown of production costs of HRC in the integrated route is presented in Figure 6. With 458 EUR/t, the average total production costs in EU27 are the third highest after Ukraine (477 EUR/t) and the United States (466 EUR/t). Note that the lowest production costs (392 EUR/t) of the most competitive EU facilities in CRU's sample are at the level of the average production costs of Indian facilities (392 EUR/t), but higher than average Russian or South Korean production costs (374 and 381 EUR/t, respectively).

Figure 6. Hot rolled coil production costs in the BF-BOF process in 2019



Source: JRC based on data from (CRU, 2020).

The reasons for the high average production costs of HRC in the integrated route in EU27 facilities lie in all the major cost elements:

- European facilities have the second highest labour costs (39 EUR/t on average), but there are also European facilities competitive to medium level labour costs in India, Brazil, Japan and Ukraine, all between 24 EUR/t and 29 EUR/t.)
- EU27 facilities have also the second highest 'other costs' (126 EUR/t in average), with some facilities competitive to average other costs in the UK, Ukraine and USA, all between 116 and 119 EUR/t). CO_2 costs are included in 'other costs' in EU27, UK and South Korea but their impact is rather small with only 2% of the total production cost in EU27.
- EU27 plants have the third highest energy costs (on average 77 EUR/t, representing 17% of total production costs) making them competitive to energy costs in Japan and Ukraine. But some EU27 plants have also competitive energy costs with the average energy costs in South Korean plants. The energy cost (63 EUR/t) of the unique UK facility of the sample is lower than all EU27 facilities
- With a share of 65% from total production costs in EU27 facilities producing HRC in integrated route, the costs of raw materials have by far the biggest influence on the production costs. The average raw materials costs of EU27 facilities (300 EUR/t) are the fourth highest. But note that the lowest value 248 EUR/t is competitive with almost all average values except in India (221 EUR/t).

European facilities are among world leaders in creating credits from recycling materials and self-generating energy. EU27 facilities are ranked third in credits, decreasing the costs of hot rolled coil by 83 EUR/t on average, with the range between 59 EUR/t and 152 EUR/t. This has a major influence in improving the level of competitiveness of European steel industry. Note that although the average credits in the EU are lower than the South Korean and Japanese averages (93 and 104 EUR/t, respectively), the best European performer in credits (lower value of the interval) beats any other competitor in the sample.

Russian plants manage to produce the cheapest hot rolled coil from BF-BOF facilities with average costs of only 374 EUR/t, which is also recognized by CRU analysts indicating that “Black sea export prices are typically the lower bound for steel prices globally” (Smith and Melkonyan, 2020). The reason for this competitiveness is in the lowest or second lowest level of all observed costs. On the other hand, their high competitiveness in most components of the costs contrast with their worst level of credits (only 21 EUR/t).

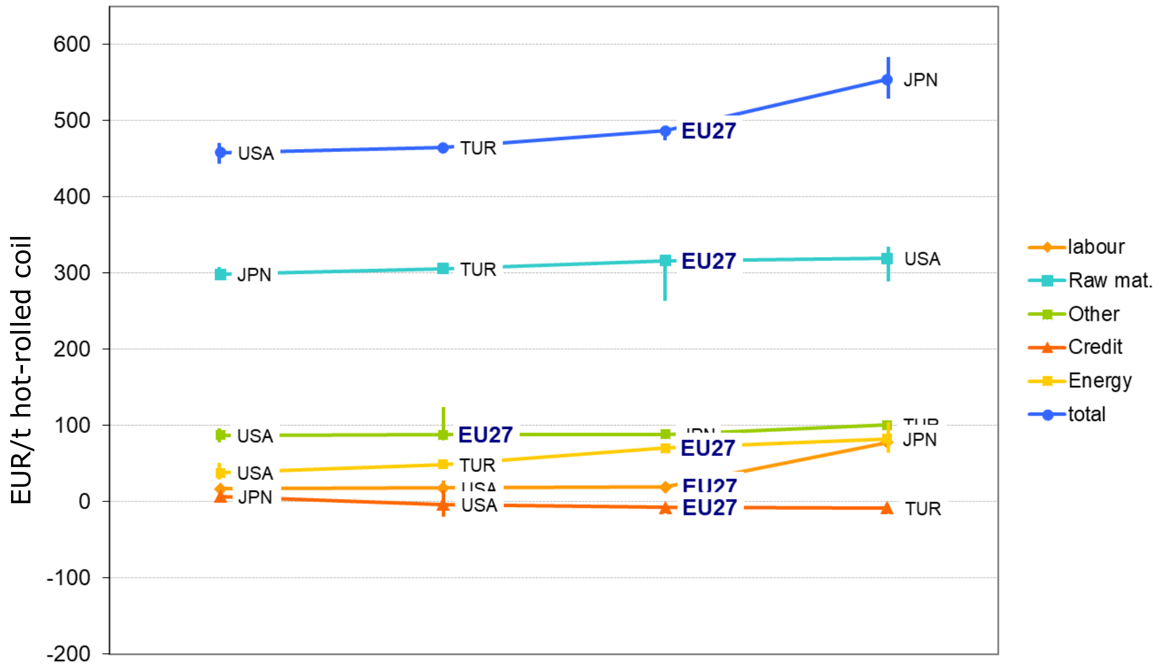
The range of total production costs of plants in the USA (413 - 552 EUR/t) is in the same range as EU27 plants. Most of the costs of USA plants are similar to those faced by EU27 plants, except for a drastic difference in energy costs, which are extremely low in the USA (33 EUR/t, 2nd lowest). This is compensated by the fact that the US plants are the second worst in creating credits for recycling materials and energy (only 24 EUR/t).

The country with the highest raw material costs, China (319 EUR/t), has the 5th lowest total costs (403 EUR/t) because it is the one with the lowest labour and other costs (13 EUR/t and 88 EUR/t respectively). Their energy cost are in central position among the countries analysed (60 EUR/t). In addition, on average Chinese plants manage to reach the 4th position of credits from recycling materials and energy (78 EUR/t), very close to the level of EU27 plants.

3.3 Hot rolled coil production costs in the recycling route

Figure 7 presents the production cost breakdown of HRC in the recycling route. EU27 facilities have second highest average production costs (486 EUR/t), after Japan (554 EUR/t). However, production costs for all other countries are quite similar. Compared to production costs in integrated route, HRC produced in the recycling route is often more expensive due to higher energy costs and lower level of credits from recycling materials and self-generating energy.

Figure 7. Hot rolled coil production costs in the EAF process in 2019



Source: JRC based on data from (CRU, 2020).

Note that the data sample only includes 15 plants and the cost differences amongst countries are mostly minimal (with a few exceptions):

- Raw material costs (65% of total costs in EU27) for all regions are very similar, a bit above 300 EUR/t. The wide range of costs in the EU27 means that there are facilities with the lowest raw materials costs of all observed countries.
- With the exception of Japan (78 EUR/t), labour costs in all other countries are within the range between 17 EUR/t in Turkey and 19 EUR/t in EU27.
- The level of credits for recycling materials and energy in EU27 plants (7 EUR/t) is within the range of USA and Turkey.
- Energy costs of EU27 facilities (71 EUR/t, representing 15% of total costs) are the second highest after Japan (83 EUR/t).
- 'Other costs' in EU27 facilities (88 EUR/t) are similar for all countries. With 0.9 EUR/tonne of HRC, the impact of the cost of CO_2 on total costs in recycling route is negligible.

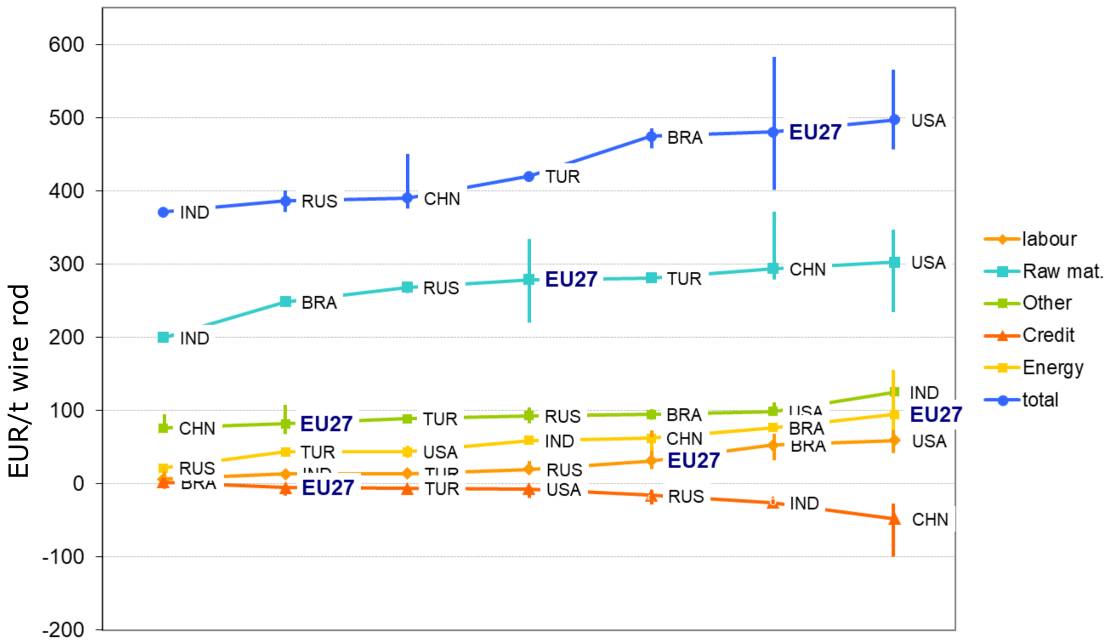
Japanese plants have the highest total costs (554 EUR/t), mainly as a consequence of the highest labour costs (78 EUR/t) and due to the fact that instead of gaining credits for recycling materials and energy, these plants have a burden of additional cost of 7 EUR/t.

Plants in the USA have the lowest total costs (458 EUR/t), which is mainly due to the lowest energy costs (38 EUR/t).

3.4 Wire rod production costs in the recycling route

Wire rod production costs in the recycling route are presented in Figure 8. With 480 EUR/t, the average total production costs in the EU27 are the second highest, after the United States (497 EUR/t). It is worth noting that there is a very wide range of costs in the EU27. It shows that some European steel manufacturers are able to compete with the average production costs of Turkish and Brazilian facilities, but are still above the average Chinese, Russian or Indian facilities which have minimum production costs of 371 EUR/t.

Figure 8. Wire rod production costs in the EAF process in 2019



Source: JRC based on data from (CRU, 2020).

High average production costs of wire rod in recycling route in EU27 facilities have several reasons:

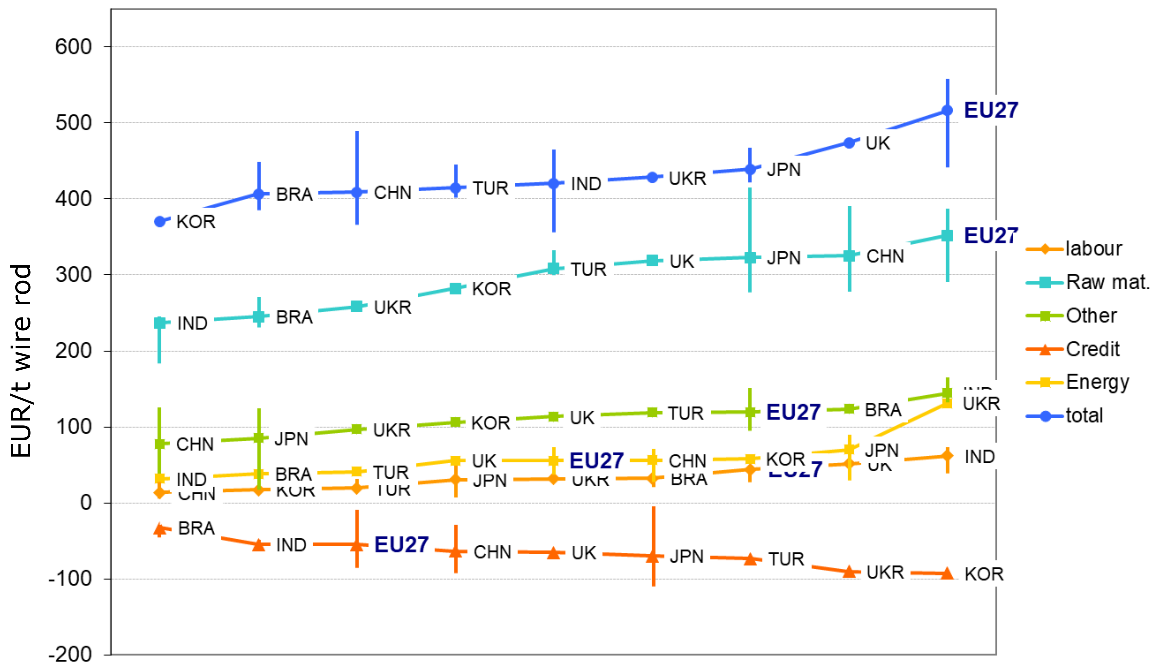
- Energy costs in the EU27 (on average 95 EUR/t, representing 20% of total costs, the highest share of all countries and varying between 74 and 156 EUR/t) are the highest).
- With only 6 EUR/t on average, EU27 facilities do not manage to gain many credits from recycling material and energy, especially when compared to Chinese facilities which manage to gain 48 EUR/t of credits.
- EU27 labour costs are the third highest with 31 EUR/t.

Average raw materials cost in the EU27 facilities are in line with those observed in other countries (279 EUR/t, representing 58% of total costs, which is close to medium value compared to other countries ranging between 52% and 75%). The range of raw material costs in EU27 (from 222 to 336 EUR/t) means that some plants have competitive raw material prices to the ones in Brazil and Russia (249 and 268 EUR/t, respectively), but not to the ones in India (200 EUR/t).

3.5 Wire rod production costs in the integrated route

Figure 9 shows the production costs of wire rod in the integrated route. EU27 facilities have by far the highest average production costs (516 EUR/t) and even the plants facing the lowest costs are barely competitive with other countries with minimum in South Korea (371 EUR/t).

Figure 9. Wire rod production costs in the BF-BOF process in 2019



Source: JRC based on data from (CRU, 2020).

The main reasons for this high level of costs in EU27 plants are the following:

- EU27 plants have the highest raw materials costs (352 EUR/t, representing 68% of total costs which is an average compared to other countries ranging between 56% and 79%), significantly higher also when compared to the second highest, China with 325 EUR/t.
- EU27 plants have the third highest labour costs (44 EUR/t) and 'other costs' (119 EUR/t), which included CO2 costs at 8EUR/t.
- The level of credits of EU27 facilities for recycling materials and energy are among the lowest ones (55 EUR/t), significantly lower than credits of South Korean plants (93 EUR/t)

Energy costs of EU27 plants (56 EUR/t) are within the range of the majority of other plants, ranging between 32 EUR/t in India and 70 EUR/t in Japan. The only extreme are energy costs in Ukraine (131 EUR/t). The share of energy costs in total costs for EU27 plants producing wire rod in integrated route is 11%, which is close to minimum comparing to other countries.

4 Conclusions

The average **production cost of the EU27** steel industry is in all cases **within the three highest production costs**. However, the range of costs amongst European plants is very wide. There are several reasons for the higher average production costs of European plants, but in general higher costs of **raw materials and labour are always the main components affecting the competitiveness**. While European producers generally face slightly higher than average energy prices, they only face the highest costs in the case of wire rod production via the EAF route. In any case, the **energy costs** usually represent between **11% and 20% of the total costs for the different production processes (the maximum share paid by a European plant is 27 %),** and are thus not the biggest factor in terms of competitiveness, but may be a significant one.

The production costs of HRC are significantly higher in the recycling than in the integrated route. The lowest cost of production of HRC in the EAF process (USA, 458 EUR/t) are at the same level as HRC produced via the BF-BOF process in the EU27 (458 EUR/t), and far higher than the most competitive costs in BF-BOF process in Russia India and South Korea..

EU27 facilities producing HRC via the integrated route have the third highest costs due to high costs of all major cost elements: second highest labour costs (39 EUR/t) and other costs (126 EUR/t), to a minor share influenced by CO_2 costs, third highest energy costs (77 EUR/t) and fourth highest raw materials costs (300 EUR/t). In this case is worth noticing that the **EU27 steel industry** is among **world leaders in creating credits from recycling materials and self-generating energy**, ranked third with average credits of 83 EUR/t (some facilities saving up to 152 EUR/t). This is a reflection of the **cumulated effect of the investments in innovation and optimisation in the European steel industry.**

HRC production costs via the EAF route are similar for most countries. The EU27 costs (486 EUR/t) are only 6% higher than the lowest average production costs (458 EUR/t in USA). It is worth noting that HRC costs via the recycling route are still much higher than the average production costs via the integrated route.

The production cost of WR from both routes is quite similar; ranging from 371 to 497 EUR/t for the recycling route and from 371 to 516 EUR/t in the integrated route. In both production routes, the production costs of EU27 facilities are among the highest. One of the main reasons for this are high labour costs and low level of credits from recycling material and energy compared to other competitors.

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List of abbreviations and definitions

BF	Blast Furnace
BOF	Basic Oxygen Furnace
EAF	Electric Arc Furnace
HRC	Hot Rolled Coil
WR	Wire Rod

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Annex

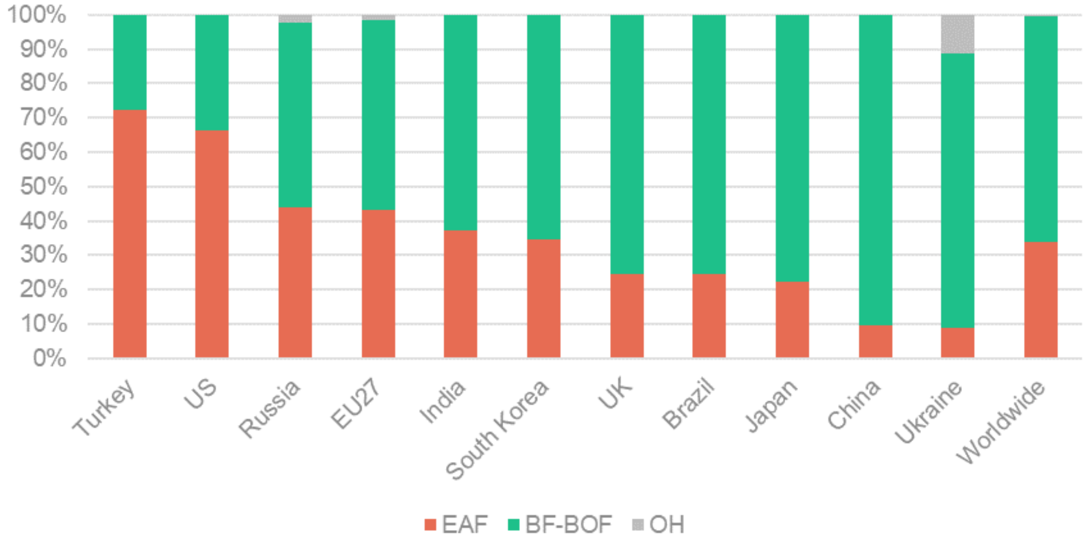
Iron and Steel manufacturing processes- adapted from (Moya and Boulamanti, 2016)

The description of Iron and Steel manufacturing processes is based on (Moya and Boulamanti, 2016).
There are two main routes to produce steel. The first one is called the 'integrated route' and is based on production of iron from iron ore. The second one, called the 'recycling route', uses scrap iron as the main iron-bearing raw material in electric arc furnaces. In both cases energy consumption is related to fuel (mainly coal and coke) and electricity. The recycling route has a much lower energy consumption (about 80%). Figure 10 shows the 'integrated route' and the 'recycling route' are at the left-hand side and right-hand side of the continuous casting, respectively.
The 'integrated route' relies on the use of coke ovens, sinter plants, blast furnaces and basic oxygen furnace (BOF) converters. The energy consumption for the integrated route is estimated to lie between 17 and 23 GJ per tonne of hot-rolled product (SETIS, 2010). The lower value is considered by the European sector as a good reference value for an integrated plant. A value of 21 GJ/t is considered as an average value throughout the EU (SETIS, 2010). It is noted that a fraction of this energy consumption may be committed to downstream processes. The fuels applied are fully exploited, first for their chemical reaction potential (during which they are converted into process gases) and then for their energy potentials, by capturing, cleaning and combusting these process gases within production processes, and for the generation of heat and electricity. Increased energy efficiency is an important characteristic of this 'cascadic fuel use', as the use of process gases does not reduce the overall energy consumption, which is the case if primary fuels are used for chemical reactions.
The 'recycling route' converts scrap iron in electrical arc furnaces (EAF). Current energy consumption for this route is estimated to lie between 3.5 and 4.5 GJ per tonne of hot-rolled product (SETIS, 2010). The lower value corresponds to a good reference plant. The higher value corresponds to today's average value within the EU.
There is an additional and older production process, practically replaced by the basic oxygen furnace, the open hearth furnaces (OH), where the impurities are removed from molten iron by blowing flames and heated air in alternating sequence. This process can be found in Czech Republic, Ukraine, Uzbekistan and Russia, where the production capacity shares reached 52%, 11%, 10% and 2 % respectively (WSD Plantfacts, 2019). In any case crude steel production capacities using open hearth furnaces (9 Mt) represents a small share of EU27 and global crude steel production capacities (1.7% and 0.6% respectively (WSD Plantfacts, 2019)).
Alternative product routes to the two main routes are provided by direct-reduced iron (DRI) technology (which produces substitutes for scrap) or the smelting reduction (which, like the blast furnace, produces hot metal). The advantage of these technologies compared to the integrated route is that they do not need raw material beneficiation, such as coke making and sintering, and that they can better adjust to low-grade raw materials. On the other hand, more primary fuels are needed, especially natural gas for direct-reduced iron technology and coal for smelting reduction. In the latter, 20-25 % savings in CO2 emissions (de Beer, Worrell, and Blok, 1998) can be achieved if the additional coal is transformed into process gases which are captured and used to produce heat and electricity for exports to the respective markets for heat and electricity. So far and for this reason, the expansion of these technologies occurs in developing countries with weak energy supply infrastructures or countries with low fuel resources. In 2012 total direct-reduced iron production was 70.9 Mt. The contribution of European DRI production boiled down to 0.65 Mt. In the third countries considered, only Russia and India have a production of DRI (5.2 and 19.7 Mt respectively). The accumulated DRI production of Egypt, Iran, Mexico, Oman, Qatar, Saudi Arabia, United Arab Emirates and Venezuela amounted to 36 Mt.
Part of the steep decrease in energy consumption in the EU industry in the last 40 years (by about 50 %) has been due to the increase of the recycling route at the expense of the integrated route (the share has increased from 20 % in the 1970s to around 40 % today). Although a prospective shift to recycling is confined by scrap availability and its quality, it is worth noticing (Figure 11) that in two of the countries studied (Turkey and the United States), the share of crude steel production capacities from the EAF route is higher than from the BOF route (72% and 66% respectively) and in one (Russia, 44%) higher than the share of the EAF route in EU27 (43 %).

Figure 10. Overview of the steel-making process and variety of products manufactured

Source: (World Steel Association, 2013)

Figure 11. Crude steel production capacities by process in selected countries



Source: JRC, (WSD Plantfacts, 2019)

According to its final shape and use, steel can be classified in two big groups: flat and long products. The flat products, produced mainly by the integrated route, include labs, hot-rolled coil, cold-rolled coil, coated steel products, tinplate and heavy plate. They provide the highest added value to the steel and are used in automotive, heavy machinery, pipes and tubes, construction, packaging and appliances. The long products, produced mainly in the recycling route, include billets, blooms, rebars, wire rod, sections, rails, sheet piles and drawn wire. The long products are used in the construction, mechanical, engineering and automotive industries. However, the historically clear cut between the production route and long or flat products is waning out. Today 100 % of long products and 70-80 % of flat products can be made with scrap (Laplace Conseil, 2013).