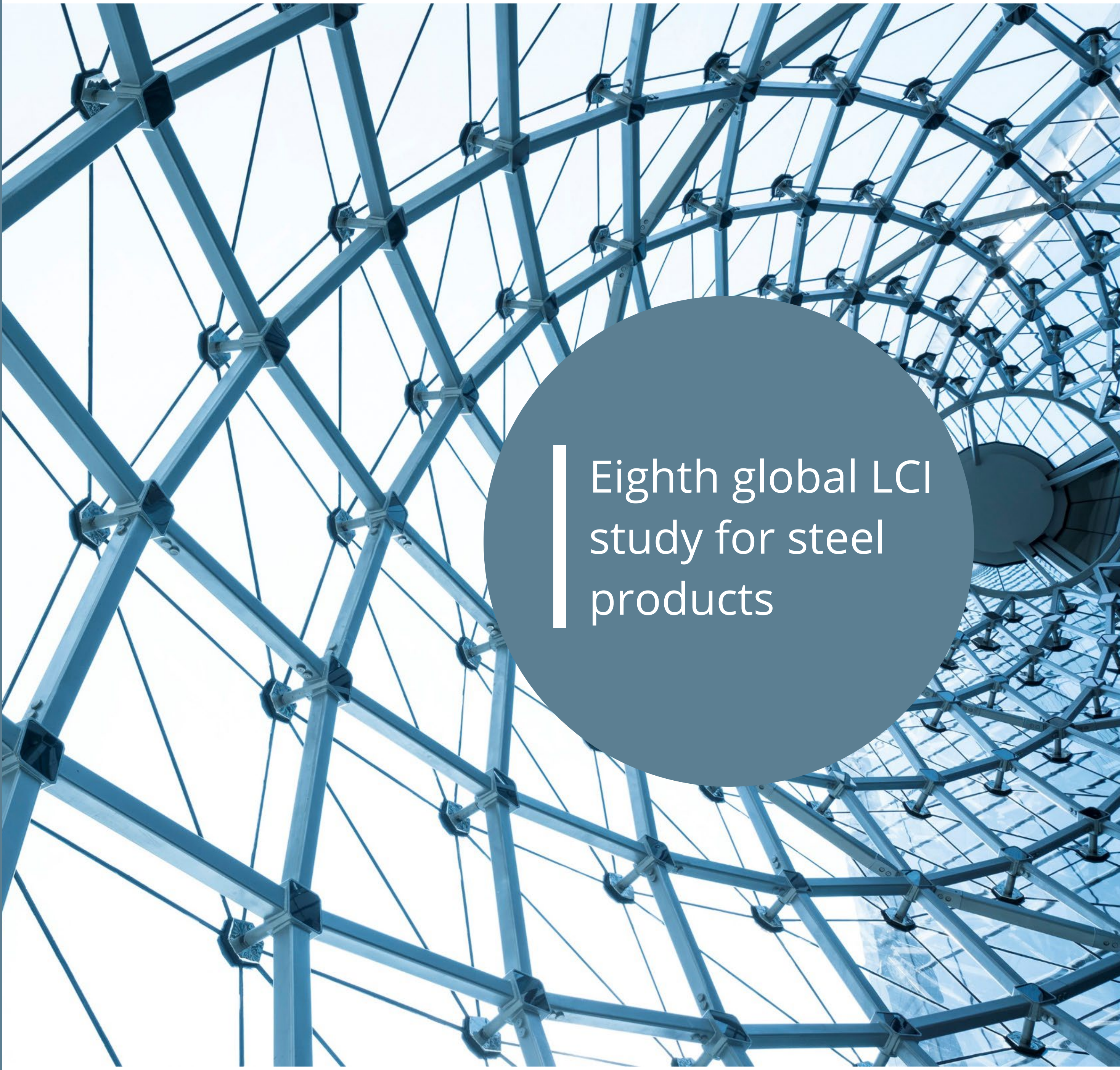
Life cycle inventory (LCI) study

2021 data release



Eighth global LCI study for steel products

worldsteel
ASSOCIATION

Table of Contents

List of figures

List of tables

Acronyms

AP	Acidification potential
BF	Blast furnace
BF Gas	Process gas produced in the blast furnace
BOF	Basic oxygen furnace
BOF Gas	Process gas produced in the basic oxygen furnace
CO Gas	Process gas produced in the coke ovens
EAF	Electric arc furnace
ECCS	Electrolytic Chrome Coated Steel (tin-free steel)
EP	Eutrophication potential
GWP	Global warming potential
HDG	Hot-dip galvanized steel
HRC	Hot rolled coil
ISSF	International Stainless Steel Forum
LCA	Life cycle assessment
LCI	Life cycle inventory
LCIA	Life cycle impact assessment
NCV	Net calorific value
PED	Primary energy demand
POCP	Photochemical Oxidant Creation Potential
worldsteel	World Steel Association

1 Project context

This report presents a summary of the 8th global World Steel Association (worldsteel) Life Cycle Inventory (LCI) Study. It provides an explanation of the implementation of the methodology, results and interpretation of the LCI data for steel products most recently updated and published in 2017. The study was originally carried out for 1994/1995 steel production data. The first update was then undertaken for 1999/2000 data, then 2005/2006, then with 2012-2015 data and again with 2016 and 2017 data. This latest update, the 2021 data release, includes new steel production data from 2019 and 2020.

The main goal of this study, which reflects the industry's ongoing commitment to improving data quality, is to update the LCI data for steel products on a global and regional basis by updating a significant proportion of the steel production data from steel companies (including upstream data) and releasing results on an **annual basis**. Currently, regional data is available for Europe and Asia for certain products. It is believed that other available datasets on steel have been derived with limited accuracy or representation and/or contain out of date information.

The data collection and methodology development have been subject to a great amount of quality control in order to provide a sophisticated database of steel product LCIs for use both internally and externally to the global steel industry.

Whilst this report aims to describe the details of the LCI study 2021, the methodology follows the World Steel Association LCI methodology report 2017 . This study has been undertaken in accordance with ISO 14040: 2006 and 14044: 2006 and while the study report itself has not been critically reviewed, the methodology report (and all previous versions of it) have been reviewed. This approach has improved the integrity of the worldsteel LCI data collection methodology and programme and helps to establish transparency. Any changes to methodology or modelling are detailed in Appendix 9.

Although this report features a comprehensive level of detail, it is intended to serve as a basis for dialogue between steel industry representatives and third parties using the data. Recommendations for improvement concerning both the documentation and the LCI data are highly welcomed. They will be considered as the worldsteel LCI database is improved in the future.

Further details on the steel industry production processes are available from other publications (available via the worldsteel website www.worldsteel.org and steeluniversity.org).

worldsteel LCI data can be requested from wordsteel.org.

2 Goal of the study

This 2021 release of steel industry data is the 7th update of worldsteel LCI data, first released in 1995. The industry has regularly collected data and released updates to ensure that the data remains representative of the current steelmaking technologies and their associated emissions and impacts.

The LCI results alone shall not be used in comparative assertions intended to be disclosed to the public. The LCI data can be used as part of an LCA for comparative studies disclosed to the public if this is stated in the goals and scope of the LCA study, is done based on a proper functional unit and is subject to a study-specific critical review by an external panel of experts.

The target audience of the study includes the World Steel Association and its members. Furthermore, aggregated and averaged data will be made available for many different external applications of the data, for technical and non-technical use, including customers of the steel industry, policy makers, LCA practitioners and academia. The data will also be made available in as many public and proprietary databases as possible, including GaBi, SimaPro, OpenLCA etc.

The goals of the project are to:

- Produce worldwide LCI data for steel industry products. The LCIs are both cradle-to-gate data and cradle-to-gate data including end-of-life recycling (end-of-life credits are separately reported).
- Provide data to support communication with industry stakeholders.
- Assist industry benchmarking and environmental improvement programmes.

The overall magnitude of the results is on the same level as previous worldsteel LCI data. The changes that have been made to the model and methodology (Appendix 9) have been made to improve the quality and representativeness of the data compared to previous versions of the model that have been used to generate the results. Where appropriate, a conservative approach has been taken.

In the past, the global steel industry LCI data was updated every 5 years or so. This changed in 2017 when worldsteel changed its strategy on LCI data to update the data on a more regular basis. Since then, worldsteel updates a proportion of the steel production data in the database on an annual basis and removes data that is older than 5 years. Upstream data is also updated annually to ensure the most relevant and up-to-date data is used. In addition, this change in strategy allows worldsteel member companies to provide data when it suits them, and not only once every five years. This allows worldsteel to produce the most recent and complete steel industry product LCIs for both global and, where possible, regions of interest and make them available for general use in the LCA community. It also allows new product datasets to be generated when there is sufficient data available. As no data supplied by the steel companies is older than 5 years old, the datasets comply with as many EPD schemes as possible which have age restriction constraints.

3 Scope of the study

3.1 Study description overview

The scope of the LCA study is defined in ISO 14044: 2006 section 4.2.3.1, and among other things outlines the function, functional unit, system boundary and cut-off criteria of the study. These are outlined in the following sections.

3.2 Functional unit

Within the scope of this study, the functional unit is the production of 1kg of a steel product at the factory gate, i.e. cradle-to-gate data. Where the data is intended to be supplied as cradle-to-gate including end-of-life recycling, the function includes the upstream burdens of the scrap used in the steelmaking process and the credits associated with the end-of-life recycling of the steel product. Further functions relating to the generation of co-products from the steel production system have been considered using the allocation procedure recommended in ISO 14040: 2006 as documented in the 2017 worldsteel LCI methodology report section 3.6.

Seventeen steel products (Table 1) were included in the study – Both ECCS and UO pipes have been re-added to the study due to the inclusion of new sites which make these products. The 17 products have been chosen as they cover the vast majority of steel products being produced today (> 95%). Additional products which have not been included at this stage are generally processed from one of the products listed below. The detailed specifications of each steel product, such as size range, gauge and coating thickness, vary from site to site and are a function of the technology, equipment and product ranges at the sites involved and are detailed in Appendix 1. The range of specifications within a product category will to some extent influence the regional and global LCI results.

Product category	Manufacturing route	List of products
Long products	Basic oxygen furnace route and Electric arc furnace route	Sections Rebar Wire rod Engineering steels
Flat products	Basic oxygen furnace route and Electric arc furnace route	Plate Hot rolled coil Cold rolled coil Pickled hot rolled coil Finished cold rolled coil Electrogalvanized steel Hot-dip galvanized steel Tinplated products ECCS Organic coated steel Welded pipes Seamless Pipe UO Pipe

Table 1: List of products covered by the study

The study focuses on carbon and low alloy steels (with alloy content lower than 2%). Notably stainless steels (with at least 12% chromium) are outside the study scope but form the basis of another study via EUROFER and the world stainless association[i].

3.3 System boundaries

The study is a cradle-to-gate LCI study with and without the end-of-life recycling of the steel as defined in the 2017 worldsteel LCI methodology report Figures 1 and 2. That is, it covers all of the production steps from the extraction of raw materials from the earth (i.e. the cradle) to finished products ready to be shipped from the steelworks (i.e. the gate). The cradle-to-gate LCI study, with end-of-life recycling, reports the net credits (the amount of end-of-life scrap minus any scrap consumed in the production of the product) associated with recycling the steel from the final products at the end-of-life (end-of-life scrap) – this is reported in addition to the cradle-to-gate data. This study does not include the manufacture of the downstream final products outside of the steelworks or their use. If the user of steel uses steel datasets including the end-of-life credits on the material level, it has to be checked that no double-counting occurs when the user models the end-of-life of the downstream product. Note that the data for net end-of-life recycling is provided separately to the cradle-to-gate LCI data, for implementation by the user themselves.

A full description of the system boundaries is given in the 2017 worldsteel LCI methodology report, section 3.3.

For this 2021 study, primary data were collected for 24 separate steelmaking process steps plus boilers, compressors, water intake, effluents, stockpile emissions and transportation of raw materials. A representation of one of the processes that data has been collected for, the basic oxygen furnace module, is given in Appendix 2. Data were also collected regarding the use of steel industry co-products, in particular process gases and slags. All this newly collected data is combined with data that has been previously collected from worldsteel members and is not older than 5 years old, in order to generate new global and regional product LCIs. Table 2 shows the total number of sites contributing to this study per process step.

Process stage	Number of sites	Process stage	Number of sites
Coke making	49	Electrogalvanizing	8
Sinter making	50	Hot-dip galvanizing	36
Pellet plant	7	Tinplate mill	13
Blast furnace	60	Organic coating line	24
Direct reduced iron (gas and coal based)	14	Section mill	24
Basic oxygen furnace	62	Heavy plate mill	22
Electric arc furnace	54	Rebar	30
Hot strip mill	58	Welded pipe	10
Pickling plant	43	Seamless Pipe	7

Cold rolling mill	43	UO Pipe	4
Annealing & tempering mill	41	Wire rod	26
ECCS	3	Engineering steels	5
Total processes			**696**

Table 2: Number of process stages represented in the study

3.3.1 Technology coverage

Steel is produced predominantly by two process routes; the basic oxygen furnace route and the electric arc furnace route (the BOF and EAF routes respectively), including those using DRI. Typical steel manufacturing flow diagrams are shown in the worldsteel methodology report, 2017, Appendix 1. Both routes are represented in this data update and the number of sites contributing data for each process is specified in Table 2.

3.3.2 Geographic coverage

The companies participating in the study produce nearly 30% (535 million tonnes) of global crude steel production (1880 million tonnes) and the contributing sites (which cover 19% of global steel production, 349 million tonnes) are located in the largest of the principal steel producing countries. The highest represented region is Europe: the sites participating represent over 41% of European steel production. The list of participating companies is shown in Appendix 3.

143 sites located in 34 countries participated in the study – this includes 71 sites providing data in 2021 from 11 steel making companies. The major steel producing countries and regions are included. These are listed below in Table 3.

Argentina	India	Russia
Australia	Italy	Saudi Arabia
Austria	Japan	Singapore
Belgium	Kazakhstan	South Africa
Bosnia	Korea	Spain
Brazil	Luxembourg	Sweden
Canada	Mexico	Thailand
China	Morocco	UK
Egypt	The Netherlands	Ukraine
Finland	New Zealand	USA

France	Poland	
Germany	Romania	

Table 3: Countries participating in the worldsteel LCI study

3.3.3 Time coverage

The data collection is related to one-year operation and the year of the data is indicated in the questionnaire for each data point. The primary data collected from the steel companies relates to production from 2016 to 2020 (see Appendix 9) and is believed to be representative of global steel production during this time frame. The new sites contributing data in 2021 have provided primary data from 2019 and 2020 steel production. Although improvements are continually being sought for the steelmaking processes, this is more of a gradual process than any major global change.

Secondary data is sourced from the GaBi database and is dated from 2013 to 2020, with the exceptions of nitrogen and oxygen production from 2007. However, as these gas processes are used to give country specific impacts, they are individually connected to the country electricity grid mix from 2017 for each of the steel sites, as outlined in Appendix 6. Each secondary dataset is listed in Appendix 5.

3.4 Application of LCIA categories

The LCI study set out to include as many inputs and outputs from the steel production route as possible so that any future studies can consider a range of impact categories. The methodological aspects for key data categories are discussed in section 3.5 of the 2017 worldsteel LCI methodology report Section 3.5.

The goal of the study is to provide the LCI profiles for a number of different steel products and not to analyse the impact categories as they are not included in an LCI profile. In addition, normalisation, grouping and weighting are not applied to the worldsteel LCI data. worldsteel has included a range of impact assessment results in this report, which are routinely reported by users from around the world. These include the following: CML impacts, EF3.0 impacts and TRACI 2.1 which are given for information purposes only to show the variation and contributions to the steel product LCIs: global warming potential, acidification potential, eutrophication potential and photochemical ozone creation potential. The CML impacts have been used to generate results included in this report for illustrative purposes only and are included in further detail in Section 6. The impact assessment is based on the methods and data compiled by the Centre of Environmental Science at Leiden University, CML 2001 – Aug. 2016 and are selected as these have always been reported historically and are one of the most used impact assessment suites for reporting LCIA results.

The following LCIA categories, which have been chosen as examples, are:

- Global Warming Potential (GWP 100 years): an impact assessment level with global effect; for steel products the GWP is mainly caused by CO_2 and methane emissions which account for over 98% of GHG emissions from the steel industry.
- Acidification Potential (AP): an impact assessment level with local effect; within the steel industry, AP is mainly caused by SO_2 and NO_x.
- Eutrophication Potential (EP): an impact assessment level with local effect; within the steel industry, EP is mainly caused by NO_x emissions.

- Photochemical Oxidant Creation Potential (POCP): an impact assessment level with local effect; within the steel industry, POCP, also known as summer smog, is mainly caused by carbon monoxide emissions.

3.5 Data collection

The LCI data for this study has been collected according to the principles set out in ISO 14040: 2006 and ISO 14044: 2006. Further clarification to data collection principles can be found in the 2017 worldsteel LCI methodology report Section 3.5.

The LCA software, GaBi version 10.6.0.110 was used to create the worldsteel LCI model and datasets, which was based on the previous steel industry model for the 2019 data collection. The initial model was created in 2006 by a team of experts including worldsteel, Sphera and the worldsteel members and represents the steel production processes. Site data were collected using the internet-based SoFi Web Questionnaire. The questionnaires are uploaded to the web-platform and each company has individual password protected access to their specific questionnaires. A separate questionnaire is available for each of the process stages for each site (a full list of questionnaires is shown in Appendix 10), an example of which is shown in Appendix 4, as well as for ancillary utilities such as boilers/power plants, compressors, alternators etc. Each of the questionnaires contains a list of input and output flows which fall into the following categories: material and energy inputs, air and water emissions, wastes, products and co-products and recovered material that can be processed internally to displace raw material inputs. Transport data for the raw materials and internal transportation fuel used was also provided in the questionnaires. The central allocation of individual access rights in SoFi by an administrator (worldsteel) ensures the confidentiality of all collected data.

Details of the upstream inputs to the steelmaking process are detailed in Appendix 5 and energy grid mixes for each country in Appendix 6.

A training manual is available to assist those providing the data via the SoFi Web Questionnaire. A number of features are available in the questionnaire in order to facilitate data collection:

- The SoFi Web Questionnaire has an export function which allows data to be collected in excel and imported into the relevant questionnaire.
- In each questionnaire, the amount of each flow per unit product for that process is shown. This gives an easy way to check that the value of the flow is in the correct range and order of magnitude and helps to avoid errors with units.
- Iron, carbon and mass balances can be seen at the process and site level to enable verification of data submission.

The data were collected by worldsteel member companies, i.e. the steel producing companies, for a 12-month period on a site-by-site and process-by-process basis, ensuring a high-quality dataset. The data represents normal or abnormal operation, but excludes accidents, spills and similar events.

3.5.1 Exceptions

In 2020, 99.5% of crude steel production was produced either via the BOF or EAF route. Open hearth production and ingot cast steel production, accounting for approximately 0.5% of global steel production, was not included. No other exceptions to the scope of this study on carbon steel products are given.

3.6 Methodological details

3.6.1 Co-products

With any multi-product system, rules are defined to relate the system inputs and outputs to each of the products. This is particularly important in the case of the BOF route, which generates important quantities of valuable co-products, but also applies equally to co-products produced in the EAF route, such as slag.

The allocation methods applied in this study are detailed in the 2017 worldsteel LCI methodology report, section 3.6.1.

Significant material co-products such as slags, which are sold to known destinations, replace functionally similar products. This information is collected from the steel companies participating in the data collection. For example, blast furnace (BF) slags can be used in cement manufacture (in cement making (replacing clinker) and as a replacement for cement), for road construction or aggregate, or as a fertiliser. On average for this study, 0.30 kg of BF slag is generated per kg of hot metal. The generation rate, which depends on the quality of the raw materials used, can be as high as 0.56 kg in some cases. On the sample of participating sites, 98% of the total amount of BF slag produced is recovered, of which 79% is used for cement making. Some slag is used for such things as on-site construction. Details on the use of slags, for the data collected, is provided in Table 4. Care should be taken in studies where both concrete (using slag) and steel are used in order to avoid double counting the credits of the slags.

Slag type	Total % recovered	Percentage use of material recovered		
		Cement	Roadstone	Fertiliser
BF slag	98%	79%	20%	1%
BOF slag	97%	6%	91%	3%
EAF slag	87%	30%	70%	0%

Table 4: Slag recovery rates and usages

System expansion is used to deal with the slags. This method allows discrimination between alternative recovery routes of steel co-products from an environmental perspective as different "credits" are given for recovery, based on the end use of the co-product. This reinforces the environmental value of using co-products for the industry. Allocation by mass scenarios do not integrate the actual use of co-products. For example, allocation applied to BF slags only considers the mass of slag recovered and does not differentiate between the environmental benefits of the different uses of the slag, e.g. replacing cement or replacing aggregates.

System expansion is also used to account for process gases (coke oven, BF and BOF gases), dusts, scales, oils etc. that are produced in the steelmaking processes and then recovered and used elsewhere. Details of the assumptions made for all recovered material are included in Appendix 8.

With further analysis, the processes linked with the system expansion retain their initial (actual) inventories of the process (e.g. cement or fertiliser production) and the expanded system processes are calculated separately. When combined, the result is the overall LCI of the product at the cradle-to-gate level.

3.6.2 Steel scrap

Methods for dealing with steel scrap are outlined in the 2017 worldsteel LCI methodology report Section 3.6.2 and have been followed in this study.

3.7 Interpretation

The results of the LCI/LCIA are interpreted according to the Goal and Scope of the study (sections 2 and 3 above). The interpretation addresses the following topics:

- Identification of significant findings such as the main contributors to the overall results or certain impact categories, see Section 6.
- Evaluation of completeness and sensitivity to justify the inclusion or exclusion of data from the system boundary or methodological choices, see Section 6.2.2.
- Conclusions, limitations and recommendations of the appropriateness of the definitions of the system function, functional unit and system boundaries, see Section 7.

3.8 Critical review

As there are no major changes to the implementation of the worldsteel methodology in this study compared to the previous study report, no critical review has been conducted. Minor changes to the model have been implemented and are detailed in Appendix 9.

4 Data quality

4.1 Data quality requirements

To ensure that worldsteel can provide the most accurate and representative data for steel industry products, the quality of the data used in the models needs to be very high. Data quality requirements from the 2017 worldsteel LCI methodology report Section 3.5.7 were followed. The data that have been used for this study can be classified in three ways:

- Primary data collected from worldsteel member companies, gate-to-gate data.
- Primary data for some upstream inputs, e.g. aluminium, from industry associations or producers, cradle-to-gate data.
- Cradle-to-gate data, plus background system from the GaBi 10.6.0.110 CUP2021.2 Professional database for upstream inputs e.g. electricity, iron ore, coal etc.

Due to the extensive checks made of the data provided by each site, the overall quality of the data is considered to be high and is representative of the systems described in terms of technological coverage. The primary steel data are collected directly from the steel producers themselves, enabling a thorough analysis and exchange with these producers. The steel industry is striving to continually improve the quality of its own data and upstream data that are used in the model.

The data collection project was managed internally within worldsteel, with the support of an LCA consultant, reporting to worldsteel's Head of Sustainability and an LCA Specialist providing specific support in Chinese. This team of people provided training and support to the worldsteel member companies who individually provided data through an online system. Thorough data verification was then carried out by the LCA team to ensure that it was complete and free from error.

4.1.1 Gate-to-gate data

All data on steel production and processing were collected on a site-by-site basis utilising the SoFi Web Questionnaire. All data submitted were checked as detailed in section 4.2. Companies were provided with a data collection user guide and were given training on how to use the SoFi Web Questionnaire. worldsteel was available for web meetings or calls to answer specific questions relating to the data collection exercise.

4.1.2 Cradle-to-gate data from industry associations

For industry supplied datasets such as aluminium and ferro alloys, the datasets were checked to ensure they were consistent with the goals and scope of the worldsteel study. Expert judgement was used to select the appropriate LCI datasets and documentation relating to these datasets is given within the dataset or can be obtained directly from the supplying industry associations.

4.1.3 Upstream GaBi data

All datasets used in the LCI model from the GaBi Professional database were created with system boundaries that align with the worldsteel methodology and modelling principles. Expert judgement and advice were used in selecting appropriate datasets to model the materials and energy for this study.

4.2 Data quality check

The SoFi Web Questionnaires were based on the worldsteel LCI model that has been developed by worldsteel and Sphera. In this way, all relevant flows, processes and interconnections between the processes were included in the model and questionnaires.

This data was then extracted by worldsteel for analysis and verification, by examining the individual processes for all sites and comparing the inputs and outputs.

4.2.1 Raw data

All completed SoFi Web Questionnaires submitted by the sites were checked individually and systematically by worldsteel.

The questionnaires were imported directly into the GaBi software on a site-by-site basis. No manual import was necessary which therefore avoided errors in conversion or typing mistakes.

4.2.2 Process, site and route data

Data checks were done at the process, site (gate-to-gate) and cradle-to-gate (route) level and at each stage, benchmarking analysis was carried out to ensure that the data provided were accurate. Data checks included:

- Carbon and iron balance per kg of product for each process
- Energy consumption per process, including the boilers
- Emissions to air and water
- Yields between different process steps and scrap produced / consumed
- Slag balance across the whole site
- Process gas balance across the whole site
- Water balance
- Cradle to gate comparison against 2 standard deviations of data for a range of impact assessments
- LCIA level checks

The product LCIs were calculated in GaBi, by averaging the available site-specific routes (by setting up individual plans) for each product included in the study. The steel product LCI average datasets were calculated using a vertical aggregation approach (see Figure 1), i.e. calculating the LCI for product A from site X and averaging with product A from site Y, based on the weighted average of the production tonnage of product A.

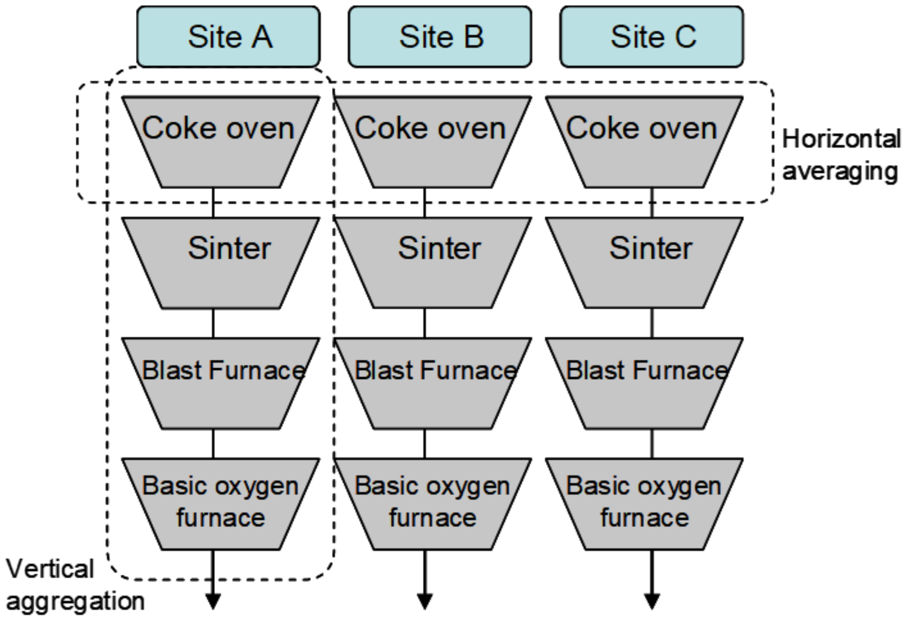


Figure 1: Horizontal averaging and vertical aggregation

The final LCI results were then compared against previous results to check them for accuracy to ensure that the final LCI results were accurate and robust and to understand any differences between the datasets.

4.2.2.1 Water emissions

Due to the uncertainty in conducting a water balance that accounts for all water inputs and outputs across a site boundary, including evaporation losses and unmeasured water inputs such as rainfall, there is a variability of data between the sites regarding water usage, consumption and water emissions. Water data forms part of the LCI of the steel products and should therefore be treated with caution. Better metering and monitoring will help to improve water-related data in the future.

4.3 Data gaps

Where there were gaps in the data, the data collector was contacted in order to provide any missing data. Where it was not possible to provide the missing data, the average value, calculated from data collected from a minimum of 3 other steel production sites, was incorporated into the dataset. This average approach was taken for missing air and water emissions data, referred to as accounted emissions, for specific emissions. This approach is detailed in the 2017 worldsteel LCI methodology report section 3.5.4.

5 LCA results and analysis

It is not the intention to provide an impact assessment of the steel products considered in this study but they are considered here as a plausibility check and for illustrative purposes only.

Life cycle inventory data are available for 17 steel products and is freely available on request via worldsteel.org. As well as in a number of LCA software tools. The data are provided using the GaBi Envision tool, which enables the data to be easily generated directly from the GaBi software, thus reducing the likelihood of errors in generating datasets. The data provided are LCI data and are provided as cradle-to-gate data as well as cradle-to-gate including end-of-life recycling (net recycling credits are reported separately to the cradle-to-gate data). A description of the data provided can be found in Appendix 7. Data is also available via excel, which includes the full LCI. The LCI data is also supplied to other database vendors for inclusion in their own databases to allow easy access of the full LCI datasets.

No analysis is presented comparing the steel product LCI data year-on-year for the following reasons: changes in the population of the datasets with new sites being added and old data being removed; changes in the technology split between the different products i.e. the percentage contribution of BOF and EAF technologies; the contribution due to the location of the steel manufacturing sites and resulting local inputs such as energy; and annually updated upstream data. These changes can result in significant changes to the datasets and so it is not meaningful to make an annual comparison of the global average results.

Typical impacts for three main steel industry products (steel sections, hot rolled coil and hot-dip galvanized steel) have been analysed and are shown in section 5.2. These products cover a wide range of use of steel containing products in different sectors. Steel sections are produced both in the EAF and in the BOF route and are rolled on a hot rolling mill. These include I-beams, H-beams, wide flange beams and sheet piling and are often found on the market for direct use. Hot rolled coil is one of the first products being produced from the BOF route and EAF route. The hot rolled coil is generally further processed into finished products by steel companies or manufacturers and can be used in transport, construction, ship-building, pressure vessels, pipelines etc. Hot-dip galvanized steel is generally hot rolled coil that has been further processed (e.g. rolling, annealing, tempering, coating) and has a thin layer of zinc to provide corrosion resistance and can be used in a number of applications for automotive, construction, domestic appliances etc.

The data are based on global average datasets and include:

- Cradle-to-gate
- Cradle-to-gate including recycling. Net credits associated with this end-of-life recycling are provided separately to the cradle-to-gate data.

The end-of-life recycling rate refers to the amount of the steel within the final product that will be recycled when the product reaches the end of its useful life. The end-of-life recycling rate of steel depends on the type of final product and its use. Typical rates for the automotive sector are above 95%, for construction around 85% and for packaging around 70%. An average of around 85% is used for all steel being recycled at the end of a product's life. These values are based on expert judgement amongst the worldsteel LCA experts and are meant as guidance only. They are believed to be conservative values as recycling of products will improve in the future. When a request for data is received by worldsteel, the user can specify their own end-of-life recycling rate(s).

5.1 LCI value of steel scrap

In order to calculate the benefits related to scrap recycling, it is necessary to calculate the LCI for steel scrap. The methodology for determining this LCI for steel scrap has been described in the 2017 worldsteel LCI methodology report section 3.6.2 and further discussed in the report's Appendix 2. A credit is given for the net scrap that is produced at the end of a final product's life. The net amount of scrap that is used is determined as follows:

Net scrap = Amount of steel recycled at end-of-life – Scrap input

The results provided in Section 5 include this net credit for scrap recycling. The impact of recycling 1kg steel scrap is shown in Table 5; this has been calculated using the equation and method in the 2017 worldsteel LCI methodology report section 3.6.2 based on data collected from the sites for this study. The results are illustrative only.

Impact category	LCIA for 1kg steel scrap
Primary energy demand, MJ	15.4
Global warming potential (100 years) kg CO_2-e	1.66
Acidification potential, kg SO_2-e	0.0031
Eutrophication potential, kg Phosphate-e	2.14E-04
Photochemical ozone creation potential, kg Ethene -e	0.0008

Table 5: Example impact categories and primary energy demand for 1 kg steel scrap

Thus, for every 1kg scrap consumed in the steelmaking process, and every 1kg of steel recycled from a final product at the end of its life, the LCIA displayed in Table 5 can be applied. The burden for scrap consumption would result in adding the steel scrap LCI per kg scrap. The credit for steel recycling at the end of the final products' life would result in subtracting the steel scrap LCI from the product LCI per kg scrap recycled. Steel production with recycled steel produces 78% fewer greenhouse gas emissions than making steel with virgin steel.

5.2 Energy demand and environmental impact categories

For the purpose of this study report, the impact assessment is based on the methods and data compiled by the Centre of Environmental Science at Leiden University as detailed in Section 3.4. Primary energy demand is also included as an indicator of overall energy demand for the production of the steel products. These data are illustrative and should not be used for specific studies. The data provided is not the LCI data. For the most up-to-date regional LCI data for all steel products, visit worldsteel.org.

The data for the steel sections comes from both the EAF and the BOF route. Based on the latest worldsteel LCI data, the net scrap content is typically around 0.56 tonnes per tonne steel section. Hot rolled coil and hot-dip galvanized steel are also produced in the EAF and BOF route, though typically with a higher proportion of BOF route so the amount of net scrap consumption is generally a lot lower, around 0.13 tonnes per tonne of hot-dip galvanised steel and 0.15 tonnes per tonne of hot rolled coil. These scrap inputs refer to the scrap generated outside the system boundary of the product being studied and is not the recycled content of the steel.

		PED MJ	GWP kg $CO_{2\text{-}e}$	AP kg $SO_{2\text{-}e}$	EP kg Phosphate-e	POCP kg ethene-e
Sections, 1kg	Cradle-to-gate	21.8	1.92	0.00368	0.00029	0.00079
	Net recycling benefit	-4.3	-0.47	-0.00087	-0.00087	-0.00023
	Cradle-to-gate including recycling	17.6	1.45	0.00281	0.00023	0.00056
Hot rolled coil, 1kg	Cradle-to-gate	25.2	2.30	0.00517	0.00043	0.00093
	Net recycling benefit	-10.4	-1.16	-0.00213	-0.00015	-0.00056
	Cradle-to-gate including recycling	14.8	1.14	0.00304	0.00028	0.00038
Hot-dip galvanized steel, 1kg	Cradle-to-gate	28.8	2.59	0.00520	0.00045	0.00089
	Net recycling benefit	-10.7	-1.19	-0.00219	-0.00015	-0.00057
	Cradle-to-gate including recycling	18.1	1.40	0.00301	0.00030	0.00032

Table 6: Life cycle impact assessment results of steel products

The net recycling credit that can be seen in Table 6 and the following figures varies depending on the scrap input and the end-of-life recycling rate chosen – for all products in Table 6 and Figures 2, 4, 6, 8 and 10, an end-of-life recycling rate of 85% has been used. For sections, where the input level of scrap is relatively high, then the net overall scrap credit at end-of-life is lower since the credits are based on the recycling rate minus the scrap input. For the products that are mainly produced via the BOF route, then the scrap inputs to the process are generally lower and therefore the net scrap end-of-life credit is much higher than a high scrap input product, for the same end-of-life recycling rates.

5.2.1 Primary energy demand, PED

The primary energy demand for the three products described above is shown in Figure 2.

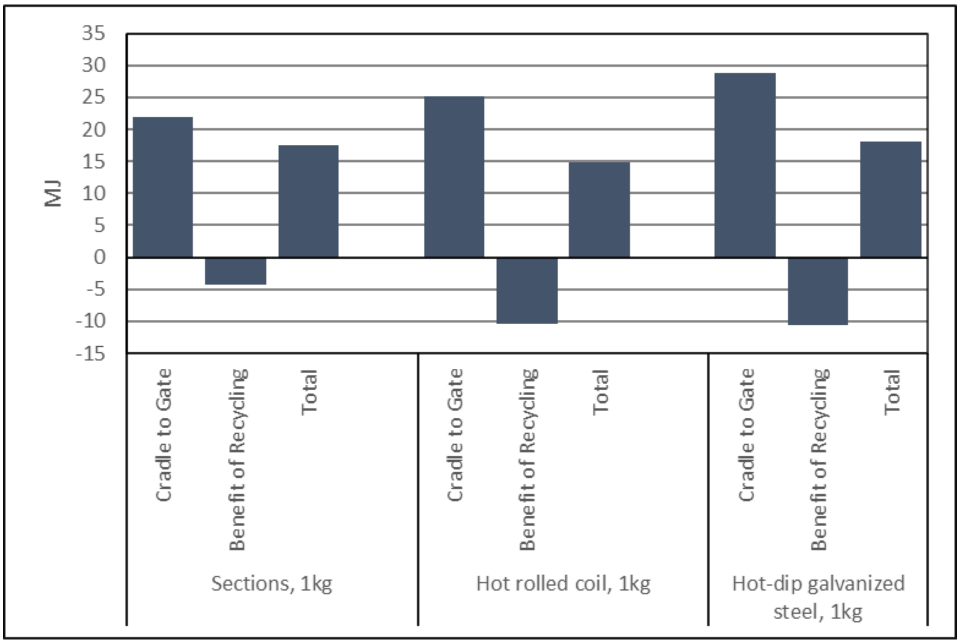


Figure 2: Primary energy demand (MJ) of steel products

The PED is made up of renewable and non-renewable resources. For the cradle-to-gate data for each of the products shown above, between 93 and 98% of the demand is from non-renewable resources, with the majority being attributable to hard coal consumption (Figure 3). The consumption of uranium is only associated with the upstream profiles of electricity consumption.

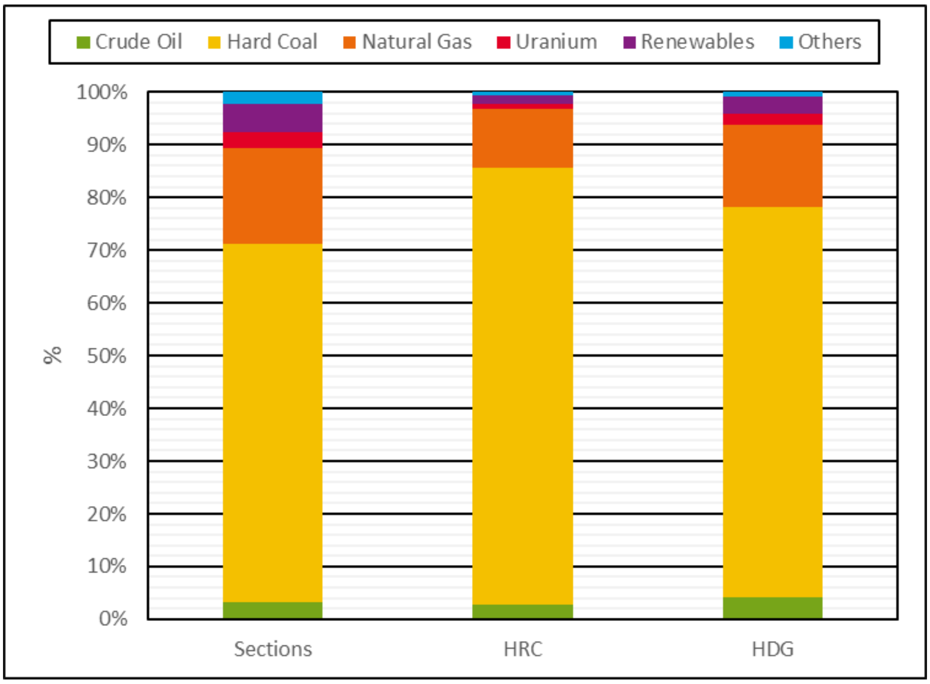


Figure 3: Contributions to primary energy demand of steel products

5.2.2 Global warming potential, GWP

The GWP for the three products described above is shown in Figure 4.

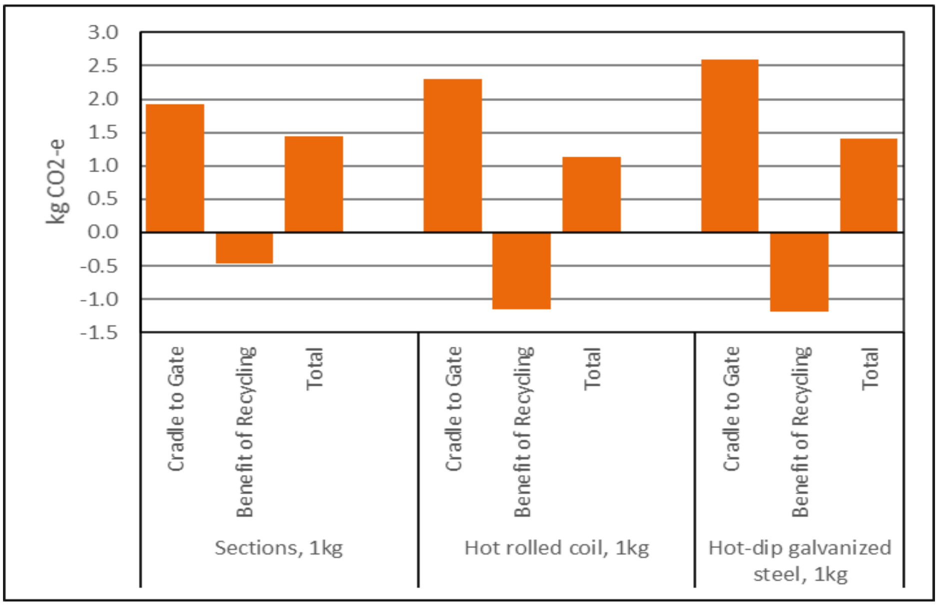


Figure 4: Global warming potential (CO_2-e) of steel products

The GWP for steel products is dominated by CO_2 and methane emissions, which account for over 99% of all GHG emissions for the steel industry. Methane emissions come predominantly from the upstream emissions of coal that is used within the process and for coke making. Figure 5 shows the contributions to the GWP, with the categories 'renewable resources' including biomass credits and 'others' including nitrous oxide, sulphur hexafluoride, NMVOCs, and hydrocarbons. This results in a small credit to the system (i.e. a negative number), which results in the overall result being less than 100% for Sections and HDG.

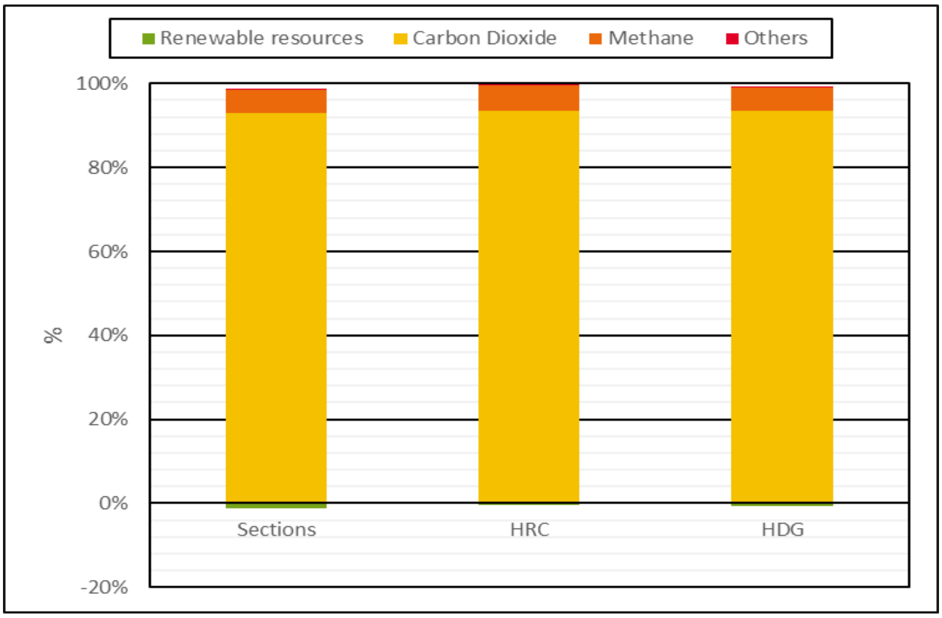


Figure 5: Contributions to gobal warming potential of steel products

5.2.3 Acidification potential, AP

The acidification potential for the three products described above is shown in Figure 6.

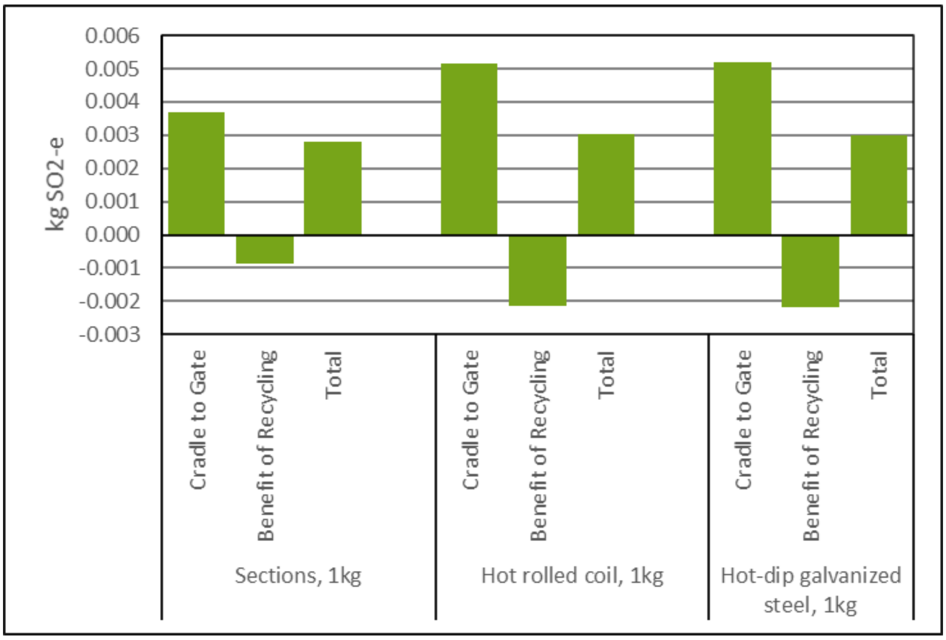


Figure 6: Acidification potential (SO_2-e) of steel products

The acidification potential for steel products is dominated by SO_2 and NO_x emissions to air, which contribute over 98% to this impact as shown in Figure 7.

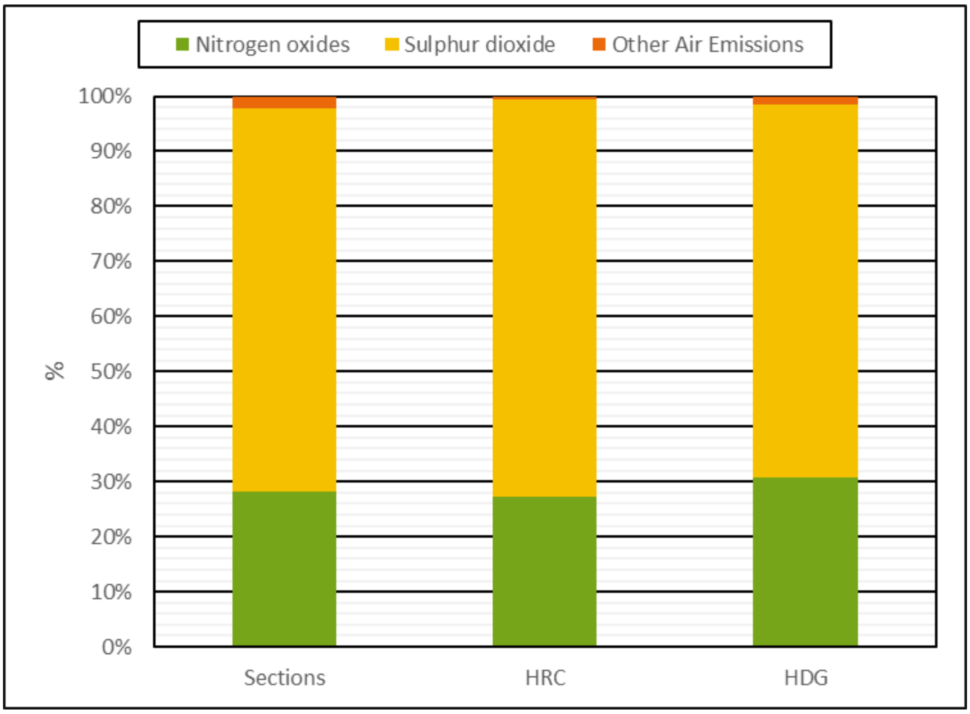


Figure 7: Contributions to acidification potential of steel products

5.2.4 Eutrophication potential, EP

The eutrophication potential for the three products described above is shown in Figure 8.

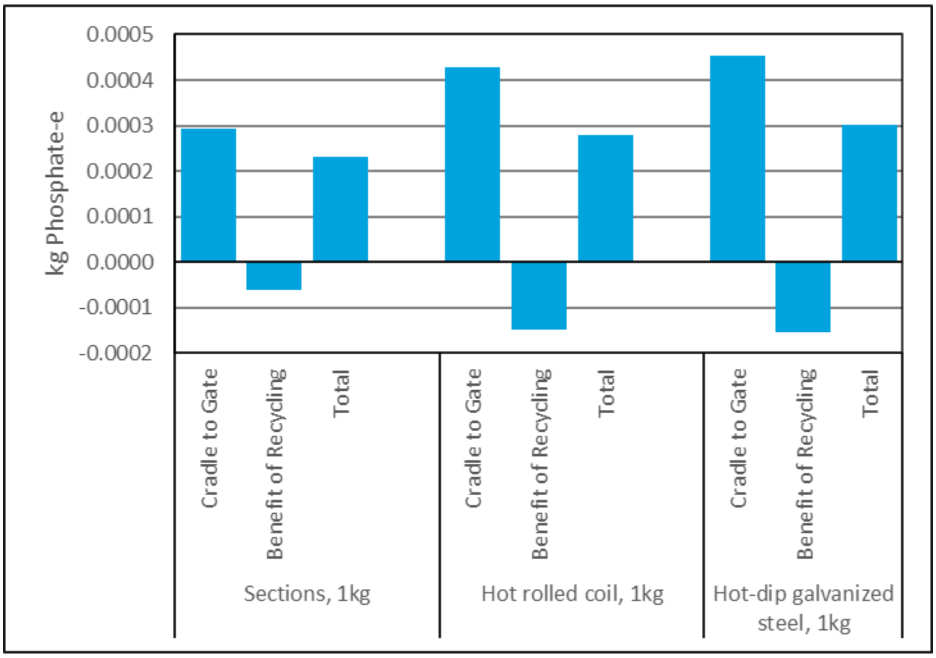


Figure 8: Eutrophication potential (PO_4^{3-}-e) of steel products

The eutrophication potential for steel products is dominated by emissions to air, which contribute over 93% to this impact. The main contributor is nitrogen oxides. Emissions to water that contribute to this impact are from nitrogen containing substances, e.g. nitrate, ammonia etc. Contributions are shown in Figure 9.

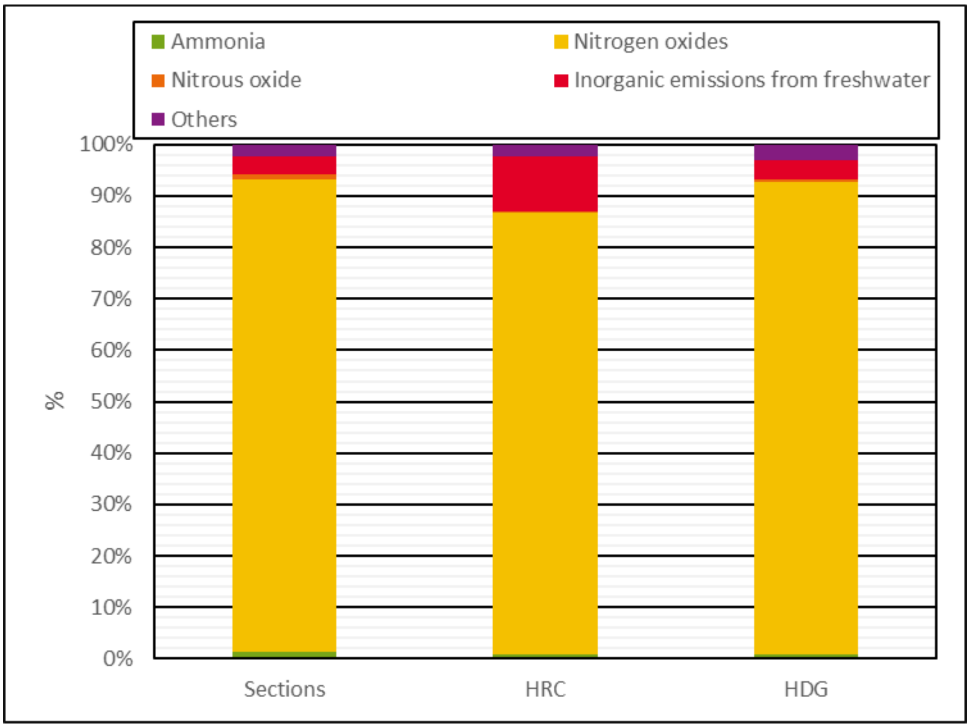


Figure 9: Contributions to eutrophication potential of steel products

5.2.5 Photochemical ozone creation potential, POCP

The POCP for the three products described above is shown in Figure 10.

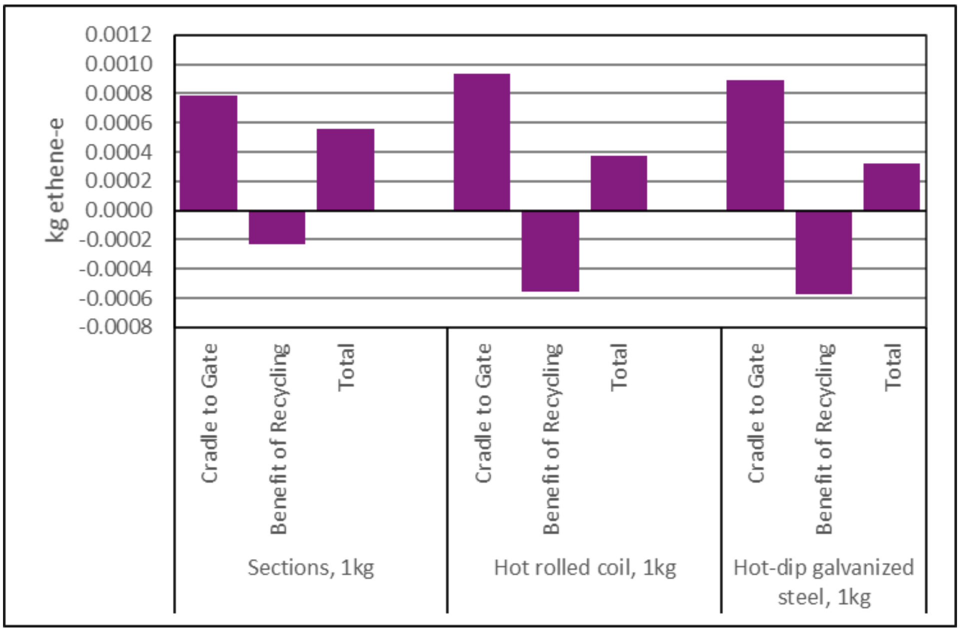


Figure 10: Photochemical ozone creation potential (C_2H_4-e) of steel products

The photochemical ozone creation potential for steel products is dominated by carbon monoxide, which accounts for over 64% of the contribution to this impact. All other major substances contributing to the POCP are shown in Figure 11.

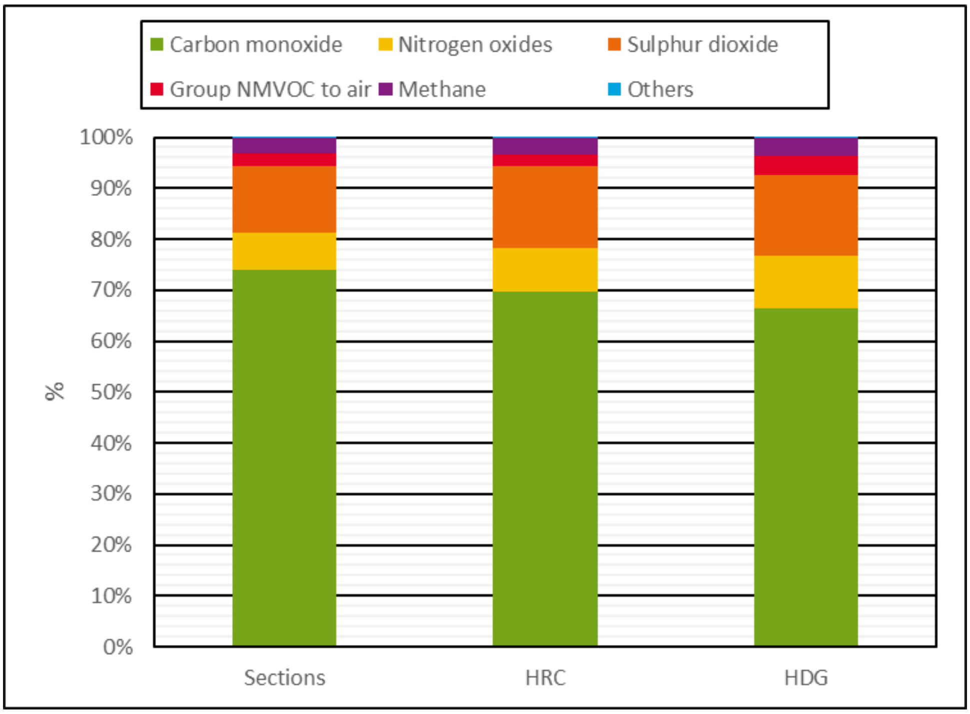


Figure 11: Contributions to POCP of steel products

5.3 Breakdown of where impacts arise for Selected Steel Products.

The analysis shown below in Figure 12, Figure 13 and Figure 14 for sections, hot rolled coil and hot dipped galvanised coil, show where environmental impacts occur in the overall production of a steel product. The data has been broken down to group the information so that for on-site production it has been separated into steel making with ancillaries (up to slab) as one group and further processing for the downstream processing of the steel slab into products such as sections / HRC / HDG into another group. Co-product debits and credits are shown as three groups: slags, process gases and other co-products. Upstream impacts are also broken down into electricity, coal, raw materials and intermediate products (i.e. coke, sinter, pellet, DRI, hot metal or slab purchased from other steel making sources). Finally, transport impacts for the main raw materials to the steel making site is accounted for in the transport group.

The impact assessment suite chosen is the CML 2016 suite of impacts, as used elsewhere in this report, and the charts show 11 of the impacts that can be calculated, namely Abiotic Depletion (ADP elements), Abiotic Depletion (ADP fossil), Acidification Potential (AP), Eutrophication Potential (EP), Freshwater Aquatic Ecotoxicity Potential (FAETP), Global Warming Potential (GWP 100 years), Human Toxicity Potential (HTP), Marine Aquatic Ecotoxicity Potential (MAETP), Ozone Layer Depletion Potential (ODP), Photochemical Ozone Creation Potential (POCP) and Terrestric Ecotoxicity Potential (TETP).

The results show that there is a range of outputs depending on the product being looked at and also that the different stages of the production processes can contribute to a greater or lesser degree depending on the product selected and the impact being looked at. This shows that when looking at the environmental performance of a product, there needs to be an examination of a range of life cycle impacts rather than concentrating only on one impact. This avoids any unintended consequences arising as a result of improvement in one environmental category, which may cause a worse performance in other environmental impacts. This demonstrates the benefits and importance of taking a full life cycle approach.

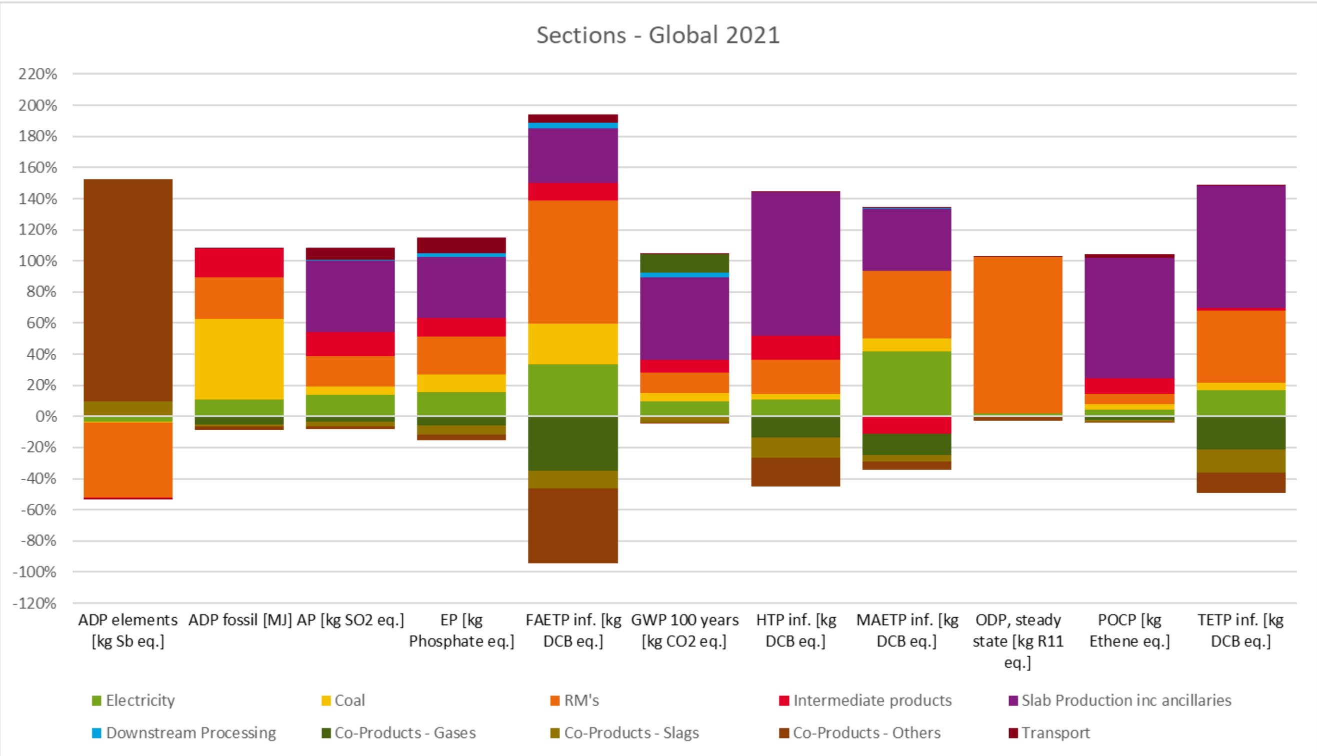


Figure 12: Impacts of steelmaking breakdown - Sections

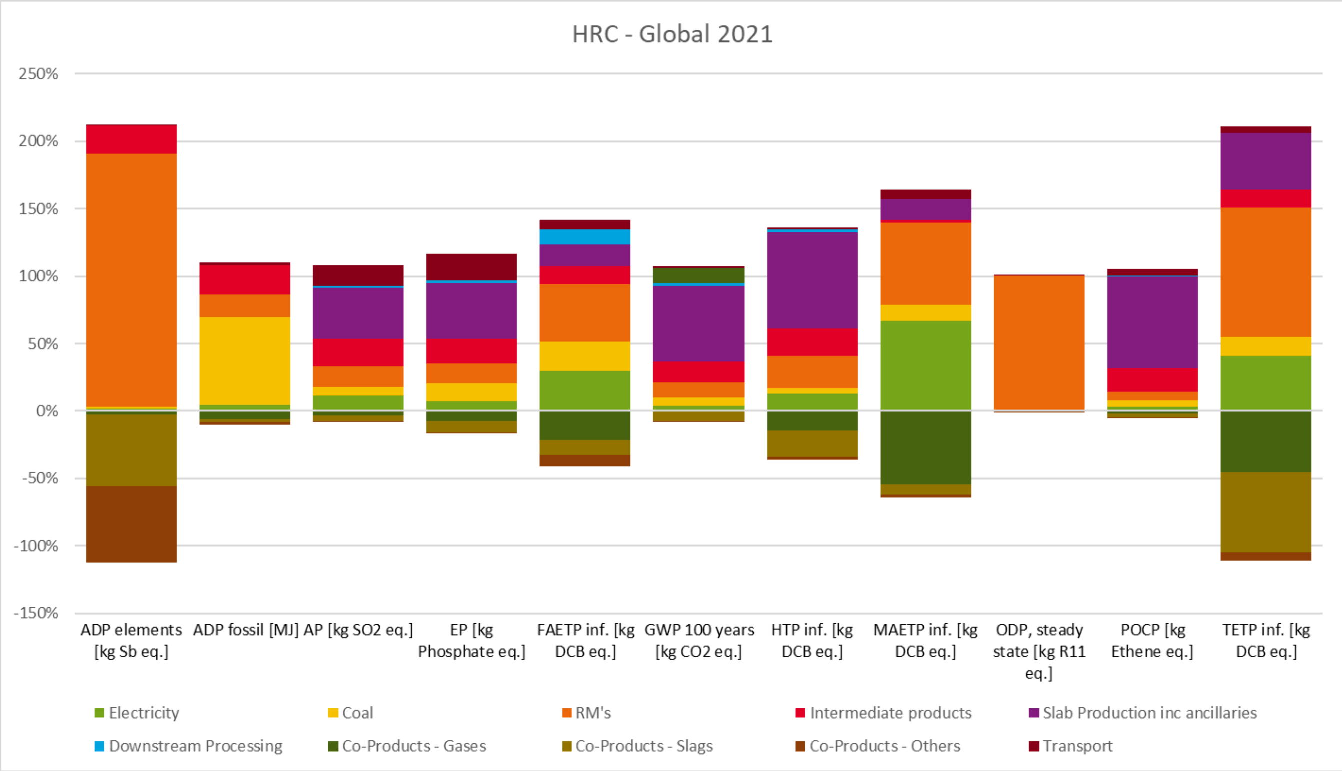


Figure 13: Impacts of steelmaking breakdown – HRC

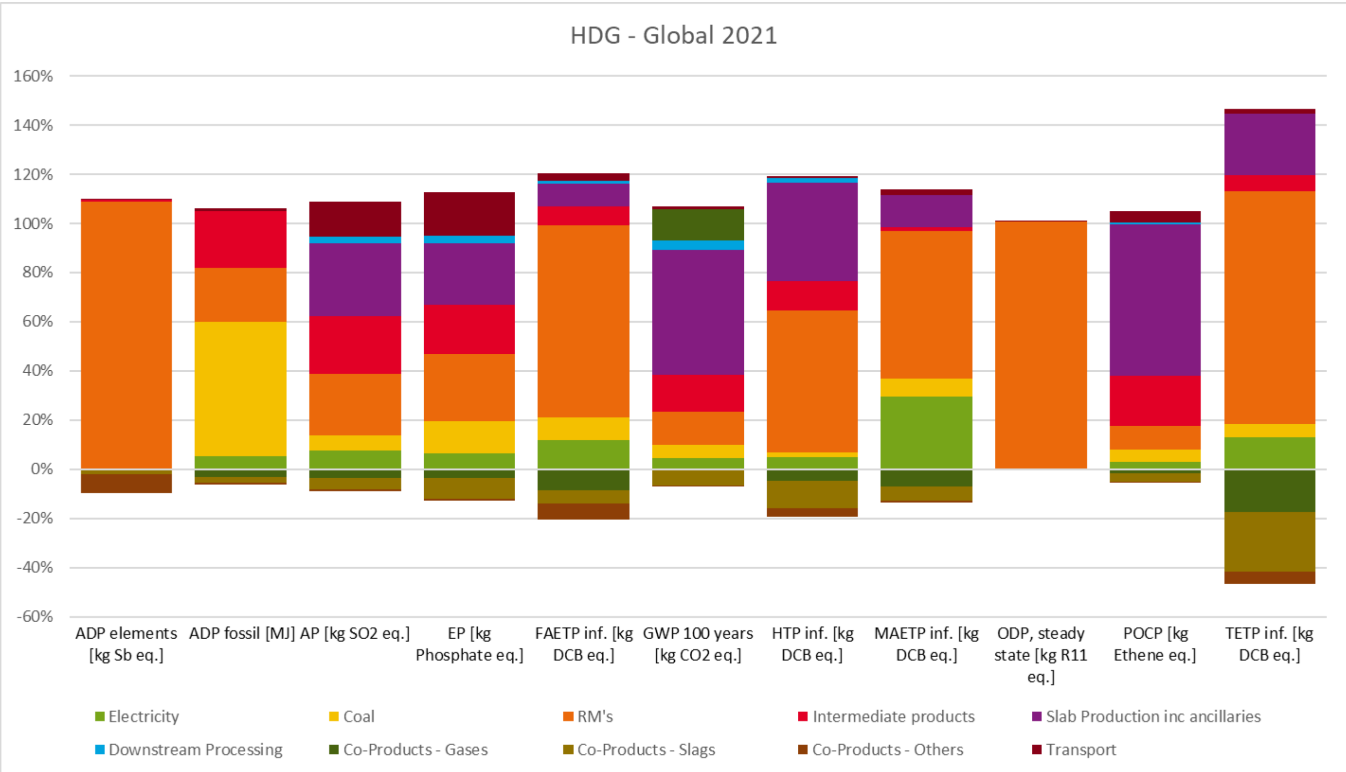


Figure 14: Impacts of steelmaking breakdown - HDG

6 Life cycle interpretation

This section of the report summarises the key contributors to the life cycle study in terms of the life cycle inventory data developed, the impact assessment categories and each of the life cycle stages included in the data.

This includes the main energy sources which contribute to the cradle-to-gate values for the primary energy demand and the main emissions that contribute to the four impact categories: GWP, acidification potential (AP), eutrophication potential (EP), and photochemical ozone creation potential (POCP).

6.1 Identification of significant issues

Figure 15 to Figure 17 show the life cycle contributions to the PED and the four impact categories discussed above, for global steel sections, hot rolled coil and hot-dip galvanised steel. The cradle-to-gate data is the 100% reference data. This is made up from the gate-to-gate data, the contribution from the upstream inputs to the steelmaking process, and the contribution from the co-product allocation. Following this, the end-of-life recycling credits are shown, followed by the overall value which is the cradle-to-gate, including end-of-life recycling. For this report, an example of 85% has been used as the amount of steel that will be recycled at the end-of-life of the steel product. PED, AP and EP are dominated by the upstream contribution, whereas the GWP and POCP impacts have a greater influence from the on-site, gate-to-gate, activities.

Credits for co-product allocation (system expansion) and end-of-life recycling generally reduce the overall impact of the products as shown. For GWP however, this is not the case as the co-product element of the impact is a burden rather than a credit. This is because the combustion of process gases from the steel works has a higher carbon impact than the credit of the fuel that is being replaced. Therefore, the utilisation of system expansion for the process gas exports from the steel industry actually increases the GWP. For steel scrap, if the end-of-life recycling rate is less than the amount of scrap input into the product, this will result in a net increase in the final results.

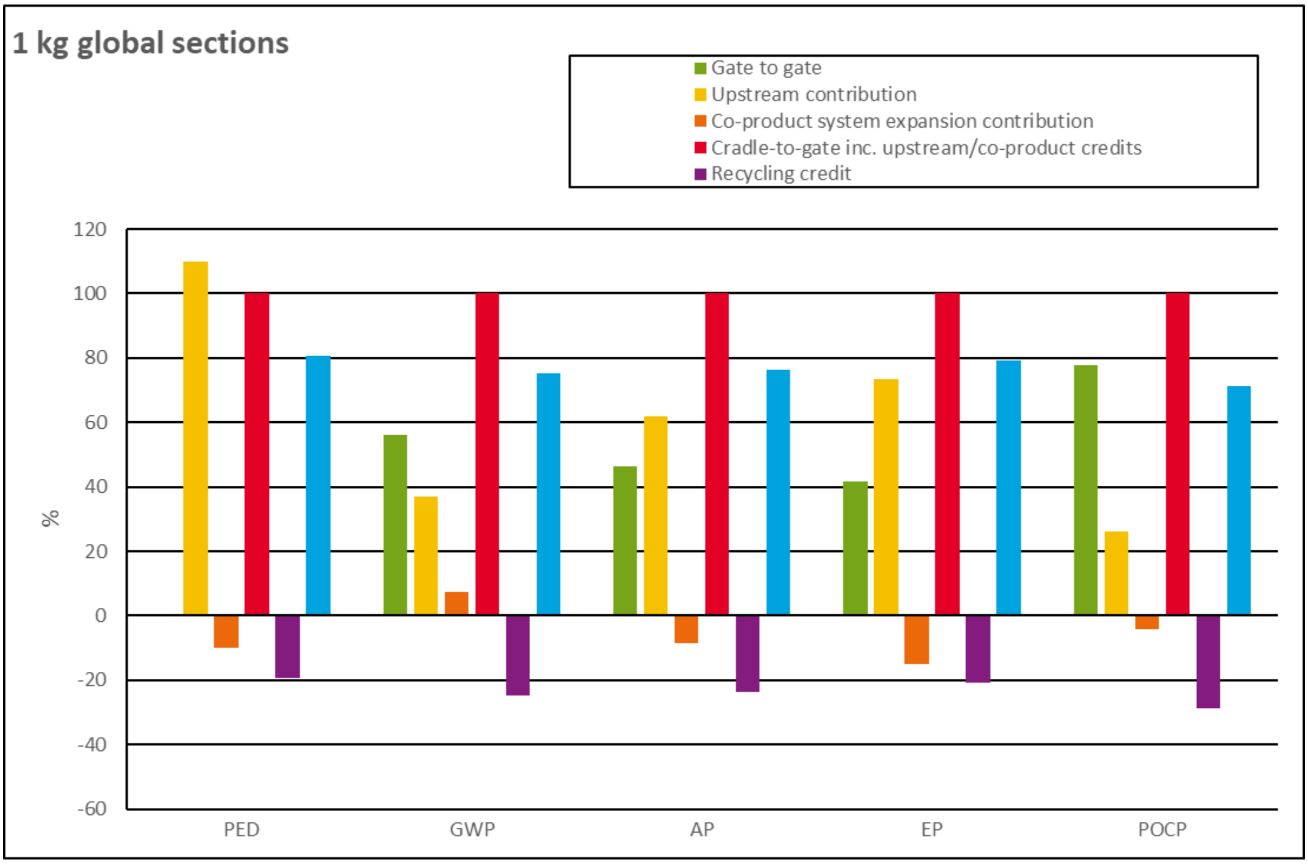


Figure 15: Life cycle contribution to PED and impact categories for sections

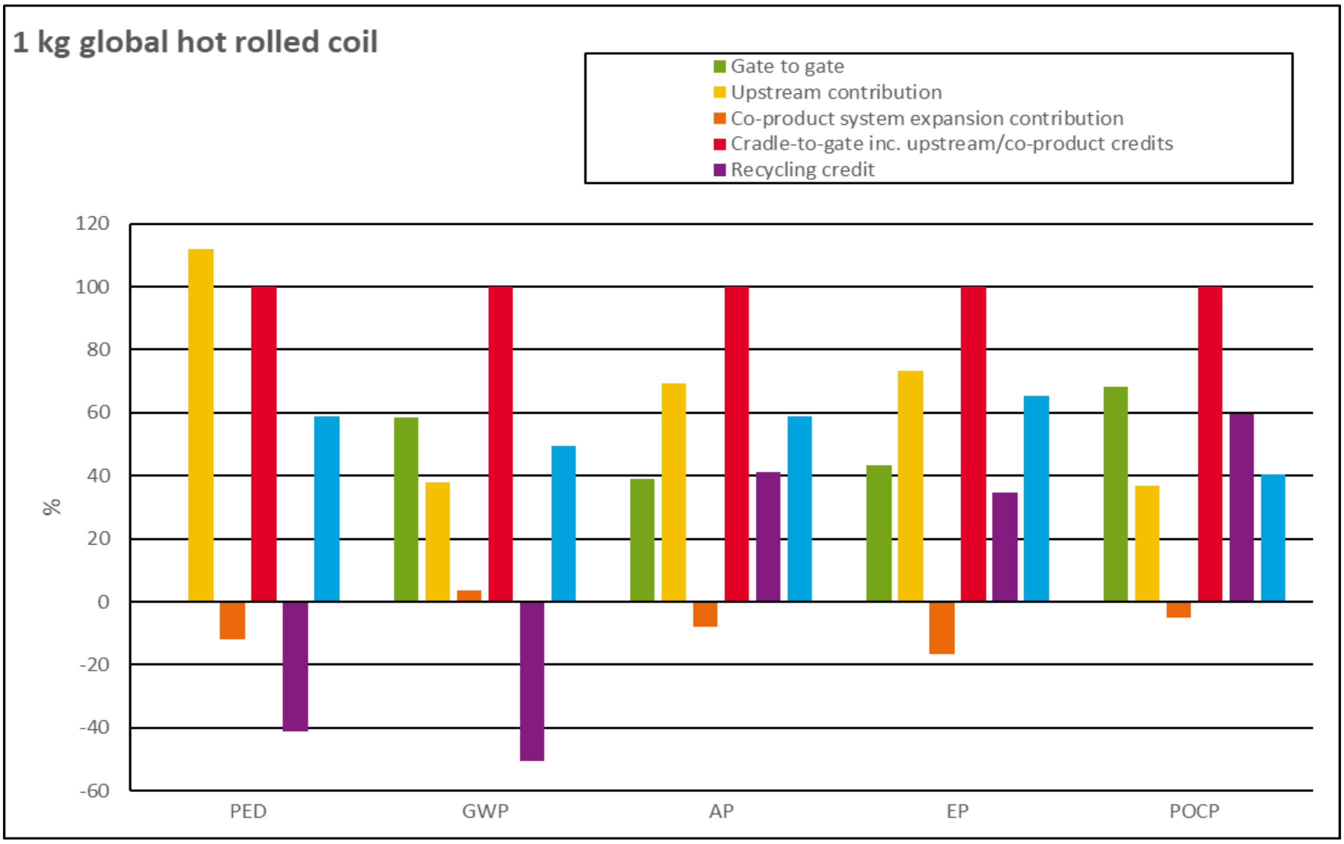


Figure 16 Life cycle contribution to PED and impact categories for HRC

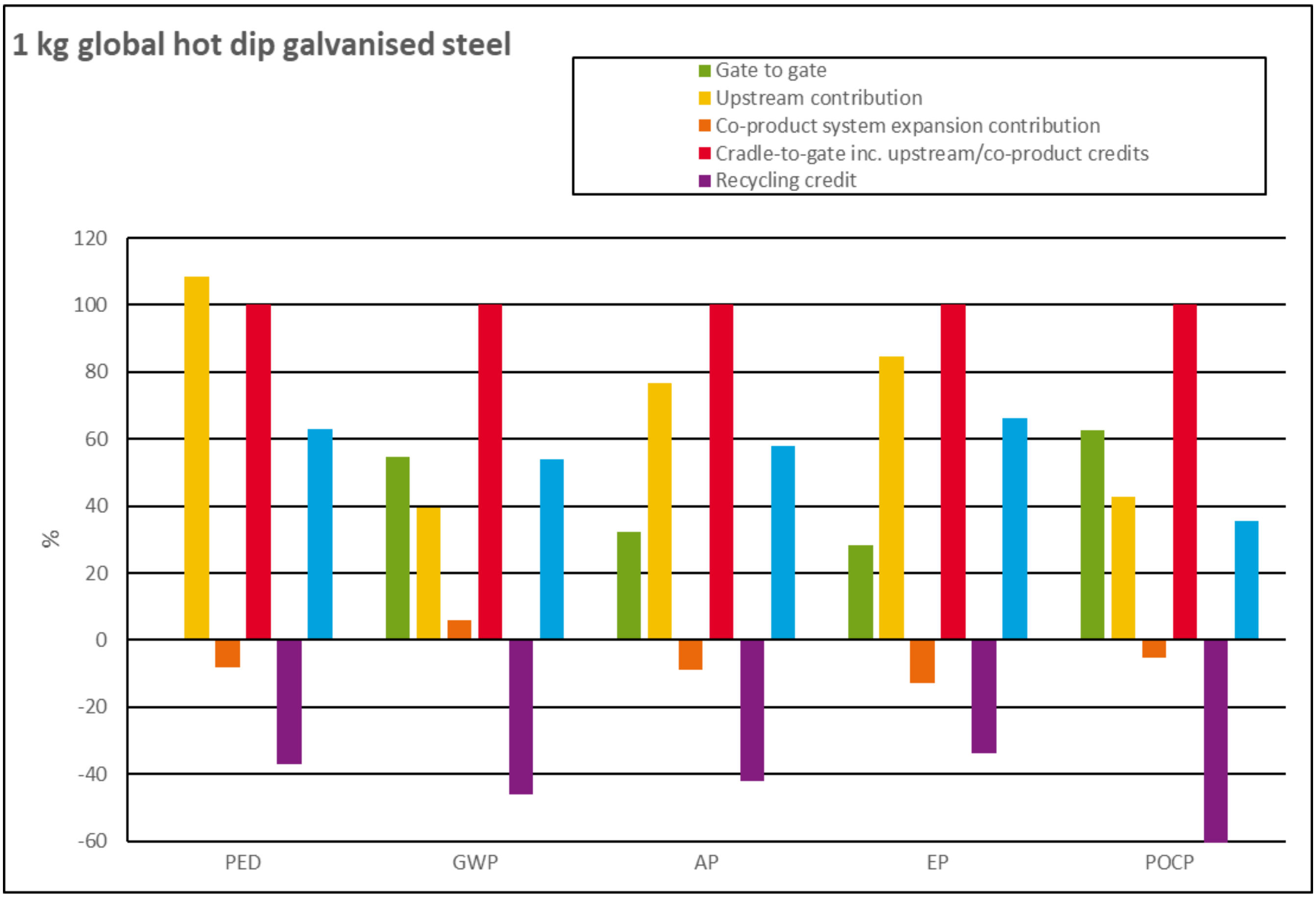


Figure 17 Life cycle contribution to PED and impact categories for HDG

Table 7 summarises the main contributors to each of the impact categories and PED. Steel production is an energy intensive industry and therefore the consumption of energy and electricity are one of the main contributors to the environmental impact of the steelmaking processes. The influence that this has on the LCIA of the product is therefore very much dependent on the geographical location of the steel works, which determines the source of electricity and energy consumption.

<table>
<tr><th>Impact category</th><th>Main contributing input/output</th><th>Main life cycle phase</th><th>Main contributing processes</th></tr>
<tr><td>Primary energy demand</td><td>Hard coal (59 – 77%)
Natural gas (10 – 16%)
Renewables (2 – 5%)</td><td>Upstream (~ 100%)</td><td rowspan="5">Upstream energy: electricity and fuels

Gate-to-gate: steel production processes up to slab production</td></tr>
<tr><td>Global warming potential (100 years)</td><td>Carbon dioxide (94%)
Methane (6%)</td><td>Gate-to-gate (> 55%)
Upstream (> 37%)</td></tr>
<tr><td>Acidification potential</td><td>Sulphur dioxide (68 – 72%)
Nitrogen oxides (27 – 31%)
Others (~1%)</td><td>Gate-to-gate (32 – 46%)
Upstream (62 – 77%)</td></tr>
<tr><td>Eutrophication potential</td><td>Nitrogen oxides (86-92%)
Ammonia (~ 1%)
Nitrous oxide (~ 1%)
Inorganic emissions to fresh water (3-11%)</td><td>Gate-to-gate (28 – 41%)
Upstream (73 – 84%)</td></tr>
<tr><td>Photochemical ozone creation potential</td><td>Carbon monoxide (67– 74%)
Sulphur dioxide (13 – 16 %)
Nitrogen oxides (7 - 10%)
NMVOCs (2 - 4%)
Methane (~3%)</td><td>Gate-to-gate (62 – 77%)
Upstream (26 – 42%)</td></tr>
</table>

Table 7: Life cycle significant flows, phases and processes (excluding end-of-life phase)

Including the end-of-life recyclability of the steel products within the LCI gives the overall life cycle impact of a steel-containing product or service excluding the final product manufacturing, use, reuse, maintenance and dismantling phases.

6.2 Completeness, sensitivity analysis and consistency checks

6.2.1 Completeness

Within the worldsteel LCI model, completeness checks were carried out at the gate-to-gate level in order to analyse:

- the completeness of data provided for each of the steelmaking processes
- the coverage of relevant energy and material inputs for each steel product
- the coverage of significant outputs (accounted emissions), co-products and wastes

Following these checks, cradle-to-gate completeness checks were then made to ensure coverage of all significant upstream data.

6.2.2 Sensitivity analysis

In any LCI methodology, certain assumptions and methodological choices have to be made. For the worldsteel methodology, a sensitivity analysis of three of these such decisions has been carried out in the past and is described below. The three aspects which were chosen are:

- system expansion: the treatment of co-products is one of the key methodological issues, particularly as the steel industry co-products are valuable and widely used.
- internal transportation: only fuel consumption (e.g. diesel, propane etc) is included
- packaging: packaging materials are excluded from the study except steel strap.

Each of these aspects are addressed in more detail below.

The recycling of steel scrap at the end of a product's life is another key aspect of the worldsteel methodology. This has not been included as part of the sensitivity analysis but the impact of including end-of-life recycling can be seen in the graphs in Section 5 and Section 6. In addition, the recycling methodology has been discussed in detail in the 2017 worldsteel LCI methodology report, Appendix 10.

6.2.2.1 Sensitivity analysis on system expansion

The relevance of applying system expansion to the co-products from the steelmaking process was analysed. The reasoning behind using system expansion has been described in section 3.6. The three products have been selected to cover a wide range of steel product applications.

	Cradle-to-gate data	GWP	PED
		Kg CO_2-e	MJ
Sections, 1kg	**Excluding system expansion**	1.79	24.31
	Including system expansion	1.92	21.84
	% Difference	7.16%	-10.17%
Hot rolled coil, 1kg	**Excluding system expansion**	2.22	28.44
	Including system expansion	2.30	25.21
	% Difference	3.25%	-11.36%
Hot-dip galvanized steel, 1kg	**Excluding system expansion**	2.46	31.45
	Including system expansion	2.59	28.78
	% Difference	5.45%	-8.46%

Table 8: Sensitivity analysis of system expansion

Table 8 shows the influence that system expansion has on the worldsteel LCI data. This also demonstrates that the steel industry co-products are valuable, whether in the form of replacing raw materials for cement, roadstone, fertiliser etc., or as a replacement for energy sources both within or external to the steelmaking site, or for export for electricity generation.

The contribution of system expansion to the GWP is +3 to 7%. Due to the relatively high carbon intensity of the process gases generated in the BOF route, when they are used to replace other energy sources with a lower carbon intensity, this will result in an additional burden being applied on the steel LCI and not a credit. The EAF production route does not produce process gases (but might use them if co-located on a BOF production route site, or with an alternative iron making process) and so products made by this route would not result in an increase in the GWP.

The contribution of system expansion to the PED ranges between -8 and -11%. This is due to the recovery of the co-products from the carbon intensive processes (coke oven, BF, BOF, alternative iron making) that can then be reused on-site or exported off-site, reducing the need for alternative energy to be produced and used.

These process gases have good calorific value and can thus be recovered very effectively. The steel sections see a lower benefit to PED as the product is made in both the BOF and the EAF and the EAF does not generate or therefore recover process gases. The more complex product, HDG steel, has a lower percentage difference because the more complex processing steps consume the process gases internally and so there is less that will be credited for further use on-site or exported.

PED and GWP are both very important aspects to be considered for steelmaking due to the energy intensity and carbon intensity of the steel industry. Other typical impact categories that are often considered in LCA studies include AP, POCP and EP, but these are not currently as relevant for the steel industry and are described further in Section 5.

Therefore, as the implementation of the system expansion method can lead to both positive and negative differences between impacts and when comparing this method with the cut-off approach (an alternative methodology where the results are likely to have the greatest difference), it was found that the overall decision to use system expansion gives a balanced picture of the shared impacts between the steel products and the co-products. The system expansion approach also allows a consistent approach to be used for all steel industry co-products, which is not always possible with other allocation methodologies.

6.2.2.2 Sensitivity analysis on internal transport

The environmental burden of internal transportation is very small. For the 2019 study, a new calculation of the internal transport impacts was made. An average energy requirement per kg crude steel was found to be 0.0035 MJ from internal diesel, gasoline and LPG consumption. For this study, the combustion of the internal transport fuels such as diesel, gasoline and LPG for on-site vehicles has been included for the first time. Modelling of the combustion impacts of these fuels has been calculated to produce 0.00024 kg CO_2 per kg crude steel.

6.2.2.3 Sensitivity analysis on packaging

In the previous LCI data collection studies, it was shown that the impacts of packaging materials were negligible. In this study, the packaging of materials supplied to the steelworks is therefore also not included. However, steel strap, which is used to hold a coil together, has been requested and supplied, when available, in the questionnaires, as this material is a steel product and data are often readily available. An upstream burden for hot rolled coil is assigned to the steel strap.

6.2.3 Consistency checks

Details of these are covered in Section 4.

7 Conclusions, limitations and recommendations

This study is representative of over 99% of current steel technologies commercially available worldwide and covers over 28% (535 million tonnes) of the steel production by company on a global basis.

The completeness and accuracy of the data have been vigorously checked to ensure that the data provided are of the highest quality for the global steel industry.

7.1 Conclusions

This study provides LCI data for 17 steel industry products on a global level, of which a number of products are also represented on a regional level (Europe and Asia, see Table 1). The addition of new sites is an ongoing process in order to increase the geographical spread and representativeness of the data. These sites are added as and when data is available.

In a full LCA study, end-of-life scenarios should always be considered. The worldsteel methodology considers the end-of-life recycling of steel products and recommends this method to be used in LCA studies.

7.2 Limitations

The data provided by the steel producers currently relates to steel production from 2016 to 2020. With continuing measures to improve the environmental performance of these companies, it should be noted that some minor improvements will occur over the coming years and these will need to be incorporated into the steel product LCI data in future updates.

In addition, there are a number of companies and regions not fully represented in this study. Nevertheless, efforts are continually ongoing to incorporate these sites within the worldsteel LCI data collection project.

The data and methodology is therefore appropriate for the products that have been listed in the report and for the steelmaking processes via the BOF steelmaking route and the EAF steelmaking route. It is not appropriate for other approaches such as open-hearth furnace steelmaking. The data should not be used for stainless steel products.

7.3 Recommendations for uses of the data

When an LCA study is to be conducted including steel LCI data, it is preferable that the practitioner contacts worldsteel to ensure that the appropriate steel product is used and that the methodological conditions are understood, in particular with respect to the end-of-life recycling of steel products.

A detailed description of the products available from worldsteel is provided in Appendix 1 and a matrix of possible uses for each product is provided in Appendix 11. As steel is a globally traded commodity, using global average data is appropriate for many studies. Regional data is also provided where a preference for regional production is made. Company specific data is not available from worldsteel.

The results from the study reflect global steel production from 2016 to 2020 and new companies and sites are continually joining the worldsteel data collection project. The worldsteel steel LCI datasets will be updated on an annual basis to include any new and updated site data. The latest LCI data is available via worldsteel.org.

The World Steel Association endeavours to provide the datasets to LCA software tools and databases in order that can be used as easily as possible. Care should be taken to ensure that the correct steel product is selected and the methodology fully understood.

8 Appendices

APPENDIX 1: DESCRIPTION OF STEEL PRODUCTS COVERED BY THE STUDY

APPENDIX 2: REPRESENTATION OF THE BOF PROCESS

APPENDIX 3: LIST OF PARTICIPATING COMPANIES

APPENDIX 4: EXAMPLE DATA COLLECTION QUESTIONNAIRE

APPENDIX 5: LIST OF UPSTREAM INPUTS AND THEIR SOURCES

APPENDIX 6: ELECTRICITY GRID MIX INFORMATION

APPENDIX 7: STEEL LCI DATA EXPLANATION

APPENDIX 8: SYSTEM EXPANSION ASSUMPTIONS

APPENDIX 9: UPDATES FROM THE 2018 STUDY REPORT

APPENDIX 10: LIST OF ALL AVAILABLE QUESTIONNAIRES

APPENDIX 11: MATRIX OF USES OF STEEL PRODUCTS

APPENDIX 12: CRITICAL REVIEW: WORLD STEEL ASSOCIATION LIFE CYCLE INVENTORY STUDY FOR STEEL PRODUCTS

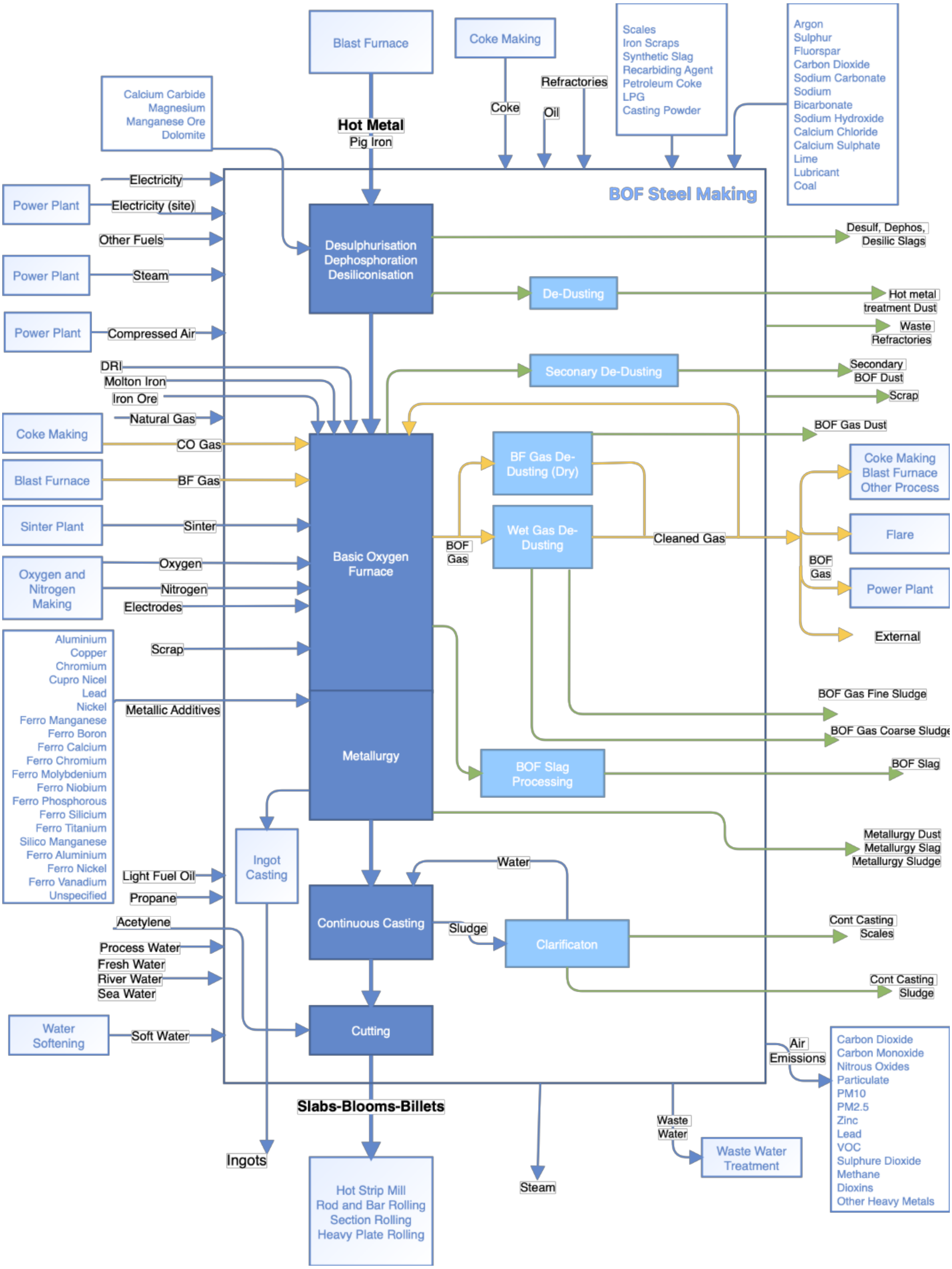
APPENDIX 1: DESCRIPTION OF STEEL PRODUCTS COVERED BY THE STUDY

Product	Product Description
Plate	A flat steel sheet rolled on a hot rolling mill; can be further processed. Includes use in the following sectors: structural steels, shipbuilding, pipes, pressure vessels, boilers, heavy metal structures, offshore structures etc. Typical thickness between 2 to 20 mm. The maximum width is 1860 mm.
Hot rolled coil	Steel coil rolled on a hot-strip mill; can be further processed. Applications in virtually all sectors of industry: transport, construction, shipbuilding, gas containers, pressure vessels, energy pipelines, etc. Typical thickness between 2 - 7 mm. Typical width between 600 - 2100 mm
Pickled hot rolled coil	Hot rolled steel from which the iron oxides present at the surface have been removed in a pickling process; can be further processed. Applications in virtually all sectors of industry: transport, construction, shipbuilding, gas containers, pressure vessels, energy pipelines, etc. Typical thickness between 2 - 7 mm. Typical width between 600 - 2100 mm
Cold rolled coil	Obtained by a further thickness reduction of a pickled hot rolled coil. This step is achieved at low temperature in a cold-reduction mill; can be further processed. Used as primary material for finished cold rolled coils and coated coils. Typical thickness between 0.15 - 3 mm. Typical width between 600 - 2100 mm
Finished cold rolled coil	Obtained by heat treatment (annealing) and strain-hardening of cold rolled steel in a way to achieve final mechanical properties making the steel suitable for further uses (forming and bending); can be further processed. Classified into the following: formable steels, high strength formable steels, weathering structural steels, structural steels, hardenable steels. They have excellent forming properties, electromagnetic properties, paintability, weldability, and are suitable for fabrication by forming, pressing and bending. Applications include domestic applications, automotive applications, lighting fixtures, electrical components (stators, rotors) and various kinds of sections roofing applications, profiled sheets, wall elements, etc. Typical thickness between 0.3 - 3 mm. Typical width between 600 - 2100 mm.

Hot-dip galvanized steel	Obtained by passing cold rolled coil through a molten zinc bath, in order to coat the steel with a thin layer of zinc to provide corrosion resistance; can be further processed. They have excellent forming properties, paintability, weldability, and are suitable for fabrication by forming, pressing and bending. Applications include domestic applications, building applications (e.g. wall elements, roofing applications), automotive applications (e.g. body in white for vehicles underbody auto parts), lighting fixtures, drums and various kinds of sections applications, profiled sheets, etc. Typical thickness between 0.3 - 3 mm. Typical width between 600 - 2100 mm.
Electrogalvanized steel	Obtained by electro plating finished cold rolled steel with a thin layer of zinc or zinc-nickel to provide corrosion resistance; can be further processed. They have excellent forming properties, paintability, weldability, and are suitable for fabrication by forming, pressing and bending. Applications include domestic applications, building applications (e.g. wall elements, roofing applications), automotive applications (e.g. body in white for vehicles underbody auto parts), lighting fixtures, drums and various kinds of sections applications, profiled sheets, etc. Typical thickness between 0.3 - 3 mm. Typical width between 600 - 2100 mm.
Rebar	A steel reinforcing bar is rolled on a hot rolling mill; can be further processed. This product is used to strengthen concrete in highway and building construction also as primary product for the wire rod process.
Engineering steel (Tool steel)	Engineering Steel is rolled on a Hot Rolling mill. It can be found on the market and is further processed into finished products by the manufacturers This steel is used in the manufacture of tools, dies, components for engines, drives, equipment, transmissions, etc.
Sections	A steel section rolled on a hot rolling mill. Steel Sections include I-beams, H-beams, wide-flange beams, and sheet piling. This product is used in construction, multi-story buildings, industrial buildings, bridge trusses, vertical highway supports, and riverbank reinforcement.
Welded pipe	A flat plate steel coil that is bended and welded into a tube. It can be found on the market for final use. A heavy-wall pipe is technically used to transport fluids (e.g. oil, gases, water, chemicals).
Seamless Pipe	The seamless pipe is manufactured using a process called “extrusion”. During this process a solid steel bar is pierced though the centre using a die, turning

	the solid steel into a tube which is processed into the correct shape and dimensions. They have an advantage in aggressive environments as there is no weld.
UO Pipe	UO pipe is usually large in diameter and produced one piece at a time by forming plates. The plate is first pressed into a U shape by the U-press, and then into an O shape by the O-press. Because relatively thick material is used for making UO pipes, submerged arc welding is used for joining. UO pipe is mainly used as line pipe for transporting petroleum and natural gas in large quantity over long distances.
Wire rod	Wire rod is a rolled steel product, produced from a semi and having a round, rectangular or other cross-section. Particularly fine cross-sections may be achieved by subsequent cold forming (drawing). Wire rod is wound into coils and transported in this form.
Tinplate	Obtained by electro plating a thin finished cold rolled coil with a thin layer of tin. It can be found on the market in coil or in sheets and is further processed into finished products by the manufacturers. Tin plated steel is used primarily in food cans, industrial packaging (e.g. small drums) Typical thickness between 0.13 - 0.49 mm. Typical width between 600 - 1100 mm.
Tin-free (ECCS)	Also known as Electrolytic Chrome Coated Steel (ECCS). Obtained by electro plating a thin finished cold rolled coil with a thin layer of chrome. It can be found on the market in coil or in sheets and is further processed into finished products by the manufacturers. ECCS is used primarily in food cans, industrial packaging (e.g. small drums). Typical thickness between 0.13 - 0.49 mm. Typical width between 600 - 1100 mm
Organic coated	Obtained by coating a steel substrate with organic layers such as paint or laminated film. The substrate is mainly hot-dip galvanized coil but may also be electrogalvanized coil, finished cold rolled coil or tin-free steel. It can be found on the market in coil or in sheets and is further processed into finished products by the manufacturers. Used in all activity sectors e.g. construction (roof, wall and ceiling claddings, lighting, radiators etc.), general industry (e.g. office furniture, heating, ventilating, air conditioning), domestic appliances (refrigerators, washing machines, small kitchen appliances, computer casings & DVD casings, etc.) and packaging. Typical thickness between 0.15 - 1.5 mm. Typical width between 600 - 1300 mm

APPENDIX 2: REPRESENTATION OF THE BOF PROCESS

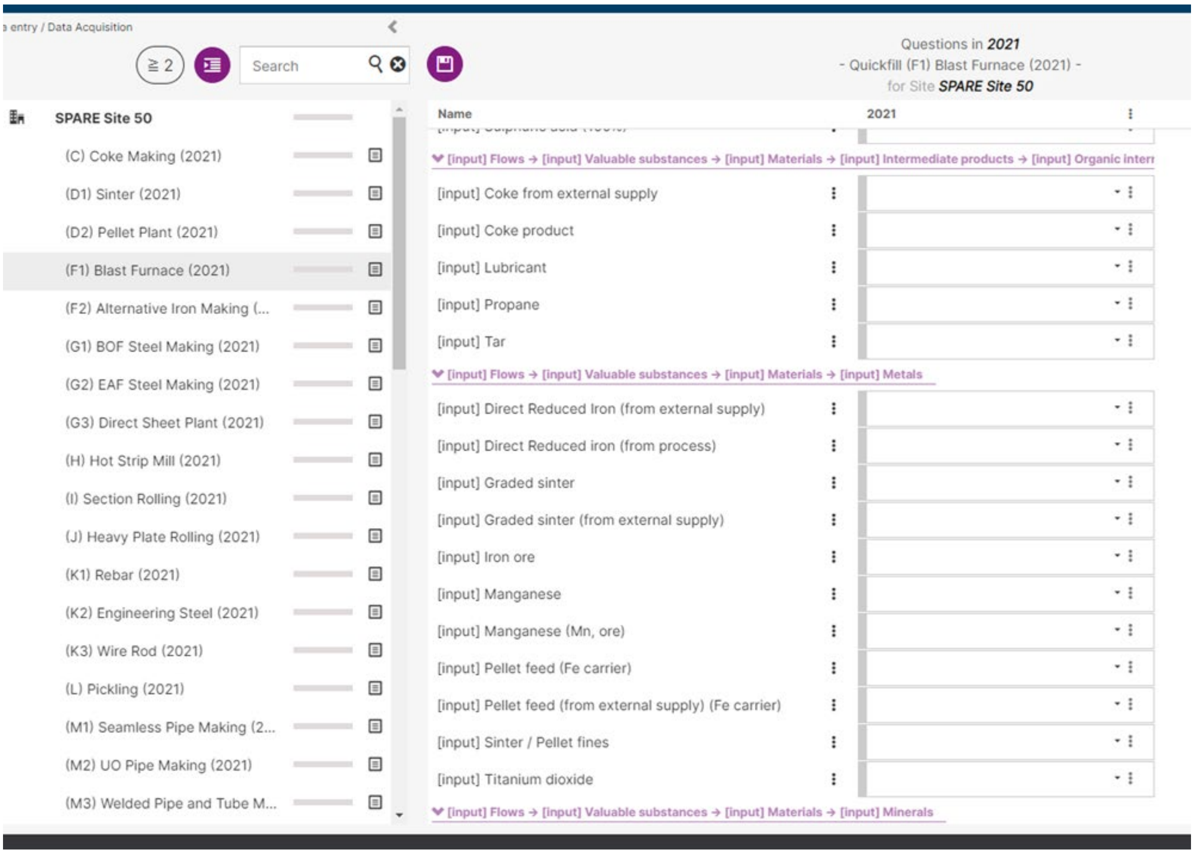


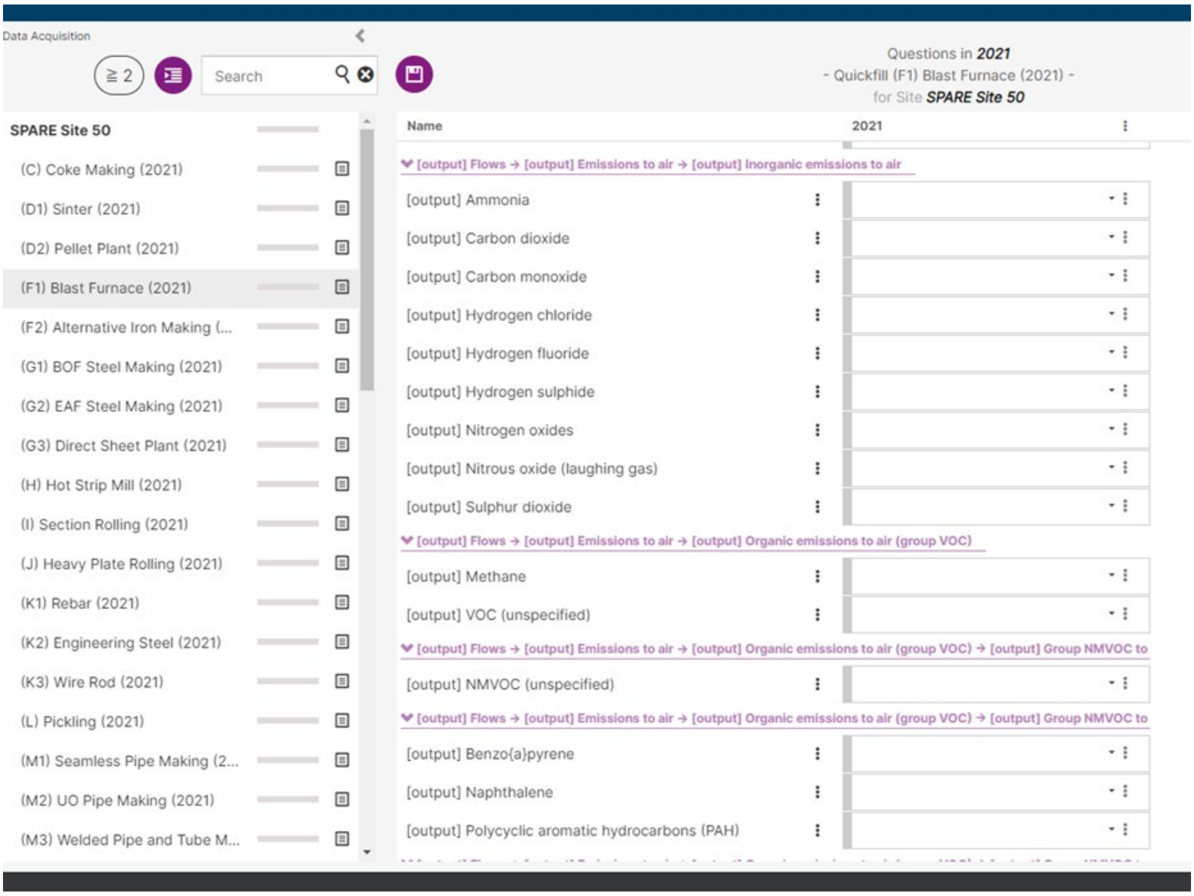
APPENDIX 3: LIST OF PARTICIPATING COMPANIES

The companies that contributed to the data released at the end of 2021 are listed below:

Aichi Steel	NLMK
ArcelorMittal	Osaka Steel
BlueScope	POSCO
British Steel	SABIC
China Baowu Group	SAIL
Daido Steel	Sanyo Special Steel
Ezz Steel	Severstal
Godo Steel	Shimizu Steel Tomakomai
Hadeed	SSAB
HBIS	Sahaviriya Steel Industries (SSI)
Itoh Ironworks Corp	Tata Steel
JFE Steel	Tenaris
JSW	Ternium
Kobe Steel	ThyssenKrupp Steel
Kyoei Steel	Tokyo Kohtetsu
Liberty Steel	Tokyotekko
Nucor	Topy Industries
Nippon Steel	voestalpine
NatSteel Holdings	

APPENDIX 4: EXAMPLE DATA COLLECTION QUESTIONNAIRE





APPENDIX 5: LIST OF UPSTREAM INPUTS AND THEIR DATA SOURCES

Item	Process Information	Country	Year	Source
Acetylene	Ethine (acetylene), SACHSSE-BARTHOLOME process	DE	2020	Sphera
Activated carbon	Activated carbon is the collective name for a group of porous carbons. They all have small amounts of chemically bonded oxygen and hydrogen and contain up to 20 % mineral matter	DE	2020	Sphera
Aluminium	Aluminium ingot mix IAI 2015. Aluminium ingot production based on data from the International Aluminium Institute (IAI).	GLO	2015	IAI
Aluminium chloride	Aluminium chloride hexahydrate	DE	2020	Sphera
Aluminium foil	Data is primarily from 2005 sources with energy mixes and ingot imports from 2009. The foil production process itself is based on European production and corresponds to a foil thickness of 5-200 micro metres.	EU-28	2020	Sphera
Aluminium sulphate	Aluminium sulphate	DE	2020	Sphera
Alumix	Proxy using Aluminium ingot mix IAI 2015. Aluminium ingot production based on data from the International Aluminium Institute (IAI).	GLO	2015	IAI
Ammonia	Ammonia is produced almost exclusively by the well-known HABER-BOSCH process.	EU-28	2020	Sphera

Ammonium sulphate	Ammonium sulphate mix (by-product)	DE	2020	Sphera
Anthracite	Country specific data, based on hard coal mix for each country	Country specific	2017	Sphera
Argon	Gaseous, LINDE process	DE	2020	Sphera
Bauxite	Opencast and underground mining	EU-28	2020	Sphera
Benzene	technology mix, from pyrolysis gasoline, reformate and toluene dealkylation	EU-28	2020	Sphera
BOF slab	1kg global BOF slab, weighted average	GLO	2021	worldsteel
Calcium chloride	(from epichlorohydrine synthesis)	DE	2020	Sphera
Carbon dioxide	From HABER-BOSCH process (ammonia synthesis, NH3/CO2)	DE	2020	Sphera
Catalyst	Ethylene glycol	EU-28	2020	Sphera
Cement	Cement (CEM I 42.5) (EN15804 A1-A3)	EU-28	2020	Sphera
Charcoal	Site data for production	GLO	2020	worldsteel
Coal	Country specific data, based on hard coal mix for each country	Country specific	2017	Sphera
Coal for coke making	Coking coal global consumption mix including transport to border of country of production	GLO	2017	Sphera
Coal for injection	Country specific data, based on hard coal mix for each country	Country specific	2017	Sphera
Coke	1kg global coke, weighted average	GLO	2021	worldsteel
Copper	Global copper mix: electrolyte copper 99,99% world -mix. Outokumpu was modelled for Chile, ISA smelt for Australia and the Mitsubishi process for Indonesia.	GLO	2020	Sphera

Corrugated board	EU-27: Corrugated board incl. paper production, average composition 2015 ts/FEFCO	EU-27	2020	Sphera
Diesel	Country/region specific	Country/region specific	2017	Sphera
Diesel (high Sulphur)	Country/region specific	Country/region specific	2017	Sphera
Diesel (low Sulphur)	Country/region specific	Country/region specific	2017	Sphera
Direct Reduced Iron	1kg global DRI, weighted average	GLO	2021	worldsteel
Dolomite	Decarboxylation process by burning mined dolomite	EU-28	2020	Sphera
Dolomite (crude)	Dolomite extraction	DE	2020	Sphera
EAF Slab	1kg global EAF slab, weighted average	GLO	2021	worldsteel
Electricity	See Appendix 6 – Country specific	Country specific	2017	Sphera
Electrode	baking petrol coke, pitch and hard coal tar	ZA	2020	Sphera
Embankment	Gravel (Grain size 2/32) (EN15804 A1-A3)	DE	2020	Sphera
Ferric chloride	direct chlorination of iron scrap	DE	2020	Sphera
Ferro chrome	Ferro Chromium (high carbon)	GLO	2020	Sphera
Ferro manganese	Production of ferro-manganese (77% Mn) with high carbon content.	ZA	2020	Sphera

Ferro molybdenum	Ferro molybdenum (67% Mo)	GLO	2017	IMOA
Ferro nickel	Ferro nickel (29% Ni)	GLO	2020	Sphera
Ferro silicum	Ferro silicon mix (91%)	GLO	2020	Sphera
Ferro vanadium	Ferro vanadium (FeV 80%)	ZA	2020	Sphera
Ferrous sulphate	Iron (II) sulphate	EU-28	2020	Sphera
Gasket (seal)	EPDM gaskets for aluminium profile (EN15804 A1-A3)	DE	2020	Sphera
Gasoline	from crude oil and bio components	EU-28	2017	Sphera
Glass wool	For glass wool production, the pure mineral primary glass is melted in a melting vat at approx. 1400°C	EU-28	2020	Sphera
Glue	Mixer of Methylenediphenyl diisocyanate ((p)MDI) and Aromatic Polyester Polyols (APP) production mix	EU-28	2014	Sphera
Heavy fuel oil	Country/region specific	Country/region specific	2017	Sphera
Hot metal	1kg global hot metal, weighted average	GLO	2021	worldsteel
Hydrochloric acid	100% hydrochloric acid mix. The 'mix' process considers the technologies involved in the production of hydrochloric acid, based on the technology distribution of the respective technology for the country.	DE	2020	Sphera
Hydrogen	Steam reforming - natural gas	EU-28	2020	Sphera
Hydrogen peroxide	50% H_2O_2. Anthraquinone process	DE	2020	Sphera

Iron Ore	worldsteel production mix of 4 Sphera datasets	GLO	2021	Sphera
Iron Sands	Proxy process to emulate iron rich sands used as raw material feed	GLO	2021	Sphera
Kerosene	From crude oil	EU-28	2017	Sphera
Lead	Lead (99.995%), primary lead produced on the traditional process route. Does not include lead and zinc recovery.	RNA	2020	Sphera
Light fuel oil	Country/region specific	Country/region specific	2017	Sphera
Lime	Calcination of limestone	DE	2020	Sphera
Limestone	Mining and beneficiation	DE	2020	Sphera
Liquefied petroleum	Liquefied gas (LPG; 70% Propane; 30% Butane), refining process	DE	2017	Sphera
Lubricants	The data set covers the entire supply chain of the refinery products.	EU-28	2017	Sphera
Magnesium	Magnesium Pidgeon process	CN	2020	Sphera
Manganese	In this dataset, only the manganese production in South Africa is accounted. 80% of the mining takes place underground and 20% in open cast operations. Typical extraction techniques are drilling, blasting, loading and hauling. The beneficiation is done at the mining site. The manganese ore is crushed and processed. Typical processing steps are washing, sizing and gravity separation. The concentrate is then reduced by intense heating in a calcination process. At temperatures of 850- 1000°C in a reducing atmosphere, the oxidation state of the manganese oxide is reduced from +4 to +2 to be soluble in acid for the electrolysis. Reductants are usually carbon sources, but also other fuels like oil or natural gas are possible. The electrolytic production of 99%	ZA	2020	Sphera

	manganese is done by addition of ammonia and sulphuric acid. The end product is manganese 99%.			
MDI (Isocyanate)	Phosgenation of methylenedianiline	DE	2020	Sphera
Mineral rock wool	Rock wool flat roof plate (120 mm)	DE	2020	Sphera
Natural gas	Country specific data, based on natural gas mix for each country	Country specific	2017	Sphera
Nickel	Global Nickel mix. The data set represents the global situation, focusing on the main technologies, the region specific characteristics and / or import statistics. The data set is a mix of South Africa, Canada, Norway, Australia and Russia.	GLO	2020	Sphera
Nitric acid	98%. Two-step oxidation of ammonia to nitrogen monoxide and further to nitrogen dioxide and the absorption of the latter in water.	DE	2020	Sphera
Nitrogen	Air and power to produce gaseous nitrogen, country specific	-	2007	Sphera
Olivine	Silica sand (Excavation and processing)	DE	2020	Sphera
Oxygen	Air, cooling water and power to produce gaseous oxygen, country specific		2007	Sphera
Paint (epoxy, melamine)	Mix of three powder coating upstreams, red, black and white	DE	2020	Sphera
Paint (epoxy, phenolic)	Mix of three powder coating upstreams, red, black and white	DE	2020	Sphera
Paint (polyester, melamine)	Mix of three powder coating upstreams, red, black and white	DE	2020	Sphera

Paint (polyurethane)	Mix of water and solvent based primer	DE	2020	Sphera
Paint (polyvinyl chloride)	Underbody protection PVC	DE	2020	Sphera
Paint (silicon modified polyester)	Mix of Coating water-based red, black and white	DE	2020	Sphera
Paint (PVDF, acrylic)	Mix of Coating solvent-based red, black and white	DE	2020	Sphera
Pellet	1kg global pellet, weighted average	GLO	2021	worldsteel
Pentane	estimated via Butane	EU-28	2020	Sphera
Petroleum coke	Country / region specific data, based on hard coal mix for each country	Country / region specific	2017	Sphera
Phosphoric acid	100%, wet process	DE	2020	Sphera
PMDI	Methylenediphenyl diisocyanate ((p)MDI)	EU-28	2018	Sphera
Polyethylene	Polyethylene low density granulate (PE-LD)	EU-28	2020	Sphera
Polyol	Aromatic Polyester Polyols (APP) production mix	EU-28	2014	PU Europe
Polyvinyl Chloride	PVC is produced by polymerization of vinyl chloride monomer to polyvinyl chloride PVC	DE	2020	Sphera
Propane	Regional specific	Region specific	2017	Sphera
Protection Foil (PE-LD)	Polyethylene Film (PE-LD) without additives	EU-28	2019	Sphera
Quartz sand	Silica sand is mined together with kaolin and feldspar using bucket excavators or bucket	DE	2020	Sphera

	chain dredgers. The material is elutriated and the sand sieved in a multi-step process.			
Refractories (all)	Sand-lime insulation brick	EU-28	2020	Sphera
Sand	Silica sand is mined together with kaolin and feldspar using bucket excavators or bucket chain dredgers. The material is elutriated and the sand sieved in a multi-step process.	DE	2020	Sphera
Serpentine	Mined, as kaolin, normally together with silica sand and feldspar using bucket excavators or bucket chain dredgers.	DE	2020	Sphera
Silico Manganese	Ferro-manganese high carbon proxy	ZA	2020	Sphera
Silicon mix	Purified, electric arc furnace process, from quartz sand	GLO	2020	Sphera
Sinter	1kg global sinter, weighted average	GLO	2021	worldsteel
Sinter/pellet fines	1kg global sinter, weighted average	GLO	2021	worldsteel
Sodium carbonate	Soda (Na_2CO_3), produced by the Solvay process	DE	2020	Sphera
Sodium chloride	Rock salt is obtained from salt mines by use of machines or leaching techniques.	EU-28	2020	Sphera
Sodium hydroxide	100% caustic soda from brine extraction, electrolysis and purification	EU-28	2020	Sphera
Sodium hypochlorite	50% solution	DE	2020	Sphera
Sodium sulphate	Sodium sulfate is a by-product in the production of boric acid.	GLO	2020	Sphera
Steam	Process steam from natural gas 85%	EU-28	2017	Sphera

Steel scrap	See section 3.6.2.	GLO	2021	worldsteel
Steel scrap processing	Steel allocation of shredder process inputs and wastes	GLO	2009	worldsteel
Steel strap	1 kg global hot rolled coil, weighted average	GLO	2021	worldsteel
Sulphur	From Crude Oil	EU-28	2017	Sphera
Sulphur dioxide	Sulphur dioxide estimation from oxygen and sulphur production	GLO	2013	Sphera
Sulphuric acid	Oxidation of sulphur over sulphur dioxide to sulphur trioxide (contact procedure in several reactors with different catalysts), loosened in concentrated sulphuric acid in several columns and forms thereby a still higher concentrated sulphuric acid.	EU-28	2020	Sphera
Surface cleaning agent	Non-ionic surfactant (fatty acid derivative)	GLO	2020	Sphera
Synthetic gas	Synthesis gas (H_2:CO = 3:1). Produced from water (steam) and methane (natural gas). The latter can be replaced with other hydrocarbons and mixtures thereof, e.g. naphtha or fuel oils.	DE	2020	Sphera
Tar	Based on hydro-skimming and more complex refineries including hydro treatment, conversion (e.g. cracking) and refining processes	EU-28	2017	Sphera
Thermal energy	Mix of thermal energy from peat and biomass	FI	2017	Sphera
Timber	Timber pine (12% moisture; 10.7% H_2O content) (EN15804 A1-A3)	DE	2020	Sphera
Tin	The dataset represents the 6 largest tin producing countries: Indonesia, Peru, Malaysia, Brazil, China, Belgium and Thailand focusing on the main technologies, the region-specific characteristics and / or import statistics.	GLO	2020	Sphera

Titanium dioxide	Chloride process	EU-28	2020	Sphera
Varnish	Clear coat solvent-based (2K)	DE	2020	Sphera
Zinc	Special high grade zinc	GLO	2020	IZA

APPENDIX 6: ELECTRICITY GRID MIX INFORMATION

The power grid mix that is used for each site is relevant to the location of each steelmaking site, by country. All data has been taken from the GaBi 10.6.0.110 CUP2021.2 software and is listed in more detail below. The data is a cradle-to-gate inventory and is in compliance with ISO 14040: 2006 and 14044: 2006.

Country	Country Code
Argentina	AR
Austria	AT
Australia	AU
Bosnia and Herzegovina	BA
Belgium	BE
Bulgaria	BG
Brazil	BR
Canada	CA
Switzerland	CH
Chile	CL
China	CN
Cyprus	CY
Czech	CZ
Germany	DE
Denmark	DK
Estonia	EE
Spain	ES

Finland	FI
France	FR
United Kingdom	GB
Greece	GR
Hungary	HU
Indonesia	ID
Ireland	IE
India	IN
Iceland	IS
Italy	IT
Japan	JP
Korea	KR
Lithuania	LT
Luxembourg	LU
Latvia	LV
Morocco	MA
Malta	MT
Mexico	MX
Malaysia	MY
Netherlands	NL
Norway	NO

New Zealand	NZ
Poland	PL
Portugal	PT
Romania	RO
Russia	RU
Saudi Arabia	SA
Sweden	SE
Slovenia	SI
Slovakia	SK
Thailand	TH
Turkey	TR
Taiwan	TW
United States of America	US
South Africa	ZA

APPENDIX 7: STEEL LCI DATA EXPLANATION

The function of this section is to explain some of the main features of the datasets and clarify potential ambiguities. Datasets have been produced for all products both globally and regionally, whenever more than three sites contributed. This is necessary to maintain confidentiality between companies and to ensure a minimum level of representativeness.

The datasets are provided as a static report created in the basis of an Envision report which has been generated using the GaBi 10.6.0.110 software and are distributed from a web-based platform via rtf format to enable ease of use of the data. Data can also be provided in the GaBi format and are available in some additional LCA software tools such as SimaPro, OpenLCA etc.

The GaBi Envision reports contain the following information:

8.1 LCI flows

Cradle-to-gate data is given as standard. Data can also be provided including the credits and burdens of steel recycling. This means that a burden is given for the steel scrap that is used in the steelmaking process and a credit for the steel that will be recycled from the final product when it reaches the end of its life. In this case the net recycling credits are also provided separately. The Scrap LCI is also given, which can be used to account for the burden of using steel scrap in the process as well as the credits for recycling steel scrap at the end of the product's life.

Only major flows are shown in the data sheets, namely the major raw materials and the "accounted" emissions (see 2017 worldsteel LCI methodology report section 3.5.4). Information on other flows is also available on request. Where end-of-life recycling has been taken into consideration, the material resource list does not add up to 1 tonne of resources per tonne of steel product due to the credits applied for end-of-life recycling.

The following sections provide more information on some of the main flows provided in the data sheets to understand the resources utilised and emissions produced within the life cycle for steel products of interest.

8.2 Iron (ore)

The mass of iron (ore) in ground is reported in kg of elemental iron and excludes the mass of overburden and the oxide element. The overburden and oxide elements are included in the full steel LCI profiles.

8.3 Steel and Iron scrap

This describes the net quantity of ferrous scrap taking account of imports and exports from the system. It includes both steel and iron scrap (although iron scrap generation and usage is generally small). When the recycling credits and burdens are included, the scrap input is not listed as the associated upstream burden has been included instead.

Ferrous scrap (as defined in the 2017 LCI Methodology Report) includes:

- Scrap input to the steelmaking process – this is the net scrap consumed in the steelmaking process and does not include internally generated scrap.

- Home scrap is considered when the scrap comes from a process which occurs on the steelmaking site, but does not contribute to any of the production stages of the product for which the LCI is provided.

8.4 Water consumption

The fresh water consumption per kg of steel product is listed in the datasets. In addition to the water used directly on site, the water used in the upstream processes is also included. Fresh water used by the steel plants has several origins: namely surface water (river and lake), deep water (e.g. mine water) or "technosphere" sources (other industrial plants, waste water treatment plants, etc.).

Blue water is also reported which is the Ground water and surface water used. It's defined by the Water Footprint Network and is requested by some practitioners.

The quantity of salt water used by the steel plants is recorded with the GaBi model (though not reported specifically in the Envision report). It is mainly used for indirect cooling and therefore it is not contaminated with pollutants coming from the processes.

The full list of water flows is available on request.

8.5 Carbon dioxide emissions

This flow indicates both fossil and mineral sources of CO_2 (e.g. combustion of natural gas, oil, lime calcinations, and the oxidation of coal). In addition to providing CO_2 data, the environmental indicator for global warming potential (100 years) is also provided, for information only, as this is one of the most common indicators currently being requested.

8.6 Particles to air (dust)

This flow includes all types of airborne particulate emissions, including >PM10, 'PM10 – PM2.5', PM 10 and PM 2.5. However, as the data are not always reported in the same format in different regions and countries, this split is not always complete.

8.7 Co-products

During the steelmaking process, there are a number of materials and gases that are produced that have a useful role either within or external to the steelmaking site. These materials that are recovered are referred to as co-products (see Appendix 8) and have been accounted for in the LCI using system expansion and therefore do not appear in the final LCI.

8.8 Waste

Materials that cannot be recovered but which are sent to landfill, incinerated, flared etc. are classified as waste. In order to comply with ILCD, any wastes or recovered materials where the final process step is unknown, have been modelled as connected to a landfill process and the associated impacts included in the overall LCI.

8.9 Primary Energy Demand

Certain material inputs, (e.g. coal, oil etc.) constitute energy as well as mass inputs, which can be calculated based on calorific value. Within the LCI data sheets, the total primary energy demand (including renewable and non-renewable resources) is provided, based on the net (low) calorific value. This information is provided for information only and should not be used in addition to the data provided in the material inputs section of the datasheet.

Total primary energy is the sum of all energy sources which are drawn directly from the earth, such as natural gas, oil, coal, biomass or hydropower energy, and includes non-renewable and renewable energy. Non-renewable energy includes all fossil and mineral primary energy sources, such as natural gas, oil, coal and nuclear energy. Renewable energy includes all other primary energy sources, such as hydropower and biomass.

A full breakdown of energy is available on request.

8.10 Life cycle impacts

Four Life Cycle Impact Assessment Indicators from the CML2001 – Aug. 2016 impact assessment suite are reported for informational purposes only. Global Warming Potential, Acidification Potential, Eutrophication Potential and Photochemical Ozone Creation Potential.

8.11 Other flows not reported

Within the data sheets, only the major raw materials are shown for simplification reasons. Concerning the air and water emissions, all 'accounted' emissions (see Section 4.3.) are reported in the data sheets.

The full list of flows is available on request. Depending on the product, a wide variety of other alloy metals such as copper, manganese and molybdenum can also be used but always in low quantity. Lead can be incorporated in higher quantities in some special products called "free cutting" steels. This was not included in the study due to lack of data. Other natural resources used for the production of crude steel are abundant materials such as sand, sodium chloride and clay.

APPENDIX 8: SYSTEM EXPANSION ASSUMPTIONS

Steel co-product	Co-product function	Avoided production	Data Source
Blast furnace slag, basic oxygen furnace slag, electric arc furnace slag	Cement or clinker production	1 tonne per tonne of cement. Portland cement (CEM I)	GaBi 10.6.0.110 (EU-28)
	Aggregate or roadstone	Gravel production	GaBi 10.6.0.110 (DE)
	Fertiliser	Lime production	GaBi 10.6.0.110 (DE)
Process gas (coke oven, blast furnace, basic oxygen furnace, off gas)	Heat production for internal or external use	Coal, heavy fuel oil, light fuel oil or natural gas	GaBi 10.6.0.110 (Country specific)
	Electricity production	1MJ gas = 0.365 MJ electricity	GaBi 10.6.0.110 (Country specific)
Electric arc furnace dust	Zinc production	1 kg dust = 0.5 kg Zinc	GaBi 10.6.0.110 (IZA)
Electricity from energy recovery	Electricity production	Electricity production	GaBi 10.6.0.110 (Country specific)
Steam from energy recovery	Heat generation	Steam production from natural gas 85% efficiency	GaBi 10.6.0.110 (EU-28)
Hot water from energy recovery	Heat generation	Steam production from natural gas 85% efficiency	GaBi 10.6.0.110 (EU-28)
Ammonia	Any ammonia application	Ammonia production	GaBi 10.6.0.110 (EU-28)
Ammonium sulphate	Any ammonium sulphate application	Ammonium sulphate production	GaBi 10.6.0.110 (DE)
Benzene	Any benzene application	Benzene production based on different technologies	GaBi 10.6.0.110 (EU-28)

BTX	Any BTX application	Benzene production based on different technologies	GaBi 10.6.0.110 (EU-28)
Scales	Metallurgical input to steelmaking	Iron ore extraction	worldsteel (2021)
Sulphuric acid	Any sulphuric acid application	Sulphuric acid production	GaBi 10.6.0.110 (EU-28)
Tar	Any tar application	Bitumen production	GaBi 10.6.0.110 (EU-28)
Used oil	Heat generation	Coal, heavy fuel oil, light fuel oil or natural gas	GaBi 10.6.0.110 (Country specific)
Zinc	Any zinc application	Zinc production	GaBi 10.6.0.110 (IZA)
Zinc dust	Any zinc application	Zinc production	GaBi 10.6.0.110 (IZA)
Electrode	Electrode making	Electrode mix	GaBi 10.6.0.110 (ZA)

APPENDIX 9: UPDATES FROM THE 2020 STUDY REPORT

This study report covers an update of the global steel industry LCI data and follows the 2017 LCI methodology report. During this 2021 update, a number of changes and updates have been made (compared to the 2020 study), and for ease of comparison, these differences are summarised here. Further information can be found in relevant sections of the report.

- The modelling software used for this update is GaBi 10.0.1 CUP2021.2. All upstream data which have not been collected by worldsteel from industry associations are based on GaBi 10.6.0.110 upstream data. The previous study used an earlier version of GaBi 10.01.
- Due to naming issues of some emission flows in GaBi 4, they were not picked up by impact assessment methodologies in GaBi. These have been corrected to ensure that all emission flows are correctly named. Currently this is done through a manual process using a flow name modification plan.
- To ensure the data is ILCD compliant, recovered material and wastes that had no final fate have now been modelled to be landfilled which will result in impacts that are higher than reality but is a conservative approach.
- Global iron ore upstream data is calculated using a 4-region-specific mix of iron ore production for 2020.
- Zinc upstream processes are an interim process adapted from the International Zinc Association (IZA) dataset in coordination with IZA while they carry out an update to their processes. This will be replaced once new IZA data is released.
- New companies and sites have been added to the database and sites with data older than 5 years have been removed from the database.
- Modifications to the modelling of the worldsteel upstream datasets were made to ensure where process gases were consumed but the producing processes were outside of the product boundary then a proxy process of Natural Gas production was substituted as using the existing system expansion modelling could lead to reduced impacts.

APPENDIX 10: LIST OF ALL AVAILABLE QUESTIONNAIRES FOR DATA COLLECTION

- Coke oven
- Sinter plant
- Blast furnace
- Alternative iron making
- Basic oxygen furnace
- Electric arc furnace
- Direct sheet plant
- Plate mill
- Hot strip mill
- Pickling plant
- Cold rolling mill
- Annealing and tempering
- Section rolling
- Rebar
- Engineering steel
- Wire rod
- Seamless pipe making
- UO pipe making
- Welded pipe making and tube making
- Electrogalvanizing
- Hot-dip galvanizing
- Electrolytic chrome coating (ECCS or tin-free steel)
- Tinplating
- Organic coating
- Softening / deionising water
- Application of co-products (slags and used oil)
- Boilers (power plants)
- External power supply
- Destination of process gases (coke oven, blast furnace, basic oxygen furnace, off gas)
- Flaring of process gases (coke oven, blast furnace, basic oxygen furnace)
- Fresh water supply
- Sea water supply
- Isolated blast air compressor
- Isolated compressed air compressor
- Isolated turbo alternator
- Stockpile emissions
- Transport for various raw materials

APPENDIX 11: MATRIX OF USES OF STEEL PRODUCTS

Sector	1 = preferable 2 = possible	Plate	Pipe (UO and welded pipe)	Hot Rolled Coil	Pickled Hot Rolled Coil	Cold Rolled Coil	Finished Cold Rolled Coil	Electro-Galvanised	Hot-Dip Galvanised	Organic Coated	Tin Plate	Electrolytic Chromed Coated Steel	Section Rolling	Rebar	Engineering Steel	Wire Rod
Automotive	Body in white				2		1	1	1	2						
	Structural parts				1		1	1	1	2						
	Engine														1	
	Drive equipment														1	
	Transmissions														1	
	Wheels				1											
	Tyres															1
Buildings and infrastructure	Profiles			1	1	2		2	1				1			
	Framing								1							
	Structural parts	1	1	1					2	1			1			
	Wall elements							1	1	1						
	Basement												1	1		
	Concrete reinforcement													1		
	Cladding			2				1	1	1						
	Roofing								1	1						
	Farm building walls								2	1						
	Gutter system (ducts)								1	1						
	Chimney ducts			2												
	Construction components			2	2			1	1	1						
	Farm building components								2	1						
	Doors and garages								2	1						
	Fences								2							
	Stairs			1					2							
	Tiles								2	1						
	Ceilings components							1	1	1						
	Floor components			1				2	1							
	Inside decoration panels									1						
	Partition walls							2	1	1						
	Inside panels food industry									1						
	Security rails on roads								1							
Domestic appliances	Furniture						2	1		1						
	White goods						1	1	1	1						
	Heating, ventilation and air conditioning						1	1	1	1						
Packaging	Steel food & general line cans									1	1	1				
	Pails											1				
	Beverage cans									1	1	1				
	Drums						1	1								
Others	Rail												1			
	Machines	2					1								1	
	Pipes		1													
	Tubes			1	2		1									
	Pools								2	2						
	Water tanks								1							
	Greenhouses								2	2						
	Signs								2							
	Tools														1	
	Dies														1	
	Wires													1		1

APPENDIX 12: CRITICAL REVIEW: WORLD STEEL ASSOCIATION LIFE CYCLE INVENTORY STUDY FOR STEEL PRODUCTS

No critical review of the updated dataset and study report has been carried out due to limited changes to the methodology, the worldsteel GaBi model and the LCI data results compared to the previously critically reviewed 2017 methodology report2 and study reports .

[1] World Steel Association Life Cycle Assessment Methodology Report, Brussels, 2011

[2] World Steel Association Life Cycle Inventory Methodology Report, 2017

[3] ISO 14040: 2006 – Environmental management – Life cycle assessment- Principles and framework

[4] ISO 14044: 2006 – Environmental management – Life cycle assessment – Requirements and guidelines

[5] ISSF LCI data for stainless steel products, www.worldstainless.org

[6] The Centre of Environmental Science at Leiden University, CML 2001 – Aug 2016

[7] The International Reference Life Cycle Data System – Compliance rules and entry-level requirements, EU JRC, 2012

[8] World Steel Association Life Cycle Inventory study report, 2017 data release, 2018

[9] World Steel Association Life Cycle Inventory study report, 2018 data release, 2019

[10] World Steel Association Life Cycle Inventory study report, 2019 data release, 2020

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