Steel Asset-level Emissions Methodology

Date: 14th September 2020

Version: 1.2

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Introduction

Sector background

As an essential material to industrialized economies, global annual steel production has doubled over the past two decades from 850 to 1,808 megatonnes. Rapid industrial growth in China has underpinned the increased steel production. China is now the world's largest producer, accounting for 51% of crude steel production (WSA, 2018).

The steel sector is the largest source of industrial emissions, accounting for 8% of anthropogenic carbon dioxide (CO_2) emissions in 2018 (*World Energy Outlook 2019*, 2019). While the CO_2 intensity of steel production has declined by an annual average of 0.7% from 2010 to 2016, under the International Energy Agency's (IEA) Sustainable Development Scenario (which aims at a temperature rise below 1.8°C) this must rise to an annual rate of 1% until 2030 (IEA, 2017). The manufacturing of steel requires significant amounts of energy. With 75% of steel production fueled with the combustion of coal, deep decarbonization will require ambitious technologies and production methods (IEA, 2017).

Steel manufactures either forge primary- or scrap-steel. Primary steel is produced in integrated steel plants in an open-hearth furnace (OHF) or basic oxygen furnace (BOF). The BOF or OHF is fed pig iron reduced in a blast furnace (BF) (de Beer et al., 2003; IEA, 2017). BFs emit 70% of the emissions in primary steel production. In a scrap-based plant, the steel is produced in an electric arc furnace (EAF) fed by recycled steel. EAFs reduce scrapped steel (or hot metal reduced via direction reduction furnace) to produce crude steel with electrodes. With the electricity as the primary energy source (45% of emissions), the carbon intensity of the electricity grid plays a critical role in reducing the CO_2 intensity of scrap steel production (de Beer et al., 2003). Globally integrated steel plants and scrap-based mini-mill plants account for 70% and 30% of global production respectively (WSA, 2018).

While the forging of scrap-steel (0.6-0.9 tonnes CO_2 per tonne steel) emits less CO_2 than primary steel (1.6-2.2 tonnes CO_2 per tonne steel), the global demand for steel exceeds the supply of recycled steel. Primary-steel can also be produced in an EAF using directed reduced iron (DRI), which requires less energy than a BF. The process can be decarbonized by introducing hydrogen (produced via electrolyse) as the reducing agent, instead of gas or coal. While this process is not yet commercial ready, a few demonstration projects are underway ("HYBRIT - Fossil-Free Steel," 2020).

Document structure

The 2° Investing Initiative (2DII) developed open source methodologies to calculate CO_2 emissions at the level of an individual asset for eight sectors (aviation, automotive, power, oil & gas, coal, shipping, cement, and steel).

This document describes the methodology step by step and suggests sources of data that can be used to apply the methodology to calculate asset-level CO_2 emissions in the steel sector. The data sources are publicly available to the extent possible. The asset-level capacity and/or production values are however still largely unavailable in the public domain.

2DII works with its data spin off Asset Resolution (AR) to source asset-level capacity and/or production values and calculate asset-level emissions in the context of its research. AR sources asset-level data from leading industry data providers and carries out complementary research in house. This document gives insights into this asset-level data. Alternative sources can be used provided they comply with the data specifications as set out in the methodology.

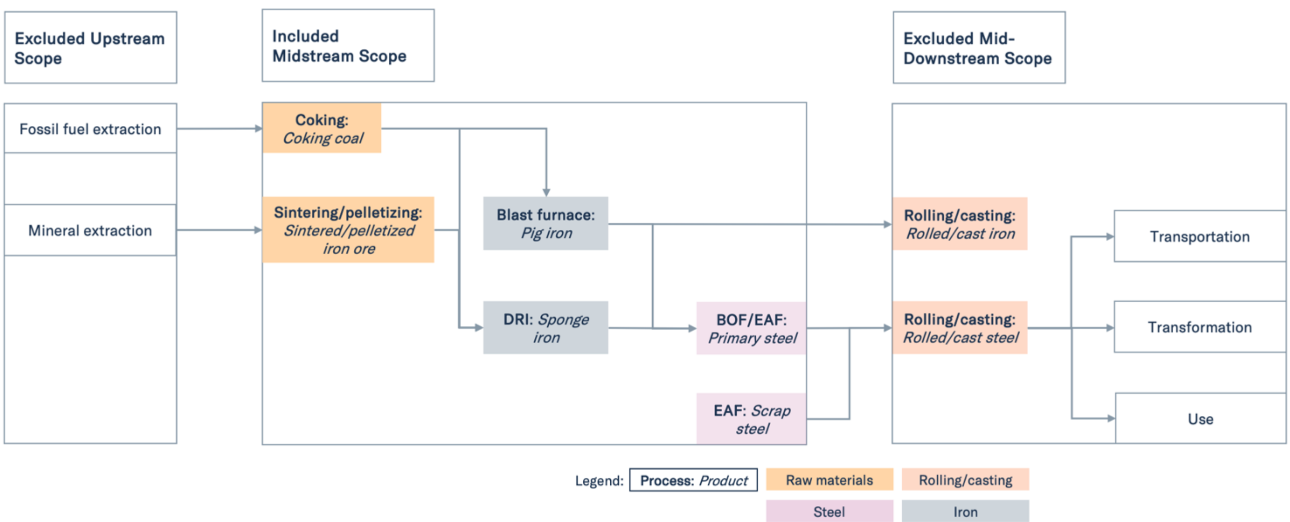
Asset Definition

In each stage of the steel sector's value-chain, under intensive temperatures and processes, the impurities of iron ore, the primary feedstock, are discarded and other elements such as nickel and manganese are added to form a more robust product, steel. Other than the sourcing of raw materials, e.g., coal and iron ore mining, all of these processes are often integrated into a single plant. However, the level of integration of the processes and the steel making technologies may vary from plant to plant. Likewise, the inputs and outputs of each plant are not zero-sum. A plant's coking furnace (CF) can feed the plant's BF, but any surplus coking coal could be diverted and sold for other industrial purposes (de Beer et al., 2003).

To account for this fact, for the steel sector, an asset is defined as a process within a steel plant (see Figure 1.1). Under the emission methodology the production values of crude steel are required, so the production is rolled-up at the level of the raw steel production, i.e., the technologies in Table 1.1. This means that only the *net-materials* and *net-energy* inputs required to produce the asset's crude steel are considered and not the plant's total material and energy consumption and production.

Figure 1.1: Steel Value-chain Scope

Description: The following chart illustrates the steel value chain process are necessary to include in the asset-level data and emissions modeling. The middle-box details the midstream processes covered in the emission methodology, while the right and left-hand boxes layout the down and upstream process that remain out of scope



Source: Authors, 2020 based on de Beer et al., 2003

The emission methodology is developed to calculate the scope 1 and 2 emission factor and absolute emissions for a steel plant (see Table 1.2). The methodology focuses on the most energy and emission intensive steel processes (see Table 2.2) — coal coking, iron ore sintering, hot metal production, and crude steel production.

The methodology does *not* calculate scope 1 and 2 emissions from the rolling and casting of steel. Likewise, the methodology does *not calculate* scope 3 emissions from raw material extract or the steel product's life-cycle use.

Table 1.2: Asset Definition

Indicator	Definition
Parameter	Asset definition
Unit	Steel plant
Denotation	Asset *i* (Technology) with process *j* (Technology Type)
Technology	AC Electric Arc Furnace, DC Electric Arc Furnace, Basic Oxygen Furnace, and Open Hearth Furnace
Technology Type	Coal Coking, Iron Ore Sintering, Hot-metal Production, and Crude Steel Production
Identifier	Unique plant location, operator, and name identifier
Source	Asset Resolution, based on various sources including PlantFacts (VEDh, 2018)

Nonetheless, the production can also be rolled-up at the level of other products if other technologies are of interest, e.g. Direct Reduction (see in the Table 1.2). In this case it is important to know that the aggregated production values of the different products should not be combined as they refer to different products.

Table 1.3: Steel Sector Products

Technology	Product
Direct Reduction Furnace (DRI)	Sponge Iron
Pelletizing	Iron Pellets
Sintering	Iron Sinter
Blast Furnace (BF)	Pig Iron
Basix Oxygen Furnace (BOF)	Steel
AC Electric Arc Furnace (AC EAF)	Steel
DC Electric Arc Furnace (DC EAF)	Steel
Open Hearth Furnace (OHF)	Steel
Coking Furnace (CF)	Coking Coal

Asset-Level Emissions Model

Asset Annual Emissions

The emissions for asset *i* for year *y* are calculated as:

$$\text{Asset emissions}_{\,i}\left[\frac{\text{t CO}_2}{\text{year}_{\,y}}\right] = \text{Asset EF}_{\,i}\left[\frac{\text{t CO}_2}{\text{t Steel}}\right] * \text{Production}_{\,i}\left[\frac{\text{t Steel}}{\text{year}_y}\right]$$

Where:

- $\text{Production}_{\,i}$ = tonnes of crude steel production per year (see Asset Production).
- $\text{Asset EF}_{\,i}$ = emission factor per tonne of crude steel (see Asset Emission Factor).

Asset Emission Factor

The emission factor per tonne of crude steel for final and intermediary steel making processes for asset *i* is calculated as:

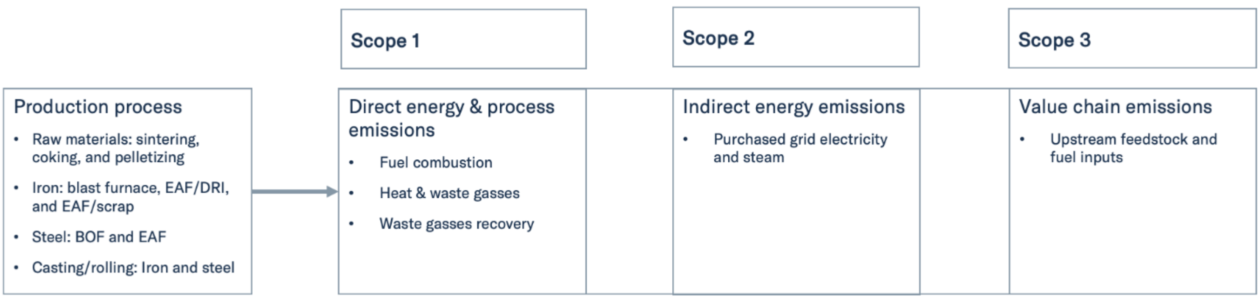
$$\text{Asset EF}_{\,i}\left[\frac{\text{t CO}_2}{\text{t Steel}}\right] = \underbrace{\text{Steel EF}_{\,i}\left[\frac{\text{t CO}_2}{\text{t Steel}}\right]}_{\text{Final process}} + \underbrace{\text{Hot metal EF}_{\,i}\left[\frac{\text{t CO}_2}{\text{t Steel}}\right] + \text{Coke EF}_{\,i}\left[\frac{\text{t CO}_2}{\text{t Steel}}\right] + \text{Sinter EF}\left[\frac{\text{t CO}_2}{\text{t Steel}}\right]}_{\text{Intermediary processes}}$$

Where:

- $\text{Steel EF}_{\,i}$ = CO_2 emitted per tonne steel for the forging of crude steel.
- $\text{Hot metal EF}_{\,i}$ = CO_2 emitted per tonne of steel for hot metal production.
- $\text{Coke EF}_{\,i}$ = CO_2 emitted per tonne of steel for coke production.
- $\text{Sinter EF}_{\,i}$ = CO_2 emitted per tonne of steel for sinter production.

Figure 2.1: Scope definitions

Description: For each process, the primary sources of emissions are identified and scoped according to standard greenhouse gas (GHG) protocol definitions (GHG Protocol Initiative, 2008).



Source: Authors, 2020 based on de Beer et al., 2003; GHG Protocol Initiative, 2008

When estimating an asset's crude steel emission factor, the proceeding processes such as the forging of hot metal in BF or the coking of coal in CF are considered. In an integrated facility, this does not cause any methodological issues. In a facility where intermediary products are sourced from various providers, it may be considered unfair to allocate all emissions to the producer of the final product, crude steel.

Asset Production

The production for asset i for year y is calculated as follows:

$$\text{Production}_{\,i}\left[\frac{\text{t Steel}}{\text{year}_{\,y}}\right] = \text{Capacity}_{\,i}\left[\frac{\text{t Steel}}{\text{year}_{\,y}}\right] * \text{Utilization factor}_{\,i}\left[\%_{\,y}\right]$$

Where:

- $\text{Capacity}_{\,i}$ = annual capacity of asset i.
- $\text{Utilization factor}_{\,i}$ = annual utilization factor of asset i.

To calculate a steel asset's annual emissions, it is necessary to either to estimate or use the actual steel production of the asset. Due to the sensitivity and challenges of collecting a global database of asset-wise production figures, the methodology estimates production using average utilization factors. The granularity of the utilization factors will vary depending on the quality and breadth of the data source(s). For each asset, the most precise utilization factor should be applied.

Table 2.2: Capacity

Indicator	Definition
Parameter	Capacity
Unit	Tonnes steel per year
Description	Annual capacity of asset *i*
Identifier	Unique plant location, operator, and name identifier
Value applied	e.g., 12000
Granularity	Asset-level
Source	Asset Resolution, based on various sources including PlantFacts (VEDh, 2018)

Table 2.3: Utilization Factor

Indicator	Definition
Parameter	Utilization factor
Unit	Tonnes of steel per year per tonne of steel capacity per year
Description	Annual utilization factor of asset *i*
Identifier	*NA*
Value applied	e.g., 65%
Granularity	Country, regional, and global averages.
Source	*Steel Statistical Yearbook 2018* (WSA, 2018)

Crude Steel Emission Factor

The emission factor for the production of crude steel for asset *i* is calculated as:

$$\text{Steel EF}_i \left[\frac{\text{t CO}_2}{\text{t Steel}}\right] = \text{Fuel EF}_{ij} \left[\frac{\text{t CO}_2}{\text{t Steel}}\right] + \text{Electricity EF}_{ij} \left[\frac{\text{t CO}_2}{\text{t Steel}}\right]$$

Where:

- Fuel EF_{ij} = fuel combustion emission factor (see Fuel Emission Factor).
- $\text{Electricity EF}_{ij}$ = electricity generation emission factor (see Electricity Emission Factor).

Hot Metal Emission Factor

The emission factor for the production of hot metal for asset *i* is calculated as:

$$\text{Hot metal EF}_i \left[\frac{\text{t CO}_2}{\text{t Steel}}\right] = \left(\text{Fuel EF}_{ij} \left[\frac{\text{t CO}_2}{\text{t Hot metal}}\right] + \text{Electricity EF}_{ij} \left[\frac{\text{t CO}_2}{\text{t Hot metal}}\right]\right) * \text{Hot metal CF}_i \left[\frac{\text{t Hot metal}}{\text{t Crude steel}}\right]$$

Where:

- Fuel EF_{ij} = fuel emission factor (see Fuel Emission Factor).
- $\text{Electricity EF}_{ij}$ = electricity emission factor (see Electricity Emission Factor).
- Hot metal CF_i = tonnes of hot metal per tonne of crude steel.

The consumption factor of the hot metal process for asset *i* is calculated as:

$$\text{Hot metal CF}_i \left[\frac{\text{t Hot metal}}{\text{t Crude steel}}\right] = \text{Mass adjustment}_i \left[\frac{\text{t Hot metal}}{\text{t Crude steel}}\right] * \left(1 - \text{Scrap ratio}_i \left[\frac{\text{t Scrap steel}}{\text{t Crude steel}}\right]\right)$$

Where:

- Scrap ratio_i = tonnes scrap steel per tonne crude steel.[2]
- Mass adjustment_i = tonnes of hot metal per tonne of crude steel.[3]

Table 2.4: Scrap Ratio

Indicator	Definition
Parameter	Scrap ratio
Unit	Tonnes scrap steel per tonne crude steel
Scope	Scope 1
Description	Share of scrap steel per tonne of crude steel for asset *i*
Identifier	*NA*
Value applied	0.95 (primary steel) and 0 (scrap steel)
Granularity	Global average by technology
Source	*NA*

[2] E.g., a scrap-EAF would have a ratio 0 to adjust for absence of hot metal, coke, and sinter in the forging of recycled steel.

[3] E.g., tonnes hot-metal needed to produce a tonne of crude steel (WSA, 2020).

Table 2.5: Mass Adjustment

Indicator	Definition
Parameter	Mass adjustment
Unit	Tonnes product per tonne steel
Scope	Scope 1
Description	Consumption of intermediary products (i.e., coke, sinter, and hot metal) for the production of crude steel for asset *i*
Identifier	*NA*
Value applied	e.g., 1.2
Granularity	Global average
Source	*Raw Materials* (WSA, 2020)

Coke Emission Factor

The emission factor for the production of coke for asset *i* is calculated as:

$$\text{Coke EF}_i\left[\frac{\text{t CO}_2}{\text{t Steel}}\right] = \left(\text{Fuel EF}_i\left[\frac{\text{t CO}_2}{\text{t Coke}}\right] + \text{Electricity EF}_i\left[\frac{\text{t CO}_2}{\text{t Coke}}\right]\right) * \text{Coke CF}_i\left[\frac{\text{t Coke}}{\text{t Crude steel}}\right]$$

Where:

- Fuel EF_i = fuel emission factor (see Fuel Emission Factor).
- Electricity EF_i = electricity emission factor (see Electricity Emission Factor).
- $\text{Coke CF}_i = \text{tonnes coke per tonne of crude steel}$

The consumption factor of the coking process for asset *i* is calculated as:

$$\text{Coke CF}_i\left[\frac{\text{t Coke}}{\text{t Crude steel}}\right] = \text{Mass adjustment}_i\left[\frac{\text{t Coke}}{\text{t Crude steel}}\right] * \left(1 - \text{Scrap ratio}_i\left[\frac{\text{t Scrap steel}}{\text{t Crude steel}}\right]\right)$$

Where:

- Scrap ratio_i = tonnes scrap steel per tonne crude steel (see Table 2.4).
- Mass adjustment_i = tonnes coke per tonne of crude steel (see Table 2.5).

Sinter Emission Factor

The emission factor for the production of sinter for asset *i* is calculated as:

$$\text{Sinter EF}_i\left[\frac{\text{t CO}_2}{\text{t Steel}}\right] = \left(\text{Fuel EF}_i\left[\frac{\text{t CO}_2}{\text{t Sinter}}\right] + \text{Electricity EF}_i\left[\frac{\text{t CO}_2}{\text{t Sinter}}\right]\right) * \text{Sinter CF}_i\left[\frac{\text{t Sinter}}{\text{t Crude steel}}\right]$$

Where:

- Fuel EF_i = fuel emission factor (see Fuel Emission Factor).
- Electricity EF_i = electricity emission factor (see Electricity Emission Factor).

The consumption factor of the sintering process for asset *i* is calculated as:

$$\text{Sinter CF}_i\left[\frac{\text{t Sinter}}{\text{t Crude steel}}\right] = \text{Mass adjustment}_i\left[\frac{\text{t Sinter}}{\text{t Crude steel}}\right] * \left(1 - \text{Scrap ratio}_i\left[\frac{\text{t Scrap steel}}{\text{t Crude steel}}\right]\right)$$

Where:

- Scrap ratio_i = tonnes scrap steel per tonne crude steel (see Table 2.4).
- Mass adjustment_i = tonnes sinter per tonne of crude steel (see Table 2.5).

Electricity Emission Factor

The electricity consumption factor for process *j* of asset *i* is calculated as:

$$\text{Electricity CF}_{ij}\left[\frac{\text{kWh}}{\text{t Product}}\right] = \text{Electricity share}_{ij}\ [\%] * \text{Energy CF}_{ij}\left[\frac{\text{MJ}}{\text{t Product}}\right] * 278\left[\frac{\text{kWh}}{\text{MJ}}\right]$$

Where:

- $\text{Electricity share}_{ij}$ = share of energy consumption from electricity (see Table 2.7).
- Energy CF_{ij} = MJ of energy consumption per tonne product (i.e. coke, sinter, hot metal, and crude steel).
- 278 = conversion from kWh to MJ.

The electricity emission factor for process *j* of asset *i* is calculated as:

$$\text{Electricity EF}_{ij}\left[\frac{\text{t CO}_2}{\text{t Product}}\right] = \text{Electricity CF}_{ij}\left[\frac{\text{kWh}}{\text{t Product}}\right] * \text{Electricity EF}_{i}\left[\frac{\text{t CO}_2}{\text{kWh}}\right]$$

Where:

- $\text{Electricity CF}_{ij}$ = kWh consumed per tonne product (i.e. coke, sinter, hot metal, and crude steel).
- $\text{Electricity EF}_{i}$ = CO_2 intensity of the grid electricity in tonne CO_2 per kWh.[4]

Table 2.6: Energy Consumption Factor

Indicator	Definition
Parameter	Energy consumption factor
Unit	MJ per tonne product (i.e., coke, sinter, hot metal, and crude steel)
Scope	Scope 1 and 2
Description	Process *j* energy consumption for asset *i*
Identifier	*NA*
Value applied	e.g., 13000
Granularity	Technology average (i.e. steel process)
Source	International Energy Agency (*Greenhouse Gas Emissions from Iron and Steel Production*, 2003)

[4] All electricity emissions are assumed to be scope 2, i.e., purchased electricity (GHG Protocol Initiative, 2008).

Table 2.7: Share of Energy Consumption from Electricity

Indicator	Definition
Parameter	Share of energy consumption from electricity
Unit	Percent share
Scope	Scope 1 and 2
Description	Process *j* share of energy consumption from electricity
Identifier	*NA*
Value applied	e.g., 10%
Granularity	Technology average (i.e. steel process)
Source	International Energy Agency (*Greenhouse Gas Emissions from Iron and Steel Production*, 2003)

Table 2.8: Electricity Emission Factor

Indicator	Definition
Parameter	Electricity emission factor
Unit	Tonnes CO2 per kWh
Scope	Scope 2
Description	CO2 intensity of the grid electricity in tonne CO2 per kWh for asset *i*
Identifier	*NA*
Value applied	e.g., 100
Granularity	Country and regional averages
Source	CO2 electricity emissions from fuel Combustion 2012, International Energy Agency (*CO2 Emissions from Fuel Combustion 2012*, 2012)

Fuel Emission Factor

The fuel consumption factor for process *j* of asset *i* is calculated as:

$$\text{Fuel CF}_{ij}\ \left[\frac{\text{MJ}}{\text{t Product}}\right] = (1 - \text{Electricity share}_{ij}\ [\%]) * \text{Energy consumption}_{ij} \left[\frac{\text{MJ}}{\text{t Product}}\right]$$

Where:

- $\text{Electricity share}_{ij}$ = share electricity of the total energy consumption (see Table 2.7).
- Energy CF_{ij} = MJ of energy consumption per tonne of product (i.e. coke, sinter, hot metal, and crude steel) (see Table 2.6).

The fuel emission factor for process *j* of asset *i* is calculated as:

$$\text{Fuel EF}_{ij}\ \left[\frac{\text{t CO}_2}{\text{t Product}}\right] = \text{Fuel CF}_{ij}\ \left[\frac{\text{MJ}}{\text{t Product}}\right] * \text{Fuel EF}_{ij} \left[\frac{\text{t CO}_2}{\text{MJ}}\right]$$

Where:

- Fuel CF_{ij} = MJ consumed per tonne of tonne of product (i.e. coke, sinter, hot metal, and crude steel) of process *j* (see Table 2.6).
- Fuel EF_{ij} = CO_2 emitted per MJ tonne product (i.e. coke, sinter, hot metal, and crude steel).

Table 2.9: Fuel Emission Factor

Indicator	Definition
Parameter	Fuel emission factor
Unit	Tonnes CO2 per MJ
Scope	Scope 1
Description	Process *j* fuel emission factor for asset *i*
Identifier	*NA*
Value applied	e.g., 0.56
Granularity	Technology average (i.e. steel process)
Source	International Energy Agency (*Greenhouse Gas Emissions from Iron and Steel Production*, 2003)

Bibliography

de Beer, J., Harnisch, J., Kerssemeecker, M., 2003. GREENHOUSE GAS EMISSIONS FROM MAJOR INDUSTRIAL SOURCES – III IRON AND STEEL PRODUCTION. International Energy Agency.
GHG Protocol Initiative, 2008. Calculating Greenhouse Gas Emissions from Iron and Steel Production. Greenhouse Gas Protocol Initiative.
HYBRIT - Fossil-Free Steel [WWW Document], 2020. . HYBRIT - Fossil-Free Steel. URL http://www.hybritdevelopment.com/steel-making-today-and-tomorrow (accessed 9.1.20).
IEA, 2017. Energy Technology Perspectives 2017. International Energy Agency.
World Energy Outlook 2019, 2019. , World Energy Outlook. International Energy Agency.
WSA, 2020. Raw Materials. World Steel Association.
WSA, 2018. Steel Statistical Yearbook 2018. World Steel Association.