European Commission

JRC TECHNICAL REPORT

GREENHOUSE GAS INTENSITIES OF THE EU STEEL INDUSTRY AND ITS TRADING PARTNERS

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2022

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EUR 31112 EN

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EU Science Hub
https://ec.europa.eu/jrc

JRC129297

EUR 31112 EN

PDF	ISBN 978-92-76-53417-4	ISSN 1831-9424	doi:10.2760/170198

Luxembourg: Publications Office of the European Union, 2022

How to cite this report: Koolen, D. and Vidovic, D., *Greenhouse gas intensities of the EU steel industry and its trading partners*, EUR 31112 EN, Publications Office of the European Union, Luxembourg, 2022, ISBN 978-92-76-53417-4 (online), doi:10.2760/170198 (online), JRC129297.

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Abstract

In this report, we estimate figures on greenhouse gas intensities in the iron and steel industry of the EU and its main global trading partners. We draw exclusively on publically available databases, and develop a transparent methodology that allows for replicability to other geographical and temporal scopes, and serves as a basis for estimating greenhouse gas intensities in other energy-intensive industries. The results show that following a top-down approach, total emissions per tonne of crude steel can be estimated from aggregated statistical data. When further disaggregating emissions to production routes and process steps, the accuracy of the results depends on the availability of data on the energy product intensity of intermediate process steps. We compare emission intensities from the EU and the global trading partners per production route and process step in the iron and steel industry and validate our EU estimates with data from the National Implementation Measures (NIMs) and EU Emissions Trading System (ETS) benchmark curves. The insights from this study contribute to an increased understanding of the risk of carbon leakage and can be used to support the implementation of default values within the framework of the Carbon Border Adjustment Mechanism.

1 Introduction

In line with the EU's ambition to become climate neutral by 2050, the iron and steel industry faces the challenging task of decarbonising while remaining competitive on a global scale. There is indeed a significant role for the sector in contributing to climate neutrality targets, with the iron and steel industry accounting for more than 7% of total global emissions (IEA, 2020a). The EU was responsible for almost 10% of global steel production in 2018 (Worldsteel, 2020) and industry experts expect economic growth to continue to push absolute steel demand, both in Europe and globally, in the coming decades. In achieving the deep decarbonisation of this energy-intensive industry, it is therefore key to correctly understand regional and national greenhouse gas (GHG) emission intensities, also in light of the international iron and steel trade. In this study, we estimate carbon dioxide (CO_2) emissions in the iron and steel sector for the EU and its main trading partners (responsible for over 90% of iron and steel imports to the EU in 2018).

European countries have gradually reduced GHG emissions from the iron and steel industry over recent decades (EEA, 2021). Currently, the carbon intensity of EU steel is amongst the lowest in the world, driven by increasing recycling rates and high scrap availability, as secondary supply of steel lowers the carbon footprint. Furthermore, major EU steelmakers have developed their own emission-reduction ambitions and strategies, with seven out of eight major EU steelmakers pledging to reach net-zero emissions by 2050 (for a more elaborate discussion on these targets, see for example Somers (2021) and Agora (2021)). At the same time, emissions from primary steel production are hard to abate and many technologies are not yet economically viable. While further recycling and technological efficiency gains will enable further emission reductions, investments in radical new technologies will be necessary to accommodate climate neutrality targets.

Emissions from the iron and steel industry are covered by the EU Emission Trading System (ETS) in Europe. Steel markets are, however, global and highly competitive, and costs related to climate policies may induce carbon leakage if businesses transfer production to other countries with more lax emission constraints or replace domestic products with more carbon-intensive imports. As this could lead to an increase in global greenhouse gas emissions, the risk of carbon leakage is currently mainly addressed through the granting of free allowances (European Commission 2021a). While free allowances have effectively protected the industry from carbon leakage risks, it may not provide sufficient incentive to transition to climate-neutral technologies (Somers, 2021). The European Commission has therefore proposed to introduce a carbon border adjustment mechanism (CBAM) as an alternative measure to mitigate risks of carbon leakage while supporting policies for the reduction of GHG emissions in the EU and globally (European Commission, 2021a). The CBAM proposes a levy on the embedded CO_2 emissions of specific goods, thereby creating a level playing field for EU producers alongside their global competitors. As it is an alternative instrument to address carbon leakage, the CBAM will progressively replace ETS free allowances.

Under the CBAM, the price of carbon for imported goods will mirror the EU ETS price, based on the weekly average auction price of EU ETS allowances. Determining the emission intensity of the imported product would either be based on the actual embedded emissions or on the basis of a default value (European Commission 2021a). The CBAM regulation proposal states that:

> *"When actual emissions cannot be adequately determined by the authorised declarant, default values shall be used. These values shall be set at the average emission intensity of each exporting country ..."* (European Commission, 2021a)

The proposal states that default values shall be determined based on the best available data. When reliable data for the exporting country is not available, it proposes that the default value shall be based on the average emission intensity of the 10% worst performing EU installations for that type of specific good. It further states that:

> *"When data adapted to specific local characteristics are available and can define more targeted default values, the latter may be used instead of default values based on EU installations."* (European Commission, 2021a)

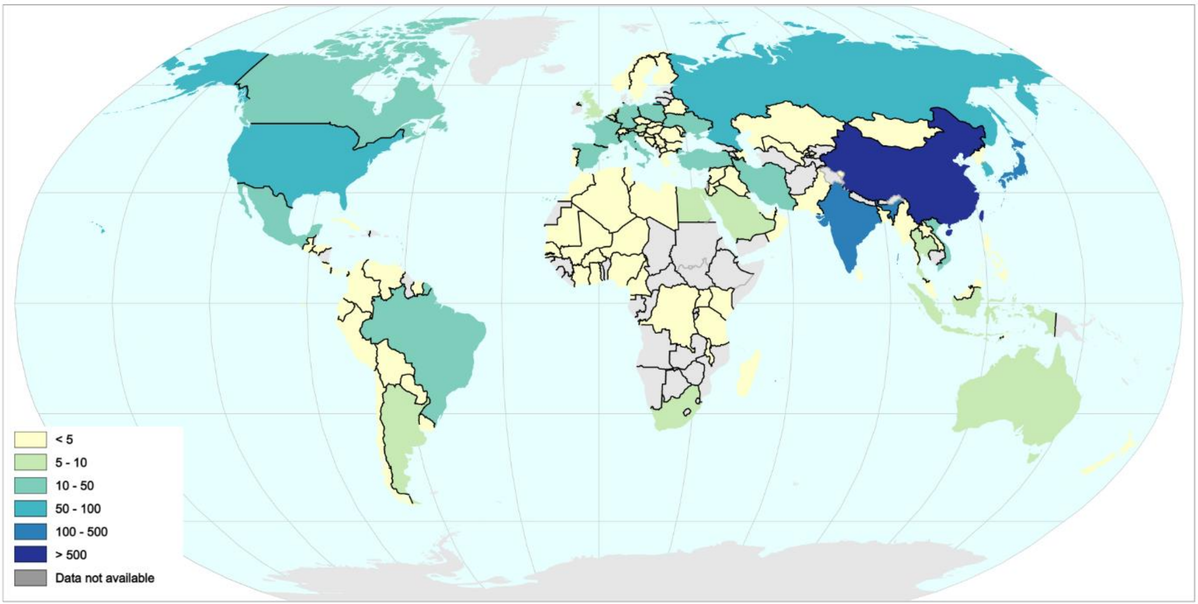
In this study, we aim to estimate CO_2 emissions and CO_2 emission intensities of the iron and steel industry for the EU and its main global trading partners. We thereby only make use of publicly available databases in order to allow for the transparent reproducibility of our estimates and their replicability to other geographical and temporal scopes. The methodology described may further serve as a basis for estimating emissions for other specific goods that fall under the CBAM.

2 Global iron and steel production and trade dynamics

Steel is produced globally and traded internationally in various (semi-)finalised forms. The production of crude steel, i.e. steel in the first solid state upon solidification of liquid steel and suitable for further processing or sale, globally reached 1 864 Mt in 2020, down by 0.9% from 1 880 Mt in 2019 but still up by 2% compared to the 1 824 Mt in 2018 (Worldsteel, 2021). Although these numbers indicate the resilience of the iron and steel sector to the COVID-19 pandemic, more pronounced regional differences occur. Against the backdrop of the pandemic, the EU's production of crude steel was down year-on-year by 12% in 2020, while production in China was up by 5.2%. Steel demand is expected to recover across the world, and in 2021, had already returned to pre-pandemic levels in emerging economies (Worldsteel, 2021).

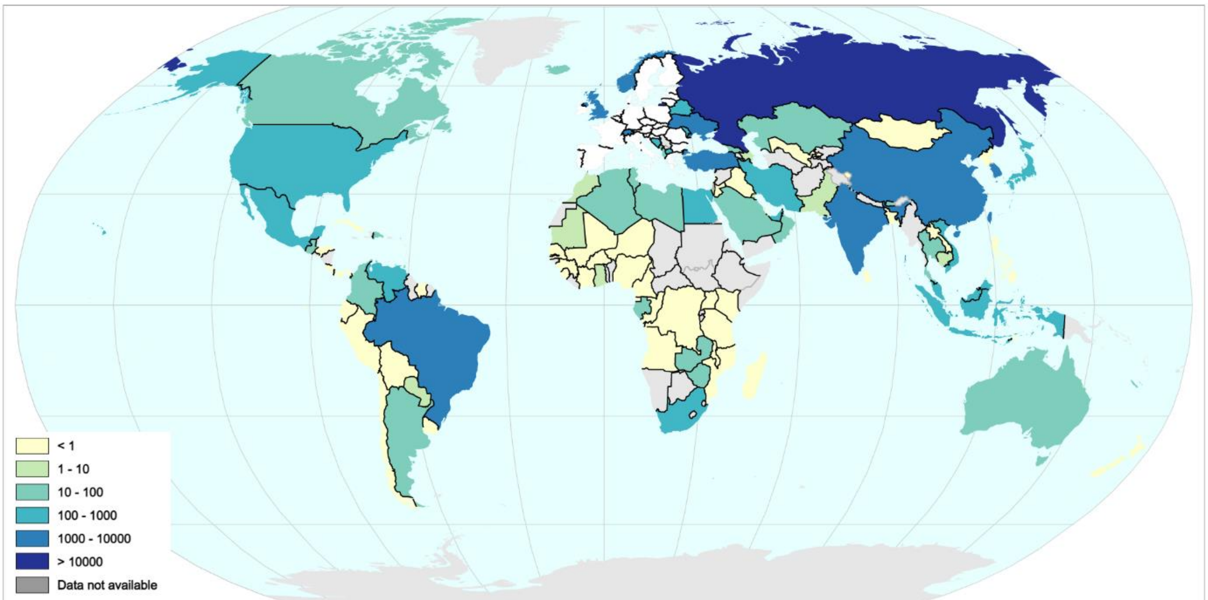
Figure 1 indicates the global production of crude steel in 2018. China dominates the sector with a production of 928 Mt. The EU27 follows as the second largest producer with 160 Mt, followed by India with 109 Mt and Japan with 104 Mt. The dominance of China has been the main contributing factor to rising global production levels as its national production rose by nearly 50% in the decade following the 2007-2008 financial crisis (Worldsteel 2021), while other countries' production levels remained relatively stable.

Figure 1: Global production of crude steel in Mt, 2018.



Source: JRC, (Worldsteel, 2020).

Figure 2: Global imports of iron and steel products to EU27, in thousand tonnes, in 2018.

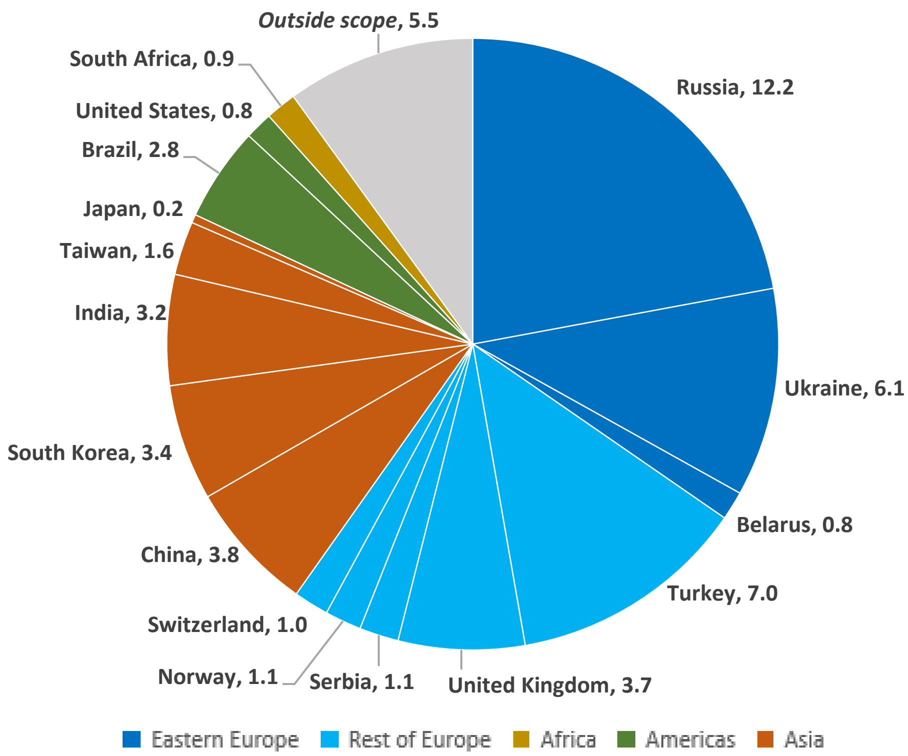


Source: JRC, (Eurostat, 2021).

The geographical scope of this study is determined using statistics on the international trade of iron and steel products. Figure 2 visualises imports by SITC code 67 (Iron and Steel) of all international partners to the EU in 2018 (Eurostat, 2021). While most trade takes place with countries bordering the EU (incl. Russia, Turkey, Ukraine and the United Kingdom), a significant proportion of imported iron and steel products comes from Asia (China, South Korea, India and Taiwan), and the Americas (Brazil and the United States).

The EU imported roughly 55 Mt crude steel in 2018. All but one of the major global crude steel producers are represented in the top 15 largest exporters to the EU. Although Japan is only the 22nd largest exporter of products to the EU, it plays a major role in the global iron and steel industry, with a production of 104 Mt crude steel in 2018. Adding Japan to the 15 largest exporters, Figure 3 visualises the 16 countries within the geographical scope of this work, accounting for more than 90% of total imports of iron and steel products to the EU in 2018.

Figure 3: Geographical scope of this study: import of iron and steel products to EU27 in 2018, in Mt.



Source: JRC, (Eurostat, 2021).

2.1 EU and third country steel production routes

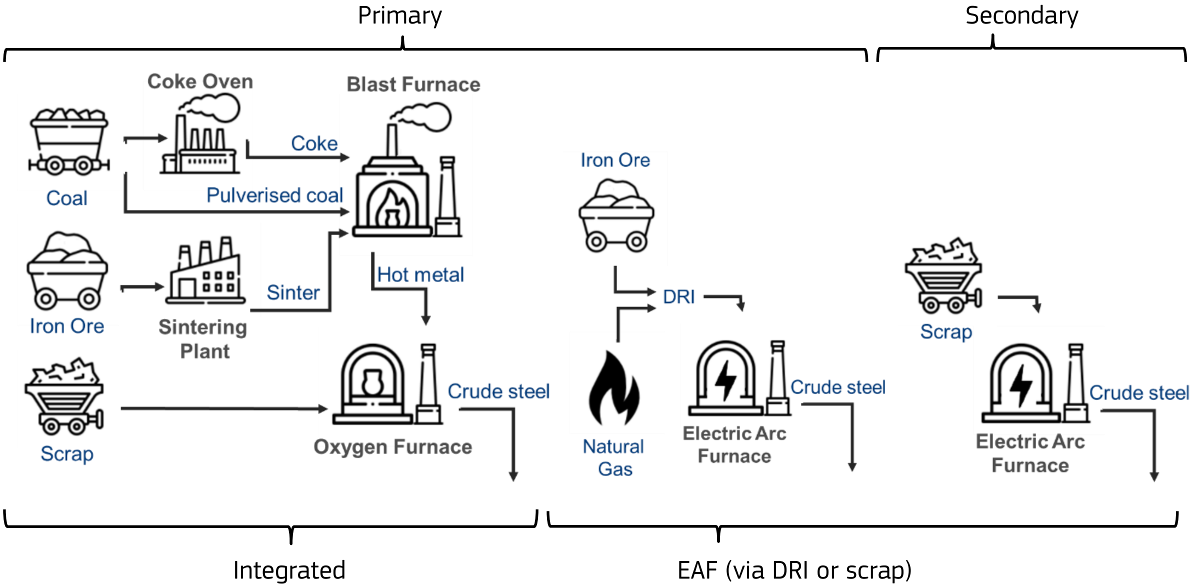
Steel is currently produced via a limited number of production processes. Figure 4 presents a simplified overview of the main production routes for steelmaking. Primary steelmaking mostly uses iron ores as feedstock for raw material preparation, iron making and steelmaking. The latter process consists in principle of melting, purifying and alloying processes. Steel via the secondary route makes use of scrap steel as the primary raw material, where the steelmaking is performed in an electric arc furnace.

The integrated route typically involves a coke oven plant, a sinter plant, a blast furnace (BF) and a basic oxygen furnace (BOF), and is also referred to as BF-BOF route[1]. Preparatory steps include coke making in the coke oven from coking coals and agglomerating iron ore in the sinter plant. Coke, sinter, lump iron ore and limestone are then fed into the blast furnace together with hot air, forming a molten metal called pig iron or

1 The open hearth furnace (OHF) also used to be a common process before the introduction of the BOF. OHF has largely been replaced by the faster and more fuel-efficient BOF, but was still operational in 2018 in Ukraine and India. When referring to the integrated process, we refer to both the BOF and OHF processes.

hot metal. By blowing high-purity oxygen through this liquid metal, the pig iron, potentially in combination with scrap steel, is converted to crude steel in the BOF. The liquid crude steel is next typically cooled down and poured into a mould during continuous casting, after which finalising steps at a steel mill may prepare the product for further purposes.

Figure 4: Main production routes for steelmaking



Source: JRC.

Another process to produce steel via the primary route is to produce Direct Reduced Iron (DRI), also called sponge iron. This process makes use of pelletised iron ore and reducing gases, typically natural gas (e.g. Midrex and Energiron HYL) or solid reducing agents like coal (e.g. Finex or coal-based rotary kiln furnaces), and removes the oxygen from the iron in a solid state to produce DRI. Currently, around 80% of DRI steelmaking makes use of natural gas, where the natural gas is reformed to a mixture of carbon monoxide and hydrogen to perform the reduction of the iron ore. When low-carbon hydrogen (e.g. produced with renewable electricity) is used as the reducing gas instead of natural gas, the process offers great potential for reducing the carbon footprint of the entire steelmaking process.

Steelmaking via the secondary route recycles scrap steel for new purposes via an Electric Arc Furnace (EAF)[2]. The energy intensity is typically much lower than that of the integrated process. High-current electric arcs melt the steel, allowing for thermal control and a range of alloy additions. Scrap steel is a valuable product with a large international market, and with an expected increase of available scrap, secondary steel may continue to satisfy a significant share of the EU's steel requirements (European Commission, 2021b). Despite the possible increasing availability of scrap steel, high-quality requirements or a low trace element content for many steel applications may continue to drive demand for primary steel in the EU (Material Economics, 2019).

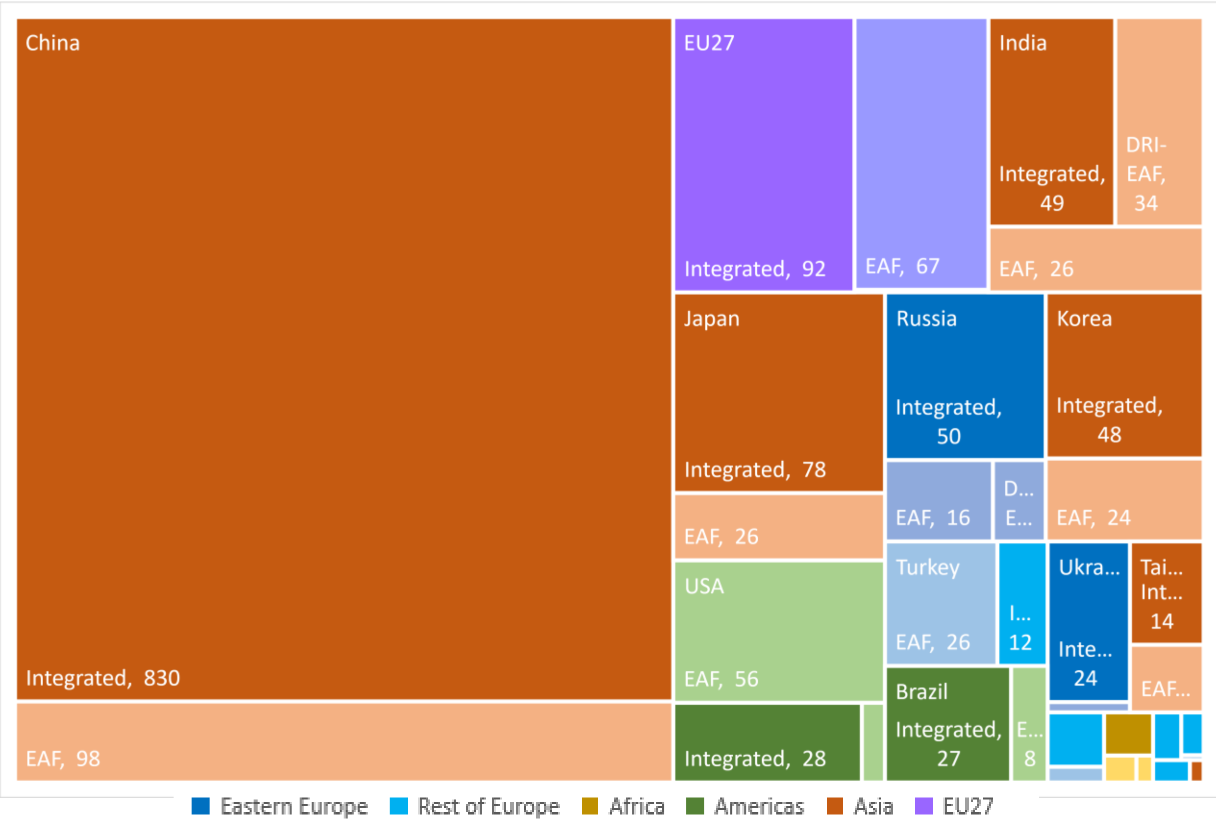
Figure 5 shows the total production of crude steel for the EU and the third countries within the scope of this study via the three main production routes. We find that a majority of countries still largely depend on the integrated route, mainly in South-East Asia where new installations are still built to accommodate a growing steel demand. The secondary route, however, supplies a significant portion of the crude steel production, being the main production route in countries like the United States and Turkey. Although DRI-EAF still plays a minor role in the global iron and steel sector, the technology has a significant production share in a selected number of third countries[3].

[2] Most direct reduction plants also make use of this process, as they are part of a steelmaking process with an EAF located on site.

[3] We refer here to both natural gas-based DRI and coal-based DRI, although large differences persist between countries. For example, coal-based DRI is the main production route for steel in India, while other DRI-producing countries typically rely exclusively on natural gas as the reducing agent.

Applying volume-weighted averages of the imports of iron and steel products in 2018 to the production routes of crude steel, we find that the imported steel consumed in the EU mainly originates from the integrated route (78%), followed by the secondary route (18%) and DRI-EAF (4%).

Figure 5: Production of crude steel by production route for the EU and its main trading partners in 2018, in Mt.



Source: JRC, (Worldsteel 2020).

2.2 Iron and steel trade by intermediate product

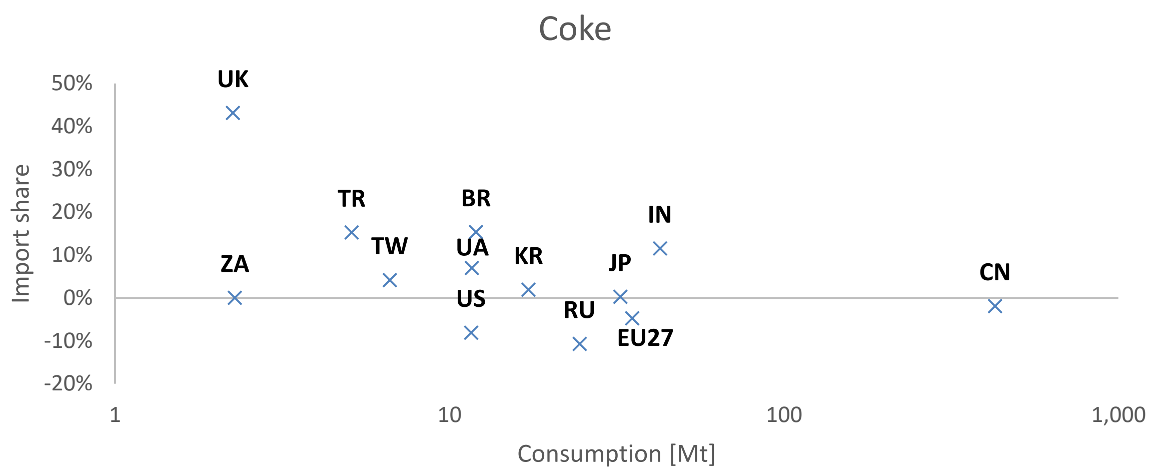
Producing crude steel requires several raw materials and intermediate products, as indicated in Figure 4. The integrated route therefore typically consists of various production plants; a coke plant producing coke oven coke from coking coals, a sinter plant to produce sinter from iron ore fines and coke, and a pellet plant agglomerating iron ore fines to create iron ore pellets[4]. Pig iron is formed in the blast furnace before it is turned into crude steel in the BOF. Alternatively, sponge iron can also be considered an intermediate product. It is produced via direct reduction of iron ore, before the EAF turns it into crude steel.

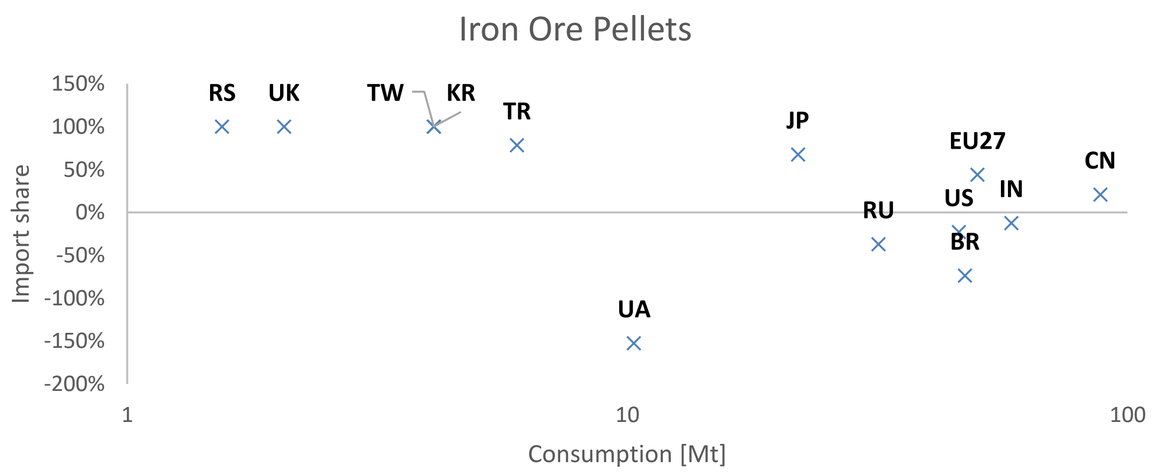
Figure 6 shows the consumption of the intermediate products, coke, pellets and pig iron, for all countries within the geographical scope, in relation to the share of net imports required to meet iron and steelmaking needs. The net import share shows the amount required of the respective intermediate product, additional to domestic production, in order to meet demand for that intermediate product. A positive share means that the shortfall needs to be imported, whereas a negative share means the respective country is a net exporter of the intermediate product. We find that demand for coke is generally met domestically (with the United Kingdom as the main exception), with most countries at around 0% net import share. The EU, China and the United States are net coke exporters, although most is kept for domestic use. Pellets, as a mechanically stable intermediate product, are traded globally, and we find a considerable number of countries relying exclusively

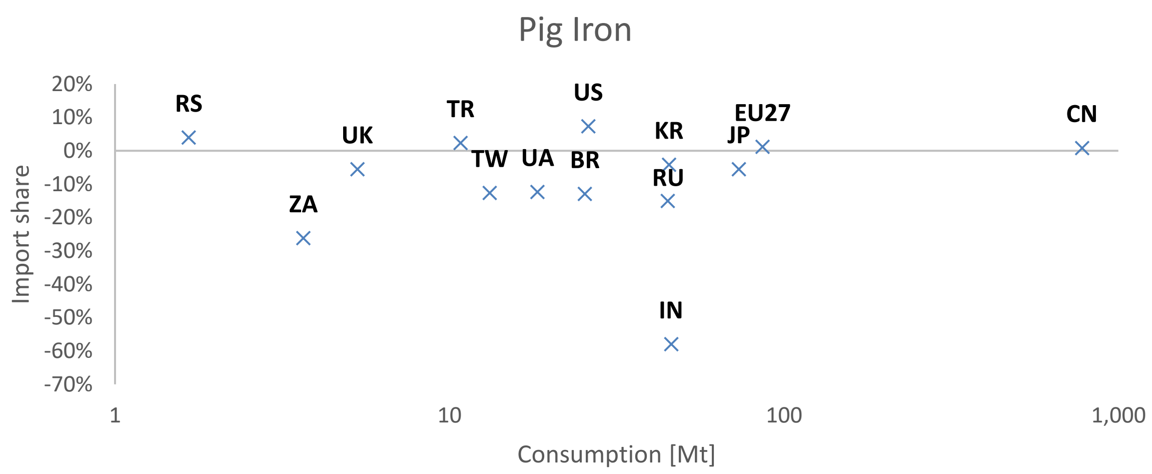
[4] Note that pellet production only takes place in a limited number of countries and most integrated steel plants import iron ore pellets. For example, Sweden and the Netherlands are the only pellet-producing MSs, and the pellet plant in the Netherlands is the only one to be part of an integrated steel production facility.

on imports[5]. We observe, finally, for pig iron, that most countries meet their own demand. India and South Africa, are, however, key exporters of this intermediate product.

Figure 6: Consumption of intermediate products (coke, pellets and pig iron) per country, and net import share required to meet the consumption of the intermediate product for iron and steel production.







Source: JRC, ((IEA, 2020b), (UN Comtrade, 2021), (Worldsteel, 2020)).

[5] Unlike pellets, sinter is not a mechanically stable product and international trade remains limited.

3 Determining greenhouse gas intensities

The main input data for this study are two publicly available databases: the extended world energy balances from the International Energy Agency (IEA) and the emission factors for stationary combustion in manufacturing industries and construction from the Intergovernmental Panel on Climate Change (IPCC). We begin by discussing both data sources in detail and go on to describe further input data sources in light of the general methodology.

3.1 Input data

3.1.1 Extended world energy balances

The extended world energy balances by the IEA are the most complete global accounting framework of energy products and their flows (IEA, 2021a). They provide statistical data of all energy sources produced, traded, transformed and consumed on a country scale for an indicated reference year. By presenting all data in a common energy unit, the energy balances further allow for comparison of sectoral energy demand as well as carbon intensities of energy flows and products. We denote a single energy product as P_i and a single energy flow as F_j.

Table 1 shows the main energy product categories as presented in the energy balances. For the purpose of this analysis, all 66 specific energy products belonging to one of these energy product categories are taken into consideration. Some energy products are of specific interest to the iron and steel industry, for example the subcategories of solid fossil fuels and manufactured gases within the coal and coal products category. The former provides specific information on energy products of interest to the iron and steel industry such as coking coal, anthracite and other bituminous coal, as well as coal products like coke oven coke. The latter includes waste gas energy products produced by the iron and steel industry in the form of coke oven gas, blast furnace gas and other recovered gases. The other main energy product of interest to the industry is natural gas. The energy balances also enable the incorporation of electricity and heat energy data.

Table 1. Energy product categories as listed in the simplified world energy balances by the IEA (2021).

Energy Product
Coal and coal products
Peat and peat products
Crude, Natural Gas Liquids and feedstocks
Oil products
Natural gas
Nuclear
Hydro
Geothermal
Solar, wind, other
Biofuels and waste
Electricity
Heat

Source: JRC, (IEA, 2021a).

In terms of energy flows, current extended world energy balances detail the flow of energy in three main blocks: Supply, Transformation and Own Energy Use, and Final Energy Consumption. The latter block has a specific energy flow related to the iron and steel industry, which is used for this study. Within the block of Transformation and Own Energy Use, specific energy flow information is available on the coke ovens and blast furnaces for both the transformation of energy and own energy use of these facilities. This allows for a specific allocation of energy to both processes within the scope of this study. Furthermore, this middle block lists energy flows for autoproduction of heat & electricity, indicating the transformation of energy for use within the own installation boundaries, as well as the main production of heat & electricity. Both of these energy flows are of interest with regard to the waste gas energy products of the iron and steel industry, notably coke oven gas, blast furnace gas and other recovered gases. Particular care needs to be taken to avoid the double counting of emissions from the use of such waste gases. Where various sources may suggest different accounting methodologies to deal with this, we discuss some of the resulting differences in the results.

3.1.2 Default emission factors

The CO_2 emission factors for stationary combustion in manufacturing industries from the IPCC (IPCC, 2021), excluding those for the energy products heat and electricity, are the only source of emission factors used in this study (in line with European Commission (2017))[6]. We apply the default CO_2 emission factors in linking energy product P_i from the extended world energy balance sheets to the fuels under consideration in the IPCC guidelines. Note that this naturally excludes some of the energy products with no emission factor, most notably hydro, geothermal, solar energy, ocean energy and wind energy. Furthermore, we note that, for a number of energy products, linking the energy product to an emission factor cannot be unambiguously determined. However, as these energy products are not of relevance to this study (i.e. no energy use for the specific energy product in the entire iron and steel industry), we consider them out of scope. The 46 energy products and respective emission factors under consideration in this study are listed in Annex 1.

Note that the use of other default emission factors may influence the final results. Deviations can occur in absolute form and in relative form, where emission factors may be compared to a reference emission factor. With respect to the latter, we discuss in section 5.1 how such deviations may affect the final outcome.

3.1.3 Further data sources

Besides the 2 main data sources listed above, the following input data is used in the scope of this study:

- Emissions per kWh of electricity and heat output (IEA, 2019): Emission statistics of electricity and heat. Contrary to the default emission factors for other energy products, these emission factors are at country level and updated yearly.
- World energy statistics on production and trade of coal (IEA, 2020b): Data source containing information on production, imports and exports of coke oven coke. Used for analysis on greenhouse gas intensities of intermediate product coke.
- Imports and exports of iron ore and concentrates (UN Comtrade, 2021): Data on imports and exports of agglomerated iron ores & concentrates (excl. roasted iron pyrites). Used for analysis on greenhouse gas intensities of intermediate product pellets. Where data on quantity (kg) is missing, estimates are based on according trade values (USD).
- Plantfacts Capacity Database (Steel Institute VDEh, 2019): Data on national capacities of pelletising plants. Derived estimates on pellet production are used for the analysis on greenhouse gas intensities of intermediate product pellets.
- Production volumes of steel and related products (Worldsteel, 2020): Production volumes via primary and secondary route, for analysis on greenhouse gas intensities of production routes; and production volumes on pig iron and DRI, for the analysis on greenhouse gas intensities of the respective intermediate product.
- Integrated Database of the European Energy Sector (Mantzos et al., 2017): Data on energy balances of the European energy system, used to estimate the relative amount of energy use for finalisation processes in the iron and steel industry. It enables the estimation of energy use for the refining and rolling processes and product finishing categories per energy product and production route.

3.2 Methodology

The general calculation method applied in this work follows the methodology in accordance with the IPCC guidelines for national greenhouse gas inventories (IPCC, 2021) to estimate total greenhouse gas emissions at national level[7]. In general, we apply a transparent, top-down methodology to estimate greenhouse gas intensities from the aggregated statistics. Energy process balances are applied on a relative basis, ensuring consistency with the aggregated statistics, for estimating the weight of the production route or intermediate product in the aggregated industry statistics. The following methodological approach ensures replicability to other geographical and temporal scopes, and creates a basis for estimating greenhouse gas intensities in other energy-intensive industries.

[6] We refer to carbon dioxide emissions specifically in this study. Besides CO_2, the methodology can similarly be applied for other greenhouse gases. For the steel industry, only CO2 emissions are however currently in the scope of annex I of the CBAM (European Commission, 2021a).

[7] We estimate emissions following the "Tier 2 Method", which calculates emissions using carbon contents specific to the individual energy products.

Total national emissions Em^T for country *n* are estimated using the following equation:

$$Em^T = \sum_j \sum_i E_{P_i,F_j} \, EF_i \tag{1}$$

Whereby E_{P_i,F_j} represents the energy involved for energy product P_i relevant to energy flow F_j, and EF_i the emission factor for energy product P_i. Energy products P_i range over all 48 energy products under consideration, listed in Annex 1, for the Transformation and own energy use of the coke oven and blast furnace energy flows as well as the Final energy consumption for the iron and steel energy flow. For the autoproduction and main production of electricity and heat energy flows in the Transformation and own energy use category, the relevant energy products P_i range consists of three waste gas categories.

In order to calculate emissions for all other process steps, as well as emissions for the production routes, we disaggregate the data according to the relative energy demand of energy product P_i in the respective process step or production route. First, the emissions stemming from finalisation processes, involving refining and rolling processes as well as energy for steel product finishing, are subtracted from total emissions per energy product. We estimate emissions to produce crude steel per country *n* and per energy product P_i:

$$Em^C = \sum_i \left[(1 - \mu_{P_i}) \sum_j E_{P_i,F_j} \, EF_i \right] \tag{2}$$

With μ_{P_i}, the national relative energy share of finalisation processes, defined by:

$$\mu_{P_i} = \frac{Vpr.r_{F_{pr},P_i} + Vsr.r_{F_{sr},P_i}}{Vpr + Vsr} \tag{3}$$

Where *Vpr* and *Vsr* represent the national absolute production volumes per primary and secondary production route, respectively, and r_{F,P_i} the respective relative energy share of the finalisation processes per route and per energy product[8]. The latter is derived from the detailed split of iron and steel energy consumption by subsector in the EU, based on the JRC-IDEES data (Mantzos et al., 2017). We denote $E^C_{P_i} = (1 - \mu_{P_i})E_{P_i}$ to represent the energy per energy product after deduction of the finalisation processes.

Energy process balances serve as input for the further disaggregation of emissions per production route and process step. Table 2 indicates the net energy intensity per process step for some of the main energy products in the iron and steel industry, based on earlier JRC publications (Moya et al. (2013) and Pardo et al. (2013)). Note that the table lists net energy intensity per tonne of product produced by the respective plant, indicating a positive sign if the energy product is consumed and a negative sign if the energy product is produced in the respective process step. Besides the listed energy products, detailed information on energy use per process step is available for products like tar, benzene, steam and waste gases. The entire energy process balance as published by Moya et al. (2013) is reproduced in Annex 2.

Table 2. Main energy product intensities per process plant for iron and steel industry (Moya et al., 2013).

Plant	unit	Coke	Coal	Electricity	Natural Gas
Coke plant	EPB_{Co} in GJ per t coke	-30.1	42.08	0.12	-
Sinter plant	EPB_{si} GJ per t sinter	1.37	-	0.09	0.09
Blast furnace	EPB_{bf} GJ per t hot metal	10.33	4.15	0.16	-
BOF plant	EPB_{bo} GJ per t semis	-	-	0.12	0.23
DRI-EAF (Gas-based)	EPB_{dri} GJ per t semis	-	0.48	2.07	9.70
DRI-EAF (Coal-based)	EPB_{dri} GJ per t semis	-	24.4	2.27	0.30
EAF (secondary)	EPB_{eaf} GJ per t semis	-	0.48	1.73	0.30

Source: JRC.

[8] For finalisation processes in the iron and steel sector, the JRC-IDEES database (Mantzos et al., 2017) differentiates between energy intensities of the primary and secondary route. Although the energy intensity of the finalisation processes does not depend on the production route, the differences account for that the primary route produces more crude steel for energy-intensive final products than the secondary route.

It is important to note that the analysis only applies energy process balances in a relative manner. In other words, it is always verified that the total emissions stemming from the aggregated statistics in the extended world energy balances match the total of all disaggregated emissions from the process steps or production routes. In order to do so, we apply a production volume weighted average over the energy products on the energy process balance to disaggregate emissions per process step level[9]:

$\forall\ PS \in [co, si, pe, bf, bof, dri, eaf]$:

$$Em^{PS} = \sum_{i} \left[\gamma_{PS,P_i} \sum_{j} E^{C}_{P_i,F_j} EF_i \right] \tag{4}$$

Where γ_{PS,P_i} represents the national relative energy use of the respective process step per energy product[10]:

$$\gamma_{PS,P_i} = \frac{Vps.EPB_{PS,P_i'}}{Vco.EPB_{Co,P_i'} + \mathrm{V}si.EPB_{si,P_i'} + \mathrm{V}pe.EPB_{pe,P_i'} + \mathrm{V}bf.EPB_{bf,P_i'} + \mathrm{V}bof.EPB_{bof,P_i'} + \mathrm{V}dri.EPB_{dri,P_i'} + \mathrm{V}eaf.EPB_{eaf,P_i'}} \tag{5}$$

Where Vps indicates the national absolute volume of the process step under consideration, as discussed in section 2.2. As noted in equation (4), this study considers seven different process steps: coke plant, sinter plant, pellet plant, the blast furnace, the basic oxygen furnace, DRI-EAF and EAF. Where the latter two also represent entire production routes, the integrated route combines the first five process steps.

Finally, in order to compare national greenhouse gas intensities of the integrated production route between countries, it is important to take note of imports and exports of intermediate products. In order to prevent the over-reporting of greenhouse gas intensities for a net exporting country of an intermediate product, applying equation (4) over the entire route should only take into account the emissions for producing the necessary volumes of the intermediate product to produce the respective national amount of crude steel via the integrated route. Similarly, when reporting the greenhouse gas intensity of a route for a net importing country of an intermediate product, emissions should be adjusted upward to take into account upstream emissions of the imported intermediate products. The emissions of the integrated route Em^{IR} are thus calculated by multiplying the process carbon intensities with the required intermediate product volume to satisfy the demand for crude steel via the integrated route Vps, ir over all process steps of the integrated route:

$$Em^{IR} = \sum_{PS} \frac{Vps, ir}{Vps} Em^{PS} \tag{6}$$

[9] Although equation (4) allows for methodological generalisability, the data granularity for the iron and steel industry in the extended world energy balances enables the isolation of the energy used in the coke oven and blast furnace process steps. We therefore simply apply equation (1), taking into account the respective energy flows EF_i for the relevant sub-installation for estimating coke oven and blast furnace greenhouse gas emissions, and exclude the two process steps from the process step range. Since, next to this transformation component, the consumption component however remains reported under the iron and steel energy flow (IEA, 2021b), emissions from the latter component are disaggregated according to text equation (4). Note that an alternative to the proposed methodological approach would be to reintroduce the blast furnaces and coke ovens in the process step range in equation (4), and derive process step emissions by applying the energy process balance to the sum of all total emissions. As this would lead to a loss of information entailed in the data granularity of the energy flows in the extended world energy balance sheets, we do not follow this approach for the iron and steel sector. This could, however, be valuable to derive process step emissions in other energy-intensive industries which have no detailed industry information on energy flow level.

[10] An energy product P_i is allocated to an energy product P_i' of the energy process balance when both can be linked unequivocally. For the remaining energy products on the energy balance sheet for which the energy process balance does not clearly define an energy product, we first control whether they are process specific, i.e. the energy product can only be attributed to one energy process in the iron and steel industry, or else apply the relative energy share over all energy products in the respective energy process step in relation to the other process steps of the energy process balance.

4 Results

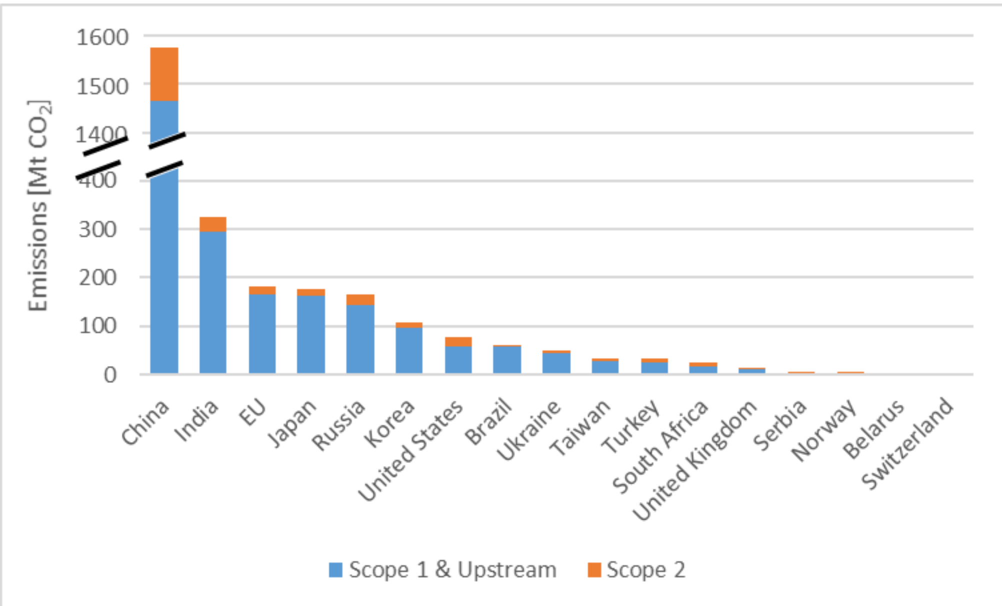
We report all CO_2 emissions and CO_2 emission intensities within the geographical scope, and qualitatively discuss the results in light of the observed international variations. Scope 1 emissions are defined as direct emissions from the iron and steel sector in a specific country. Scope 2 emissions stem from indirect emissions, related to the consumption of purchased electricity, steam and heat. We further consider upstream emissions representing the net scope 1 emissions from imported and exported goods. Upstream emissions thus include the scope 1 emissions in the country of origin of the imported product and the (negative) scope 1 emissions of the exported product, but exclude other associated emissions from, for example, transport and mining, as they are not part of the iron and steel industry in the aggregated statistics. As such, scope 1 & upstream emissions represent the scope 1 emissions after removing scope 1 emissions corresponding to exported intermediate products and adding scope 1 emissions corresponding to imported intermediate products.

Where we highlight the main results below, reported CO_2 emission intensities can be found in Annex 3, ordered by country, scope, production route and process step. We finally note that where the initial results indicated country-specific particularities in the public data sources, we consulted public or commercial data to verify the input data. Resulting country-specific edits deviating from the described methodology can be found in Annex 4.

4.1 Total CO_2 emissions

Total CO_2 emissions, scope 1 plus upstream emissions and scope 2 emissions, for all countries within the geographical scope, are shown in Figure 7 for the year 2018. The majority of the emissions can be attributed to Asian countries. We find that emissions from China (1 576 Mt) significantly exceed CO_2 emissions from India (325 Mt), the EU (183 Mt), Japan (176 Mt) and Russia (166 Mt). Note that emissions depend significantly on the share of the respective production routes in total national steel production.

Figure 7: Total CO_2 emissions from the iron and steel industry.



Source: JRC.

We validate our methodology by comparing our total EU emissions with the emissions reported by the European Environment Agency (EEA). These emissions are reported by the respective countries to the EU Greenhouse Gas Monitoring Mechanism (EEA, 2021) and reflect the GHG inventory as reported under the United Nations Framework Convention on Climate Change (UNFCCC) (UNFCCC, 2021). Note that emissions specifically related to the iron and steel industry are only reported within the GHG inventory for Annex I countries. Furthermore, emissions from fuel combustion in coke ovens are reported under the energy industry rather than the manufacturing industry, and are thus excluded from the comparison. We find our top-down estimate on EU CO_2 emissions of the iron and steel industry (excluding coke oven emissions) to deviate by only 0.75% from the bottom-up emissions as reported to the EEA.

EU emissions of the iron and steel industry in t CO_2, 2018
(excluding emissions from fuel combustion in coke ovens)

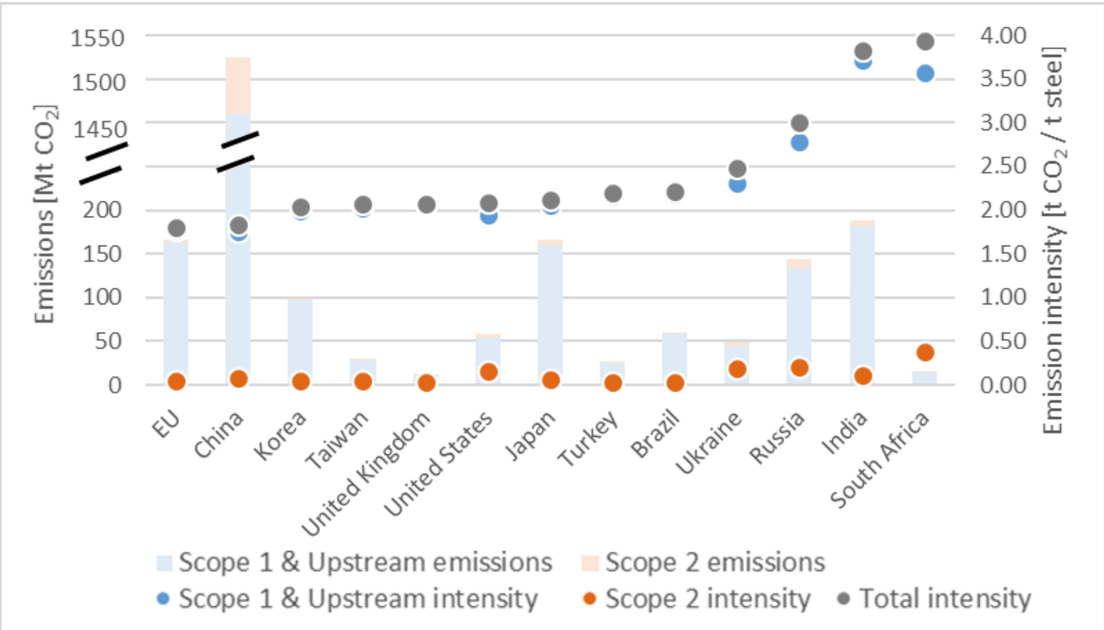
EEA	*JRC*	*Discrepancy*
151 592 882	152 736 863	+0.75%

4.2 Emissions per production route

Total CO_2 emissions, scope 1 plus upstream emissions and scope 2 emissions, of the integrated route, are shown in Figure 8. We find the same countries represented in the top five as in the above section, indicating for large emitters the relatively large weight of integrated route emissions in total CO_2 emissions. China reports 1 525 Mt of CO_2 emissions, followed by India (188 Mt), the EU (167 Mt), Japan (166 Mt) and Russia (144 Mt). Note that in this study, emissions from the DRI-EAF production route are not reported under the integrated route.

CO_2 emission intensities for the integrated route, calculated as the integrated route emissions divided by the production of crude steel via the integrated route, are represented by the dots in Figure 8. We find that the total carbon intensities (scope 1 & upstream + scope 2) of most countries range between 1.8 and 4.0 t CO_2 per t steel, with the EU and China reporting the lowest at 1.81 and 1.84 t CO_2 per t steel, respectively. At the higher end are South Africa and India with carbon intensities above 3.8 t CO_2 per t steel.

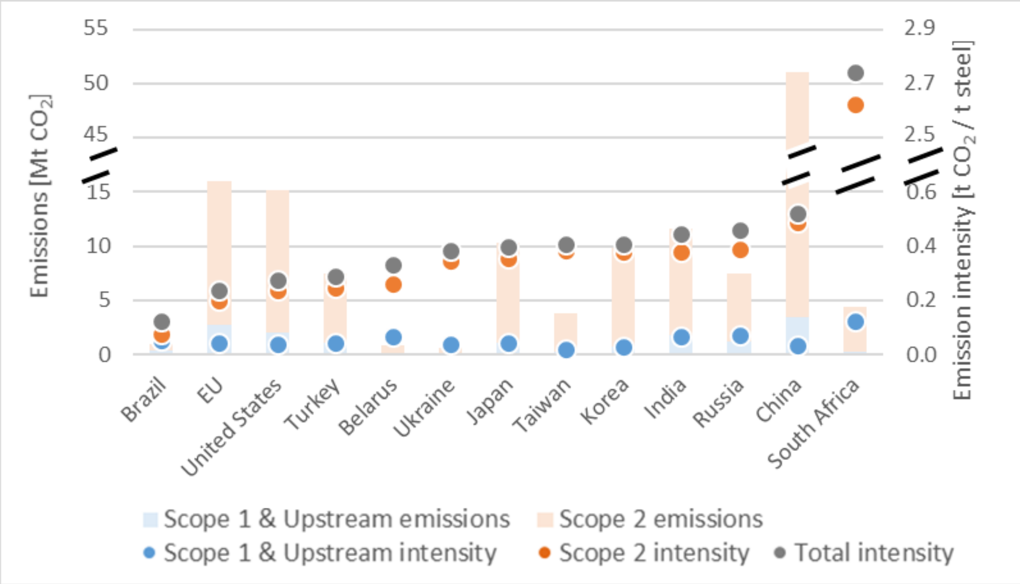
Figure 8: Integrated route CO_2 emissions and carbon intensity.



Source: JRC.

Figure 9 shows the CO_2 emissions and CO_2 emission intensity for the EAF route. Note that emissions of the secondary route are typically reported including scope 2 emissions, as electricity required for the electric arc furnace represents the highest demand of energy for these processes. We find that the CO_2 emission intensity of the EAF route is for most countries below 0.6 t CO_2 per t steel. South Africa is an exception, as the electricity intensity for steel produced via the EAF route is the highest, in combination with the fact that South African electricity is the most CO_2 emission-intensive (990 g CO_2 per kWh) of all countries within the scope of this report. Brazil, on the other hand, presents notably low scope 2 emissions for the EAF route, mainly driven by the availability of less carbon-intensive hydroelectric power.

Figure 9: EAF route CO_2 emissions and carbon intensity.



Source: JRC.

4.3 Integrated route emissions by process step

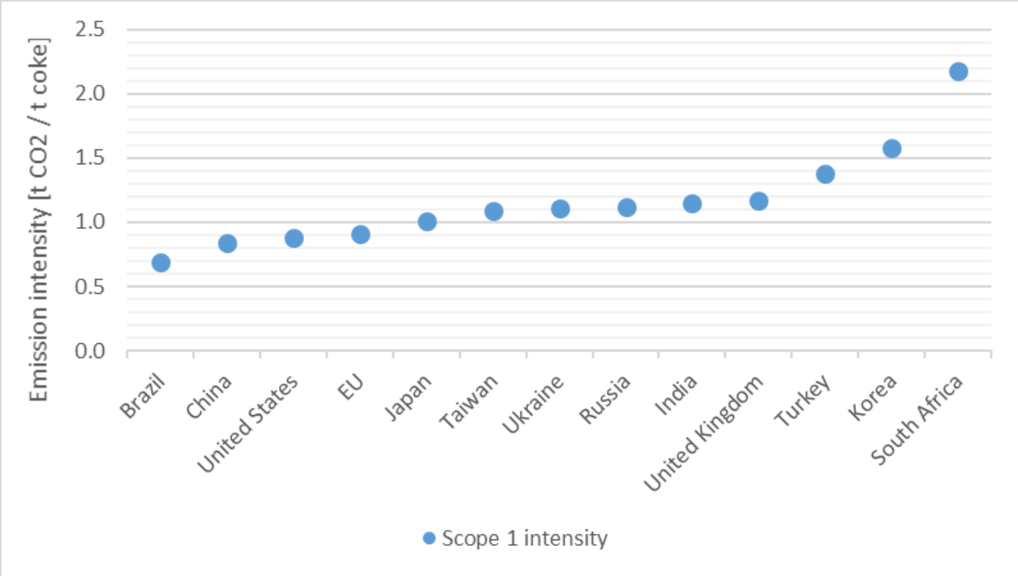
In this section, we report CO_2 emissions and CO_2 emission intensities per process step for the integrated route, according to the relevant product benchmarks in the EU ETS (Coke (2), Sinter (3) and Hot Metal (4)). As indicated in the methodology section, the disaggregation of emissions to sub-installation level depends on a single, generic and country-independent energy process balance (also see Annex 2). Such allocation of emissions works relatively well for processes that are distinctly different in the use of primary energy products, for example the integrated route and secondary route. For processes where primary energy products are similar across various processes, the accuracy of the results may decrease as small variations between countries in energy use, efficiency or product are not represented. The results should thus be interpreted to give a general indication of the CO_2 emissions and CO_2 emission intensity, rather than to give exact point estimates.

CO_2 emission intensities for coke production are visualised in Figure 10. Coke oven emissions are estimated by adding the detailed data of the coke oven's energy flow within the Transformation and own energy use category of the extended world energy balances and the relevant autoconsumption of waste gases. The most GHG-efficient countries (Brazil and China) report carbon intensities below 0.85 t CO_2 per t coke, whereas Korea and South Africa are at the higher end with emission intensities above 1.50 t CO_2 per t coke.

Figure 11 presents CO_2 emission intensities for the sinter plant. As no specific energy flow information is available for the sinter process within the aggregated statistics, emissions are estimated by disaggregating emissions from the iron and steel energy flow within the Final Energy Consumption category, applying the energy process balance according to equation (4). We find emission intensities to be relatively comparable across countries, between 0.33 and 0.91 t CO_2 per t sinter. India and Russia are on the higher end with values above 0.9 t CO_2 per t sinter.

Finally, CO_2 emission intensities from hot metal production are presented in Figure 12. These emissions include all emissions to produce crude steel from both the BF and BOF installations, but, following the ETS, are shown in t CO_2 per t hot metal. Here the numbers indicate that China, Japan, and the United States are at the lower end with values below 0.45 t CO_2 per t hot metal, in line with the expectation for more efficient installations. Serbia and South Africa report values above 1.1 t CO_2 per t hot metal.

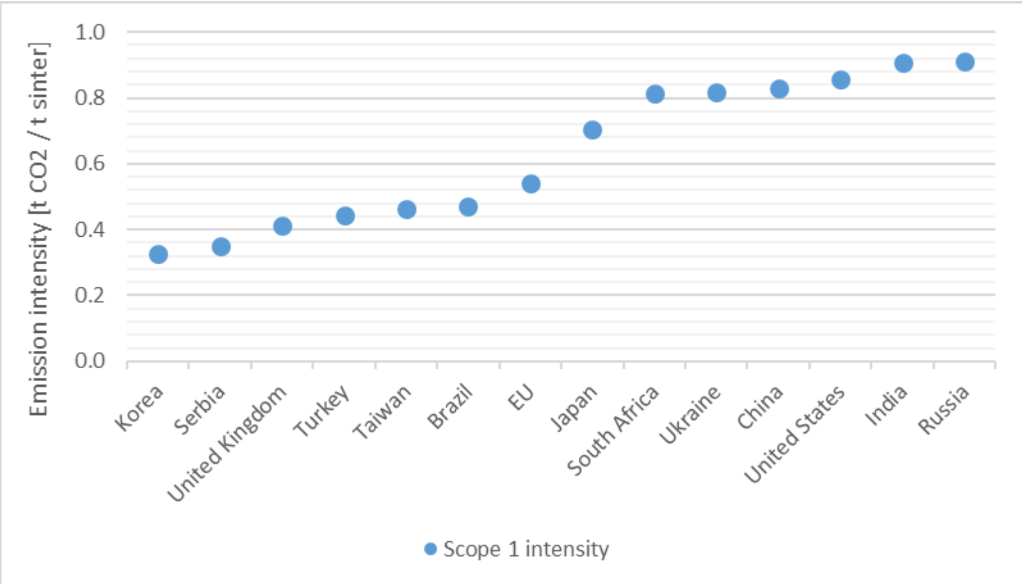
Figure 10: JRC estimates on the coke process step carbon intensity.



Note: The methodology for deriving the JRC estimates treats waste gases like any other energy product, and therefore does not follow the ETS guidelines on the attribution of emissions for the production and use of waste gases. For comparison, JRC ETS estimates presented in Chapter 5 do apply the ETS guidelines.

Source: JRC.

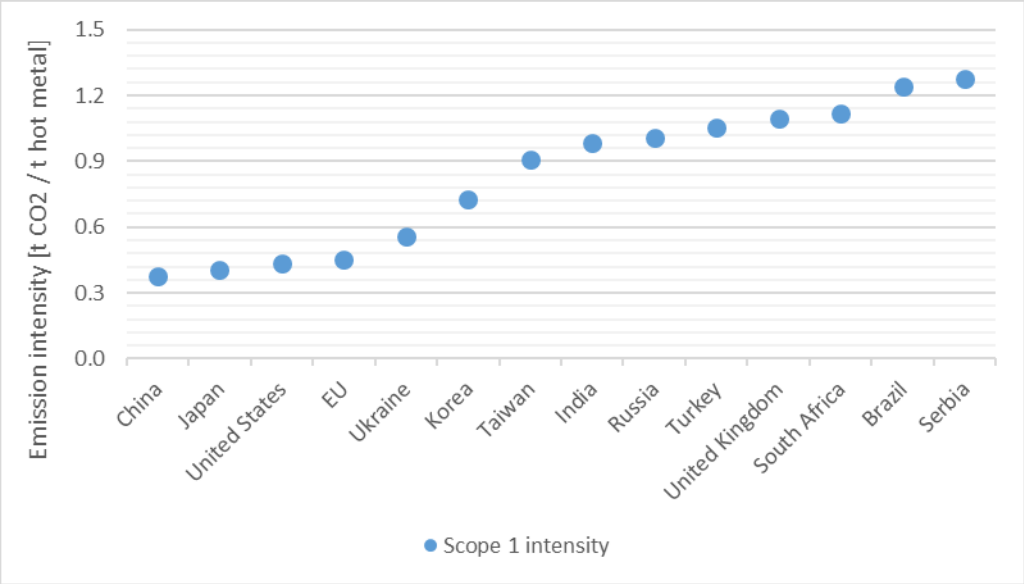
Figure 11: JRC estimates on the sinter process step carbon intensity.



Note: The methodology for deriving the JRC estimates treats waste gases like any other energy product, and therefore does not follow the ETS guidelines on the attribution of emissions for the production and use of waste gases. For comparison, JRC ETS estimates presented in Chapter 5 do apply the ETS guidelines.

Source: JRC.

Figure 12: JRC estimate on the hot metal process step carbon intensity.



Note: The methodology for deriving the JRC estimates treats waste gases like any other energy product, and therefore does not follow the ETS guidelines on the attribution of emissions for the production and use of waste gases. For comparison, JRC ETS estimates presented in Chapter 5 do apply the ETS guidelines.

Source: JRC.

5 NIMs and ETS benchmark curves

The EU-ETS directive (European Commission, 2021c) stipulates that free allocation of ETS allowances is based on benchmark values. In short, the directive indicates that the setting of benchmark values takes place via a bottom-up approach, as opposed to the top-down approach followed in this study. Data on GHG intensities per installation are collected for all installations falling under the product benchmark. The benchmark value for a specific product is determined as the average of the 10% most efficient installations, and the number of free allowances is obtained by multiplying the benchmark values with the respective activity levels of the specific installations. All inputs, outputs and related emissions of a sub-installation are assigned to the product benchmark. While there is thus no differentiation in terms of production technology, methods or input sources for a single specific product benchmark, different product benchmarks for the iron and steel industry allow for differentiation between production routes and process steps.

Data collected by the EU Member States and EFTA countries form the basis for benchmark updates and are submitted as part of the National Implementation Measures (NIMs). The data collected in autumn 2019 can serve as comparison with the results in this study. The emissions in the NIMs assigned to the respective sub-installations follow the following formula:

$$Em^{NIM} = Em^{DIR} + Em^{\Delta H} + Em^{\Delta WG} + Em^{\Delta EL} \tag{7}$$

Whereby Em^{NIM} stands for the final emissions for the sub-installation as reported in the NIM, Em^{DIR} are the direct emissions as monitored for the purpose of emission reporting, $Em^{\Delta H}$ are the emissions related to the attribution of net imports of heat, $Em^{\Delta WG}$ are a correction for the net import of waste gases, and finally $Em^{\Delta EL}$ are the net emissions resulting from the exchangeable electricity quantity and the electricity produced in the sub-installation.

The 6 product benchmarks, with fixed definitions of their system boundaries, of specific relevance to the iron and steel sector, are reported in Table 3.

Table 3. No. of benchmark and sub-installation name as reported in the NIMs, of relevance to the iron and steel sector.

BM	Sub-installation
(2)	Coke
(3)	Sintered ore
(4)	Hot metal
(5)	EAF carbon steel
(6)	EAF high alloy steel
(7)	Iron casting

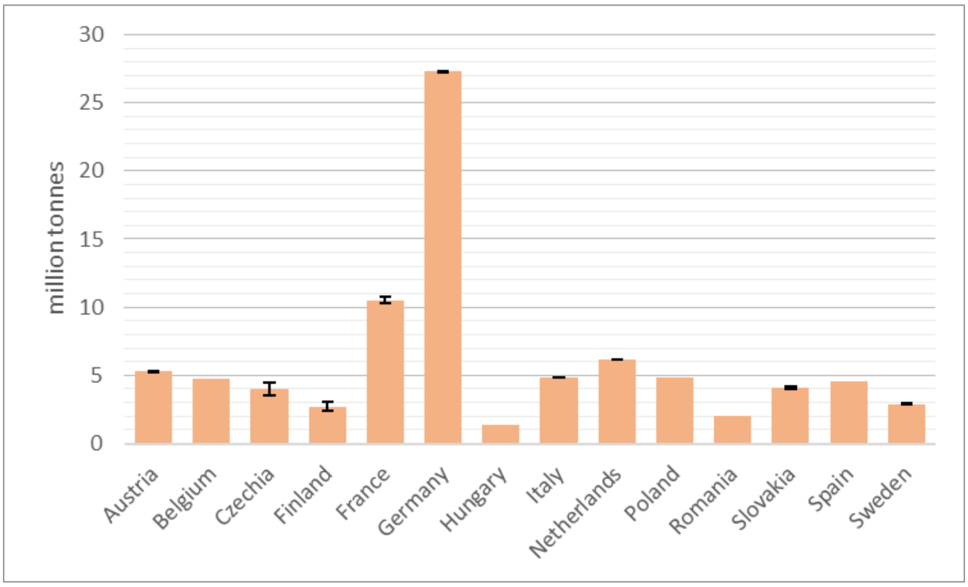
Source: JRC (NIM).

5.1 Comparison with the NIMs

In the following we discuss how our scope 1 emission estimates for the process steps compare with the emission values reported in the NIMs for the respective sub-installations. In order to compare carbon intensities per sub-installation, we compare both production volumes, named Historic Activity Levels (HAL), and CO_2 emissions, named Attributed Emissions. As the data is collected on a confidential basis in the context of the NIMs, we do not report any absolute differences but only indicate, making use of whiskers, the relative maximum difference with our estimated result.

Although carbon intensities are typically reported per tonne of crude steel, the emissions under the hot metal product benchmark include all emissions related to the process steps from the blast furnace to the production of crude steel. Therefore the HAL volumes as reported by the NIMs are compared to the production volumes of the intermediate product hot metal obtained from Worldsteel (2020). Figure 13 reports the production volumes of hot metal. We find that of the 14 EU Member States producing hot metal, eight countries report the exact same HAL volume and four countries are within a 2% difference. The Czech Republic and Finland show, in relative terms, the largest differences, with production volumes differing by approximately 10% from the reported HAL volumes.

Figure 13: Production levels of hot metal (pig iron). Whiskers indicate max. deviation from the NIM historic activity levels.



Source: JRC (Worldsteel (2021), NIM).

In order to compare total CO_2 emissions related to the production of crude steel, it is important to understand the methodological differences of our approach regarding the attribution of emissions for the production and use of waste gases. The regulation on the determination of rules for harmonised free allocation of emission allowances states that the emissions from waste gases are split in two parts, except when they are used in the same product benchmark sub-installation as where they are produced (European Commission, 2019). This means that waste gases imported from another sub-installation are treated differently from when the waste gas is used within the sub-installation. More precisely, when the waste gas is exported to another product benchmark sub-installation, the amount of emissions assigned to the production of the waste gas within the producing sub-installation equals:

$$Em^{WG} = E_{WG}\,(EF_{WG} - EF_{NG}.\eta) \tag{7}$$

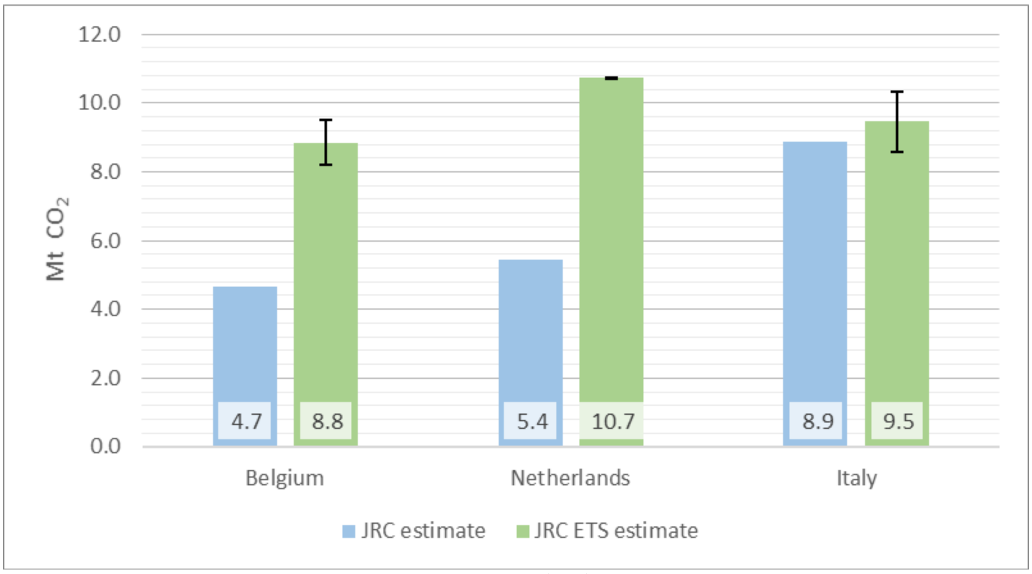
Whereby EF_{NG} represents the emission factor of the reference gas, equals 56.1 t CO_2/TJ for natural gas, and η is set to 0.667, a factor that accounts for the difference in efficiencies between the combustion of the waste gas and the reference gas. Naturally, by inserting this relative component into the equation, comparing the emissions from the waste gas to the emissions of the reference gas, the results differ from our methodical approach, which estimates absolute emissions according to equation (4).

The regulation further stipulates that the emissions assigned to the consumption of the waste gas are determined by multiplying the calorific value of the imported waste gas by the value of the fuel benchmark. This is done to avoid any technology differentiation amongst imported waste gases. In the current update of the benchmark values for the period of 2021-2025 (European Commission, 2021d), this value is set to 42.6 t CO_2/TJ. Although for the current analysis, with reference year 2018, a value of 56.1 t CO_2/TJ is applied, it is worth noting that altering the emission factor for the fuel benchmark from the reference gas would induce further differences from our methodological approach as described.

Figure 14 visualises the total CO_2 emissions from the three integrated route sub-installations, coke (2), sintered ore (3) and hot metal (4). The JRC estimates follow our methodological approach, while the JRC ETS estimate specifies emissions after applying the rationale described above to the attribution of emissions for the production and use of waste gases. For this analysis, we focus on the integrated steel facilities in Belgium, the Netherlands and Italy as these countries present a significant production of crude steel and allow a straightforward comparison, having only a single facility in the integrated route. We observe significant differences between both estimates across all sub-installation products. Indeed the IPCC puts forward an emission factor for blast furnace gas of 260 t CO_2/TJ and 44.4 t CO_2/TJ for coke oven gas. For the product benchmark sub-installation exporting blast furnace gas, a significant proportion of the emissions related to the waste gas remains at the facility, as the calorific value is multiplied by a positive factor (260 t CO_2/TJ - 56.1 t CO_2/TJ * 0.667). For the product benchmark sub-installation importing blast furnace gas, a significant proportion of emissions is not attributed to the facility, as the fuel benchmark is significantly lower than the indicated blast furnace waste gas emissions factor. Although the reasoning also holds for the waste gas categories of coke oven gas and other recovered gases, the effect is less pronounced, as the emission factors are closer to the emission factor of the reference gas and the fuel benchmark.

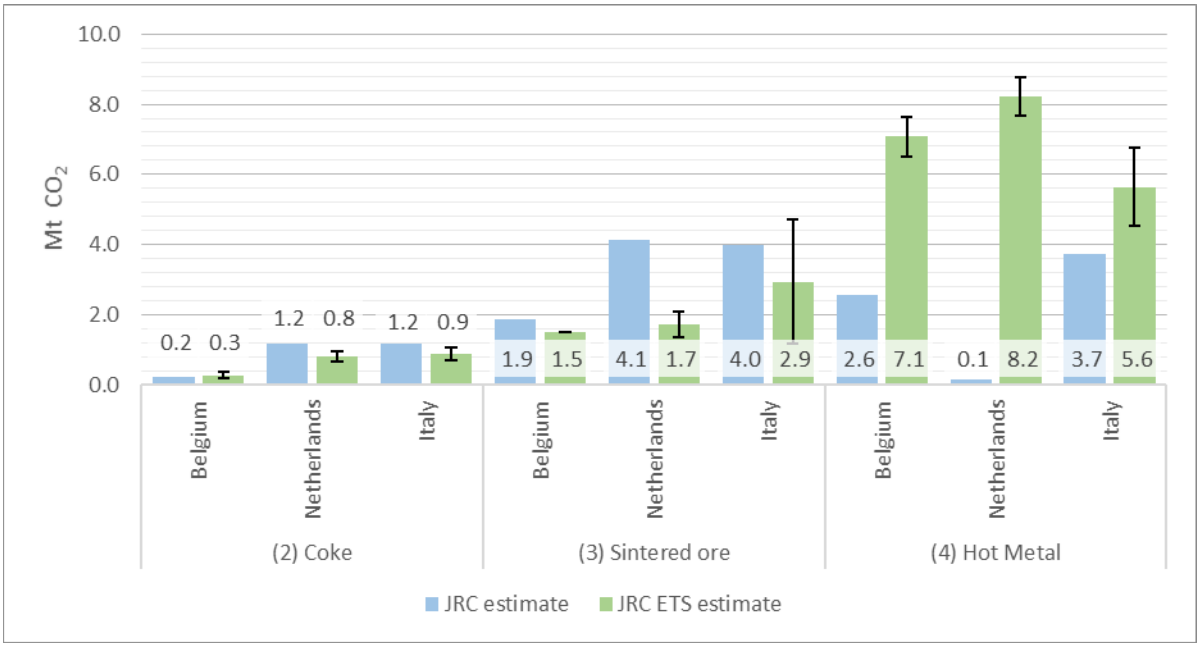
After taking into account the differences with respect to waste gases, the whiskers indicate a relatively favourable comparison between the estimates and the total integrated route emissions as reported by the NIMS. The maximal differences are approximately 10% of the total emissions, but the Netherlands, for example, report almost no difference.

Figure 14: Total CO_2 emissions for the integrated route. JRC estimates follow the outlined methodology, while the JRC ETS estimate specifies emissions after applying the ETS rationale as described to the attribution of emissions for the production and use of waste gases. Whiskers indicate max. deviation from the emissions reported under the NIMs.



Source: JRC (NIM).

Figure 15: CO_2 emissions per ETS sub-installation. JRC estimates follow the outlined methodology, while the JRC ETS estimate specifies emissions after applying the ETS rationale as described to the attribution of emissions for the production and use of waste gases. Whiskers indicate max. deviation from the emissions reported under the NIMs.



Source: JRC (NIM).

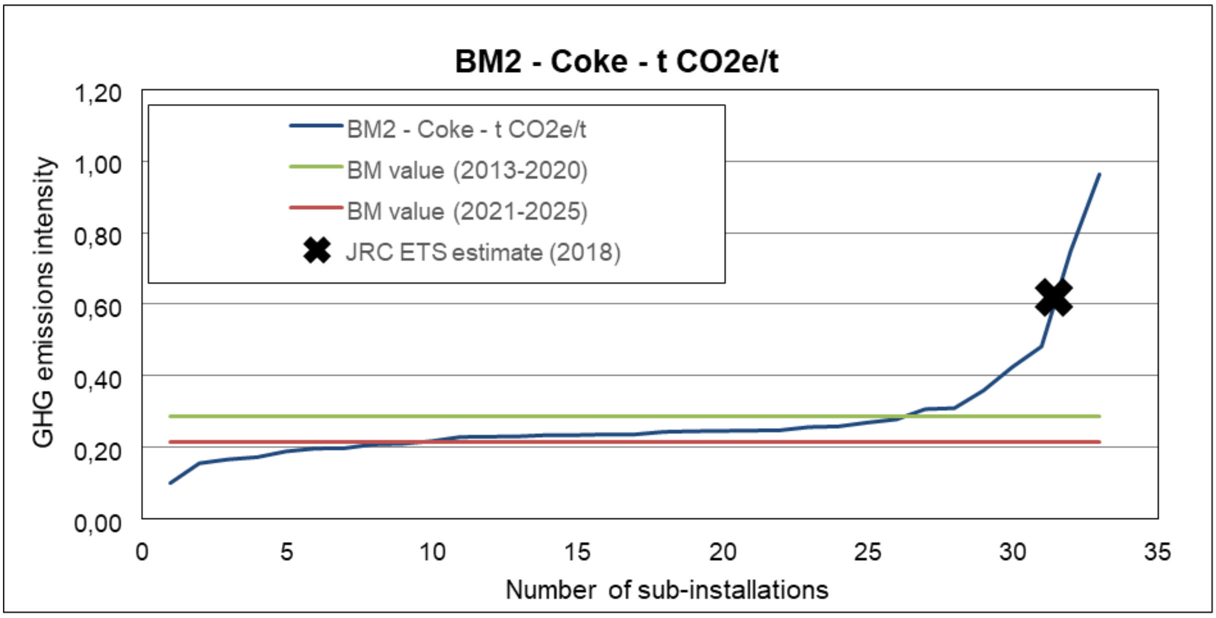
Figure 15 visualises the CO_2 emissions per sub-installation. As above, we observe relatively large differences between both estimates, related to the allocation of waste gases. Following the methodology applied in the NIMs, we find our estimates for Belgium and the Netherlands to approach the actual NIM values, with reported emission differences for all product benchmarks below 0.5 Mt. In terms of relative differences, the comparison yields the best results for the sinter and hot metal product benchmarks. We find a relative poor comparison for Italy, with high relative differences for all product benchmarks. As the current single integrated steel facility (Taranto) could be mixed into the statistics with a recently closed facility (Trieste), this highlights the importance of data validation in the aggregated statistics.

5.2 Comparison with the ETS benchmark curves

Finally, we compare the 2018 JRC ETS estimates for these three products with the published benchmark curves by the European Commission (2021e), based on the years 2016/2017. We plot the JRC ETS estimate of the EU emission intensity for coke, sinter and hot metal on the published benchmark curves, respectively, in Figures 16, 17 and 18.

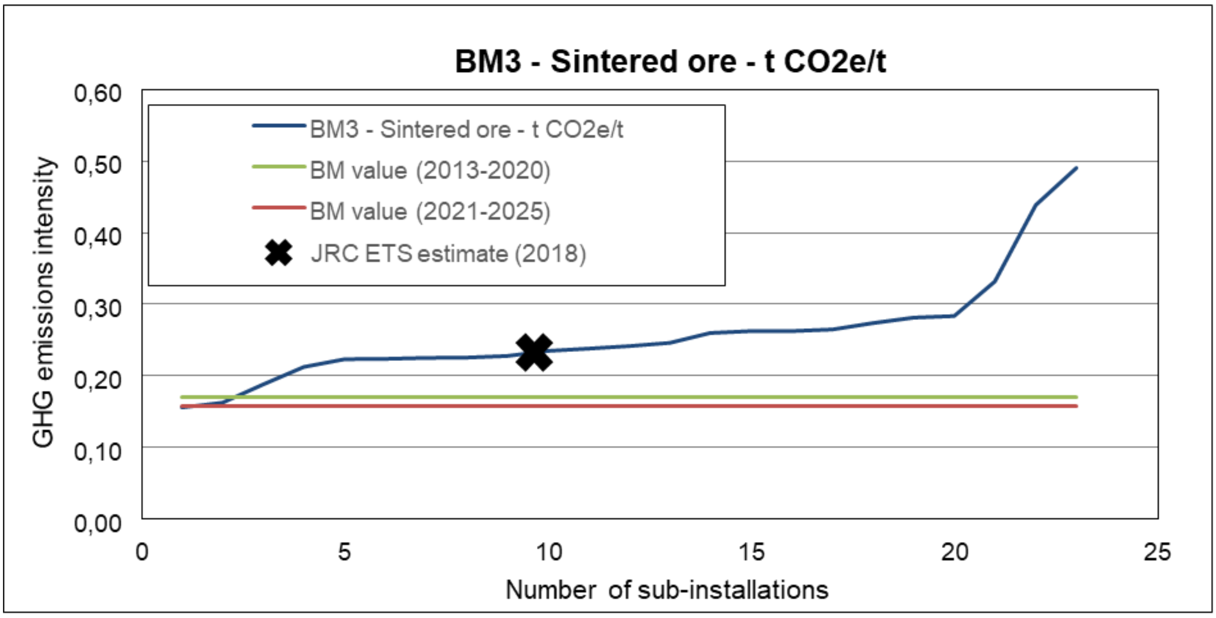
We find our estimate for the coke sub-installation to be at the higher end of the benchmark curve. Note that as absolute emissions for this sub-installation are, as indicated, relatively low, differences with the aggregated statistics may result more quickly in deviations between the emission intensity estimates. For the sub-installations sinter and hot metal, the JRC ETS estimates approach the published weighted average emission intensities very well, with absolute differences remaining below 6%. These results therefore suggest that the difference with respect to the published value of the coke sub-installation are due to deviations in the aggregated statistics, rather than methodological differences.

Figure 16: Comparison of the 2018 JRC ETS emission intensity estimate with the 2016/2017 benchmark curve for the coke sub-installation.



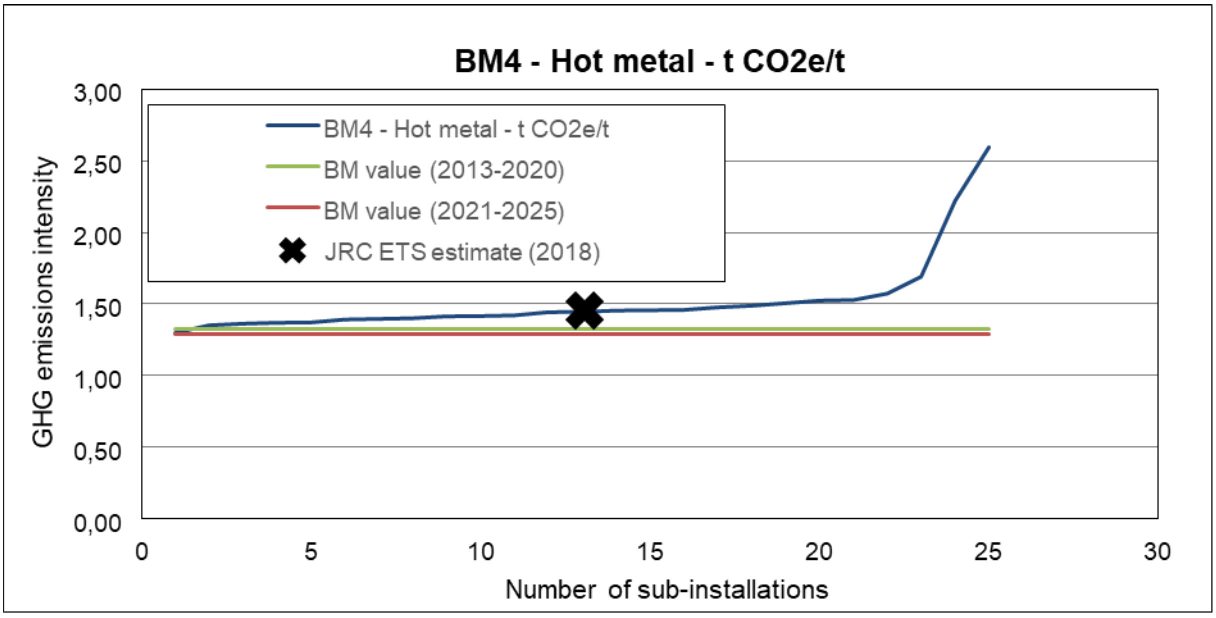
Source: JRC (based on European Commission, 2021e).

Figure 17: Comparison of the 2018 JRC ETS emission intensity estimate with the 2016/2017 benchmark curve for the sinter sub-installation.



Source: JRC (based on European Commission, 2021e)

Figure 18: Comparison of the 2018 JRC ETS emission intensity estimate with the 2016/2017 benchmark curve for the hot metal sub-installation.



Source: JRC (based on European Commission, 2021e)

6 Conclusions

This report studies CO_2 emission intensities in the iron and steel sector of the EU and its global trading partners. We apply a top-down approach, drawing on publicly available datasets, and develop a transparent methodology to disaggregate emissions and estimate emission intensities of specific production routes and process steps. The proposed methodology may be replicated to other geographical and temporal scopes, and creates a basis for estimating greenhouse gas intensities in other energy-intensive industries.

We analyse iron and steel GHG intensity, making use of aggregated statistical data for the EU and 16 major steel-producing countries that account for over 90% of steel imports to the EU. We apply energy process balances to disaggregate, in a relative manner, the data into estimates of GHG intensities of production routes and process steps, ensuring methodological consistency across the results. The developed methodology further allows differentiation between scope 1, scope 2 and upstream estimates and indicates the importance of accounting for net imports of intermediate products in estimating GHG intensities, taking into account the significant global trade of intermediate products in the iron and steel sector.

We find that the proposed top-down approach enables the estimation of total GHG intensities with a relatively low error margin for the iron and steel industry. The accuracy of GHG intensity estimates for production routes and process steps may, however, reduce with every disaggregation step. Where energy products are largely unrelated across production routes but more similar across process steps, the former typically yields estimates with a higher certainty. The results for the process steps should therefore be interpreted to give a general indication of the relative emission intensity.

Following the proposed top-down methodology, we can compare carbon intensities of the iron and steel production routes and process steps in the EU and its 16 major global trading partners. For the integrated route, we find that the EU and China report the lowest emission intensities, whereas India and South Africa are at the higher end of the spectrum. The latter two countries also present high carbon intensities for the secondary route, mainly driven by high scope 2 emissions. The emissions intensities of the process steps in the integrated route follow a similar pattern, where relative differences may be explained on the basis of primary energy resources and plant efficiencies. We also find some particularities in the publicly available datasets and note that the accuracy of the results depends on the quality and precision of the aggregated statistics.

The published values in the ETS benchmark curves allow to validate our estimates for EU Member States. Accounting for methodological differences in the attribution of emissions for the production and use of waste gases, we find absolute differences to be low. Especially for the sinter and hot-metal sub-installations, the estimates match the published values very well.

The insights from this study are directly relevant to the knowledge framework around the risk of carbon leakage in the wider context of the European Green Deal, and can be used to support the implementation of default values within the framework of the Carbon Border Adjustment Mechanism.

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List of abbreviations and definitions

BF	Blast Furnace
BKB	Brown Coal Briquettes
BOF	Basic Oxygen Furnace
CBAM	Carbon Border Adjustment Mechanism
EAF	Electric Arc Furnace
ETS	Emission Trading System
DRI	Direct Reduced Iron
EEA	European Environment Agency
GHG	Greenhouse Gas
HAL	Historic Activity Level
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
JRC-IDEES	Joint Research Centre Integrated Database of the European Energy Sector
NIM	National Implementation Measure
OHF	Open Hearth Furnace
UNFCCC	United Nations Framework Convention on Climate Change

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Annexes

Annex 1. Mapping of extended world energy balance energy products and respective IPCC emission factors

Table A1. Mapping of IEA energy products (IEA, 2021a) and corresponding IPCC emissions factors (IPCC, 2021).

Energy Product (IEA)	Emission Factor (tCO_2/TJ) (IPCC)	Energy Product (IEA)	Emission Factor (tCO_2/TJ) (IPCC)
Crude Oil	73,3	Sub-Bituminous Coal	96,1
Natural Gas Liquids	64,2	Lignite	101,0
Motor Gasoline excl. biofuels	69,3	Oil Shale and Oil Sands	107,0
Aviation Gasoline	70,0	Brown coal briquettes (BKB)	97,5
Gasoline type Jet Fuel	70,0	Patent Fuel	97,5
Kerosene type Jet Fuel	71,5	Coke Oven Coke	107,0
Other Kerosene	71,9	Gas Coke	107,0
Gas/Diesel Oil excl. biofuels	74,1	Coal Tar	80,7
Fuel Oil	77,4	Gas Works Gas	44,4
Liquefied Petroleum Gases (LPG)	63,1	Coke Oven Gas	44,4
Ethane	61,6	Blast Furnace Gas	260,0
Naphtha	73,3	Other Recovered Gases	182,0
Bitumen	80,7	Natural Gas	56,1
Lubricants	73,3	Municipal Waste (non-renewable)	91,7
Petroleum Coke	97,5	Industrial Waste	143,0
Refinery Feedstocks	73,3	Peat	106,0
Refinery Gas	57,6	Primary Solid Biofuels	100,0
Paraffin Waxes	73,3	Charcoal	112,0
White Spirit & SBP	73,3	Biogasoline	70,8
Other Oil Products	73,3	Biodiesels	70,8
Anthracite	98,3	Other Liquid Biofuels	79,6
Coking Coal	94,6	Biogases	54,6
Other Bituminous Coal	94,6	Municipal Wastes (renewable)	100,0

Source: JRC (IEA (2021), IPCC (2021)).

Annex 2. Energy process balance

Table A2. Net energy process balance per process step in the iron and steel industry (Moya et al., 2013)

		Total	**Coke**	**Coal**	**Tar**	**Benzole**	**Electricity**	**Steam**	**Natural gas**	**Coke oven gas**	**Blast furnace gas**	**BOS gas**
Coke plant	GJ/t coke	6.54	-30.10	42.08	-1.28	-0.48	0.12	0.26	0.00	-5.83	1.77	0.00
Sinter plant	GJ/t sinter	1.55	1.37	0.00	0.00	0.00	0.09	0.00	0.09	0.00	0.00	0.00
Pellet plant	GJ/t pellet	0.90	0.33	0.00	0.00	0.00	0.14	0.00	0.43	0.00	0.00	0.00
Blast furnace	GJ/t hot metal	12.31	10.33	4.15	0.00	0.00	0.16	0.42	0.00	0.32	-3.07	0.00
BOS plant	GJ/t semis	0.12	0.00	0.00	0.00	0.00	0.12	-0.22	0.23	0.00	0.00	0.00
DRI-EAF	GJ/t semis	12.25	0.00	0.48	0.00	0.00	2.07	0.00	9.70	0.00	0.00	0.00
Rotary-EAF	GJ/t semis	26.68	0.00	24.40	0.00	0.00	1.98	0.00	0.30	0.00	0.00	0.00
Electric arc furnace	GJ/t semis	2.50	0.00	0.48	0.00	0.00	1.73	0.00	0.30	0.00	0.00	0.00

Source: JRC (Moya et al., 2013).

Annex 3. CO_2 emission intensity results

Table A3. CO_2 emission intensity of the entire iron and steel industry in tonne CO_2 per tonne steel.

	Scope 1 & Upstream	Scope 1	Scope 2	Total*
EU	1.04	1.03	0.11	1.15
Belarus	0.07	0.07	0.26	0.33
Brazil	1.71	1.83	0.04	1.75
China	1.58	1.58	0.12	1.70
India	2.70	2.86	0.28	2.97
Japan	1.55	1.55	0.14	1.69
Korea	1.34	1.34	0.16	1.50
Norway	0.44	0.44	0.06	0.50
Russia	1.98	2.12	0.33	2.30
Serbia	1.86	1.39	0.25	2.11
South Africa	2.82	2.96	1.29	4.11
Switzerland	0.08	0.08	0.02	0.10
Taiwan	1.23	1.25	0.18	1.41
Turkey	0.70	0.65	0.18	0.88
Ukraine	2.13	2.23	0.20	2.33
United Kingdom	1.60	1.45	0.05	1.65
United States	0.68	0.70	0.21	0.90

**Total = Scope 1 & Upstream + Scope 2*

Source: JRC.

Table A4. CO_2 emission intensity per production route in tonne CO_2 per tonne steel.

	Integrated route				EAF route			
	Scope 1 & Upstream	Scope 1	Scope 2	Total*	Scope 1 & Upstream	Scope 1	Scope 2	Total*
EU	1.77	1.76	0.04	1.81	0.04	0.04	0.20	0.24
Belarus					0.07	0.07	0.26	0.33
Brazil	2.19	2.34	0.03	2.21	0.05	0.05	0.07	0.12
China	1.76	1.76	0.08	1.84	0.03	0.03	0.49	0.52
India	3.72	4.08	0.11	3.83	0.07	0.07	0.38	0.45
Japan	2.05	2.05	0.07	2.12	0.04	0.04	0.36	0.40
Korea	2.00	2.00	0.05	2.05	0.03	0.03	0.38	0.41
Russia	2.79	3.01	0.21	3.00	0.07	0.07	0.39	0.46
Serbia	2.06	1.54	0.19	2.26	0.06	0.06	0.76	0.82
South Africa	3.57	3.79	0.37	3.94	0.12	0.12	2.62	2.74
Switzerland					0.08	0.08	0.02	0.10
Taiwan	2.02	2.06	0.05	2.07	0.02	0.02	0.39	0.41
Turkey	2.17	2.01	0.03	2.20	0.04	0.04	0.25	0.29
Ukraine	2.30	2.41	0.19	2.49	0.04	0.04	0.35	0.39
United Kingdom	2.05	1.86	0.03	2.08	0.04	0.04	0.13	0.16
United States	1.94	1.99	0.15	2.09	0.04	0.04	0.24	0.27

**Total = Scope 1 & Upstream + Scope 2*

Source: JRC.

Table A5. CO_2 emission intensity of the process steps of the integrated route in tonne CO_2 per tonne of product.

	Coke		Sinter		Pellet		Blast furnace		Basic oxygen furnace			
	Scope 1	Scope 2	Scope 1	Scope 2	Scope 1	Scope 2	Scope 1	Scope 2	Scope 1	Scope 2	Upstream	Total*
EU	0.91	0.01	0.54	0.01	0.06	0.02	0.31	0.01	0.13	0.01	0.00	0.14
Brazil	0.69	0.00	0.47	0.00	0.05	0.01	1.11	0.00	0.14	0.01	0.00	0.14
China	0.84	0.00	0.83	0.03	0.06	0.05	0.27	0.00	0.10	0.04	0.00	0.14
India	1.15	0.01	0.91	0.02	0.06	0.03	0.86	0.00	0.19	0.03	0.00	0.22
Japan	1.00	0.04	0.70	0.02	0.04	0.03	0.30	0.00	0.10	0.02	0.00	0.13
Korea	1.57	0.00	0.33	0.02			0.59	0.00	0.13	0.03	0.00	0.16
Russia	1.11	0.00	0.91	0.09	0.08	0.06	0.88	0.00	0.14	0.04	0.00	0.17
Serbia			0.35	0.11			0.97	0.00	0.28	0.06	0.00	0.34
South Africa									0.16	0.18	0.00	0.35
Taiwan	1.08	0.00	0.46	0.02			0.75	0.00	0.17	0.03	0.00	0.19
Turkey	1.37	0.00	0.45	0.01	0.10	0.02	0.87	0.00	0.17	0.02	0.00	0.19
Ukraine	1.11	0.02	0.82	0.06	0.08	0.05	0.45	0.00	0.12	0.03	0.00	0.15
United Kingdom	1.17	0.00	0.41	0.01			0.84	0.01	0.26	0.01	0.00	0.26
United States	0.88	0.01	0.86	0.02	0.10	0.02	0.37	0.08	0.06	0.02	0.00	0.08

**Total = Scope 1 + Scope 2 + Upstream*

Source: JRC.

Net imports of iron and steel intermediate products

Estimating GHG emission intensities of the intermediate product, coke, is based on data on production, imports, and exports of coke oven coke (IEA, 2020b). While for Russia, IEA data on coke oven coke imports and exports match the UNdata energy statistic database (UNdata, 2022), numbers on the production of coke oven coke differ significantly. Comparing the GHG intensity for the coke oven process with data from commercial sources suggest that the IEA number on coke oven coke production (41 248 kt) should be replaced with the UN data (27 094 kt).

Similarly, analysing pellet GHG intensities is based on data on imports and exports of the intermediate product pellets (UN Comtrade, 2021) for data on imports and exports, and data on national capacities of pelletising plants (Steel Institute VDEh, 2019) for estimating the national production of pellets. Data for Austria and Taiwan are, however, missing in the UN Comtrade database. As there is no pellet plant capacity indicated for these countries in the Plantfacts Capacity Database, data on pellet imports are calculated as weighted averages of pellet consumptions per tonne of steel produced via the integrated route for EU countries for Austria, and for all countries within the geographical scope for Taiwan, multiplied by steel production via the integrated route in the respective countries.

Energy balances

The extended world energy balances (IEA, 2021a) serve as the main input data to the model. The balances allow for a high level of data granularity with respect to the iron and steel industry. Supply, Transformation and own energy use, and Final Energy Consumption form the three main energy flows. The latter block has a specific energy flow related to the iron and steel industry. Within the block of Transformation and own energy Use, specific energy flow information is available on the coke ovens and blast furnaces for both transformation of energy and own energy use of these facilities. This allows for a specific allocation of energy to both processes.

However, for some countries, the world extended energy balances suggest that the allocation between the above energy flows is (partially) missing. China, India, and South Africa report no consumption of blast furnace gas in coke ovens, while India and South Africa report none in autoproduction of electricity. Rather, the data on use of blast furnace gas reported under the iron and steel energy flow suggests that all energy used from this waste gas is reported under this energy flow. For China, we reallocated 33% of blast furnace gas emissions from iron and steel energy flow to coke ovens, based on the calculated weighted average share of blast furnace gas consumption in coke ovens out of the total blast furnace gas consumption in coke ovens and iron and steel energy flow for the remaining countries within the scope. Similarly, for India and South Africa, we reallocated 16% and 41% of blast furnace gas emissions from iron and steel energy flow to coke ovens and autoproduction of electricity, respectively, based on the calculated weighted average share of blast furnace gas consumption in coke ovens and autoproduction of electricity out of the total blast furnace gas consumption in coke ovens, autoproduction of electricity, and iron and steel energy flow for the remaining countries within the scope.

Following the above adjustment for coke oven coke production volume in Russia, we update the consumption of cokes in both the iron and steel and blast furnace energy flow based on the UNdata energy statistic database (UNdata, 2022). We split the UN data on coke oven coke consumption for the pellet plant, sinter plant and blast furnaces based on the energy process balance (Moya and Pardo, 2013). Finally, we adjust the consumption of coking coal consumption accordingly in Russian coke ovens.

KJ-NA-31112-EN-N

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Publications Office of the European Union

doi:10.2760/170198

ISBN 978-92-76-53417-4